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SEMINAR OPTIČNE KOMUNIKACIJE

ZBORNIK

SEMINAR ON OPTICAL COMMUNICATIONS

PROCEEDINGS

Ljubljana, 5. - 7. 2. 2025

UNIVERZA V LJUBLJANI
Universitas Labacensis

Univerza v Ljubljani, Fakulteta za elektrotehniko
University of Ljubljana, Faculty of Electrical Engineering

27. SEMINAR OPTIČNE KOMUNIKACIJE

Ljubljana, 5. do 7. februarja 2025

ZBORNIK

27TH SEMINAR ON OPTICAL COMMUNICATIONS

Ljubljana, 5 to 7 February 2025

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UREDILA/EDITORS:
Tomi Mlinar, Boštjan Batagelj

Kataložni zapis o publikaciji (CIP) pripravili v Narodni in univerzitetni knjižnici v Ljubljani

COBISS.SI-ID 224970243

ISBN 978-961-243-477-9 (PDF)

URL: https://sok.fe.uni-lj.si/zborniki

Naslov: 27. Seminar optične komunikacije-Zbornik / 27th Seminar on Optical Communications-Proceedings

Uredila / Editors: Tomi Mlinar, Boštjan Batagelj

Založnik: Založba FE, Ljubljana
Izdajatelj: Fakuleta za elektrotehniko, Ljubljana
Urednik: prof. dr. Sašo Tomažič
Kraj in leto izida: Ljubljana, 2025
1. elektronska izdaja

SOK 2025
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Gradivo za interno uporabo na 27. seminarju Optične komunikacije SOK 2025.
Material for internal use at the 27th Seminar on Optical Communications SOK 2025.

Uredila / *Editors:* Tomi Mlinar, Boštjan Batagelj

Predgovor

Z veseljem vam predstavljava zbornik referatov seminarja Optične komunikacije, ki tudi letos združuje prispevke raziskovalcev in strokovnjakov s področja optičnih komunikacij. Seminar ponuja vpogled v aktualne trende in inovacije na tem hitro razvijajočem se področju, pri čemer je letos glede na to, da je 2025 leto kvantane znanosti in tehnologije, poudarek na kvantnih komunikacijah.

Program seminarja se prične s pregledom "Smeri razvoja in najnovejših dosežkov v optičnih komunikacijah", ki ga predstavi Boštjan Batagelj (UL Fakulteta za elektrotehniko), in nadaljuje s prispevkom Mateja Meže (Megatel) o "Širokopasovni povezljivosti prihodnosti". Stanko Taškov (AKOS) predstavi "Regulatorni pogled na optična omrežja", sledijo pa tehnične razprave, kot so "Izzivi pri izvajanju diagnostike na PON" (Mitja Golja, Kontron) in "Testiranje in uvedba opreme novejše generacije v pasivnem optičnem omrežju Telekoma Slovenije" (Tomislav Goluža, Telekom Slovenije).

V nadaljevanju prvega dne seminarja Gorazd Penko (T-2) predstavi "Optimizacijo dostopovnega omrežja z vidika cen električne energije", Pavel Praček (T-2) pa se posveti "Koherentni tehnologiji" in njenemu vplivu na IPoDWDM omrežja. Milorad Sarić (IBIS Instruments) razloži uporabo "Fiber as a distributed sensor", Peter Lukan (Lumentum) pa se osredotoči na "Izzive pri razvoju erbijevih vlaken". Dan zaključuje Luka Mustafa (IRNAS) s predstavitvijo "100Gbps KORUZA FSO".

Drugi dan seminarja se prične s prispevkom Blaža Bertalaniča (IJS) o vlogi optičnih tehnologij pri razvoju umetne inteligence, sledi pa tehnični sklop, v katerem Sven Krüger (HUBER+SUHNER Cube Optics AG) predstavi "Porabo električne energije in CO2 odtis v optičnih metro omrežjih". Nadaljujejo Neil Hobbs (EXFO) s "Testing Challenge of moving from 800G to 1.6T" in Graeme Allott (HUBER+SUHNER Polatis) s temo "Optical Circuit Switching". Kvantni vidik seminarja zaokroža Marta Buffa (NOKIA) s prispevkom "Quantum-Safe Networks" in Faezeh Mousavi (Univerza v Trstu) s temo "Quantum Communication and Information".

Zaključni dan seminarja prinaša predstavitve uporabe optike v radarski tehniki. Luka Podbregar (UL Fakulteta za elektrotehniko) in Mirco Scaffardi (CNIT) govorita o "Microwave Photonics in Radar Technology", Tomáš Horváth (BUT) razpravlja o "Sensitivity of fiber optic cables to acoustic vibrations", Andrej Souvent (Operato) pa predstavi "Uporabo optičnega vlakenskega senzorja v energetiki". Igor Plevnjak (IBIS Instruments) obravnava temo "FTTH Technology trends", Jiri Štefl (Optokon) pa zaključuje seminar s temo "Tactical Networks in Harsh Environments".

Vse te raziskave in inovacije dokazujejo, da optične komunikacije ostajajo ključen dejavnik pri oblikovanju prihodnosti telekomunikacij. Zahvaljujeva se vsem avtorjem za njihove dragocene prispevke in upava, da bo zbornik spodbuda za nadaljnje raziskovanje in sodelovanje na tem hitro razvijajočem se področju.

Tomi Mlinar, Boštjan Batagelj, Ljubljana, 5. februarja 2025

urednika zbornika

Foreword

We are pleased to present the proceedings of the Optical Communications seminar, which once again brings together contributions from researchers and experts in the field of optical communications. The seminar offers an insight into current trends and innovations in this rapidly developing field, with this year's focus on quantum communications, given that 2025 is the year of quantum science and technology.

The seminar program begins with an overview of the "Development directions and latest achievements in optical communications" presented by Boštjan Batagelj (UL Faculty of Electrical Engineering), followed by Matej Meža (Megatel) with his contribution on "Broadband Connectivity of the Future." Stanko Taškov (AKOS) presents the "Regulatory Perspective on Optical Networks," followed by technical discussions such as "Challenges in Diagnosing PON" (Mitja Golja, Kontron) and "Testing and Deployment of Next-Generation Equipment in Telekom Slovenije's Passive Optical Network" (Tomislav Goluža, Telekom Slovenije).

Later on the first day, Gorazd Penko (T-2) presents "Optimization of Access Networks from the Perspective of Electricity Costs," while Pavel Praček (T-2) discusses "Coherent Technology" and its impact on IPoDWDM networks. Milorad Sarić (IBIS Instruments) explains the use of "Fiber as a Distributed Sensor," and Peter Lukan (Lumentum) focuses on "Challenges in the Development of Erbium Fibers." The day concludes with Luka Mustafa (IRNAS) presenting "100Gbps KORUZA FSO."

The second day of the seminar begins with Blaž Bertalanič (IJS) discussing the role of optical technologies in artificial intelligence development. This is followed by a technical session in which Sven Krüger (HUBER+SUHNER Cube Optics AG) presents "Electrical Power Consumption and CO2 Footprint in Optical Metro Networks." Next, Neil Hobbs (EXFO) discusses "Testing Challenge of Moving from 800G to 1.6T," and Graeme Allott (HUBER+SUHNER Polatis) examines "Optical Circuit Switching." The quantum aspect of the seminar is rounded off by Marta Buffa (NOKIA) with her contribution on "Quantum-Safe Networks" and Faezeh Mousavi (University of Trieste) with "Quantum Communication and Information."

The final day of the seminar features presentations on the use of optics in radar technology. Luka Podbregar (UL Faculty of Electrical Engineering) and Mirco Scaffardi (CNIT) discuss "Microwave Photonics in Radar Technology," Tomáš Horváth (BUT) examines "Sensitivity of Fiber Optic Cables to Acoustic Vibrations," and Andrej Souvent (Operato) presents "Application of Optical Fiber Sensors in Energy." Igor Plevnjak (IBIS Instruments) covers "FTTH Technology Trends," and Jiri Štefl (Optokon) concludes the seminar with "Tactical Networks in Harsh Environments."

These studies and innovations demonstrate that optical communications remain a key factor in shaping the future of telecommunications. We would like to thank all the authors for their valuable contributions and hope that this proceedings will serve as an inspiration for further research and collaboration in this rapidly evolving field.

Tomi Mlinar, Boštjan Batagelj — *Ljubljana, 5 February 2025*

Editors of the Proceedings

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Boštjan Batagelj

Univerza v Ljubljani, Fakulteta za elektrotehniko

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Povzetek

Sodobna optična omrežja, od podmorskih povezav do širokopasovnega dostopa v domovih, še naprej napredujejo z rekordnimi investicijami spletnih velikanov v podmorske kable. Tehnološki napredek, kot so kvantne informacijske tehnologije, umetna inteligenca in kvantno šifriranje, izboljšuje zmogljivost, varnost in zanesljivost optičnih povezav. Nove tehnike, vključno s koherentnimi komunikacijami in večdimenzionalnimi modulacijskimi formati, še dodatno prispevajo k razvoju integrirane optike in komunikacijskih naprav.

Abstract

Modern optical networks, ranging from high-performance submarine connections to broadband access in homes, continue to evolve, with record investments by tech giants in submarine cables. Technological advancements, such as quantum information technologies, artificial intelligence, and quantum encryption, enhance the performance, security, and reliability of optical connections. New techniques, including coherent communications and multidimensional modulation formats, further drive the development of integrated optics and communication devices.

Biografija avtorja

Boštjan Batagelj je profesor na Fakulteti za elektrotehniko Univerze v Ljubljani, kjer predava predmete optične komunikacije, radijske komunikacije in satelitske komunikacije. Raziskovalno delo opravlja v Laboratoriju za sevanje in optiko, kjer se med drugim ukvarja z fizičnim nivojem prenosnih in dostopovnih telekomunikacijskim omrežji zasnovanih na radijski in optični tehnologiji. Je avtor več kot 400 člankov, dvanajstih patentnih prijav in sodeluje v domačih ter mednarodnih raziskovalnih projektih s področja optičnih in radijskih komunikacij.

Author's biography

Boštjan Batagelj is a professor at the Faculty of Electrical Engineering at the University of Ljubljana, where he teaches optical communication, radio communication and satellite communication. He conducts research in the Radiation and Optics Laboratory, where he deals, among other things, with the physical layer of portable and access telecommunications networks based on radio and optical technology. He is the author of more than 400 articles, twelve patent applications and participates in national and international research projects in the field of optical and radio communications.

UNIVERZA V LJUBLJANI Fakulteta za elektrotehniko | IKT Katedra za informacijske in komunikacijske tehnologije | LSO Laboratorij za sevanje in optiko | SOK 2025 sok.fe.uni-lj.si

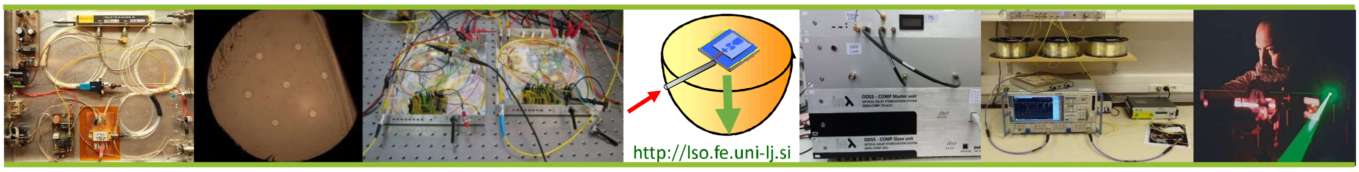
27. seminar optične komunikacije

Smeri razvoja in najnovejši dosežki v optičnih komunikacijah

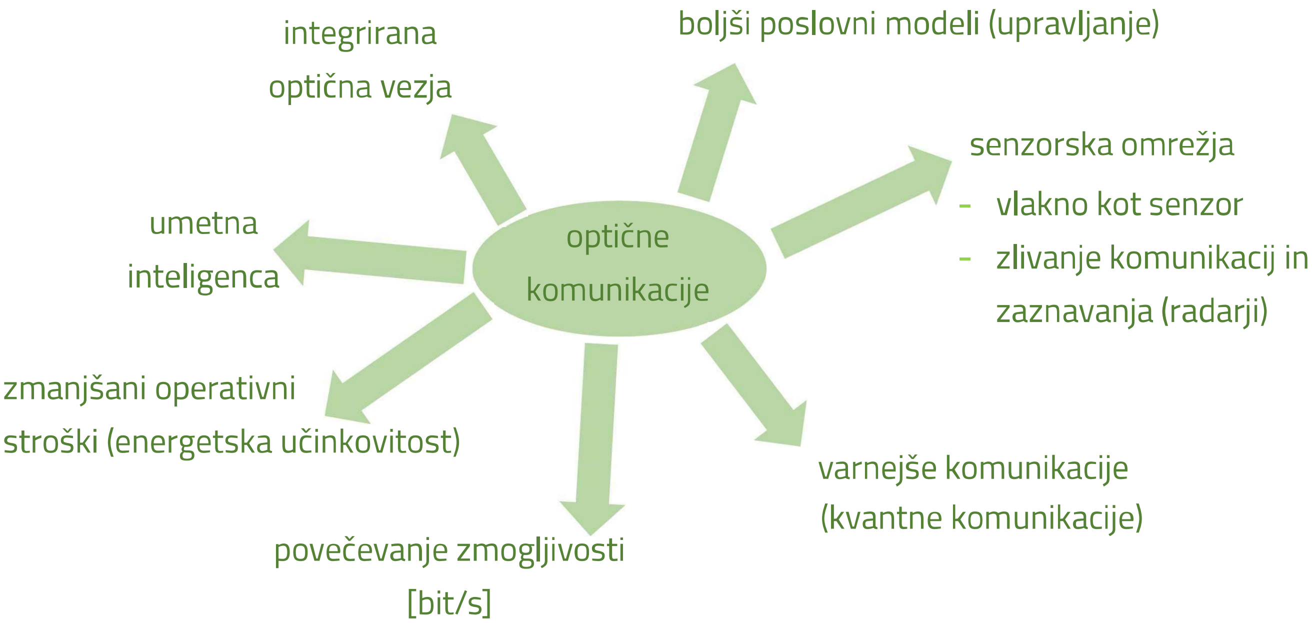
prof. dr. Boštjan Batagelj

bostjan.batagelj@fe.uni-lj.si

5. februar 2025



Smeri razvoja v optičnih komunikacijah



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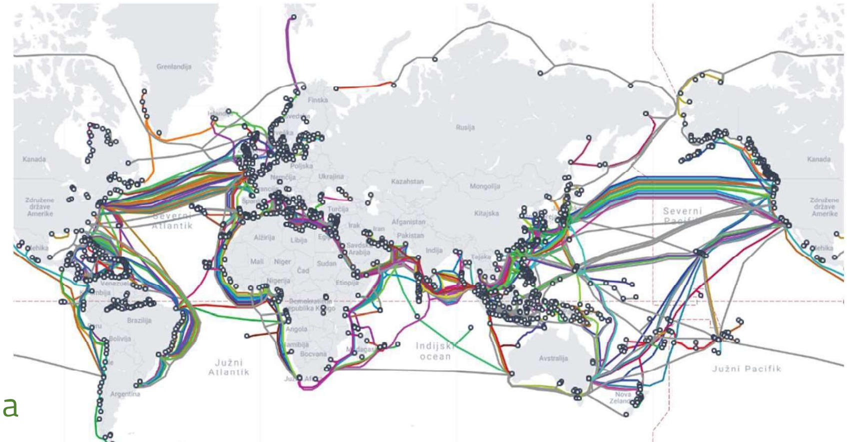
Vlakno na najdaljših razdaljah

- Trenutno imamo več kot 530 delujočih optičnih kabelskih podmorskih kablov.
- Podmorski optični kabli prenašajo več kot 98% mednarodnega prometa.
- Meta, Google, Microsoft in Amazon v lasti ali v najemu skoraj polovico razpoložljivih podmorskih zmogljivosti.



www.submarinecablemap.com

- Svetlobni ojačevalniki so ključna tehnologija za DWDM prenos.
- Trenutno je več kot 100 podmorskih zvez z zmogljivostjo večjo od Tbit/s.
- Skoraj vsi podmorski kabli zgrajeni po 2010 so načrtovani za vsaj nekaj Tbit/s.
- Obstoječi kabli se nadgrajujejo.

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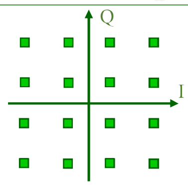
Nadgradnja kabla MAREA

- Februarja 2018 je bila dokončana do tedaj najbolj zmogljiva medkontinentalna povezava MAREA dolžine 6.644 km s skupno zmogljivostjo 160 Tbit/s, ki sega med ZDA (Virginia Beach) in Španijo (Bilbao).
- Lastništvo:
  Meta (25 %), Microsoft (25 %), Telxius [Telefónica] (50 %)
-

www.submarinecablemap.com

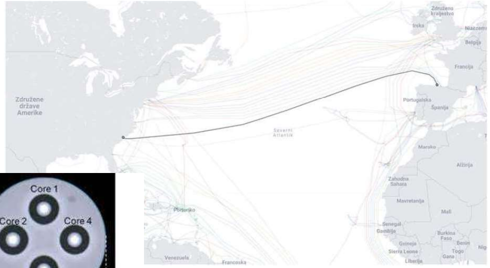


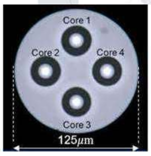
- Uporaba modulacijskega formata 16-QAM s 4 bit/simbol
- Nadgradnja v PM-16-QAM (polarizacijsko multipleksiranje)
- Dosežena spektralna učinkovitost 6,41 bit/s/Hz.
- 8 vlakenskih parov * 20 Tbit/s/par = 160 Tbit/s
- 8 vlakenskih parov * 25 DWDM kanalov * 400 Gbit/s na posamezni kanal = 160 Tbit/s
- 8 vlakenskih parov * 26 Tbit/s/par = 208 Tbit/s

vir: https://www.submarinenetworks.com

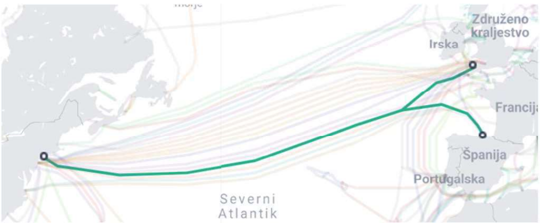
Najbolj zmogljiv - Anjana

- Načrtovan za Q4 2024, vendar prestavljen na Q1 2025.
- Povezuje Španijo in ZDA (dolžina 7121 km)
- Lastnik: Meta
- 24 vlakenskih parov
- 20 Tbit/s / par = 480 Tbit/s
- uporablja tehnologijo prostorskega multipleksiranja (angl. space-division multiplexing – SDM)





Do sedaj najbolj zmogljiv - Grace Hopper Cable System

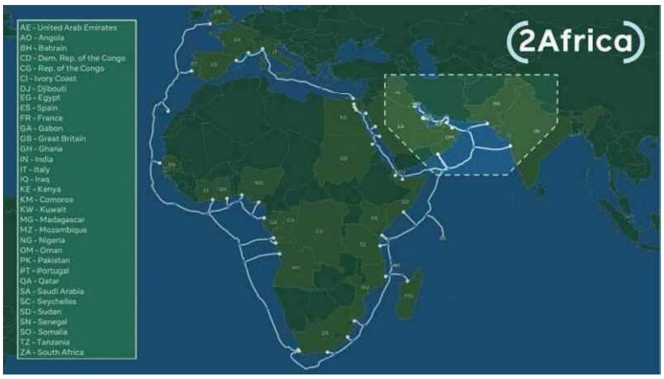


- Povezuje Španijo, UK in ZDA (dolžina 6250 km)
- Lastnik: Google (2022)
- 16 vlakenskih parov
- 22 Tbit/s / par = 352 Tbit/s

vir: https://en.wikipedia.org/wiki/Grace_Hopper_(submarine_communications_cable)

Najdaljši podmorski optični kabel

vir: https://www.2africacable.net

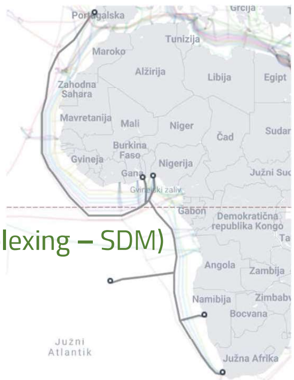


- v pogon bo spuščen začetek 2024
- 45.000 km, 46 vozlišč v 33 državah
- 16 vlakenskih parov (SDM) * 5,6 Tbit/s / vlakno = 180 Tbit/s

- Od 1999 najdaljši je bil SEA-ME-WE 3 z 39.000 km, ki so ga letos izključili iz obratovanja.

vir: https://www.submarinenetworks.com/en/systems/euro-africa/equiano

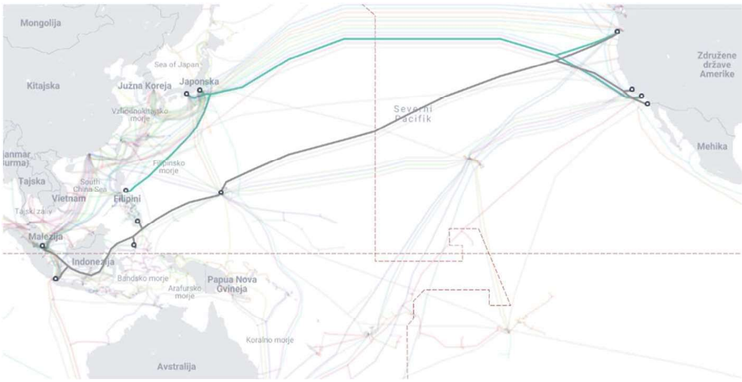
- Equiano (14. podoceanski kabel, ki ga je financiral Google)
  - v pogon bo spuščen začetek 2023
  - uporabljal bo tehnologijo prostorskega multipleksiranja (angl. space-division multiplexing – SDM)
  - 12 vlakenskih parov * 12 Tbit/s / vlakno = 144 Tbit/s
  - 20x večja zmogljivost od trenutnega kabla na zahodni obali Afrike



Najdaljši odseki podmorskih optičnih kablov

- JUPITER Cable System (2021) dolžine 14.557 km s 5 vlakenskimi pari in skupno zmogljivostjo 60 Tbit/s.

vir: https://www.submarinenetworks.com/en/systems/trans-pacific/jupiter



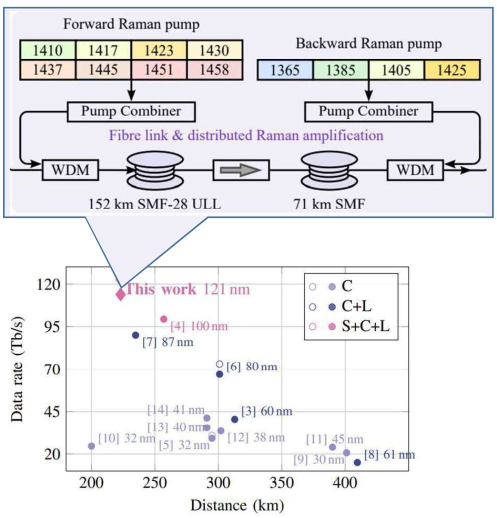
- Bifrost Cable System (2024) dolžine 16.460 km s 12 vlakenskimi pari in zmogljivostjo 10,4 Tbit/s / par = 125 Tbit/s.

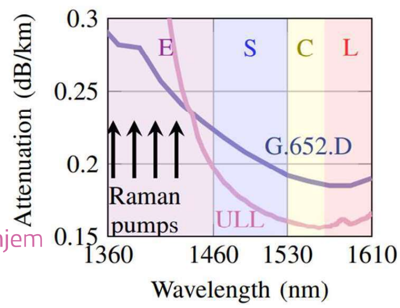
vir: https://www.submarinenetworks.com/en/systems/trans-pacific/bifrost

Rekordna propustnost optičnega vlakna

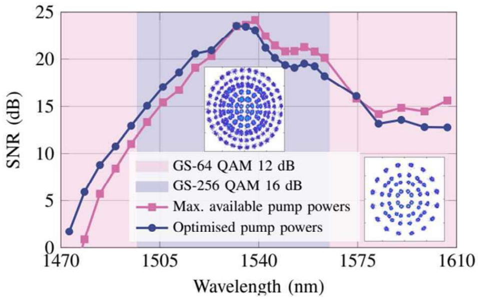
vir: J. Yang et al., "122.6 Tb/s S+C+L Band Unrepeatered Transmission over 223 km Link with Optimised Bidirectional Raman Amplification," in Journal of Lightwave Technology, doi: 10.1109/JLT.2024.3521233

- 122,6 Tbit/s prenos preko 223 km v pasovih S+C+L (121 nm (15,6 THz)) brez vmesnih repetitorjev z Ramanovim ojačenjem





ULL (ultra-lowloss) s slabljenjem 0,16 dB/km @ 1550 nm



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Umetna inteligenca (angl. Artificial Intelligence – AI) lahko pomaga optičnim komunikacijam

AI in ML na fizični ravni optičnega omrežja (optični prenos)

- izboljšanje nastavitve optičnih gradnikov (oddajnika, ojačevalnika, sprejemnika)
- kvalitetnejše načrtovanje optičnega omrežja
- avtomatski nadzor omrežja
- izboljšanje kvalitete prenosa
- porazporeditev (rekonfiguracija) omrežja
- izboljšanje delovanja optičnega omrežja
- prepoznavanje modulacijskih formatov
- ublažitev vlakenskih nelinearnosti
- nadzor parametrov omrežja (OSNR, CD, PMD, n_2)

vir: JavierMata, et al. "Artificial intelligence (AI) methods in optical networks: A comprehensive survey" Optical Switching and Networking Volume 28, April 2018, pp. 43-57.
vir: D. Zibar, M. Piels, R. Jones and C. G. Schäeffer, "Machine Learning Techniques in Optical Communication," in Journal of Lightwave Technology, vol. 34, no. 6, pp. 1442-1452, 15 March15, 2016, doi: 10.1109/JLT.2015.2508502

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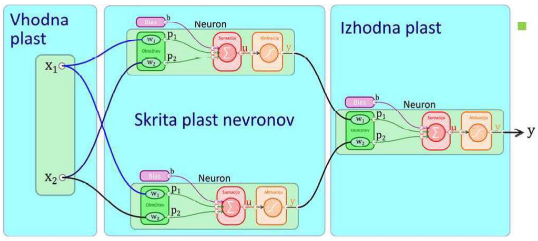
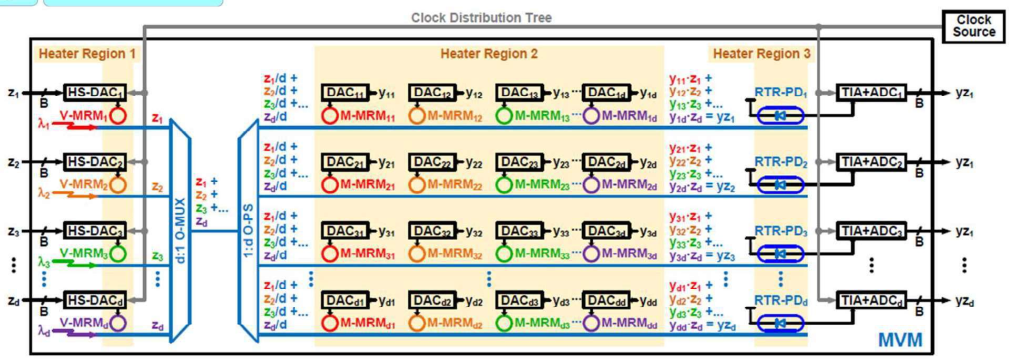
Svetloba lahko pomaga umetni inteligenci



- Zgradba umetne nevronske mreže



vir: https://medium.com/@renemarkovic/nevronska-mre%C5%BEa-kot-univerzalna-fit-funkcija-976b7bb07c0b
vir: Hsueh, Tzu-Chien, Yeshaiahu Fainman and Bill Lin. "ChatGPT at the Speed of Light: Optical Comb-Based Monolithic Photonic-Electronic Linear-Algebra Accelerators." ArXiv abs/2311.11224 (2023): n. pag.

Kvantno leto

- Letos obeležujemo 100 let od začetnega razvoja kvantne mehanike.
- Zato so Združeni narodi razglasil 2025 za mednarodno leto kvantne znanosti in tehnologije (IYQ) 2025

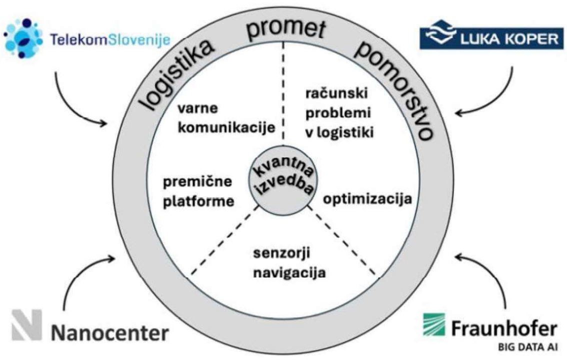
INTERNATIONAL YEAR OF Quantum Science and Technology

- Beseda kvant se nanaša na način, kako snov absorbira ali sprošča energijo - v diskretnih paketih ali kvantih.
- Julija 1925 je 23 letni Werner Heisenberg v znanstveni reviji "Zeitschrift für Physik" poslal v objavo članek z naslovom "On quantum-theoretical reinterpretation of kinematic and mechanical relationships".

vir: Kristian Camilleri, How quantum mechanics emerged in a few revolutionary months 100 years ago, Nature, januar 2025 https://www.nature.com/articles/d41586-024-04217-0
vir: Quantum mechanics 100 years on: an unfinished revolution, https://www.nature.com/articles/d41586-025-00014-5

Kvantne tehnologije za transport in komunikacije v 21. stoletju (KTTK 21)

- Transportni sistemi prihodnosti bodo morali biti okoljsko sprejemljivi, varni, razpoložljivi in robustni.
- Velik interdisciplinarni projekt UL vključuje 5 fakulteti n 4 zunanje partnerje.
- S pomočjo kvantnih tehnologij naslavlja probleme na področju logistike, prometa in pomorstva:
  - varne komunikacije na premične platforme,
  - kvantni algoritmi za optimizacijo logističnih problemov,
  - uporaba kvantnih senzorjev za inercialno navigacijo, ko se v zahtevnih pogojih ne moremo zanašati na satelitsko navigacijo.



FPP UNIVERZA V LJUBLJANI Fakulteta za pomorstvo in promet
FMF UNIVERZA V LJUBLJANI Fakulteta za matematiko in fiziko
FRI UNIVERZA V LJUBLJANI Fakulteta za računalništvo in informatiko
EF UNIVERZA V LJUBLJANI Ekonomska fakulteta
FE UNIVERZA V LJUBLJANI Fakulteta za elektrotehniko

TK ⇨ IKT

Cilj **telekomunikacij** je prenesti signal najboljše kakovosti z najmanjšo porabo moči in pasovne širine s pomočjo najenostavnejše strojne opreme.

Informacijsko komunikacijske tehnologije (IKT) združujejo procese in naprave za zajem, obdelavo, shranjevanje, prenos in interpretacijo informacij ter s tem povezujejo ljudi in stvari v največje zadovoljstvo uporabnika.

Kvantna IKT

- Kvantna informacijsko-komunikacijska teorija je širši pojem od klasične Shannonove informacijske teorije.

Kvantna IKT omogoča:

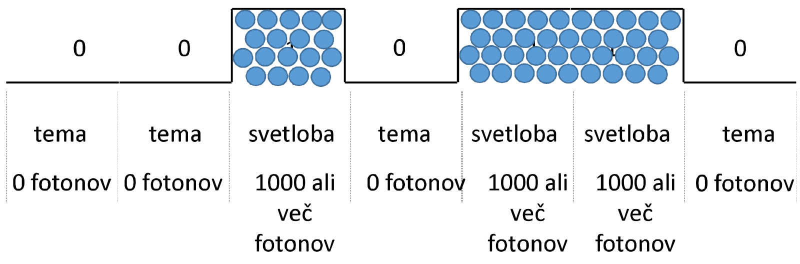
- kvantno generiranje naključnih števil
- kvantno šifriranje (šumno šifriranje)
- **prenos ključa s pomočjo prepletenosti**
- kvantno računalništvo
- kvantni internet
- kvantno steganografijo (skrivanje podatkov)
- kvantno teleportacijo
- **kvantno senzoriko**
- kvantno sinhronizacijo
- kvantno strojno učene (algoritmi)

vir: Boštjan Batagelj, "Varnost v bodočih optičnih komunikacijskih sistemih", Avtomatika, 2018, št. 167, str. 10-14, https://www.researchgate.net/publication/329363712

vir: A. Manzalini, L. Artusio, The Rise of Quantum Information and Communication Technologies. Quantum Reports. 2024; vol. 6, no. 1, pp. 29-40. https://doi.org/10.3390/quantum6010003

Številska (digitalna) zveza

- Danes uporabljamo številske (digitalne) zveze.

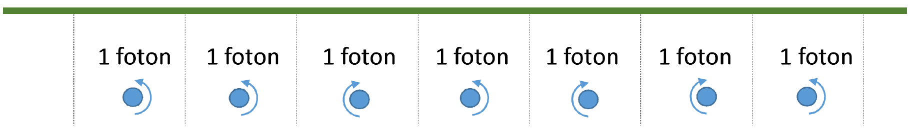


nivo logičnega simbola "1"

nivo logičnega simbola "0"

- Za večjo varnost (težje prisluškovanje) zmanjšujemo število oddanih fotonov.

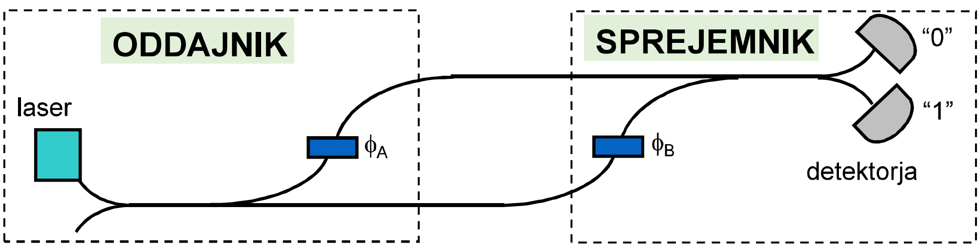
zveza s posameznimi delci



Vir: C.H.Bennet, Quantum cryptography using any two nonorthogonal states, Physical Review Letters, Vol.68, 1992, str. 3121-3124

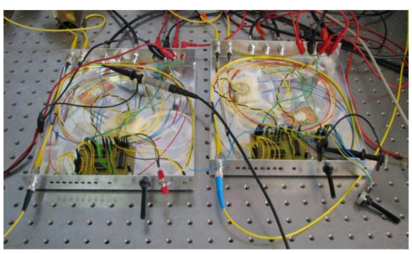
Praktična izvedba B92 v LSO

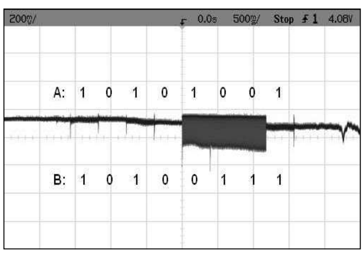
- Kodiranje bitov s spreminjanjem faze.
- Osnova je Mach-Zehnderjev vlakenski interferometer



vir: J. Tratnik, B. Batagelj, Predstavitev ideje kvantnega šifriranja in pregled osnovnih tehnik kvantnega razdeljevanja ključa. Elektrotehniški vestnik, letn. 75, št. 5, str. 257-263, 2008.

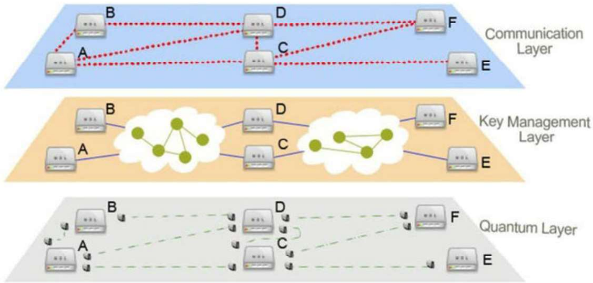
vir: TRATNIK, Jurij. Poskus uporabe optičnega interferometra za varen prenos šifrirnega ključa: diplomsko delo. Ljubljana, 2007.





Standardizacija

- European Telecommunications Standards Institute (ETSI) (specificira QKD od 2008)
  - vmesniki, varnostna dokazila, specifikacije modula, karakterizacija gradnikov, zaščita pred napadi trojanskega konja v sistemih QKD, karakterizacija opičnega izhoda oddajnih modulov QKD, nadzorni vmesnik, pregled omrežne arhitekture



- International Telecommunication Union (ITU)'s Telecommunication Standardisation (ITU-T)
  - ITU-T study group (SG) 13: 5G and beyond
  - ITU-T study group (SG) 17: security studies

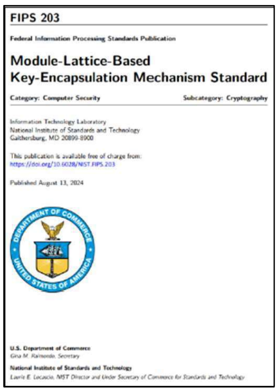
vir: https://www.etsi.org/technologies/quantum-key-distribution
vir: https://www.itu.int/rec/T-REC-Y/en

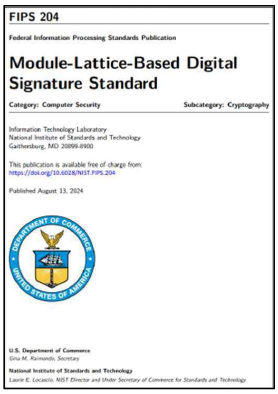
2024 NIST objavi 4 PQC

Prvi PQC standardi (FIPS - Federal Information Processing Standards) so bili objavljeni avgusta 2024:

- FIPS 203: ML-KEM (KYBER)
- FIPS 204: ML-DSA (DILITHIUM)
- FIPS 205: SLH-DSA (SPHINCS+)
- FIPS 206: FN-DSA (FALCON) – UNDER DEVELOPMENT

vir: WWW.NIST.GOV/PQCRYPTO


FIPS 203
Federal Information Processing Standards Publication
Module-Lattice-Based Key-Encapsulation Mechanism Standard
Category: Computer Security Subcategory: Cryptography
Information Technology Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8900
This publication is available free of charge from:
https://doi.org/10.6028/NIST.FIPS.203
Published August 13, 2024
U.S. Department of Commerce
Gina M. Raimondo, Secretary
National Institute of Standards and Technology
Laurie E. Locascio, NIST Director and Under Secretary of Commerce for Standards and Technology


FIPS 204
Federal Information Processing Standards Publication
Module-Lattice-Based Digital Signature Standard
Category: Computer Security Subcategory: Cryptography
Information Technology Laboratory
National Institute of Standards and Technology
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This publication is available free of charge from:
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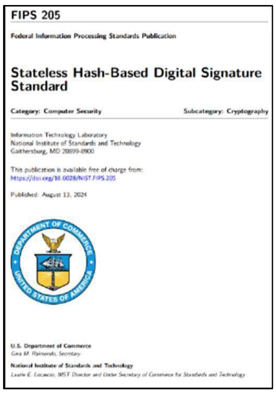
FIPS 205
Federal Information Processing Standards Publication
Stateless Hash-Based Digital Signature Standard
Category: Computer Security Subcategory: Cryptography
Information Technology Laboratory
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Senzorska omrežja

- Zaznavanje z optičnimi vlakni uporablja fizikalne lastnosti svetlobe, da med potovanjem vzdolž vlakna zazna spremembe temperature, zunanjih sil, vibracij (akustika) in drugih parametrov.
- Zaznavanje z optičnimi vlakni uporablja vlakno kot senzor za ustvarjanje na tisoče neprekinjenih zaznavnih točk vzdolž vlakna.

788 Vol. 8, No. 6 / June 2021 / Optica Research Article

optica

Polarization sensing using submarine optical cables

Antonio Mecozzi,[1,*] Mattia Cantono,[2] Jorge C. Castellanos,[3] Valey Kamalov,[2] Rafael Muller,[2] and Zhongwen Zhan[3]
[1] Department of Physical and Chemical Sciences, University of L'Aquila, L'Aquila 67100, Italy
[2] Google Inc., 1600 Amphitheatre Parkway, Mountain View, California 94043, USA
[3] Seismological Laboratory, California Institute of Technology, Pasadena, California 91125, USA
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Received 8 March 2021; revised 2 May 2021; accepted 2 May 2021 (Doc. ID 424307); published 10 June 2021

Observation of polarization modulation at the output of a submarine link, extracted from a standard coherent telecom receiver, can be used to monitor geophysical events such as sea waves and earthquakes occurring along the cable. We analyze the effect of birefringence perturbations on the polarization at the output of a long-haul submarine transmission system, and provide analytical expressions instrumental to understanding the dependence of the observed polarization modulation on the amplitude and spatial extension of the observed events. By symmetry considerations, we show that in standard single mode fibers with random polarization coupling, if polarization fluctuations are caused by strain or pressure, the relative birefringence fluctuations are equal to the relative fluctuations of the polarization averaged phase. We finally show that pressure induced strain is a plausible explanation of the origin of polarization modulations observed in a long submarine link. The presented analysis paves the way for the transformation of transoceanic fiber optic links during operation into powerful sensing tools for otherwise inaccessible geophysical events occurring in the deep ocean.

https://doi.org/10.1364/OPTICA.424307

scientific reports

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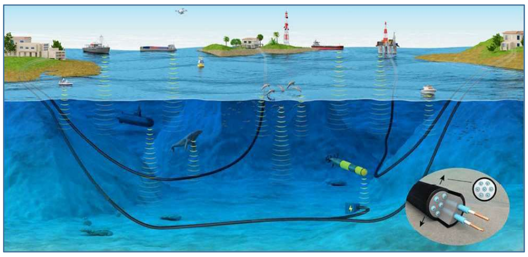
OPEN **Submarine optical fiber communication provides an unrealized deep-sea observation network**

Yujian Guo[1,3], Juan M. Marin[1,3], Islam Ashry[1], Abderrahmen Trichili[1], Michelle-Nicole Havlik[2], Tien Khee Ng[1], Carlos M. Duarte[2] & Boon S. Ooi[1]

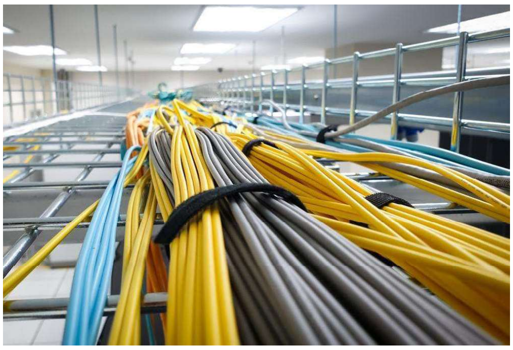
Oceans are crucial to human survival, providing natural resources and most of the global oxygen supply, and are responsible for a large portion of worldwide economic development. Although it is widely considered a silent world, the sea is filled with natural sounds generated by marine life and geological processes. Man-made underwater sounds, such as active sonars, maritime traffic, and offshore oil and mineral exploration, have significantly affected underwater soundscapes and species. In this work, we report on a joint optical fiber-based communication and sensing technology aiming to reduce noise pollution in the sea while providing connectivity simultaneously with a variety of underwater applications. The designed multifunctional fiber-based system enables two-way data transfer, monitoring marine life and ship movement near the deployed fiber at the sea bottom and sensing temperature. The deployed fiber is equally harnessed to transfer energy that the internet of underwater things (IoUTs) devices can harvest. The reported approach significantly reduces the costs and effects of monitoring marine ecosystems while ensuring data transfer and ocean monitoring applications and providing continuous power for submerged IoUT devices.

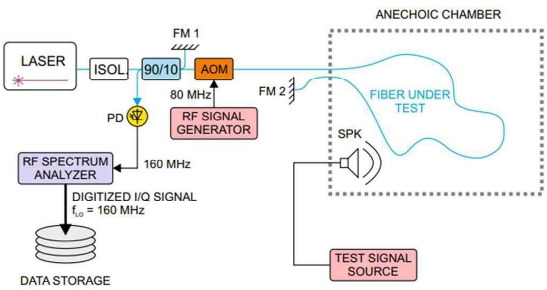


vir: Guo, Y., Marin, J.M., Ashry, I. *et al.* Submarine optical fiber communication provides an unrealized deep-sea observation network. *Sci Rep* **13**, 15412 (2023). https://doi.org/10.1038/s41598-023-42748-0

Akustična senzorska omrežja

vir: Guo, Dejdar, P., Mokry, O., Cizek, M. et al. **Characterization of sensitivity of optical fiber cables to acoustic vibrations.** Sci Rep 13, 7068 (2023). https://doi.org/10.1038/s41598-023-34097-9





www.nature.com/scientificreports

scientific reports

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OPEN **Characterization of sensitivity of optical fiber cables to acoustic vibrations**

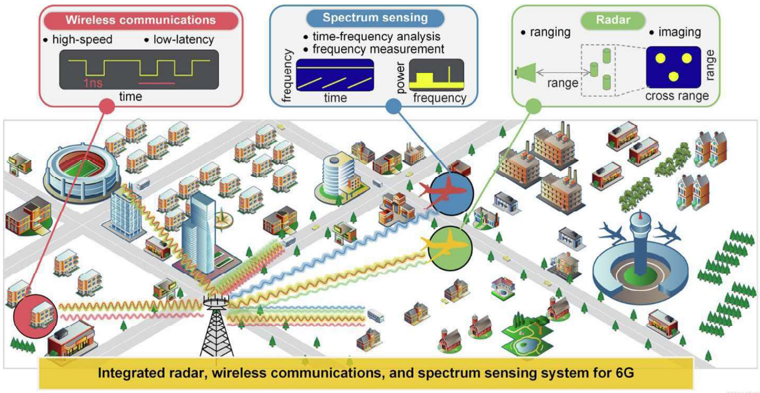
Petr Dejdar[1], Ondrej Mokry[1], Martin Cizek[2], Pavel Rajmic[1], Petr Munster[1], Jiri Schimmel[1], Lenka Pravdova[2], Tomas Horvath[1] & Ondrej Cip[2]

Fiber optic infrastructure is essential in the transmission of data of all kinds, both for the long haul and shorter distances in cities. Optical fibers are also preferred for data infrastructures inside buildings, especially in highly secured organizations and government facilities. This paper focuses on a reference measurement and analysis of optical fiber cables sensitivity to acoustic waves. Measurement was carried out in an anechoic chamber to ensure stable conditions of acoustic pressure in the range from 20 Hz to 20 kHz. The frequency response, the signal-to-noise ratio per frequency, and the Speech Transmission Index are evaluated for various types of optical fiber cables and different ceiling tiles, followed by their comparison. The influence of the means of fixing the cable is also studied. The results prove that optical fiber-based infrastructure in buildings can be exploited as a sensitive microphone.

Nowadays, optical fibers are increasingly often used for both data and non-data transmission. Many research groups focus on protection of fiber based infrastructures against data eavesdropping that can be done by several techniques[1]. Some data transmissions are not encrypted and even if they are, there is a high risk that in near future, these data will be decryptable by quantum computers. Therefore, the hot topics today are quantum encryption and post-quantum encryption. A relatively unexplored area is fiber optic sensing for vibrations in the acoustic, thus, audible spectrum.

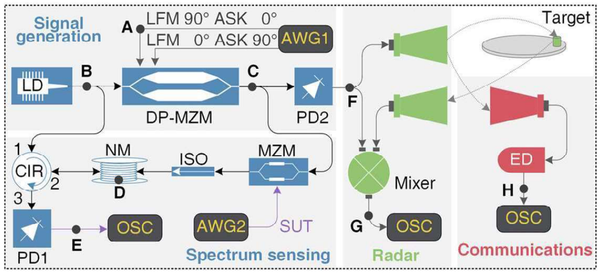
Zlivanje komunikacij in zaznavanja

vir: Shi, T., Chen, Y. & Yao, J. Seamlessly merging radar ranging and imaging, wireless communications, and spectrum sensing for 6G empowered by microwave photonics. *Commun Eng* **3**, 130 (2024). https://doi.org/10.1038/s44172-024-00279-0



petek, 7. februar 2025:

- **Kako optika pomaga v radarski tehniki?**
  Luka Podbregar, Fakulteta za elektrotehniko
- **Microwave Photonics in Radar Technology**
  Mirco Scaffardi, CNIT



Širokopasovna povezljivost prihodnosti: Od tehnologij do uporabniških pričakovanj

The future of broadband: From technologies to user expectations

Matej Meža

Megatel

matej.meza@megatel.si

Povzetek

Razvoj dostopa do interneta gre v smeri združevanja najnaprednejših tehnologij, kar danes predstavlja kombinacija fiksnih (optičnih) in brezžičnih (5G+) tehnologij. Uporabniki pričakujejo od sodobnih komunikacijskih sistemov vedno višje hitrosti, večjo zanesljivost in dostopnost. Trendi nakazujejo premik k ponudbi zgolj podatkovnih storitev, saj uporabniki vedno pogosteje posegajo po OTT-storitvah namesto tradicionalnih paketov trojčka ali četverčka. Uporabniki se delijo glede na prioritete – nekateri dajejo prednost kakovosti, drugi pa cenovni dostopnosti. Ob omejenem številu prebivalcev na trgu je prostora le za nekaj operaterjev, ki lahko zagotavljajo konkurenčnost in trajnost.

Abstract

The development of Internet access is moving towards combining the most advanced technologies, which today represents a combination of fixed (optical) and wireless (5G+) technologies. Users expect increasingly higher speeds, greater reliability and accessibility from modern communication systems. Trends indicate a shift towards offering only data services, as increase use OTT services instead of traditional triple or quadruple packages. Users are divided according to priorities - some give priority to quality, while others to affordability. With a limited number of inhabitants on the market, there is room for only a few operators who can ensure competitiveness and sustainability.

Biografija avtorja

Matej Meža je soustanovitelj in generalni direktor podjetja Mega M d.o.o. Po končani velenjski gimnaziji je diplomiral na Fakulteti za elektrotehniko v Ljubljani in kasneje pridobil naziv magister elektrotehniških znanosti. Poleg vodenja podjetja predava na Višji strokovni šoli Velenje in povezuje gospodarstvo s šolstvom. Vodil je številne domače in mednarodne projekte s področja telekomunikacij, umetne inteligence in digitalnih storitev. Dejaven je na področju trajnostne mobilnosti in širitve zelenih tehnologij pod blagovno znamko MegaTel eMobility.

Author's biography

Matej Meža is the co-founder and CEO of Mega M d.o.o. After completing high school in Velenje, he graduated from the Faculty of Electrical Engineering in Ljubljana and later earned a master's degree in electrical engineering. In addition to leading the company, he teaches at the Velenje Higher Vocational College and connects the business sector with education. He has led numerous domestic and international projects in telecommunications, artificial intelligence, and digital services. He is actively involved in sustainable mobility and the expansion of green technologies under the MegaTel eMobility brand.

Širokopasovna povezljivost prihodnosti:

Od tehnologij do uporabniških pričakovanj

mag. Matej Meža, CEO

Mega Tel

FE UNIVERSITY OF LJUBLJANA Faculty of Electrical Engineering

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AGENDA

- Kratka prestavitev podjetja Mega M d.o.o.
- Tematska področja:
  - Fiksni (optični) ali brezžični (5G+) dostop;
  - Kakšna so pričakovanja tipičnega uporabnika in kakšna bodo čez dve, tri, pet let;
  - Kam gredo storitve: trojček/četverček ali bo samo internet in vse OTT?
  - Za koliko operaterjev je prostora pri dveh milijonih prebivalcev;
- Zaključne misli

3

KDO SMO

Ponudnik celovitih IKT storitev in rešitev eMobilnosti z blagovno znamko MegaTel

- 23 let izkušenj
- Sedež podjetja v Velenju
- Slovenski in mednarodni trgi:

Jugovzhodna Evropa, Združeni arabski emirati, Savdska Arabija

- 35 visoko izobraženih zaposlenih
- Preko 1700 poslovnih strank

4

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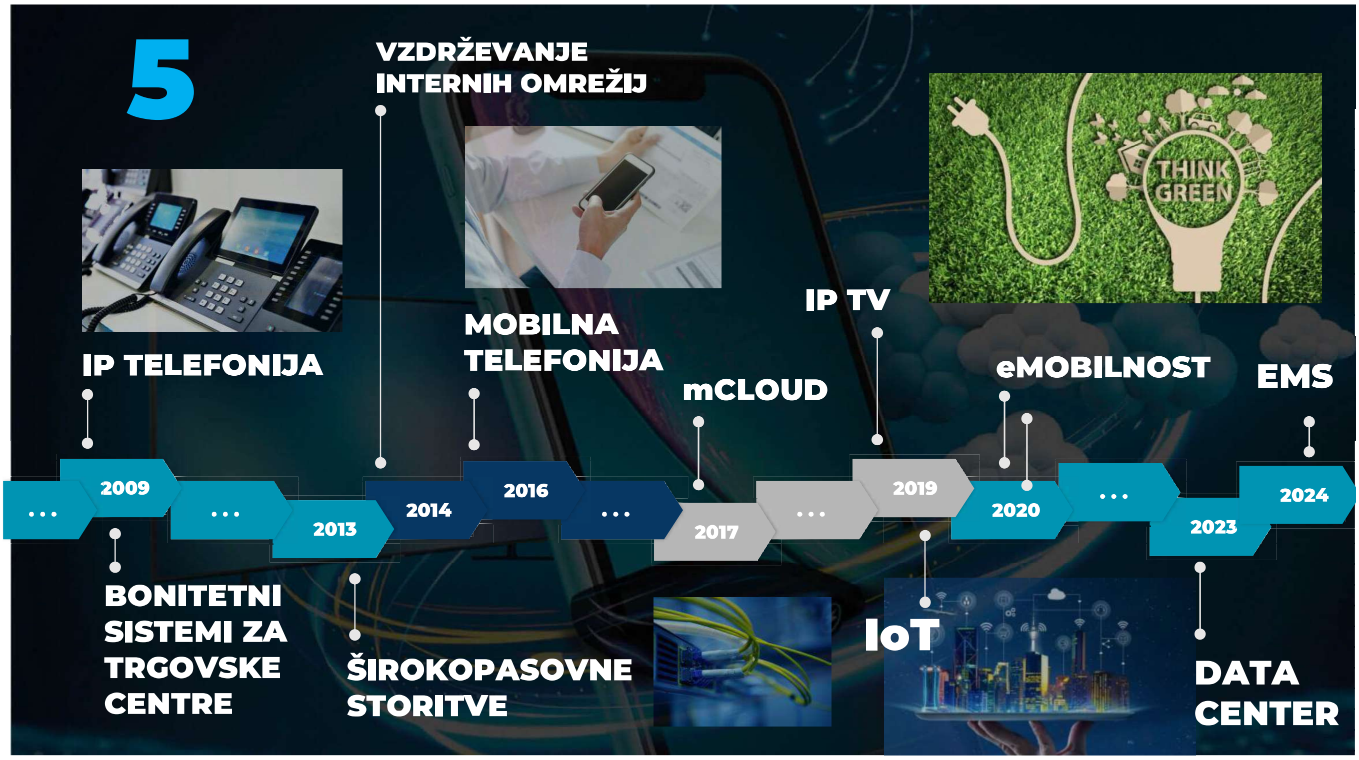
5
VZDRŽEVANJE INTERNIH OMREŽIJ
IP TELEFONIJA
MOBILNA TELEFONIJA
mCLOUD
IP TV
THINK GREEN
eMOBILNOST
EMS
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2009
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2013
2014
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2019
2020
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2023
2024
BONITETNI SISTEMI ZA TRGOVSKE CENTRE
ŠIROKOPASOVNE STORITVE
IoT
DATA CENTER


6
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ZAUPAJO NAM!

7

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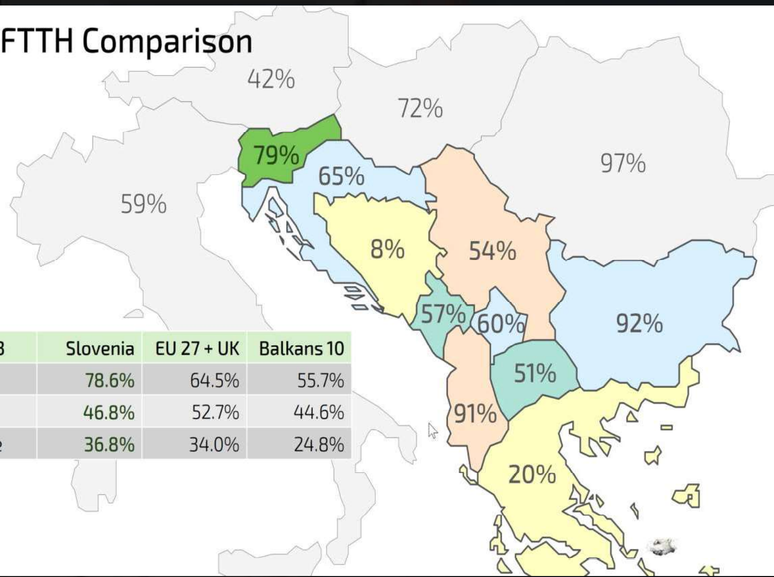
FTTH V REGIJI

Regional FTTH Comparison



September 2023	Slovenia	EU 27 + UK	Balkans 10
Coverage rate	78.6%	64.5%	55.7%
Take-up rate	46.8%	52.7%	44.6%
Penetration rate	36.8%	34.0%	24.8%

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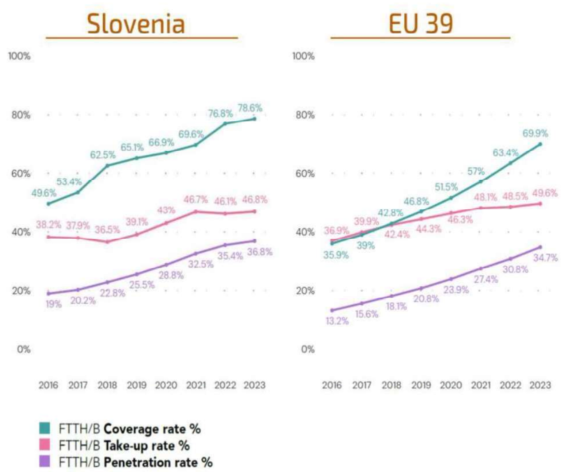
FTTH V REGIJI

Key FTTH Facts for Slovenia in 2023

September 2023	Slovenia	EU 39
Total households	884 k	349 m
HH passed	695 k	244 m
Subscribers	325 k	121 m
Coverage rate	78.6%	69.9%
Take-up rate	46.8%	49.6%
Penetration rate	36.8%	34.7%

Last 3 years	Slovenia	EU 39
HH passed growth	17.4%	24.2%
Subscribers growth	17.6%	28.0%



9

Fiksni (optični) ali brezžični (5G+) dostop?

OPTIKA ALI 5G?

Kaj bo prevladalo?

- V urbanih območjih bo optika (FTTH) še naprej standard, saj ponuja izjemne hitrosti in stabilnost.
- V ruralnih območjih bo 5G v prfi fazi prevzel primat, saj omogoča visoke hitrosti brez potrebe po dragih izkopih za kable, vendar bo sčasoma tudi tam optika.
- Odročne lokacije bo 5G prevzel primat.
- Hibridni pristop: Operaterji že ponujajo kombinacijo optike in 5G (npr. FTTH za statično uporabo + 5G kot backup oz. za mobilno rabo).

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PRIČAKOVANJA

Kakšna so pričakovanja tipičnega uporabnika in kakšna bodo čez dve, tri, pet let?

Trenutno uporabniki pričakujejo:

- Stabilno in hitro povezavo (500 Mbps – 1 Gbps v mestih, vsaj 100 Mbps drugje)
- Nizko latenco (gaming, delo od doma, VR/AR)
- Neomejene podatkovne pakete brez "skritih" omejitev
- Fleksibilnost (mobilna + fiksna povezava brez prekinitev)
- Cenovno dostopne rešitve

11

PRIČAKOVANJA

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Kaj se bo spremenilo čez 2-5 let?

- Generativna AI bo močno izboljšala personalizacijo storitev.
- Digitalni asistenti (ChatGPT, Gemini, Deepseek, ...) bodo postali še bolj prisotni v vsakdanjem življenju.
- Več avtomatizacije – od pametnih domov do virtualnih pomočnikov.
- Blockchain in decentralizacija bosta pridobivala pomen (identitete, finance).
- Metaverse in XR (razširjena in virtualna resničnost) bosta bolj integrirana v vsakdanjo uporabo.
- Personalizacija na podlagi AI bo prešla na naslednjo raven – vsebine, nakupovanje, zdravstvo itd.
- Bolj intuitiven vmesnik – manj klikanja, več naravnega govora in gest.
- Napredni bio-senzorji bodo del vsakdanje tehnologije (zdravstveno spremljanje v realnem času).

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PRIHODNOST

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Kam gredo storitve: trojček/četverček ali bo samo internet in vse OTT?

- Tradicionalni TV paketi bodo skoraj izginili, nadomestili jih bodo OTT paketi ali popolnoma prilagojena vsebina na zahtevo.
- Operaterji se bodo preoblikovali v "digitalne agregatorje", ki bodo ponujali internet + možnost dodajanja različnih storitev (Netflix, Spotify, gaming).
- Povezljivost bo postala primarna storitev, vse drugo bodo dodatne digitalne vsebine.

Kaj to pomeni za operaterje in uporabnike?

- Uporabniki bodo imeli več fleksibilnosti – plačali bodo samo internet in si po želji dodajali storitve.
- Operaterji se bodo morali prilagoditi in namesto prodaje TV paketov ponujati dodatne storitve, kot so VOD (video na zahtevo), gaming, varnostne rešitve, pametni dom, oblak ipd.
- Konvergenca fiksnega in mobilnega interneta – uporabniki ne bodo več ločevali med mobilno in Wi-Fi povezavo, vse bo povezano v enotno storitev.

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KOLIKO OPERATERJEV?

Za koliko operaterjev je prostora pri dveh milijonih prebivalcev?

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- **Velikost trga in povpraševanje –** Čeprav se zdi, da manjši trg pomeni manj operaterjev, lahko konkurenca ostane visoka, če je dovolj povpraševanja in če regulator omogoča konkurenčne pogoje. Penetracija mobilne v SLO 130 %, v nekaterih državah 250 %.
- **Infrastruktura –** Večji operaterji z lastnimi omrežji imajo konkurenčno prednost, manjši pa pogosto uporabljajo infrastrukturno gostovanje (najem omrežja od večjih).
- **Regulacija in konkurenca –** Če je trg močno reguliran in spodbujena konkurenca, lahko obstaja več ponudnikov, ki uporabljajo enako infrastrukturo.
- **Profitabilnost –** Če je trg premajhen za donosno poslovanje več operaterjev, pride do združitev ali prevzemov, kar zmanjša število ponudnikov. Na področju mobilne telefonije to ni tako prisotno kot na področju manjših CATV operaterjev.

Primeri dogajanja v zadnjem desetletju

- Trije operaterji mobilne s svojim omrežjem. Ni ambicij po prihodu novih.
- Pojav virtualnih mobilnih operaterjev – vzamejo le mali tržni delež.
- Konsolidacija CATV trga. Agregatorski ponudniki premalo učinkoviti.

Regulatorni pogled na optična omrežja
A regulatory view on fiber networks

Stanko Taškov
Agencija za komunikacijska omrežja in storitve Republike Slovenije
stanko.taskov@akos-rs.si

Povzetek
Evropski zakonodajni okvir se prilagaja prehodu iz monopolne tržne strukture na oligopolno, kar zahteva spremembe v zakonodaji. Direktiva o znižanju stroškov širokopasovnih omrežij (Broadband Cost Reduction Directive - BCRD) se nadgrajuje v Akt o gigabitni infrastrukturi (Gigabit Infrastructure Act - GIA). Evropski zakonik o elektronskih komunikacijah (European Electronic Communications Code - EECC) opredeljuje smeri nadaljnjih sprememb, kar vključuje prispevke, kot so bela knjiga, poročili Maria Draghija in Enrica Lette ter odzivi deležnikov. V okviru EECC se vidik varnosti preusmerja v Direktivo NIS2, medtem ko se hkrati oblikuje Zakon o digitalnih omrežjih (Digital Network Act), ki dodatno naslavlja izzive digitalne infrastrukture.

Abstract

The European legislative framework is adapting to the transition from a monopolistic market structure to an oligopolistic one, requiring changes in legislation. The Broadband Cost Reduction Directive (BCRD) is being upgraded to the Gigabit Infrastructure Act (GIA). The European Electronic Communications Code (EECC) defines the direction of future changes, incorporating contributions such as the white paper, the Draghi and Letta reports, and stakeholder reactions. Within the EECC, security aspects are being shifted to the NIS2 Directive, while the Digital Network Act is being developed to further address challenges related to digital infrastructure.

Biografija avtorja

Stanko Taškov je diplomiral na Fakulteti za elektrotehniko in računalništvo Univerze v Ljubljani ter magistriral na Fakulteti za elektrotehniko. Poklicno pot je začel leta 1990 v podjetju Iskra Elektrozveze, nato pa nadaljeval v Iskratelu, kjer je napredoval do vodstvenih položajev in vodil razvoj telekomunikacijskih rešitev. Leta 2011 se je pridružil podjetju Halcom kot projektni vodja za mobilno bančništvo, leto kasneje pa prevzel vodenje IT na AKOS-u. Kasneje je delal na Oddelku za regulacijo elektronskih komunikacij in sodeloval pri mednarodnih projektih v Gruziji. Od leta 2024 vodi Sektor za elektronske komunikacije, kjer je odgovoren za regulacijo telekomunikacijskih trgov in sodelovanje z mednarodnimi organizacijami.

Author's biography
Stanko Taškov graduated from the Faculty of Electrical Engineering and Computer Science at the University of Ljubljana and later earned a master's degree from the Faculty of Electrical Engineering. His professional career began in 1990 at Iskra Elektrozveze, followed by Iskratel, where he was promoted to leadership positions and led the development of telecommunications solutions. In 2011, he joined Halcom as a project

manager for mobile banking solutions and took over IT management at AKOS a year later. Later he worked in the Department for Electronic Communications Regulation and participated in international projects in Georgia. Since 2024, he has been leading the Sector for Electronic Communications, responsible for telecommunications market regulation and cooperation with international organizations.

Regulacija trgov elektronskih komunikacij

Seminar optičnih komunikacij

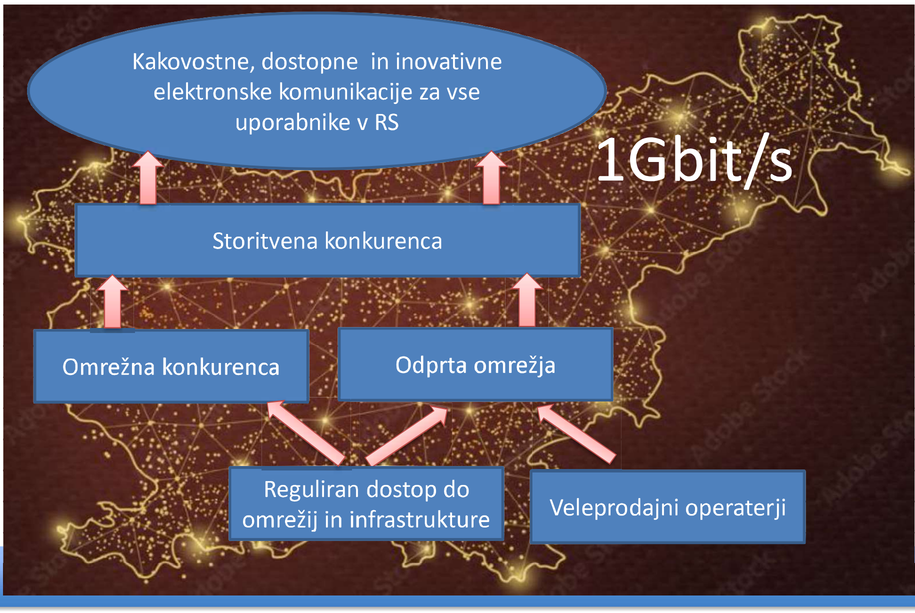
Ljubljana, 7.2.2025

Spremembe na trgu

- Iz monopolnega trga komunikacij in množice ponudnikov storitev trg prehaja v oligopolnega tako pri komunikacijah kot pri ponudnikih storitev
- Ogromne spremembe v verigi dodane vrednosti
  - Glavna inovacije in glavni zaslužki so v storitvah, elektronske komunikacije so zgolj infrastruktura
  - Strateško obvladovanje ključnih točk pri uvajanju novih storitev s strani nekaj ponudnikov (primer Google, Microsoft, …)
- Njeno Veličanstvo uporabniška izkušnja
- Bliskovite tehnološke spremembe, oblačne tehnologije, umetna inteligenca, obogatena in virtualna resničnost, kvantno računalništvo
- Optika je v zlati dobi: nesporno zmagovalna tehnologija, ki se še vedno izjemno hitro razvija, ponekod pa se že kažejo omejitve, zlasti ekonomske

AKOS

Glavni cilji regulacije trga elektronskih komunikacij



- Storitvena konkurenca povsod po ozemlju republike Slovenije
- Omrežna konkurenca povsod kjer je ekonomsko upravičeno / odprta omrežja
- Racionalno investiranje: skupne gradnje in souporaba infrastrukture
- Nizke vstopne ovire

AKOS

Glavni izzivi evropske regulacije

- Povečanje konkurenčnosti EU kot celote
- Ponovno postati ena od vodilnih regij po razvitosti komunikacij (fiksno in mobilno)
- Pomanjkanje inovacij: telekomi malo inovirajo, večino inovacij prispevajo ponudniki opreme in programske hiše, pa tudi tu evropski ponudniki zaostajajo
- Zmanjšati zaostanek na področjih digitalnih storitev
- Varnost in odpornost omrežij
- Overbuild v urbanih področjih, slabo omrežje v ekonomsko manj zanimivih področjih → kako spodbuditi vlaganja na redkeje poseljenih področjih?

AKOS

Bela knjiga, Poročili Draghija in Lette

- Nizek ARPU v primerjavi z glavnimi konkurenti (Fiksna omrežja: ZDA: 58,6€, EU: 22,8€, Japonska 24,4 €, Koreja 13,1 €)
- Zelo fragmentiran trg → operaterji ne dosegajo ekonomije obsega

}

- Operaterji težko zberejo kritično maso za velike investicije in inovacije
- Zaostajanje pri uvedbi prebojnih tehnologij (npr. 5G)

- Kot ukrepe za izboljšanje priporočajo
  - Koncentracije na trgu vključno s popravki regulacije, ki bi bila naklonjena manjšemu številu vseevropskih operaterjev
  - Večja sinhronizacija regulacije, zlasti na področju dodeljevanja frekvenc
  - Vseevropski (veleprodajni) produkti
  - Čezmejno sodelovanje
  - Fokus investicij v nepokrita področja, ne pa postavljanje še n-te infrastrukture v mestih

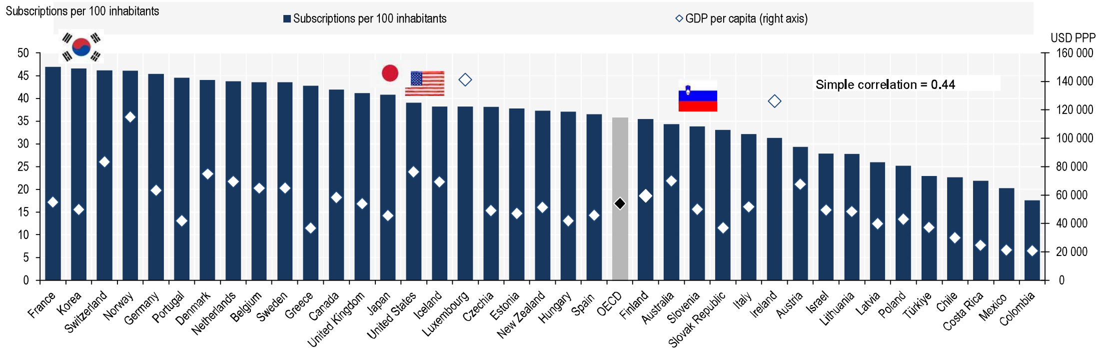
AKOS

Bela knjiga, Poročili Draghija in Lette – odzivi deležnikov

- Odzivi po pričakovanjih
  - Razmeroma naklonjeni pri velikih operaterjih
  - Zelo odklonilni pri alternativnih operaterjih
  - Odklonilni pri manjših državah članicah, ki nimajo potencialnih kandidatov za vseevropskega operaterja (nevarnost marginalizacije)
  - Problem v manjših državah tudi s stališča nacionalne varnosti, lokacija obdelave osebnih/prometnih podatkov izven države (kritične komunikacije, OPT s prednostjo, PPDR, etc.)

AKOS

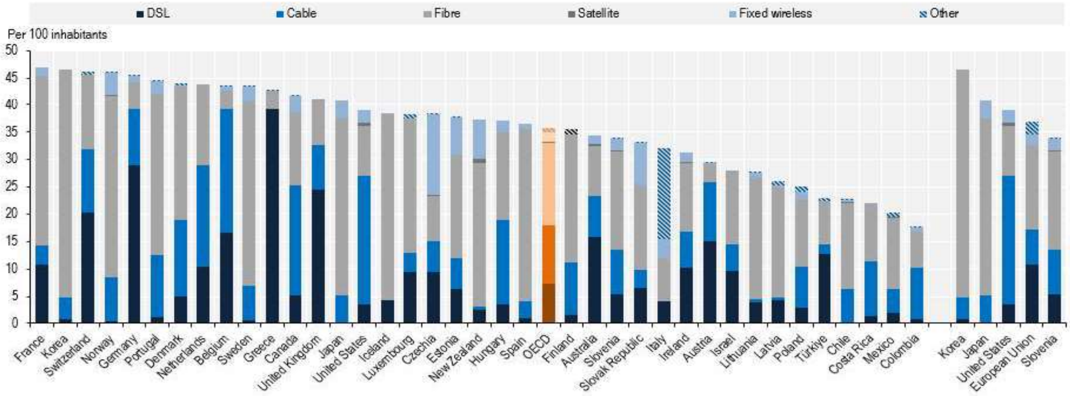
BDP vs. naročnine na širokopasovni dostop



- Obstaja šibka korelacija med BDP in številom naročnin na 100 prebivalcev
- Veliko faktorjev, ki imajo vpliv, ki bi ga bilo potrebno izločiti (npr. velikost gospodinjstva)

AKOS

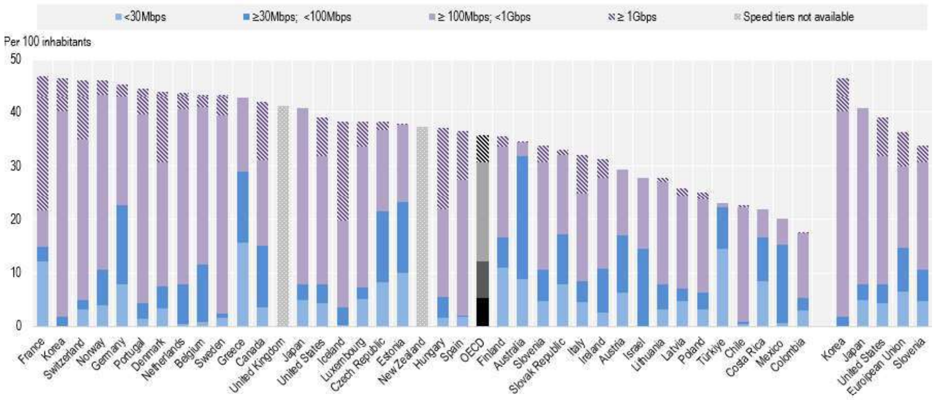
Fiksni širokopasovni dostop



- Število naročnikov na 100 prebivalcev med EU in ZDA nekoliko odstopa (39,1 : 36,8)
- V primerjavi z ZDA je v EU veliko DSL, a tudi veliko več optike. V ZDA je veliko kabla
- Podatki za Kitajsko v OECD statistiki niso dostopni, statistika Svetovne banke imajo neprimerljive podatke

AKOS

Hitrosti fiksnega dostopa



- Hitrost v Koreji zelo odstopa, tudi v ZDA so višje. Na Japonskem le malo naročnin nad 1 Gbit/s. V EU še veliko hitrosti pod 100 Mbit/s
- EU zelo neizenačena: prvak je Francija, ki ima 50% naročnin 1Gbit/s+ (pa tudi 25% pod 30 Mbit/s), po drugi strani pa ima Grčija 68% naročnin manj kot 100 Mbit/s

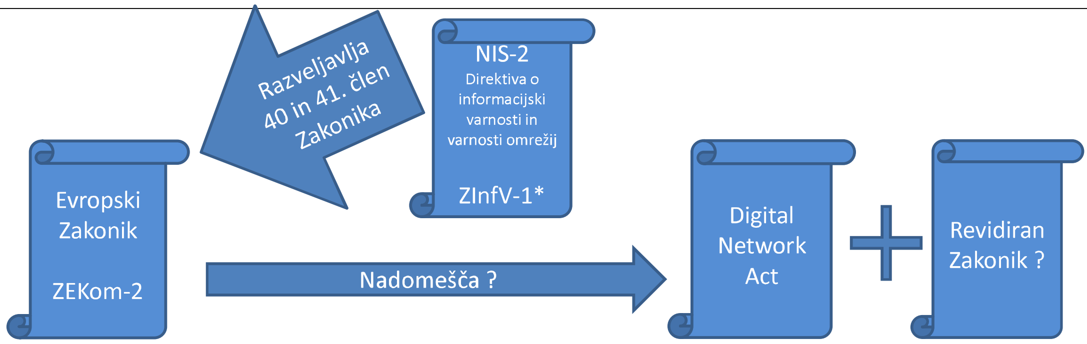
AKOS

Razvoj evropskega regulatornega okvirja

- Ambiciozni evropski (in slovenski) cilji: gigabitna povezljivost za vse do 2030
- Koliko (fiksnih) omrežij je že dovolj za učinkovito konkurenco?
- Ali je sploh še potrebna predhodna (ex-ante) regulacija → ali zadošča samo simetrična regulacija + konkurenčno pravo
- Sinhronizacija zakonodaje in posledično regulacije: V zadnjem času se vse bolj uporabljajo Uredbe (direktno veljavne in uporabljive) namesto Direktiv, ki se morajo prenesti v nacionalno zakonodajo. Doseganje kompromisov na nivoju EU je težje.

AKOS

Razvoj evropskega regulatornega okvirja - omrežja

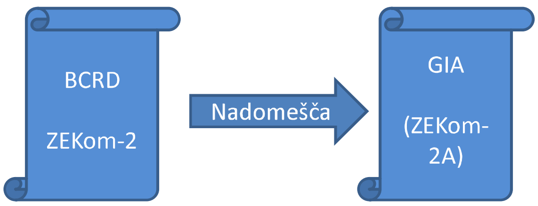


- EU je z Belo knjigo odprla prvi krog razprave o spremembah regulatornega okvirja. Smer še ni jasna, določila se bo konec 2025 ali v prvi polovici 2026
- Razprava o Zakoniku je še v začetni fazi.

ZInfV-1 – Zakon o informacijski varnosti je še v pripravi
ZEKom-2 – Zakon o elektronskih komunikacijah

AKOS

Razvoj evropskega regulatornega okvirja – gradbeniška infrastruktura

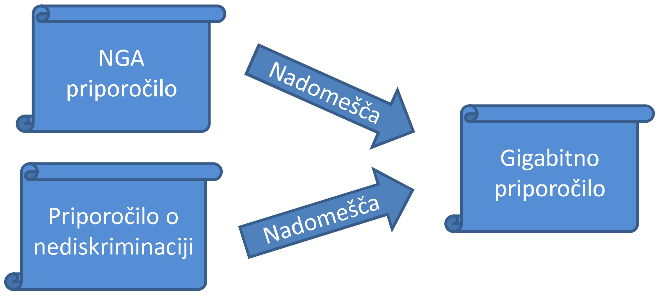


- BCRD je bil povsod po EU (ne samo v Sloveniji) manj neuspešen
- GIA je začela ambiciozno, a na koncu ni prinesla večjih sprememb
- Smernice, ki jih mora sprejeti BEREC gredo trenutno bolj v smeri splošnih dokumentov

BCRD – Broadband Cost Reduction Directive
GIA – Gigabit infrastructure Act

AKOS

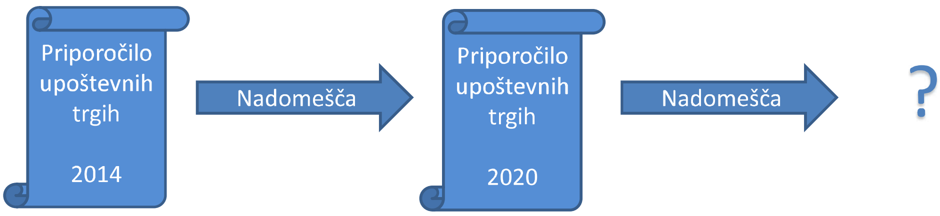
Razvoj evropskega regulatornega okvirja – omrežja



- Gigabitno priporočilo je podobno predhodnima dokumentoma, še največ novosti je pri ukinjanju bakrenega omrežja
- Cenovna sidra se postopoma opuščajo (ali pa vsaj posodabljajo)

AKOS

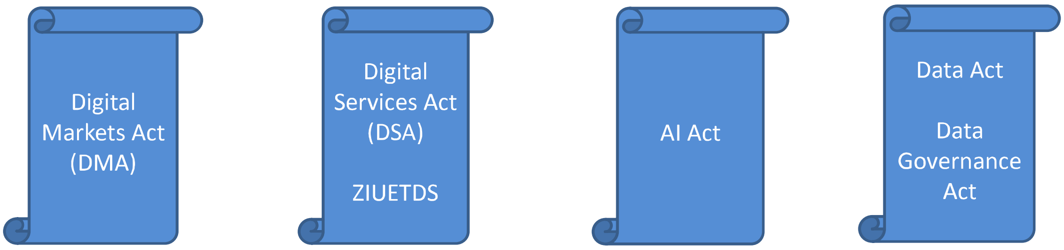
Razvoj evropskega regulatornega okvirja - omrežja



- Sedanje Priporočilo Komisije predvideva le še dva upoštevna trga na nivoju EU
- Pričakuje se revizija, morda bo Priporočilo ukinjeno. Breme dokazovanja, da je potrebna predhodna regulacija, bo tako za vse trgi v celoti na regulatorju
- Ponekod v EU se kot dodaten upoštevni trg uveljavlja trg gradbeniške infrastrukture
  - Razlika od GIA je, da GIA velja za vse operaterje komunikacij (in druge lastnike gospodarske javne infrastrukture), upoštevni trg pa le za operaterja s pomembno tržno močjo

AKOS

Razvoj evropskega regulatornega okvirja - storitve



- Vsi akti so Uredbe, torej so direktno uporabljajo
- Izvajanje DMA je izrecno v pristojnosti Evropske Komisije
- V primeru DSA in AI akta sta potrebna izvedbena zakona, ki določita nosilca nacionalnih nalog. Izvedbeni zakon za AI akt je še v pripravi.
- AI Act in Data Act sta že sprejeta, AI Act se uporablja šele v manjšem delu, Data Act pa še ne

ZIUETDS - Zakon o izvajanju Uredbe (EU) o enotnem trgu digitalnih storite

Izzivi pri izvajanju diagnostike na PON

PON Diagnostic Challenges

Mitja Golja

Kontron

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Povzetek

Za nemoteno izvajanje širokopasovnih storitev je potrebna naprednejša diagnostika v optičnih omrežjih. V podjetju Kontron smo k tem izzivu pristopili celostno in zagotavljamo diagnostiko na različnih nivojih (fizični nivo, omrežni nivo, aplikacijski nivo). V predavanju bomo predstavili različne načine diagnostike, izzive s katerimi smo se srečali pri vpeljavi in potrebne spremembe na produktih.

Abstract

For the reliable operation of broadband services, more advanced diagnostics in optical networks are required. At Kontron, we have developed end-to-end approached this challenge and provide diagnostics at different levels (physical level, network level, application level). We will present different methods of diagnostics, the challenges we encountered during implementation, and the necessary changes to the products.

Biografija avtorja

Mitja Golja je zaposlen v podjetju Kontron kot direktor razvoja poslov v poslovni enoti dostop. Odgovoren je za pripravo tržnih strategij in razvoja poslov novih tehnologij. Ima več kot 15 let izkušenj z globalnimi širokopasovnimi operaterji in se strastno ukvarja z razvojem produktov, poslovnih modelov in strategij. Pred vodenjem razvoja poslov je delal na več vodilnih pozicijah v podjetju Iskratel, med drugim je bil odgovoren za vodenje produktne linije in razvoja.

Author's biography

Mitja Golja is a Business Development Director at Kontron's Business Unit Broadband. He is responsible for new market strategies and go-to-market initiatives for new technologies. He brings 15+ years of global operating experience in the broadband-networking industry and a deep passion for product business development and strategy to Kontron. Prior to heading business development, Mitja held various management positions within Iskratel. Amongst others he was in charge for product line management and R&D.

Izzivi pri izvajanju diagnostike na PON

Dr. Mitja Golja

Februar 2025

Zakaj izvajati diagnostiko optičnih omrežij?

- Nemoteno zagotavljanje storitev
- Izpolnjevanje SLA
- Skrb za zadovoljstvo uporabnikov

Tipični problemi na optičnih omrežjih 1/2

Okvare na fizični infrastrukturi:

- prekinitev vlakna (gradbena dela, glodalci, vremenski pojavi, itd.)
- umazani oz. poškodovani konektorji itd.
- slabljenja zaradi krivin
- problemi na spojih – splicing
- vstop vode v spojke, konektorje itd.

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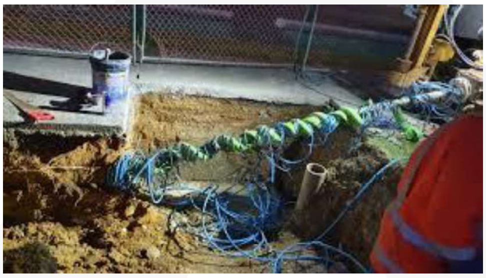
Primeri: gradbena dela



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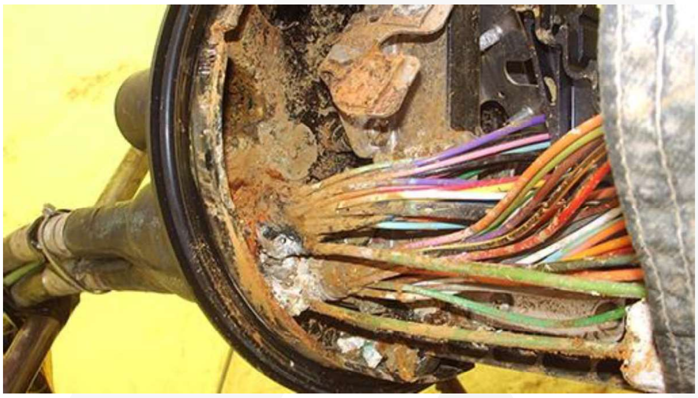
Vir: https://www.norscan.com/5-cable-killers-that-destroy-buried-fiber-cable/

Primeri: Vdor vode/sneg v optično spojko



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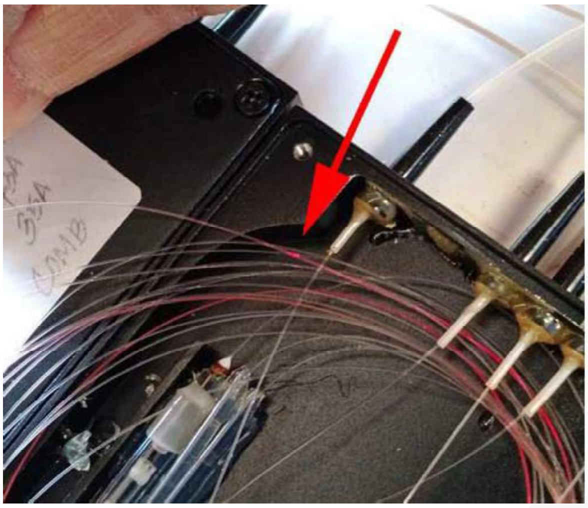
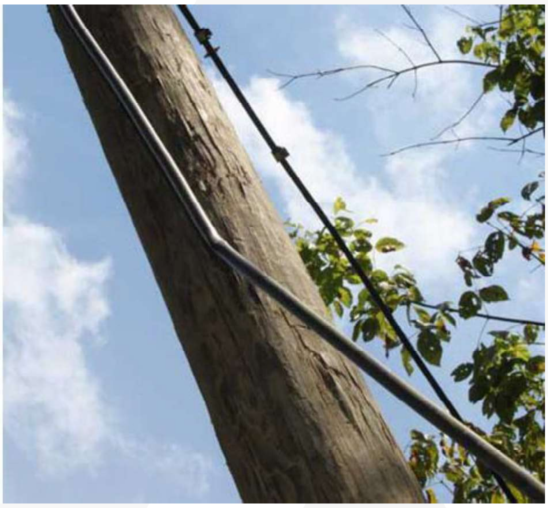
Vir: https://www.norscan.com/5-cable-killers-that-destroy-buried-fiber-cable/

Primeri: izgube zaradi krivin, poškodb





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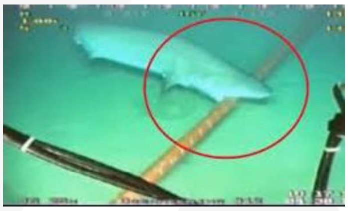
Vir: https://www.norscan.com/5-cable-killers-that-destroy-buried-fiber-cable/

Primeri: poškodbe s strani živali





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Vir: https://www.norscan.com/5-cable-killers-that-destroy-buried-fiber-cable/

Primeri: vremenski vplivi - strela

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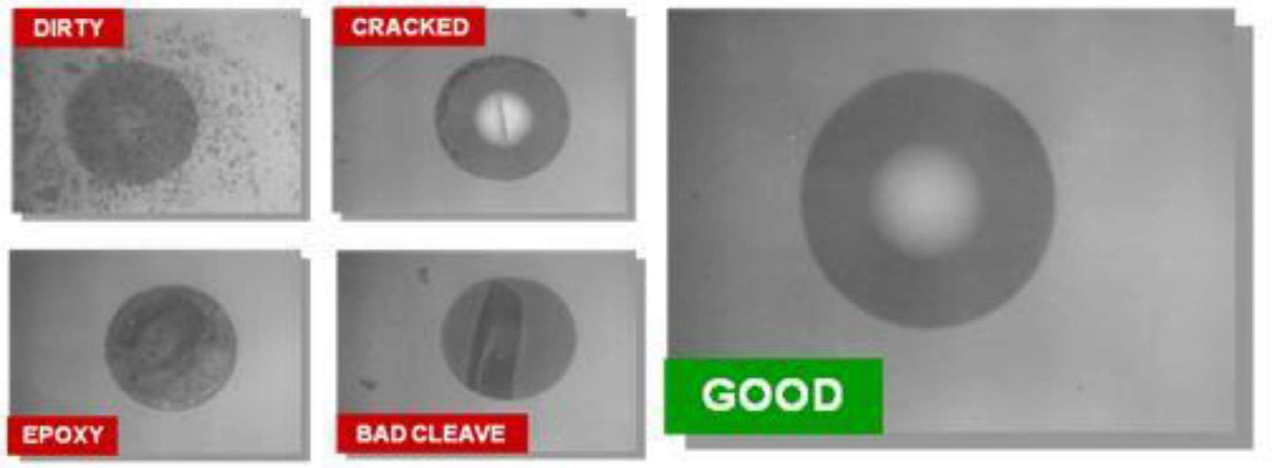
Vir: https://www.norscan.com/5-cable-killers-that-destroy-buried-fiber-cable/

Umazani in poškodovani konektorji



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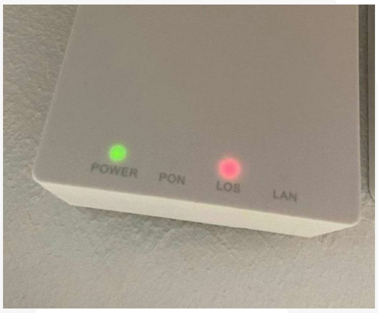
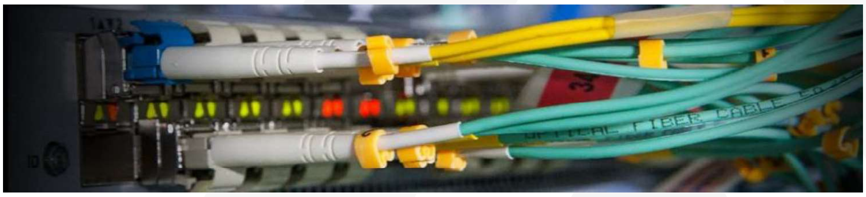
Tipični problemi na optičnih omrežjih 2/2

Okvare na aktivni opremi:

- Izpad napajanja
- Problemi na ONT/OLT opremi
  - SW problemi
  - Napačne konfiguracije
- Težave na zalednih sistemih
- Staranje opreme





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Diagnostika in meritve

- Izvajanje na različni nivojih in opremi
  - fizična infrastruktura
  - podatkovni nivo

- Tipične meritve fizične infrastrukture pri inštalaciji in obratovanju:
  - slabljenje (dB), povratno optično slabljenje (dB), dolžina (metrih), moč (dBm)
  - Uporaba OTDR

- Diagnostika in mertive na aktivni opremi
  - Moči signalov OLT in ONT, različni števci prometa in statusi, alarmi
  - Aktivne prometne meritve (npr. Speedtest)

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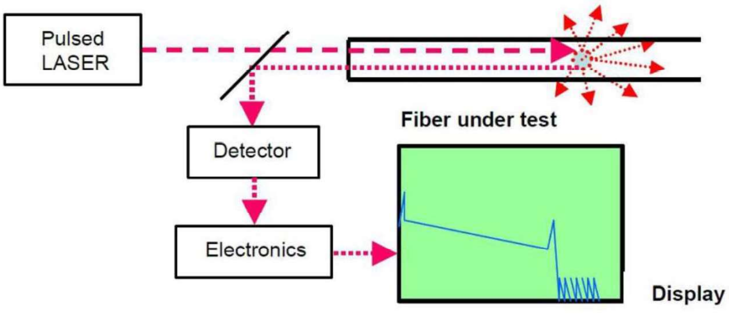
OTDR meritve

OTDR - Optical Time Domain Reflectometer

Optična reflektometrija v časovnem prostoru



Detekcija in lokacija napak, določanje izgub signala na optični poti

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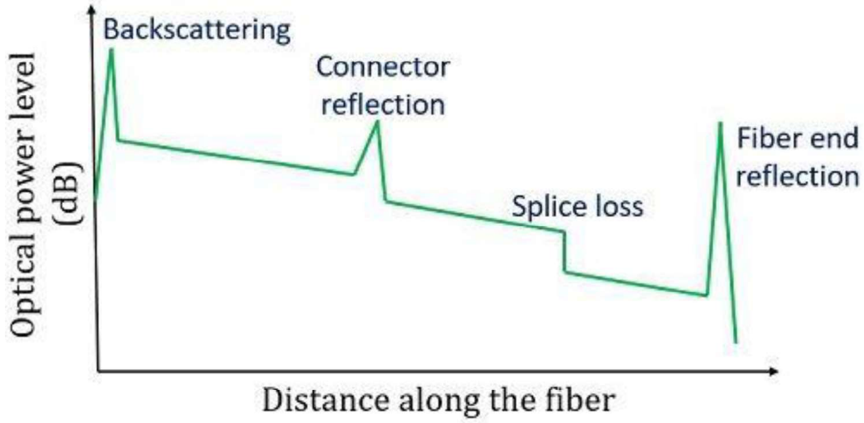
Vir: Medium.com, Introduction to OTDR

Tipični prikaz OTDR meritve



Fresnelov odboj na zvarih in napakah v trasi

Odboji na konektorjih

Rayleigh-ov sipanje po vlaknu

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Vir: https://circuitglobe.com/optical-time-domain-reflectometer.html

Zahteve za CPE/ONT pri uporabi OTDR

- Wavelength range: 1650 ± 5 nm
- Nominal reflectance 1645 to 1655: Target -26 ± 3 dB
- Reflectance Ripple 1645 to 1655: < 1dB (using < 0.2 nm laser linewidth)
- Temperature dependency 15°C to 35°C: < 0.5 dB

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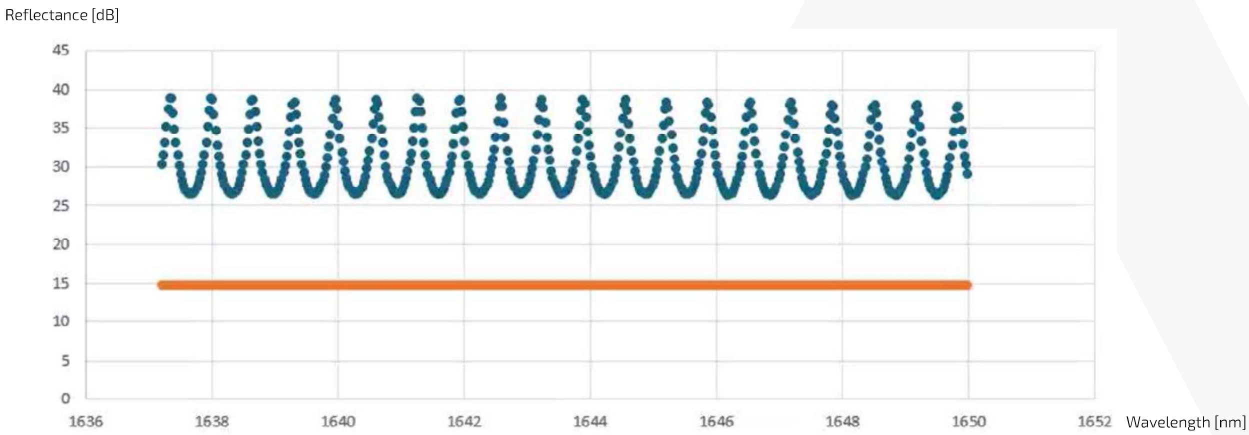
Frekvenčna odvisnost refleksije v CPE/ONT napravah



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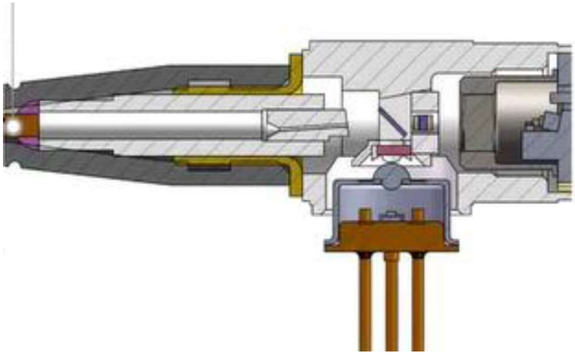
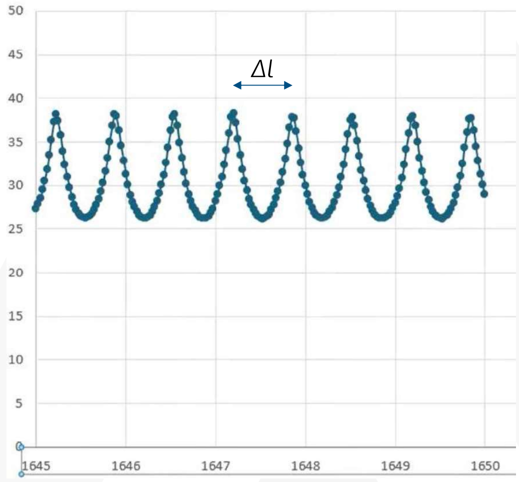
Zgradba BOSA - Bidirectional Optical Sub. Assembly

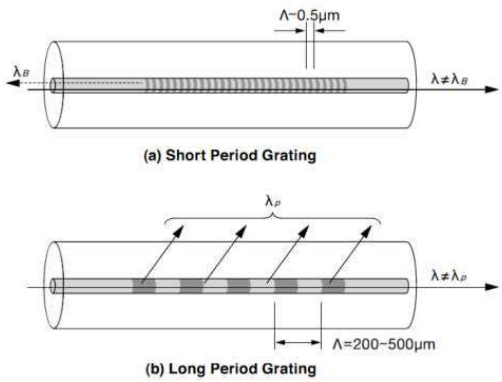


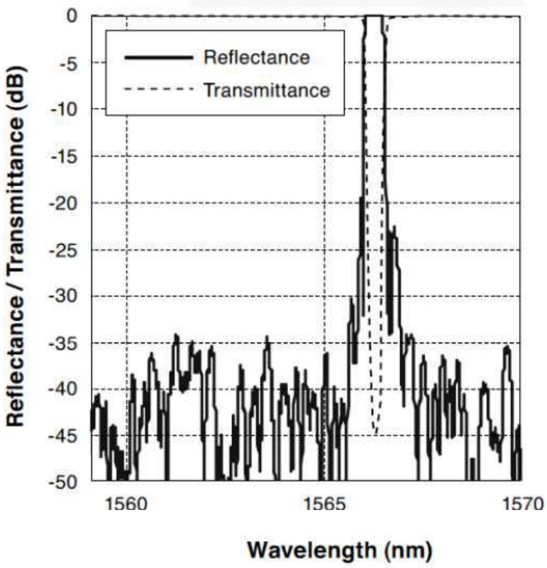


$$\Delta l = \frac{\lambda_0^2}{2 \cdot \Delta\lambda} = \frac{\lambda_0^2}{2 \cdot (FSR)} = \frac{(1640nm)^2}{2 \cdot (0.67nm)} = 2mm$$

OTDR reflektorji

– Uporaba Braggove strukture



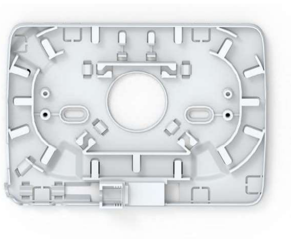
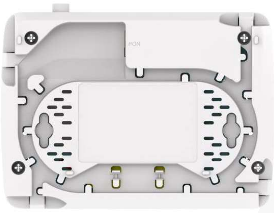


Vir: Sumitomoelectric, Technical Note of Fiber Bragg Grating embedded Fiber Optic Reflector

Tipi OTDR reflektorjev

- Vmesniki, konektorji, vlakenski element

- Lokacija reflektorja!
- Karakteristike (smernost, primerna odbojnost)!

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Aktivne prometne meritve

Aktivne prometne meritve

- Omogočajo realne vpogled v delovanje storitev preko celotne omrežja
- Običajne meritve: prenos k sebi (download), prenos od sebe (upload), zakasnitev, izgube paketov,…
- Standardi, aplikacije:
  - TR-143 (Enabling Network Throughput Performance Tests and Statistical Monitoring),
  - TR-471 (Maximum IP-layer Capacity Metric and Methods of Measurement)
  - Speedtest by Ookla
  - iPERF, nPERF, SamKnows,…
- Testiranje specifičnih aplikacij, storitev, protokolov

Izzivi aktivnih meritev

- Pri izvajanju aktivnih meritev se moramo zavedati omejitev omrežja, strežnikov in klientov, npr:
  - Wi-Fi omejitve
  - Performančne omejitve PC, mrežnih kartic, klientov, itd.
  - Zasedenost omrežja z drugimi storitvami (statistični multipleks)
- Interpretacija rezultatov!

Sklep

- Potrebno je izvesti meritve optičnega omrežja ob inštalaciji
- Diagnostika in izvajanje različnih meritev med obratovanjem
  - Različni nivoji: L1-L7
  - Različne storitve in aplikacije
- Pomembnost pravilne interpretacije rezultatov

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Thank You for Attention

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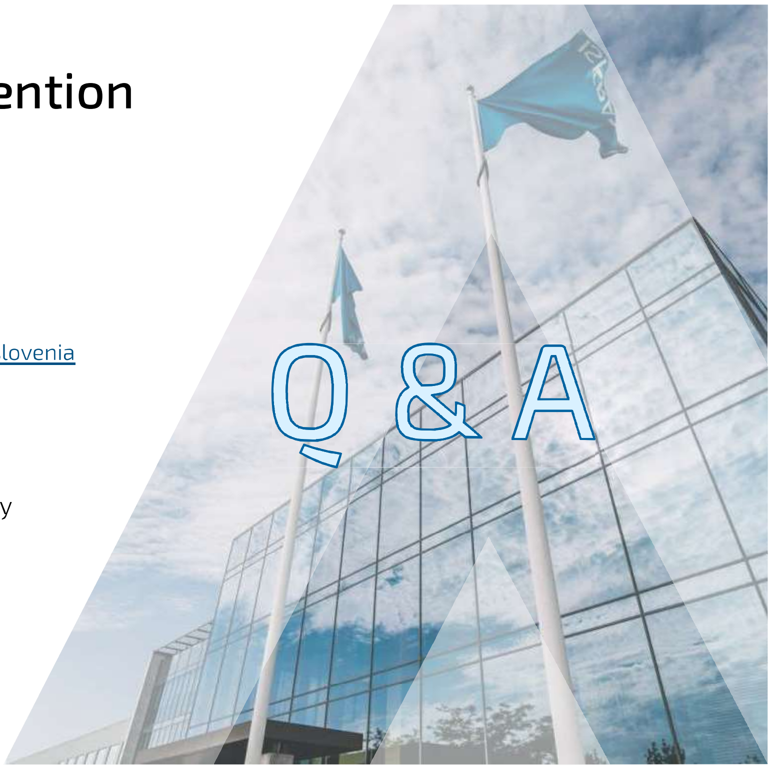
Family Friendly Enterprise



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Testiranje in uvedba opreme novejše generacije v pasivnem optičnem omrežju Telekoma Slovenije

Testing and implementation of newer generation equipment in Telekom Slovenije's passive optical network

Tomislav Goluža

Telekom Slovenije

tomislav.goluza@telekom.si

Povzetek

Razvoj optičnih omrežij je ključen za razvoj gigabitne družbe. Večina trenutnih dostopovnih omrežjih temelji na topologiji točka-več točk. Kljub temu da trenutni vzorci prometa kažejo na dejstvo, da tehnologija GPON zadostuje potrebam uporabnikov operaterji postopoma uvajajo tudi novejše PON tehnologije, kot je XGSPON. Za uspešno uvedbo PON tehnologij novejših generacij je pomembna interoperabilnost med proizvajalci aktivne opreme. Operater kot uporabnik opreme tukaj igra pomembno vlogo pri testiranju in uvedbi opreme v svoje omrežje. Pri testih je poleg priporočil organizacij, ki skrbijo za standarde pomembno upoštevati resnične scenarije uporabe opreme v omrežju v katerem sobivajo različni ponudniki storitev na različnih tipih uporabniške opreme. Za prehod uporabnika na novejšo tehnologijo je potrebno zamenjati ali nadgraditi obstoječo aktivno opremo in izvesti prehod vseh uporabnikov na istem razcepniku na novo opremo. Prihod 25GPON in 50GPON tehnologij bo od ponudnikov storitev zahteval premislek in odločitev katero od teh tehnologij in na kakšen način vključiti v svoje obstoječe optično distribucijsko omrežje da bo možno sobivanje v frekvenčnem prostoru. Ključna odločitev, ki jo bo operater moral sprejeti bo ali ohraniti GPON tehnologijo v omrežju in jo združiti z novimi tehnologijami ali pa se popolnoma preusmeriti na XGSPON in naprej.

Abstract

The development of optical networks is key to the development of a gigabit society. Most current access networks are based on a point-to-multipoint topology. Despite the fact that current traffic patterns indicate that GPON technology meets the needs of users, operators are gradually introducing newer PON technologies, such as XGSPON. Interoperability between active equipment manufacturers is important for the successful introduction of newer generation PON technologies. The operator, as the user of the equipment, plays an important role in testing and introducing equipment into its network. In addition to the recommendations of organizations responsible for standards, it is important to consider real scenarios of equipment use in a network in which different service providers coexist on different types of user equipment. In order to transition a user to a newer technology, it is necessary to replace or upgrade the existing active equipment and transition all users on the same splitter to new equipment. The arrival of 25GPON and 50GPON technologies will require

service providers to consider and decide which of these technologies and how to integrate them into their existing optical distribution network to enable coexistence in the frequency space. The key decision that the operator will have to make will be whether to maintain GPON technology in the network and combine it with new technologies or to completely switch to XGSPON and beyond.

Biografija avtorja

Tomislav Goluža je magistriral na Fakulteti za elektrotehniko Univerze v Ljubljani. V Telekomu Slovenije je zaposlen 16 let. Zaposlen je v Razvojnem laboratoriju, kjer opravlja testiranje MSAN in CPE opreme in pripravlja tehnične rešitve za vpeljavo v produkcijsko omrežje Telekoma Slovenije. Poleg testiranja skrbi za vpeljavo nove opreme in tehnologij v fiksnem širokopasovnem dostopovnem omrežju Telekoma Slovenije. Ukvarja se tudi z raziskavami in razvojem na področju fiksnega širokopasovnega dostopa, v zadnjem času s poudarkom na PON tehnologijah.

Author's biography

Tomislav Goluža holds a master's degree from the Faculty of Electrical Engineering, University of Ljubljana. He has been with Telekom Slovenije for 16 years. He is employed in the Development Laboratory, where he performs testing of MSAN and CPE equipment and prepares technical solutions for introduction into the production network of Telekom Slovenije. In addition to testing, he is responsible for the introduction of new equipment and technologies in the fixed broadband access network of Telekom Slovenije. He is also engaged in research and development in the field of fixed broadband access, with a recent emphasis on PON technologies.

Testiranje in uvedba opreme novejše generacije v pasivnem optičnem omrežju Telekoma Slovenije

27. seminar Optične komunikacije

Tomislav Goluža
Ljubljana, 5. februar 2025

TelekomSlovenije

Agenda

1. Uvod – Skupina Telekom Slovenije
2. Izvedba GPON in XGSPON tehnologije v omrežju TS
3. Izzivi pri testiranju skladnosti PON aktivne opreme
4. Sobivanje PON tehnologij; 25GS-PON in/ali 50G-PON

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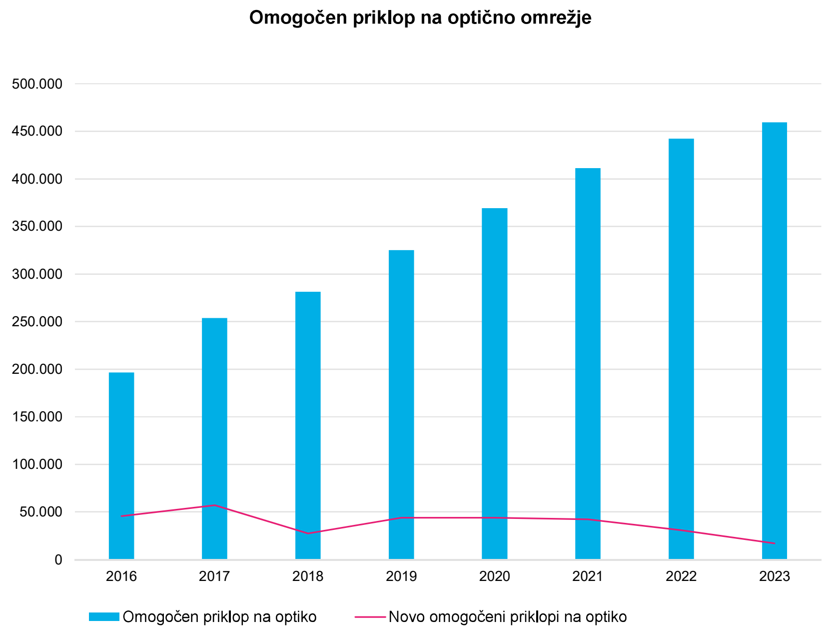
Priklop na optično omrežje omogočamo več kot polovici slovenskih gospodinjstev

Telekom Slovenije upravlja z največjim omrežjem v državi.

Smo v fazi intenzivne modernizacije mobilnega omrežja. Konec leta 2023 smo s tehnologijo 5G pokrivali več kot **60 % prebivalstva,** s tehnologijo LTE/4G pa več kot 97 % prebivalstva.

Možnost priklopa na lastno optično omrežje omogočamo že več kot **460.000** oziroma **več kot polovici slovenskim gospodinjstvom**.



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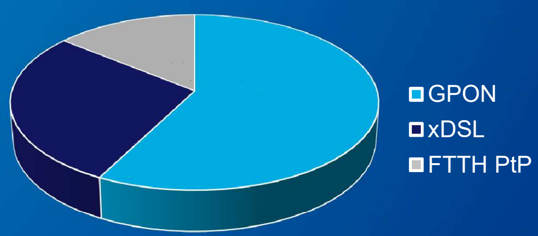
Fiksni širokopasovni dostop v TS (1)

- **Časovnica – ključni mejniki:**
  - **2002: ADSL (IPTV storitev v letu 2003)**
  - **2003; uvedba IPTV**
  - **2007: FTTH PtP in VDSL2**
  - **2015: IPTV service over LTE**
  - **2016: GPON**
  - **2017: G.Fast field trial**
  - **2021: XGSPON (comboPON)**
  - **2022: 25-GSPON lab trial**
- **Delež uporabnikov po tehnologiji dostopa**



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Fiksni širokopasovni dostop v TS (2)

- Močna konkurenca - prisotnost štirih operaterjev
- TS PON omrežje odprto za druge operaterje po konceptu VULA (Virtual Unbundled Local Access)

- Prestavitev uporabnikov na PON:
  - Prestavitev z xDSL tehnologije (ADSL2+ in VDSL2)
  - Prestavitev z FTTH point-to-point dostopa (100Mbit/s ali 1Gbit/s)

- Vmesna rešitev (tam, kjer ni možen priklop na optiko):
  - FWA (Fixed Wireless Access)

GPON v TS (1)

- Uvedba leta 2016
- Močna vozlišča z možnostjo koncentracije velikega števila uporabnikov
- Uporablja se dva nivoja deljenja signala, do 64 uporabnikov
- Razpon (PON Link Range) 20km, realne razdalje največ do 40km

- Aktivna oprema:
  - Multi-vendor okolje - različni proizvajalci OLT in ONU opreme
  - Avtomatiziran proces konfiguracije, oz. vročanja storitev; integracija OLT/NMS v TS OSS sisteme

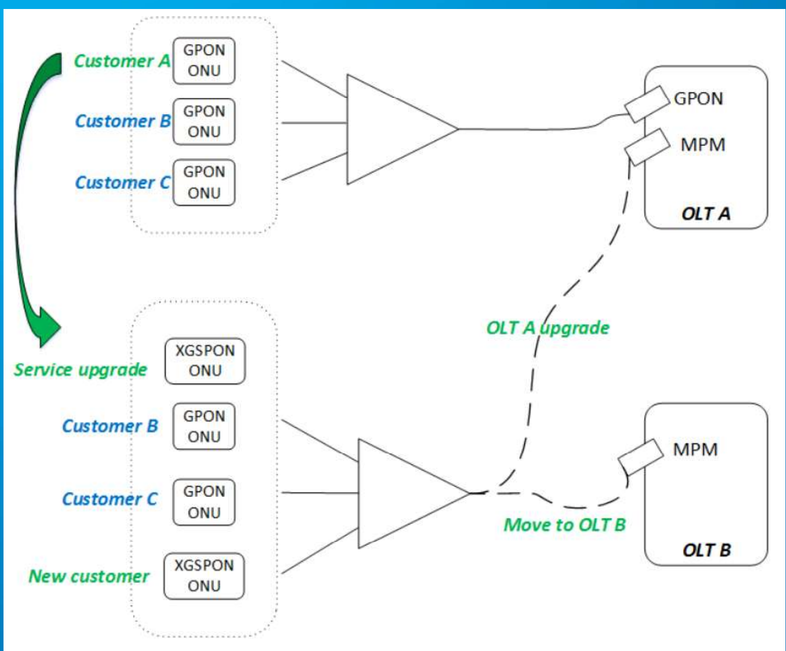
- Asimetrični internet paketi za rezidenčne uporabnike
- Hitrosti: do 1Gbit/s downstream

GPON v TS (2)

- Spremljanje vzorcev prometa na GPON OLT portih (2.5/1.25 Gbit/s) skupnih za več uporabnikov kaže da tehnologija trenutno zadostuje za večino uporabnikov

- Uporabniška oprema:
  - Rezidenčni GPON Gateway
  - Bridge ONU naprave (demarkacija v primeru VULA dostopa)
  - SFP ONU moduli – primerni za priklop poslovnih strank in agregacijo baznih postaj (podpora za PTP/SyncE)

Migracija uporabnika z GPON na XGSPON

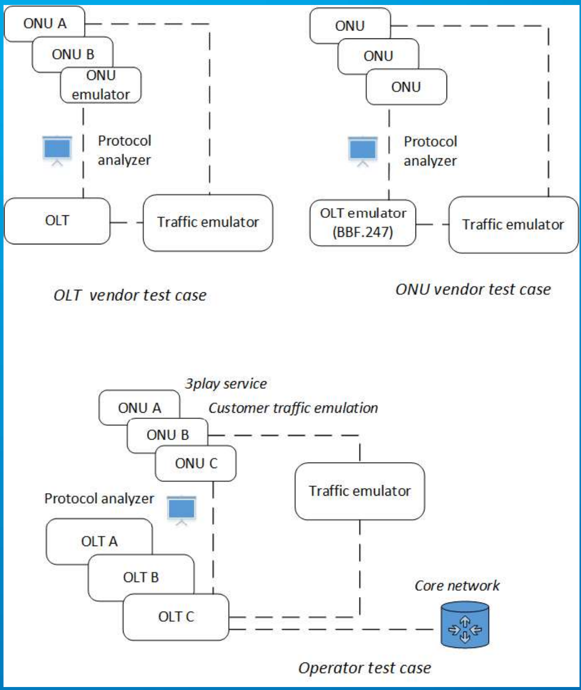


Nadgradnja storitve:
- Kapaciteta OLT 10/10 Gbit/s
- Internet paket (trenutno) 2Gbit/s v downstreamu

- Ob migraciji enega uporabnika je potrebno prestaviti celotno vejo uporabnikov na nov PON port, ki omogoča uporabo obeh tehnologij preko istega vlakna (combo)

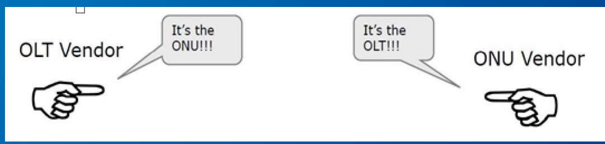
- OLT B = redundančno vpeto, visoko razpoložljivo vozlišče z zmogljivimi 10 in 100Gbit/s vmesniki

Skladnost in interoperabilnost PON



- Testiranje OLT
  - *TR-255 GPON Interoperability Test Plan*
- Testiranje in certifikacija ONU
  - *BBF.247 GPON ONU Certification*

- Testiranje OLT/ONU pri operaterju:
  - Testi interoperabilnosti (različni proizvajalci opreme, licence, itn.)
  - Upravljanje ONU naprav; OMCI (ONU management and Control Interface)
  - Testi specifične konfiguracije OLT/ONU, uporabniški primeri



Interoperabilnost - najbolj pogoste težave

- Težave z delovanjem multicast prometa: povezano z uporabo posebnega multicast GEM porta na OLT ali številom multicast kanalov na ONU
- Prioritizacija prometa v upstreamu na ONU
- Delovanje netagiranega prometa (brez VLAN oznake na vhodu)
- Prepustnost prometa (XGS-PON ONUs)
- Delovanje IPv6
- Težave ONU ob konfiguraciji različnih T-CONT tipov za različne storitve
- Težave z delovanjem storitev ob vklopljeni enkripciji (starejši ONU)
- Nepravilna sekvenca delovanja PON LED lučk na ONU
- Nadgradnja programske opreme ONU preko OMCI (bridge ONU)
- Povrnitev ONU na tovarniške nastavitve preko OMCI
- Podpora za PLOAM Dying gasp
- Neodzivanje ONU ali dolg odzivni čas na določene OMCI zahteve
- Nestabilno delovanje po prekinitvi na OLT portu

Težave na terenu – najbolj pogoste napake

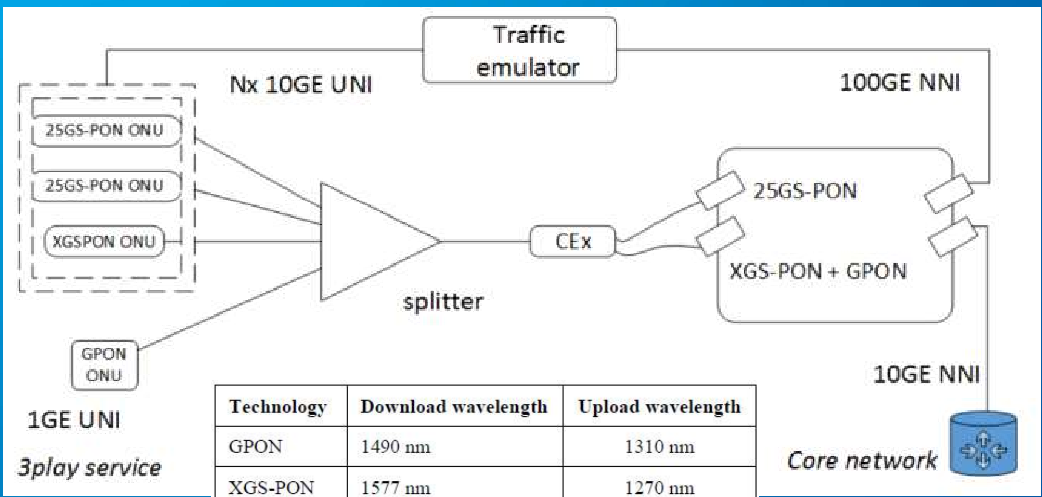
- Težave s sprejemom pri uporabniku:
  - ONU down (loss of signal)
  - Slab nivo sprejema. Pojav BIP (bit-interleaved parity) in HEC (header error code) napak.
  - Napačen konektor, neustrezno speljana vrvica
  - Vezava; napačen OLT port
  - Postavitev ONU pri uporabniku – pregrevanje.
  - Pomembno za diagnostiko: vpogled v zgodovino za uporabnika

- Napake na trasi; poslabšanje sprejema pri več uporabnikih hkrati
- Neodzivanje ONU ali daljši odzivni čas na določene OMCI zahteve

- Rogue ONU
- Napačni priklopi terminalne opreme – problem Alien

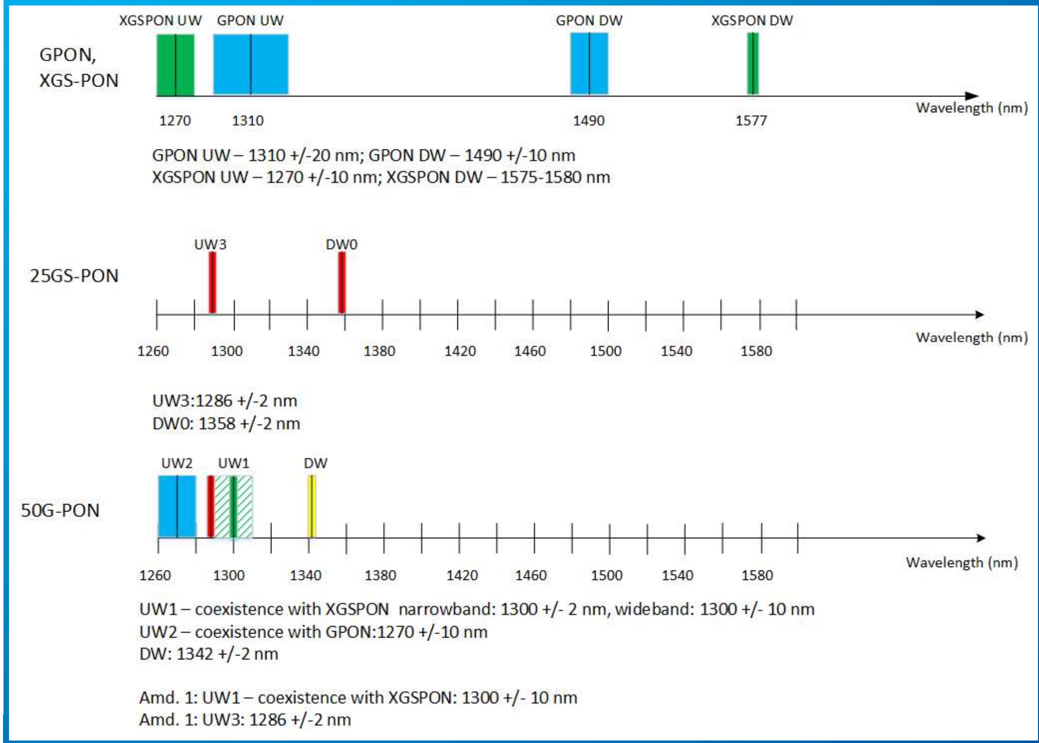
25GS-PON: test sobivanja z GPON in XGSPON

- 25GS-PON trial (25Gbps/10Gbps)



Technology	Download wavelength	Upload wavelength
GPON	1490 nm	1310 nm
XGS-PON	1577 nm	1270 nm
25GS-PON	1358 nm (DW0)	1286 nm (UW3)

Scenariji sobivanja PON (coexistence)



Trenutna combo rešitev:
GPON/XGS-PON

25GS-PON sobivanje:
- GPON/XGSPON/25GS-PON

50G-PON sobivanje:
- GPON/XGS-PON/50G-PON asymm.
- XGSPON/ 50G-PON symm.

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Zaključek

- **GPON je standardiziran leta 2004, vendar je še vedno prevladujoča tehnologija na fiksnem širokopasovnem dostopu. Vzorci prometa na OLT še vedno kažejo da zadostuje za večino uporabnikov.**
- **Prehod iz GPON na XGSPON se večinoma izvaja z uporabo combo opreme na strani OLT. Kljub temu da je standardiziran že leta 2016 pričakuje se da bo prehod na XGSPON v večji meri časovno sovpadal s prihodom WIFI7 tehnologije na domačih oddaljenih prehodih.**
- **Pri testiranju aktivne PON opreme (OLT in ONU) je poleg testov interoperabilnosti ključna preverba delovanja realnih scenarijev konfiguracije opreme.**
- **Vendor proprietary rešitve ne smejo biti sprejete s strani operaterja.**
- **Problem sobivanja PON tehnologij (upstream "busy area") – odločitev operaterja v bližnji prihodnosti – ohraniti GPON ali izvesti popoln prehod na XGSPON in naprej.**
- **Prehod na novejšo tehnologijo pogojuje cena in dostopnost ONU naprav.**

TelekomSlovenije

Hvala za pozornost!

tomislav.goluza@telekom.si

Optimizacija dostopovnega omrežja z vidika cen električne energije, vpliv XGS-PON na količino podatkovnega prometa in rezultati meritev Wi-Fi 7

Optimization in Terms of Electricity Costs, the Impact of XGS-PON on Data Traffic Volume, and Wi-Fi 7 Measurement Results

Gorazd Penko

T-2

gorazd.penko@t-2.com

Povzetek

V prispevku je predstavljena stroškovna analiza porabe električne energije z vidika naročniških CPE naprav v realnem omrežju, ter stroškovna analiza porabe električne energije z vidika dostopovnih omrežnih elementov tehnologij GPON, XGS-PON, P2P FTTH in VDSL2. Prikazan je tudi možen vpliv enega XGS-PON priključka na podatkovni statistični multipleks na dostopovnem omrežnem elementu. Omenjeni pa so tudi rezultati testov tehnologije WiFi 7, kot podaljšek priključka XGS-PON v rezidenčnem objektu.

Abstract

A cost analysis of electricity consumption from the perspective of subscriber CPE devices in a real network will is presented, along with a cost analysis of electricity consumption for access network elements of GPON, XGS-PON, P2P FTTH, and VDSL2 technologies. The potential impact of a single XGS-PON connection on data statistical multiplexing at the access network element is also demonstrated. Additionally, test results of Wi-Fi 7 technology, as an extension of the XGS-PON connection within a residential building, are discussed.

Biografija avtorja

Gorazd Penko je vodja Referenčnega laboratorija pri telekomunikacijskem operaterju T-2, kjer je odgovoren za tehnološki razvoj fiksnih dostopovnih omrežij in naročniških naprav. Diplomiral je na Fakulteti za elektrotehniko Univerze v Ljubljani in leta 1998 začel delovati na področju razvoja ADSL tehnologije v Sloveniji. Kasneje je vodil razvoj in upravljanje širokopasovnih tehnologij, kot so VDSL1, VDSL2, GPON in XGS-PON. Dejaven je na mednarodnih konferencah ter redno predstavlja raziskave in projekte, povezane z optičnimi in brezžičnimi omrežji. Trenutno vodi implementacijo tehnologije XGS-PON in raziskuje najnovejše Wi-Fi 7 ter Wi-Fi 7 Mesh tehnologije.

Author's biography

Gorazd Penko is the head of the Reference Laboratory at the telecommunications operator T-2, responsible for the technological development of fixed access networks and customer premises equipment. He graduated from the Faculty of Electrical Engineering at the University of Ljubljana and began working in 1998 on the development of ADSL technology in Slovenia. He later led the development and management of broadband technologies such as VDSL1, VDSL2, GPON, and XGS-

PON. He is active in international conferences and regularly presents research and projects related to optical and wireless networks. He is currently leading the implementation of XGS-PON technology and researching the latest Wi-Fi 7 and Wi-Fi 7 Mesh technologies.

Optimizacija dostopovnega omrežja z vidika cen električne energije,

vpliv XGS-PON na količino podatkovnega prometa

in rezultati meritev Wi-Fi 7

GORAZD Penko, Vodja referenčnega laboratorija

Vsebina

- O podjetju T-2 d.o.o
- Optimizacija dostopovnega omrežja z vidika cen električne energije
- Vpliv XGS-PON na količino podatkovnega prometa
- Rezultati meritev Wi-Fi 7 in Wi-Fi 7 Mesh v realnem okolju
- Povzetek, Zaključek

T-2 Storitve

FIXED INTERNET ACCESS

IPTV, VOD

MOBILE TELEPHONY

FIXED TELEPHONY

MOBILE TV TV2GO

SERVICES FOR INDUSTRY VERTICALS

HOSTING FOR BUSINESS USERS

T-2 MEJNIKI

2004
Ustanovitev podjetja T-2

Pričetek gradnje optičnega omrežja

Podpis pogodbe o dobavi sistema fiksne telefonije

2005
Vključen prvi naročnik na osnovi xDSL tehnologije

Prva poslovalnica T-2 v Ljubljana-Črnuče

2006
Vključen prvi optični FTTH naročnik

T-2 prvi HD TV ponudnik storitev v Sloveniji

2007
Prvi v Sloveniji predstavi video na zahtevo (VoD)

Več kot 100 zaposlenih

Več kot 50.000 naročnikov fiksnega širokopasovnega dostopa

2008
Prva T-2 UMTS bazna postaja

Lansiranje T-2 mobile telefonije in storitev mobilnega interneta

Prvi v Sloveniji ponudi triple-play paket

2009
10,000 poslovnih naročnikov

Prvi v Sloveniji ponudi prostorski zvok (Dolby digital) prek IPTV

2010
Prvi v Sloveniji s ponudbo „Quad Play“

200 zaposlenih

Prvi v Sloveniji z 3D TV in 48-urnim TV časovnim zamikom (Delay TV)

2011
Prvi T-2 mobilni paketi

Možnost dostopa do storitev T-2 preko TS LLU optičnih povezav

2012
Predstavitev T-2 aplikacije Tv2go

Selitev sedeža podjetja na novo lokaciji v Ljubljani. Novo lastništvo T-2

100.000 naročnikov fiksnega omrežja in 50.000 mobilnih naročnikov

2013
Ustanovitev klua zvestobe T-2

Več kot 300 zaposlenih

Nov spletni portal T-2 Tv2go

2014
100.000 članov T-2 kluba

60.000 FTTH naročnikov

Športni vrhunci nova TV funkcija

2015
Nov Horizont uporabniški portal

Več kot 190.000 naročnikov

2016
Začetek uporabe tehnologije GPON

Mobilno omrežje LTE

T-2 Klub ima več kot 200.000 članov

2017
100.000 mobilnih naročnikov

7-dnevni TV časovni zamik

2018
Dobrodelna akcija T-2♥Življenje

Prvi v Sloveniji z 4K TV programi

Več kot 250.000 fiksnih in mobilnih naročnikov

T-2 TV APP za pametne televizorje

2019
Pridobitev certifikata Best Buy Business Offer

Predstavitev Wi-Fi Mesh storitev

2020
Zlata medalja za Innbox Mesh

Prevzem podjetja Inatel d.o.o.

Aplikacija YouTube prek T-2 Set-up box

2021
Certifikat Družbeno Odgovoren delodajalec

Prevzem Telesat d.o.o.

Razvita platforma „Pametna mesta“ na osnovi lastnega razvoja

2022
Uvedba storitev 5G

Pridobitev certifikata ISO 27001

2023
Lansiranje tehnologije XGS-PON, ki temelji na opciji Combo

Pogodba z Mestno občino Ljubljana o vzpostavitvi digitalne urbane platforme (Smart City)

2024
Prvi preizkus Wi-Fi 7 tehnologije IEEE 802.11be

Lansiranje VoLTE, VoWiFi in T-2 ščit

800Gb hrbtenična povezava

2025

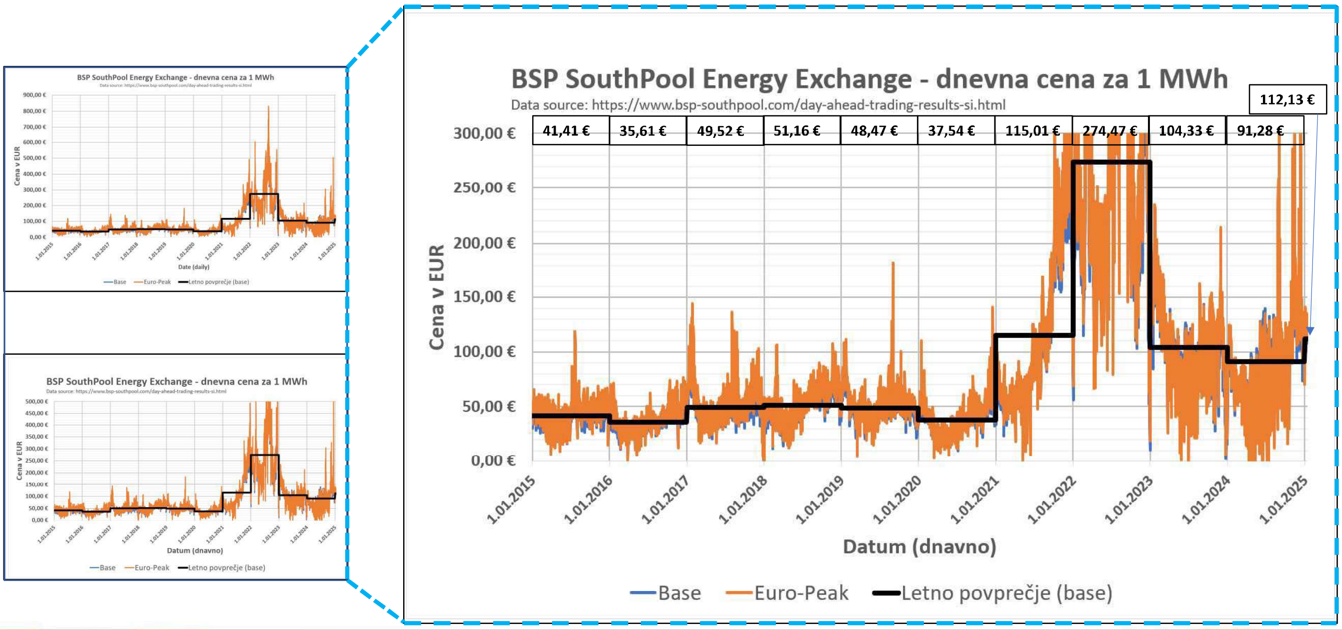
V delu ☺

Basic features of WiFi 7 technology

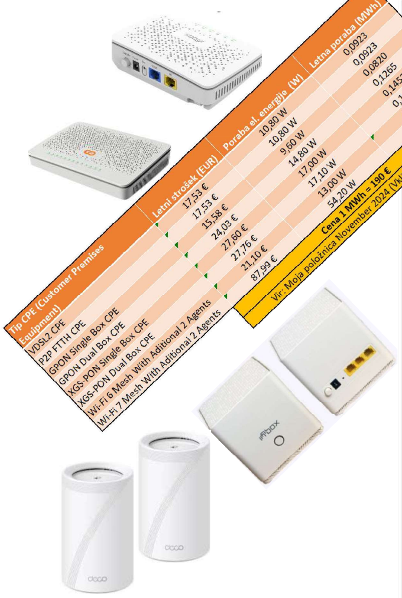
Optimizacija dostopovnega omrežja

- ➢Gibanje cen el. Energije zadnjih 10 let
- ➢Ocena stroškov el. Energije na strani naročnika in operaterja
- ➢Ocena ROI (Return Of Investment)
- ➢Rezultat zniževanja stroškov obratovanja iz naslova selitev P2P FTTH na P2MP FTTH v T-2

BSP SouthPool Energy Exchange Prices from <u>2015 to Jan. 2025</u>



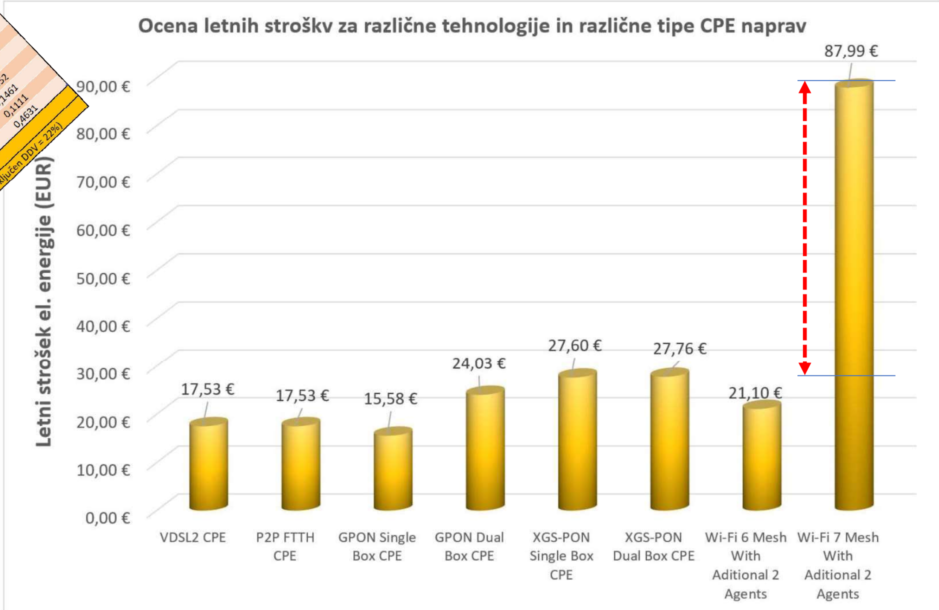
Naročniške naprave(CPE) – Ocena letnega stroška porabe el. energije



Tip CPE (Customer Premises Equipment)	Letni strošek (EUR)	Poraba el. energije (W)	Letna poraba (MWh)
VDSL2 CPE	17,53 €	10,80 W	0,0923
P2P FTTH CPE	17,53 €	10,80 W	0,0923
GPON Single Box CPE	15,58 €	9,60 W	0,0820
GPON Dual Box CPE	24,03 €	14,80 W	0,1265
XGS-PON Single Box CPE	27,60 €	17,00 W	0,1452
XGS-PON Dual Box CPE	27,76 €	17,10 W	0,1461
Wi-Fi 6 Mesh With Aditional 2 Agents	21,10 €	13,00 W	0,1111
Wi-Fi 7 Mesh With Aditional 2 Agents	87,99 €	54,20 W	0,4631

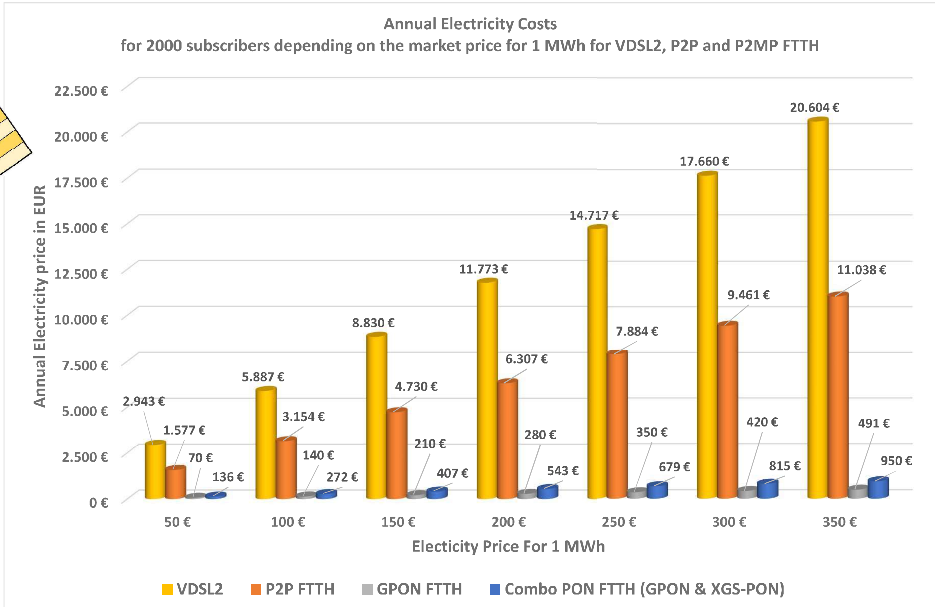
Cena 1 MWh = 190 €

Vir: Moja položnica November 2024 (Vključen DDV = 22%)



TK Oprema v centrali – Ocena letnih stroškov el. energije

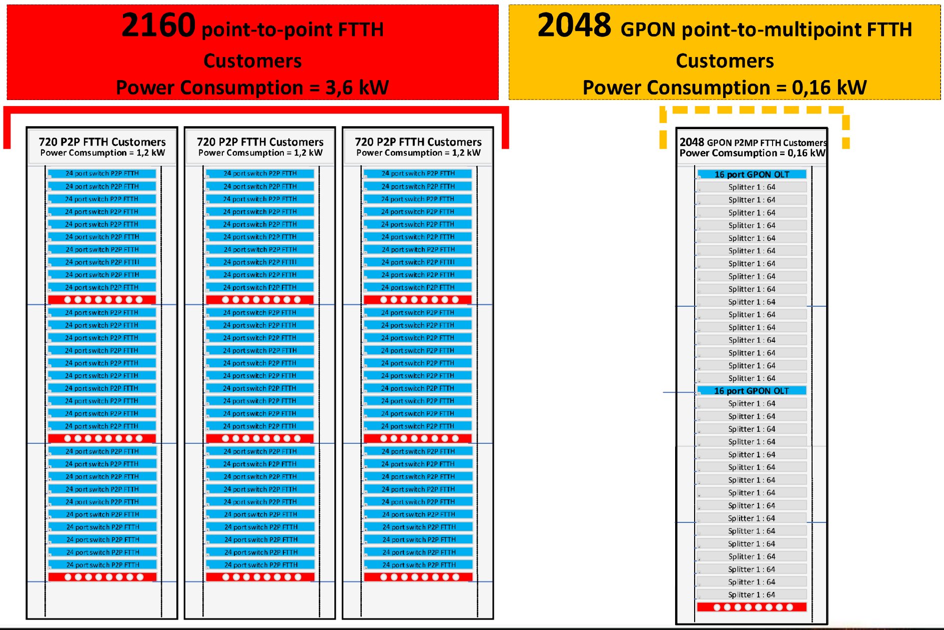
Type Of Central Office Aggregation Equipment Equipment	Power Consumption (W)	Consumption per Subscriber (W)
VDSL2 DSLAM	80,00 W	3,33 W
P2P FTTH L2 Switch	40,00 W	1,67 W
GPON OLT (splitter 1 : 64)	80,00 W	0,08 W
Combo PON OLT (splitter 1: 64)	154,00 W	0,15 W



Poraba prostora v TK centrali - P2P FTTH v primerjavi s P2MP FTTH (GPON)

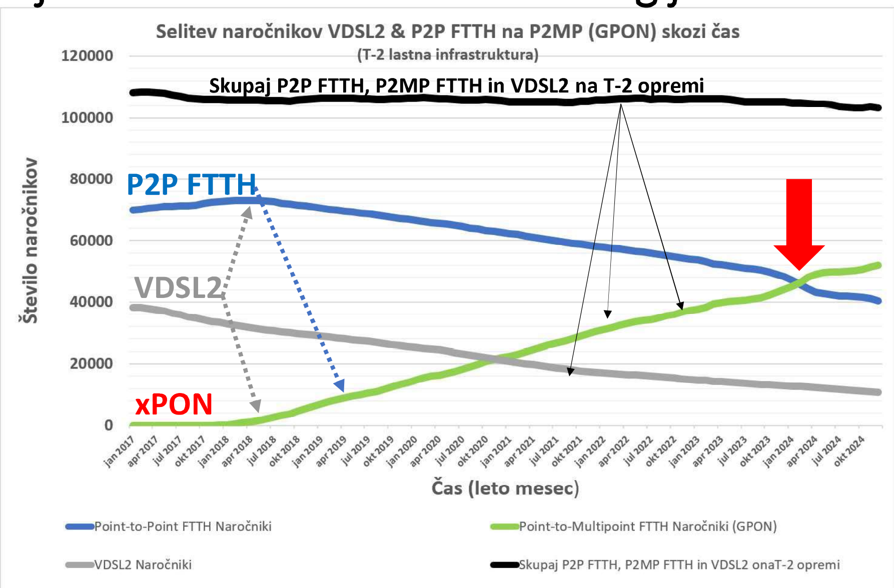
P2MP FTTH (GPON) zahteva le 1/3 prostora, ki sta ga prej uporabljali tehnologiji P2P FTTH in VDSL2

Razmerje porabe energije je približno 1:20 v korist GPON, brez hlajenja.



REZULTAT = Migracija naročnikov na nove tehnologije

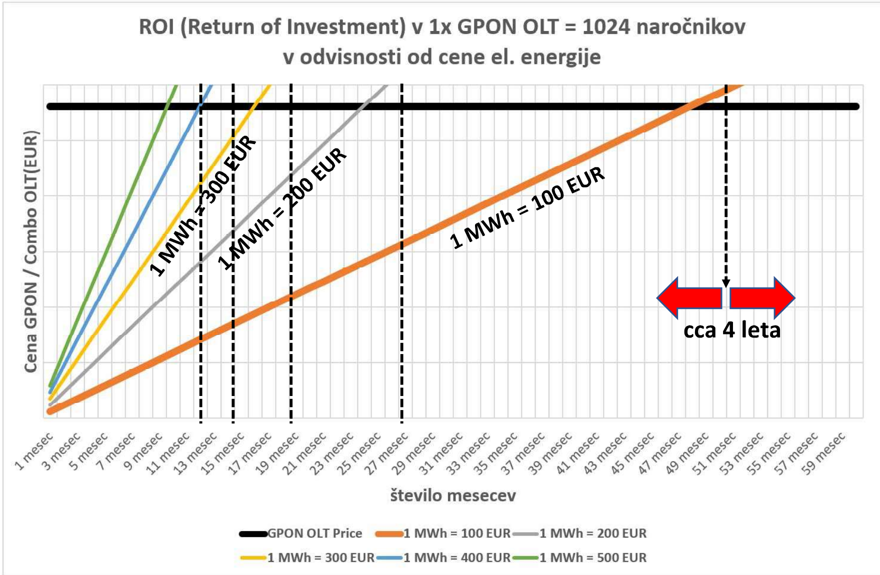
- Vključevanje novih naročnikov na GPON in po potrebi na XGS-PON
- V procesu odprave napake, se izvede migracija na GPON
- P2P FTTH naročniki se sistematično preključujejo **na GPON (P2MP)**
- VDSL2 naročniki se preklјučujejo **na P2MP FTTH GPON** (ali P2P FTTH)
- Po potrebi se naročniki že preklјučujejo tudi na **XGS-PON** (glede na dejanske potrebe naročnika)



ROI (Return Of Investment)

- Če upoštevamo samo stroške investicije v GPON OLT in razliko v ceni električne energije med P2P FTTH in P2MP FTTH

- Stroški vzdrževanja:
  - Zamenjava CPE naročnika,
  - Stroški dela monterja
  - Drugo,...



Basic features of WiFi 7 technology

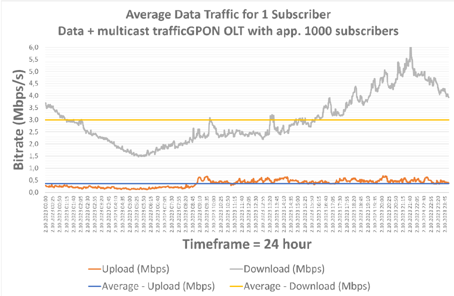
Vpliv XGS-PON na količino podatkovnega prometa

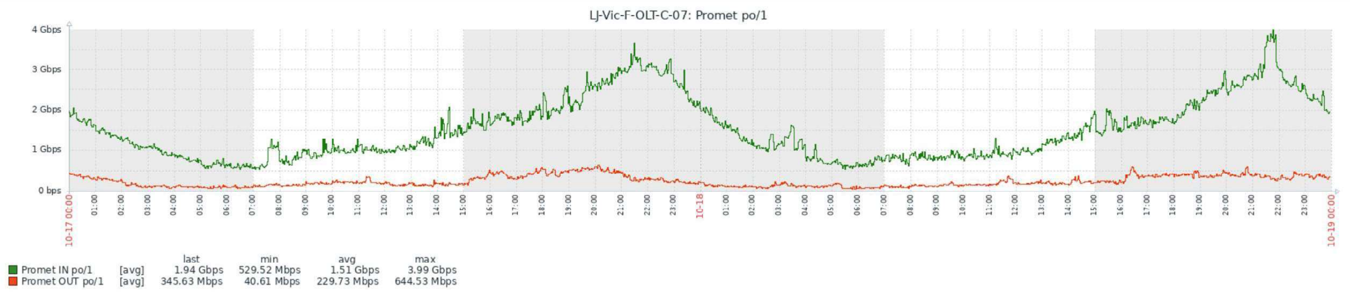
- ➢Simulacija podatkovnega prometa na enem xPON priključku,
  - ➢Ocena vpliva na hrbtenično omrežje,...

Realen podatkovni promet – xPON OLT – 1016 naročnikov

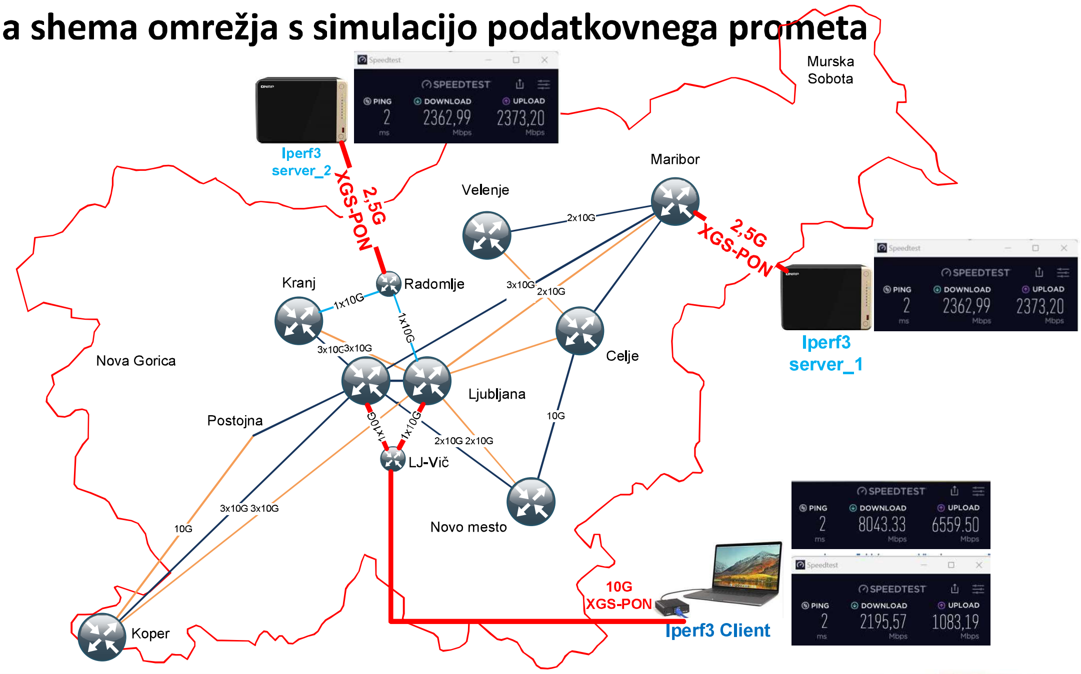
- Peak traffic:
    - Download = 3,99 Gbps,
    - Upload = 644 Mbps

- Average traffic per subscriber (including multicast):
    - Download = cca 3 Mbps,
    - Upload = 0,366 Mbps

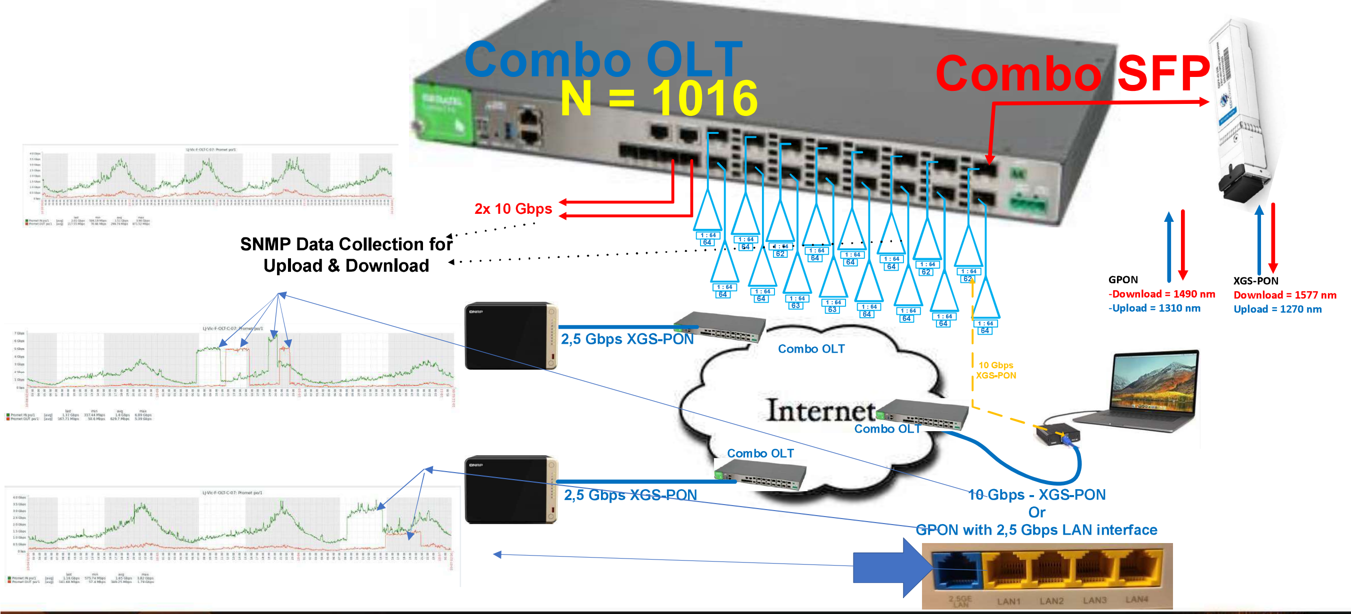




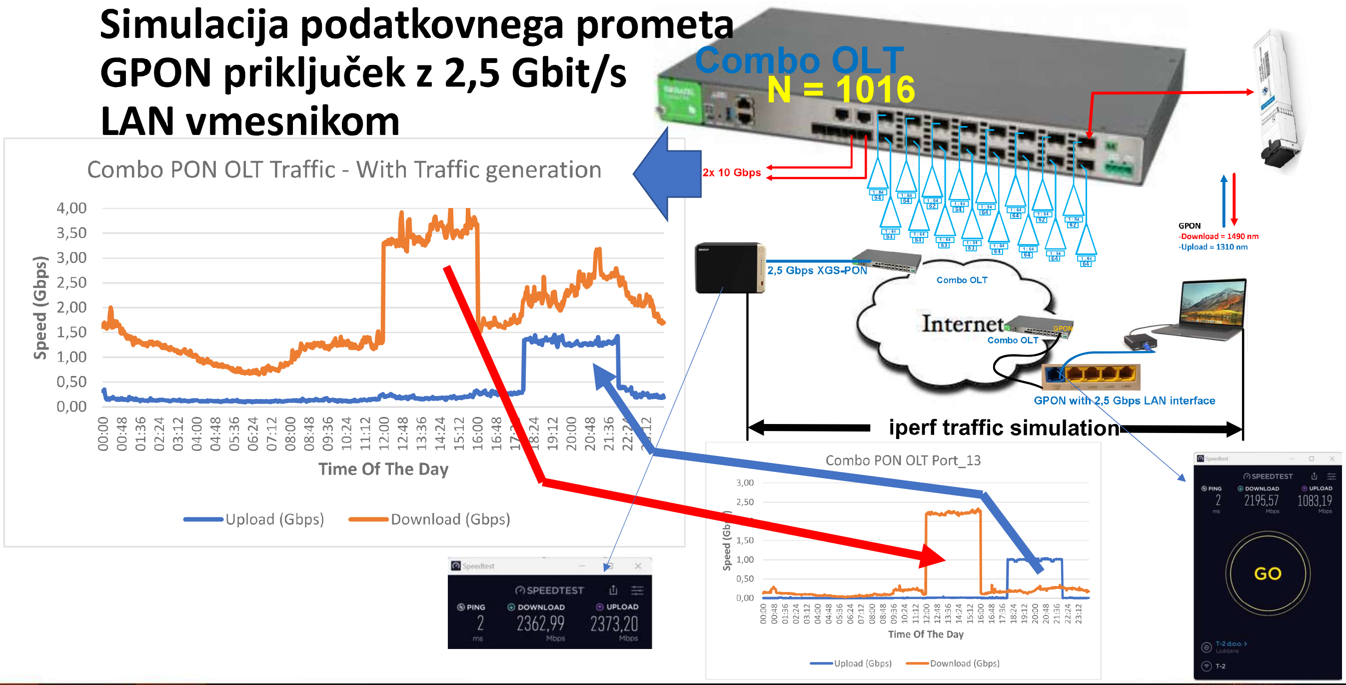
(1) Merilna shema omrežja s simulacijo podatkovnega prometa



(2) Merilna shema omrežja s simulacijo podatkovnega prometa



Simulacija podatkovnega prometa GPON priključek z 2,5 Gbit/s LAN vmesnikom



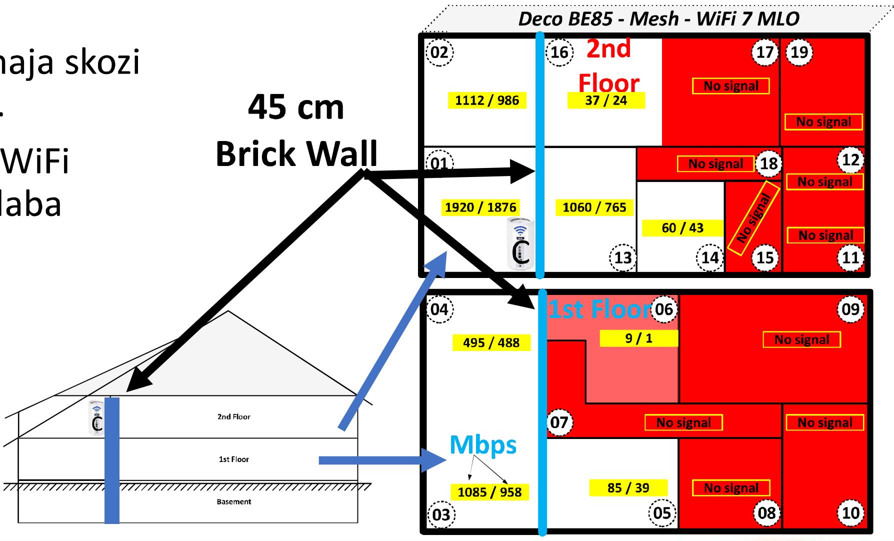
Basic features of WiFi 7 technology

Rezultati meritev Wi-Fi 7 in Wi-Fi 7 Mesh v realnem okolju

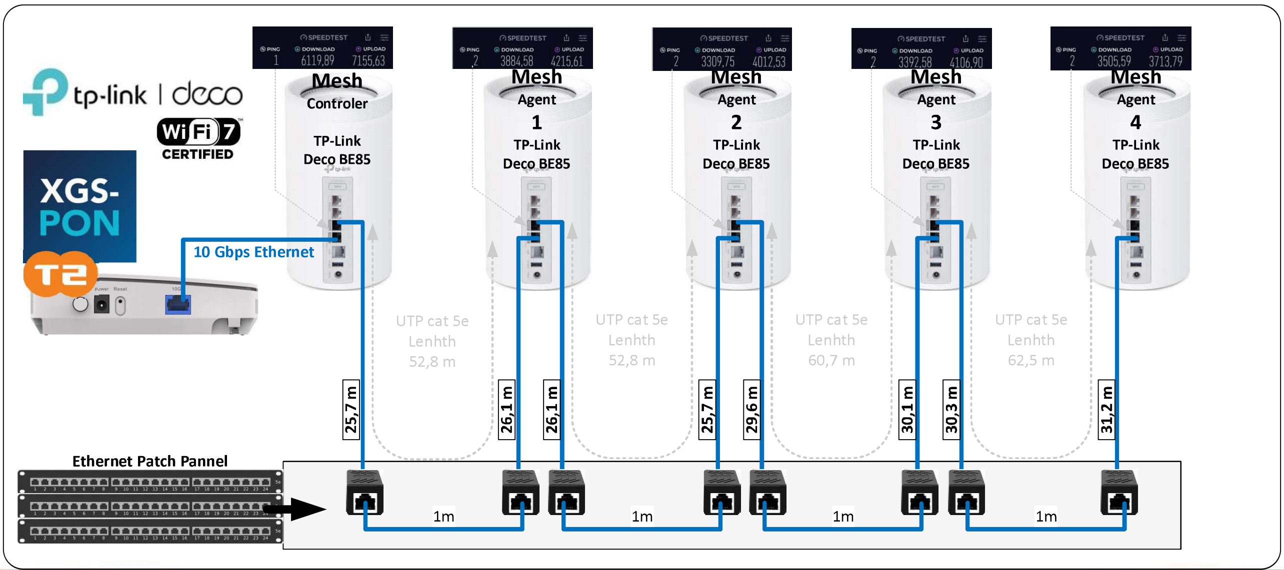
- Primerjava Wi-Fi 6 in WiFi 7 v realnem rezidenčnem okolju v identičnih tehničnih pogojih

Primer: Wi-Fi 7 v rezidenčnem objektu

- WiFi signal slabo prehaja skozi debelo opečno steno.
- Pokritost hiše z enim WiFi usmerjevalnikom je slaba
- Rešitev = Mesh WiFi

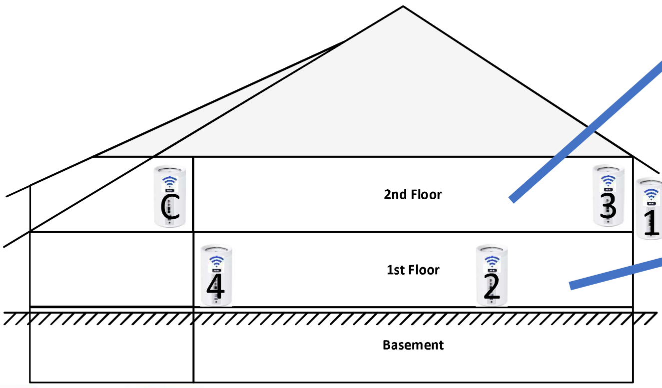


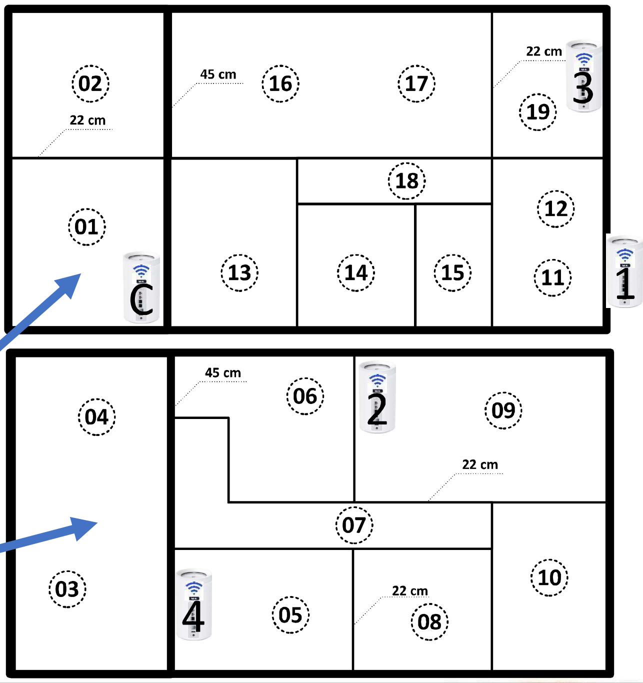
Shema ožičenja omrežja WiFi 7 Mesh v stanovanjskem objektu



Rezidenčni objekt (hiša)

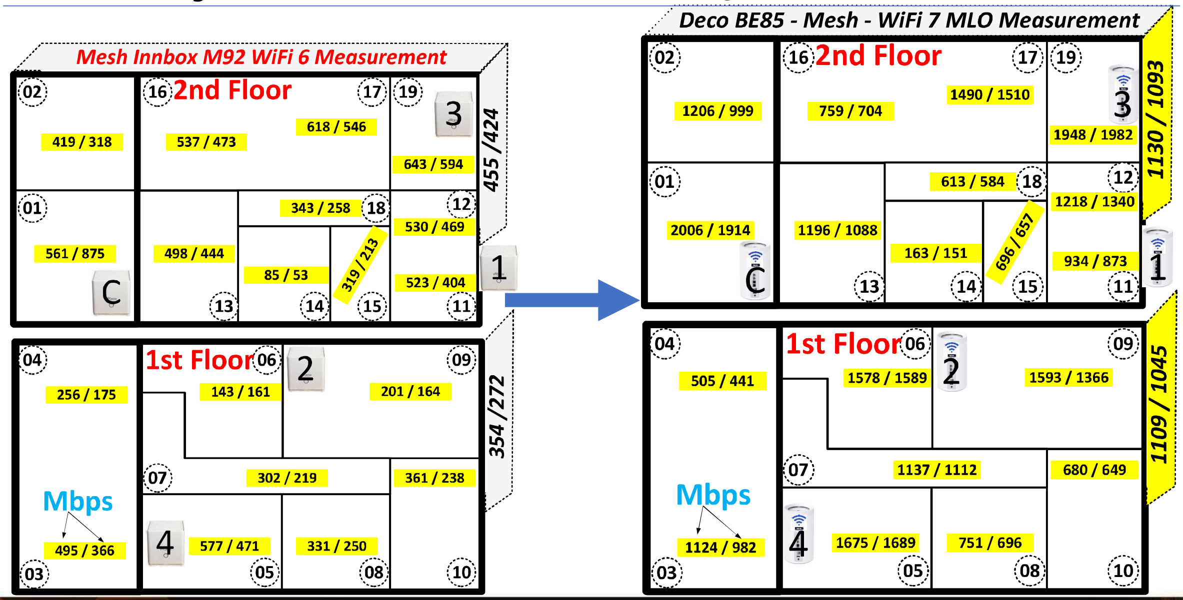
Mesh vozlišča, distribucijske in merilne točke



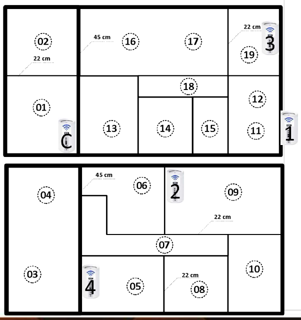


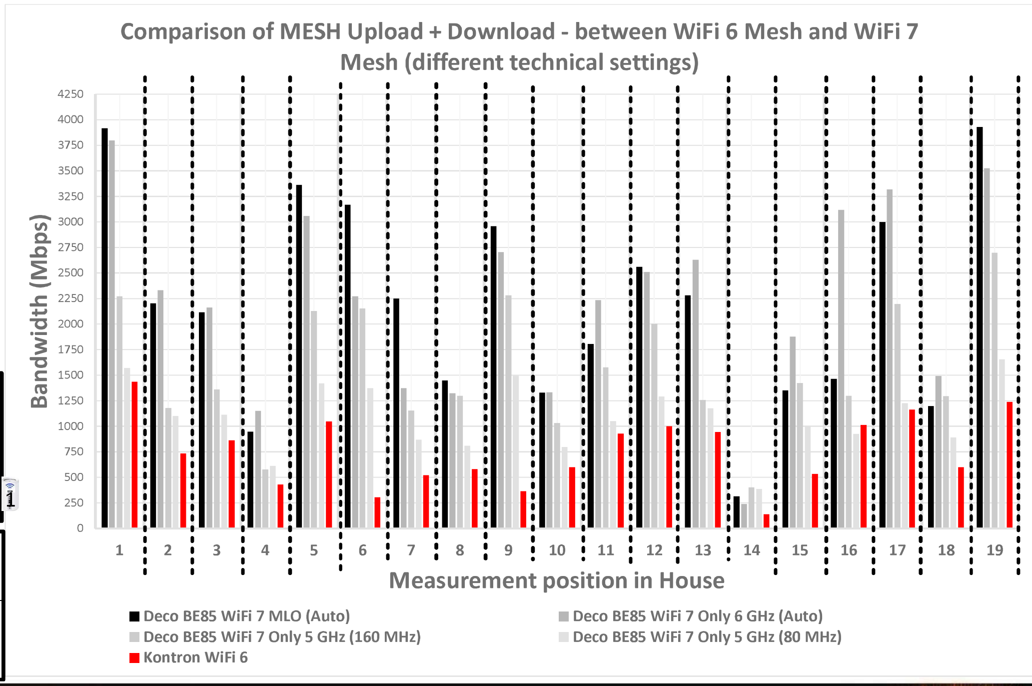
WiFi 7 Mesh - Ookla Speedtest Rezultati

Primerjava: Danes Wi-Fi 6 Mesh & Jutri Wi-Fi 7 Mesh



Rezultati primerjav različnih možnosti / opcij Mesh Wi-Fi 6 in Wi-Fi 7





Povzetek:

- Nove tehnologije v fiksnem dostopu:
  - Stroški el. energije,….., optimizacije,
  - Transformacija dostopovnih omrežij,
  - Vpliv na transformacijo (nadgradnjo) hrbteničnega omrežja,
    - Statistični multipleks podatkovnega prometa
  - Wi-Fi tehnologije sledijo razvoju dostopovnih omrežij
    - Wi-Fi 7 je cca 2 do 4x „hitrejši“ od Wi-Fi 6 v praksi,…

Zaključek

Vprašanja ?

GORAZD Penko
Vodja referenčnega laboratorija
T-2 d.o.o.
Verovškova 64A,1000 Ljubljana
Slovenija
e-mail: gorazd.penko@t-2.com
Phone: +386 64 113 000

WiFi 7

XGS-PON

Hvala…

Koherentna tehnologija: Preobrat v omrežjih IPoDWDM

Coherent Technology: A Revolution in IPoDWDM Networks

Pavel Praček

T-2

pavel.pracek@t-2.com

Povzetek

Ali smo pripravljeni na revolucijo v omrežjih? Koherentni optični moduli na novo definirajo način prenosa podatkov in s tem močno ogrožajo tradicionalne pristope. S standardi, kot sta 400ZR in OpenZR+, koherentna tehnologija odstranjuje potrebo po transponderjih in omogoča neposredno povezovanje naprav v IPoDWDM omrežjih. Rezultat? Nižji stroški, radikalno zmanjšana poraba energije ter bistveno manjša zasedenost prostora.

Abstract

Are we ready for a network revolution? Coherent optical modules are redefining how we transmit data, posing a significant challenge to traditional approaches. With standards like 400ZR and OpenZR+, coherent technology eliminates the need for transponders, enabling direct device connections in IPoDWDM networks. The result? Lower costs, radically reduced energy consumption, and less space required.

Biografija avtorja

Pavel Praček je univerzitetni študij zaključil na Fakulteti za elektrotehniko Univerze v Mariboru. Leta 2001 se je pridružil podjetju Siol, kjer je sprva upravljal IP omrežne sisteme, nato pa razširil delo na razvoj storitev, kot so IPTV in VoIP. Leta 2004 je bil med prvimi zaposlenimi v podjetju T-2, kjer je prevzel načrtovanje in izgradnjo novega operaterskega omrežja. Od ustanovitve podjetja vodi Sektor za TK omrežje in sodeluje pri razvoju nadgradenj IP omrežja. Trenutno se osredotoča na uvedbo neprekinjenega poslovanja in kibernetsko varnost podjetja.

Author's biography

Pavel Praček completed his university studies at the Faculty of Electrical Engineering at the University of Maribor. In 2001, he joined Siol, initially managing IP network systems and later expanding his work to the development of services such as IPTV and VoIP. In 2004, he was among the first employees at T-2, where he took on the planning and construction of a new network. Since the company's founding, he has led the Telecommunications Network Sector and participated in the development of IP network upgrades. He is currently focused on implementing business continuity and cybersecurity measures within the company.

Koherentna tehnologija preobrat v omrežjih IPoDWDM

Pavel Praček, Vodja sektorja za TK omrežje

AGENDA

1) Predstavitev omrežja T-2
2) Zgodovina koherentne tehnologije
3) Osnove koherentne tehnologije
4) Standardizacija
5) Testiranje in implementacija
6) Zaključek

1) Predstavitev omrežja T-2

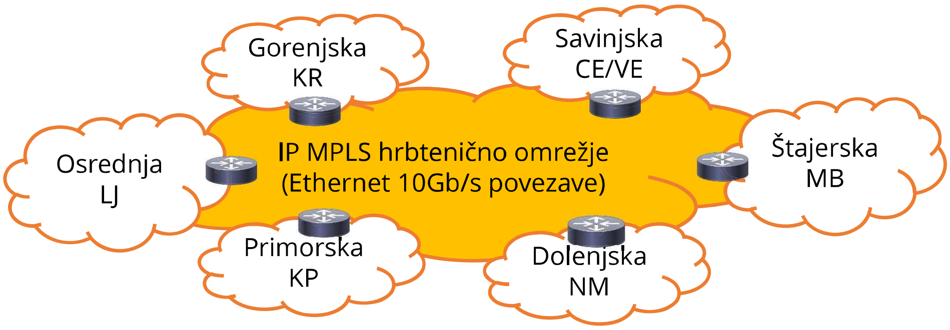
- Podjetje T-2 d.o.o. (maj 2004)
  - Začetek ponujanja storitev – september 2005
  - Zaposlenih: cca. 420
  - Fiksni naročniki: cca. 155.000
  - Število hrbteničnih kolokacij: 6
  - Število dostopovnih lokacij: >230

- T-2 je od začetne postavitve hrbtenično omrežje postavil na temeljih IP MPLS usmerjevalnega optičnega omrežja
  - Brez aktivnega transportnega omrežja (brez ROADM)

1) Predstavitev omrežja T-2

- IP MPLS hrbtenično omrežje T-2 razdeljeno na 6 regij:

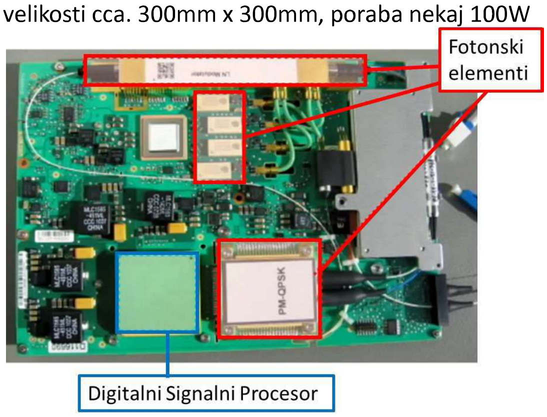
Osrednja LJ, Štajerska, Gorenjska, Primorska, Dolenjska, Savinjska



2) Zgodovina koherentne tehnologije

- Komercialna raba od leta 2010, predvsem z uvedbo 100Gbps optičnih transportnih sistemov.
  - v obliki linijskih kartic z vgrajenim optičnim vmesnikom (predvsem zaradi uporabe signalnih procesorjev (DSP), ki so bili med drugim potrebni za obdelavo signala, kodiranega z **amplitudo, fazo in polariteto nosilnega signala**)
  - izločeni optični vmesnik (2015): OIF, CFPx, QSFPx

Tipična 100G koherentna transponder linijska kartica velikosti cca. 300mm x 300mm, poraba nekaj 100W

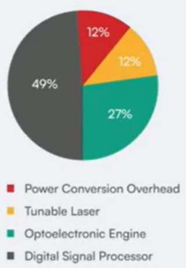


https://www.fibermall.com/blog/coherent-transceiver-overview.htm

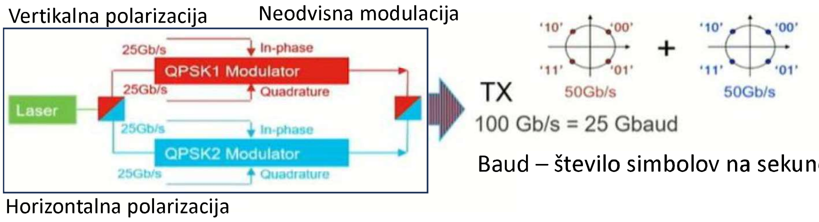
2) Zgodovina koherentne tehnologije

Koherentni optični moduli:

Uporaba direktno v usmerjevalnikih in stikalih

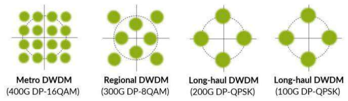
	Uporaba v transportnih sistemih in delno v usmerjevalnikih				
					
Modul	5x7 OIF	4x5 OIF	CFP	CFP2	QSFP-DD
Velikost (mm)	127x178	102x127	82x145	41,5x102,5	18x89
Poraba (W)	90	45	32	24	15

3) Osnove koherentne tehnologije – 100Gbps primer



Baud – število simbolov na sekundo

Koherentna modulacija:
QPSK – 2 bit / simbol
8QAM – 3 bit / simbol
16QAM – 4 bit / simbol

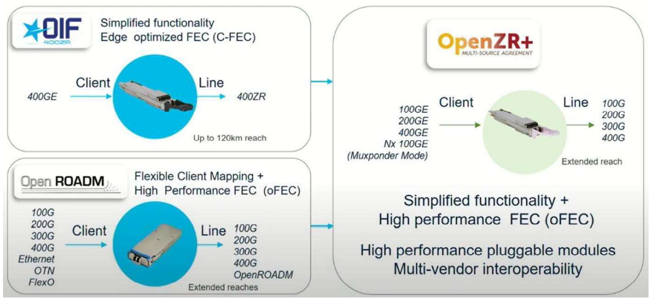


- prednost na performansah v primerjavi z nekoherentnimi moduli
- napredna korekcija napak (oFEC)
- nizka poraba energije
- velikost modula - intenziteta portov - manj prostora
- nižja cenovna vrednost

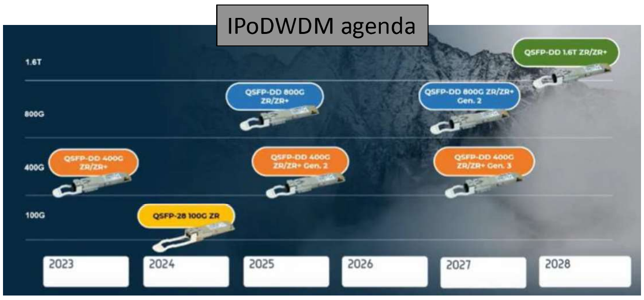
Generacija	leto	max hitrost
GEN30	2010	100 - 200 Gbps
GEN60	2017	400-600 Gbps
GEN120	2022	600-800 Gbps

https://www.youtube.com/watch?v=p5JJpcnPcc4

4) Standardizacija 400G DCO vmesnika



IPoDWDM agenda



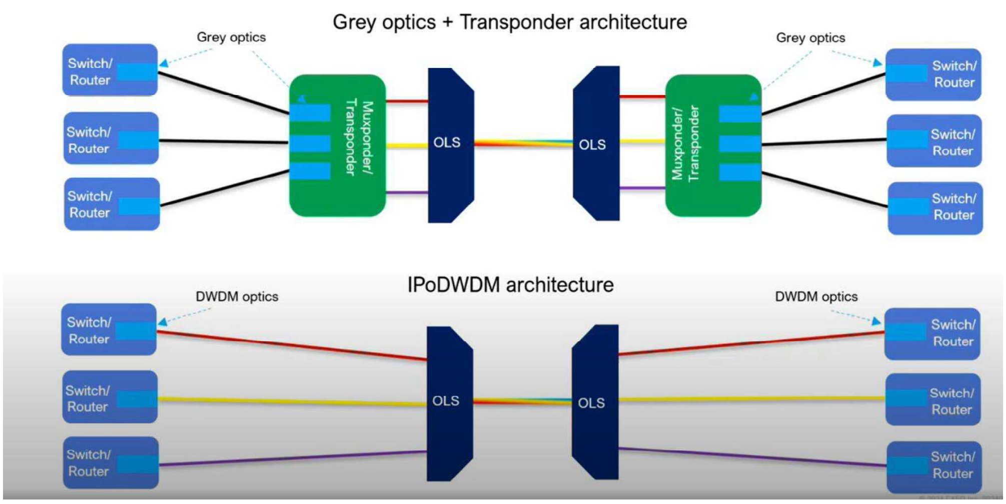
https://www.youtube.com/watch?v=p5JJpcnPcc4
https://www.youtube.com/watch?v=UbLz8_fAGXw

4) 400G QSFP-DD 400ZR & OpenZR+ HP specifications

Parameter	OIF 400ZR	Metro	Regional	Long-haul	ULH
Standards compliance (Ethernet/OTN Standard, for e.g. 100GBASE-LR4)	IEEE 802.3TM-2018				
MSA compliance (SFF, for e.g. SFF-8665)	OIF 400ZR Implementation Agreement (IA)	OpenZR+ MSA			
Speed	1x400 Gigabit Ethernet, 4x100 Gigabit Ethernet		3x100 Gigabit Ethernet	2x100 Gigabit Ethernet	1x100 Gigabit Ethernet
Transceiver Type (i.e., SFP, SFP+, XFP, CFP, etc..)	QSFP-DD				
Digital Diagnostic Monitoring	Module temperature (Celsius) Pre-FEC BER, Uncorrected FER, SNR Tx power (dBm), Rx power (dBm) OSNR (dB)				
Signaling rate	478.750Gbps, (59.84375GBd), +/-20ppm	481.1Gbps, (60.14GBd), +/-20ppm	360.8Gbps, (60.14GBd), +/-20ppm	240.6Gbps, (60.14GBd), +/-20ppm	120.3Gbps, (30.07GBd), +/-20ppm
Modulation format	DP-16QAM	DP-16QAM	DP-8QAM	DP-QPSK	DP-QPSK
FEC types	Concatenated FEC (CFEC)	OFEC			
Channel plan wavelength range	1567.13 ~ 1528.77 nm				
Channel spacing	75GHz or greater				50GHz or greater
Optical transmitter output power (on)	Min. 0dBm, Tx output power accuracy: +/-1.5dB				
Optical receiver input sensitivity (unamplified or dark-fiber applications)	-20dBm	-23dBm	-26dBm	-30dBm	-32dBm
Optical receiver minimum OSNR (back-to-back), worst-case, EOL	26dB	23.5dB	20dB	15dB	12dB
Distance (unamplified)	80km	92km	104km	120km	128km
Distance (amplified, CD limited 17 ps/nm)	140km	700km	1050km	1400km	2800km
Maximum Power consumption (W)	18.9W	22.5W	21.6W	21W	16.3W

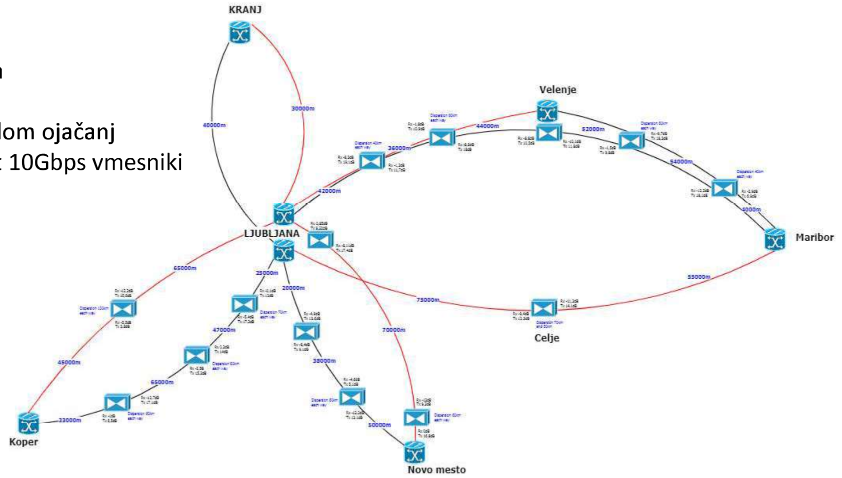
https://apps.juniper.net/hct/model/?component=QDD-400G-ZR-M-HP

5) Možnosti implementacije



5) Testiranje

- Na kratkih razdaljah brez ojačanja
- Na dolgih razdaljah
- Na dolgih razdaljah z večjim številom ojačanj
- Testiranje v sobivanju za ethernet 10Gbps vmesniki



5) Testiranje in implementacija (transportni nivo)

```
ppracek@LJ-T2B-PTX-01> show interfaces diagnostics optics et-0/1/0
Physical interface: et-0/1/0
    Module temperature                  :  42 degrees C / 107 degrees F
    Module voltage                      :  3.217 V
    Module max power                    :  23 W
    Wavelength channel number           :  22
    Wavelength setpoint                 :  1545.32 nm
  Lane 0
    Laser bias current                  :  203.399 mA
    Laser output power                  :  1.598 mW / 2.03 dBm
    Laser temperature                   :  38 degrees C / 100 degrees F
    Laser receiver power                :  0.013 mW / -18.72 dBm
    Rx power (signal)                   :  0.01 mW / -18.90 dBm
    Lane chromatic dispersion           :  1419.0 ps/nm
    Lane differential group delay       :  2.0 ps
    Lane carrier frequency offset       :  290.0 MHz
    Lane polarization dependent loss    :  0.3 dB
    Lane snr                            :  14.8 dB
    Lane Optical signal-to-noise ratio  :  29.9 dB
ppracek@LJ-T2B-PTX-01>
```

```
ppracek@LJ-T2B-PTX-01> show interfaces et-0/1/0 extensive
Physical interface: et-0/1/0, Enabled, Physical link is Up
  Description: RegCore-LJ-MB-PTX-01_et-0/1/0-ch40-400G-ae1
  Link-level type: Ethernet, MTU: 9192, LAN-PHY mode, Speed: 400Gbps
  Wavelength     : 1545.32 nm, Frequency: 194.000 THz
  Traffic statistics:
   Input  bytes  :     583345086455592       11124309000 bps
   Output bytes  :     204821838519682       4632758264 bps

  Optic FEC Mode  :              OFEC
  Optic FEC statistics:
    Corrected Errors                  782239220676237
    Uncorrected Words                 0
    Corrected Error rate              2357157757
    Uncorrected Error rate            0
    Corrected Error Ratio (    336572 seconds average)  4.92e-03
ppracek@LJ-T2B-PTX-01>
```

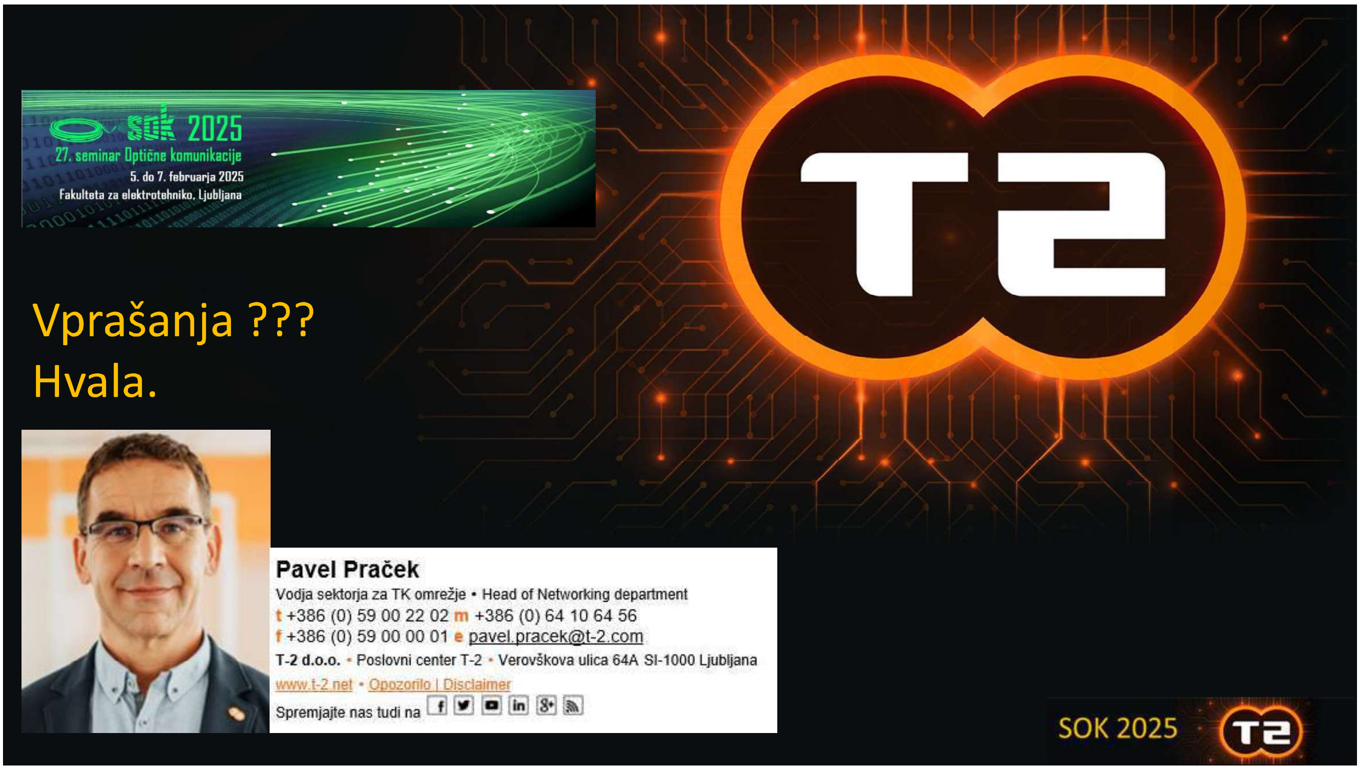
5) Testiranje in implementacija

```
ppracek@LJ-T2B-PTX-01> show configuration interfaces et-0/1/0
description RegCore-MB-LJ-DARS-MB-PTX-01_et-0/1/0-ch40-400G-ae1;
ether-options {
   802.3ad ae1;
}
optics-options {
   wavelength 1545.32;
   tx-power 2;
}
ppracek@LJ-T2B-PTX-01>
```

```
ppracek@LJ-T2B-PTX-01> show configuration interfaces ae1
description LJ-MB-PTX-01-800G-ae1;
vlan-tagging;
mtu 9192;
aggregated-ether-options {
   link-speed mixed;
   lacp {
      active;
      periodic fast;
   }
}
unit 10 {
   description LJ-MB-PTX-01-800G-ae1;
   vlan-id 10;
   family inet {
      mtu 1500;
      address x.x.x.x/31;
   }
   family inet6 {
      mtu 1500;
      address x:x:x::x/127;
   }
   family mpls;
}
ppracek@LJ-T2B-PTX-01>
```


6) Zaključek

- ZA:
  - Visoka robustnost vmesnikov in prilagodljivost hitrosti 100, 200, 400Mbps,
  - Daljši doseg
  - Večja odpornost na motnje, visoka stabilnost
  - Zmanjšanje prostora in intenziteta portov, porabe energije, hlajenja
  - Nižji stroški
- POMANJKLJIVOSTI:
  - Interoperabilnost med proizvajalci opreme in proizvajalci vmesnikov
  - Upravljanje sistema – usmerjevalnika, združena transportni in IP omrežni nivo


SOK 2025
27. seminar Optične komunikacije
5. do 7. februarja 2025
Fakulteta za elektrotehniko, Ljubljana
Vprašanja ???
Hvala.
Pavel Praček
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Optično vlakno kot porazdeljeno tipalo
Fiber as a distributed sensor

Milorad Sarić

IBIS Instruments

milorad.saric@ibis-instruments.com

Povzetek

Za potrebe sodobnih telekomunikacij narašča trend nenehnega polaganja novih optičnih kablov. Dodatna uporaba tega medija kot senzorja za različne meritve povečuje izkoriščenost in stroškovno učinkovitost celotnega sistema. V prispevku podajamo pregled številnih razpoložljivih tehnoloških trendov za različne meritve (porazdeljeni senzorji), kot tudi uporabne vrednosti v različnih infrastrukturnih in drugih izzivih.

Abstract

For the needs of modern telecommunications, the trend of constantly laying new optical cables is increasing. The additional use of this medium as a sensor for various measurements increases the utilization and cost-effectiveness of the entire system. In this paper, we provide an overview of the many available technological trends for various measurements (distributed sensors), as well as their utility in various infrastructure and other challenges.

Biografija avtorja

Milorad Sarić je inženir tehnične podpore s 16-letnimi izkušnjami na področju predprodajne in poprodajne podpore testnih in merilnih rešitev. Diplomiral je na Fakulteti za elektrotehniko v Beogradu. V podjetju Ibis Instruments je zaposlen od leta 2018. Odgovoren je za celovito tehnično podporo testnih in merilnih rešitev za dostopovna in optična omrežja. Izvedel je številne projekte implementacije, nadgradnje ali migracije sistemov za upravljanje optičnih omrežij v regiji Zahodnega Balkana in je odgovoren za spremljajočo tehnično podporo na teh sistemih.

Author's biography

Milorad Sarić is a technical support engineer with 16 years' experience in presales and postsales support of test and measurement solutions. He graduated from the Faculty of Electrical Engineering in Belgrade. He is employed at Ibis Instruments since 2018. Milorad is responsible for complete technical support for test and measurement solutions for Access and Fiber Optic networks. He carried out numerous projects of implementation, upgrade or migration of Optical Network Management Systems throughout the Western Balkans region, and he is responsible for accompanying technical support on those systems.

Fiber as a distributed sensor

Milorad Sarić
Technical support for Wireline portfolio

Agenda

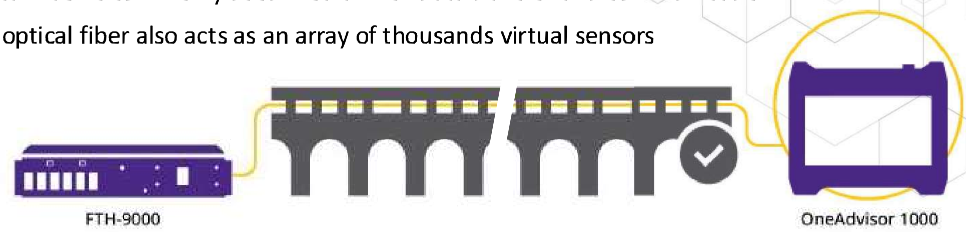
- **Optical Fiber Sensing Basics**
- **Applications and Use Cases**
- **Integrated Fiber Ecosystem**

Optical Fiber Sensing Basics

Distributed Fiber Optic Sensing: A different use of fiber

Optical fiber is commonly used medium for data transfer and communication.

BUT optical fiber also acts as an array of thousands virtual sensors



Fiber sensing technology involves the integration of optical fibers within the infrastructure to monitor various physical parameters in real time. These fibers are capable of detecting changes in temperature, strain, or mechanical pressure waves or iginated by a multitude of events. The technique is called “distributed fiber optic sensing,” where a standard SM optical fiber can act as an extended sensor over long distances and with high spatial resolution, covering vast areas of critical infrastructure.

Advantages:

- Fiber as a passive sensor doesn’t need any electrical sources. It is immune to radiation, EMI, ESD, compatible with ATEX zone and harsh environments.
- Interrogator is a single-ended measurement device <u>requiring only one fiber</u>
- Fiber Sensing brings Cost Effectiveness, Proactive Maintenance, Longevity and Durability and Easy Scalability.

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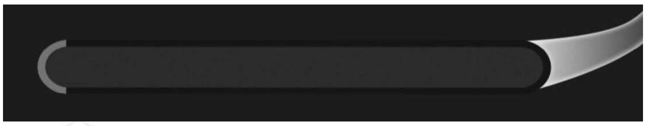
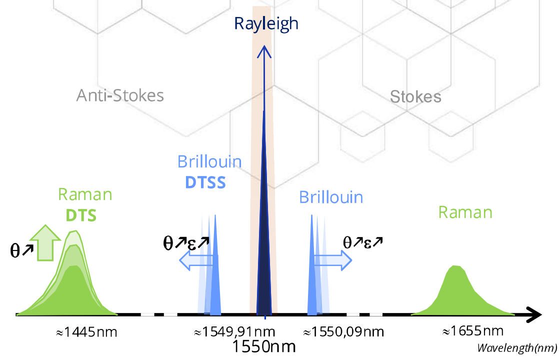
OTDRs & Optical Fiber Sensing

Pulses of light are **sent**
Backscattered light is **received**
The backscatter is interrogated
Changes in characteristics
Caused by external stimulus





Rayleigh OTDR → **Fiber Monitoring** - Loss, Reflections & Failures
Raman OTDR → Distributed **Temperature** Sensing (**DTS**)
Brillouin OTDR → Distributed **Temperature & Strain** Sensing (**DTSS**)
Coherent Rayleigh OTDR → Distributed **Vibration/Acoustic** Sensing (**DVS/DAS**)

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DTSS basics

Strain is an issue, BOTDR measures Strain

- **40 year fiber lifetime <u>only if</u> stress level is maintained below 20% of the proof test** (20% of 100kpsi corresponds to 2000με)- Corning

Total allowable stress design guidelines for any length, resulting in zero failures
Table 2

Duration of Applied Stress	Allowable Safe Stress in Relation to σ_p	Allowable Safe Stress (kpsi) when σ_p = 100 kpsi
40 years	1/5 σ_p	20 kpsi
4 hours	1/3 σ_p	33 kpsi
1 second	1/2 σ_p	50 kpsi

σ_p = proof stress

Strain is measured in microstrain, με

1 με = is the elongation or compression of 1µm for a distance of 1m

or in percentage 1 με = 0,0001%

- **B-OTDR test already becoming a Topic in ITU**
  - Draft revised Recommendation ITU-T L.310 (ex L.53) (for Consent, 26 February 2016). TD 538 Rev. 2 (PLEN/15).

Table 3/L.53 – Suitable test methods for point-to-multipoint access networks

Category	Activity	Item	Methods
Preventative maintenance	Surveillance	Detection of fibre loss increase	OTDR/loss testing
		Detection of signal power loss increase	Power monitoring
		Detection of water penetration	OTDR testing
	Testing	Measurement of fibre fault location	OTDR testing (Note 1)
		Measurement of fibre strain distribution	B-OTDR testing
		Measurement of water location	OTDR testing(Note 1)

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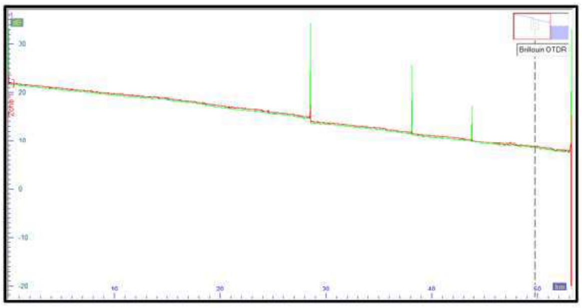
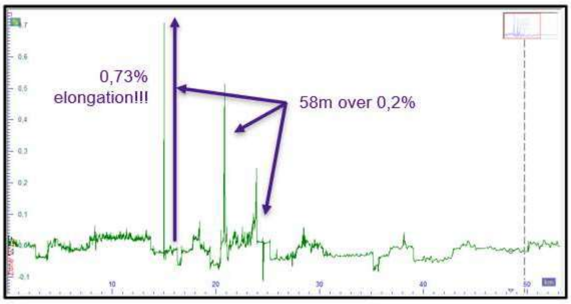
Attenuation vs Elongation

Comparison of OTDR and **B-**OTDR Measurements

Standard OTDR
Attenuation & Reflections



Brillouin OTDR
Strain



Measurements on same 50km long Urban Underground Cable

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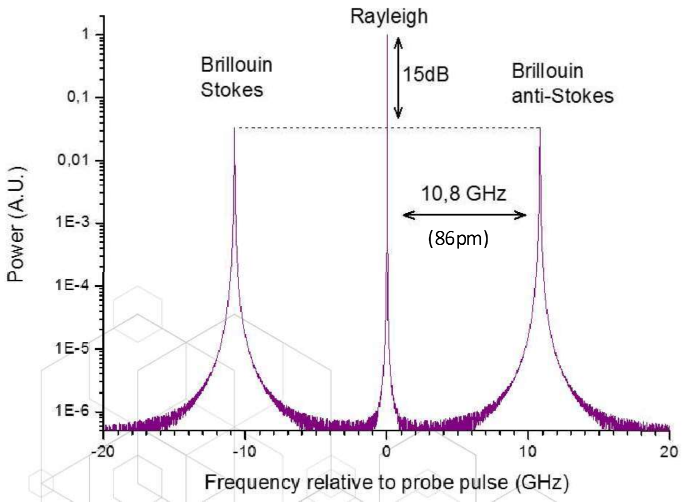
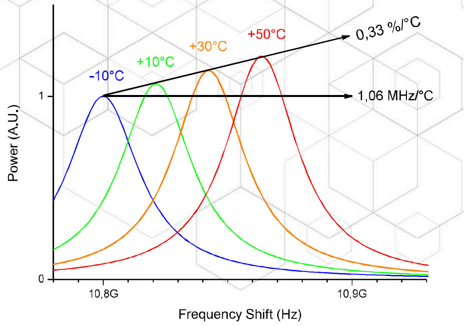
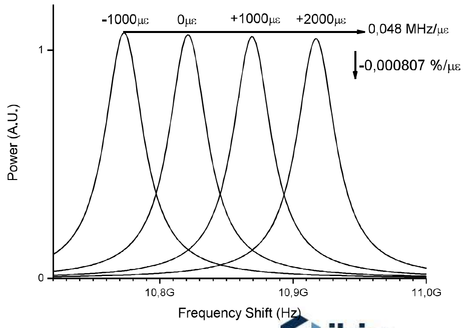
Backscattered Light Spectrum







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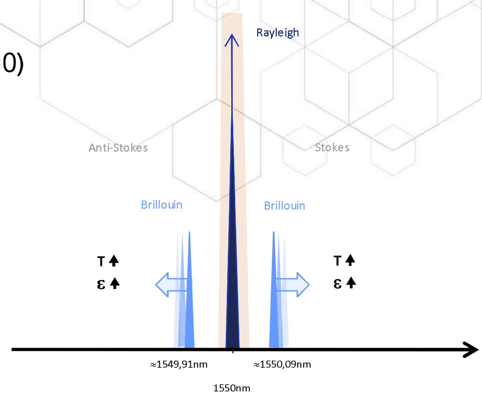
Measurements, Measurands, Coefficients and Offsets

B-OTDR measures

- **Brillouin Frequency Shift** vs **Time** (pulse launched at t=0)
- **Brillouin Power** vs **Time**
- **Rayleigh Power** vs **Time**



Temperature & Strain vs Position

- **Time** → **Distance**
- **Brillouin Frequency** → linearly dependent to **Temperature** & **Strain** (two coefficients, one offset)
- **Brillouin Power** → linearly dependent to **Temperature** & **Strain** (two coefficients, one offset)
- **Rayleigh Power** → **Fiber Losses**

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B-OTDR Modes of Operation

Temperature only Brillouin Frequency Shift and $C_{\vartheta}^{T} = 1,06\ MHz/°C$

Strain only Brillouin Frequency Shift and $C_{\vartheta}^{\varepsilon} = 0,048\ MHz/\mu\varepsilon$

- **Temperature & Strain**

$$\begin{pmatrix} \Delta\vartheta_B \\ \Delta P \end{pmatrix} = \begin{bmatrix} C_{\vartheta}^{\varepsilon} & C_{\vartheta}^{T} \\ C_{P}^{\varepsilon} & C_{P}^{T} \end{bmatrix} \begin{pmatrix} \varepsilon \\ \Delta T \end{pmatrix}$$

PATENTED

ϑ_B	Brillouin Frequency
P	Brillouin/Rayleigh Power Ratio
ε	Strain
T	Temperature

$C_P^T = 0{,}33\ \%/°C$

$C_P^{\varepsilon} = -0{,}000807\ \%/\mu\varepsilon$

Landau-Placzek Ratio $= \frac{P_{Rayleigh}}{P_{Brillouin}} = \frac{f(attenuation)}{f(\varepsilon, T, attenuation)} = f(\varepsilon, T)$

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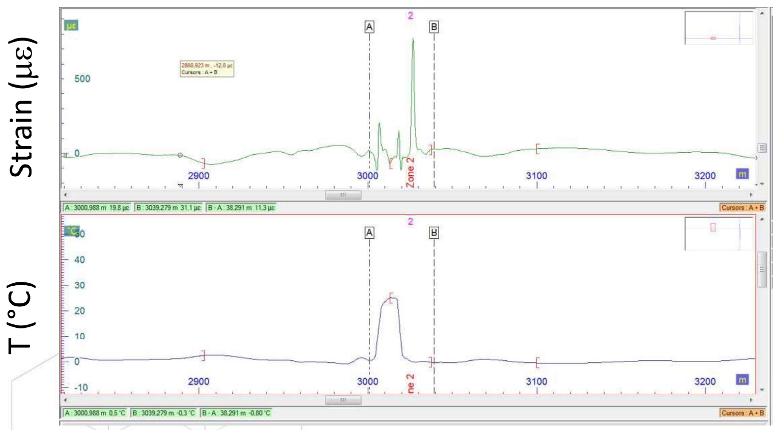
Unique Decorrelation Method



Fiber distance (m)

Enables single-ended solutions requiring only one fiber and having combined measurement capabilities for **simultaneous temperature and strain** measurement

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What are the different units?

Measures elongation at every point along the sensing fiber

L ΔL

$$\text{Elongation} = \frac{\Delta L}{L}$$

Temperature & Strain units

- Temperature is given in ° Celsius
- Strain is given in microstrain, με
  - 1 με = it's an elongation or compression of 1µm for a distance of 1 m,
  - also in percentage 1 με = 0,0001%
- Brillouin Shift :
  - 1 MHz= 1°C = 20με = 0,002% for a fiber

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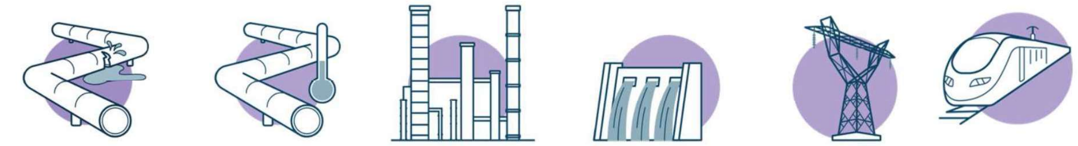
Applications and Use cases

DTS - Applications

Buildings & Infrastructure (roads, railways, industry facilities)	Fire Detection
Pipelines (oil, gas (LPG), water…)	Leak Detection
Electrical utilities (power cables)	Hot Spots | Depth of Cover | RTTR/Ampacity | Smart Grid



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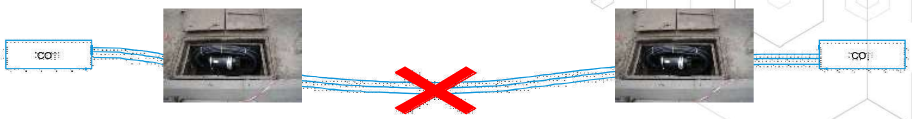
Use Case - Cable or Fiber Identification



Identify faulty cables at manhole with other cables still carrying traffic

Identify cables at outage site for repair

Identify faulty cables at manhole with other cables still carrying traffic

Method – DTS with cold air spray		**Benefits**
▪ Use Raman OTDR at CO and a cold air sprayer at site or manhole when the cable is not opened. ▪ The cold air will be sprayed to the cable surface, and the temperature change can be picked up by the Raman OTDR, thus the cable can be tagged		▪ Identify cable without open or cut, non-intrusive ▪ Freezing activity on one cable will not affect other cable ▪ Distance reach can be >=20km considering the Dynamic Range of Raman OTDR, test setup and link's loss

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DTSS - Applications

Buildings & Infrastructure (roads, rails, bridges, dams, dikes)	Fire Detection | Structural Health Monitoring | Seismic areas | Landslides Monitoring | Crack/deformation detection
Pipelines (oil, gas (LPG), water…)	Leak Detection | Pipeline Integrity Management
Electrical utilities (power cables)	Hot Spots | Depth of Cover | RTTR/Ampacity | Smart Grid Asset Health Monitoring |Overstressed line identification/Icing
Telecoms/MSOs (fiber cables)	Asset Health Monitoring |Overstressed fiber identification/Fiber aging Installation loads/quality

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Use Case - Aerial Cables Health Monitoring

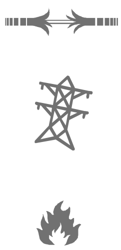
OPGW / ADSS cables

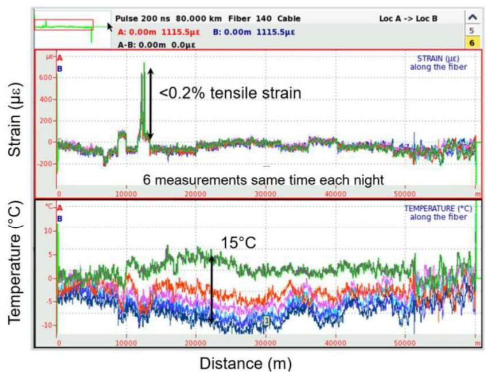
Strain

- Installation loads / quality
- Objects on cables
- Ice loads
- Wind loads
- Ground & towers/piles movements
- Seasonal thermal loads

Temperature

- Hot Spots (e.g. OPGW near HV)





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DAS - Applications

Security services/Government	Real-time Perimeter Monitoring | Border Security
Infrastructure (roads, rails...)	Intelligent Transport (Smart Cities)
Pipelines (oil, gas (LPG), water...)	Leak Detection | Pipeline Integrity Management | Hot Tapping | PIG Tracking
Electrical utilities (power cables and equipment health)	Asset Protection/Third-party interference detection | Electrical arcing | Electrical substation & three-phase switch Monitoring
Telecoms/MSOs (fiber cables)	Asset Protection/Third-party interference detection
Industry (equipment health)	Operations and fatigue monitoring (fans, conveyor belts...) | Perimeter Security

Third Party Intrusion/Security | Geo-Technics and Seismic | Rail & Road Monitoring | Industrial Process Monitoring | Structural Health Monitoring | Power Cable Monitoring | Pipeline Condition Monitoring

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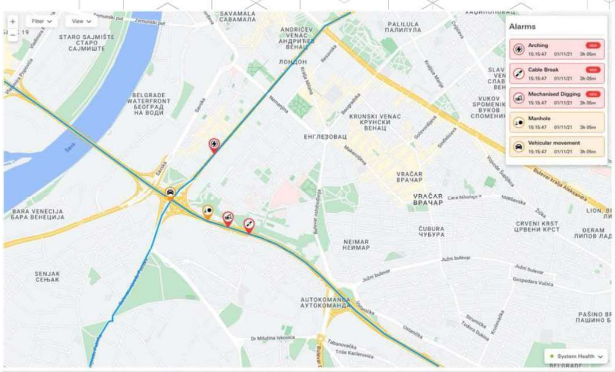
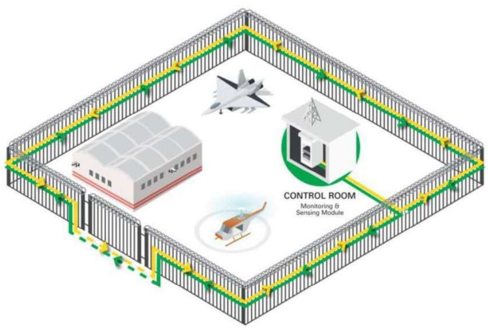
DAS threat detection for

People & vehicle movement
Fence climbing & cutting
Tunnelling and excavation (manual and mechanized)
Man-hole Interaction & cable tampering
Cable & joint faults
Cable bend/stretching and arching/flashover
Leak Detection
Ground Deformation





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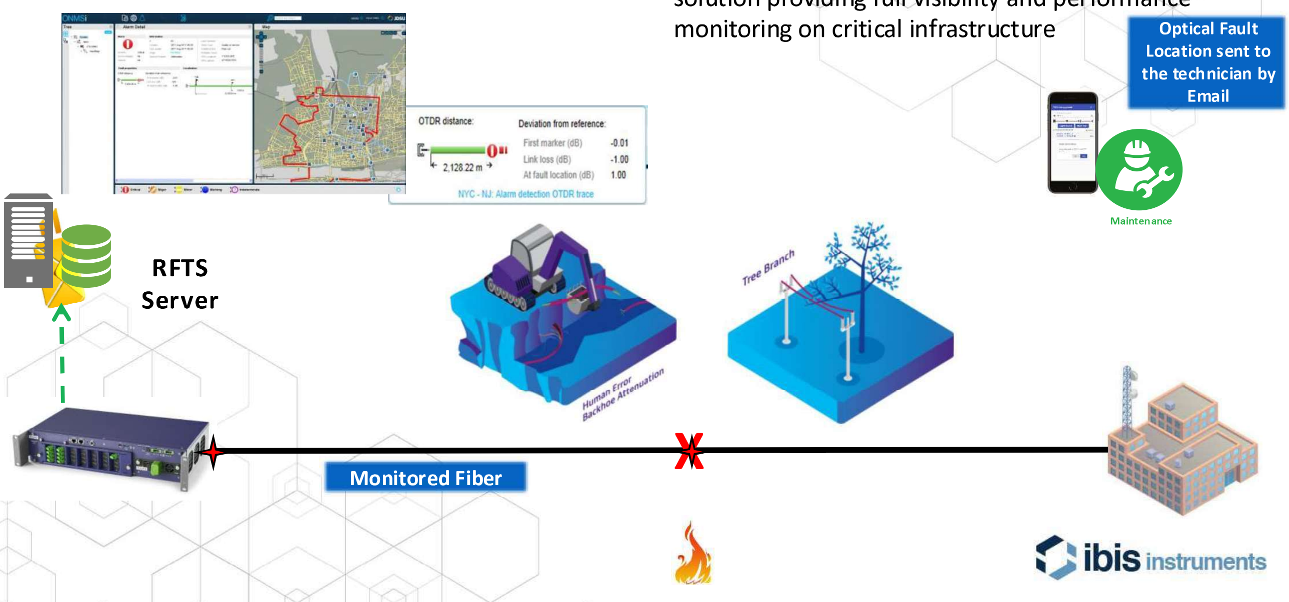
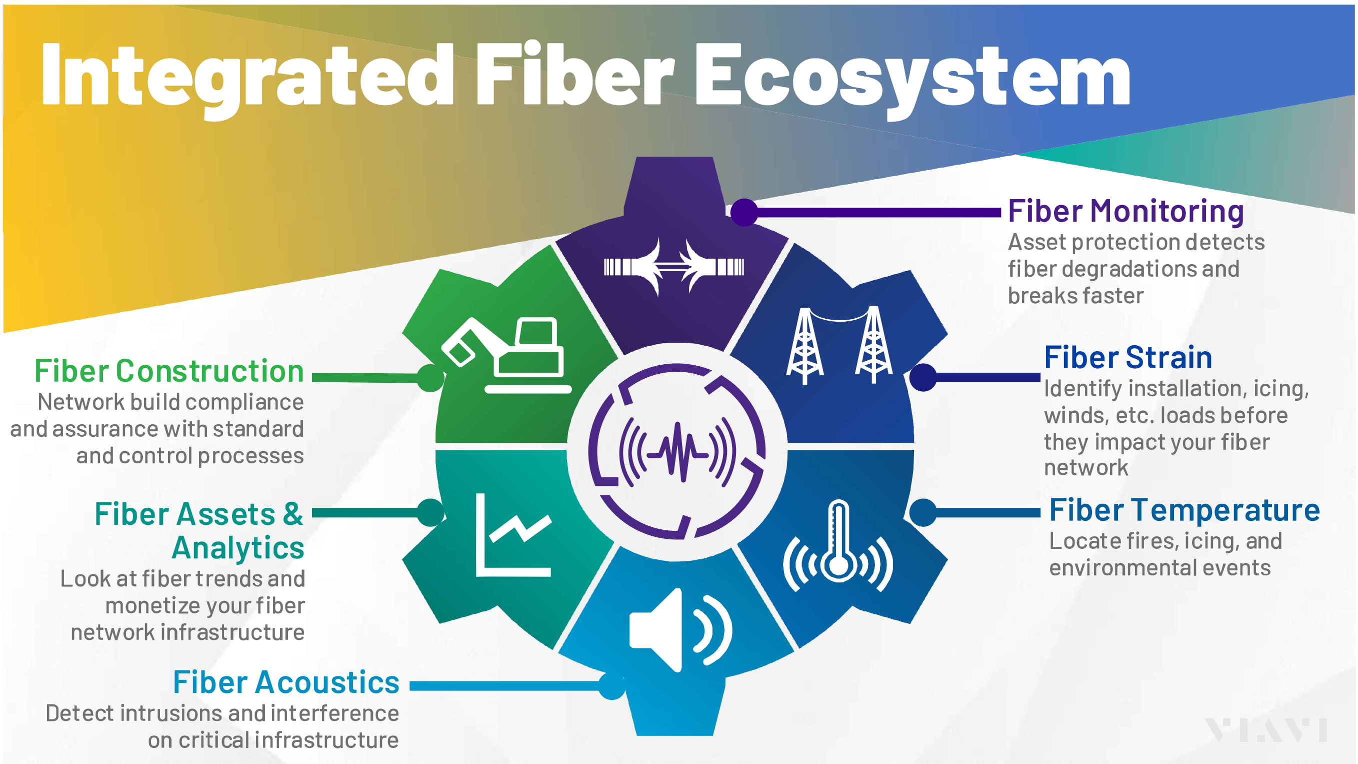
Integrated Fiber Ecosystem

Monitoring Solution

Automatic Monitoring & Alarm Management

Integrated real-time asset protection and analytics solution providing full visibility and performance monitoring on critical infrastructure





Full visibility and performance monitoring on critical infrastructure

Fiber Sensing Solutions for Power
Real-Time Holistic Cable Monitoring
- Real-time Thermal Rating (RTTR) and cable temperature
- Cable exposure and Depth of Burial (DoB)
- Fault localization and event detection

Fiber Sensing Solutions for Pipelines
Real-Time Asset Monitoring
- Leak prevention, detection and localization
- Third party interference and Hot Tapping
- PIG Tracking

Fiber Sensing Solutions for Protection/Security
Real-Time Perimeter Monitoring
- People and vehicle detection
- Fence cutting and climbing
- Tunnelling and excavation (manual and mechanized)

Fiber Sensing Solutions for Telecoms Networks
Network Monitoring, Security, and Protection
- Cable health monitoring
- Third party interference, damage or theft
- Smart cities and environmental sensing

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Izzivi pri razvoju erbijevih vlaken
Challenges in the development of erbium fibers

Peter Lukan

Lumentum

peter.lukan@lumentum.com

Povzetek

Erbijeva vlakna se že več desetletij uporabljajo za ojačevalnike v telekomunikacijah. Čeprav sodijo med specialna vlakna, so v tem smislu že komercialna stalnica z daljšo tradicijo. Kljub temu so tehnologije za njihovo proizvodnjo različne, kar prinaša tudi različnost izzivov pri njihovem razvoju. Podjetje Lumentum ima lastno razvito tehnologijo za dopiranje kvarčnih stekel in je po začetnem fokusu na razvoj iterbijevih laserskih vlaken zakorakal tudi v razvoj erbijevih vlaken. Ta predstavitev je namenjena orisu procesa razvoja in izdelave erbijevih vlaken ter nekaterih izzivov, ki ta razvoj spremljajo.

Abstract

Ebium doped fibers have been in use in telecom amplifiers for many decades. Although they are classified as specialty fibers, they are in this sense an off the shelf product with a longer tradition. Despite this, there are different existing fabrication technologies in use which yield different types of challenges when developing the fibers. Lumentum company developed its own proprietary technology for doping quartz glass and after initially focussing on ytterbium doped laser fiber development stepped into erbium doped fiber development too. This presentation aims at illustrating the development process and fabrication process of erbium doped fibers and a few challenges related to this development.

Biografija avtorja

Peter Lukan je direktor razvoja v podjetju Lumentum, ki se ukvarja z razvojem in proizvodnjo specialnih optičnih vlaken za močnostne laserje in telekomunikacije ter laserskih komponent za močnostne laserje. Podjetje spada v ameriško multinacionalko in je naslednik slovenskega fotonskega podjetja Optacore. Peter sodeluje na področju specialnih vlaken od leta 2013, ko je v podjetju Optacore vodil meritve na vlaknih, po prevzemu leta 2017 je sodeloval pri razvoju laserskih vlaken za močnostne laserje kot vodja oddelka za specialna vlakna, ob nadaljnji rasti podjetja je prešel na vodstveno funkcijo v razvoju.

Author's biography

Peter Lukan is the Director of Development at Lumentum, a company engaged in the development and production of special optical fibers for power lasers and telecommunications, as well as laser components for power lasers. The company is part of an American multinational and is the successor to the Slovenian photonics company Optacore. Peter has been involved in the field of special fibers since 2013, when he led fiber measurements at Optacore. After the takeover in 2017, he participated in the development of laser fibers for power lasers as the head of the special fibers department. With the further growth of the company, he moved to a management function in development.

Izzivi pri razvoju erbijevih vlaken

Peter Lukan

5 Februar 2025

Uvod

- Kratka predstavitev podjetja (3 min)
- Proizvodnja specialnih vlaken (5 min)
- Erbijeva vlakna (5 min)
- Izzivi pri razvoju erbijevih vlaken (15 min)

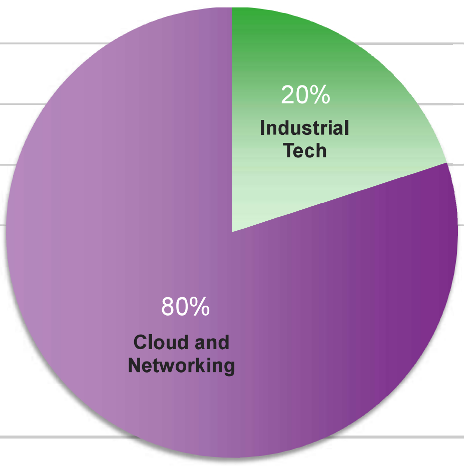
Kratka predstavitev podjetja Lumentum

World’s Leading Photonics Component and Module Supplier

$1.36B	FY24[1] revenue
8000	employees
2100	patents

Leadership positions in:

- Telecom transport and transmission
- 400/800G data center transceivers and lasers
- Industrial and consumer diode lasers



FY24 Revenue by Segment

1. Fiscal year ended June 29, 2024

Global Footprint

Americas

San Jose, California USA
- Corporate headquarters

Ottawa, Ontario Canada

Campinas, Brazil

EMEA

Milan, Italy

Škofljica, Slovenia

Zug, Switzerland

Zurich, Switzerland

Caswell, UK

Paignton, UK

APAC

Dongguan, China
Shenzhen, China
Wuhan, China
Hong Kong SAR, China
Sagamihara, Japan
Takao, Japan
Tokyo, Japan
Seongnam-si, Republic of Korea
Penang, Malaysia
New Taipei City, Taiwan
Pathumthani, Thailand

Best-in-class manufacturing partners

Global presence – close to our customers
R&D and operations excellence centers across the globe

LUMENTUM

Photonics at the Forefront of Many Long-Term Trends

DNA sequencing
Pharmaceutical screening
Bio detection and analysis

Demographics and Power of Genomics

4G→5G→next-gen mobile
Flex, glass, PCB
LCD→ OLED / uLED

New Materials and Precision in Microelectronics

Cloud
Data centers
AI

Compute and Content Storage and Delivery

HD→ 4K→8K
Work from home
Telehealth
Remote learning

Increasing Bandwidth Requirements

5G wireless
Streaming video
IOT

Trends in Data Consumption and Mobility

PHOTONICS ARE A CRITICAL AND ENABLING TECHNOLOGY

New Materials, Processes, and Precision in Industrial Applications

Laser cutting and welding
Additive manufacturing

Energy Efficiency and Climate Change Concerns

Electric vehicles
Green manufacturing

Security Needs

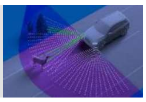
Biometric security
Cashless transactions
Secure access control

Emergence of AR / VR and Computational Imaging

Entertainment
Education
Remote work
Ease of life

Machine Vision Revolution

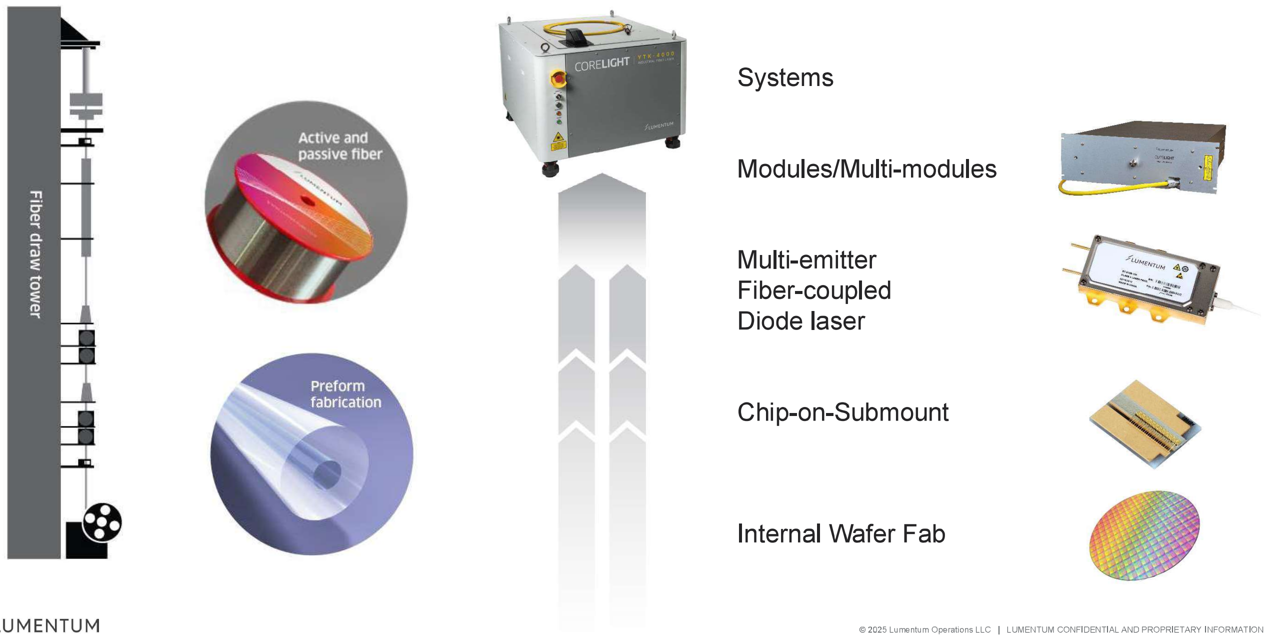
LiDAR for ADAS & AVs
Smart infrastructure
Industry 4.0



LUMENTUM

Vertically Integrated Platforms for Diverse Applications

Lumentum Vertical Integration, from wafer to laser solutions



Stavba 1 – proizvodnja vlaken

- **Total area 1500 sqm**
- Production area: 600 sqm (Clean room 230 sqm)
- R&D: 75 sqm
- Warehouse: 135 sqm
- Offices: 635 sqm
- Other (gas station, IT room,..): 100 sqm

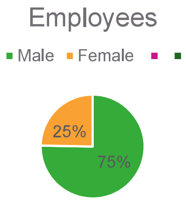
Stavba 2 – proizvodnja dostavnih vlaken in razvojni laboratoriji

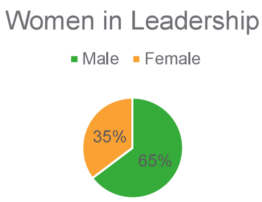
- **Total area: 2400 sqm**
- Production area: 260 sqm (Clean room 170 sqm)
- R&D: 565 sqm
- Warehouse: 145 sqm
- RSC(Laser repair service center): 130 sqm
- Other (lobby, electrical room,...): 162 sqm
- Offices: 935 sqm

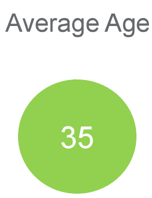
Employee Growth

2019 → 2020 → 2021 → 2022 → 2023

2019	2020	2021	2022	2023
28 employees	29 employees	39 employees	89 employees	97 employees



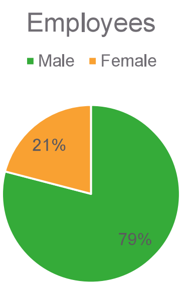


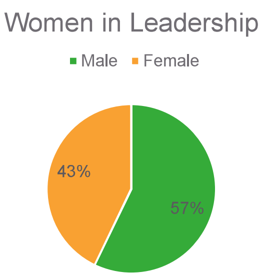


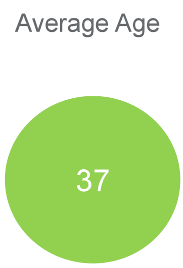
Slovenia

2022	2023	2024	2025
75 employees	95 employees	88 employees	86 employees

Today: 86 employees (68 male, 18 female)



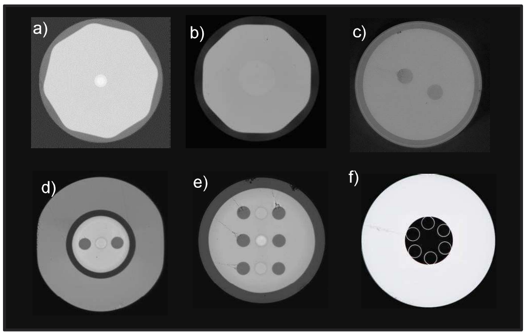




Proizvodnja specialnih vlaken

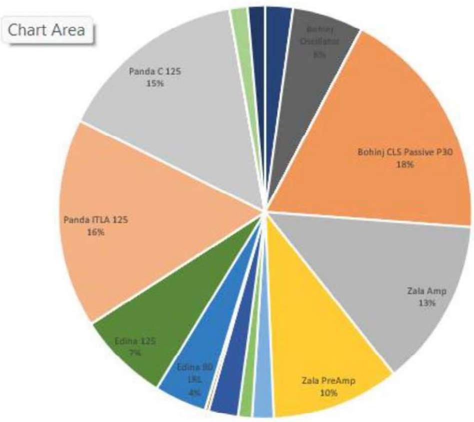
Specialna vlakna

Primeri specialnih vlaken

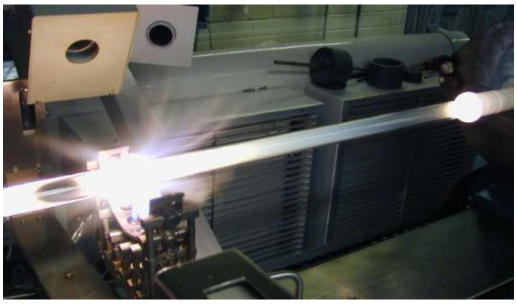


a) Triple-clad Yb doped fiber, b) VLMA Yb doped fiber, c) PM double-clad fiber, d) RE doped PM double-clad fiber, e) Multicore Yb doped PM fiber, f) Hollow Core fiber

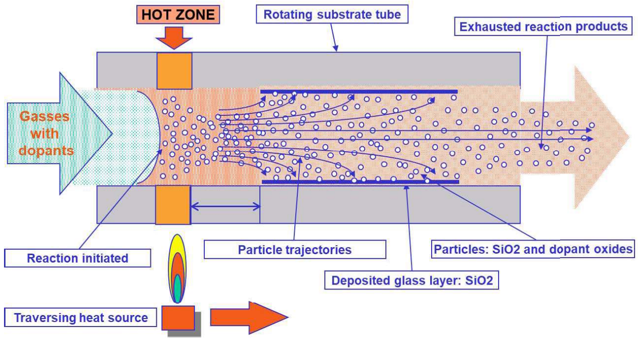
Velika raznovrstnost vlakenskih produktov



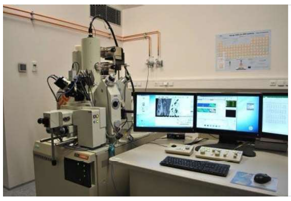
MCVD tehnologija + interno razvit sistem za dopiranje kelatov

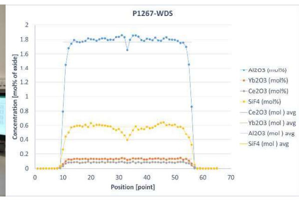


Vgradnja aktivnih dopantov v steklo s pomočjo tehnike MCVD (Modified Chemical Vapor Deposition)



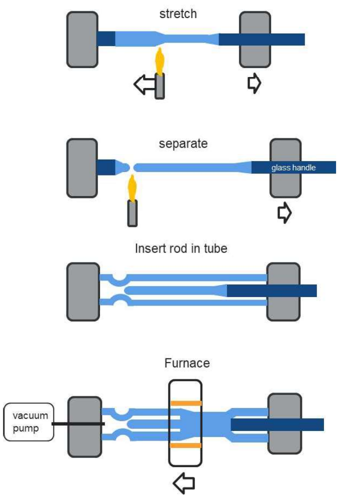
Proces depozicije stekla (shematsko)



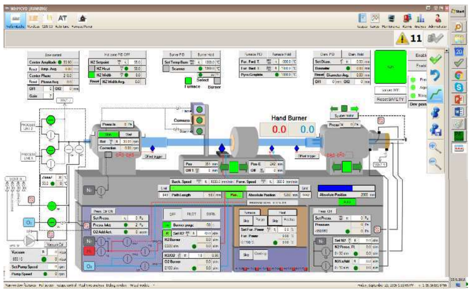


Meritve kemijske sestave z elektronskim mikroskopom z WDS sondo (Wavelength Dispersive Spectroscopy)

Preoblikovanje stekla



Proces raztegovanja in oplaščenja (shematsko)



Uporabniški vmesnik

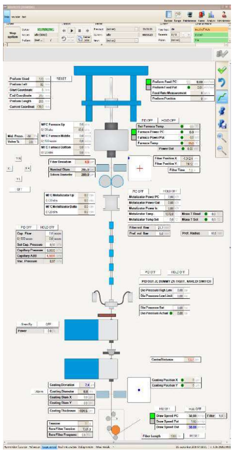
MCVD lab

Vlečni stolp

Nočni pogled

Pogled od spodaj

Uporabniški vmesnik



Merilni laboratorij za vlakna

10 merilnih postaj za optične in geometrijske meritve vključno z močnostnim laserjem

Vlakenski previjalnik z nivojskim testom

Digestorij s postajo za avtomatizirano jedkanje vlaken

Erbijeva vlakna

Poslovna priložnost

Motivacija

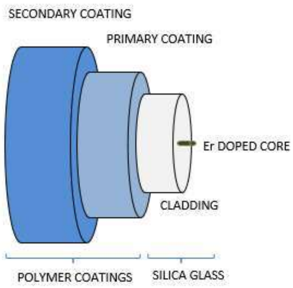
- Lumentum proizvaja EDFA-je za obstoječe telekom stranke
- Potreba po L-band EDFA-jih na trgu se veča
- Razvoj cenovno konkurenčnih LRL (L-band Reduced Lenght) vlaken za obstoječe in nove produkte
- Vertikalna integracija in njene dobrobiti
- Nekateri dobavitelji imajo slabše tehnološke možnosti za visoko vsebnost erbija in oblikovanje manjšega jedro vlakna za manjši polmer zavoja/omota

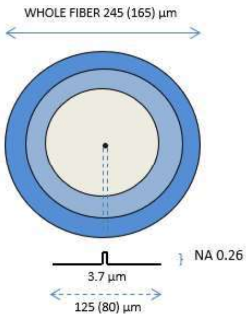
Lumentum EDFA

Primer tipičnih karakteristik LRL erbijevega vlakna

Top level specifications:

Product Description	
Physical Characteristics	
Cladding Diameter	**125 µm**
Coating Diameter	**245 µm**
Core/Cladding Concentricity Error	**< 0.3 µm**
Optical Characteristics	
Cutoff Wavelength	**1000-1300 nm**
Peak Absorption @ 1530 nm	**30.0 dB/m**
Mode Field Diameter @ 1550 nm	**4.9 µm**
Numerical Aperture	**0.26**
Mechanical and Environmental	
Proof Test Level	**2%**

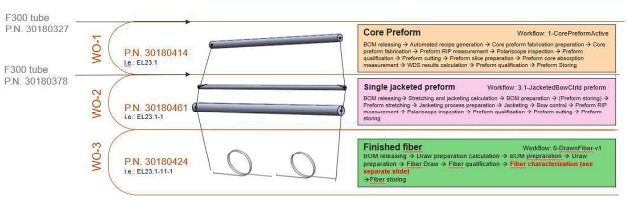


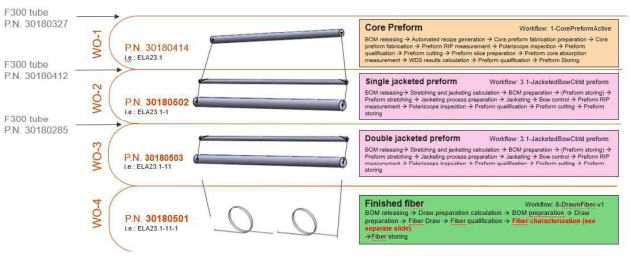


Proizvodni proces

80µm vlakno

125µm vlakno





Eno vlečenje → ~30 km vlakna

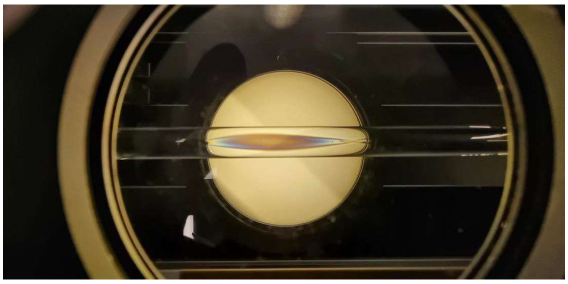
Izzivi pri razvoju erbijevih vlaken

Izzivi z vidika razvoja vlakna

- Dodatne zahteve vlakna oziroma proizvodnega procesa
  - Nizko slabljenje ozadja (background loss)
  - Visoko dopiranje erbija
  - Homogenost erbijeve absorpcije vzdolž vlečenega vlakna
  - Stabilen enorodovni profil lomnega količnika
  - Nezaželena eliptičnost jedra
  - Vlečenje tankih 80 μm vlaken pri višjih vlečnih hitrostih (~180m/min)
- Performančne zahteve na nivoju EDFA
  - Gain shape consistency (ponovljivost odvisnosti ojačanja od valovne dolžine)
  - Noise figure (odvisnost šuma od valovne dolžine)
  - Dynamic gain tilt
  - Pump efficiency
- Testi zanesljivosti in staranja

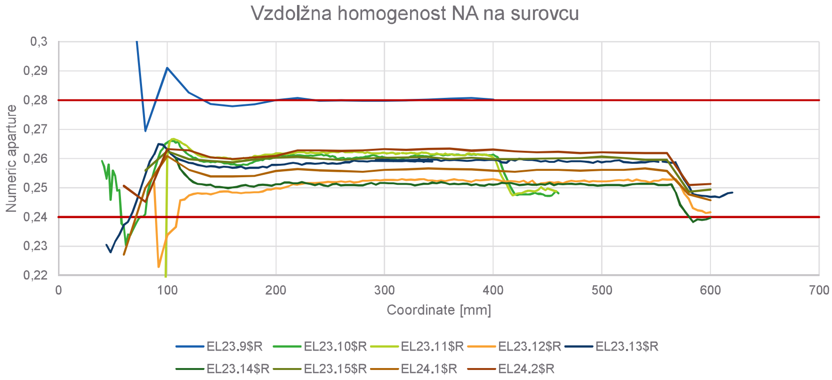
Težki začetki

- Spoznavanje s procesom pri novi sestavi stekla
- Začetek: spiralno jedro
- Nadaljevanje: „bežeče“ jedro



Slika surovca: spiralno jedro

Vzdolžna homogenost

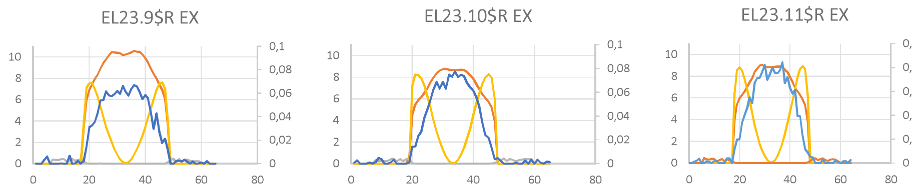


Doseženo:

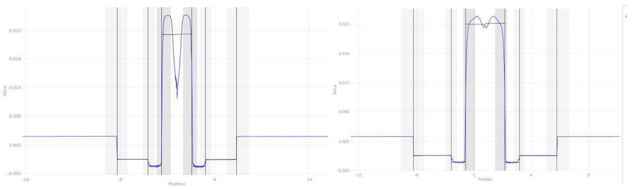
- Ustrezno ciljanje NA, dobra vzdolžna homogenost
- Povečano depozicijsko dolžino (→ več materiala v enem procesu)

Uniformnost lomnega količnika in kompozicija stekla

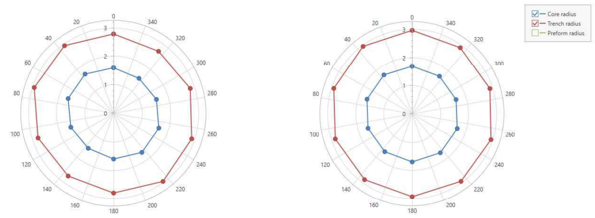
➢ Optimizacija sestave stekla in profila dopantov



➢ Optimizacija profila lomnega količnika



➢ Reševanje ovalnosti jedra

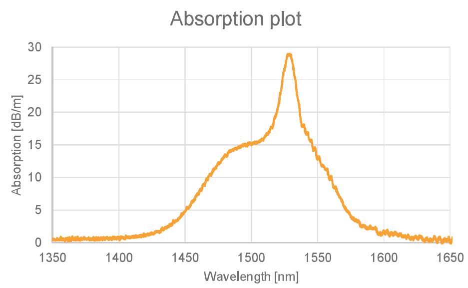


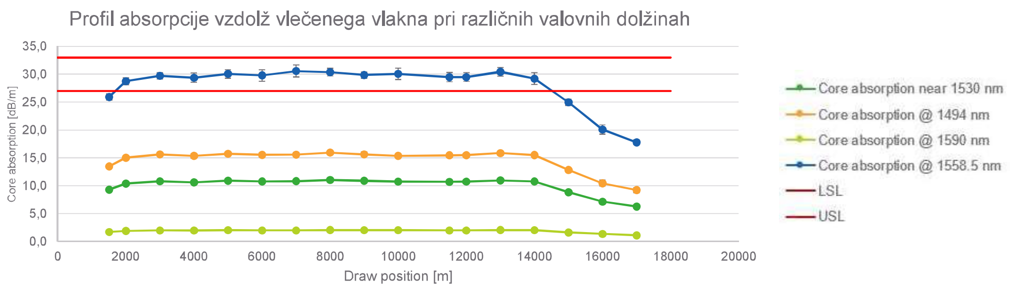
EL23.5$R ✗ EL23.8$R ✓

LUMENTUM

Visoka in homogena absorpcija vzdolž vlečenja

- Homogena absorpcija pokazana vzdolž celotne dolžine vlečenja – nemerljivo majhna (znotraj šuma)
- Dosežena absorpcija 33 dB/m @1530nm z nizkim slabljenjem 6dB/km @1200nm (background loss)
- Ponovljivo ciljanje visoke absorpcije 30 ± 3 dB/m @1530nm





LUMENTUM

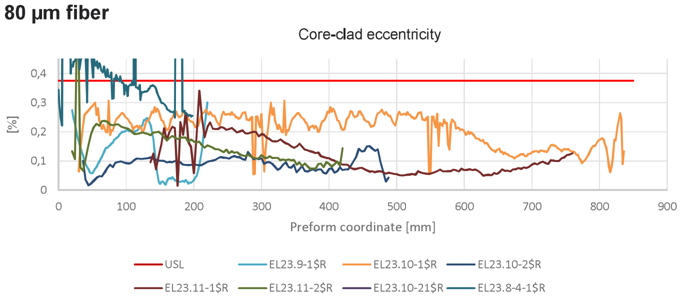
Razvoj procesa izdelave aktivnega stekla

grey	no data (no fiber)
red	not ok
green	ok

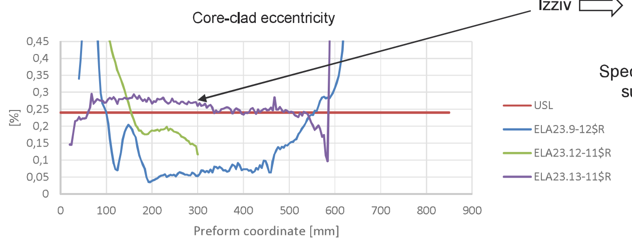
SN	Longitudinal homogenity	Index dip	Core ellipticity	Absorption	Background loss
EL23.1$R	not ok	no data (no fiber)	no data (no fiber)	no data (no fiber)	no data (no fiber)
EL23.2$R	not ok	no data (no fiber)	no data (no fiber)	no data (no fiber)	no data (no fiber)
EL23.3$R	not ok	no data (no fiber)	no data (no fiber)	no data (no fiber)	no data (no fiber)
EL23.4$R	ok	not ok	ok	no data (no fiber)	no data (no fiber)
EL23.5$R	ok	not ok	not ok	no data (no fiber)	no data (no fiber)
EL23.6$R	ok	ok	not ok	no data (no fiber)	no data (no fiber)
EL23.7$R	ok	ok	not ok	ok	no data (no fiber)
EL23.8$R	ok	ok	ok	not ok	no data (no fiber)
EL23.9$R	ok	ok	ok	ok	not ok
EL23.10$R	ok	ok	ok	ok	ok
EL23.11$R	ok	ok	ok	ok	ok
EL23.12$R	ok	ok	ok	ok	ok
EL23.13$R	ok	ok	ok	no data (no fiber)	no data (no fiber)
EL23.14$R	ok	ok	ok	no data (no fiber)	no data (no fiber)
EL23.15$R	ok	ok	ok	no data (no fiber)	no data (no fiber)
EL24.1$R	ok	ok	ok	no data (no fiber)	no data (no fiber)
EL24.2$R	ok	ok	ok	no data (no fiber)	no data (no fiber)

Preoblikovanje stekla

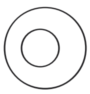
80 µm fiber



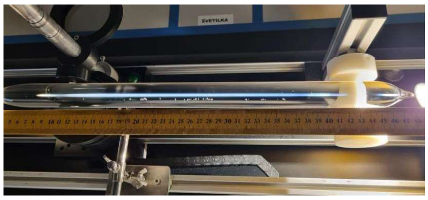
125 µm fiber



Izziv

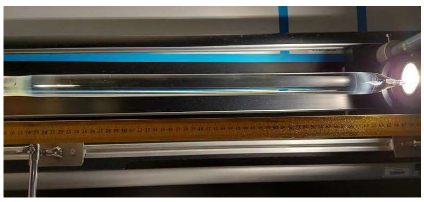


Specifikacije na ravni substratne cevi



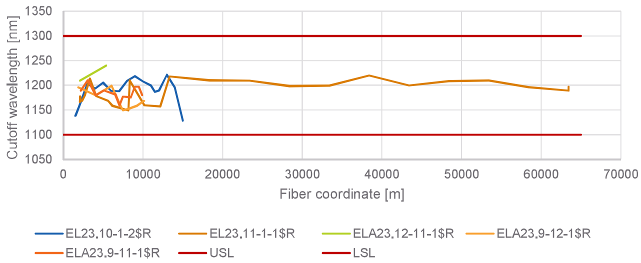
Mehurčki zaradi plaščenja

Optimizacija recepta



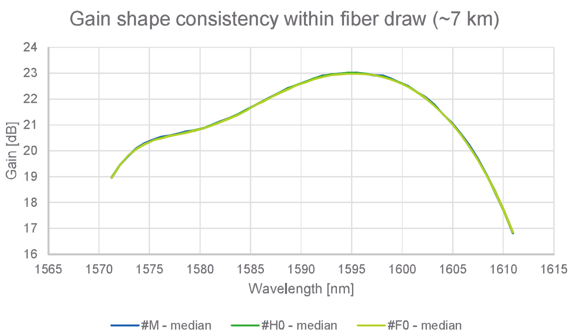
Brez mehurčkov

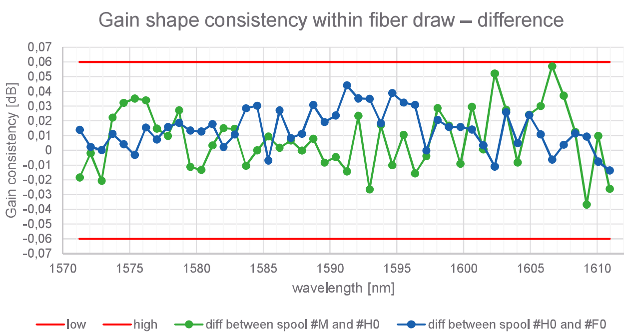
Ciljanje mejne valovne dolžine

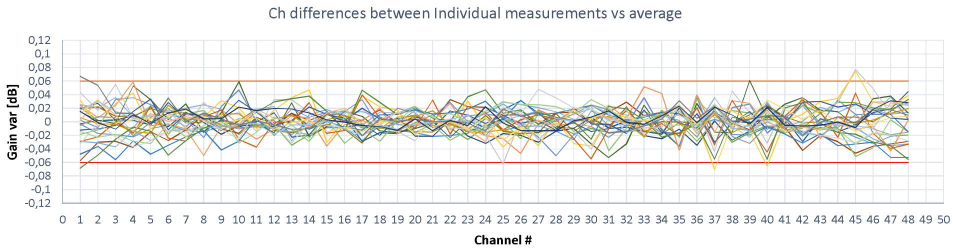


- Klasični del procesnega repertoarja pri proizvodnji enorodovnega vlakna
- Za stabilnost ciljanja mejne valovne dolžine potrebujemo
  - Stabilnost premera jedra
  - Dober algoritem ciljanja s surovca na vlakno
- Tolerančna analiza optičnih lastnosti
- Optične simulacije za MFD

Performančna testiranja – gain shape consistency

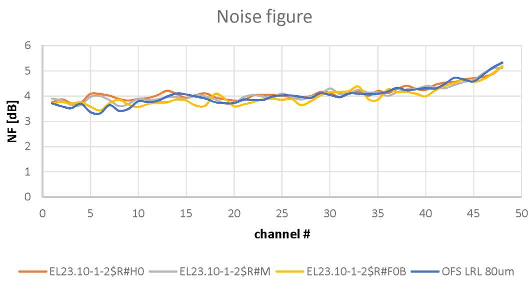


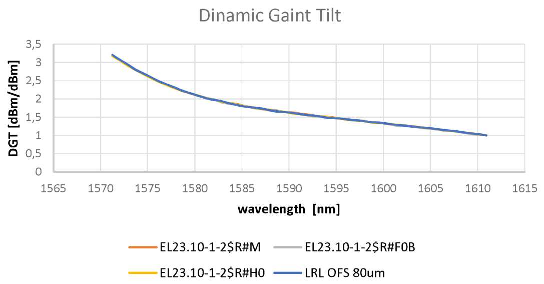




- Izziv: izrazito velik merilni šum
- Razvoj recepta za varjenje

Performančna testiranja – ostali parametri





Criteria for L-band Fiber at module level

	Requirement	Unit	Measured
Max Dynamic Gain Tilt	< 0.5	dB/dB	0.08
Noise Figure	<0.2	dB	0.05
Pump Efficiency	> -5	%	-2.4

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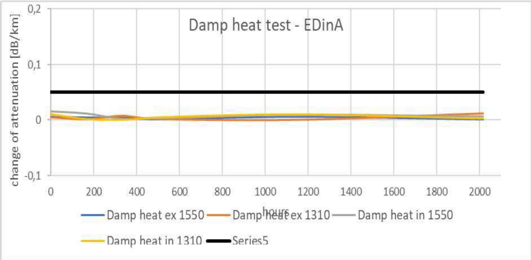
Strategija produktne zanesljivosti/staranja

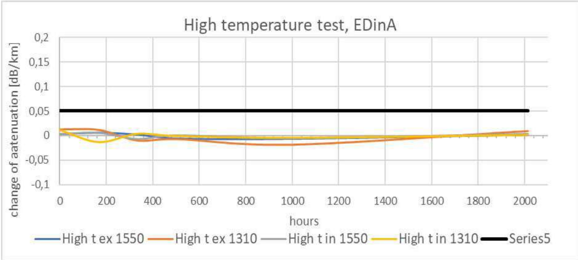
- Strategija testov zanesljivosti je v skladu s telekom standardi, osredotoča se na teste nanosa

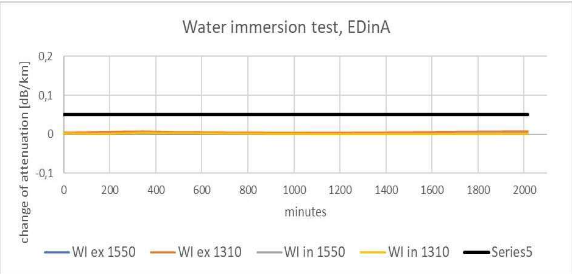
Purpose	Test name	Pass/Fail	Standard
Coating test	Temp. cycling -60°C / +85°C	added loss <0.05dB/km	Meet or exceed GR-20-Core
Storage test	Dry heat 85°C	added loss <0.05dB/km	Meet or exceed GR1221
Accelerated aging	Damp heat 85°C/85RH	added loss <0.05dB/km	Meet or exceed GR1221
Coating test	Water immersion 23°C	added loss <0.05dB/km	Meet or exceed IEC 60793-1-53
Coating strippability	Strip force	average 1.0N<5N	Meet or exceed GR-20-Core
Fiber strength	Dynamic tensile strength	3.14GPa @15% Weibull & 3.8GPa @50%Weibull	Meet or exceed GR-20-Core
Fiber strength	Dynamic fatigue	stress corrosion susceptibility parameter < 20	Meet or exceed GR-20-Core
Fiber strength	Strength retention	tensile strength > 0.69 GPa (100kpsi)	Meet or exceed GR-20-Core

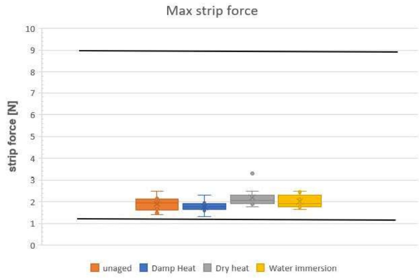
LUMENTUM

Testi zanesljivosti nanosa





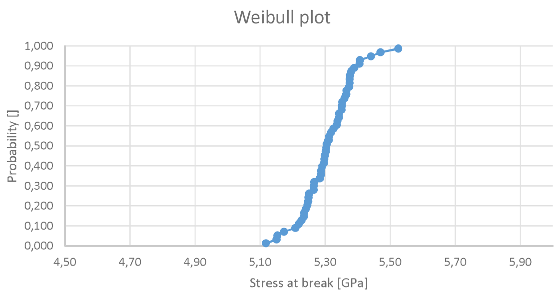




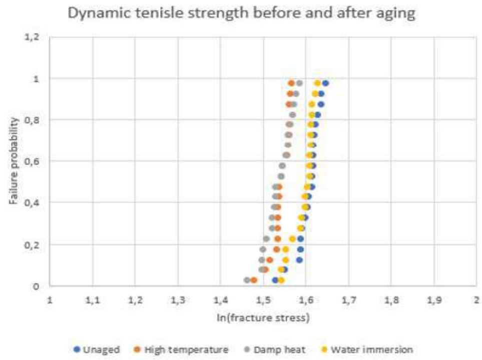
- ➤ Kriterij prirastka slabljenja < 0.05 dB/km je bil izpolnjen za vsa testiranja

Trdnost vlakna

- Vlakna so testirana za elongacijsko napetost med previjanjem na napetosti 200 kpsi
- Analiza trdnosti vlaken je bila izvedena s pomočjo dinamometra



SN:	EL23.7-2-1
# measurements:	52
Sample length:	60 cm
Shape parameter:	79
Scale parameter:	5.34 GPa



Testi mehanske trdnosti uspešni na staranih in nestaranih vlaknih

Testiranje v H2 atmosferi

Z internim znanjem razvita komora za H2 teste

LUMENTUM

Hvala za pozornost!

Uporabnost brezžičnega optičnega komunikacijskega sistema KORUZA in razvoj v smeri 100 Gbps

KORUZA wireless optical communication practical applications and 100 Gbps evolution

Luka Mustafa

IRNAS

musti@irnas.eu

Povzetek

Ta predstavitev obravnava uporabnost sistema brezžičnih optičnih komunikacij KORUZA v industriji, s poudarkom na brezžičnem optičnem prenosu s hitrostmi do 100 Gb/s. Poglobili se bomo v priklopne aplikacije za avtonomne sisteme, aplikacije ultra hitrega linearnega gibanja, kot tudi uvajanje v omrežno infrastrukturo.

Abstract

This presentation explores practical industrial applications of wireless optical applications, focusing on free-space optical technology with thoughputs of up to 100 Gbps. We shall dive into the docking applications for autonomous systems, ultra fast linear motion applications as well as deployment in the networking infrastructure.

Biografija avtorja

Luka Mustafa vodi razvoj naprednih vdelanih sistemov pri IRNAS, ki ga je ustanovil leta 2014 v Sloveniji. Pod njegovim vodstvom multidisciplinarna ekipa razvija vdelane izdelke ter sisteme, prilagojene zahtevnim okoljem in specializiranim aplikacijam. Njihovo delo pokriva širok spekter področij, od povezanih medicinskih naprav za podporo zdravstveni oskrbi, povezanih senzorjev v industriji, ter naprav, ki temeljijo na tehnologijah NB-IoT in LTE-M za zanesljivo komunikacijo na oddaljenih lokacijah. IRNAS razvija tudi napredne optične sisteme, ki se uporabljajo v telekomunikacijah, industrijskih aplikacijah ter drugih zahtevnih okoljih, kjer je potrebna hitrost in zanesljivost optične komunikacije, vendar ni možno uporabiti optičnega vlakna ali radijske komunikacije.

Author's biography

Luka Mustafa leads the development of advanced embedded systems at IRNAS, which he founded in Slovenia in 2014. Under his leadership, a multidisciplinary team develops embedded products and systems tailored to demanding environments and specialized applications. Their work covers a wide range of areas, from connected medical devices to support healthcare, connected sensors in industry, and devices based on NB-IoT and LTE-M technologies for reliable communication in remote locations. IRNAS also develops advanced optical systems used in telecommunications, industrial applications, and other demanding environments where the speed and reliability of optical communication are required, but fiber or radio communication is not possible.

KORUZA

wireless optical communication practical applications and 100 Gbps evolution.

Luka Mustafa, IRNAS Founder & CEO

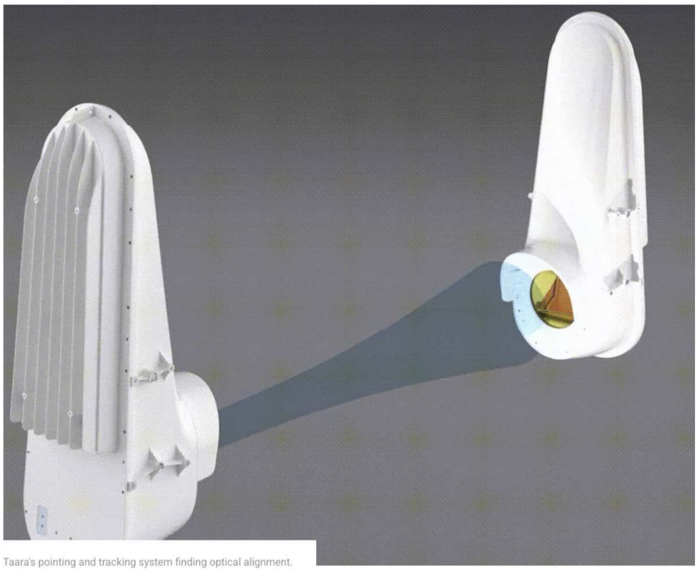
www.irnas.eu

Let’s imagine the wireless optical future

Terrestrial long range wireless fiber

https://x.company/projects/taara/

- 20km
- 20 Gbps
- Challenges:
  - Structural stability of towers
  - Weather impact

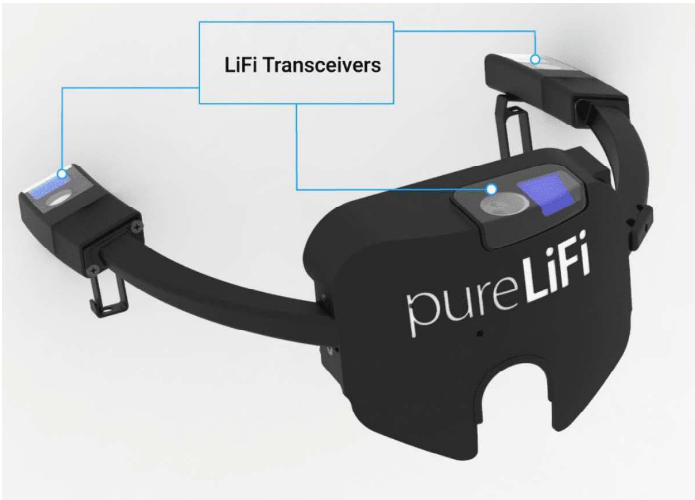


Taara's pointing and tracking system finding optical alignment.

Indoor LiFi connectivity for VR

https://www.purelifi.com/products/lifi-halo/

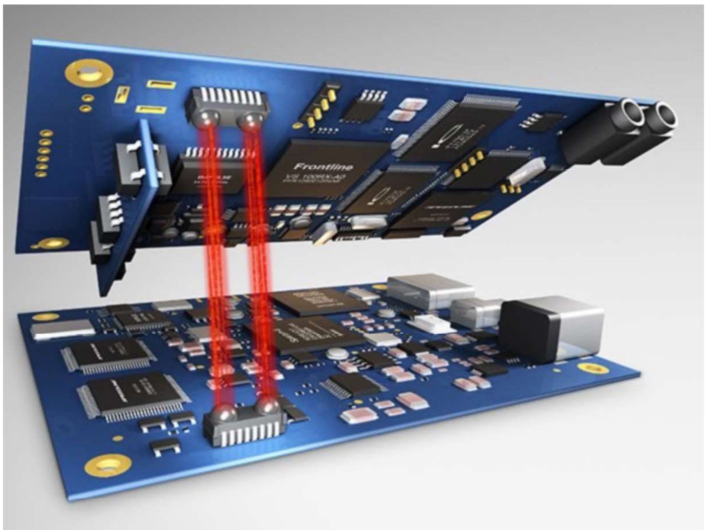
- High-density of high-throughput links possible
- Challenges:
  - Power consumption
  - Orientation



Docking

https://www.ipms.fraunhofer.de/en/press-media/press/2022/LiFi-Gigadock-at-ISS-space-station.html

- Up to 12.5 Gbps and up to 10 cm
- Can be rotated
- Challenges:
  - Alignment
  - Range subject to application

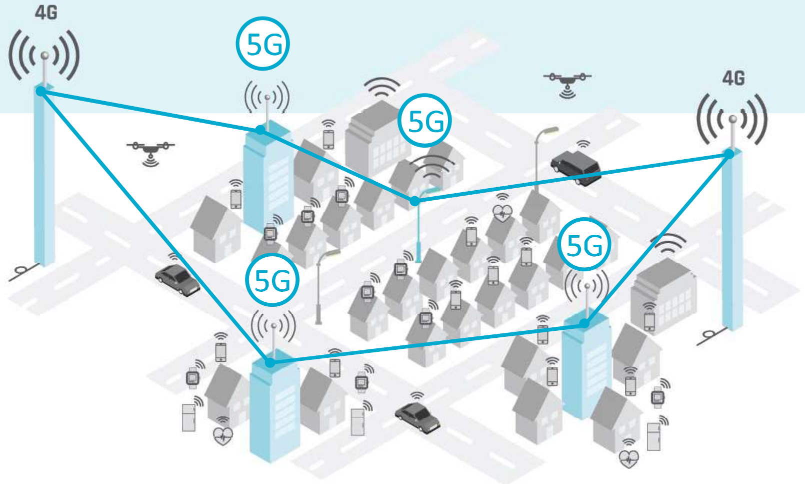


Terrestrial short range wireless fiber

http://koruza.net

- 1/10/100 Gbps
- Optimized for 150m
- Challenges:
  - Structural stability
  - Weather impact

APPLICATIONS - CELLULAR NETWORKING



Healthcare monitoring systems

Driverless cars navigation

Drones/robotics applications

Connected consumers devices

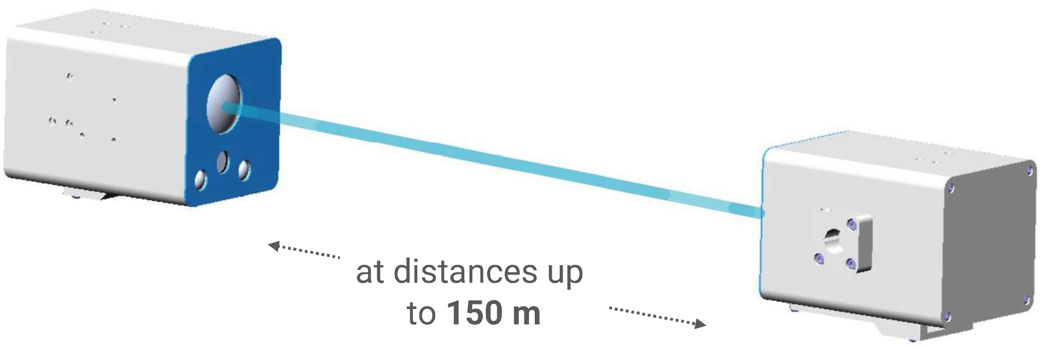
KORUZA offers **secure** point-to-point transmission over an **eye-safe** collimated beam of infra-red light.

1 Gbps

10 Gbps

100 Gbps

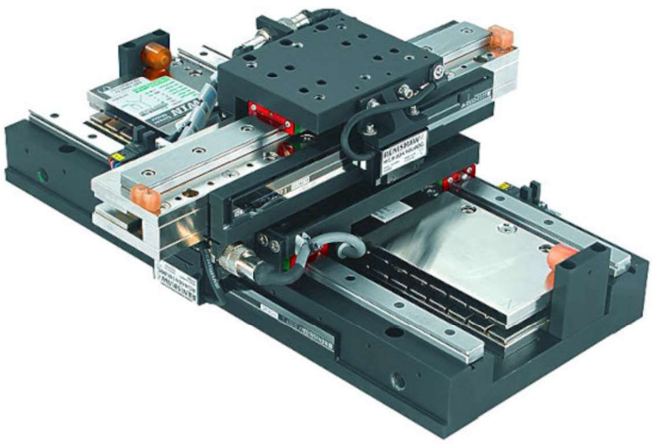
FUTURE



Unique applications

Linear motion

- Ultra-fast 10 m/s+
- High acceleration 30G+
- Challenges
    - Drag chain speed
    - Fiber bending cycles

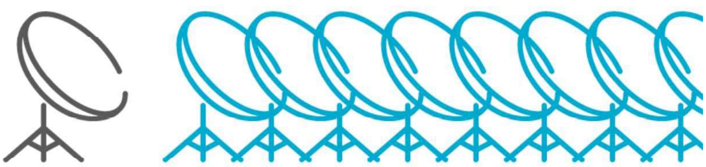


Docking

- Autonomus vehicles producing 1 GB/s of data
- Short docking times – particulary if not battery powered
- Requirement to offload 1-10 TB of data in minutes
- Data security concerns

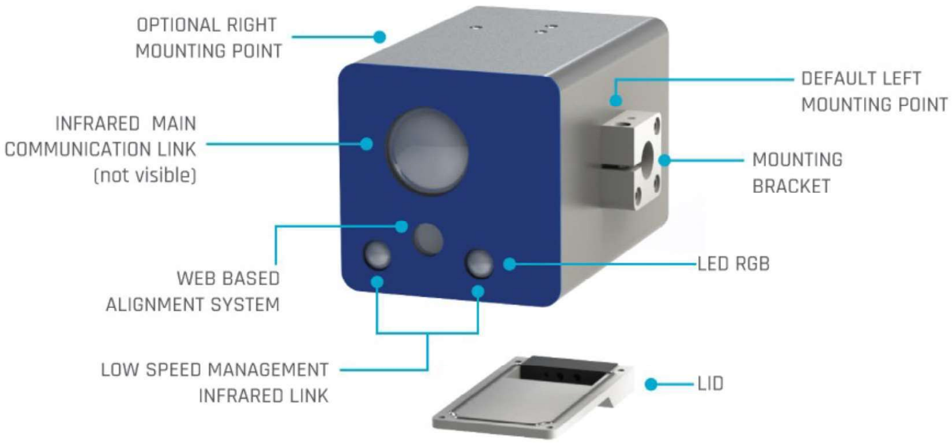
RF quiet/secure environment

- RF telescopes with no fixed ingrastructure
- Air-gap systems
- Requirement for temporary large data transfers



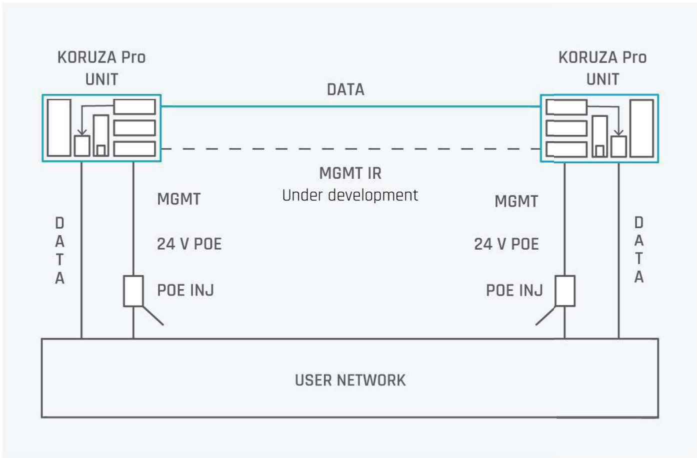
Evolution to 100 Gbps KORUZA systems

Unit Description

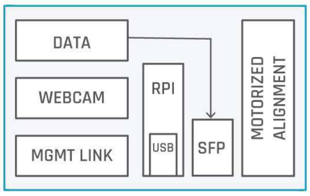


Link Diagram

KORUZA Pro NETWORK DIAGRAM

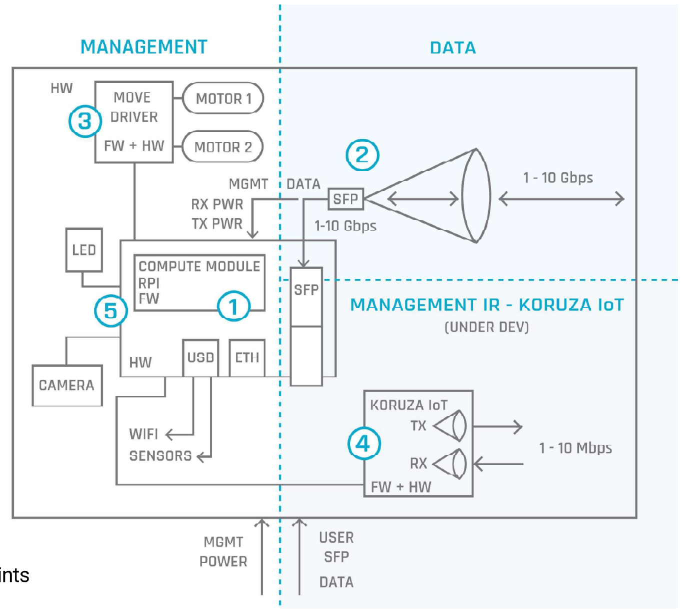


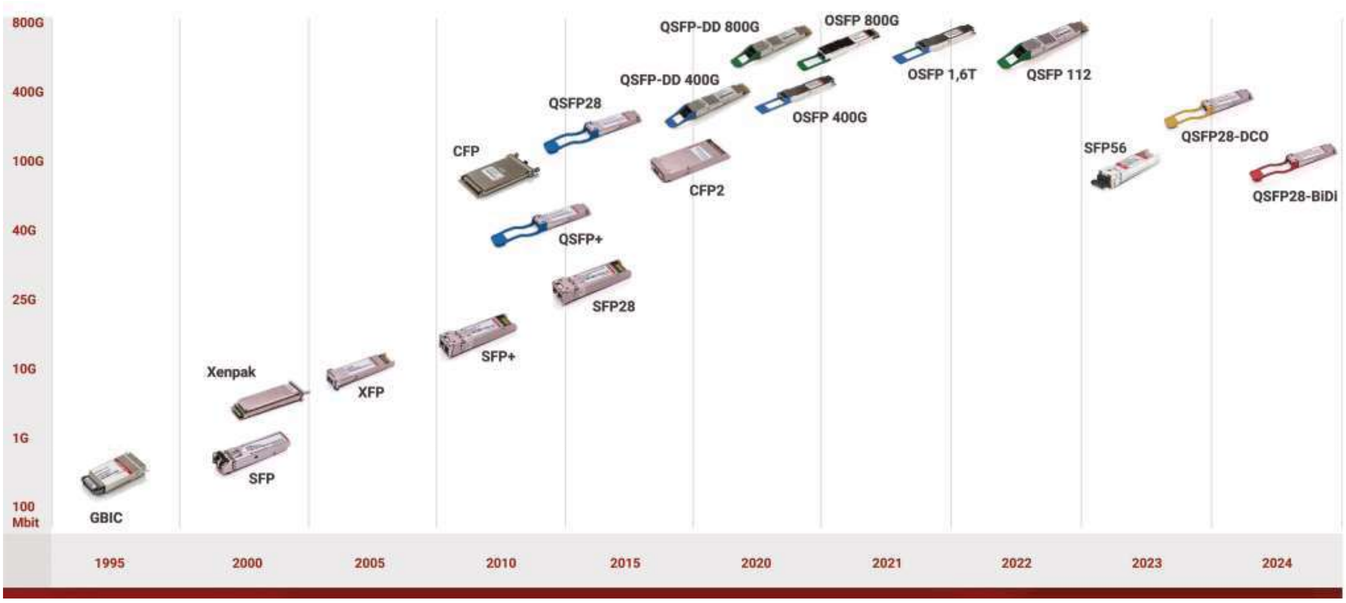
KORUZA Pro UNIT DIAGRAM



Block Diagram

1. COMPUTE MODULE
   - → Main processor with RPi compute module – Linux
   - → High-speed data transmission
   - → Alignment algorithms + management
   - → FW +HW
2. OPTICAL ARM
   - → Lens to SFP transceiver
   - → Alignment webcam
   - → HW
3. MOVE DRIVER
   - → Controls two motors for alignment
   - → FW+ HW
4. KORUZA IoT
   - → Unit-unit management communication
   - → Under development
   - → FW+HW
5. ENCLOSURE AND MAIN STRUCTURE
   - → IP57 enclosure with mounting options and cable entry points
   - → HW





https://www.prooptix.com/news/transceiver-form-factors/

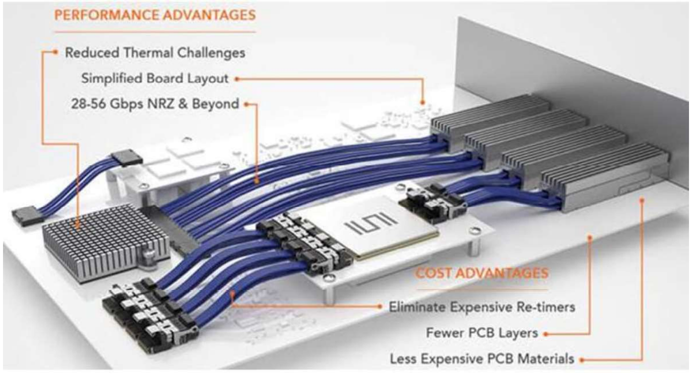
QSFP28 100G BiDi

- OOK 4x 25G over single optical path
- PAM4 1x 100G over single optical path

- Unlocking FSO applications

Electrical connections challenge

- Multi-hop connections between FSO transceiver and interconnect degrade signal
- 25G electrical lanes are a challenge at low-cost and distance up to 50cm



https://blog.samtec.com/post/samtec-and-molex-share-high-speed-product-ip/

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Kako optične tehnologije lahko pomagajo umetni inteligenci?
How can optical technologies help artificial intelligence?

Blaž Bertalanič

Institut Jožef Stefan

blaz.bertalanic@ijs.si

Povzetek

ChatGPT je v zadnjih nekaj letih povsem spremenil pomen besede "umetna inteligenca", kot smo jo poznali do sedaj. Milijoni dnevno rešujejo svoje težave s pomočjo te tehnologije, ki se vedno bolj zažira v vse pore našega življenja. Toda tako kot vsaka stvar ima tudi ChatGPT svojo ceno. Ali ste vedeli, da ChatGPT dnevno porabi kar 621,4 MWh električne energije? Prevedeno na emisije CO_2 to znaša približno 275 ton dnevno. Toda ali obstaja alternativa? V zadnjih letih se pospešeno razvijajo tehnologije na področju optičnega računanja, ki bi lahko pomembno pohitrile kompleksne računske operacije, ki jih lahko najdemo v modelih umetne inteligence, kot je ChatGPT. Lahko ta tehnologija vodi do optičnih nevronskih mrež, ki bodo izboljšale učinkovitost modelov in zmanjšale njihovo porabo električne energije?

Abstract

In the last few years, ChatGPT has completely changed the meaning of the word "artificial intelligence" as we know it. Millions of people solve their problems every day with the help of this technology, which is increasingly embedded in every pore of our lives. But like everything, ChatGPT also has its price. Did you know that ChatGPT consumes 621.4 MWh of electricity per day? Translated into CO2 emissions, this amounts to approximately 275 tons per day. But is there an alternative? In recent years, technologies in the field of optical computing have been rapidly developing, which could significantly speed up the complex computational operations that can be found in artificial intelligence models such as ChatGPT. Could this technology lead to optical neural networks that will improve the efficiency of the models and reduce their electricity consumption?

Biografija avtorja

Blaž Bertalanič je podoktorski raziskovalec na Institutu Jožef Štefan. Njegovo glavno področje raziskovanja je zasnova novih algoritmov umetne inteligence za različna področja uporabe glede na njihovo energijsko in računsko učinkovitostjo. Za svoje delo je prejel tudi nagrado za "najboljši članek" na konferenci WiMob.

Author's biography

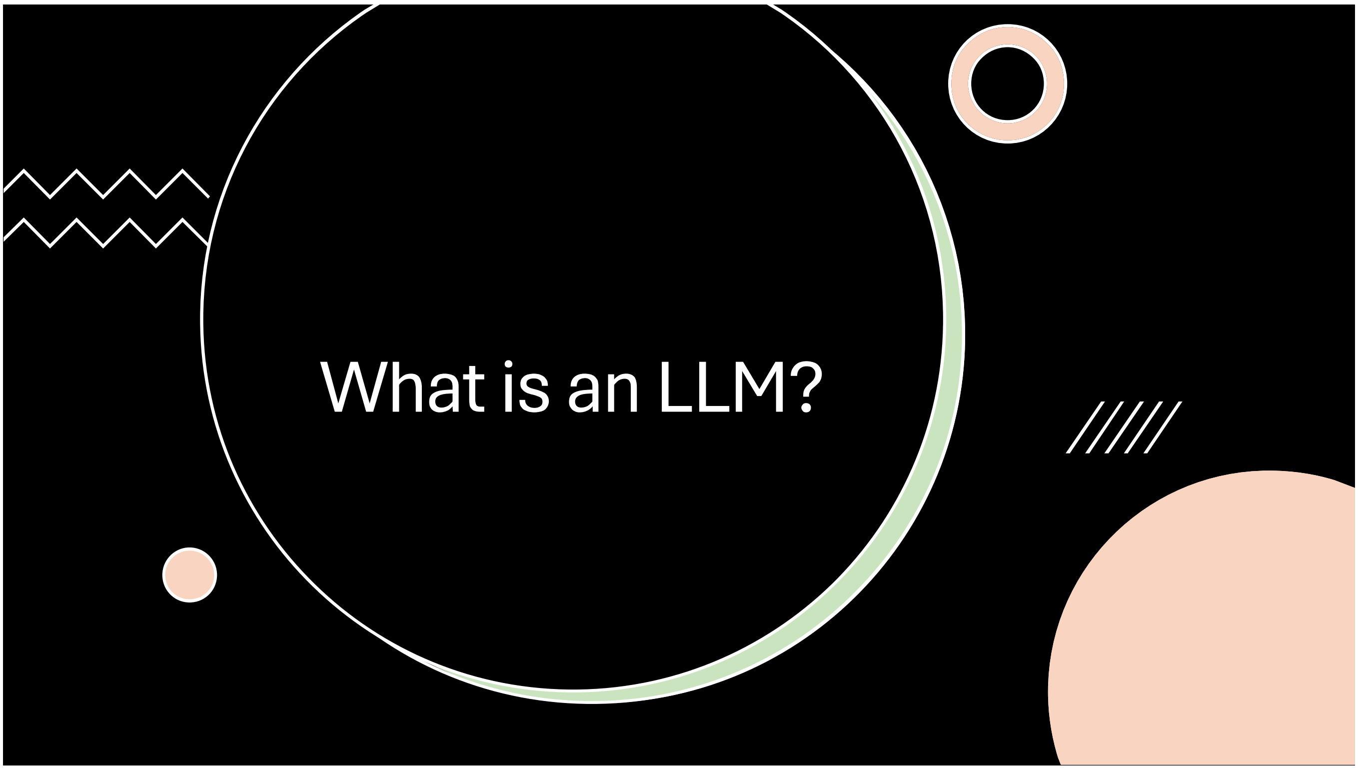
Blaž Bertalanič is a Postdoctoral Researcher at Jozef Stefan Institute. His main research interests are based on development of novel AI algorithms for different application area with focus on energy and computational efficiency. For his work he also received "best paper award" at a WiMob conference.

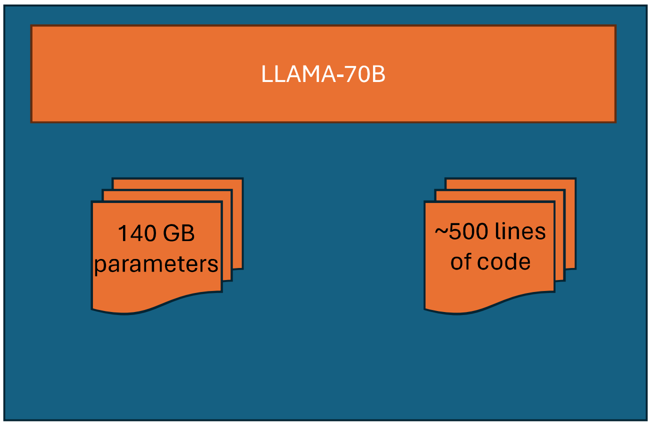
Light at the end of the tunnel: How Optics Can Help AI

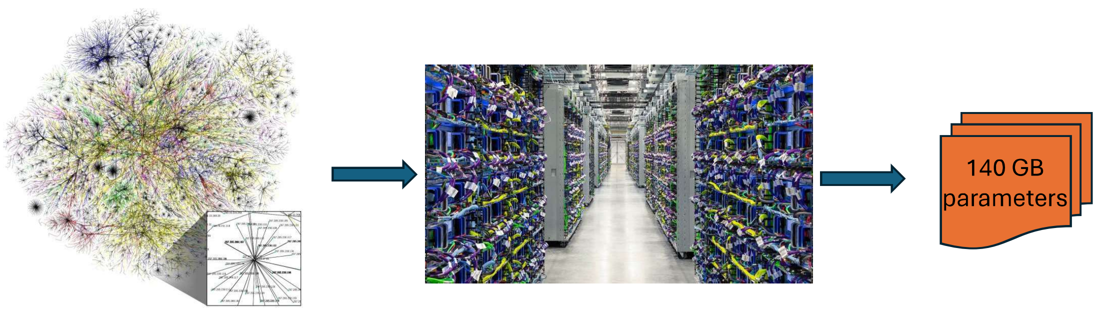
A Sustainable Path for Advanced AI

Dr. Blaž Bertalanič

Institut
"Jožef Stefan"
Ljubljana, Slovenija



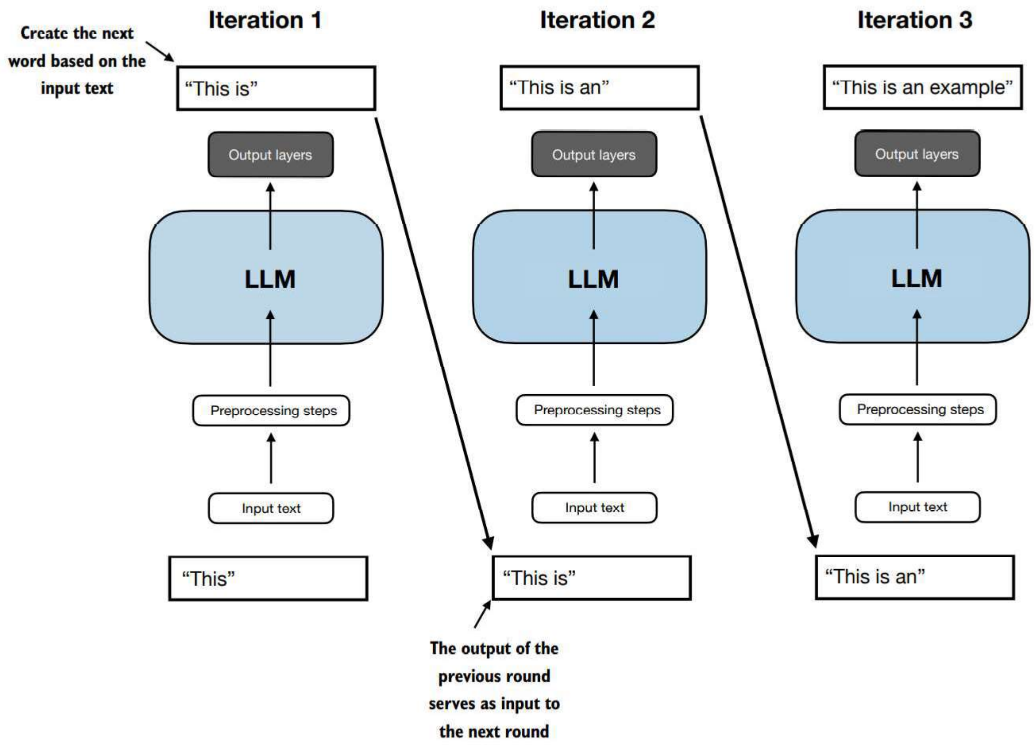




Internet chunk
~10TB

~6000 GPUs for 12 days,
~10^24 FLOPs,
price: 2M$

*Numbers for LLAMA 2-70B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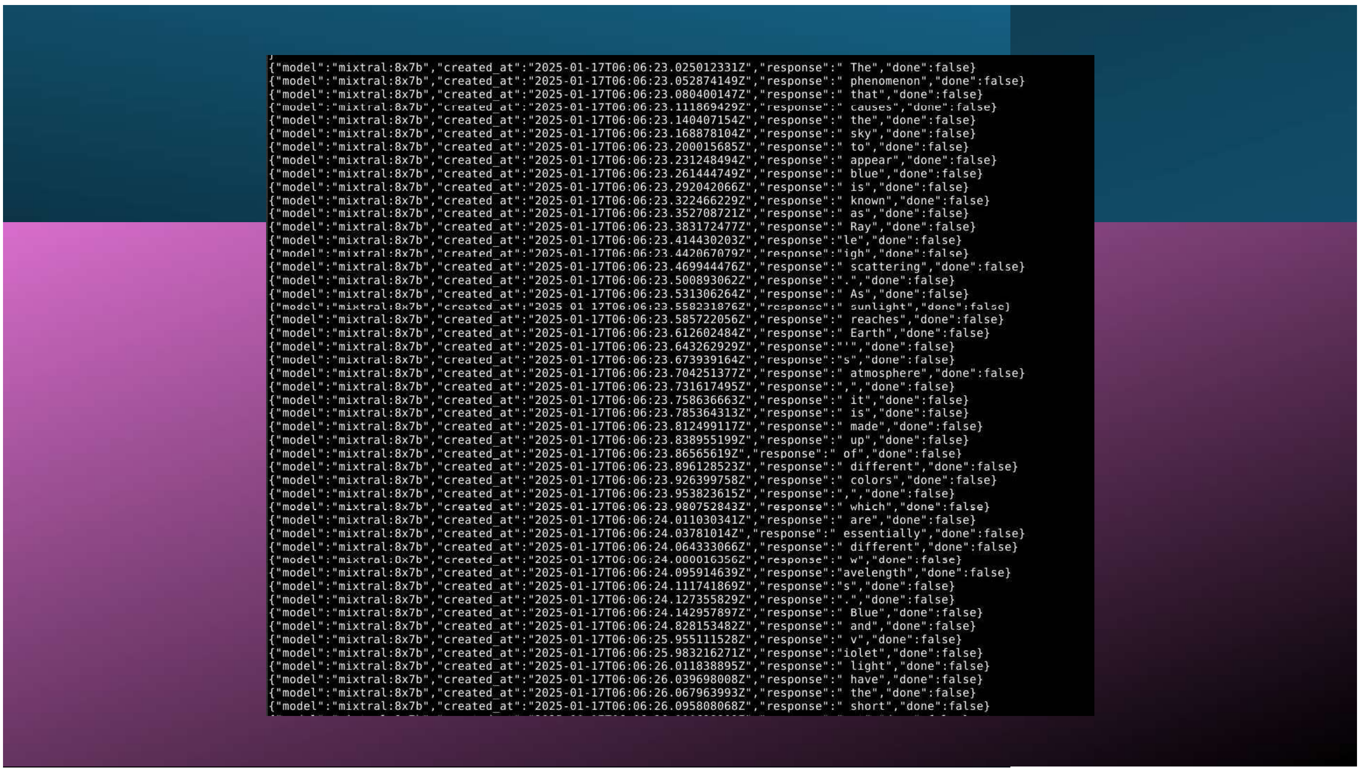
Iteration 2
Iteration 3
Create the next word based on the input text
"This is"
"This is an"
"This is an example"
Output layers
Output layers
Output layers
LLM
LLM
LLM
Preprocessing steps
Preprocessing steps
Preprocessing steps
Input text
Input text
Input text
"This"
"This is"
"This is an"
The output of the previous round serves as input to the next round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While Google’s energy use for search is relatively modest, ChatGPT requires significantly more. Every time a user inputs a prompt, ChatGPT’s massive language model processes it, using an estimated **2.9 Wh of energy**. That’s nearly ten times what it takes for a single Google search.

With around **200 million queries** daily, this adds up to about **621.4 MWh every day**.

It required **62.3 GWh** to train GPT-3/GPT-4

By 2040, some predict that around 80 percent of all energy usage on the planet will be devoted to data centers and computing

https://balkangreenenergynews.com/chatgpt-consumes-enough-power-in-one-year-to-charge-over-three-million-electric-cars/

Is there a better way?

Basic concept of ML

$$y = X \cdot W + b$$

$$X = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \qquad W = \begin{bmatrix} 0.5 \\ 1.0 \end{bmatrix} \qquad b = \begin{bmatrix} 0.1 \\ 0.2 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix} \cdot \begin{bmatrix} 0.5 \\ 1.0 \end{bmatrix} = \begin{bmatrix} 1 \cdot 0.5 + 2 \cdot 1.0 \\ 3 \cdot 0.5 + 4 \cdot 1.0 \end{bmatrix} = \begin{bmatrix} 2.5 \\ 5.5 \end{bmatrix}$$

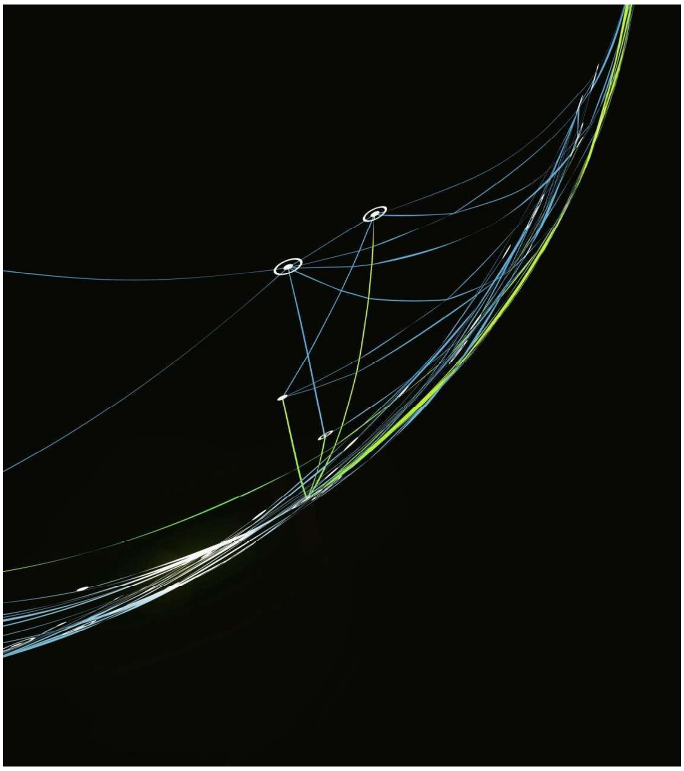
$X \cdot W$

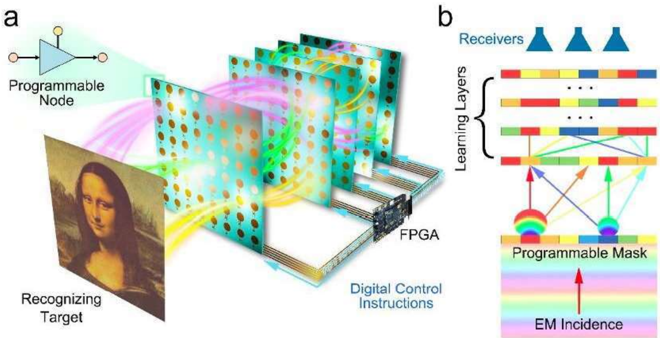
$$\begin{bmatrix} 2.5 \\ 5.5 \end{bmatrix} + \begin{bmatrix} 0.1 \\ 0.2 \end{bmatrix} = \begin{bmatrix} 2.6 \\ 5.7 \end{bmatrix}$$

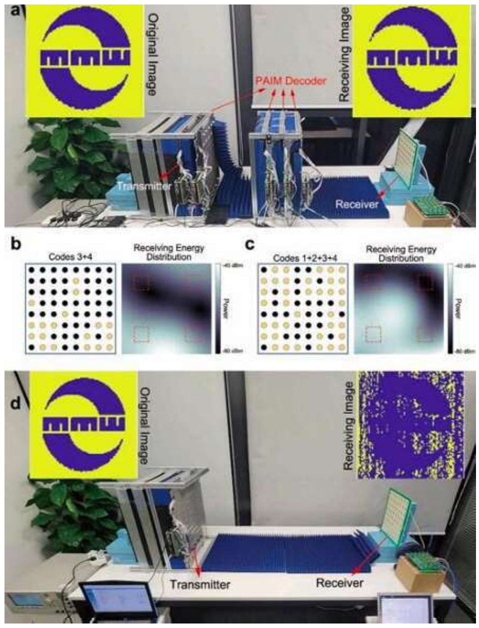
$X \cdot W + b$

What Are Optical Neural Networks (ONNs)?

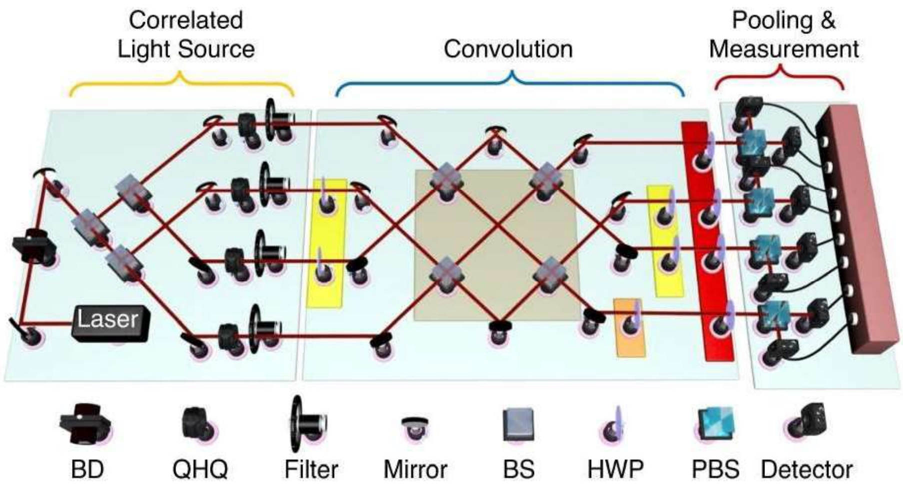
- Optical neural networks (ONNs) are AI systems that use light-based components to perform computations, replacing traditional electronic circuits.
- **Photonics Basics:**
  - Light (photons) is used as the carrier of information.
  - Photons interact via optical systems like waveguides and modulators to process data.
- **Core Technology:**
  - Optical fibers and chips
  - Light sources like lasers
  - Detectors that convert light back to electronic data
- **Why Optical?**
- Light travels faster than electricity.
- Less energy is dissipated as heat.
- Natural parallelism in optical systems.







https://www.nature.com/articles/s41928-022-00719-9



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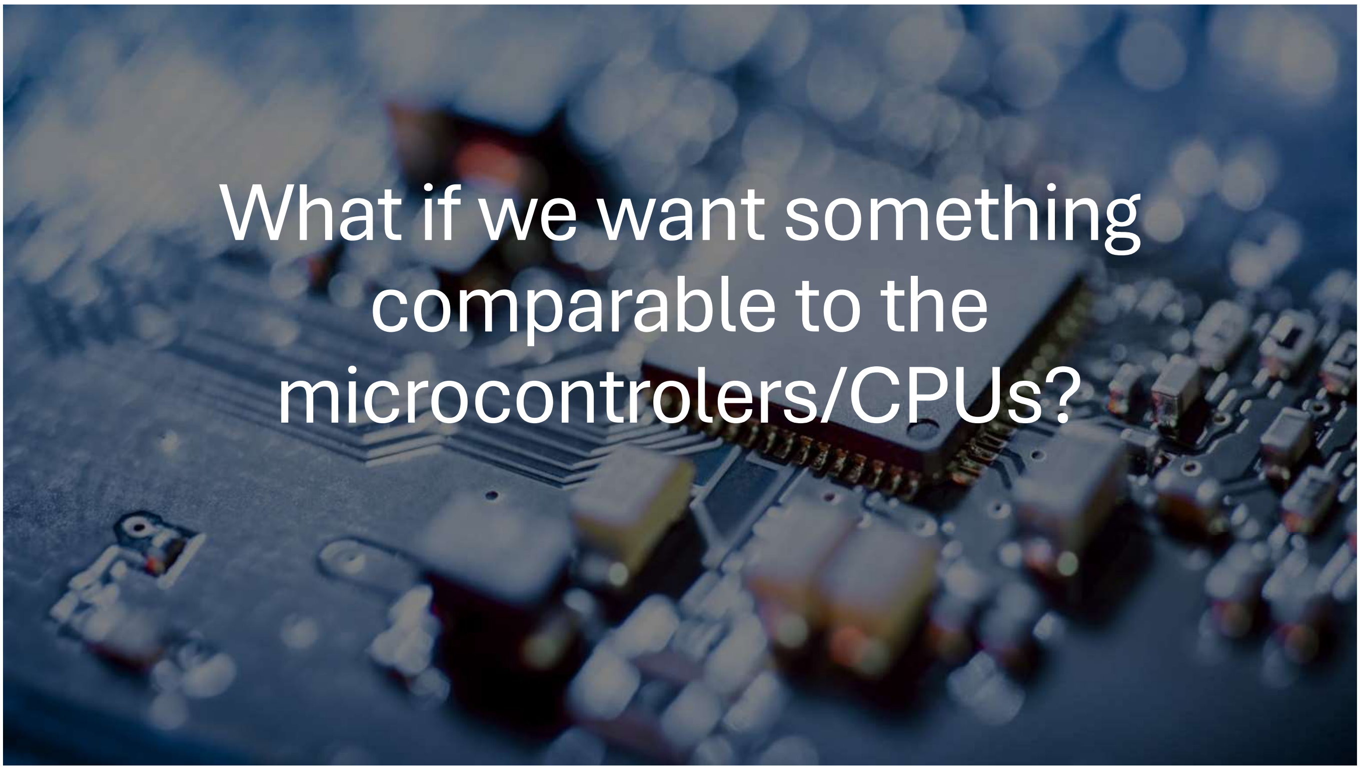
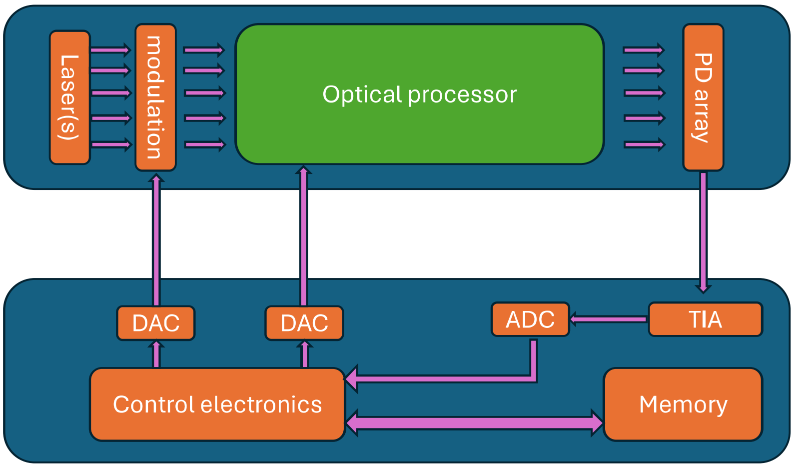


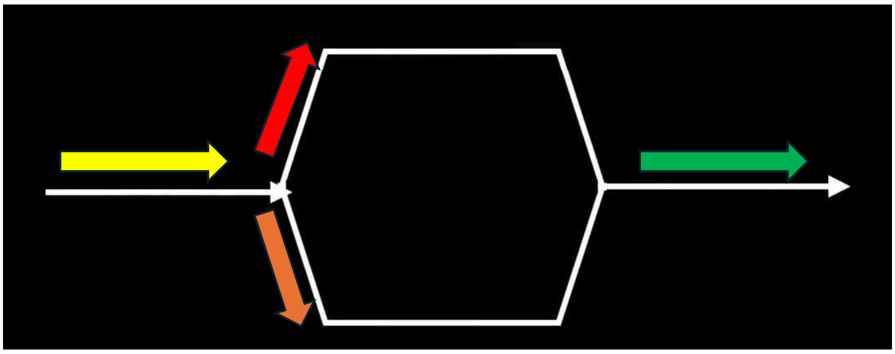
Basic concept



Input data → Light modulation → Optical matrix operations → Output

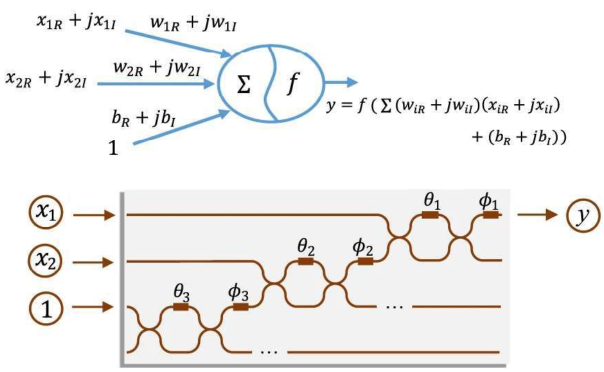
Nanophotonic processor

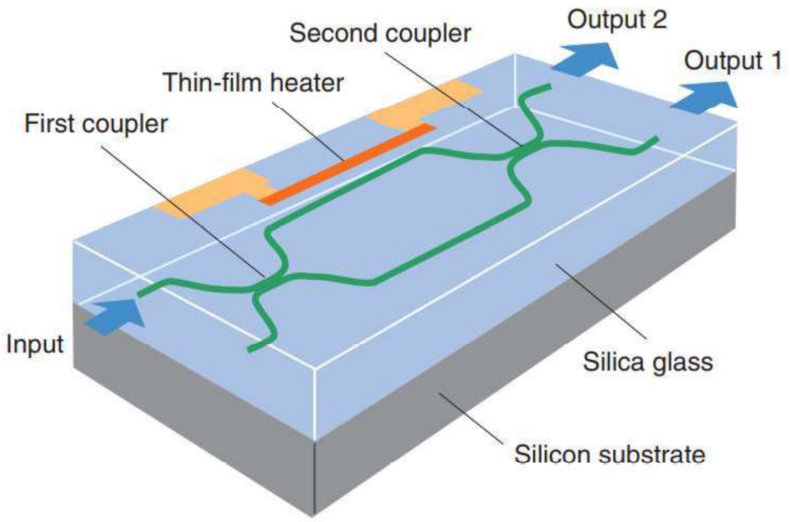
- Developed by Lightmatter
- Replaces TPU Multiply-Accumulator circuits with Mach-Zehnder interferometer (MZI)



$$y = X \cdot W + b$$

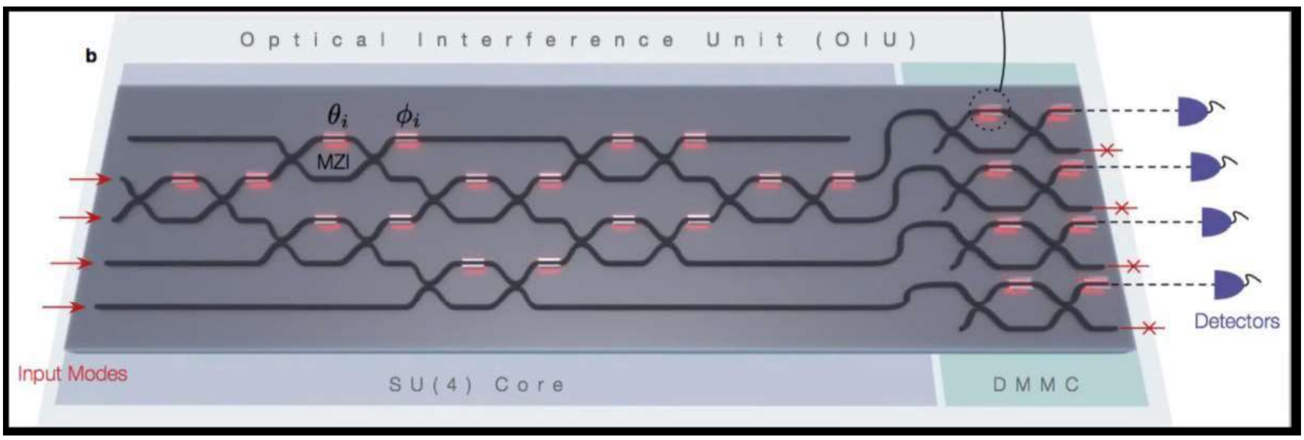
(a)





https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201002sf4.pdf&mode=show_pdf

- Computation takes 100ps



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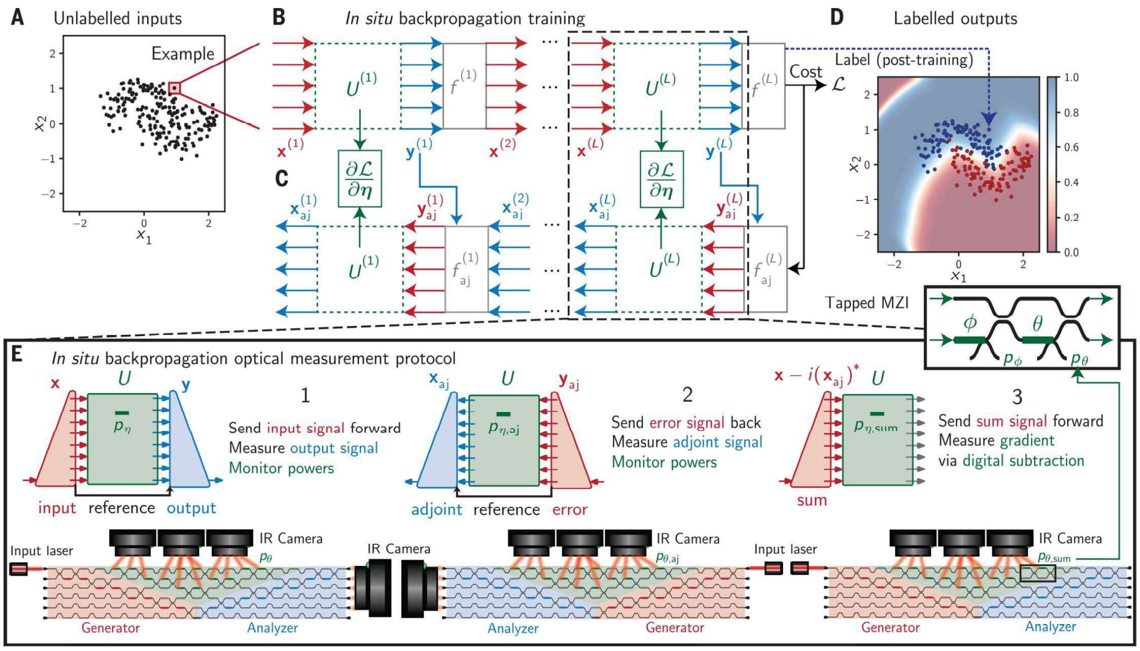

Applications of ONNs

- Emerging Opportunities:
  - Real-Time AI Inference: Speech recognition and translation on edge devices.
  - Medical Imaging: High-resolution scans processed with minimal latency and energy.
  - NLP Models: Running large-scale language models efficiently for real-time queries.
  - Autonomous Vehicles: Faster and more energy-efficient image and LIDAR processing.
  - IoT Devices: Energy-efficient AI deployment in low-power environments.
  - Military applications (e.g., radar systems).
  - Financial systems for high-frequency trading.

Challenges and Limitations

- Precision and Noise:
  - Analog photonics can suffer from precision errors and noise in computations.
- Fabrication Complexity:
  - Manufacturing photonic chips is more challenging than traditional silicon chips.
- Cost:
  - Initial costs of optical components and integration into existing systems.
- Software Integration:
  - Current AI frameworks are designed for electronic systems, requiring new programming paradigms.
- Hybridization Needs:
  - Non-linear operations still rely on electronic components in most ONNs.
- Size:
  - Adding additional components increases the size of the processor

Case Studies and Research

- MIT's Photonic Chips (now LightMatter):
  - Achieved over 100x energy savings in matrix computations with hybrid combination of electronic and photonic circuits.
- LightOn Research:
  - Demonstrated energy-efficient AI inference for language models using photonics. (But development stopped)
- Stanford University:
  - Working on backpropagation with optical/photonic neural networks
- Salience Labs:
  - Photonic chip for neural networks

Institut
"Jožef Stefan"
Ljubljana, Slovenija

Thank you

blaz.bertalanic@ijs.si

Poraba električne energije in pripadajoči ogljični odtis optičnih transportnih omrežij

Electrical power consumptions and associated CO2 footprints associated with Optical Metro Transport Networks

Sven Krüger

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Povzetek

»Internet« z vsemi povezanimi aplikacijami in tehnologijami je eden največjih svetovnih povzročiteljev emisij CO_2 in porabe energije. Medtem ko so usposabljanje algoritmov umetne inteligence in podatkovni centri v hiperrazsežnosti zagotovo na vrhu seznama, prispevek prenosa podatkov k/od uporabnikom ni zanemarljiv. Pritisk na operaterje telekomunikacijskih podjetij, da zmanjšajo svoj neposredni in posredni ogljični odtis, močno narašča. Poleg tega so stroški energije za delovanje teh omrežij že glavni dejavnik operativnih stroškov. Ker se količina podatkov, ki jih je treba prenesti, ne bo zmanjšala, ampak zagotovo povečala, je ključnega pomena uporaba transportnih tehnologij z najmanjšo možno porabo energije. Potem ko so se druge študije osredotočile na dostopovna omrežja se bomo v tem prispevku na metro transportna omrežja, ki se uporabljajo za promet v sprednjem, srednjem in zalednem delu mobilnega omrežja, uporabniški promet v zalednem rezidenčnem ali poslovnem delu omrežja (npr. FTTx, xDSL), medsebojno povezovanje podatkovnih centrov na razdaljah do približno 80 km. Ta omrežja se zanašajo na dve bistveno različni tehnologiji prenosa podatkov: a) aktivni (WDM) transportni sistemi in b) pasivni (WDM) transportni sistemi. Preučili bomo podrobnosti metro podatkovnega transporta in primerjali aktivni in pasivni transportni sistem glede na njuno porabo energije na povezavo (od konca do konca). Uporaba pasivnega prenosa omogoča prihranek energije nad faktorjem 100 na povezavo v primerjavi s prenosom enake količine podatkov z aktivnimi sistemi.

Abstract

The „Internet“ with all associated applications and technologies is one of the world's major contributors to CO2 emissions and energy consumption. While AI algorithm training and hyper scale Data Centers are certainly on top of the list the contribution of transporting the data to / from its users is not negligible. The pressure on Telco Operators to reduce their direct and indirect CO2 footprint is severely increasing. Moreover, energy costs for operating these networks are already the major OPEX factor. As the amount of data to be transported will not decrease but certainly increase it is crucial to utilize transport technologies with the lowest possible energy consumption. After other studies have focused e.g. on Access Networks, we will here focus on Metro Transport Networks which are used for front / mid / backhauling mobile traffic, backhauling residential (e.g. FTTx, xDSL) or enterprise

customer traffic, interconnecting data centers over distances up to approx. 80 km. Those networks rely on two fundamentally different data transport technologies, so called Active (WDM) Transport Systems versus Passive (WDM) Transport. We will look into the details of Metro Data Transport and compare Active vs Passive Transport means in respect to their power consumption per link (end to end). Utilizing Passive Transport allows energy saving beyond a factor of 100 per link compared to transporting the same amount of data with Active Systems.

Biografija avtorja

Sven Krüger ima več kot 25 let izkušenj v industriji optičnih vlaken in komunikacij. Kariero je začel kot raziskovalec na Fraunhofer Institute IMM, nato pa je bil del ustanovne ekipe in izvršnega vodstva Cube Optics AG. Potem ko je leta 2024 povečal CUBO do dobičkonosnosti z znatno rastjo in komercialno prodajo podjetju Huber+Suhner, je od takrat odgovoren za upravljanje izdelkov in prodajo v poslovni enoti CUBO, znotraj oddelka COM podjetja Huber+Suhner. Ima diplomo iz fizike na univerzi Johannes Gutenberg v Mainzu.

Author's biography

Sven Krüger looks back on more than 25 years' experience in the fiberoptics and communication industry. He started his career as researcher at the Fraunhofer Institute IMM and was then part of the founding team and executive management of Cube Optics AG. After growing CUBO to profitability with substantial growth and trade sale to Huber+Suhner in 2024, he is since then responsible for Product Management and Sales at the CUBO business unit within Huber+Suhner's COM division. He holds a Diploma degree in Physics from the Johannes Gutenberg University of Mainz.

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Motivation – The Importance of Power Consumption for Telecoms

- Steve Harris, **Digital Transformation / Orange Enterprise (**March 2023):

  "The **telecoms** industry is responsible for **2-3% of the total power consumption of humankind.** According to **GSMA** research, energy costs today **represent between 20% and 40%** of a telecoms company's **OPEX**" (www.orange-business.com/en/blogs/greening-telecoms-network)

- **McKinsey** Study "The growing imperative of energy optimization for Telco Networks"(Nov 2024):
  - "large operators have seen their energy **cost increases outpace sales growth by more than 50 percent.**"
  - "**Pressure** is likely also to come from **regulators** around the world, as they begin to adopt their own decarbonization goals and factor sustainability considerations into their policies."
    https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-growing-imperative-of-energy-optimization-for-telco-networks

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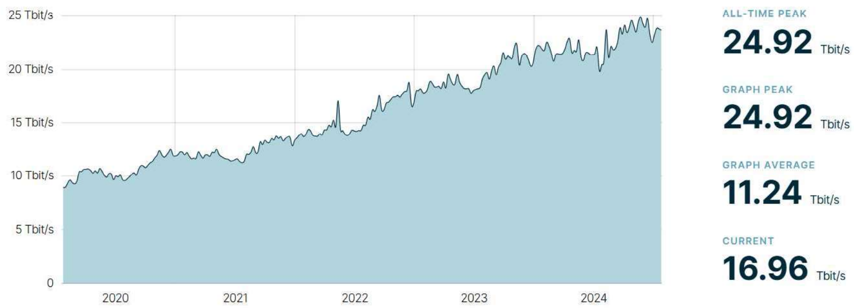
How Can Telco Energy Consumption be reduced?

- No-brainer (?):
- **less data** consumption / transport
- usually **no option** (see e.g. **DECIX** peering traffic https://www.de-cix.net/de/services/globepeer/statistiken)



- If a given data load / service must be transported, then only the **choice of Transport Technology** provides options for power savings!
- See e.g. study on comparing **Access Technologies** (FTTx, HFC vs. DSL) by Prysmian: "Energy consumption of telecommunication access networks" https://europacable.eu/wp-content/uploads/2021/01/Prysmian-study-on-Energy-Consumption.pdf
- Here focus on **Metro Transport Networks**

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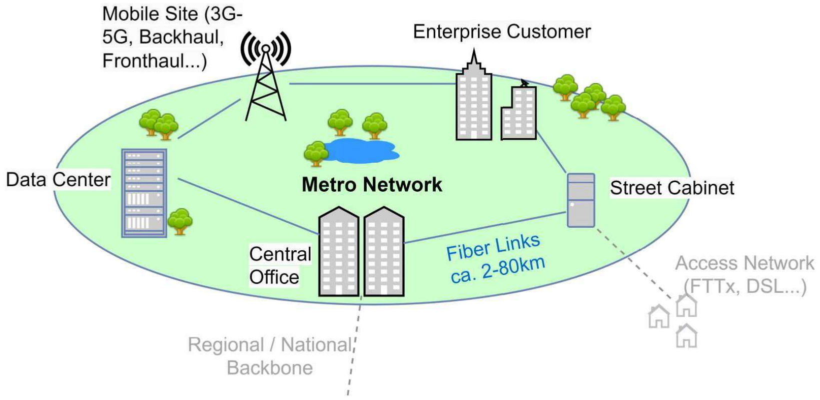
Fokus on Metro Transport Networks

- **Fiber** based link distances **ca. 2 to 80km**
- **Topologies:** Ring, Point-2-Point daisy chain…
- **Protocols**: Ethernet, CPRI, eCPRI, FiberChannel, OTN, SDH etc
- **Data Rates:** 1Gig to multiple 400Gig



- Various **applications** (often on same fiber link): **Backhauling** of Residential Access (DSL, FTTx…), **Mobile** Front/Mid/Backhauling, **DC** Interconnect, **Enterprise** Access, Private Networks etc
- Two Basic Technologies used in Network Nodes to transport data from node to node:
  Passive Transport vs. Active Transport

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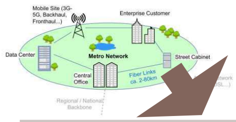
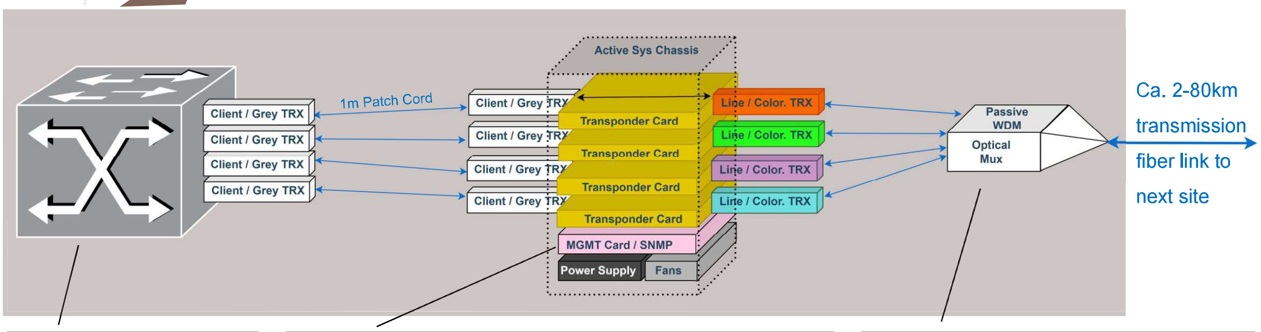
Traditional Approach: Active (WDM) Transport Systems – Transponding



Metro Network Node / Site

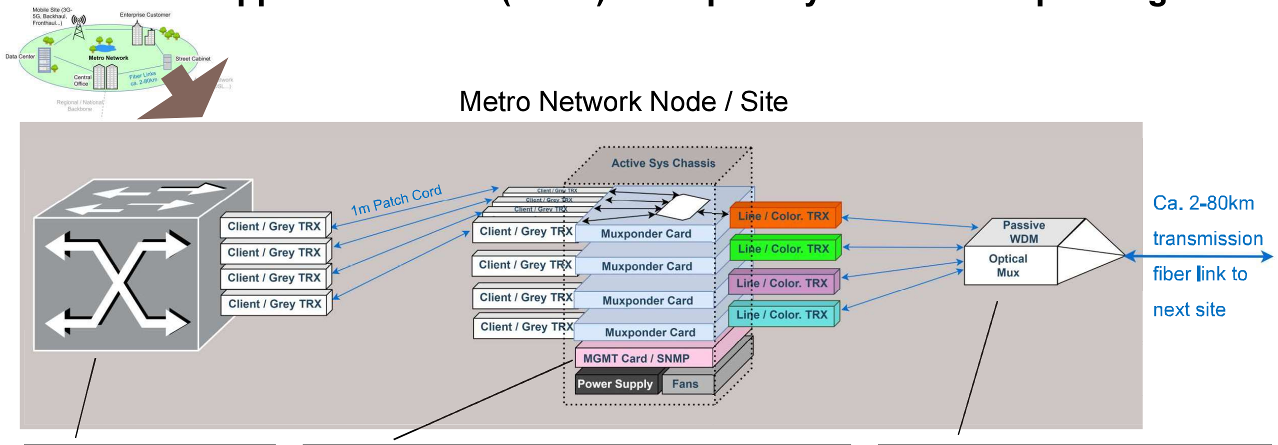


- Application / source of data to be transported
- e.g. Ethernet Router, Switch, DSLAM, OLT, BBU, RU etc

- **Active (WDM) Transport System**, **converting** Client Signals (e.g. MMF, short reach TRX) into Transmission Signals (e.g. DWDM 80km reach TRX)
- Chassis featuring Transponder Cards, Management Card, Power Supplies, Fans and Client + Line Transceivers + additional SW connected to NOC

- Optional Passive Optical Wavelength Division Multiplexer
- De/Muxing multiple services (“colors” of light signals) into 1 transmission fiber (pair) to next node
- (Often housed in Act Sys Chassis)

Traditional Approach: Active (WDM) Transport Systems – Muxponding

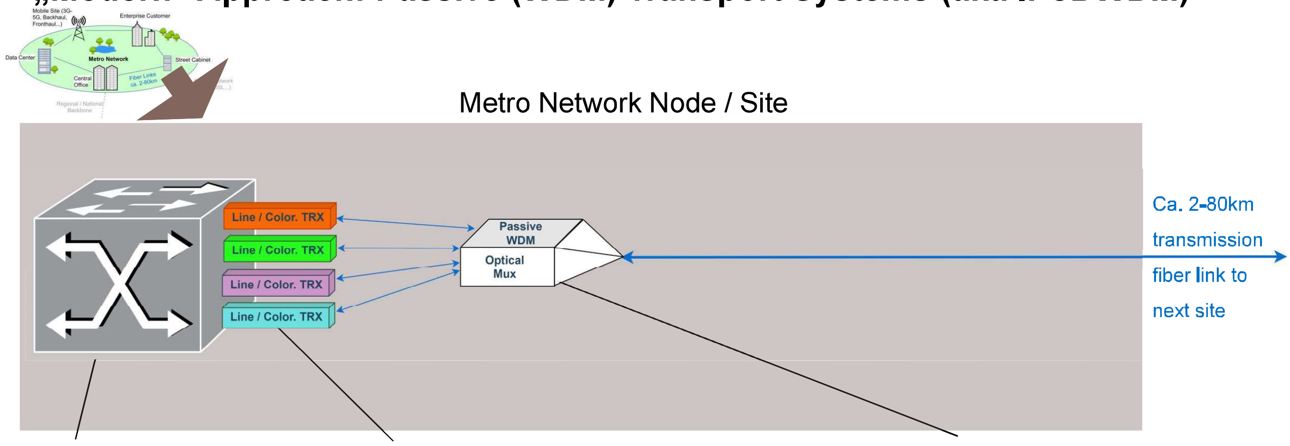


- Application / source of data to be transported
- e.g. Ethernet Router, Switch, DSLAM, OLT, BBU, RU etc

- **Active (WDM) Transport System**, **muxponding** (electrical aggregation) of **many** Client Signals (e.g. MMF, short reach TRX) into **one** Transmission Signals (e.g. DWDM 80km reach TRX)
- Chassis featuring Muxponder Cards, Management Card, Power Supplies, Fans and Client + Line Transceivers + additional SW connected to NOC

- Optional Passive Optical Wavelength Division Multiplexer
- De/Muxing multiple services ("colors" of light signals) into 1 transmission fiber (pair) to next node
- (Often housed in Act Sys Chassis)

„Modern" Approach: Passive (WDM) Transport Systems (aka IPoDWDM)



- Application / source of data to be transported
- e.g. Ethernet Router, Switch, DSLAM, OLT, BBU, RU etc

- **Line Transceivers (e.g. DWDM 80km)**, directly plugged into Data Source (Host) equipment, e.g. Router
- Managed (also in NOC) exactly in same manner as client transceivers

- Optional Passive Optical Wavelength Division Multiplexer
- De/Muxing multiple services ("colors" of light signals) into 1 transmission fiber (pair) to next node
- (Often housed in Act Sys Chassis)

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Limitations of Passive Transport

- Host equipment must **support line transceivers** (e.g. host system power restrictions, MSA type etc).
- Host equipment must be **owned by network operator** (i.e. eliminating Act Sys eliminates **demarcation**)
- Struggle between **operational responsibilities** (IP department vs transport department)
- Per se reach is always given by reach of Line Transceivers, counts for Active & Passive Transport

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Methodology

- **METRO** (!) Links = “typical distances of around 30-80km”
- **Only comparing the Transport** Technology, NOT including the “application”, i.e. routers, switches, DSLAMs etc
- **Not incl. optional additional amplifiers** as those would come on top in all cases
- Comparing power on **per link base** (incl. both nodes), looking at data rates of **1G, 10G, 25G, 100G, 400G**
- **Power normalized on per link base**: the power consumed by the chassis itself, the power supplies themselves etc is broken down for 1 line in said active system and related to 1 colored TRX at client speed in the host
- Hence model allows calculation of specific scenarios by multiplying services
- **Aggregation based on equivalent Cient data rate** for comparison with **Line TRX** (e.g. 100G client aggregation into 400G Line, we need to compare it to the alternative of 100G transport, not 400G Colored Transceivers in the host)

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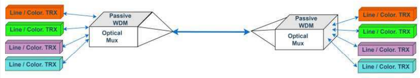
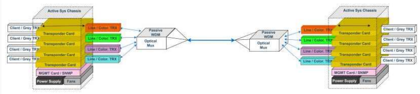
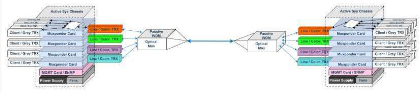
Accounted Power Consumption PER LINK for 4 Transport Scenarios

	Scenario	Fully included Equipment	Proportionately included Equipment
Passive Transport	Grey TRX	2pcs Grey (long reach) TRX	
Passive Transport	pWDM	2pcs Colored WDM Line TRX	
Active Transport	Trans-ponding	4pcs Grey (shortest reach) TRX 2pcs Colored WDM Line TRX	2pcs Transponder Card 2pcs Chassis, each incl. 2 Fan 2pcs *redundant* Power Supply 2pcs Management Cards
Active Transport	Mux-ponding[1]	4pcs Grey (shortest reach) TRX	2pcs Muxponder Card 2pcs Line TRX (colored or not) 2pcs Chassis, each incl. 2 Fans 2pcs *redundant* Power Supply 2pcs Management Card







[1]Huge variety of Muxponding: e.g. 400G aggregation of 2x 200G or 4x 100G or multiple 10Gs + 100G, various protocols etc. For comparison model is based on cards aggregating the next lower E rate (and no mixes) of model.

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Device Power Consumption per Data Sheet – Transceivers (1-25Gig)

Transceiver Type	Power Consumption (max) [W]
1G SFP SX (500m, MMF)	1
1G SFP ZX (80km, Industrial Temperature Range)	1
1G SFP CWDM ZX (80km)	1
1G SFP DWDM EZX (120km)	1,2
10G SFP+ SR (500m, MMF)	1
10G SFP+ SR (500m, MMF, Ind. Temp)	1
10G SFP+ LR (10km, Ind. Temp.)	1
10G SFP+ ZR+ (100km, Ind. Temp.)	1,8
10G SFP+ CWDM ZR (80km)	1,5
10G SFP+ CWDM ZR (80km, Ind. Temp)	1,6
10G SFP+ DWDM ER (40km)	1,3
10G SFP+ DWDM ER (40km, Ind. Temp)	1,6
10G SFP+ DWDM ZR (80km, Ind. Temp.)	1,6
25G SFP28 SR (500m, MMF)	1
25G SFP28 LR (10km)	1,2
25G SFP28 ER (40km)	1,8
25G SFP28 CWDM LR ("40km")	1,2
25G SFP28 DWDM LR ("40km", Ind. Temp.)	2

Short Reach Client Grey TRX
Long Reach Client / Line Grey TRX
Line WDM Colored TRX

- (almost) independent of data rate (at 1-25G)!
- Max. reach has / has no significant influence
- Specified operating **case** (!) temperature range (Standard 0 to 70°C vs. Ind. Temp. -40° to 85°C) makes a difference
- Colored WDMs (often) use **TECs**!

Note: Depicted example TRX is Huber+Suhner CUBO TRX. However, underlying data used in this model originates from ca. 10 manufacturers. Shown values are average values over multiple makers, however, are mostly anyway identical

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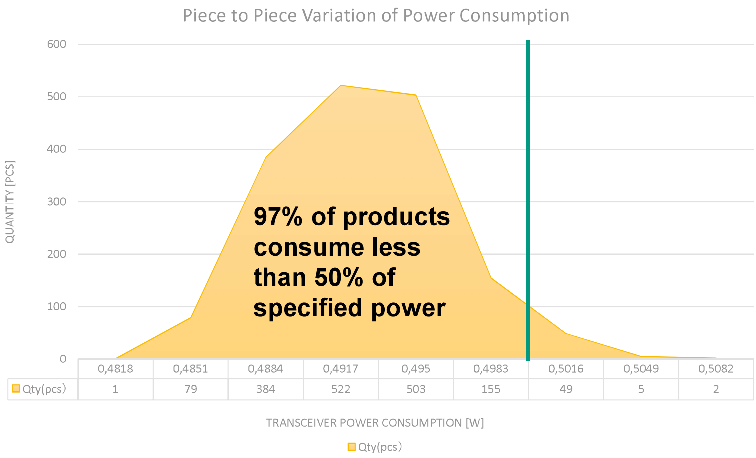
TRX Power Consumption: Data Sheet vs Part to Part Variation

Example 1G LX SFP



1G SFP LX
Product number 85210507
Identifier CSS-303A11
Variation: 10km, 1310nm, LC/PC duplex, Singlemode
Type 1G SFP LX
Media Reach Type10km, 1310nm, Singlemode fiber
Protocol 1G Ethernet, 1G Fiber Channel, CPRI 2

https://www.hubersuhner.com/en/shop/product/transceivers/pluggable-transceivers/1g-2-5g-6g-8g-10g/85210507/1g-sfp-lx

Key features
- Multi-protocol support
- Data rate 125 Mbps and 1.0625...1.25 Gbps
- Reach up to 10km
- Wavelength 1310nm
- LC/PC duplex connector
- Singlemode fiber
- Temp. range 0 ... 70°C
- Link budget at least 11 dB
- **Power consumption < 1 W**

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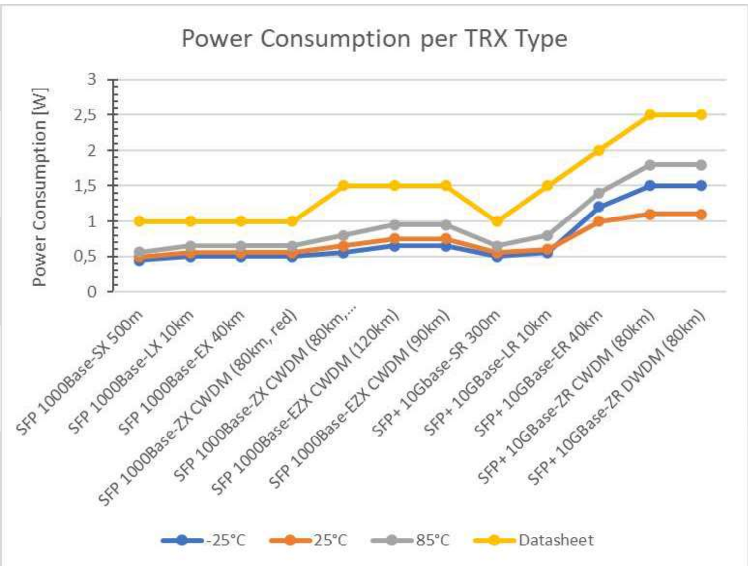
TRX Power Consumption: Influence of Case Temperature



- Power Consumption of Client & Line TRX at 1 & 10Gig **highly depending on case temperature**
- But always only a fraction of data sheet values

Note: Depicted example TRX is Huber+Suhner CUBO TRX. However, underlying data used in this model originates from ca. 10 manufacturers. Shown values are average values over multiple makers, however, are mostly anyway identical

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Device Power Consumption per Data Sheet – Transceivers (100-400Gig)

Transceiver Type	Power Consumption (max) [W]
100G QSFP28 SWDM4 (100m, MMF)	3,5
100G/40G QSFP28 SR1.2 (100m, MMF)	3,5
100G QSFP28 SR4 (150m, MMF)	2
100G QSFP28 LR4 (10km)	4
100G QSFP28 LR4 (10km, Ind. Temp.)	5
100G QSFP28 LR4 (10km, Hermetic)	3,5
100G QSFP28 ER4 lite (30km)	4,5
100G QSFP28 ER4 (40km, Ind. Temp)	5,5
100G QSFP28 ZR4 (80km)	6,5
100G QSFP28 ZR4 (80km, Ind. Temp.)	7,5
100G QSFP28 DWDM ZR (100km)	5,5
100G **QSFP28 Coherent** (limited DSP, 80km Ind. Temp.)	6
100G **QSFPDD Coherent** (full DSP, 800km)	23,6
400G QSFP56-DD SR8 (100m, MMF)	10
400G QSFP56-DD DR4 (500m SMF)	10
400G QSFP56-DD LR4 (10km)	12
400G QSFP56-DD ER8 (40km)	15,4
400G **QSFP56-DD Coherent** DWDM ZR+ (full DSP, 800km)	23,6

Short Reach Client Grey TRX
Long Reach Client / Line Grey TRX
Line WDM Colored TRX

Power Consumption:

- Becoming very dependent on data rate!
- Different product designs can make a difference
- Main driver is **modulation** technology, i.e. "**Direct Detect**" vs. "**Coherent**"
- Importance of CAUI for ≥100G

Note: Depicted example TRX is Huber+Suhner CUBO TRX. However, underlying data used in this model originates from ca. 10 manufacturers. Shown values are average values over multiple makers, however, are mostly anyway identical

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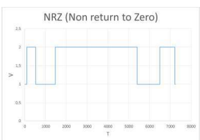
Direct Detect vs Coherent TRX Technology

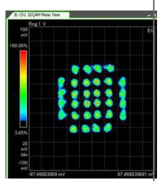
Direct Detect

- Simple modulation (NRZ / On-off keying / PAM4)
- Sensitive to dispersion effects



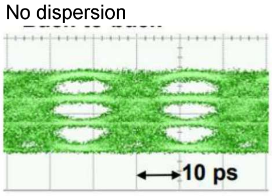
Coherent

- Complex modulation (QPSK, QAM, PM-QPSK), amplitude, phase, polarization modulation
- Requires complex signal processors which also compensate dispersion effects

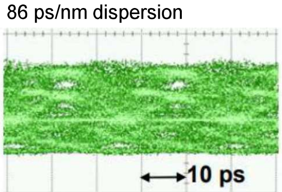


Dispersion Effects on Signal Quality (e.g. PAM4)

No dispersion

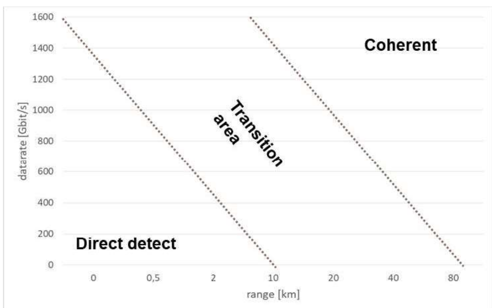


86 ps/nm dispersion

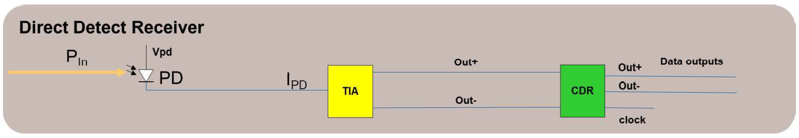


Dispersion effects increase with data rate /& distance

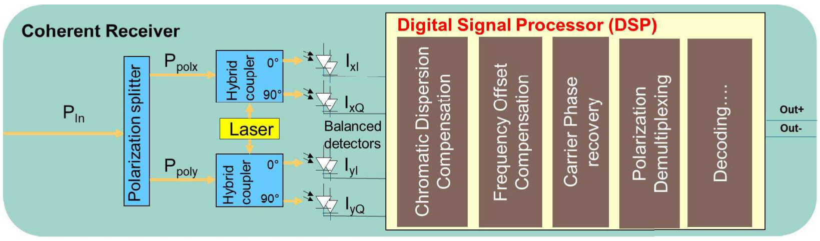
TRX Technology as Function of Reach & Rate



Direct Detect vs. Coherent TRX: Main Difference are the Receivers



Direct Detect TRX:
few & simple optoelectronics



Coherent TRX
- Much more (opto-)electronics
- Extremely power-hungry **DSP** processor chip
- Which also contains **Muxponder** and **data processing** functionalities

Summary on TRX Power Consumption

- Data Sheets state the **max power** consumption. Can hugely differ from **actual power** consumption.
- Model is based on **typical power** consumption. I.e. average of **part-to-part variation** and **25°C** as case temperature (& ambient temperature for Active Systems)
- **Direct Detect** TRX 1G, 10G, 25G (100G) typically consume **40-60%** of their given max (57% used in model).
- **Coherent** TRX (≥ 100G) depending on specific **DSP** designs, typical power is around **75-90%** of data sheet (max) value and (87% used in model)

Notes on Active Transport System Power Consumptions

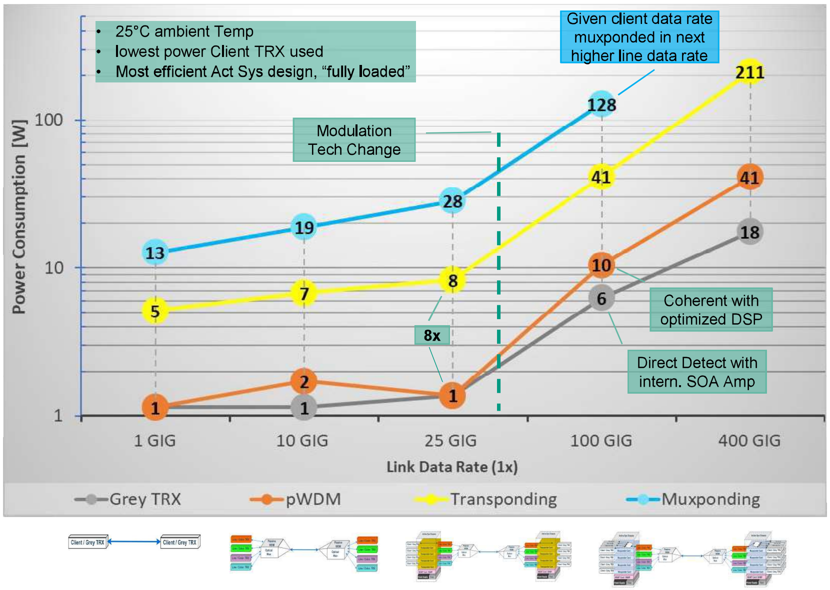
- The power consumption (actual, typical, max.) for a given system functionality greatly **varies from vendor to vendor,** caused by differing **design** (used electronics and chips…) and **additional features**
- Biggest variation is on **muxponding** variants.
- A not "**fully loaded"** / utilized chassis, line card etc consumes much more power per service.
- Power consumption of electronics rises with **ambient temperature** (here "typical" assumed as 25°C!)
- Here shown "typical" power consumption values represent a best-case scenario based on A) **lowest power system** and B) **fully loaded smallest possible set-up** (i.e. no 3HU Chassis with 2 line cards for 1 service)
- **Most of deployed Active Transport solutions use much more power than our "Typ. Model"!**

Note: Depicted example Active System products originate from Huber+Suhner. However, underlying data used in this model originates from various vendors.

Notes on Cooling / AC

- All scenarios are calculated **with and without external (AC) cooling,** reflecting only additional cooling for the transport, not the routers etc.
- Again, how much energy is needed to cool off e.g. 1W depends on too many factors to be precisely reflected.
- Common effect of "**over cooling**": cooling capacity is mostly over dimensioned (data sheet based calculations!) beyond the actual cooling needs, which again leads to **additional** (significant) power consumption.
- As a good approximation of **power for cooling we used a factor of 2**, i.e. every W that you have on transport requires (at very least) another W for cooling. I.e. external cooling will at least double the power used of power needed to transport data. (Inside **DCs** it is commonly a **factor of 3**)

Comparing "Typ." Power Consumption per Link [W] – Excl. external Cooling



- Consumption **not *necessarily* scales 1:1** with bit rate
- Shown Active scenarios are most favorable mux / transponding designs (incl. TRX selection)
- **Transponding typ. 4-5 times** higher power consumption **than pWDM**
- Muxponding uses approx. **10-20 times** power **of pWDM**

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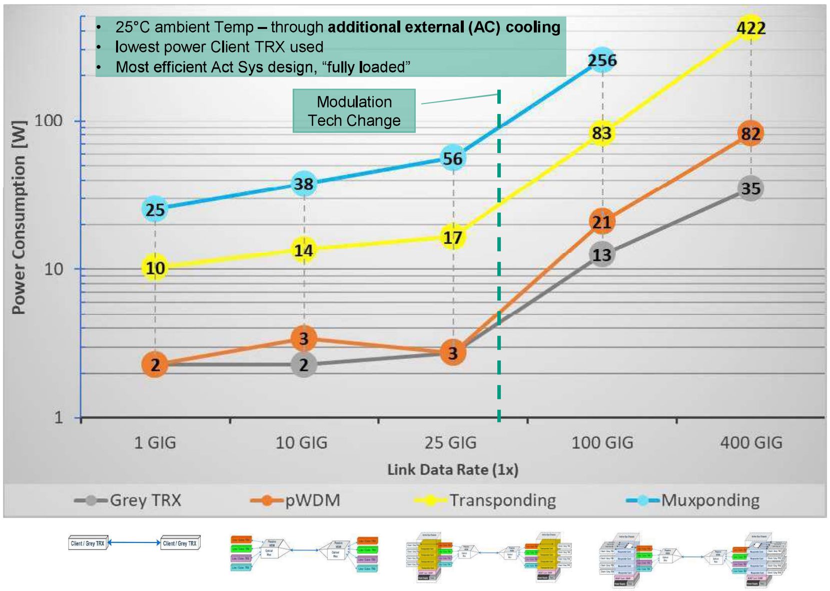
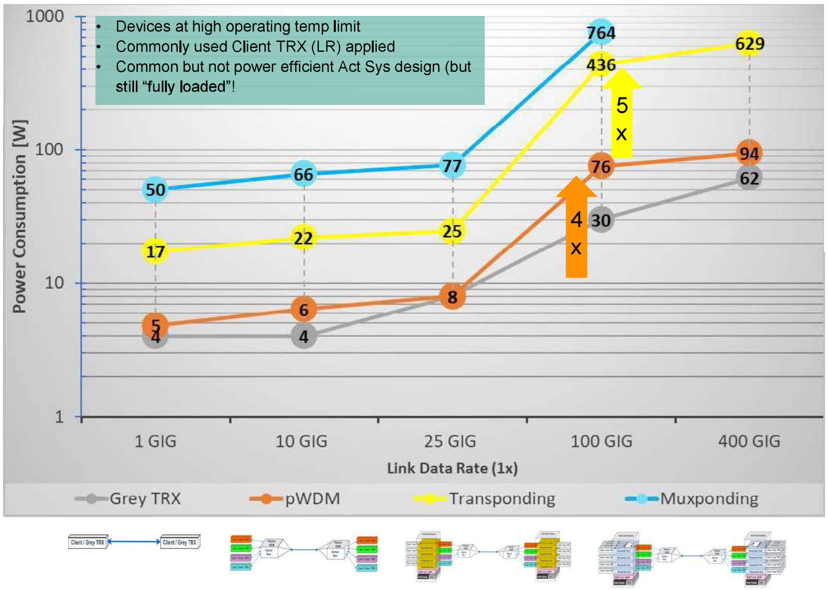
Comparing "Typ." Power Consumption per Link [W] – Incl. external Cooling



- No brainer, based on model assumptions all **power consumption will simply double**
- However, it makes a huge difference if you double e.g 1W vs. 19W (especially if you operate more than 1 link)

Comparing "Max." Power Consumption per Link [W] – Excl. external Cooling



- Operating devices at **high operating temp limits**
- Use of "**Industrial Temp**" TRX and common **LR TRX as Client**
- **Common ActSys power consumptions** (not power optimized designs etc)
- Results in ca. **2-3 times of power consumption for pWDM** compared to "Typ incl. cooling" scenario
- **Increase** of ca. **4-5 times for Active** Transport
- Can **increase necessary power consumption by a factor >100 times!**

Summary

- With the unbroken trend of **increasing data rates** in transport networks the power usage will not decrease but increase further
- Although the **power consumption** does not per se increase 1:1 with the data rate it **can even outpace the rate increase** by inappropriate transport network designs and methods
- This results in consuming up to **>100 times more electrical power than technologically necessary** for transporting the given data load
- This energy inefficiency combined with the growing data rate is becoming an **OPEX threat** for carriers.
- However **Passive Transport is cutting down** those (direct energy and CO2) **costs by at least a factor of 5 to 20**!
- Note, **less electronics deployed** in the network also means the same reduction of CO2 **Scope 3** for the network operators (Scope 3 = CO2 generated at production of devices at suppliers)

Izzivi testiranja pri prehodu iz 800G na 1,6T

Testing Challenge of moving from 800G to 1.6T

Neil Hobbs

EXFO

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Povzetek

Prispevek podaja pregled novih trendov in izzivov pri testiranju in kvalifikaciji optičnih transportnih sistemov nove generacije vse do hitrosti 1.6 Tbit/s.

Abstract

The paper provides an overview of new trends and challenges in testing and qualifying next-generation optical transport systems up to speeds of 1.6 Tbit/s.

Biografija avtorja

Neil Hobbs, tehnični prodajni svetovalec in strateški poslovni vodja pri EXFO EMEA, je v industriji telekomunikacijskih testiranj in meritev prisoten že približno 30 let. Kariero je začel v kraljevi mornarici kot specialist za komunikacije in elektronsko bojevanje na podmornicah. V zgodnjih 90-ih je prešel v komercialne telekomunikacije pri Mercury Communications (zdaj Vodafone), kjer je delal pri namestitvi, zagonu in vzdrževanju omrežij. Od leta 1996 se ukvarja s testiranjem in meritvami telekomunikacijskih omrežij, pokrivajoč tehnologije od PDH & SDH do Ethernet in Fiber Channel. Leta 2004 se je pridružil podjetju EXFO kot specialist za transport in podatkovne komunikacije ter nudil tehnično prodajno podporo. Danes se osredotoča na poslovni razvoj in testne rešitve za omrežja do 800G, s 1,6T v prihodnosti.

Author's biography

Neil Hobbs, EXFO EMEA's Technical Sales Support and Strategic Business Manager, has been in the telecom test and measurement industry for around 30 years. He began his career in the Royal Navy as a Communications & Electronic Warfare specialist on submarines. In the early 90s, he transitioned to commercial telecom, working at Mercury Communications (now Vodafone) in installation, commissioning, and network operations. Since 1996, he has specialized in telecom test and measurement, supporting technologies from PDH & SDH to Ethernet and Fiber Channel. He joined EXFO in 2004 as a Transport & Datacom specialist, providing technical sales support. Today, he focuses on business development and test solutions for networks up to 800G, with 1.6T on the horizon.

Testing Challenges of Moving to 1.6T

FOKAB – Managing Director - Mitja Vodopivec
EXFO Regional Sales Manager – Vratislav Blazek
EXFO Technical Pre Sales & BDM - Neil Hobbs

High Speed Market Trends & Drivers

1 AI/ML driving bandwidth demand

- New 200G/lane transceivers (800G DR4/FR4/LR4, 1.6T DR8)

2 DCI connectivity

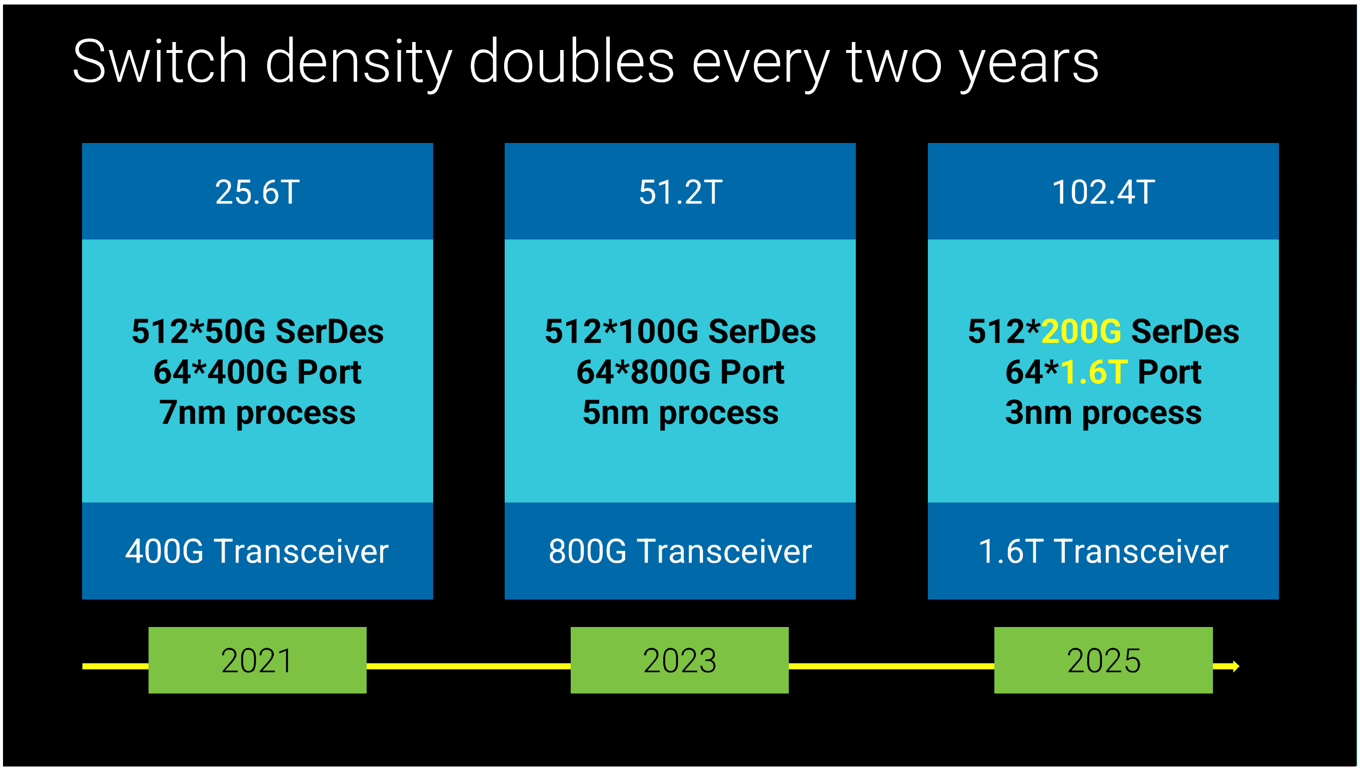
- 400G-ZR
- 800G-ZR
- 1.6T-ZR

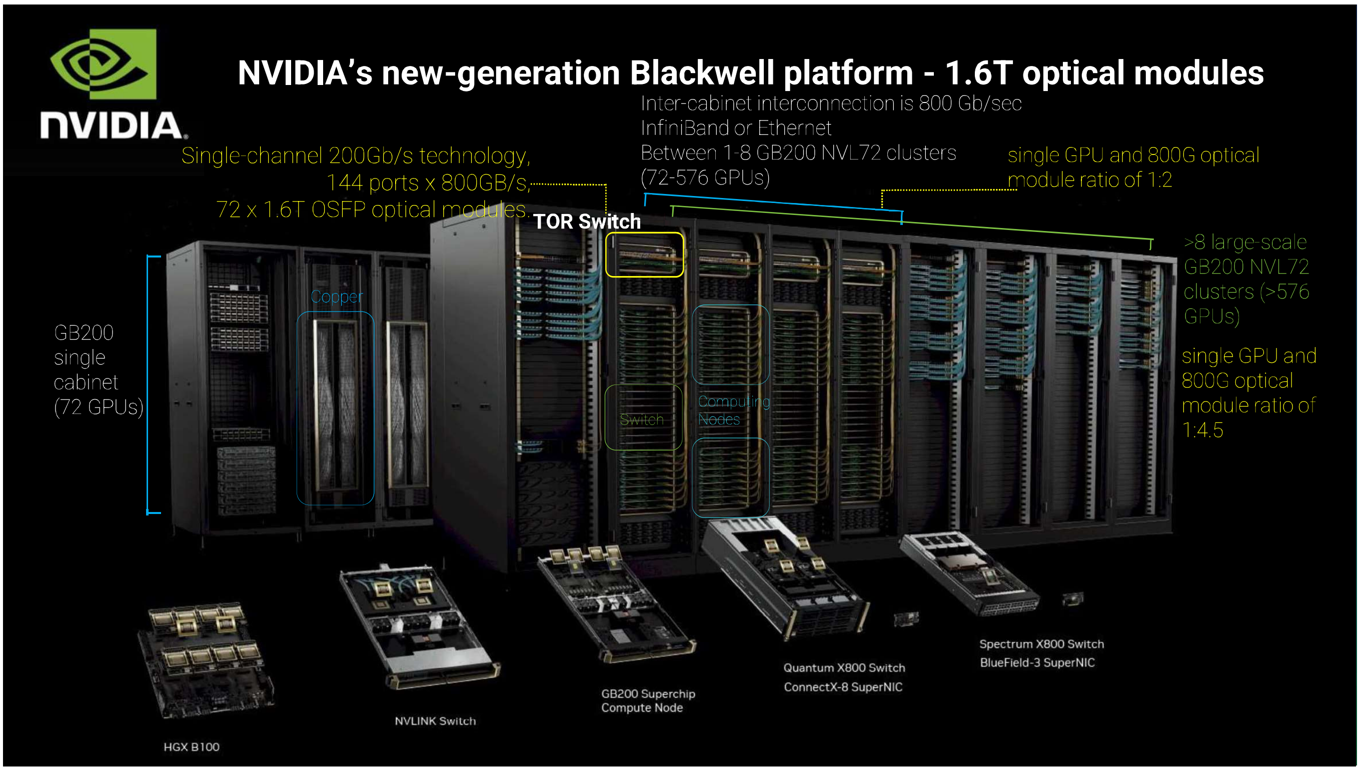
3 Low Power/Low Latency

- Low power,
- Low latency transceivers
- (LPO and LRO)

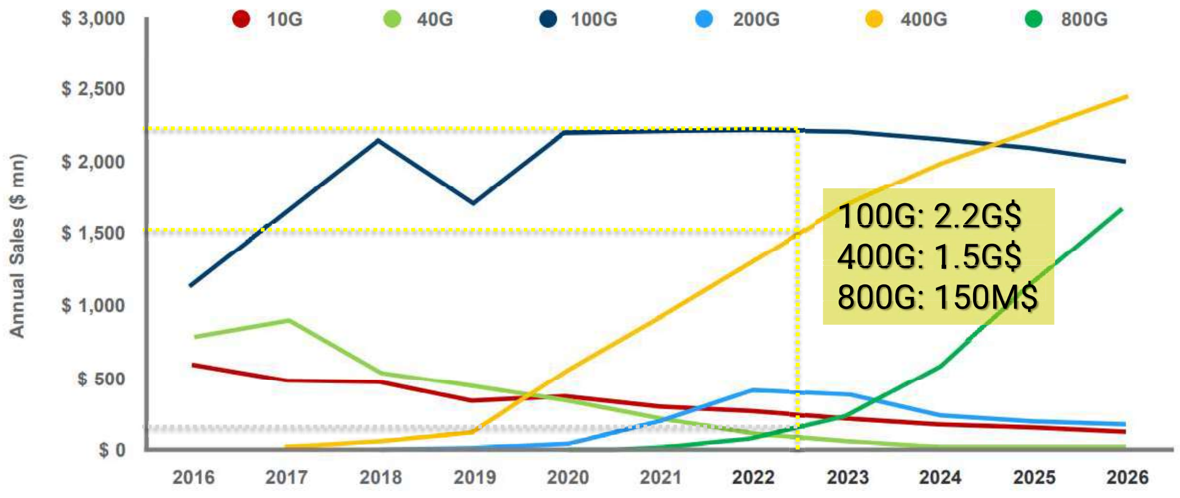
4 Disaggregated Optical Networks

- Open Line systems/3rd party TRX/IPoDWDM leveraging coherent transceivers


Switch density doubles every two years
25.6T
512*50G SerDes
64*400G Port
7nm process
400G Transceiver
51.2T
512*100G SerDes
64*800G Port
5nm process
800G Transceiver
102.4T
512*200G SerDes
64*1.6T Port
3nm process
1.6T Transceiver
2021
2023
2025


NVIDIA
NVIDIA's new-generation Blackwell platform - 1.6T optical modules
Inter-cabinet interconnection is 800 Gb/sec
InfiniBand or Ethernet
Between 1-8 GB200 NVL72 clusters
(72-576 GPUs)
Single-channel 200Gb/s technology,
144 ports x 800GB/s,
72 x 1.6T OSFP optical modules
single GPU and 800G optical
module ratio of 1:2
TOR Switch
>8 large-scale
GB200 NVL72
clusters (>576
GPUs)
single GPU and
800G optical
module ratio of
1:4.5
GB200
single
cabinet
(72 GPUs)
Cooper
Switch
Computing
Nodes
HGX B100
NVLINK Switch
GB200 Superchip
Compute Node
Quantum X800 Switch
ConnectX-8 SuperNIC
Spectrum X800 Switch
BlueField-3 SuperNIC

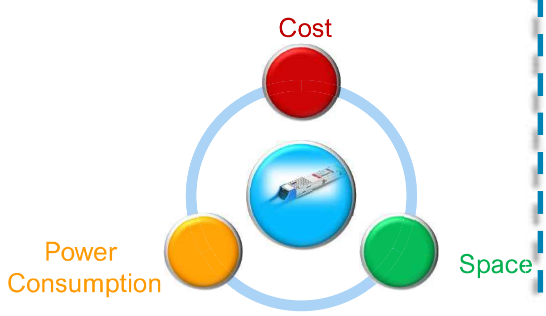
Transceiver sales up to 2026

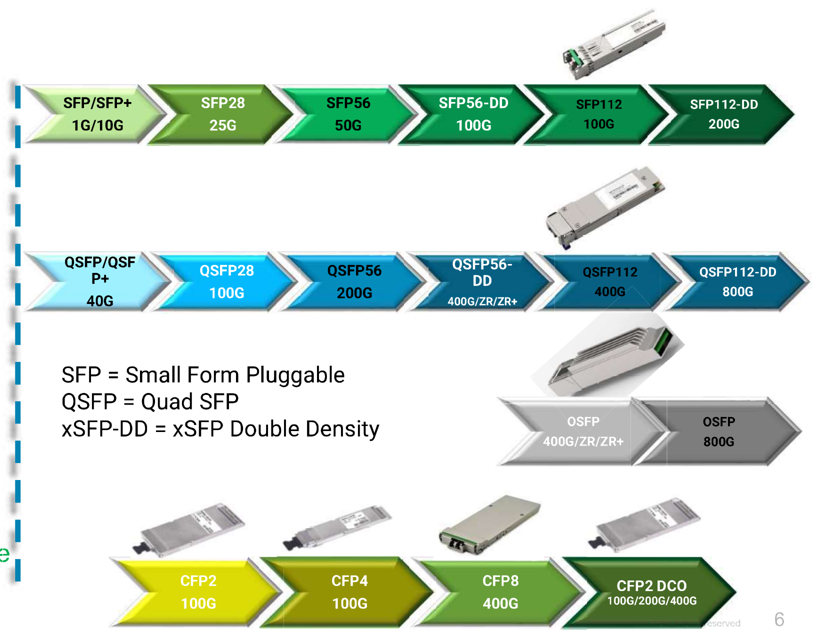


Source: Corning

Transceiver Form Factor Evolutions

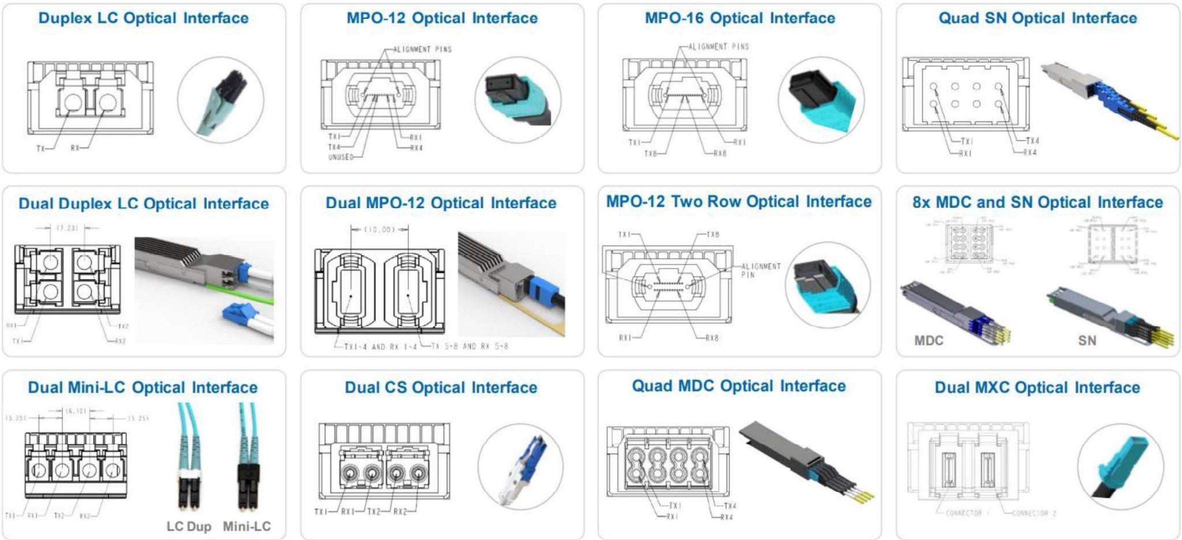
Driver in transceiver design





SFP = Small Form Pluggable
QSFP = Quad SFP
xSFP-DD = xSFP Double Density

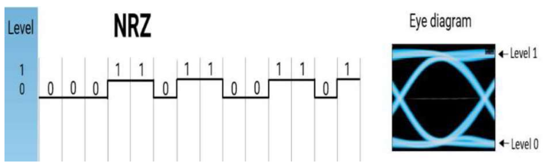
Type of interface on transceiver modules



NRZ VS PAM4

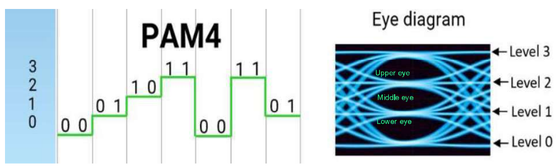
Non-Return to Zero (NRZ)

- NRZ is a binary (two levels) modulation represented by logic 0 and logic 1
- NRZ transmits one bit per symbol
- NRZ modulation served as the base of modern high-speed interfaces until 2012
- NRZ is PAM2 with 1 bit/symbol



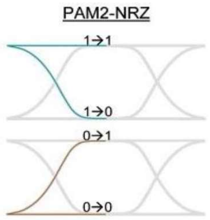
Pulsed-Amplitude Modulation 4 levels (PAM4)

- PAM4 encodes four levels, represented by four combinations of two bits logic: 00, 01, 10 and 11.
- The PAM4 eye diagram presents three eye openings and four levels.
- PAM4 transmits 2 bits per symbol, therefore the Baud rate is twice the bits per second



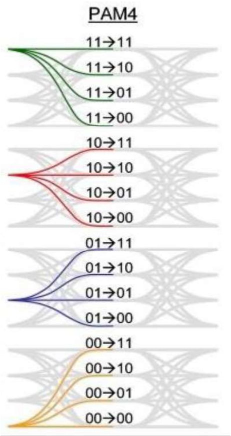
Symbol transition NRZ vs PAM4

NRZ:
2 symbol' transitions with none return to zero when 2 consecutive 1s



PAM2: 1 bit/symbol

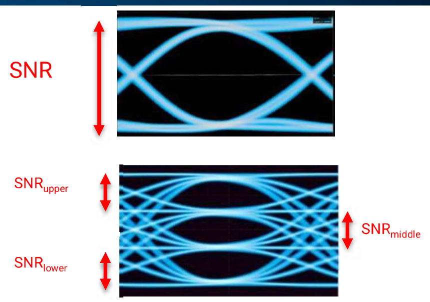
PAM4:
16 symbol' transitions
6 different rise and fall times



PAM4: 2 bit/symbol

Challenges introduced by PAM4

- PAM4 signal is more susceptible to noise:
  Signal to Noise Ratio (SNR) divided by 3 compared to NRZ
- PAM4-based units consume higher power than a transceiver supporting NRZ because of the need for more advanced equalization

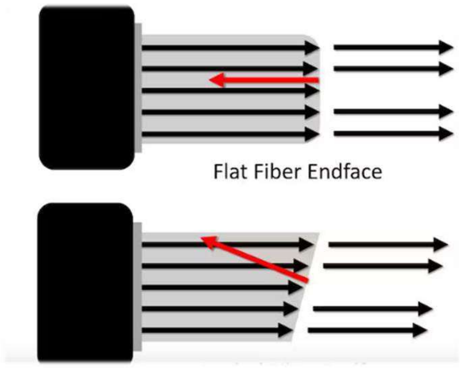


400G interfaces: Baud rate, lanes & modulation

Module type	# of I/O lanes	Electrical I/O	I/O Baud rate	Module bandwidth
400GBASE-LR8	8	50Gbps – PAM4	25G	400Gbps
400GBASE-FR8	8	50Gbps – PAM4	25G	400Gbps
400GBASE-DR4	4	106.25Gbps – PAM4	53G	400Gbps
400GBASE-SR16	16	26.56Gbps – NRZ	26.56G	400Gbps

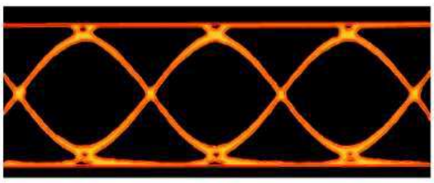
PAM4 Optical Challenge: Multiple reflections

- ✓ PAM4 is very susceptible to **M**ulti**P**ath **I**nterference (MPI) caused by **multiple reflections** originating from fiber **connectors**, **transmitters** and **receivers**...
  - ✓ MPI is heavily dependent on both the number and return loss specifications of the connectors in the end-to-end link



PAM4 modulation

Up to 25Gb/s

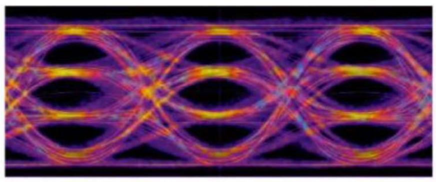


1 Level

0 Level

NRZ: 1 bit per clock cycle

From 50Gb/s



3 Level

2 Level

1 Level

0 Level

PAM4: 2 bits per clock cycle

Forward Error Correction (FEC) required to achieve error free performance with PAM4 modulation

Forward Error Correction (FEC)

What is FEC?

FEC (Forward Error Correction) is an advanced coding technique that detects and autocorrect errors through the links

Principle of FEC

FEC transforms transmitted data into code words that include redundant data. The receiver decoder uses the added redundancy to detect and correct errors that may occur in the message.

Why do we use FEC?

For 100G+ components, **a healthy BER is not enough to guarantee the quality of transmission**, so the IEEE defined the **FEC as mandatory** in the specifications for 100G & 400G Ethernet (IEEE 802.3bs task group).

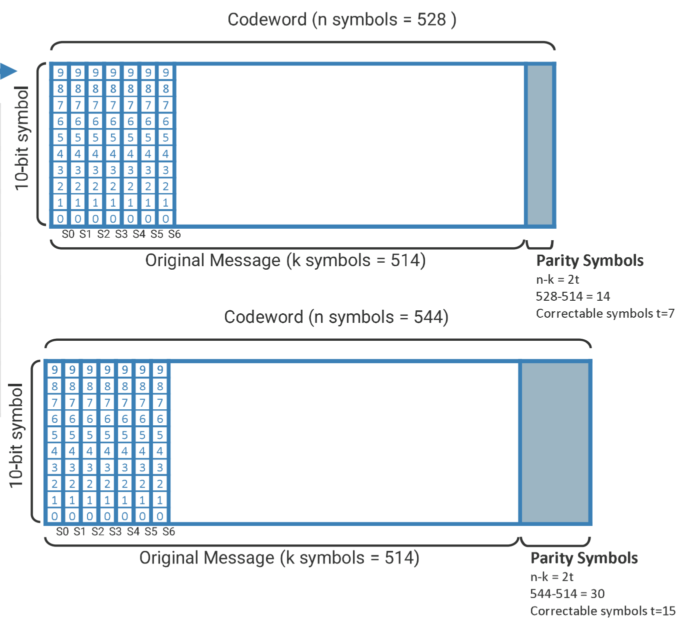
Types of FEC

The IEEE802.3bj standard specifies transmission methods using Reed Solomon FEC (**RS-FEC**).

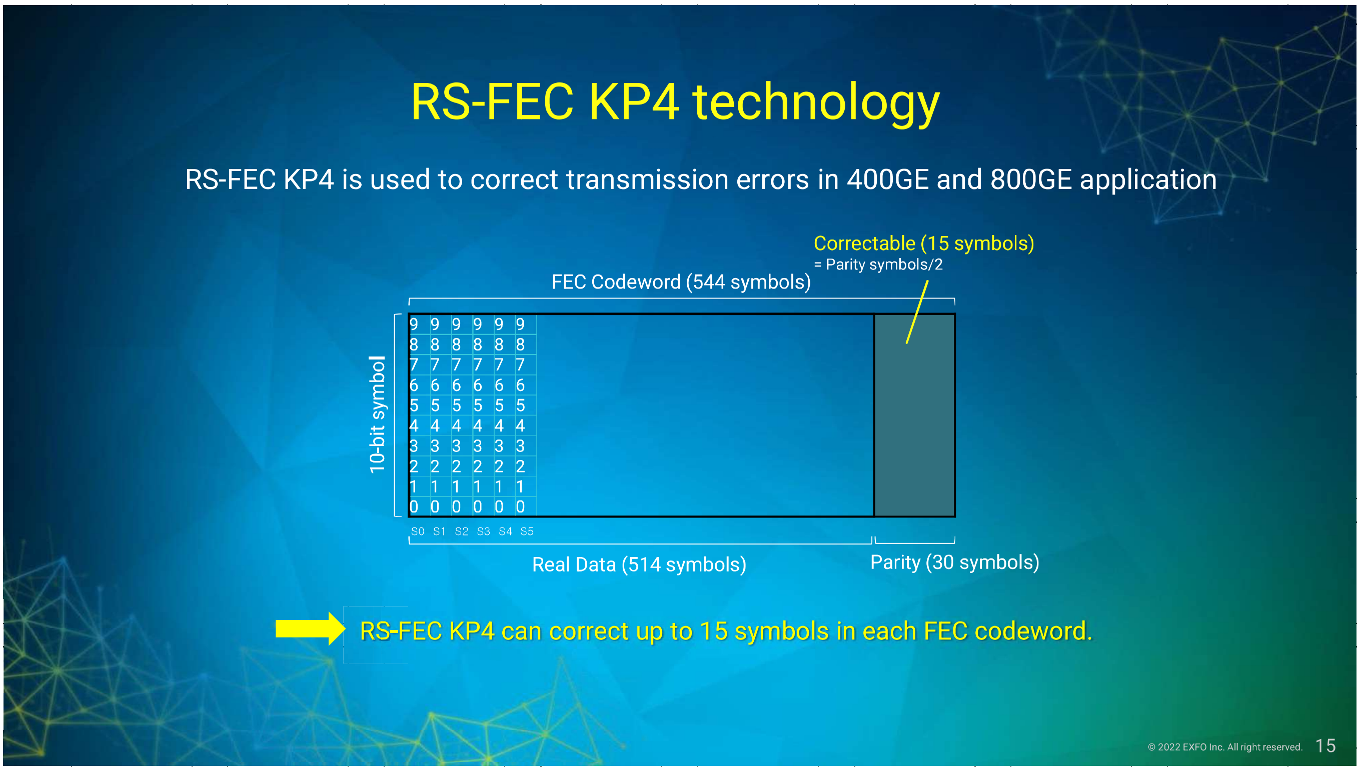
In this standard, 100GBase-CR4/KR4 uses RS (528, 514) and 100GBase-KP4 uses RS (544, 514).

Types of RS-FEC

Parameter	Symbol	KR4 (NRZ PHY)	KP4 (PAM4 PHY)
FEC encoding		RS(524, 514)	RS(544, 514)
Total symbols	n	528	544
Message symbols	k	514	514
Parity symbols	2t(n-k)	14	30
Bits per symbol	m	10	10
Correctable symbols	**t**	**7**	**15**



Note: KR4 FEC has a lower overhead (or code rate) than KP4 FEC but weaker error correction capability *t*=7


RS-FEC KP4 technology
RS-FEC KP4 is used to correct transmission errors in 400GE and 800GE application
Correctable (15 symbols)
= Parity symbols/2
FEC Codeword (544 symbols)
10-bit symbol
S0 S1 S2 S3 S4 S5
Real Data (514 symbols)
Parity (30 symbols)
RS-FEC KP4 can correct up to 15 symbols in each FEC codeword.
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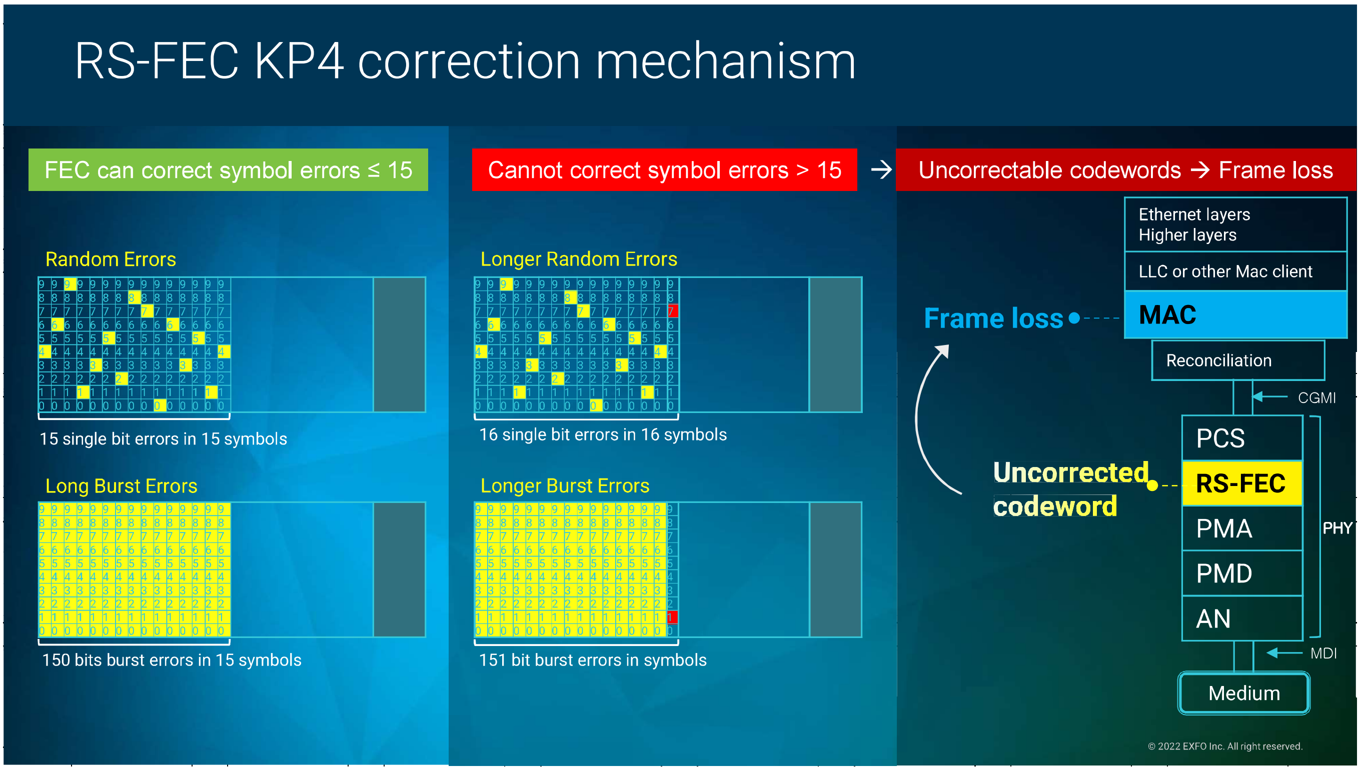
15


RS-FEC KP4 correction mechanism
FEC can correct symbol errors ≤ 15
Random Errors
15 single bit errors in 15 symbols
Long Burst Errors
150 bits burst errors in 15 symbols
Cannot correct symbol errors > 15
Longer Random Errors
16 single bit errors in 16 symbols
Longer Burst Errors
151 bit burst errors in symbols
Uncorrectable codewords → Frame loss
Ethernet layers
Higher layers
LLC or other Mac client
MAC
Frame loss
Reconciliation
CGMI
PCS
RS-FEC
PMA
PMD
AN
PHY
Uncorrected codeword
MDI
Medium
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FEC & PAM4 Analysis

Summary | Alarms/Errors | FEC Statistics | Traffic | Logger

Symbol Error per Correctable Codeword		
Number of Symbols	Codeword Count	%
1	208152664	86.7933414318289
2	28738280	11.9829902739246
3	2723140	1.13546670623764
4	198934	0.082949438419868
5	11950	0.00498278720137
6	606	0.000252683602011
7	37	0.00001542787669
8	2	0.000000833939281
9	1	0.00000041696964
10	0	0.0
11	0	0.0
12	0	0.0
13	0	0.0
14	0	0.0
15	0	0.0

% = Codeword Count / Total Correctable Codeword

Other Statistics	Codeword Count	%
Error-free Codeword	775799388	76.3864011295776
Uncorrectable Codeword	0	0.0

% = Codeword Count / Total Codeword

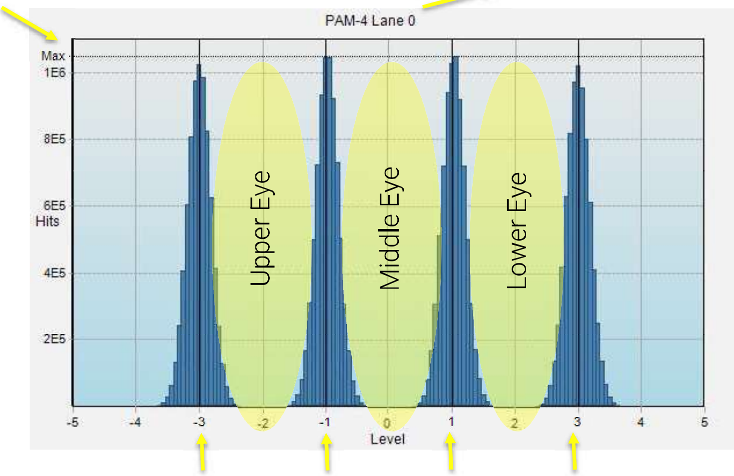
Optimal way to Characterized the received PAM4 signal.

User can see the PAM eyes without an Oscilloscope

All lanes are scanned and saved on the report

Analyzing the electrical eye is a key requirement of the PAM4 analysis

Lane # number



PAM 4 Levels

High Speed 400G Summary

PAM4

8x50G

4x100G
CWDM

Electrical

Optical

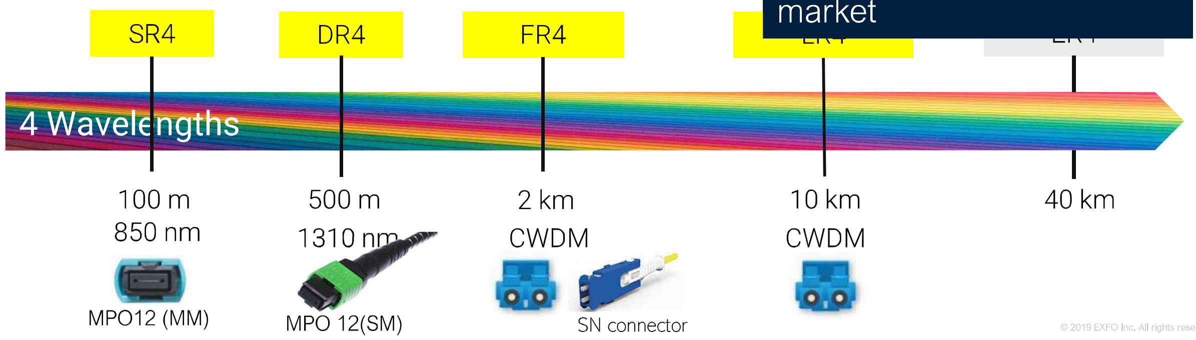
1271 nm

1291 nm

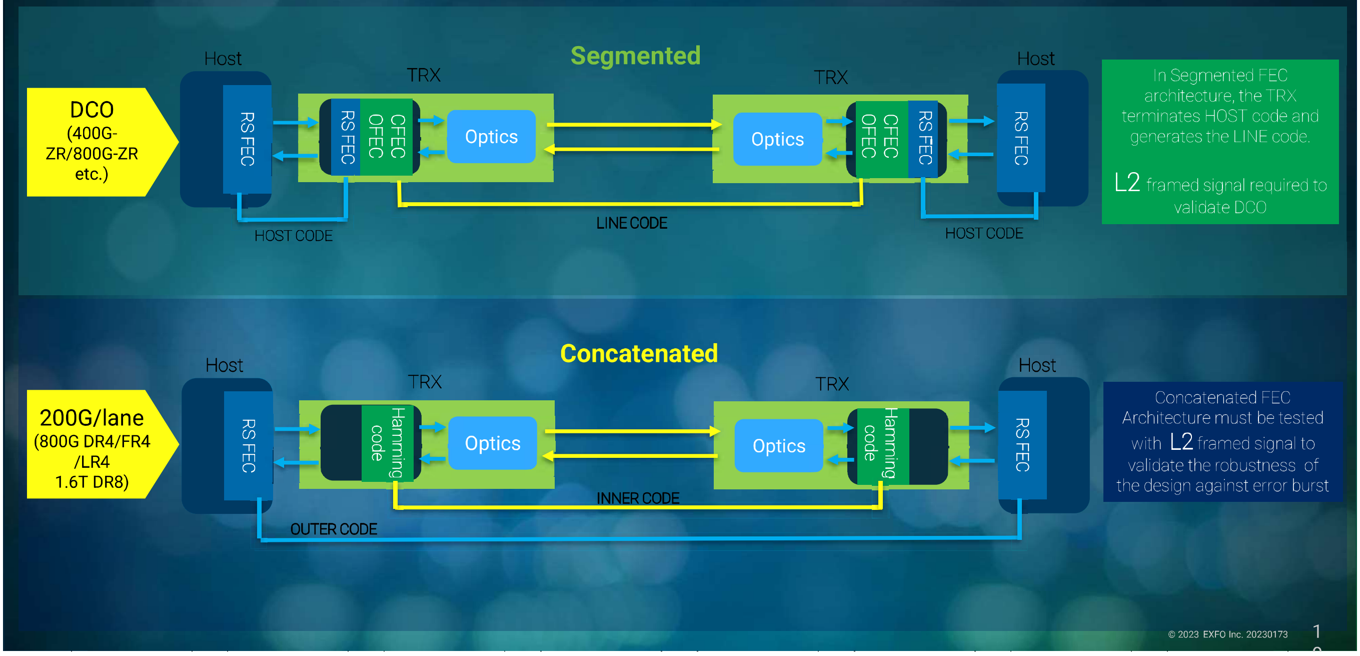
1311 nm

1331 nm

VERY popular on the market



FEC moving inside the Transceiver

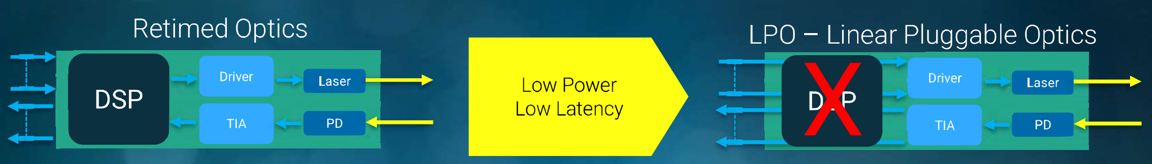


IEEE 802.3dj Task Force

Item	Technology	Capability
1	1.6TBASE-DR8-2 (FECi)	1.6 Tb/s, inner FEC, 2 km, parallel
3	1.6TBASE-DR8 (FECi)	1.6 Tb/s, inner FEC, 500 m, parallel
4	1.6TBASE-?R8 (FECo place holder)	1.6 Tb/s, reach TBD, parallel
5	800GBASE-LR4 (assume always inner FEC)	800 Gb/s, 10 km
6	800GBASE-FR4 (FECi)	800 Gb/s, inner FEC, 2 km, duplex
7	800GBASE-LR1(10km Coherent)	800 Gb/s, reach TBD, duplex
8	800GBASE-DR4-2 (FECi)	800 Gb/s, inner FEC, 2 km, parallel
10	800GBASE-DR4 (FECi)	800 Gb/s, inner FEC, 500 m
11	800GBASE-ER1 (Coherent)	800 Gb/s, 20 km (and future 80km)
12	400GBASE-DR2-2 (FECi)	400 Gb/s, inner FEC, 2 km, parallel
13	400GBASE-DR2 (FECi)	400 Gb/s, inner FEC, 500 m
14	400GBASE-?R2 (FECo place holder)	400 Gb/s, reach TBD
15	200GBASE-FR1 (FECi)	200 Gb/s, inner FEC, 2 km, parallel
16	200GBASE-DR1 (FECi)	200 Gb/s, inner FEC, 500 m
17	200GBASE-?R1 (FECo place holder)	200 Gb/s, reach TBD

Ref: https://www.ieee802.org/3/dj/public/24_01/brown_3dj_02_2401.pdf

Challenges of LPO testing



Best TDECQ ≠ Best BER
TDECQ@TP2 is not calculated with real host receiver response

Best BER ≠ Best BER with Switch
CH response is different between test environment and real host

SerDes is key
Test scenario should mimic real switch behavior

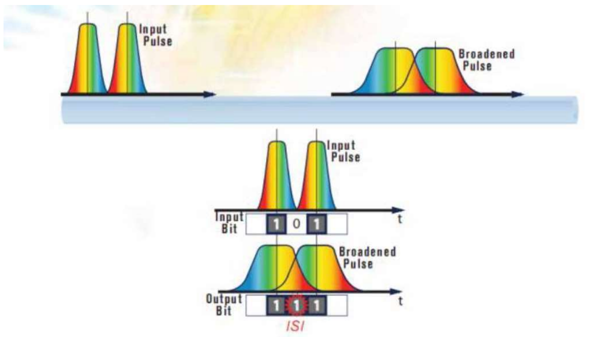
Tuning is hard & long
Each port requires specific optimization

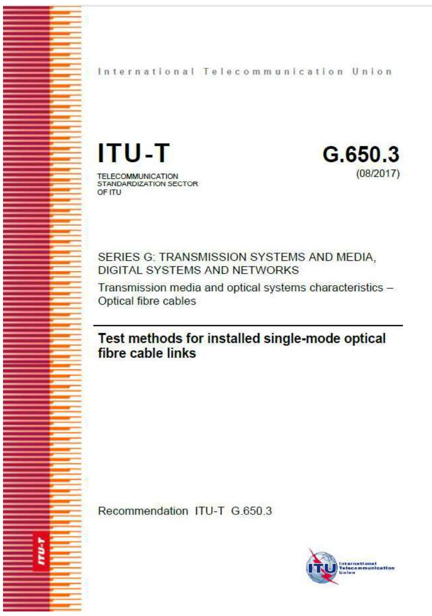
Reflection / Noise
BER, TDECQ don't easily capture it

FEC Tails/Margin
BER and FEC tail stability is key performance indicator

Advanced G.650.3 Recommendations

- Dispersion testing completes the recommendations for fiber characterization.
- Two types of dispersion:
  - Chromatic Dispersion (CD)
  - Polarization Mode Dispersion (PMD)




International Telecommunication Union

ITU-T
TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

G.650.3
(08/2017)

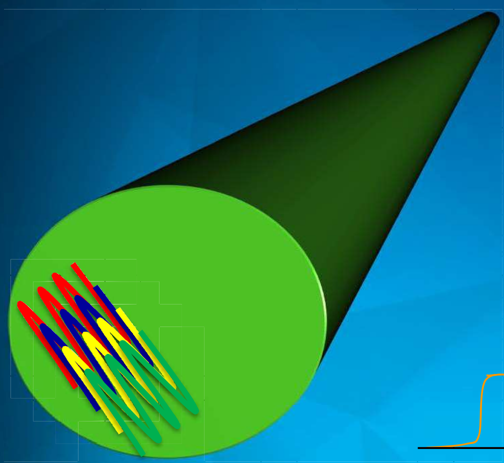
SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS
Transmission media and optical systems characteristics – Optical fibre cables

Test methods for installed single-mode optical fibre cable links

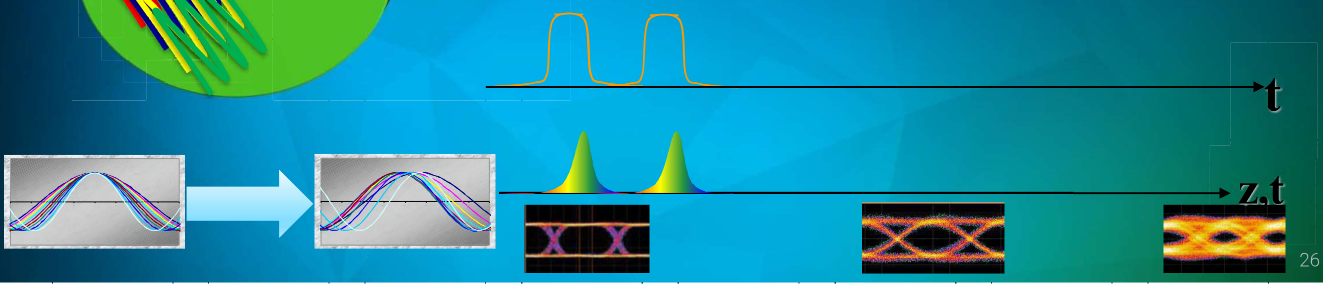
Recommendation ITU-T G.650.3

Bandwidth limitations induced by dispersion

Chromatic Dispersion



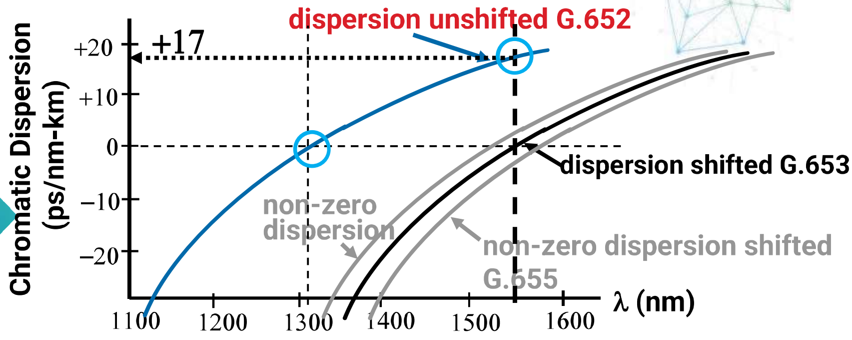
- Different wavelengths travel at different speeds in a fiber, causing pulse broadening
- Limits how fast and how far a signal will travel
- Higher bit rates are less robust



CD chart gives two interesting pieces of information:

1. Dispersion for a specific wavelength.
   G.652 fiber CD is ~ +17 ps/nm/km @ 1550 nm.

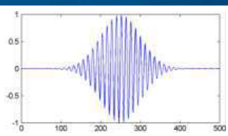
2. Zero dispersion wavelength.
   G.652 λ0 is ~ 1310 nm.



Fiber Type	ITU Specification	Attenuation (dB/km) 1310 nm	Attenuation (dB/km) 1550 nm	Chromatic Dispersion (ps/nm*km) 1310 nm	Chromatic Dispersion (ps/nm*km) 1550 nm
9/125 Standard Single-mode	G.652	0.32	0.22	0	17
9/125 Cut-off shifted (pure Silica Core)	G.654	0.32*	0.17	0	18
9/125 Dispersion Shifted	G.653	0.32*	0.22	-15	0
9/125 NZDSF	G.655	0.35*	0.22	N/A	4-6

Facts About Chromatic Dispersion

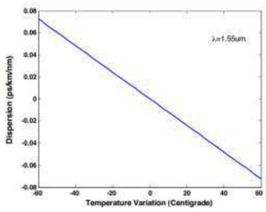
Chromatic dispersion (CD) is linear:



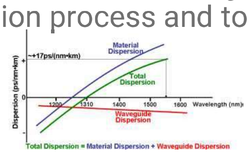
CD increases proportionally with distance

17ps/(nm-km) +/-2 nm @ 1550 nm G.652

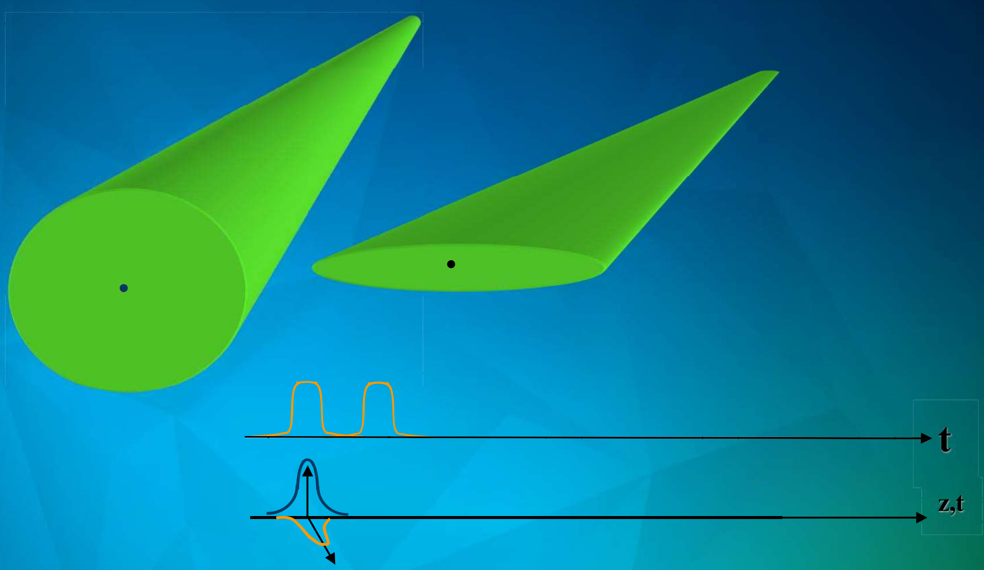
CD does not change (much) over time



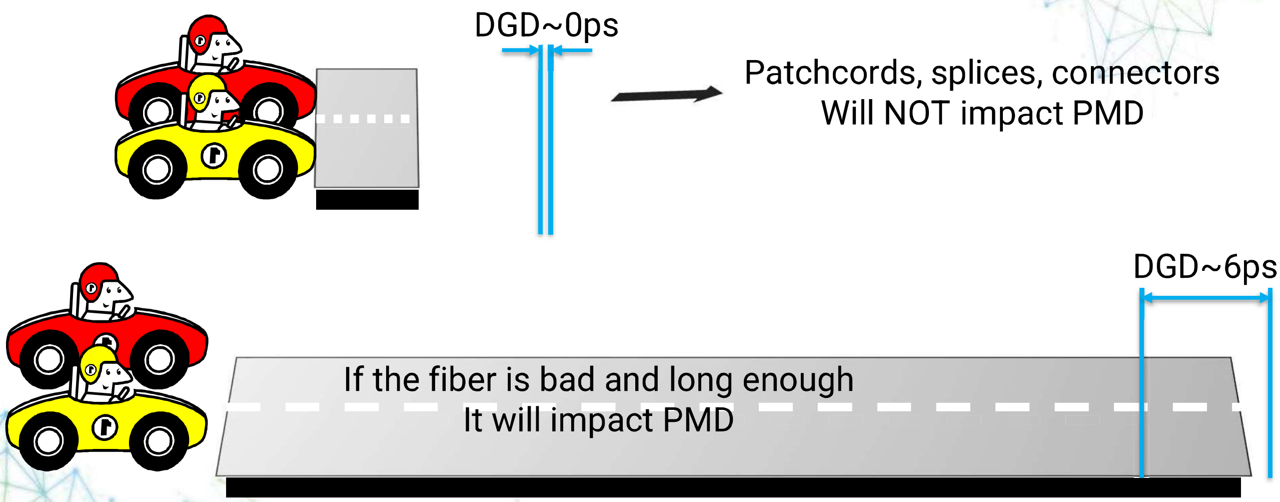
There is no "FAIL" in the field, because the CD properties are set during manufacturing. The values measured are used to adjust the compensation process and to select the optimum set of transmitter/receiver.



Polarization Mode Dispersion PMD



PMD and delay accumulation…



Fact: PMD accumulates with the $\sqrt{distance}$

Facts about Polarization Mode Dispersion

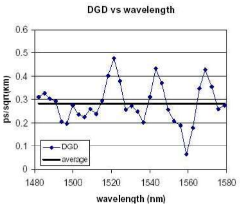
A good fiber is a 0 ps fiber.

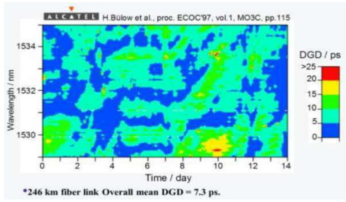
PMD is a defect, such as high loss or a macrobend.

The PMD coefficient is specified by cable manufacturers

DGD is a stochastic phenomenon, aka it could be described using statistics and probability mathematics, which implies the following consequences:

- DGD changes over time, but PMD is pretty stable
- 0ps < DGD "now" (or instantaneous) < DGD MAX
- DGD MAX could be 3 or 4 times higher than PMD





90% of PMD is induced during the "fibering" and "cabling" process and about 10% during the installation process .

Noncoherent and coherent transceivers reach are also limited by DGD MAX (PMD)

If PMD "FAILs" in the field, the main PMD contribution can be identified and the identified fiber section should be replaced

Different Dispersion Tolerances

Access/business

P2P Mesh and rings topologies

CWDM/LWDM/DWDM

Transitioning from 10GigE to 25/50GigE

Direct modulation transmission limited by CD/PMD

Customers already asking for 100GigE

Mass market: low cost: limited dispersion tolerances

Metro/DCI

Ring and mesh topologies

CWDM/LWDM/DWDM

Deploying 25/50/100/400G

Mix of coherent and non coherent channels

Customers already asking for 800GigE

Low to medium dispersion tolerance

Backbones

Mesh networks

DWDM and ROADM

Flex grisd/Flex-E, 200/400/600/800G

Deploying any rate on any path

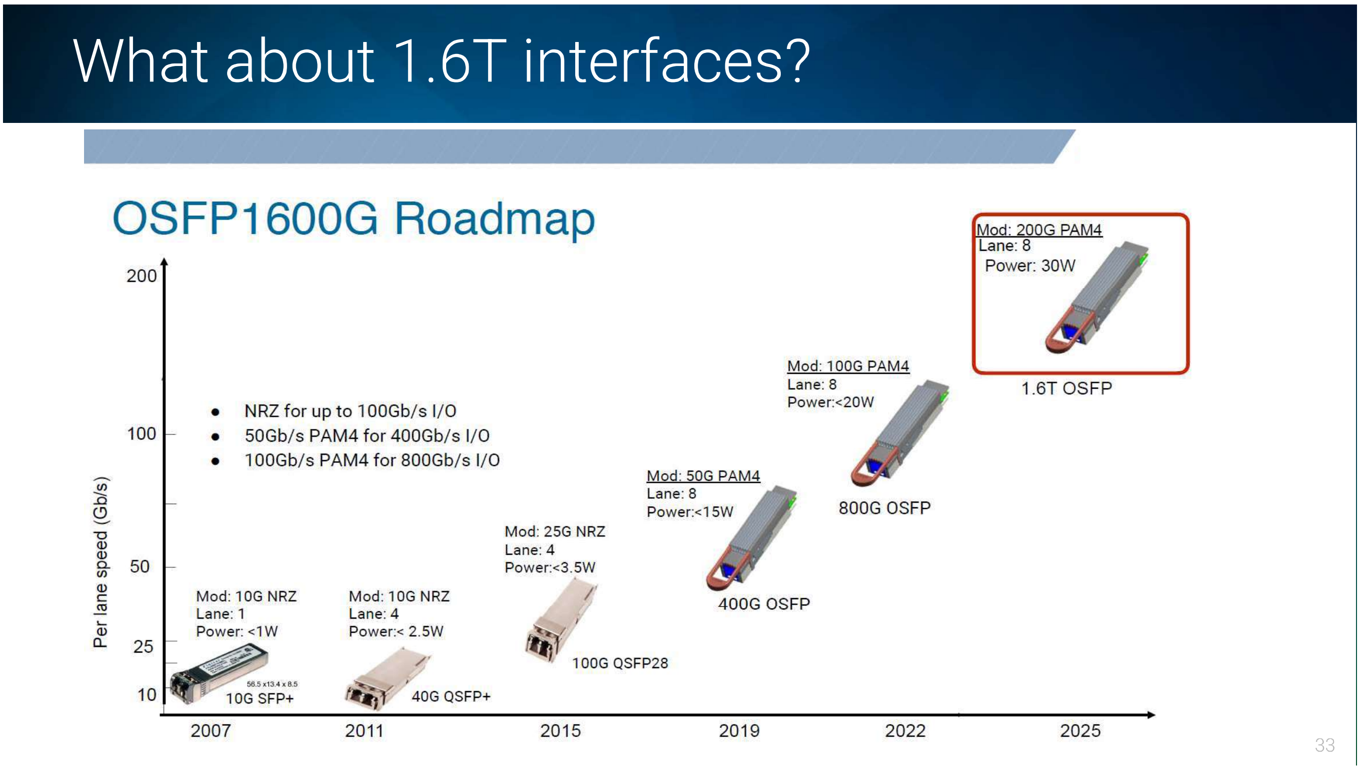
Coherent channels

Amplification: EDFA and RAMAN

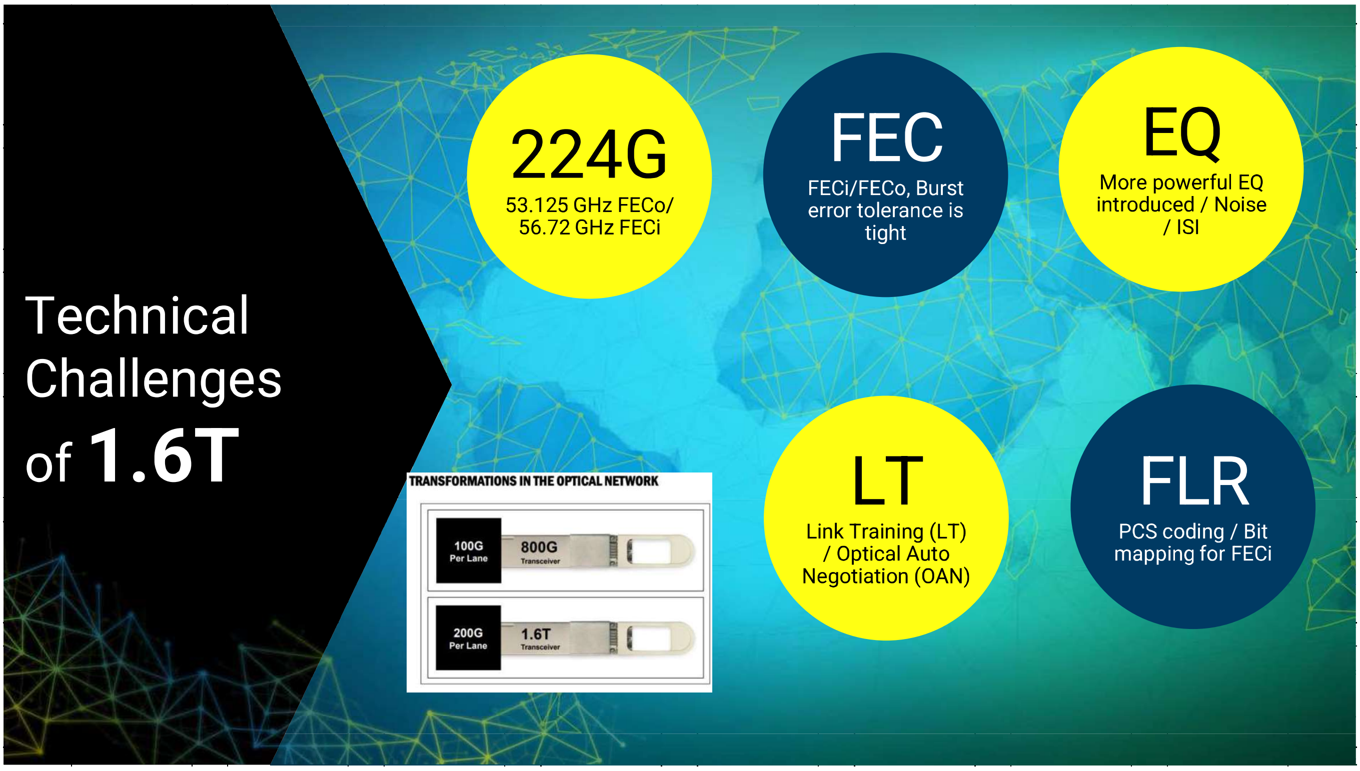
Sensitive to NLEs

Medium to high dispersion tolerances

400ZR example of dispersion tolerance: CD max 1600ps/nm, PMD 10ps max (DGD MAX?)



What about 1.6T interfaces?
OSFP1600G Roadmap
Per lane speed (Gb/s)
200
100
50
25
10
NRZ for up to 100Gb/s I/O
50Gb/s PAM4 for 400Gb/s I/O
100Gb/s PAM4 for 800Gb/s I/O
Mod: 10G NRZ
Lane: 1
Power: <1W
10G SFP+
Mod: 10G NRZ
Lane: 4
Power:< 2.5W
40G QSFP+
Mod: 25G NRZ
Lane: 4
Power:<3.5W
100G QSFP28
Mod: 50G PAM4
Lane: 8
Power:<15W
400G OSFP
Mod: 100G PAM4
Lane: 8
Power:<20W
800G OSFP
Mod: 200G PAM4
Lane: 8
Power: 30W
1.6T OSFP
2007
2011
2015
2019
2022
2025
33



Technical Challenges of 1.6T
224G
53.125 GHz FECo/ 56.72 GHz FECi
FEC
FECi/FECo, Burst error tolerance is tight
EQ
More powerful EQ introduced / Noise / ISI
LT
Link Training (LT) / Optical Auto Negotiation (OAN)
FLR
PCS coding / Bit mapping for FECi
TRANSFORMATIONS IN THE OPTICAL NETWORK
100G Per Lane
800G Transceiver
200G Per Lane
1.6T Transceiver


EXFO High Speed Portfolio
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NEW!
MAX-840
Entry Level 400G
RFC/BERT/TGEN
Dual Port 1G-100G
Single Port 400G
Non modular
No coherent
FTBx 88480
Professional 400G
RFC/BERT/TGEN
Modular/Portable
Dual Port 1G-400G
Coherent Capable
OTN
FTBx 88482
Quad port 400G
RFC/BERT/TGEN
Modular/Portable
Quad Port 1G-400G
Independent tests
Coherent Capable
OTN
FTBx 88800
800G LAB
Modular/Portable/Rackmount
Dual Port 200/400
Single port 800G
Coherent up to 800ZR


Host-to-module interoperability
DCO BERT and CMIS tester
CMIS
Multi-client and application support
Power consumption and thermal behavior
Wavelength management
Optical Power management
Performance Monitoring
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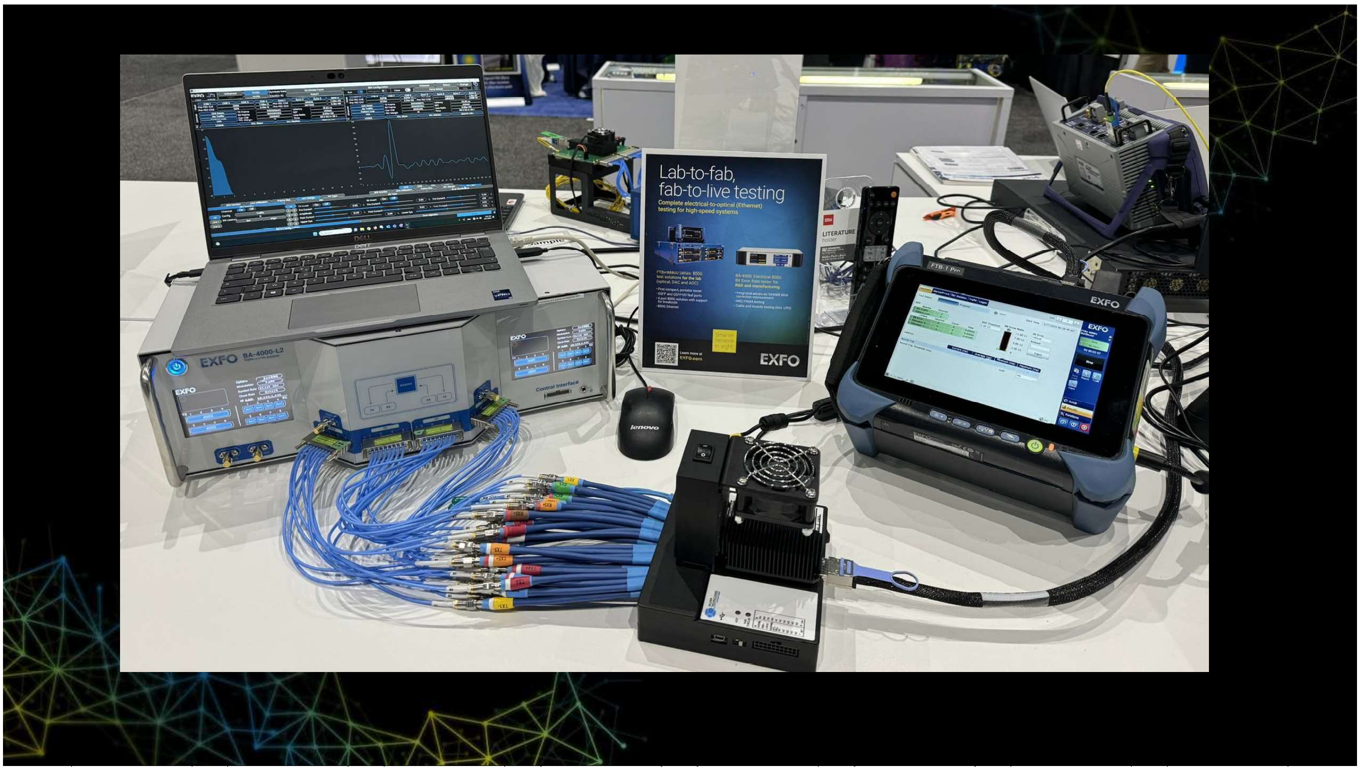
Host-to-module interoperability
DCO BERT and CMIS tester
Simple Configuration Full suite testing
Support ZR/ZR+
Pass/Fail Verdict
DCO iOptics
EXFO
Modify
Interface
400ZR (CFEC, 16QAM, DWDM Amplified) [478.75 Gbit/s]
400ZR (CFEC, 16QAM, Unamplified) [478.75 Gbit/s]
400ZR+ (OFEC, 16QAM) [481.108374 Gbit/s]
OK
Cancel


Lab-to-fab, fab-to-live testing
Complete electrical-to-optical (Ethernet) testing for high-speed systems
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Optična stikala: Tehnologija, ki je dozorela – od laboratorijske avtomatizacije do omrežne umetne inteligence

Optical Circuit Switching: A technology that's come of age From lab automation to networking AI

Graeme Allott

HUBER+SUHNER Polatis

graeme.allott@hubersuhner.com

Povzetek

Ta prispevek daje vpogled na naraščajočo uporabo optičnih stikal za avtomatizacijo prve plasti od njihovega pojava v devetdesetih letih prejšnjega stoletja. Medtem ko so se sprva uporabljala za aplikacije zunaj omrežja, kot sta avtomatizacija testnih laboratorijev in nadzor omrežja, so zaradi pojava računalništva v oblaku in zlasti umetne inteligence v zadnjih letih optična stikala zavzela osrednji položaj v novih omrežnih arhitekturah. Zaradi visokih hitrosti preklapljanja, nizke zakasnitve, preglednosti za vrsto signalov in bitnih hitrosti ter zelo nizke porabe energije v primerjavi z električnimi stikali, mnoga podjetja resno razmišljajo o uporabi optičnih stikal za svoje podatkovne centre z umetno inteligenco.

Abstract

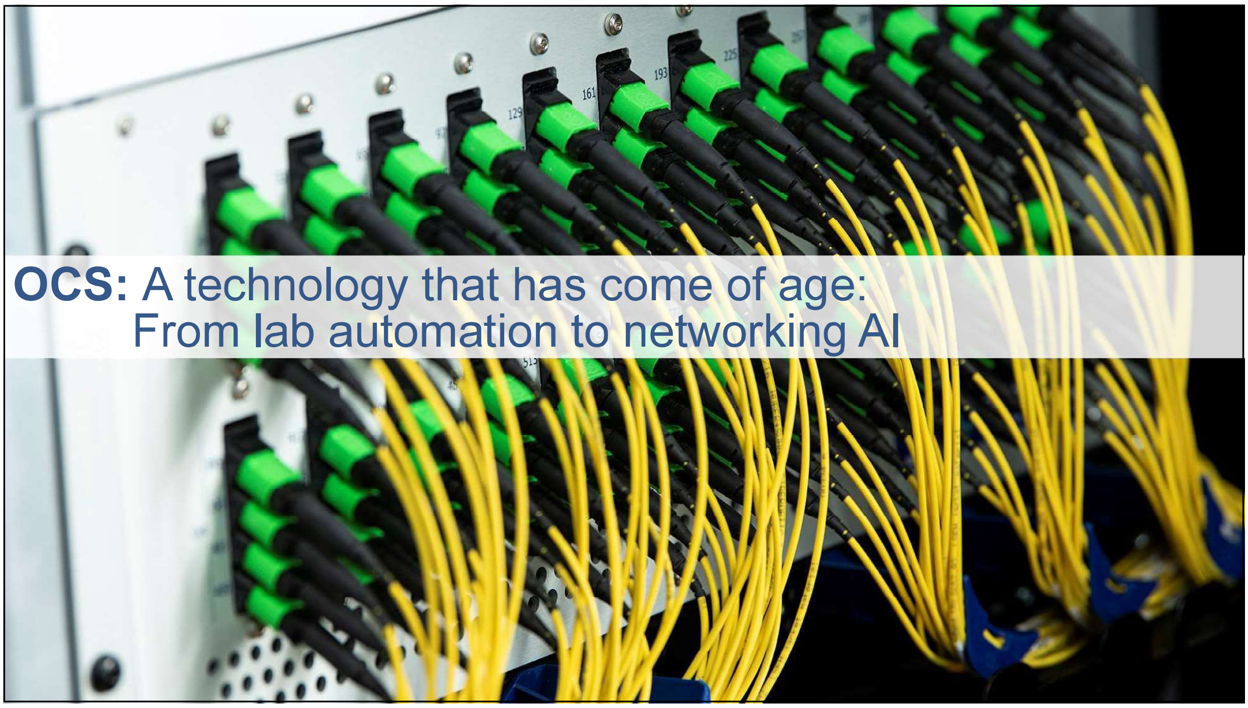
The presentation gives a perspective on the growing deployment of optical circuit switches for layer one automation since their emergence in the 1990's. While initially utilised for off-network applications such as test lab automation and network monitoring, the advent of cloud computing and in particular AI in recent years has seen optical circuit switches take a central position in new network architectures. Thanks to their high switching speeds, low latency, transparency to signal types and bit rates, and very low power consumption compared to electrical switches, optical circuit switches are now being seriously considered by Hyperscalers and others for their AI data centres.

Biografija avtorja

Graeme Allott je na poti, da bo v tehnološkem sektorju delal še nadaljnjih 20+ let. Graeme je odraščal v Južni Afriki in nadaljeval študij procesnega in komunikacijskega inženiringa na Tehnološki univerzi Durban. Kariero je začel kot terenski inženir v paradržavnem komunalnem podjetju. Podal se je v tujino v države, vključno z ZAE, Belgijo, Združenim kraljestvom in ZDA, kjer se je 16 let osredotočal na dejavnosti testiranja in merjenja radijskih frekvenc in optičnega prenosa. Naslednja 4+ leta je delal pri HUBER+SUHNER in opravljal različne vloge, kjer se je zdaj znašel kot direktor prodaje za Severno Ameriko v podatkovnih centrih in omrežjih s fiksnim dostopom.

Author's biography

Graeme Allott is on a journey to continue working in the technology sector for another 20+ years. Growing up in South Africa, Graeme pursued studies in process and communication engineering from Durban University of Technology. With a career beginning as a field engineer in the parastatal utility. He ventured abroad to countries including UAE, Belgium, UK and USA, *focussing efforts over 16 years for test and measurement activities in radio frequency and optical transmission. For the next 4+ years he has been with HUBER+SUHNER, holding various roles, where he now finds himself as the Sales Director for North America in Data Center and Fixed Access Networks.*



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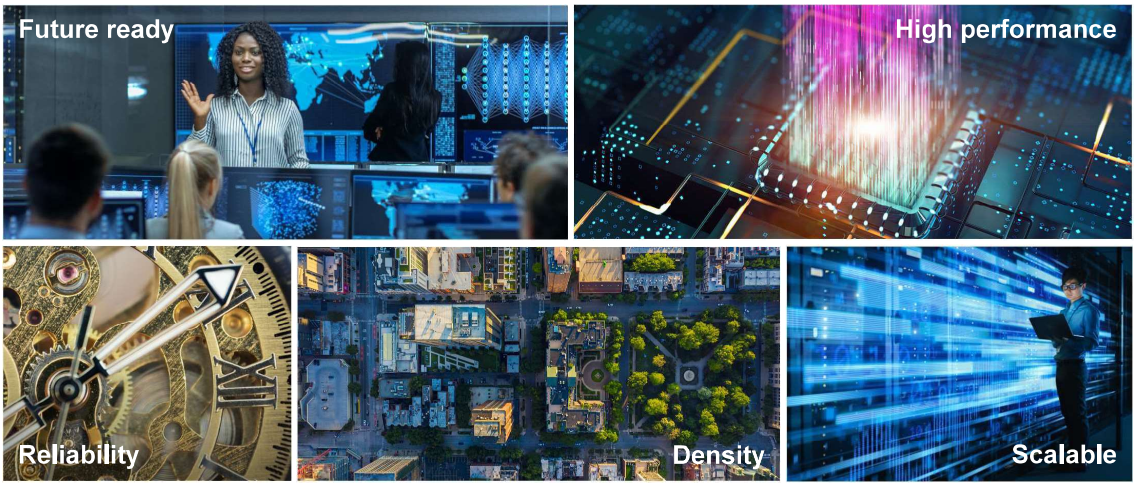
Agenda

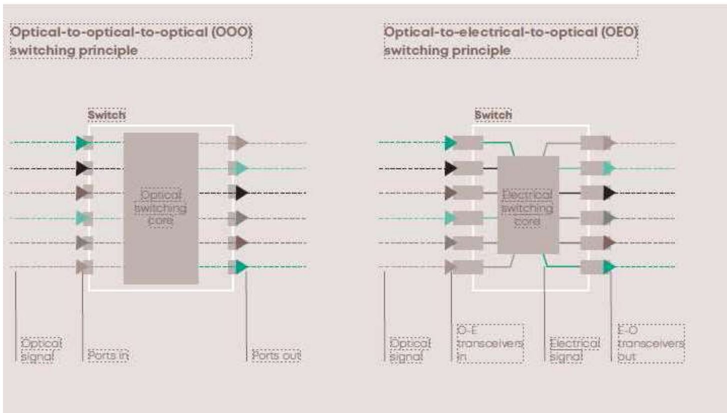
- What is OCS?
- OCS brief history
- Lab automation
- Lawful intercept
- Quantum
- Google DC deployment
- AI/ML and beyond

Introduction



What is OCS?

Optical Circuit Switching



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Key parameters: OCS (OOO) vs OEO

Parameter	All-Optical Switch	OEO Routers and Switches
Technology	All-Optical (OCS)	Optical to Electrical to Optical (OEO)
Switch Time	Slower (25-50 msecs)	Faster (µsecs)
Switch Latency	Much Lower (~50ns)	Higher: (µsecs to msecs)
Cost Per Port	Lower	Higher
Power Usage Per Bit	Much Lower	Higher
Traffic Grooming	No (Good for large flows)	Yes (Good for small flows)
Future proof (10 Gbps –> 1.6+ Tbps)	Yes	No
Supported Traffic Types	All - Format Independent	Specific – Limited by Transponders and Electronics
Supported Data Rates	All – Data Rate Independent	Specific – Limited by Transponders and Electronics
Ideal Applications	Circuit Switching of High Bit-Rate Traffic	Packet Switching and Traffic Grooming

There is a role for both OOO and OEO technologies in today's data centers

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OCS brief history

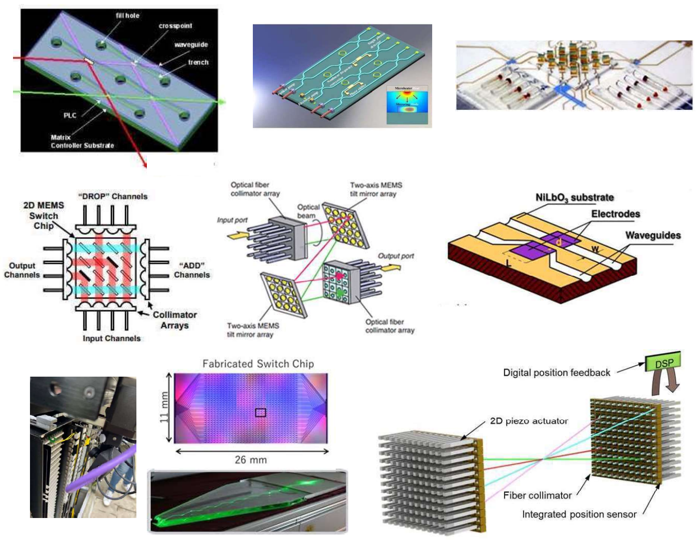
Many technologies were researched over the years - but few succeeded

A few interesting OCS technologies

- Bubble jets in index-matching fluid
- Thermo-optic
- Electro-optic holograms
- 2D and 3D MEMS
- Lithium Niobate
- Robotic switches
- Photonic integrated Circuits (PiC)
- Polymer optical waveguides
- Piezoelectric

Why were some technologies more successful?

- Scalability: N^2 versus 2N switch technologies
- Low and consistent connection loss across all ports
- Good overall mix of optical performance specs
- Switch cost in line with the application value



Lab automation

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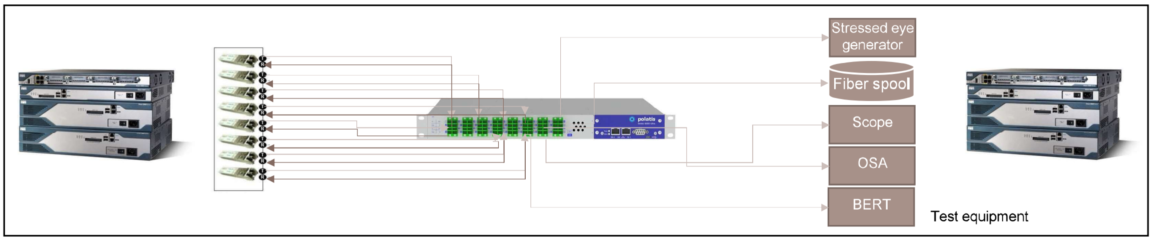

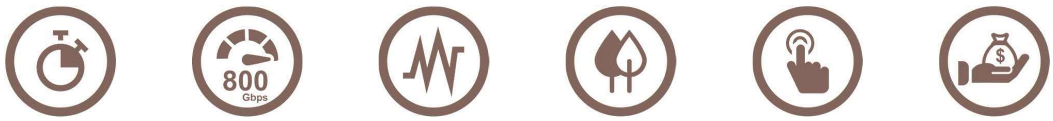

Man hours | Data rate | Bandwidth | Energy | Repeatability | Capex /Opex

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Lawful intercept

Tasking

The Intercept System is tasked to route data streams of interest to the collection/analysis tools

Oceans of data in

Collection/Analysis tools drill in and extract drops of valuable intelligence

Critical drops of intelligence out

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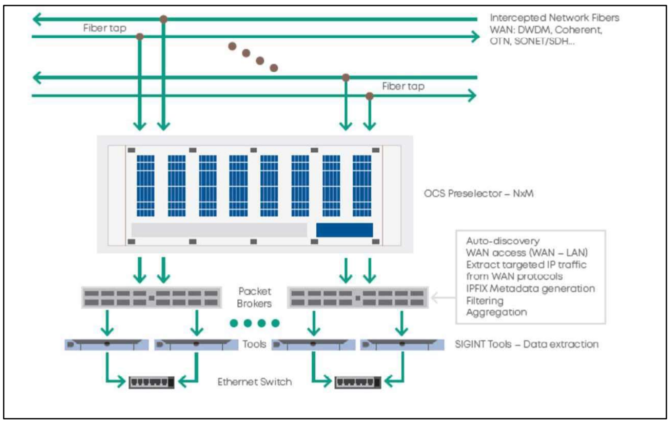
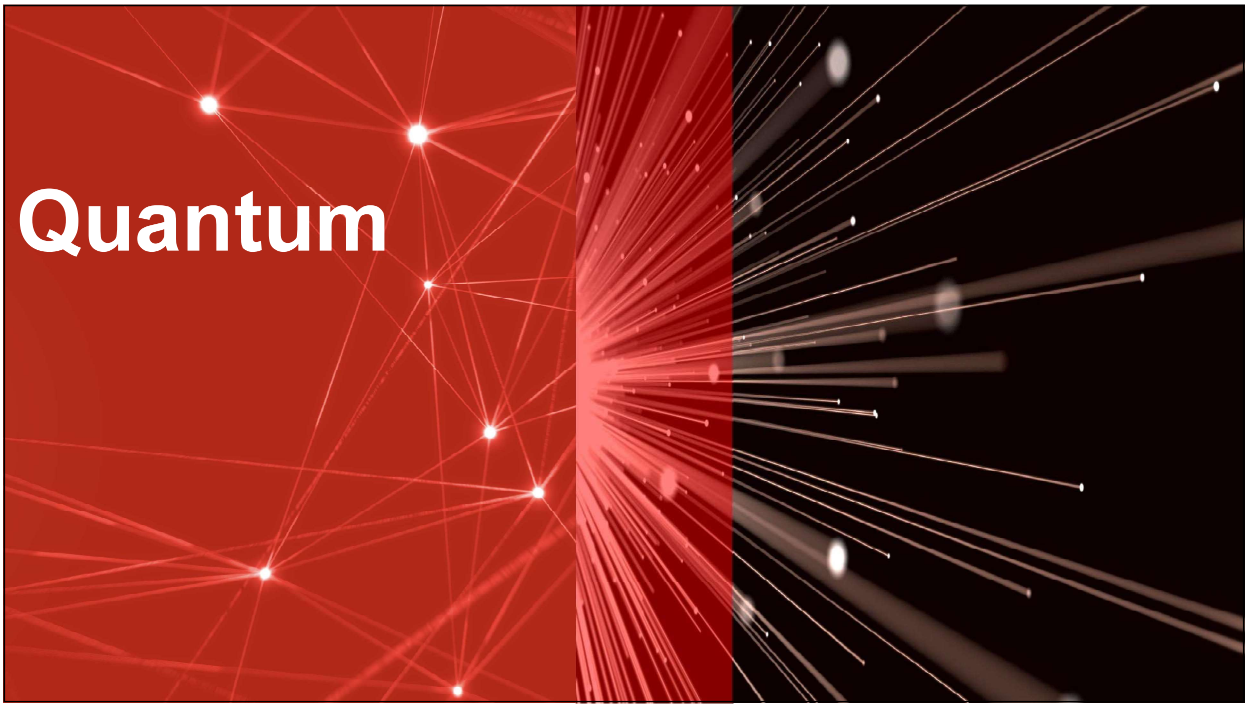
Lawful intercept



Collection of signals of any kind to gain information advantage on an adversary

- Directed at agents of foreign governments
- Authorized differently than LI
  - In USA the FISA courts authorize intelligence collection within their borders
  - Outside of USA collection is governed by Intelligence Agency policies



Quantum

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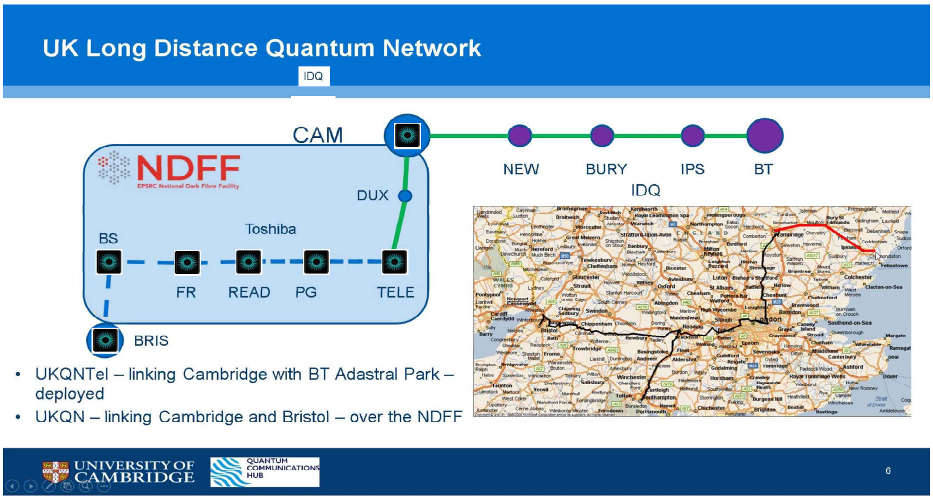

Quantum

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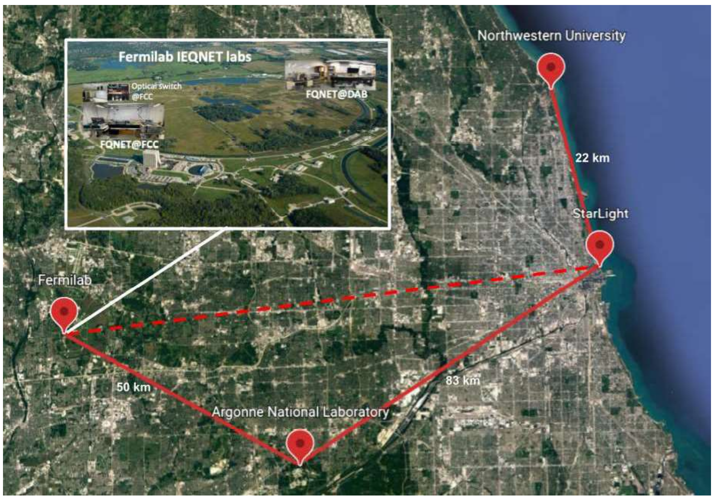
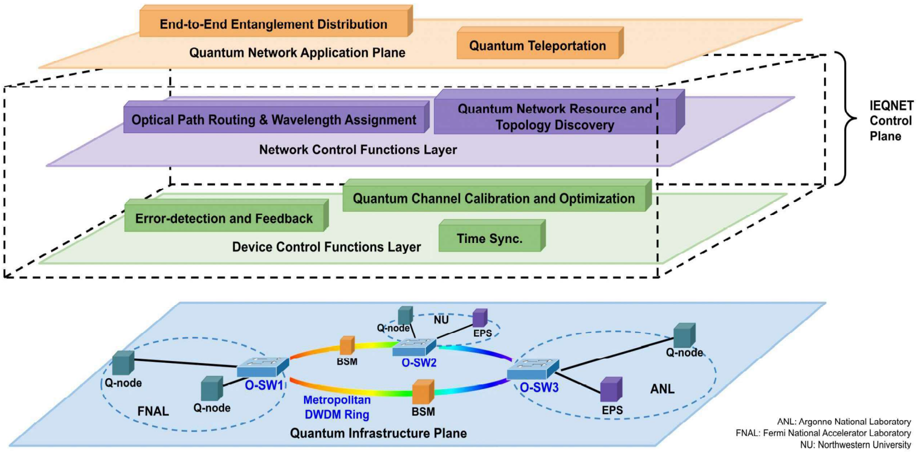
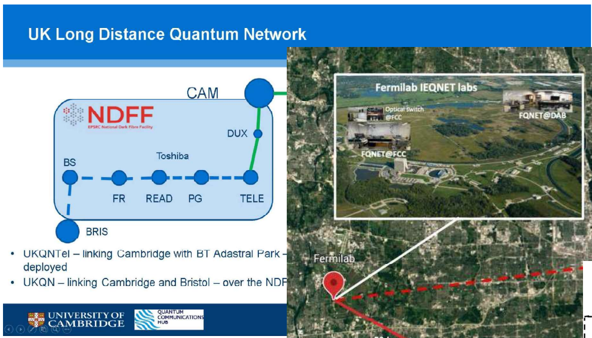


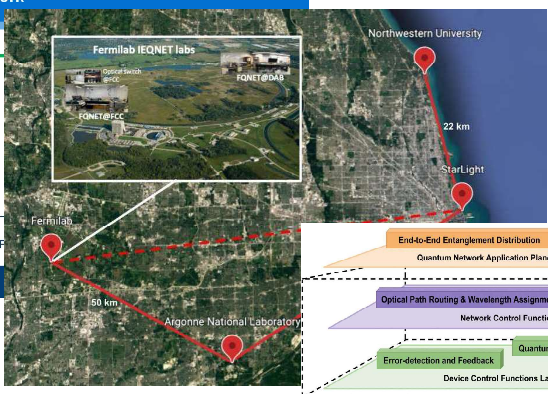
Fermilab Feb 2023

Quantum



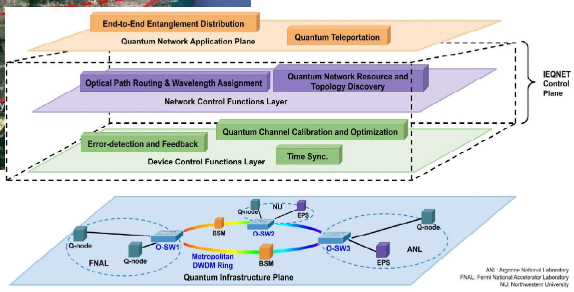
Quantum





H+S Polatis in OFCnet Quantum Demonstration

OCS routes different quantum entangled wavelengths to spatially separated users



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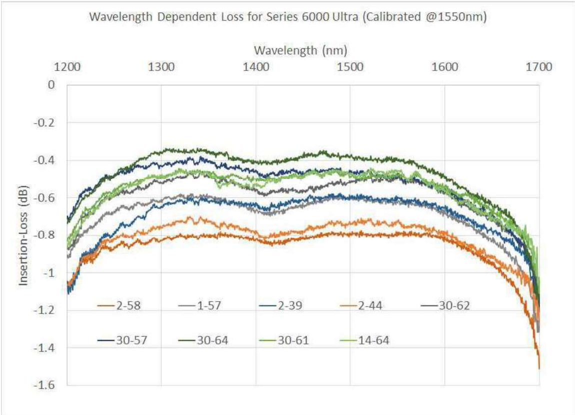
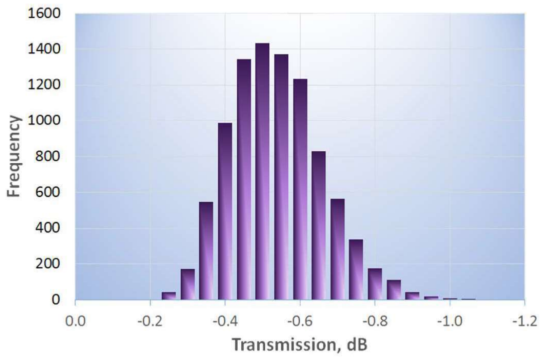
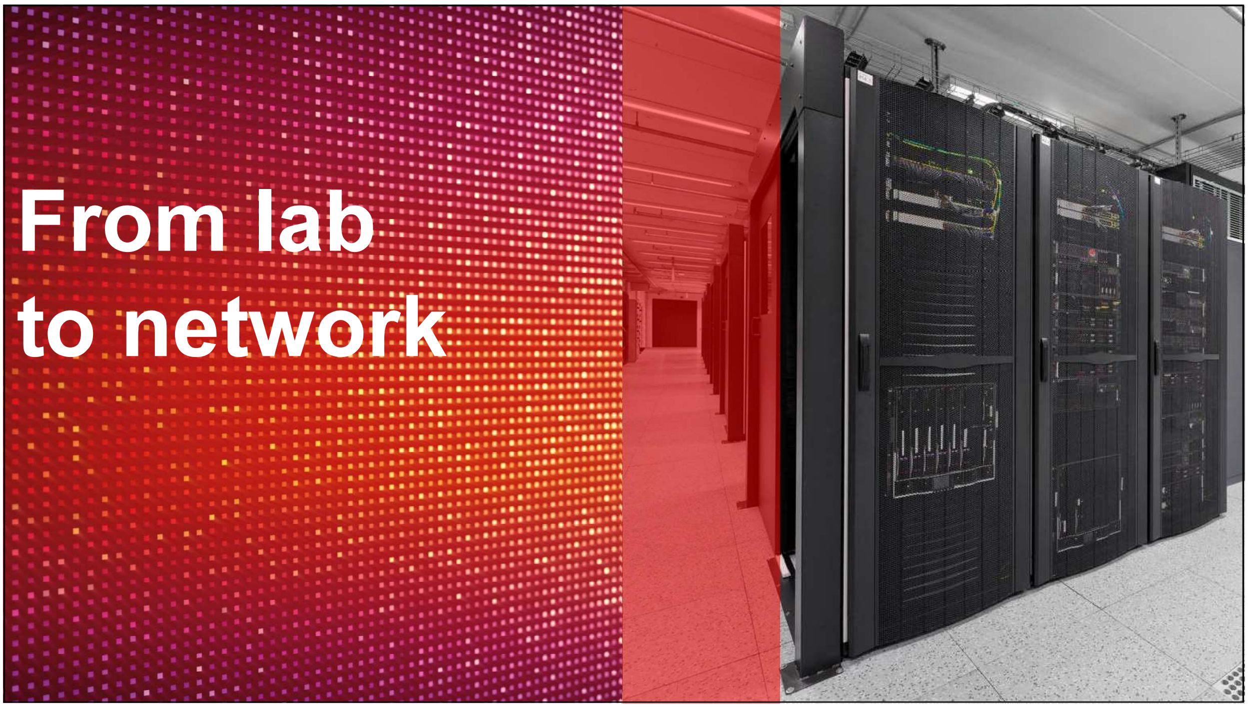
Quantum





- Less than 0.6dB median loss, 1.2dB max
- Enables low loss multi-stage fabrics



Disaggregation in a lab

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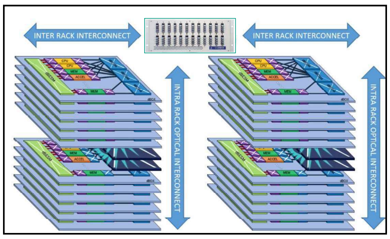
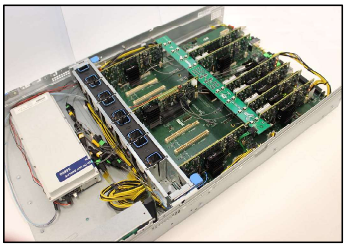
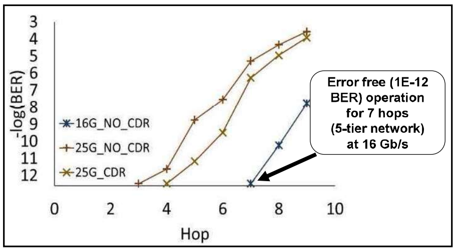
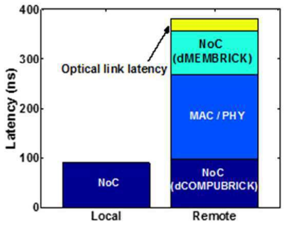






dReD Box
Disaggregated Recursive Datacenter-in-a-Box



A. Saljoghei et al., OFC 2018

Exascale HPC

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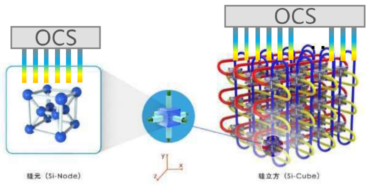
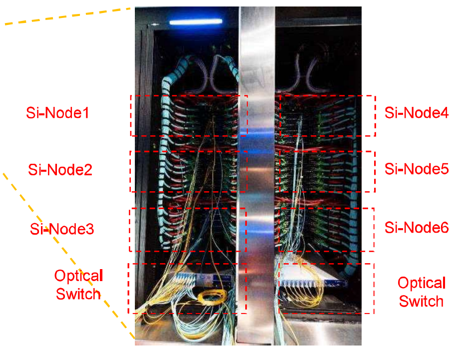
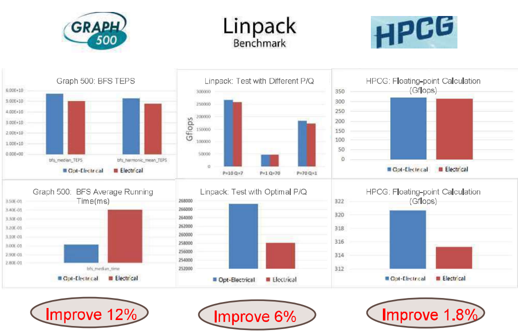




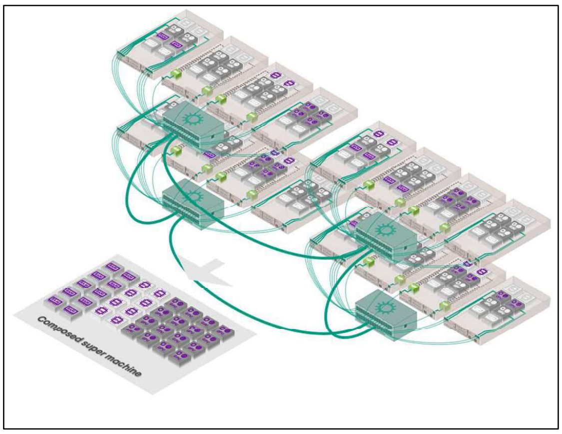


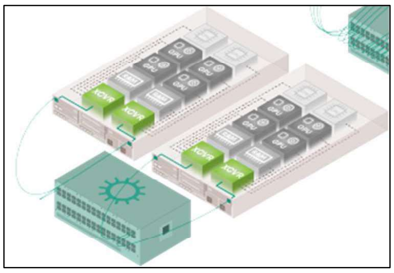
- Global competition to realize first exascale high-performance computing platform (>1 exaflop/s)
- Sugon/ICT (Beijing) lead one of 2 China national projects using highly interconnected 6D torus + fast optical links
- Polatis optical switches provides dynamic connectivity between HPC nodes where low latency (delay) is critical
- HPC OXC prototype shows promising improvement against performance benchmarks – every percentage point counts!

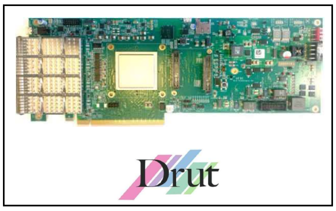
Institute of Computing Technology, CAS

Sugon 中科曙光

Commercial disaggregation



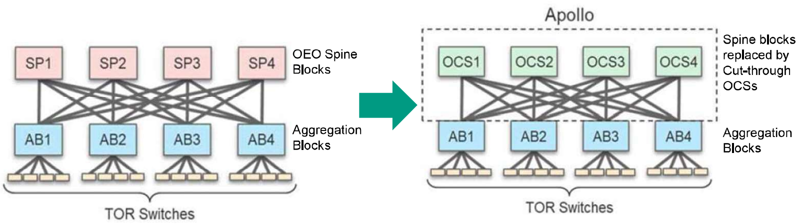


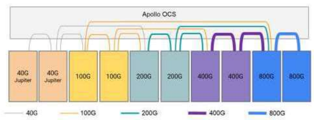


What's happened in the DC market?

OCS (Optical Circuit Switches) in next Generation Datacenter Networks (DCN)

- Google evolved its DCN architecture from a clos topology with OEO spline switches to a direct-connect topology that utilizes OCS'





- The re-architecture has scaled the Google DCN to deliver:
  - **30%** lower CapEx
  - **30%** higher throughput
  - **40%** lower power consumption
  - **50%** less downtime
  - **10%** faster flow completion time
  - **5x** reduction in network downtime
- Google have released technical papers and presented findings at OFC / Sigcomm in '22 and '23 – **this caused quite a stir in the DC market!**
- To date **Google is the only Hyperscaler to publicly use OCS'** in their DCN, others are investigating – Microsoft, Meta, Tesla, AWS etc.
- The control plane software to achieve the re-architecture is the barrier to entry.

References:
1. Singh et al., Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Googles Datacenter Network, ACM SIGCOMM, August 2015
2. Poutievski et al., Jupiter Evolving: Transforming Google's datacenter with OCSs and SDN, ACM SIGCOMM, Aug. 2022.
3. Urata, et al., (2022). Mission Apollo: Landing Optical Circuit Switching at Datacenter Scale, ArXiv

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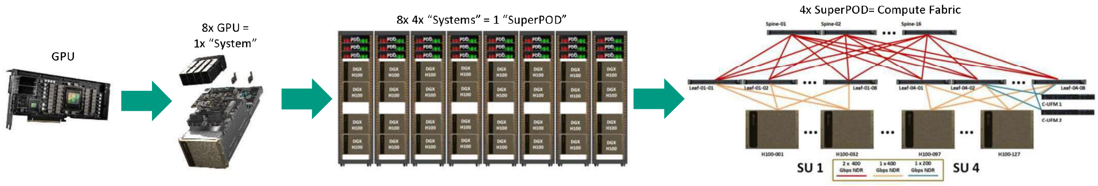
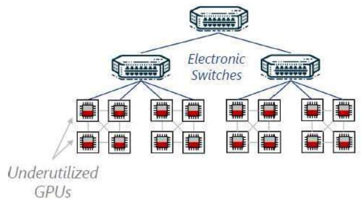
Artificial Intelligence (AI) / Machine Learning (ML)

- GPUs have become the foundation of artificial intelligence. NVIDIA is the No1 GPU manufacturer, NVIDIA GPU's power ChatGPT.
- Typically, today 'AI capability' is built out using clos / fat tree topology with spine / leaf or core / edge switches :



- Present AI Architecture issues are the same as for the DCN:
  - Network bottlenecks / stranded resources
  - High Capex Costs
  - High Opex Costs



Source: NVIDIA, & Lucidean

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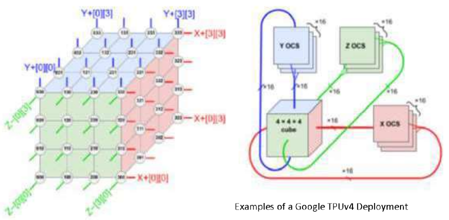
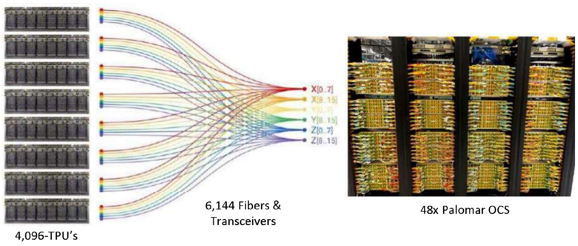
Aritificial Intelligence (AI) / Machine Learning (ML)

64 (4x4x4) TPU's* are electrically connected using Google's 6D inter-chip-interface



Examples of a Google TPUv4 Deployment

Google then uses OCS'es to connect together optically a 4,096-TPU* Superpod configured in a 3D torus cluster



*TPU = Tensor Processing Unit. is a specialized ASIC developed by Google for accelerating machine learning workloads.

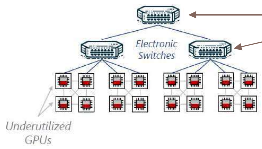
Source: Google & LightCounting

AI hardware scaling

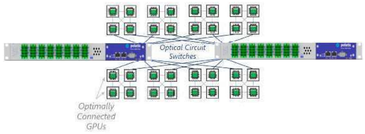
- AI now dominates DC deployments, Worldwide Spending on AI-Centric Systems Will Pass $300 Billion by 2026 and is likely to extend for the next 10years.

The Problem

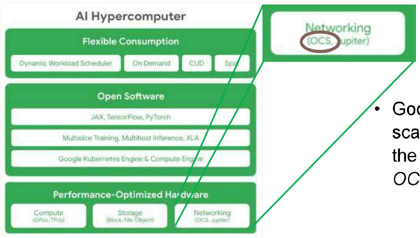
- High Capex & Opex
- Scalability
  - AI clusters reaching 100,000 GPU's
  - Network bottlenecks / stranded resources



- Current Core / Edge Node Switch
  - 64 Port 800G InfiniBand (OEO) Spine / Leaf Switch
  - 32x OSFP 800G SR8 PAM4 Transceivers
  - Approx **2,183W** each 'Node'
  - Equivalent to a 128x128 OCS @ **<100W**



- New 'disruptive' technologies and suppliers are looking at hardware and software solutions that create new scalable 'photonic fabrics' with Optical Circuit Switches at there core. Offering easy to scale, lower cost, future proof AI deployments.



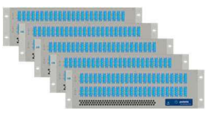
- Google are creating 'AI Hypercomputers' based on next generation more powerful and scalable TPU's (the v5p is up to 8960 per pod) using 3D and 6D torus networks (6D allows the network to detour faulty nodes / TPU's) utilizing higher port count OCS' - "*300×300 OCS with improved reliability and enhanced features for link-quality monitoring*." *

*Lightwave Fabrics: At-Scale Optical Circuit Switching for Datacenter and Machine Learning Systems. Google - SIGCOMM '23.

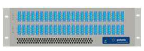
Source: Lucidean & Google

Evolution summary

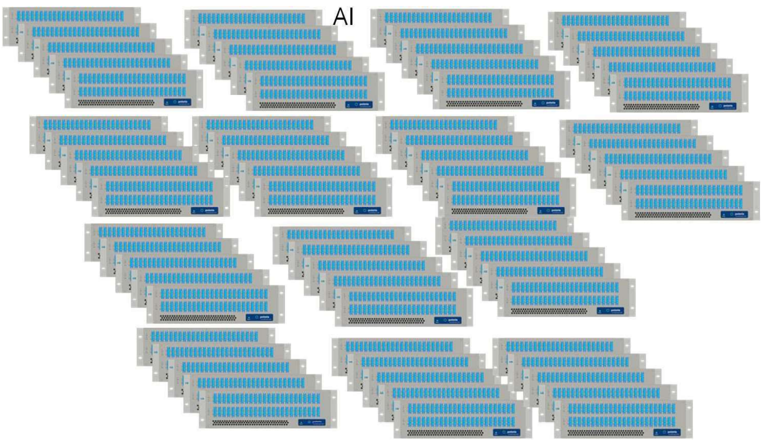
- Lab automation



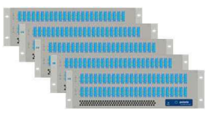
Quantum

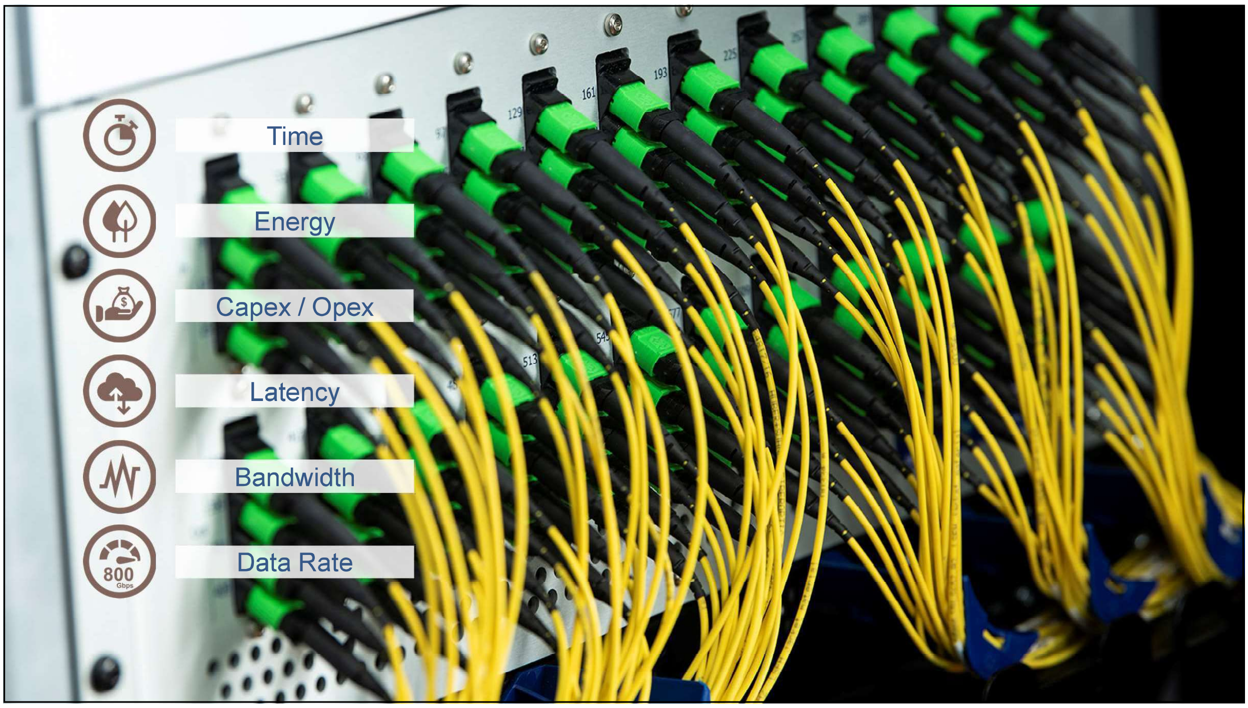


AI



- Cybersecurity




Time
Energy
Capex / Opex
Latency
Bandwidth
Data Rate
800
Gbps


Connecting – today and beyond

Disclaimer

HUBER+SUHNER

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Kvantno varna omrežja
Quantum-Safe Networks

Marta Buffa

NOKIA

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Povzetek

S svojim hitrim napredkom kvantno računalništvo obljublja eksponentno hitrejše izvajanje nalog kot najmočnejši običajni superračunalniki. Čeprav to obljublja pomemben napredek za številne industrije, predstavlja tudi resne grožnje celovitosti, zaupnosti in pristnosti podatkov. Da bi obravnavali te grožnje in uspevali v kvantnem gospodarstvu, moramo sprejeti proaktivne, v prihodnost usmerjene ukrepe za razvoj in implementacijo kvantno varnih varnostnih rešitev. Nokiina kvantno varna omrežja (QSN) temeljijo na dokazanem pristopu poglobljene obrambe, ki ustvarja agilno in odporno kvantno varno povezovalno infrastrukturo. Pristop Nokie zagotavlja orodja, potrebna za zaščito podatkov pred kvantnimi grožnjami danes in je zmožna stalne evolucije, da je vedno korak pred prihodnjimi grožnjami.

Abstract

With its rapid advancements, quantum computing holds the promise of performing tasks exponentially quicker than the strongest conventional supercomputers. While this promises significant advancements for many industries, it also poses substantial threats to data integrity, confidentiality and authenticity. To address these threats and thrive in a quantum economy, we must take proactive, forward-looking measures to develop and implement quantum-safe security solutions. Nokia's Quantum-Safe Networks (QSN) are based on a proven defense-in-depth approach, creating an agile and resilient quantum-safe connectivity infrastructure. Nokia's approach provides the tools needed to secure data against quantum threats today, capable of continuous evolution to stay ahead of future threats.

Biografija avtorja

Marta Buffa trenutno zaseda položaj vodje poslovnega razvoja v skupini za strateško rast v Nokijinem oddelku za optiko. Specializirana je za kvantno varne komunikacijske tehnologije in izkorišča svoje tehnično strokovno znanje na področju načrtovanja optičnih omrežij in sistemskega inženiringa za prepoznavanje novih poslovnih priložnosti v različnih industrijskih sektorjih. Da bi to dosegla, tesno sodeluje s strankami in medfunkcionalnimi ekipami za premostitev vrzeli med najsodobnejšo tehnologijo in povpraševanjem na trgu z inovacijami, optimizacijo in razširitvijo poslovnih strategij.

Author's biography

Marta Buffa currently holds the position of Business Development Manager in the Strategic Growth Team within Nokia's optics division. Specializing in quantum-safe communication technologies, she leverages her technical expertise in optical network design and systems engineering to identify and unlock new business opportunities across various industry sectors. To

achieve this, she collaborates closely with customers and cross-functional teams, bridging the gap between cutting-edge technology and market demand to innovate, optimize, and expand business strategies.

Kvantne komunikacije in informacije: od dokaza koncepta do praktične izvedbe

Quantum Communication and Information: from proof of principle to practical implementation

Faezeh Mousavi

University of Trieste

sayedehfaezeh.mousavi@units.it

Povzetek

Ta prispevek naslavlja temeljno skrb glede varnosti v klasičnih kriptosistemih. Kvantne komunikacije (QC) ponujajo obetavno rešitev za vzpostavitev varnih omrežij, ki temeljijo na načelih kvantne mehanike. Quantum Key Distribution (QKD) in Quantum Secure Direct Communication (QSDC) sta dva vodilna pristopa v QC. Medtem ko se prvi osredotoča na pogajanja o ključih, drugi omogoča neposreden prenos skrivnih sporočil brez potrebe po nastavitvi zasebnega ključa. Naše delo obsega celoten razvojni spekter QC, od začetnih laboratorijskih demonstracij dokazovanja koncepta do praktičnih implementacij na terenu. Predstavili smo nov protokol kvantno varne direktne komunikacije QSDC s stalno spremenljivko, ki izrablja koherentna in stisnjena stanja v optičnih vlaknih in izboljšujemo protokole QKD z diskretnimi spremenljivkami. Uporabnost vidimo v varni brezžični pomorski komunikaciji med obalo in ladjami ter v komunikaciji po optičnih vlaknih regionalnih kvantnih mrež. Ta predstavitev se posveča posebnostim teh projektov, osvetljuje našo pot od teoretičnih izvajanj do praktičnih aplikacij in razpravljala o drugih povezanih prizadevanjih pri izvajanju kvantnih omrežij.

Abstract

Addressing the fundamental concern of security in classical cryptosystems, quantum communication (QC) offers a promising solution for establishing secure networks grounded in the principles of quantum mechanics. Quantum Key Distribution (QKD) and Quantum Secure Direct Communication (QSDC), are two forefront approaches in QC, while the former focuses on key negotiation, and the latter enables the direct transmission of secret messages without the need for a private key setup. Our work spans the entire development spectrum of QC, from initial proof-of-principle lab demonstrations to in-field practical implementations. We have demonstrated the novel continuous variable-QSDC protocol using coherent and squeezed states over optical fibers, and are advancing discrete variable-QKD protocols across free-space channels, notably for secure marine communication between shore and ships, and across optical fiber for the establishment of regional quantum networks. This presentation will delve into the specifics of these projects, highlighting our journey from theoretical constructs to practical real-world applications, and discussing other related endeavors in the implementation of quantum networks.

Biografija avtorja

Faezeh Mousavi je leta 2018 doktorirala iz fizike na Inštitutu za napredne študije temeljnih znanosti v Iranu in se v sodelovanju z univerzo Padova v Italiji ukvarjala z integriranimi optičnimi napravami za strukturirano visokodimenzionalno kvantno porazdelitev ključev na osnovi fotonov. Nato je svoje raziskave nadaljevala kot podoktorska študentka na Teheranski politehniki in raziskovala uporabo strukturirane svetlobe v komunikacijskih sistemih. Leta 2021 se je pridružila Univerzi v Trstu kot podoktorska sodelavka, kjer je delala v laboratoriju za kvantne komunikacije in informacije (National Institute of Optics, CNR-INO, Area Science Park, Basovizza). Trenutno je raziskovalna sodelavka oddelka za fiziko, kjer se ukvarja s kvantnimi komunikacijami (protokola QKD in QSDC), kvantnim računanjem (optimizacijski algoritmi), integrirano kvantno fotoniko, kvantnimi omrežji in strukturiranimi fotoni.

Author's biography

Faezeh Mousavi received her PhD in physics from the Institute for Advanced Studies in Basic Sciences, Iran, in 2018, working on integrated optical devices for structured photon-based high-dimensional quantum key distribution, in collaboration with Padova University in Italy. Then, she continued her research as a postdoc at Tehran Polytechnique, exploring the application of structured light in communication systems. In 2021, she joined the University of Trieste as a postdoctoral fellow, working at the Quantum Communication and Information lab (National Institute of Optics, CNR-INO, Area Science Park, Basovizza). She is currently a research associate of the Physics department pursuing her interests in quantum communications (QKD and QSDC protocols), quantum computation (optimization algorithms), integrated quantum photonics, quantum networks, and structured photons.

Quantum Communication and Information; from Proof of Principle to Practical Implementation

Faezeh Mousavi

Physics Department, University of Trieste, Italy
Quantum Communication and Information (QCI) lab, National Institute of Optics, CNR-INO, Trieste, Italy

February 6, 2025

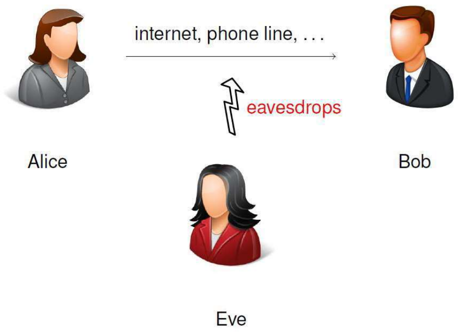
Outline

- Why Quantum Communication?
  - Standard today's classical cryptography
  - Realization of quantum approaches
- Proof-of-Principle Quantum Communication Schemes
  - Quantum Secure Direct Communication
  - Quantum Key Distribution
- In-Field Quantum Communication Schemes

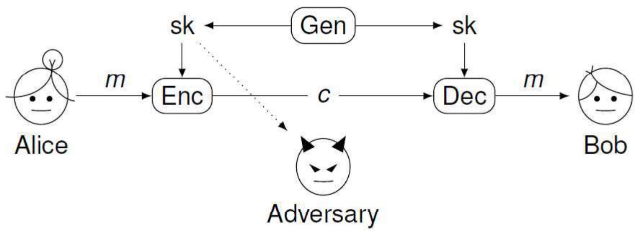
Why Quantum Communication?

- **Security; Basic Concern of Communication**
- **Secure communication → cryptography:** Science dedicated to **keeping secret the content of a message** from third parties (adversaries, spy, Eavesdropper)

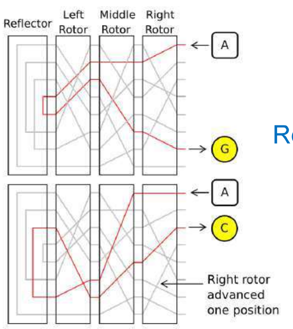
Information Security Objectives:
- **Confidentiality**
- **Integrity**
- **Authentication**



Cryptography in the Old time




Enigma machine



Enigma principle

Reputed **unbreakable**


Turing's computer


Alan Turing

Full cryptanalysis of Enigma

Standard today’s classical cryptography

1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)

Security → based on the complexity of **factorizing** large numbers in their prime numbers

Given two primes p and q.
easy to compute N = p × q
hard to get p and q from N (**factorization**)

Is RSA crackable?
Yes! With efficient factorization **algorithm** + **supercomputer**

- In 2010: 768-bit has been cracked
- In 2020: French Institute for Research in Computer Science (INRIA) recommended keys > 2048 bits

Standard today’s classical cryptography

1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)

Security → based on the complexity of **factorizing** large numbers in their prime numbers

Given two primes p and q.
easy to compute N = p × q
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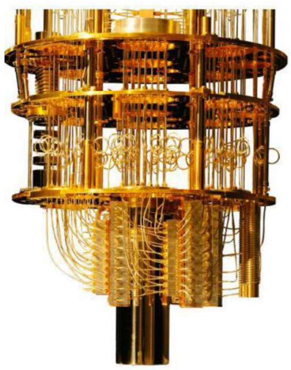
Is RSA crackable?
Yes! With efficient factorization algorithm + supercomputer

- Computers are always better and better
- What about a **Quantum Computer**?



Standard today's classical cryptography

1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)

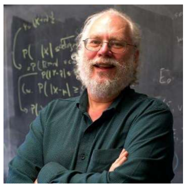
Security → based on the complexity of **factorizing** large numbers in their prime numbers

Jeopardize by Quantum: Shor's algorithm

Polynomial-time quantum algorithms for **RSA**

RSA1024 – classic ≈ 400 years

RSA1024 – quantum ≈ hours



Peter Shor

(**Large) Quantum computers** will be able to **break current public-key cryptography**

C. Gidney, "How to factor 2048 bit RSA integers in 8 hours using 20 million noisy qubits." *Quantum* 5 (2021): 433.

Standard today's classical cryptography

1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)

2- Symmetric (Private Key) → One-Time Pad (OTP), (Vernam, 1917)

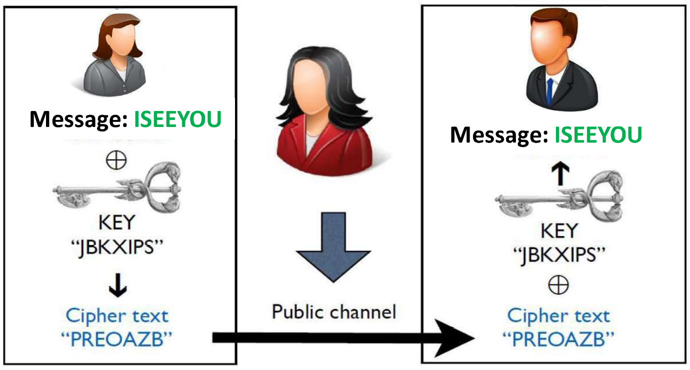
OTP Protocol:
- Alice and Bob share a **random** key [k]
- On her side, Alice computes : [m]⨁[k]=[c]
- Alice sends [c] to Bob
- On his side, Bob computes : [c]⨁[k]=[m]

Alice	[m]	0 1 1 0 0 1 1 0 0 0 1 0 1 1 0 0
Alice & Bob	[k]	1 0 0 1 1 0 0 1 1 0 1 0 1 0 0 1
Alice computes	[c]=[m]⊕[k]	1 1 1 1 1 1 1 1 1 0 0 0 0 1 0 1
Alice sends	[c]	
Bob computes	[c]⊕[k]	0 1 1 0 0 1 1 0 0 0 1 0 1 1 0 0

Standard today's classical cryptography

✗ **1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)**
2- Symmetric (Private Key) → One-Time Pad (OTP)

- ☛ OTP is perfectly secret (mathematically)
- ☛ Each key cannot be used more than once
- ☛ Key is as long as the message



Eve can extract no information as she doesn't know the key

Standard today's classical cryptography

✗ **1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)**
2- Symmetric (Private Key) → One-Time Pad (OTP)

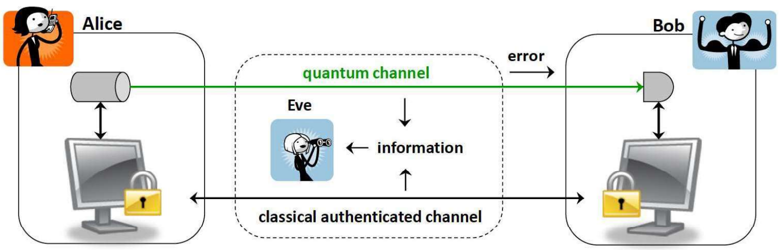
Limitations:
- ☛ Randomness of [k] !
- ☛ [k] has to be secret, only known by the two parties → A & B need to have an agreement before or to establish their [k]s at remote locations

Solutions :
- Alice (Trieste) & Bob (Ljubliana) meet every morning in Postojna to exchange wallets of secret keys!!!
- Alternative: Use of Quantum Mechanics via a quantum channel

Standard today's classical cryptography

✗ **1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)**

2- Symmetric (Private Key) → One-Time Pad (OTP)



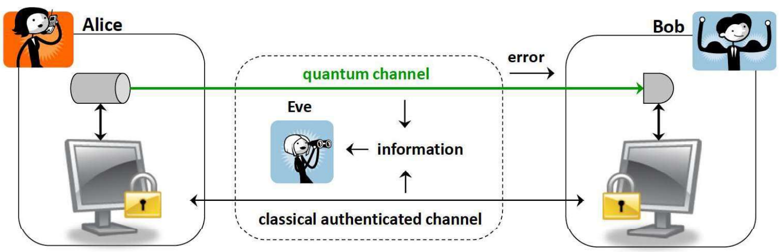
Quantum-Key Distribution (QKD) Scheme

Security based on **no-cloning** theorem, **uncertainty** principle, **Bell**'s theorem

Standard today's classical cryptography

✗ 1- Asymmetric (Public-key) → Rivest-Shamir-Adleman (RSA)

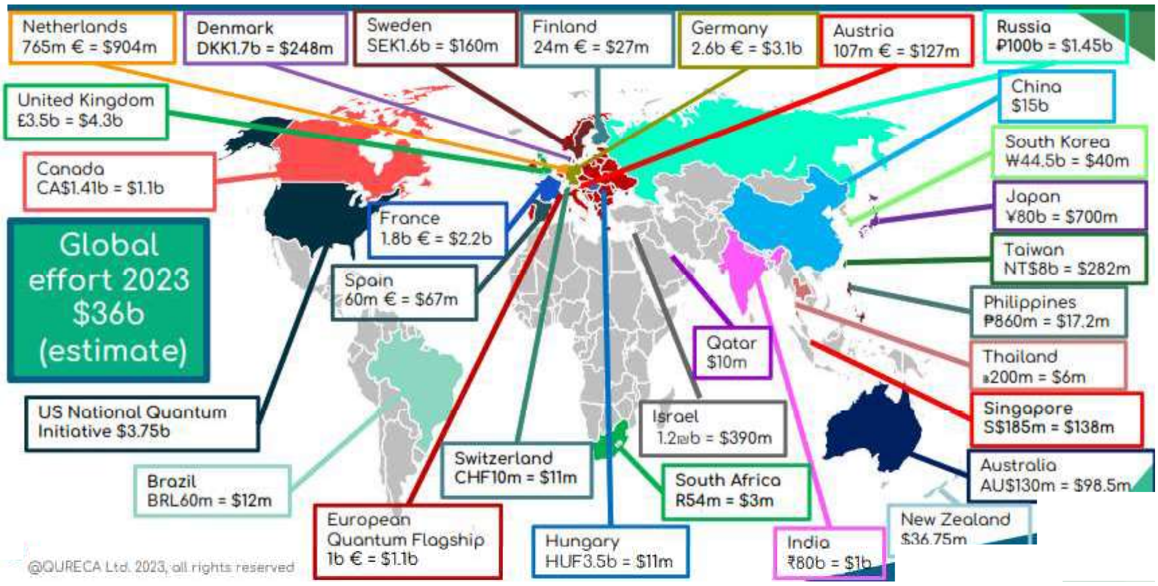
✓ **2- Symmetric (Private Key) → One-Time Pad (OTP)**



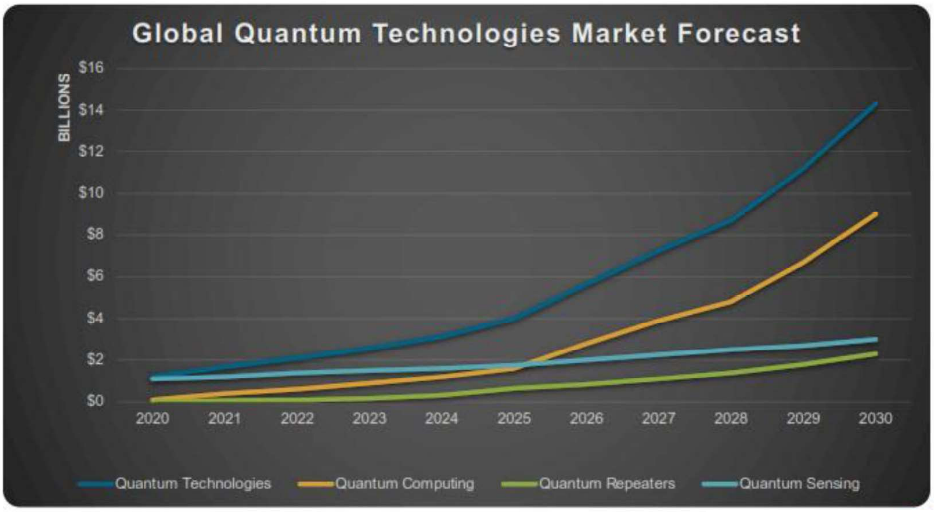
Quantum-Key Distribution (QKD) Scheme

Security based on **no-cloning** theorem, **uncertainty** principle, **Bell**'s theorem

Quantum Effort Worldwide (public funding)

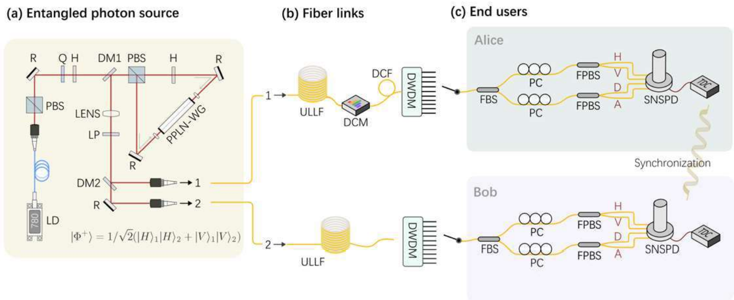


Quantum Market Size

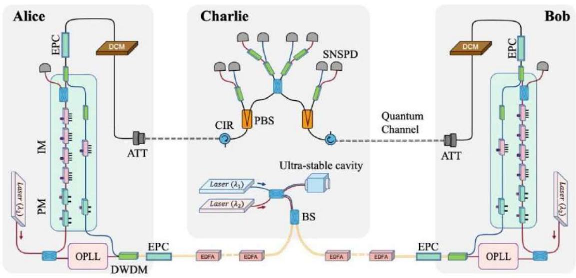


Quantum Communication Realization

- **Fiber-based QKD**
- Free-space QKD
- Space-QKD



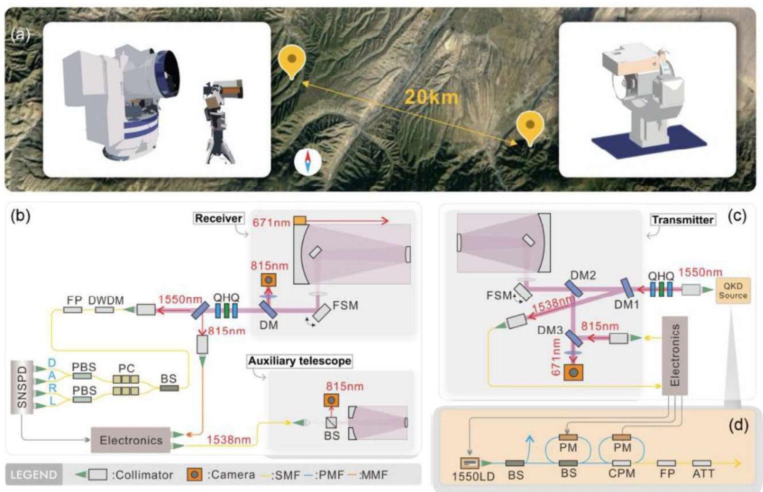
Zhuang, Shi-Chang, et al. "Ultrabright-entanglement-based quantum key distribution over a **404-km**-long optical fiber." *arXiv e-prints* (2024): arXiv-2408.



Liu, Yang, et al. "**1002 km** twin-field quantum key distribution with finite-key analysis." *Quantum Frontiers* 2.1 (2023): 16.

Quantum Communication Realization

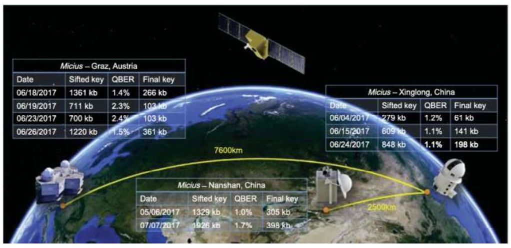
- Fiber-based QKD
- **Free-space QKD**
- Space-QKD



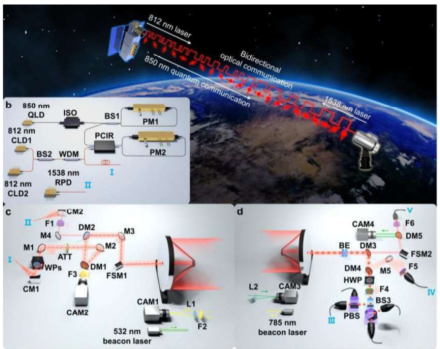
Cai, Wen-Qi, et al. "Free-space quantum key distribution during daylight and at night." *Optica* 11.5 (2024): 647-652.

Quantum Communication Realization

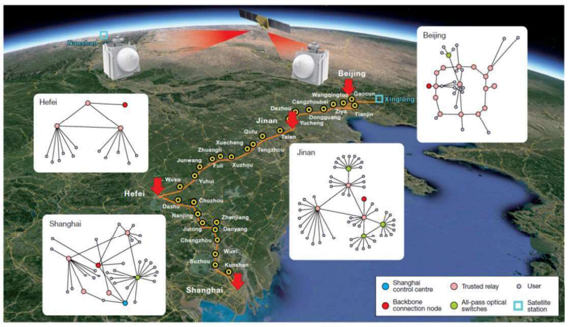
- Fiber-based QKD
- Free-space QKD
- **Space-QKD**



Liao, Sheng-Kai, et al. "Satellite-relayed intercontinental quantum network." *Physical review letters* 120.3 (2018): 030501.

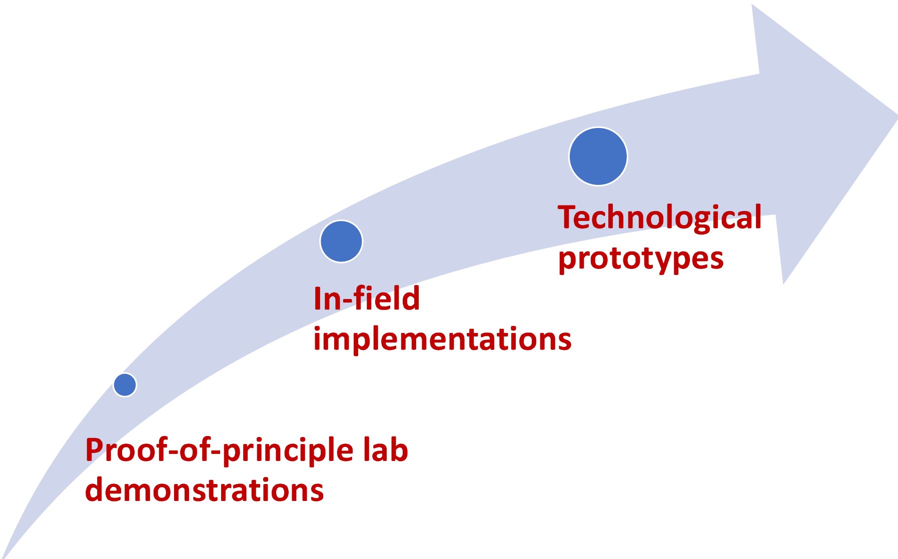


Li, Yang, et al. "Microsatellite-based real-time quantum key distribution." *arXiv preprint arXiv:2408.10994* (2024).

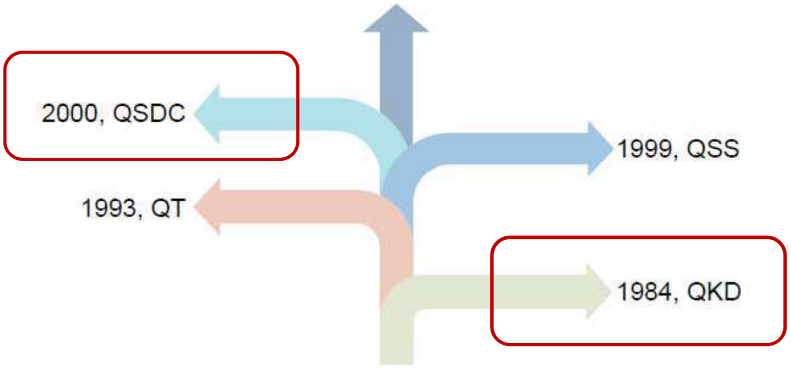


Chen, Yu-Ao, et al. "An integrated space-to-ground quantum communication network over **4,600 km**." *Nature* 589.7841 (2021): 214-219.

Quantum Communication Approach



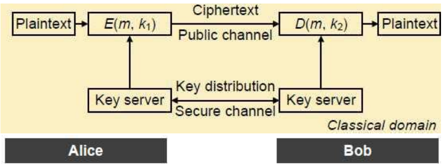
Proof-of-Principle Quantum Communication



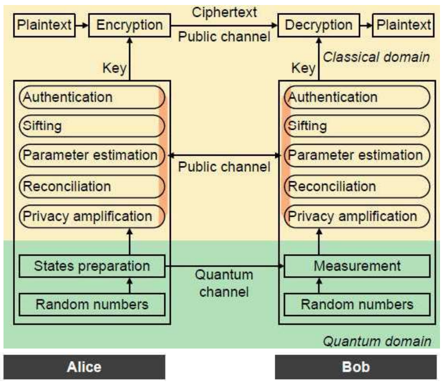
Main branches of **quantum communication. QKD**, quantum key distribution; **QT**, quantum teleportation; **QSS**, quantum secret sharing; **QSDC**, quantum secure direct communication.

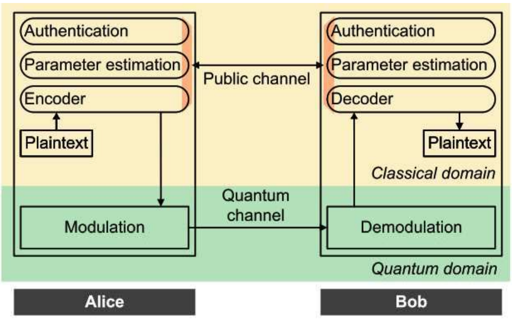
Dong Pan, The Evolution of Quantum Secure Direct Communication: On the Road to the Qinternet, arXiv:2311.13974v1

Different models of communication systems



Classical cryptosystem





QSDC system. No key distribution, no key management, and no ciphertext are required

QKD system: Key agreement by QKD, information transmission via classical communication

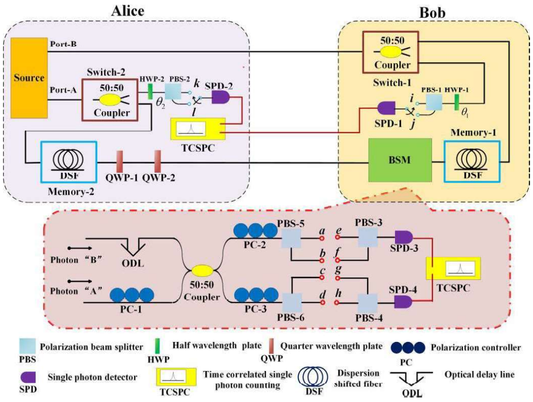
arXiv:2311.13974v1

Quantum Secure Direct Communication (QSDC)

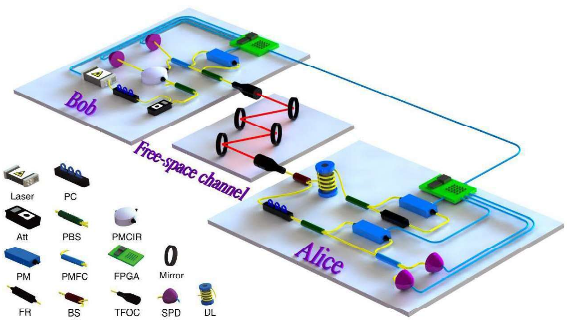
Directly transmission of secret information through quantum channel without a pre-distributed cryptographic key

Similar to **QKD**:

- Based on **entanglement** and **Prepare-and-Measurement**



Zhu, F., Science Bulletin, 62(22), 1519-1524 (2017)



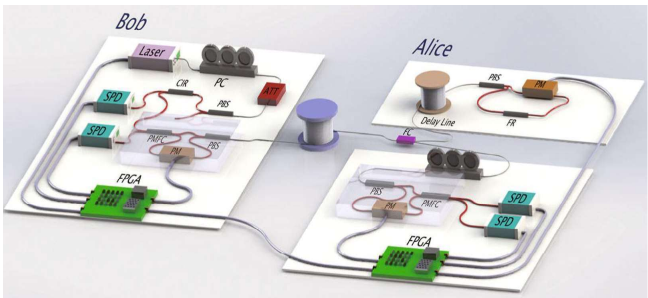
D. Pan, Photonics Res. 8,9 1522–1531 (2020)

Quantum Secure Direct Communication (QSDC)

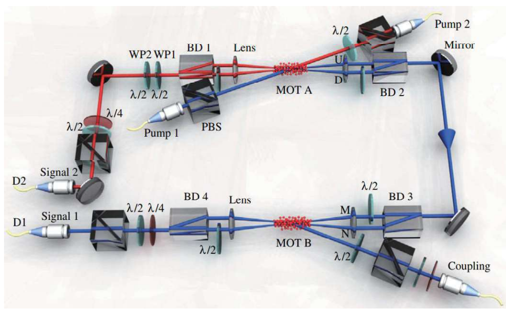
Directly transmission of secret information through quantum channel without a pre-distributed cryptographic key

Similar to **QKD**:

- Based on **entanglement** and **Prepare-and-Measurement**
- Development over **optical-fiber** and **free-space** channels



Qi, Ruoyang, et a *Light: Science & Applications* 8.1, 22 (2019)



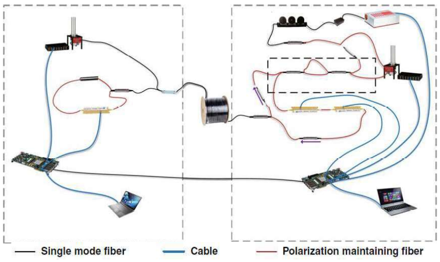
Zhang, W. *Physical review letters* 118.22, 220501 (2017)

Quantum Secure Direct Communication (QSDC)

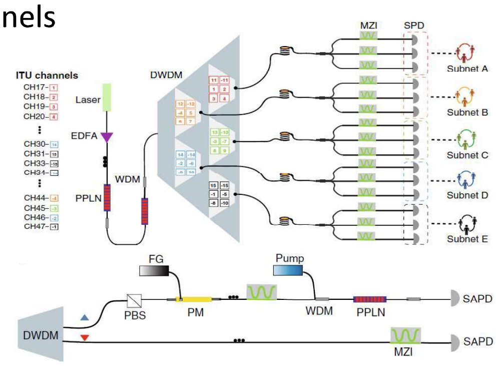
Directly transmission of secret information through quantum channel without a pre-distributed cryptographic key

Similar to **QKD**:

- Based on **entanglement** and **Prepare-and-Measurement**
- Development over **optical-fiber** and **free-space** channels
- **Long distance** and **Networking** via QSDC



H. Zhang, Realization of quantum secure direct communication over **100 km fiber** with time-bin and phase quantum states, Light-Sci. Appl. 11:83, (2022)



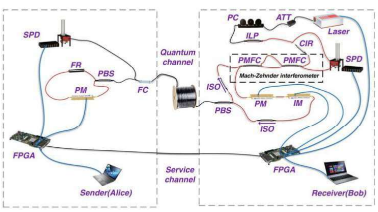
Z. Qi, A 15-user quantum secure direct communication Network, Light: Science & Applications 10:183 (2021)

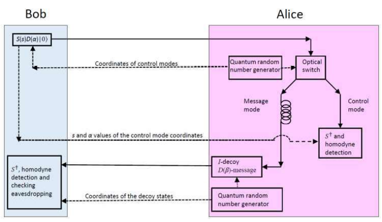
Quantum Secure Direct Communication (QSDC)

Directly transmission of secret information through quantum channel without a pre-distributed cryptographic key

Similar to **QKD**:

- Based on **entanglement** and **Prepare-and-Measurement**
- Development over **optical-fiber** and **free-space** channels
- **Long distance** and **Networking** via QSDC
- Encoding over **discrete-variables (DV)** (polarization, phase, time bin, …) & **continuous-variables (CV)** (quadratures of quantized field, $\Delta X_1 \Delta X_2 \geq 1/4$)





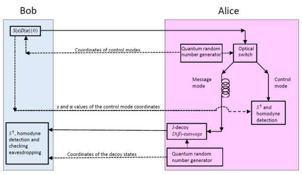
S. Srikara, Continuous variable direct secure quantum communication using Gaussian states." *Quantum Information Processing* 19:1-15 (2020)

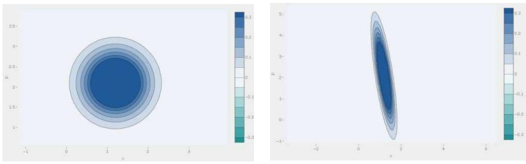
Quantum Secure Direct Communication (QSDC)

Directly transmission of secret information through quantum channel without a pre-distributed cryptographic key

Similar to **QKD**:

- Based on **entanglement** and **Prepare-and-Measurement**
- Development over **optical-fiber** and **free-space** channels
- **Long distance** and **Networking** via QSDC
- Encoding over **discrete-variables (DV)** (polarization, phase, time bin, …) & **continuous-variables (CV)** (quadratures of quantized field, $\Delta X_1 \Delta X_2 \geq 1/4$)
- CV encoding via **coherent** states and **squeezed** states

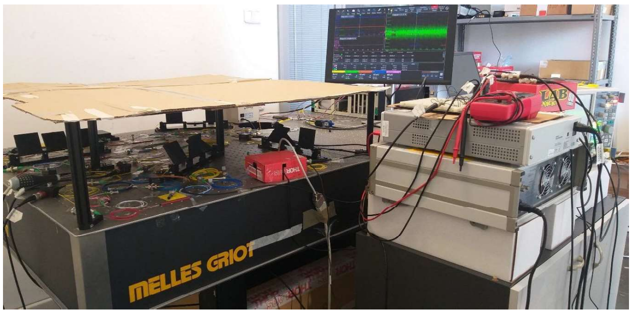




S. Srikara, Continuous variable direct secure quantum communication using Gaussian states." *Quantum Information Processing* 19:1-15 (2020)

CV-QSDC

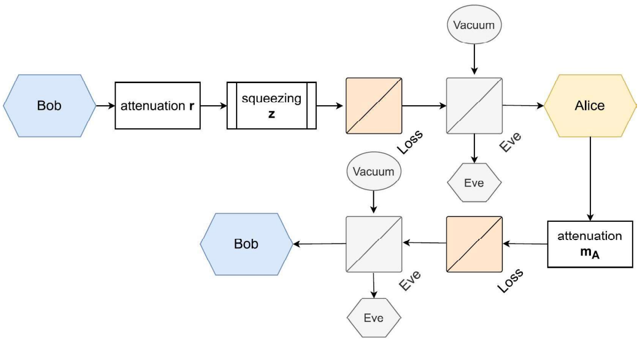
Implementation of continuous-variable quantum secure direct communication (QSDC) with squeezed states on optical fibers considering beam splitter attack

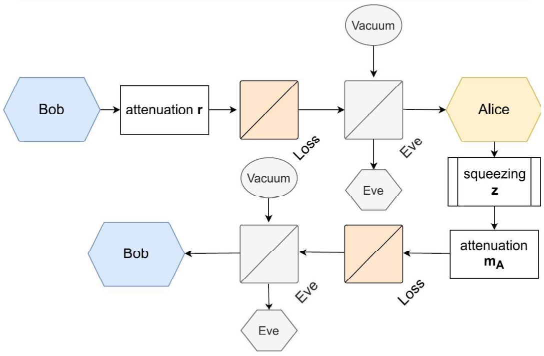


Practical quantum secure direct communication with squeezed states, ***arXiv preprint arXiv:2306.14322***

CV-QSDC Protocol

Symmetric Protocol: Bob initializes his quantum states by applying both attenuation and squeezing, then sends them to Alice via a quantum channel (subject to losses & BS-attack by Eve. Alice encodes her message via attenuation and uses the channel back to Bob (again subject to losses and eavesdropping)





Asymmetric Protocol: Bob only initializes the states via attenuation and Alice applies squeezing. The rest of the protocol is similar to the symmetric one.

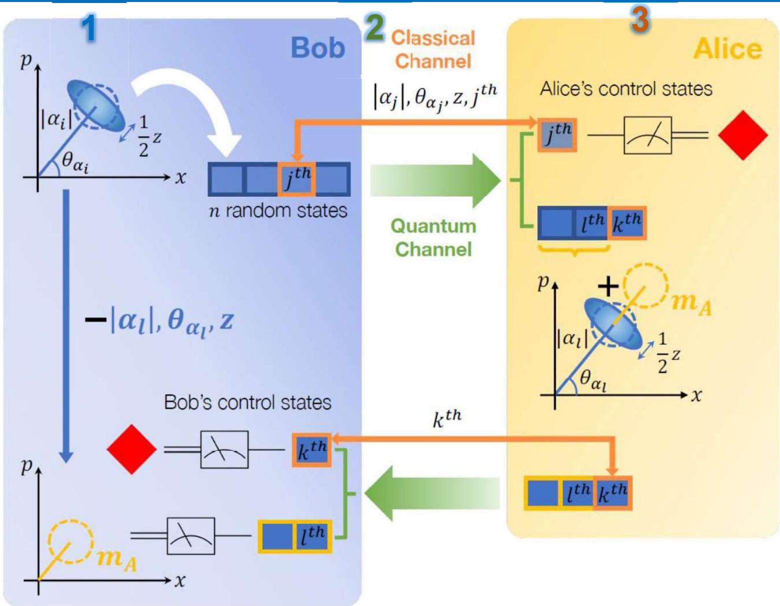
Symmetric Protocol

1- Bob, a legitimate information receiver, prepares a sequence of n **coherent** states $|\alpha_i\rangle$ with amplitude and phase $|\alpha_i|$ and θ_{α_i} ($i \in \{1, . . . , n\}$), both randomly.

He applies squeezing to those states so that the uncertainty of the **squeezed** state $S(z)\,|\,\alpha_i\,\rangle$ is below the vacuum.

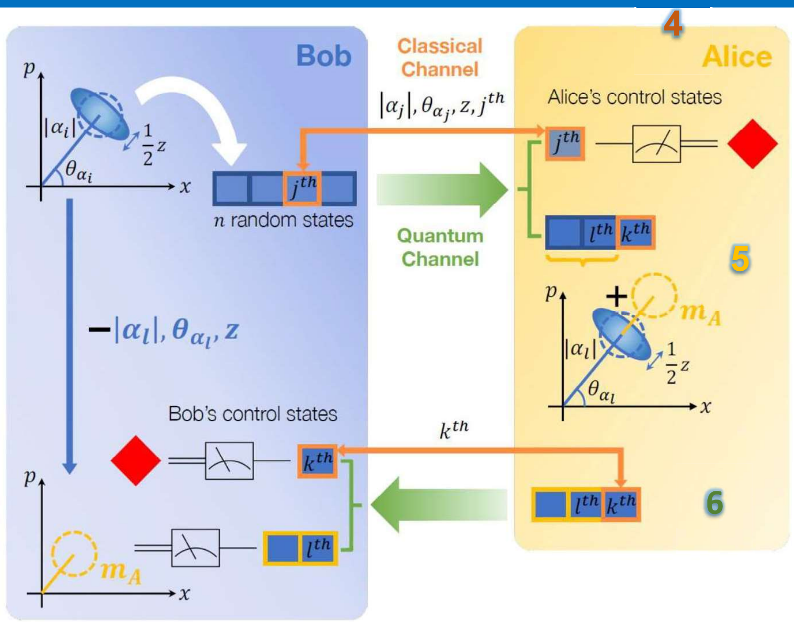
2- Bob sends the prepared n states $S(z)$ $|\alpha_i\,\rangle$ to Alice via a **quantum channel**.

3- Alice uses an optical switch to randomly select a subset $J \subset I$ of the incoming states as **control** states and measures them via homodyne detection. She sends the indexes $\{\, j \in J\}$ to Bob via a **classical channel**, whereas she injects the message states into an optical delay.



Proposed symmetric protocol

Symmetric Protocol



Proposed symmetric protocol

4- Bob shares the information | α_j | and θ_{α_j} via the **classical** channel with Alice. If the measured values correspond to a tolerable limit, then they continue; otherwise, she discards the protocol, and they start again.

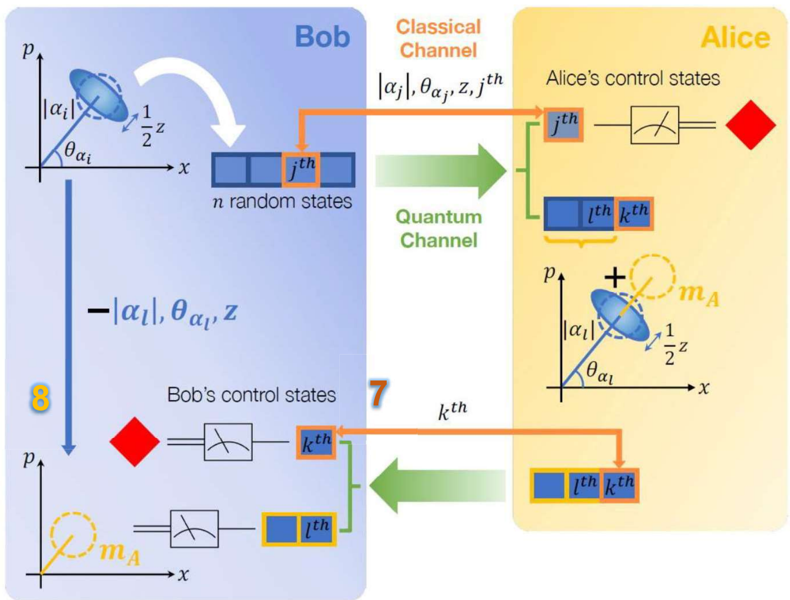
5- Alice chooses subset $L \subset I \setminus J$ of states from the remaining states and encodes her **message** $m_A \in$ R on them by applying an attenuation. The remaining states K = (($I \setminus J$) \ L) are as **decoys**.

6- Alice sends all the $I \setminus J$ states to Bob via the same **quantum channel**.

Symmetric Protocol

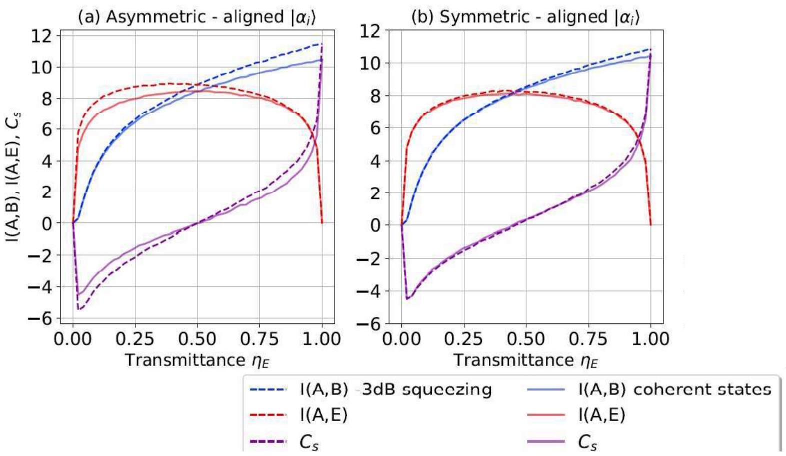
7-**Bob** performs homodyne measurement on the incoming states along the squeezed quadrature direction, and checks for eavesdropping by comparing to the corresponding $|\alpha_k|$ ($k \in K$) values for the **decoy** states.
For this, Alice communicates their indices via a **classical** communication channel. Bob also verifies that the uncertainty on measurements is compatible with the initially applied squeezing.

8- **Bob** retrieves the **message** in other states by subtracting the amplitude of the message states by the amplitude $|\alpha_i|$ of the initial states.



Proposed symmetric protocol

Symmetric vs Asymmetric Protocols



$$I_{\text{asym}}(A,B) = \log_2\left(\frac{0.01\eta_E^2\eta_L^2 \text{Var}(x\sqrt{m_A})}{\frac{1}{2}\left(1-0.99\eta_E\eta_L(1-z^2)\right)}\right)$$

$$I_{\text{asym}}(A,E) = \log_2\left(\frac{0.01\eta_E(1-\eta_E)\eta_L^2 \text{Var}(x\sqrt{m_A})}{\frac{1}{2}\left(1-0.99(1-\eta_E)\eta_L(1-z^2)\right)}\right)$$

$$I_{\text{sym}}(A,B) = \log_2\left(\frac{0.01\eta_E^2\eta_L^2 \text{Var}(x\sqrt{m_A})}{\frac{1}{2}\left(1-0.99\eta_E^2\eta_L^2 \text{Var}(m_A)(1-z^2)\right)}\right)$$

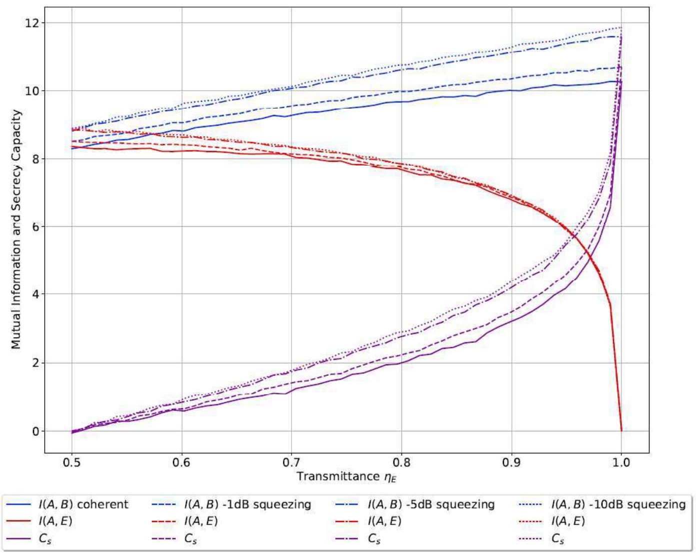
$$I_{\text{sym}}(A,E) = \log_2\left(\frac{0.01\eta_E^2\eta_L^2 \text{Var}(x\sqrt{m_A})}{\frac{1}{2}\left(1-0.99\eta_E(1-\eta_E)\eta_L^2 \text{Var}(m_A)(1-z^2)\right)}\right)$$

Secrecy Capacity $C_s = \max_{p_A}[I(A,B) - I(A,E)]$

$I\ (A,B)$: mutual information between Alice and Bob
$I\ (A,E)$: mutual information between Alice and Eve

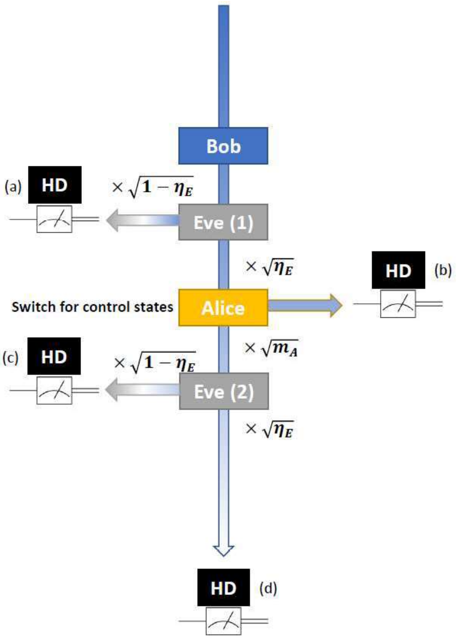
Asymmetric Protocol

Our squeezing level: -1 dB



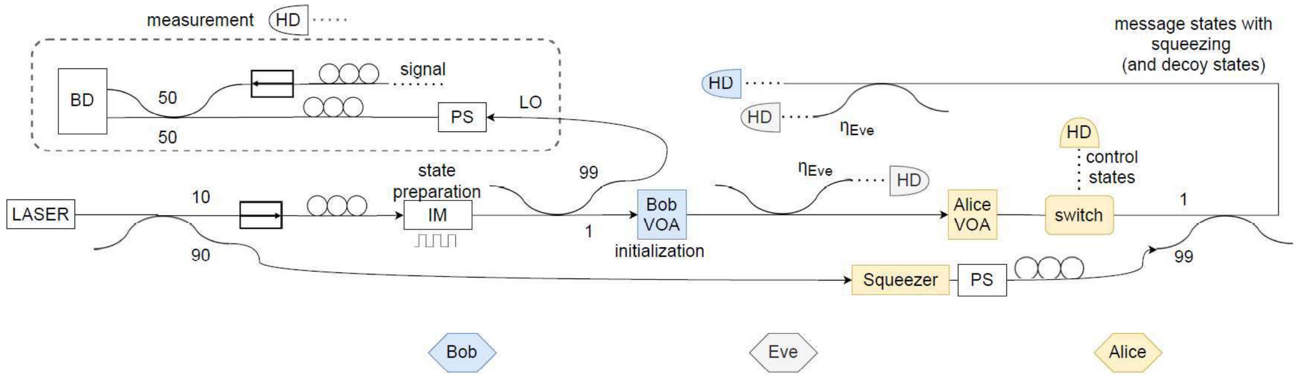
Numerical prediction of the effect of different squeezing levels in the asymmetric aligned coherent states

Experiment in case of BS attack



Measurements for a **beam splitter attack**:
(a) Eve uses a BS between Bob and Alice and measures,
(b) Alice measures the control states,
(c) Eve uses again a BS between Bob and Alice and measures,
(d) Bob measures the decoy and message states

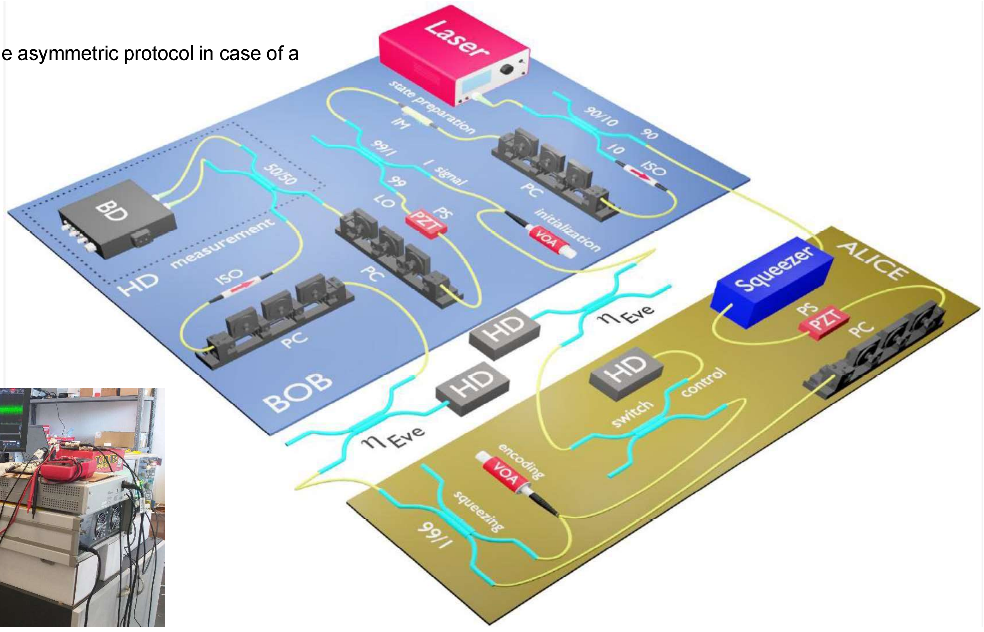
Experimental setup for BS attack

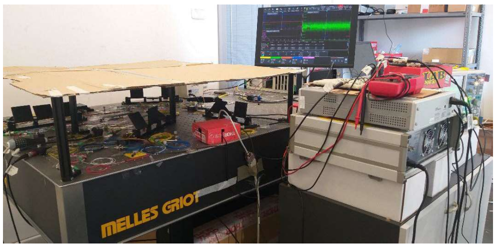


Experimental setup to implement the mentioned measurements by Eve, Alice, and Bob

Asymmetric Protocol

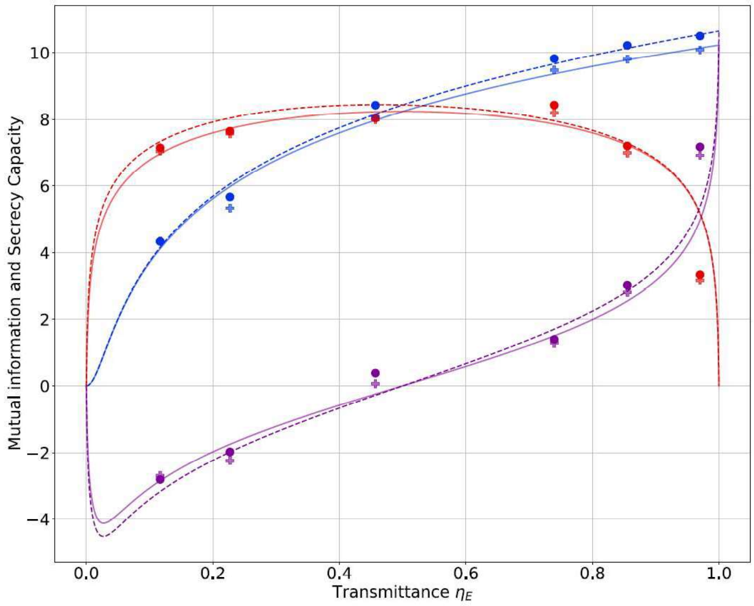
Experimental setup for implementing the asymmetric protocol in case of a beam splitter attack (measurement **d**).





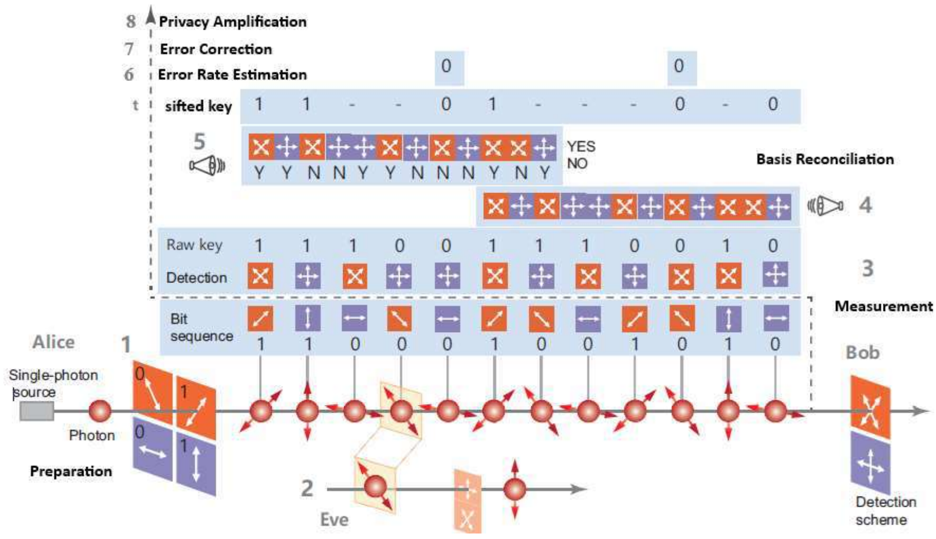
Experimental Results

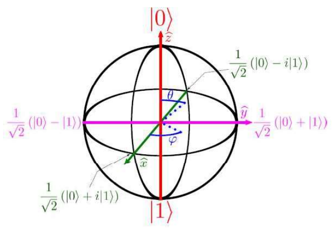
Experimental (circles/crosses) results and analytical calculations for a squeezing of -1dB (dash line) and coherent states (solid line).
Red: mutual information between Alice and Eve, Blue: mutual information between Alice and
Bob, Purple: secrecy capacity.



Practical quantum secure direct communication with squeezed states, *arXiv preprint arXiv:2306.14322, and Accepted in Optics Express*

Single-Photon QKD Protocols





General Scheme of a BB84 QKD Protocol

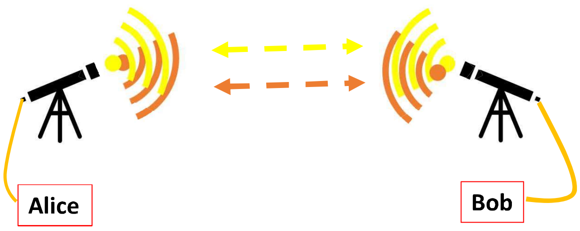
Proof-of-Principle QKD Protocols

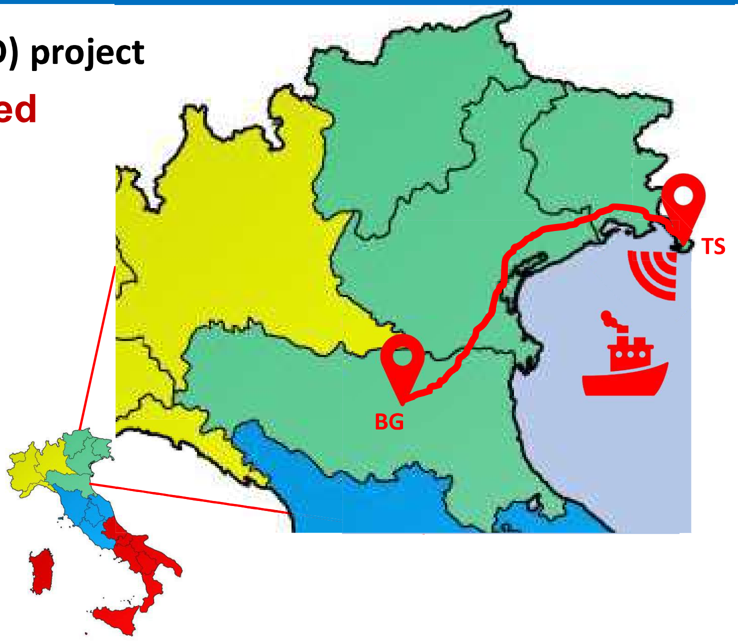
- **Phase noise effects in Time-bin QKD protocols**
- **Implementation of a two-way Gaussian-modulation CV-QKD** → Increased robustness to noise, higher security threshold, robust to loss
- **Implementation of a Twin-field QKD protocol → longer channels**
- **Establishment of a small QKD-based network in the lab- framework based on O-band in WDM system**

In-Field Projects

- Quantum Deployment Italy (QUID) project

Free-space QKD between a fixed station (shore) and a moving one (ship)



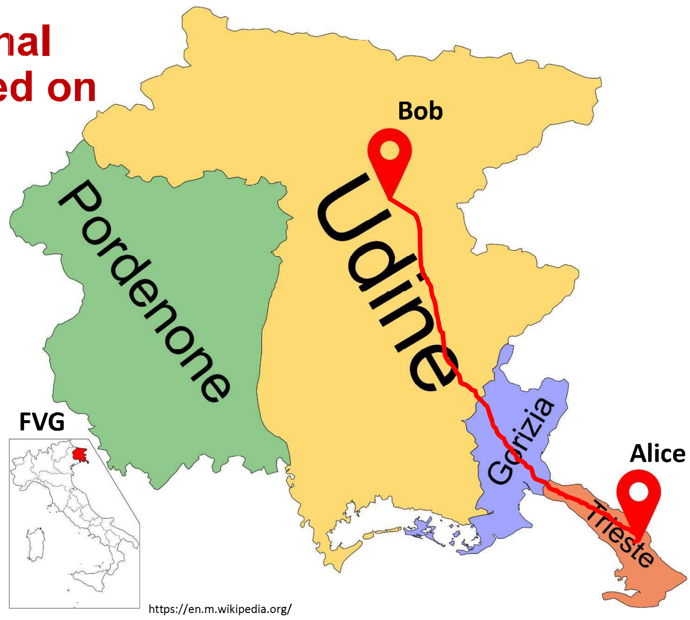


In-Field Projects

UNIVERSITÀ DEGLI STUDI DI UDINE

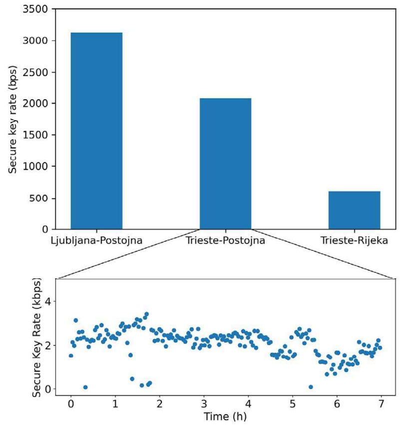
UNIVERSITÀ DEGLI STUDI DI TRIESTE

In-field QKD between educational institutes (UniTs & UniUd) based on dark fibers of the metropolitan network

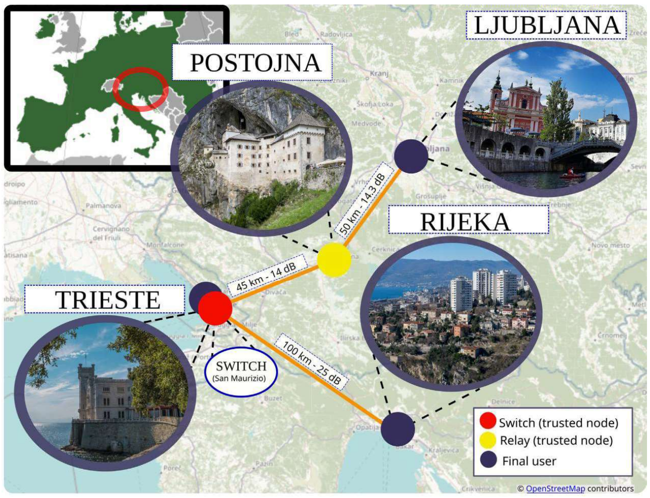


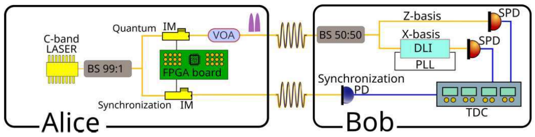
In-Field Projects

- **Deploying an Inter-European Quantum Network**



Adv. Quantum Technol. 2023, 6, 2200061





Our Colleagues

UNIVERSITÀ DEGLI STUDI DI TRIESTE

CNR-INO ISTITUTO NAZIONALE DI OTTICA CONSIGLIO NAZIONALE DELLE RICERCHE


Angelo Bassi (UniTS)


Alessandro Zavatta (CNR-INO)


Francesco Scazza (UniTS & CNR-INO)


Ahmad Kamkar (UniTS)


Giorgio Giorgetti (UniTS & LightNet)


Matteo Paris (UniMi)


Iris Paparelle (CollFr &CR-INO)


Michele Fontanini (UniTS & LightNet)


Marta Perosa (UniTs)


Fabrizio Barbuio (UniTS)


Carlo Tortora (UniTS)


Maša Kocijančič (UniTS)

Thank you for your attention!

Join us!

sayedehfaezeh.mousavi@units.it

SiQUID: Slovensko kvantno omrežje
SiQUID: Slovenian Quantum Network

Lara Ulčakar

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Povzetek

Kvantna komunikacija ponuja fundamentalno bolj varno izmenjavo informacij kot klasična komunikacija. Trenutna podatkovna varnost temelji na asimetričnih kriptografskih algoritmih, ki jih prihajajoči kvantni računalnik podre. Poleg tega se lahko trenutno zašifrirano komunikacijo shrani in se jo čez par let dekodira z zmogljivejšim klasičnim računalnikom. Kvantna izmenjava ključev (QKD) je protokol, pri katerem prejemnika prejmeta simetričen skrivni ključ. Protokol omogoča teoretično brezpogojno varnost, saj se zaradi zakonov kvantne mehanike kakršnokoli prisluškovanje lahko zazna. Projekt SiQUID bo vzpostavil državno in eksperimentalno omrežje za kvantno izmenjavo ključa. Omrežji bosta temeljili na najsodobnejšem protokolu porazdelitve prepletenosti BBM92. Skrivni ključ se ustvari, ko prejemnik pomeri prepleteni foton v naključno izbranih bazičnih polarizacijah. V prispevku je predstavljen protokol BBM92 in eksperimentalna izvedba izvora prepletenih fotonov in prejemniščih modulov. Na eksperimentalnem omrežju je testiran protokol zamenjave prepletenosti, ki je ključni korak k komunikaciji med zelo oddaljenimi uporabniki in prihodnjemu celovitemu kvantnemu omrežju.

Abstract

Quantum communication offers a fundamentally more secure exchange of information than classical communication. Current data security is based on asymmetric cryptographic algorithms, which are being undermined by the upcoming quantum computer. In addition, currently encrypted communication can be stored and decoded in a few years by a more powerful classical computer. Quantum key distribution (QKD) is a protocol in which the recipients receive a symmetric secret key. The protocol provides theoretically unconditional security, since any eavesdropping can be detected due to the laws of quantum mechanics. The SiQUID project will establish a national and experimental network for quantum key exchange. The networks will be based on the state-of-the-art BBM92 entanglement distribution protocol. The secret key is generated when the recipient measures an entangled photon in randomly selected basic polarizations. The article presents the BBM92 protocol and an experimental implementation of the entangled photon source and module receivers. The experimental network tests the entanglement exchange protocol, which is a key step towards communication between very distant users and a future comprehensive quantum network.

Biografija avtorja

Lara Ulčakar je doktorirala leta 2020 na Fakulteti za matematiko in fiziko v Ljubljani na področju teoretične fizike kondenzirane snovi. Na Inštitutu Jožefa Stefana je

bila zaposlena šest let in delala na temah spinskih kubitov in topoloških izolatorjev. Dve leti je delala kot podatkovna inženirka v svetovalnem podjetju BE-terna. Od leta 2023 je zaposlena na Fakulteti za matematiko in fiziko v Ljubljani v Laboratoriju za kvantno optiko in kvantne osnove. Tam je aktivni član projekta SiQUID in se ukvarja s kvantno komunikacijo, kvantnim spominom in kvantno optomehaniko. Na fakulteti predava Nanofiziko in Klasično mehaniko.

Author's biography

Lara Ulčakar received her PhD in 2020 from the Faculty of Mathematics and Physics in Ljubljana in the field of theoretical condensed matter physics. She was employed at the Jožef Stefan Institute for six years, working on the topics of spin qubits and topological insulators. She worked as a data engineer at the consulting company BE-terna for two years. Since 2023, she has been employed at the Faculty of Mathematics and Physics in Ljubljana in the Laboratory for Quantum Optics and Quantum Fundamentals. There, she is an active member of the SiQUID project and works on quantum communication, quantum memory and quantum optomechanics. She lectures on Nanophysics and Classical Mechanics at the faculty.

Funded by
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NOO | THE RECOVERY AND RESILIENCE PLAN

SiQUID

Slovenian Quantum Communication Infrastructure Demonstration

SiQUID: Slovensko kvantno omrežje

Lara Ulčakar
Ljubljana, 7 Februar 2025

PUBLIC INFORMATION

Osnutek

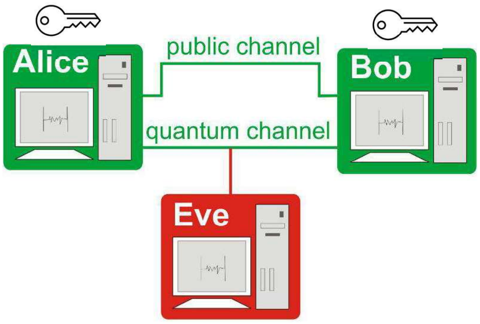
- Kaj je kvantna distribucija ključa (QKD)?
- Kako deluje QKD na osnovi prenosa prepletenosti?
- Varnost QKD
- QKD v Sloveniji: projekt SiQUID
- Integracija v EU mrežo

Kvantna izmenjava ključa (QKD)

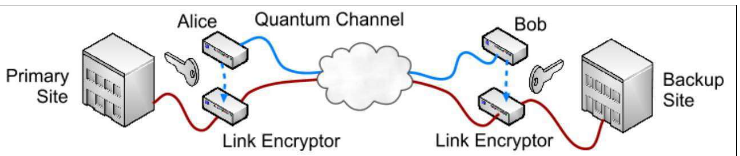
- Generacija simetričnega skrivnega ključa med dvema uporabnikoma. **Kvantno razširjeni enkriptor**.
- Fizična rešitev za **teoretično nezlomljivo** varno komunikacijo.
- Komunikacija na ravni **fotonov**.
- **Prisluškovanje je vedno možno detektirati** preko povišane kvantne napake **QBER**.

Koraki QKD:

1. Izmenjava in detekcija kvantnih stanj
2. Postprocesiranje ključa



Uporaba QKD



Varovanje kritične infrastrukture in tajnih podatkov

- Bančna industrija
- Data centri in oblačno računanje
- Vlada in obrambna industrija
- Varovanje občutljivih podatkov v odmaknjenih data centrih

QKD na osnovi prepletenosti se lahko v prihodnje razširi na kvantni internet

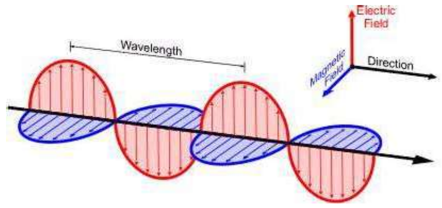
- Porazdeljeno kvantno računanje
- Mreža kvantnih senzorjev
- Sinhronizacija ur

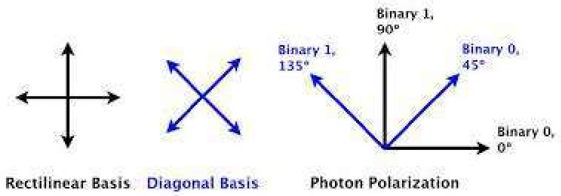
Kvantni opis svetlobe

- Maxwell 1861: elektromagnetno valovanje, ki se širi po prostoru s hitrostjo c.
- **Polarizacija**: smer električnega polja
- Einstein 1905: **fotoni** so neločljivi paketi energije svetlobe
- Ob **meritvi** foton **naključno** izbere polarizacijo.
- Kvantno stanje je **superpozicija** stanj meritve $|H\rangle$ in $|V\rangle$.

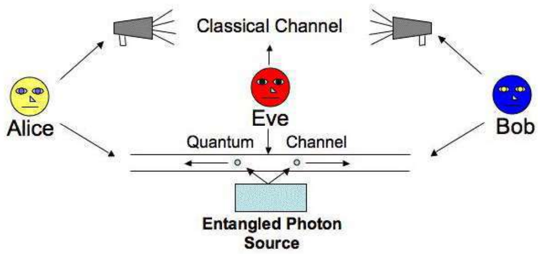
$|\Psi\rangle = (|H\rangle + |V\rangle)/\sqrt{2}$ diagonalna

- Merimo lahko v drugi bazi, recimo $|D\rangle$ in $|A\rangle$.
- $|\Psi\rangle = |D\rangle$





QKD na osnovi prepletenosti



- Prepleteno stanje

$\sqrt{2}|\psi\rangle = |HV\rangle + |VH\rangle = |DA\rangle + |AD\rangle$

- Naključno izbrani bazi H/V ali D/A.
- Prepis meritev v bite:
  - $|H\rangle \to 0$
  - $|V\rangle \to 1$
  - $|D\rangle \to 0$
  - $|A\rangle \to 1$
- **Sejanje:** Obdržita bite pomerjene v isti bazi. Surovi ključ.
- QBER $= N(ista\ polarizacija)/N$, če je previsoko, prisluškovanje, STOP
- **Odpravljanje napak**
- **Povišanje zasebnosti:** hash ključa

	Alic e	Bob	Alice	Bob	Alice	Bob	Alice	Bob
Baza	D/A	H/V	H/V	D/A	H/V	H/V	D/A	D/A
Rezutat	D	V	H	D	V	H	D	A
Bit	0	1	0	0	1	0	0	1
Sejanje	No	No	No	No	Yes	Yes	Yes	Yes

Varnost QKD

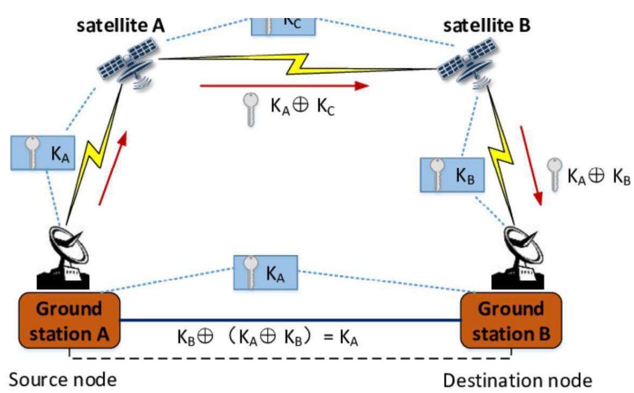
- Postprocesiranje vključuje izmenjavo informacij po **javnem kanalu**.
- Informacijski teoretični varnostni dokazi izpeljejo **varnosti parameter** ε. Ta predstavlja verjetnost razodetja ključa.
- Standard: **ε**=10^{-10} - ekvivalenten razodetju ključa v 30.000 letih
- Odvisen je od parametrov postprocesiranja, te se določi pred začetkom QKD: dolžina ključa, dovoljena QBER, izmenjana količina podatkov pri odpravi napak, dolžina hasha

$$\varepsilon = 2^{-\zeta} + \frac{1}{2}\sqrt{2^{-(\varpi-\theta)\left(\log\frac{1}{t}-\hbar\;(\delta+\nu)\right)+\lambda+\zeta+\phi}} + 2\omega^{-\frac{(\varpi-\theta)\breve{\alpha}^{2}\nu^{2}}{\varpi(\theta+1)}}$$

- Kvantni vdori (**quantum hacking**): fizični napadi na opremo izkoriščajo nepopolnosti

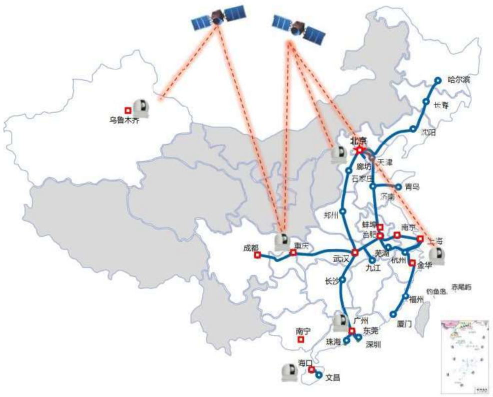
Arhitektura QKD omrežja

- Kvantna stanja se lahko pošilja preko **optičnih vlaken** ali po **prostem prostoru**.
- Optična vlakna: brez aktivnih elementov. Temna ali osvetljena vlakna (več šuma).
- Kvantni kanal mora biti **avtentificiran**.
- Doseg ~100km, eksponentno slabljenje v vlaknih
- Večje razdalje: prenosna vozlišča, povezave prek satelitov, kvantni repetitorji

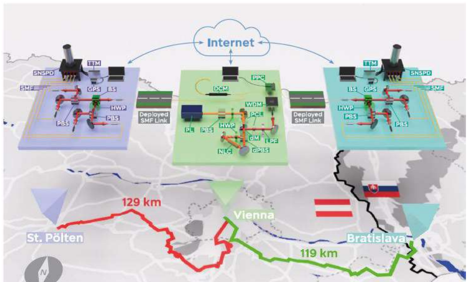


Rekodna QKD omrežja

- Kitajska uporablja **pripravi-in-pomeri QKD** za komercialne namene (bančništvo, telefonski klici). Preko 10000km dolžine. Jinan-1 satelit



- **Distribucija prepletenosti** preko satelita, več kot 1200km razdalje (Kitajska)
- Distribucija preko 400km optičnih vlaken (Kitajska 2024)
- Distribucija preko 200km optičnih vlaken (Avstrija 2022)



S. P. Neumann et al., Nature Comm. 13, 6134 (2022).

Komercialni produkti

Pripravi-in-pomeri QKD

Prenos ključa 300 kb/s pri 10 dB izgub, doseg po SM vlaknih 150km

Toshiba

Think quantum

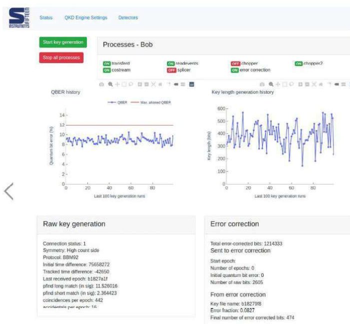
Id Quantique

QKD preko prepletenosti

SPEQTRAL

V prodaji od 2024! Prenos ključa 100MBit/s @ 10km (2dB slabljenje kanala). Ali 12 x 256bit AES ključa na uro@ 350km

Quantum industries



S-fifteen Instruments

SiQUID: Slovenian Quantum Communication Infrastructure Demonstration

Del Euro-QCI iniciative, slovenski nacionalni projekt

Začetek projekta: 1.1.2023

Konec projekta: 31.12.2025

Sredstva: EUR 4.48M

- EU: EUR 2.24M
- NOO: EUR 2M
- Beyond Semiconductor d.o.o.: EUR 0.24M

Ključni kontakti:

- Anton Ramšak (FMF), koordinator projekta
- Rainer Kaltenbaek (FMF), znanstveni in tehnični koordinator
- Barbara Dorić (FMF), projektni vodja

Spletna stran: http://siquid.fmf.uni-lj.si/

Konzorcij

- Koordinator: Fakulteta za matematiko in fiziko (Anton Ramšak)
- Inštitut Jožefa Stefana (Peter Jeglič)
- Beyond Semiconductor d.o.o. (Matjaž Breskvar)
- URSIV: urad vlade za informacijsko varnost (Marjan Kavčič)
- UVTP: urad vlade za varovanje tajnih podatkov (Mojca Mikac)

URSIV

Republika Slovenija UVTP Urad Vlade RS za varovanje tajnih podatkov

University of Ljubljana Faculty of Mathematics and Physics

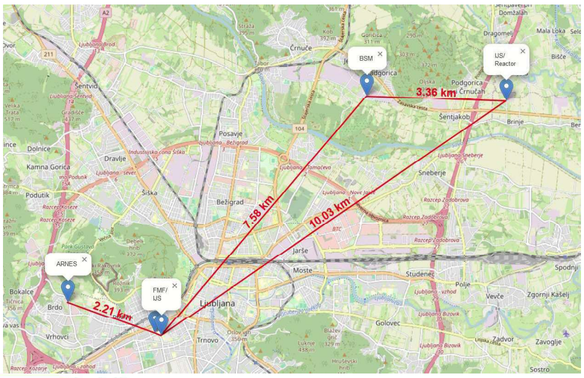
Institut "Jožef Stefan" Ljubljana, Slovenija

BEYOND SEMICONDUCTOR

Arhitektura omrežja

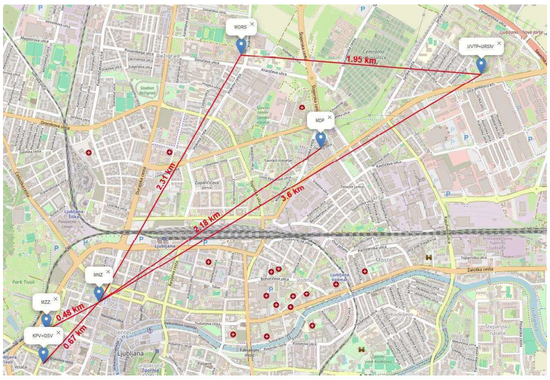
Eksperimentalno omrežje:

5 vozlišč na akademskih inštitucijah
Izvor zgrajen na FMF in IJS,
SNSPD od ID Quantique za detekcijo
Iskanje vlaken: ARNES and IJS



Državno omrežje:

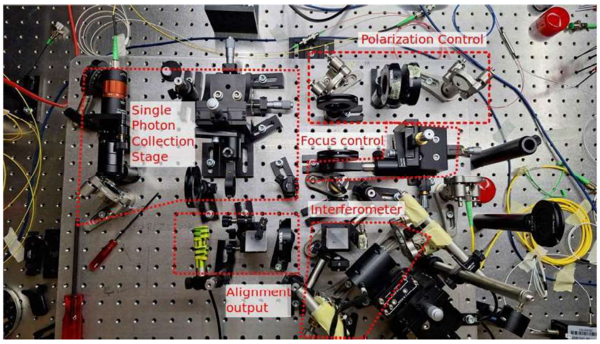
6 vozlišč na državnih ustanov
Izvor in detektorji proizvedeni pri Beyond
Kombinirani z XIPHRA klasičnimi enkriptorji
TEMPEST varovanje pred uhajanjem informacij
Iskanje vlaken: MDP



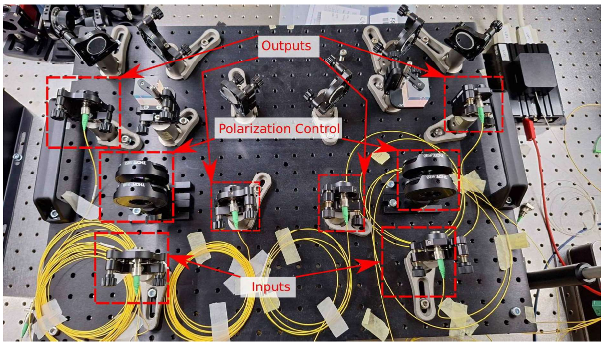
SiQUID QKD sistem

- Eksperimentalni sistem je zgrajen na prenosljivih optičnih nosilcih velikosti 40cm x 60cm.
- Beyond: industrijski, bolj robust sistem, ki paše v 1U rack

Izvor prepletenih fotonov



Sprejemnik

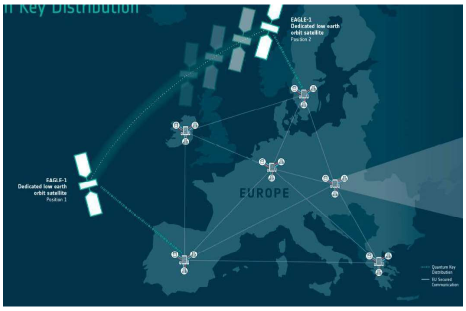


Razvoj v prihodnje

EuroQCI: konec 2025/26, nacionalni projekti

Connecting Europe Facility: 2025-

- Optične povezave med sosednjimi državami
- Postaja za povezavo s satelitom EAGLE-1
- Do 50% krije EU
- Prijava kot mednarodni konzorcij
- S strani NOO imamo zagotovljeno 1 mio, za izvedbo potrebnih 3mio strani države
- Nevarnost, da Slovenija izvisi iz EU omrežja
- Rok prijave: 13.2.2025

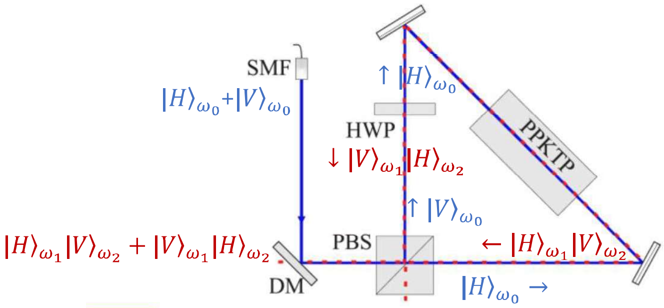


Vprašanja?

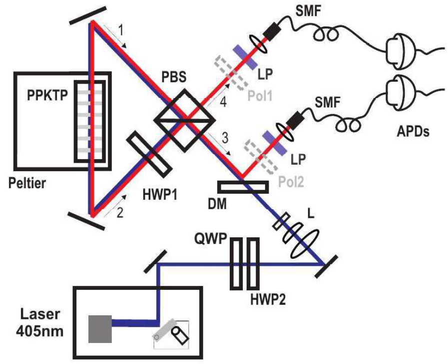
?

Izvor prepletenih fotonov

- **SPDC** proces v litijevem niobatu: pretvori laserske fotone v pare fotonov $|H\rangle_{\omega_0} \rightarrow |H\rangle_{\omega_1}|V\rangle_{\omega_2}$, tako da $\omega_0 = \omega_1 + \omega_2$.
- Kristal je vgrajen v **Sagnacov interferometer**, kar generira prepletenost.
- **Interferometer**: optična postavitev, ki razcepi svetlobo v dva dela, ki potujeta po različnih poteh. Točne meritve pozicije, hitrosti, rotacije.

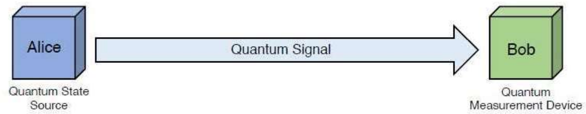


A. Fedrizzi et al. Opt. Exp. (2007)



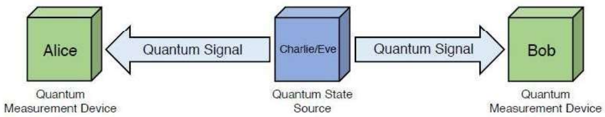
Tipi QKD in varnostne pomakljivosti

Prepare-&-Measure Scheme



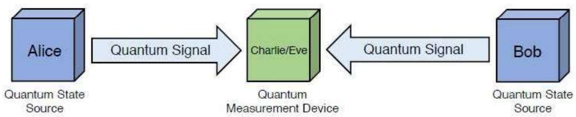
Kvantni napadi na oddajnik in sprejemnik

Entanglement-Based Scheme



Kvantni napadi na sprejemnik. Z naprednejšo opremo se lahko nadgradi v device-independent QKD. Lahko služi kot **ogrodje kvantnega interneta**.

Measurement-Device-Independent Scheme



Kvantni napadi na oddajnika.

Selected use cases and applications

Governmental QKD Network

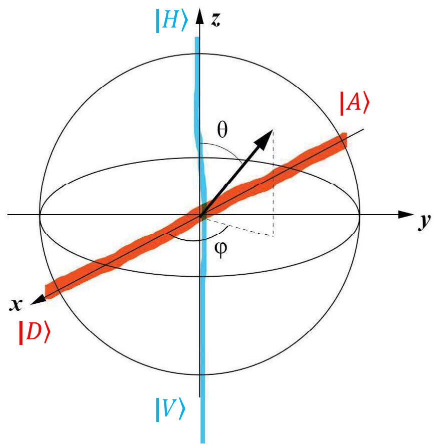
- Quantum-enhanced communication use cases
- Quantum-enhanced encryptor (QEE) application
  - Distribution of quantum key material

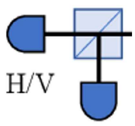
Experimental QKD Network

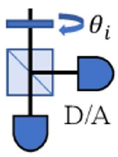
+ Research infrastructure
+ Advanced quantum communication and entanglement distribution use cases
  - ✓ Long distance QC
  - ✓ Entanglement swapping
  - ✓ Quantum teleportation
  - ✓ ...

Qubit - quantum bit

- **Bit**: 0 or 1, classical unit of information
- **Qubit**: quantum superposition of $|0\rangle$ and $|1\rangle$.
- $|\Psi\rangle = a|0\rangle + b|1\rangle$
- Any 2-level system: electron spin, or photon polarization
- H/V measurement basis, binary values:
  - Horizontal: $|H\rangle \to 0$
  - Vertical: $|V\rangle \to 1$
- D/A measurement basis, binary values
  - Diagonal: $|D\rangle = (|H\rangle + |V\rangle)/\sqrt{2} \to 0$
  - Antidiagonal: $|A\rangle = (|H\rangle - |V\rangle)/\sqrt{2} \to 1$







Relevant Security Standards

- **ETSI GS QKD 003 and 011** – component characterization
- **ETSI GS QKD 004** – application interface
- **ETSI GS QKD 005** – the baseline document for establishing security proofs for the implemented QKD key exchange mechanism;
- **ETSI GS QKD 008** – for the protection against physical attacks;
- **ETSI GS QKD 012 -** Device and Communication Channel Parameters for QKD Deployment
- **ETSI GS QKD 016** – Protection Profile for the security evaluation of QKD modules

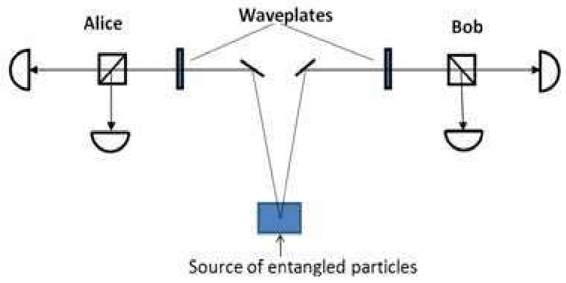
- **TEMPEST SDIP-27 Leve**l – for side-channel attacks;
- **ISO/IEC 23837** - Security requirements, test and evaluation methods for quantum key distribution
- **AES-256** and **SHA3-512** – for symmetric cryptographic primitives and hash functions.

$|H\rangle = (|D\rangle + |A\rangle)/\sqrt{2}$

$|V\rangle = (|D\rangle - |A\rangle)/\sqrt{2}$

Entanglement

- Quantum superpositions of multiparticle states. States of individual particles **cannot be separated**! $|\Psi\rangle \neq |\alpha\rangle_1|\beta\rangle_2$
- Example: $|\Psi\rangle = (|H\rangle_1|V\rangle_2 + |V\rangle_1|H\rangle_2)/\sqrt{2} = (|D\rangle_1|A\rangle_2 + |A\rangle_1|D\rangle_2)/\sqrt{2}$
- Polarization of singular photons is not defined!
- **Stronger correlations** than in classical physics.
- Measurements:
  - If Alice $|H\rangle_1$, Bob $|V\rangle_2$.
  - If Alice $|H\rangle_1$, $|V\rangle_2$, but if Bob in D/A basis, 50% for $|D\rangle_2$ and 50% for $|A\rangle_2$.
- Can be used for random key generation between two parties: QKD!



Objectives

1. Define **national quantum network architecture** and its **integration in EuroQCI**
2. Aim for **higher security** using quantum-enhanced encryptors (QEEs)
3. Develop experimental quantum systems and QEEs with attention to **industrialization**
4. Strengthen **European autonomy** in quantum and quantum-enabling technologies
5. Deploy first quantum systems and QEEs and **integrate** them with existing networks
6. Gather data on performance, reliability and **lessons learned**
7. Grow **national expertise**

Kvantni opis svetlobe

- Einstein 1905: elektromagnetno polje sestoji iz paketov energije $h\nu$: **photon**
- Fotoni se lahko obnašajo kot **neločljivi delci**!
- Ob **meritvi** foton **naključno** izbere polarizacijo.
- **Statistika** mnogih meritev da informacijo o stanju
- Kvantno stanje je **superpozicija** stanj meritve $|H\rangle$ in $|V\rangle$.

$|\Psi\rangle = (|H\rangle + |V\rangle)/\sqrt{2}$

- Merimo lahko v drugi bazi, recimo $|D\rangle$ in $|A\rangle$.
- $|\Psi\rangle = |D\rangle$

- Einstein 1905: elektromagnetno polje sestoji iz paketov energije $h\nu$: **photon**
- Fotoni se lahko obnašajo kot **neločljivi delci**!
- Ob **meritvi** foton **naključno** izbere polarizacijo.
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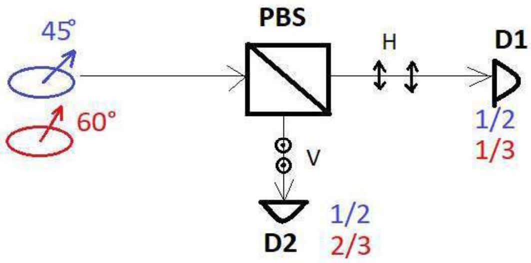
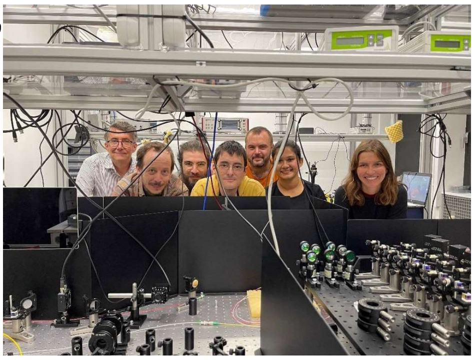


Building quantum expertise

Young researchers being trained

4 postdoctoral researchers (FMF & IJS)
6 PhD students (FMF & IJS)
6 undergraduate students (FMF & IJS)

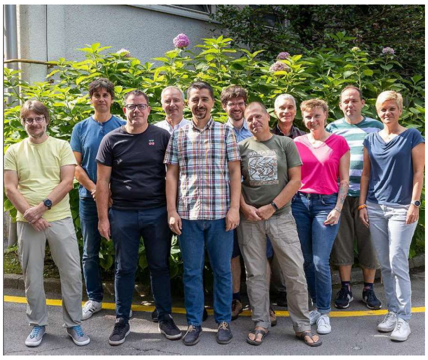
FMF lab



Engineers being supported

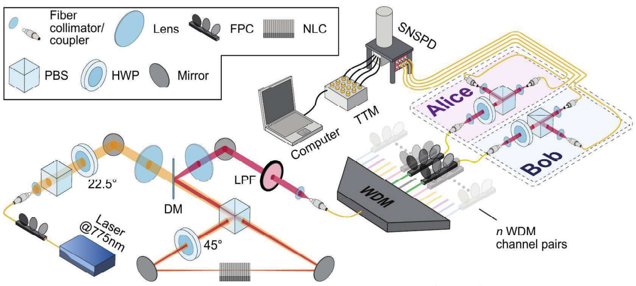
6 Engineers from BSC being made familiar with techniques in quantum optics and have been involved in SiQUID

IJS

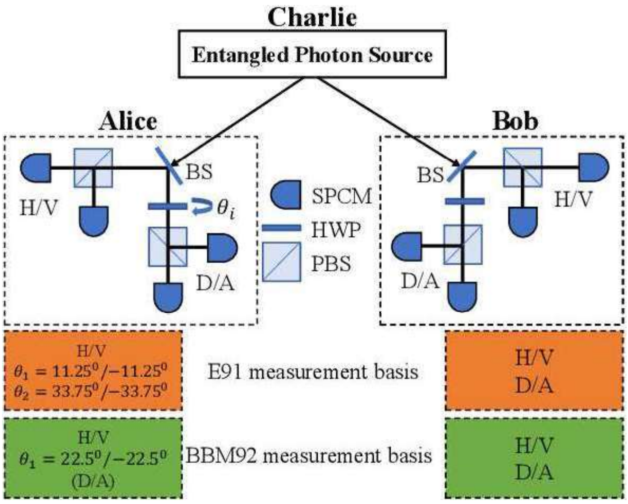


Receiver module

- BBM92 protocol: each receiver has 4 detectors. A pair measures in H/V basis, another pair in D/A basis.
- The basis choice is made randomly by a beam-splitter (BS).



S. Neumann et al. Quantum (2022)



Biswas, A. et. al, arXiv:2307.02149 (2023)

Security of QKD – quantum channel

Imperfect physical implementation enables **quantum hacking**, which tries to obtain information related to the key. Hacking targets sender or receiver modules. Most of hacking can be evaded suitable countermeasures.

1. **Side-channels:** imperfections in implementation leaking information related to key

Optical path difference	Receiver module	Change detector roles, equalize optical paths
Detector backflash	Receiver module	EM filter at receiver, change roles of detectors
Laser encoding flash	Sender module	EM shield around sender module

2. **Quantum attacks** directly target equipment and manipulate it

Intercept-and-resend	Receiver module	Eavesdropper detected in increased QBER
Photon number splitting	Sender module	Attenuation of signals at sender
Blinding attack	Receiver module	Add attenuator in front detector, dark fibres
Trojan horse attack	Receiver module	Add attenuator in front detector, dark fibres

Optični adiabatni sklopniki za integracijo kvantnih enofotonskih virov na SiN integrirana fotonska vezja

Optical adiabatic couplers for integrating quantum single-photon sources onto SiN integrated photonic

Miloš Ljubotina, Andraž Debevc, Marko Topič and Janez Krč

Univerza v Ljubljani, Fakulteta za elektrotehniko

milos.ljubotina@fe.uni-lj.si

Povzetek

Fotonska integrirana vezja (angl. PIC) zajemajo tehnologije, ki predstavljajo spodbudno osnovo za razvoj kvantnih tehnologij. Pri tem je ključnega pomena učinkovitost posameznih integriranih gradnikov kvantne fotonike, zaradi česar je potrebno izkoristiti različne tehnologije oziroma materialne platforme, ki služijo izdelavi kvantnih fotonskih integriranih vezij (angl. QPIC). Gradnike, izdelane na različnih platformah, je z ustreznimi postopki heterogene integracije mogoče fizično združiti s skupno temeljno platformo. Ključen dejavnik za pravilno delovanje celotnega sistema je učinkovit optičen sklop integriranih gradnikov. V našem prispevku predstavljamo naš pristop k načrtovanju adiabatnih sklopnikov med integriranimi kvantnimi gradniki in temeljno platformo, osnovano na materialni platformi silicijevega nitrida (angl. SiN), pri čemer se oziramo na postopek heterogene integracije z mikroprenosnim tiskom. Prikazani so optimizirane sklopniki za primer integracije enofotonskih virov, kjer upoštevamo pomembne napake in negotovosti, ki izvirajo iz postopkov izdelave QPIC.

Abstract

Photonic integrated circuit (PIC) technologies represent a promising base for the research and development of quantum technologies. Here, an important factor is the efficiency of individual integrated quantum photonic components, which dictates the need to harness the capabilities of different material platforms used for fabrication of quantum photonic integrated circuits (QPICs). Components fabricated on different platforms can be physically integrated with a common interposer platform by employing appropriate heterogeneous integration techniques. A key factor for the correct operation of the whole system is efficient optical coupling of the integrated components. In our contribution, we present our approach to the design of adiabatic couplers between integrated quantum components and a silicon nitride (SiN) based interposer platform, where we consider the micro-transfer printing heterogeneous integration technique. We show optimised couplers for the case of single-photon sources, where we account for important variations and uncertainties that originate from QPIC fabrication processes.

Biografija avtorja

Miloš Ljubotina je leta 2020 končal magistrski študijski program Elektrotehnika na Fakulteti za elektrotehniko Univerze v Ljubljani. Istega leta se je na tej fakulteti vpisal v doktorski študijski program in postal mladi raziskovalec v Laboratoriju za fotovoltaiko in optoelektroniko, kjer se ukvarja s področjem integrirane fotonike. Njegova primarna raziskovalna dejavnost vključuje načrtovanje, optimizacijo, optično modeliranje in karakterizacijo fotonskih integriranih vezij in posameznih gradnikov le-teh.

Author's biography

Miloš Ljubotina received his MSc in Electrical Engineering at the Faculty of Electrical Engineering, University of Ljubljana, Slovenia, in 2020. He is continuing his studies as a PhD candidate at the same faculty and a member of the Laboratory of Photovoltaics and Optoelectronics since October 2020. His main research activities include design, optimisation, optical modelling, and characterisation of photonic integrated circuits and their individual components in the field of integrated photonics.

Optični adiabatni sklopniki za integracijo kvantnih enofotonskih virov na SiN integrirana fotonska vezja

Miloš Ljubotina, Andraž Debevc, Marko Topič in Janez Krč

University of Ljubljana, Faculty of Electrical Engineering,
Laboratory of Photovoltaics and Optoelectronics (LPVO),
Tržaška 25, 1000 Ljubljana, Slovenia

UNIVERZA V LJUBLJANI | FE Fakulteta za elektrotehniko

LPVO University *of Ljubljana* Faculty *of Electrical Engineering*

Vsebina

1. **Uvod v tematiko in motivacija**

2. **Optimizacija adiabatnega sklopnika** (med SiN in GaAs)

3. **Preliminarni eksperimentalni rezultati učinkovitosti optimiziranega sklopnika**

University of Ljubljana
Faculty of Electrical Engineering

Vsebina

1. **Uvod v tematiko in motivacija**

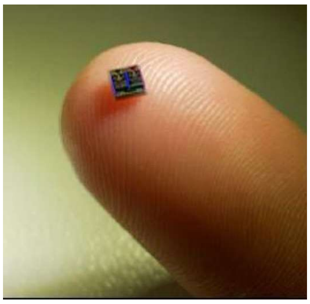
2. **Optimizacija adiabatnega sklopnika** (med SiN in GaAs)

3. **Preliminarni eksperimentalni rezultati učinkovitosti optimiziranega sklopnika**

University of Ljubljana
Faculty of Electrical Engineering

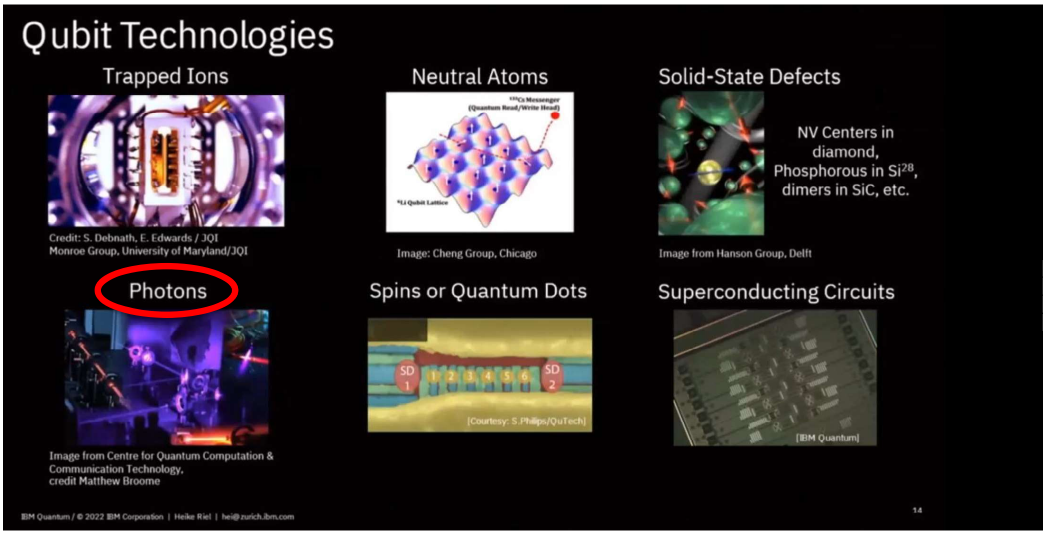
Fotonska integrirana vezja (angl. PIC)

- Integracija fotonskih gradnikov ponuja številne prednosti v primerjavi z diskretnimi rešitvami (cena, razširljivost, dodatna funkcionalnost, …)



info@vlcphotonics.com
www.vlcphotonics.com

Fotonika v Kvantnih Tehnologijah

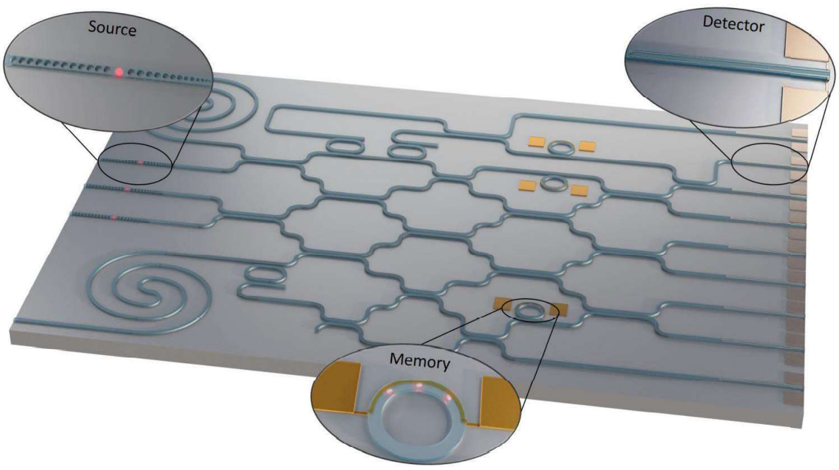


Courtesy of Dr. Heike Riel, IBM, SPIE 2022 conference

Kvantna Fotonska Integrirana Vezja (angl. QPIC)

QPIC za kvantno:

- komunikacijo
- računstvo
- simulacijo
- zaznavanje



Vir: A. Lohmann et al., Quantum PIC Position Paper, April 2022

Quantum photonic integrated circuit, including non-linear optics (spirals) and quantum light sources (red dots) in nano-beam cavities, quantum memories (rings including ions), and superconducting detectors (strips), as well as active and passive photonic elements (taken from Nat Rev Phys (2021): https://doi.org/10.1038/s42254-021-00398-z)

µTP4Q

"A versatile quantum photonic IC platform through micro-transfer printing"

QUANTERA

Partner Number	Country	Institution/ Department
1 Coordinator	BE	Ghent University (UG)
2	DK	University of Copenhagen (NBI)
3	DK	Sparrow Quantum (SQ)
4	DE	University of Muenster (MU)
5	CH	Swiss centre for electronics and microtechnology (CSEM)
6	SLO	Univerza v Ljubljani (UL)

Call: QuantERA II JTC 2021

Call topic
Applied Quantum Science

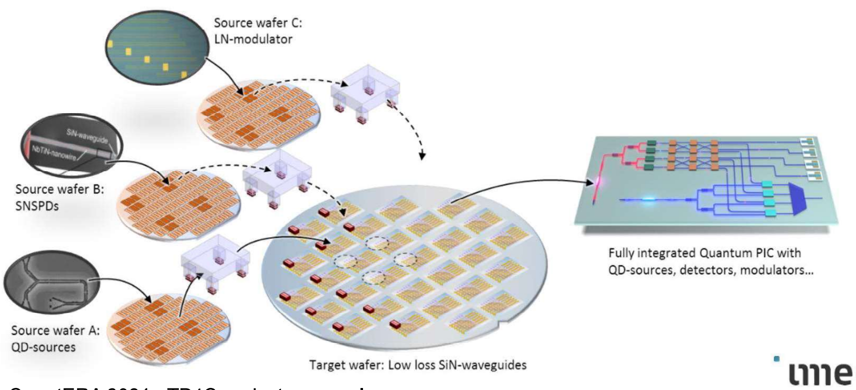
Start date
May 2022

Duration
36 months

Funding support
€ 1 547 570

Mikroprenosen tisk (micro-transfer printing - µTP)

- µTP omogoča **heterogeno integracijo več materialnih platform**
- Točnost poravnave pod ±0.5 µm (3σ)

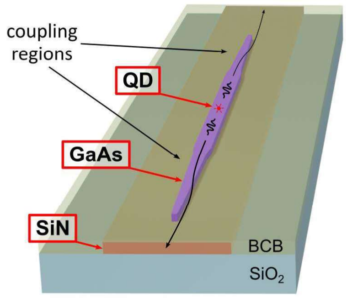


QuantERA 2021 uTP4Q project proposal

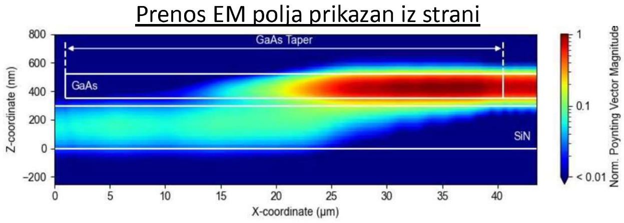
Adiabatni sklopnik med GaAs in SiN za enofotonske vire

- Adiabatni sklopnik služi **učinkovitemu** prenosu fotonov (iz GaAs v SiN)
- Pomembno je upoštevati **realne pogoje:**
  - neidealna poravnava valovodov
  - varianca dimenzij
  - …

3D prikaz strukture



Prenos EM polja prikazan iz strani



LPVO University of Ljubljana
Faculty of Electrical Engineering

Vsebina

1. Uvod v tematiko in motivacija
2. **Optimizacija adiabatnega sklopnika** (med SiN in GaAs)
3. Preliminarni eksperimentalni rezultati učinkovitosti optimiziranega sklopnika

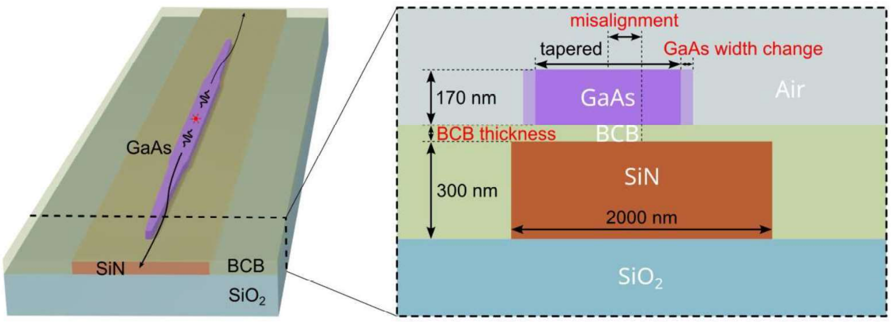
Struktura sklopnika in odstopanja pri izdelavi

- Sim./opt. programska oprema: Lumerical MODE, Lumerical FDTD, Python SciPy
- Valovna dolžina = **930 nm**
- Ciljne karakteristike sklopnika:
  - Dolžina **< 50 μm**
  - Učinkovitost **> -0.2 dB**

Parameter	Območje
Misalignment	0 – 500 nm
BCB Thickness	0 – 50 nm
GaAs Width Error	-20 – 20 nm

3D prikaz strukture

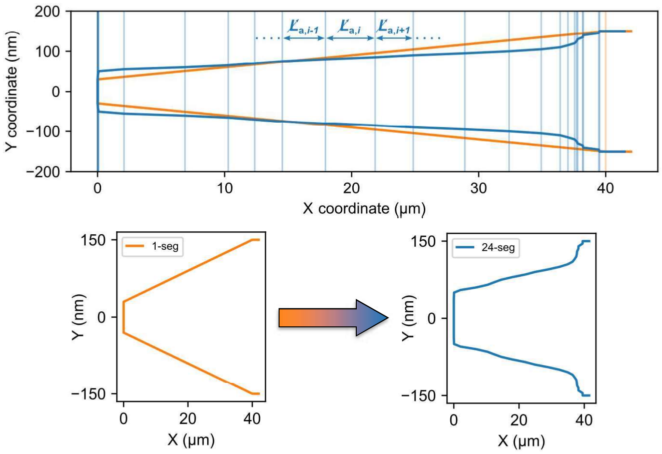
presek strukture in odstopanja



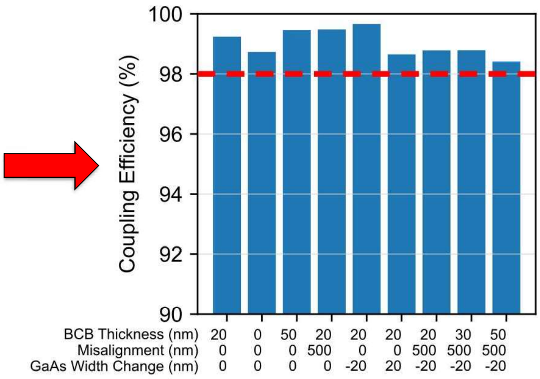
Optimizacija geometrije sklopnika

- **Učinkovitost optimiziranega sklopnika > 98 %** tudi ob upoštevanju odstopanj

Optimizacija z metodo EME



Verifikacija z metodo 3D FDTD



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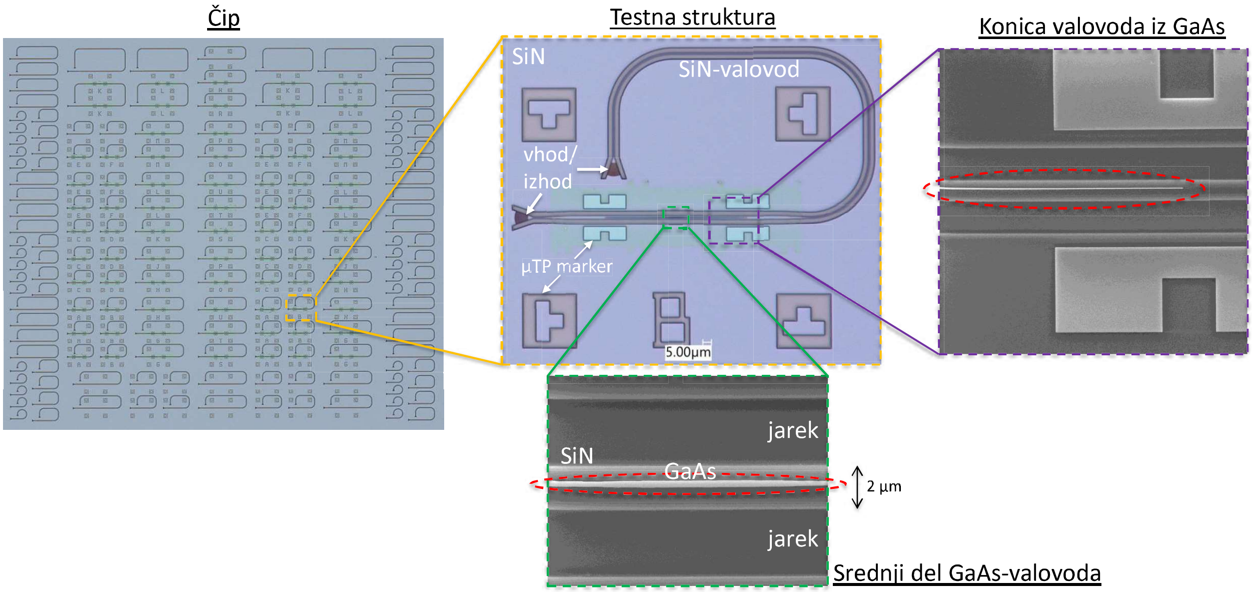
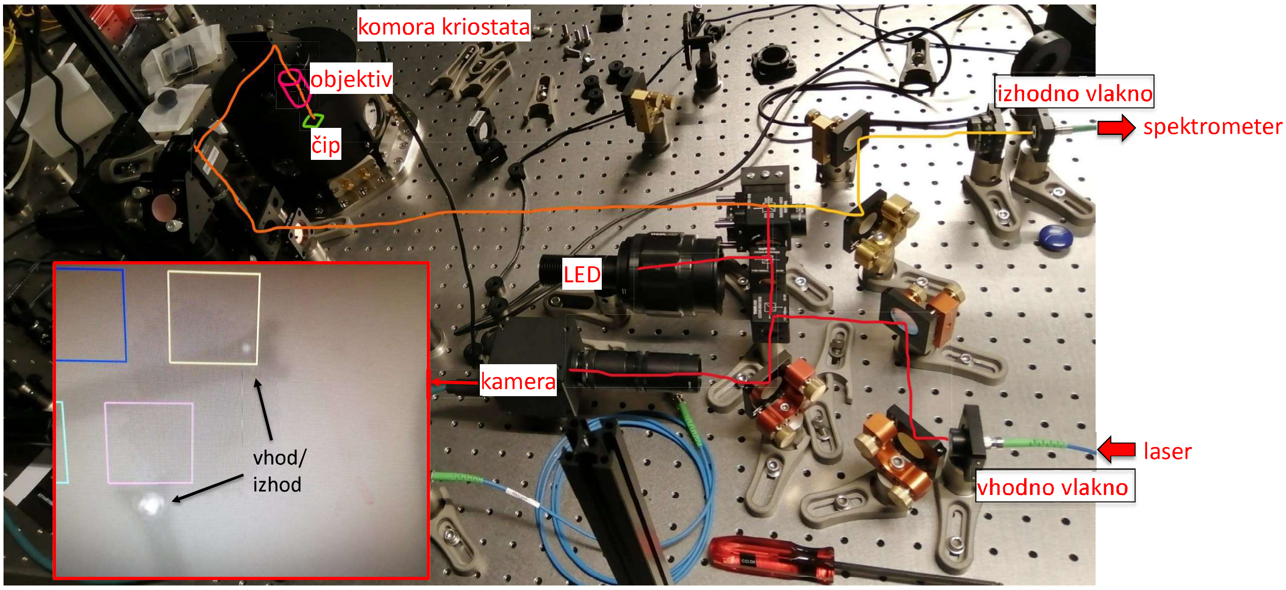
Izdelane strukture (slike iz optičnega mikroskopa in SEM)

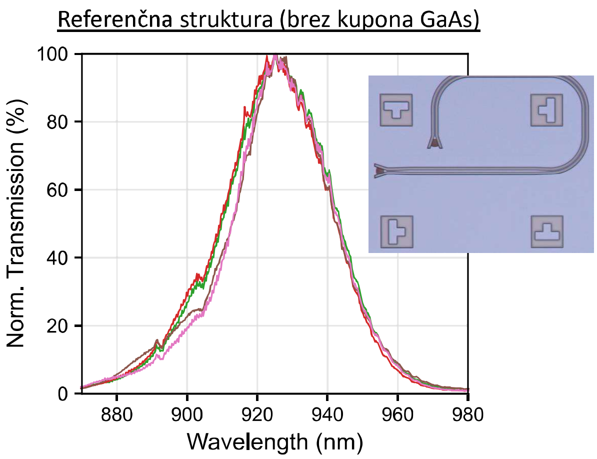


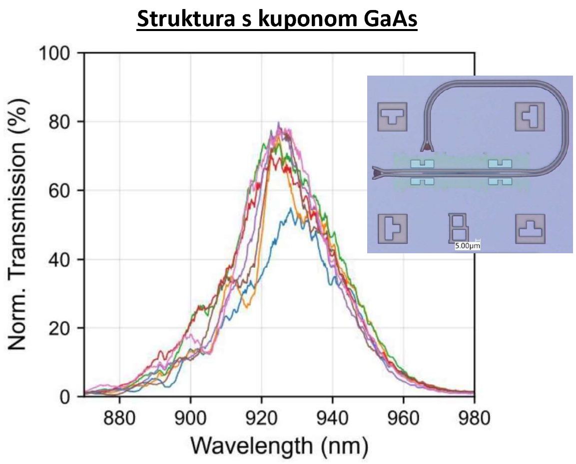
Meritve optične transmisije pri temperaturi 4 K



Preliminarni rezultati meritev

- **Prva eksperimentalna ocena učinkovitosti: ~87 % (-0.6 dB)**





Zahvala

Leonardo Midolo, Zhe Liu, Marcus Albrechtsen in Atefeh Shadmani, Inštitut Nielsa Bohra, Danska

Dries Van Thourhout in Jasper De Witte, Univerza v Gentu, Belgija

Funded by the European Union

QUANTERA

QuantERA II programme (GA No: Grant Agreement No 101017733)

uTP4Q

REPUBLIC OF SLOVENIA
GOV.SI
Ministry of Higher Education, Science and Innovation

Slovene contract No: C3330-22-252001

aris Slovenian Research and Innovation Agency

Research Programme Photovoltaics and Electronics (P2-0415)

Izkoriščanje kvantnih pojavov za senzorske tehnologije naslednje generacije

Harnessing Quantum Phenomena for Next-Generation Sensing Technologies

Erik Zupanič

Institut Jožef Stefan

erik.zupanic@ijs.si

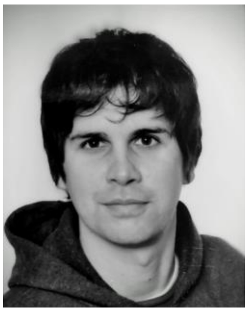
Povzetek

Kvantni senzorji izkoriščajo edinstvene lastnosti kvantnih pojavov, kot so superpozicija, prepletenost in kvantna koherenca, da dosežejo občutljivost in natančnost merjenja, ki daleč presegajo zmožnosti klasičnih tehnologij. Ti senzorji naslednje generacije imajo transformativni potencial na različnih področjih, vključno z navigacijo, spremljanjem okolja, biološko diagnostiko in raziskavami, presegajo klasične meje in utirajo pot nadaljnjemu znanstvenemu in tehnološkemu napredku. Vendar pa uresničitev tega potenciala zahteva premagovanje pomembnih izzivov, kot so zahteva po ekstremnih pogojih delovanja, težave pri miniaturizaciji in integraciji ter ohranjanje kvantne koherence zunaj nadzorovanih okolij. Predstavljena bodo osnovna načela, trenutno stanje in primeri uporabe kvantnih senzorskih tehnologij ter njihova vloga na prihodnosti merjenja in zaznavanja.

Abstract

Quantum sensors harness the unique properties of quantum phenomena, such as superposition, entanglement, and quantum coherence, to achieve sensitivities and measurement accuracies far beyond the capabilities of classical technologies. These next-generation sensors hold transformative potential across diverse fields, including navigation, environmental monitoring, biological diagnostics, and research, surpassing classical limits and paving the way for further scientific and technological advancements. However, realizing this potential requires overcoming significant challenges, such as the demand for extreme operational conditions, difficulties in miniaturization and integration, and preserving quantum coherence outside controlled environments. The basic principles, current status and application examples of quantum sensor technologies will be presented, as well as their role in the future of measurement and sensing.

Biografija avtorja



Erik Zupanič je raziskovalec v Laboratoriju za ultrahladne atome Instituta Jožef Stefan in soustanovitelj podjetja AtomQL d.o.o. Raziskovalno in razvojno deluje na področju kvantnih tehnologij s poudarkom na razvoju novih tehnik s hladnimi ioni in atomi za potrebe kvantne senzorike in kvantnega računalništva.

Author's biography

Erik Zupanič is a researcher at the Laboratory for Ultracold Atoms at the Jožef Stefan Institute and a co-

founder of the company AtomQL d.o.o. His research and development work focuses on quantum technologies, with an emphasis on the development of new techniques with cold ions and atoms for applications in quantum sensing and quantum computing.

Izkoriščanje kvantnih pojavov za senzorske tehnologije naslednje generacije

Erik Zupanič

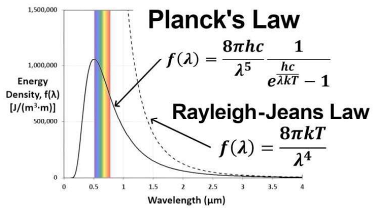
Institut
"Jožef Stefan"
Ljubljana, Slovenija

ATOM QUANTUM LABS

ATOM QUANTUM LABS

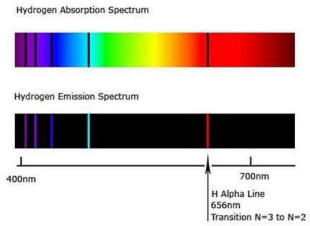
Klasična mehanika na koncu 19. stoletja

- Klasična mehanika opisuje gibanje **mikro- in makro-skopskih** delcev
- Velja pri **majhnih hitrostih** (v << c) in za **velike objekte**
- **Newtonovi zakoni, deterministična narava, ohranitveni zakoni**



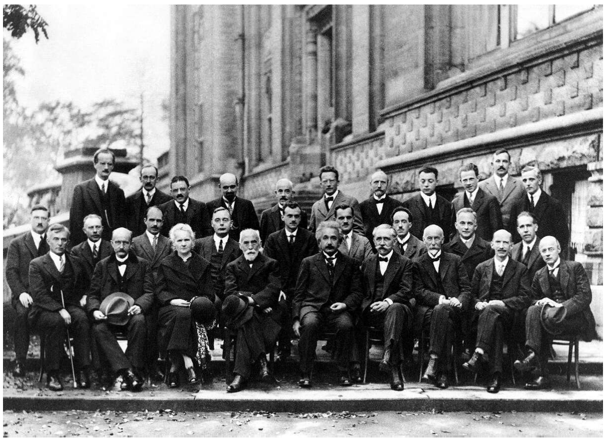
Klasična mehanika odlično opisuje vsakdanje pojave, a odpove pri **zelo majhnih** (kvantni pojavi) in **zelo hitrih** (relativistični pojavi) sistemih!

Ne razloži pa:
- Sevanje črnega telesa (ultravijolična katastrofa)
- Fotoelektričnega pojava
- Spektralne črte atomov
- Splošna nestabilnost atomov
- …



Kvantna mehanika

1927 Solvay Conference on Quantum Theory



Bohr, Born, de Broglie, Dirac, Heisenberg, Pauli, Schrödinger.

Klasična fizika → Kvantna fizika (iz determinističnih zakonov v verjetnostne napovedi)

Nova orodja: kvantni operaterji, valovne funkcije, kvantna superpozicija

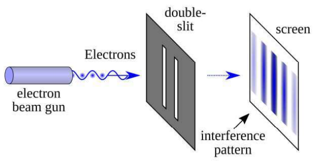
Praktične posledice: Razumevanje lastnosti atomov in molekul omogoča razvoj novih tehnologij.

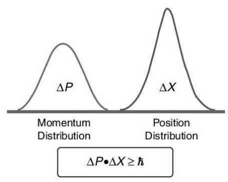
ATOM QUANTUM LABS

Kvantna mehanika

Glavne ideje kvantne mehanike

- **Kvantizacija –** Energija in nekateri drugi fizikalni parametri so diskretni
- **Valovno-delčni dualizem –** Delci (npr. elektroni) se obnašajo kot valovi in delci hkrati (*de Broglie*)
- **Verjetnostna narava –** Kvantna mehanika ne podaja determinističnih rezultatov, ampak verjetnostne napovedi
- **Nedoločenost (Heisenbergov princip) –** Nemogoče je hkrati natančno določiti položaj in gibalno količino delca
- **Kvantno prepletanje –** Delci so lahko v koreliranih stanjih ne glede na razdaljo
- **Superpozicija –** Kvantni sistemi lahko obstajajo v več stanjih hkrati, dokler niso izmerjeni





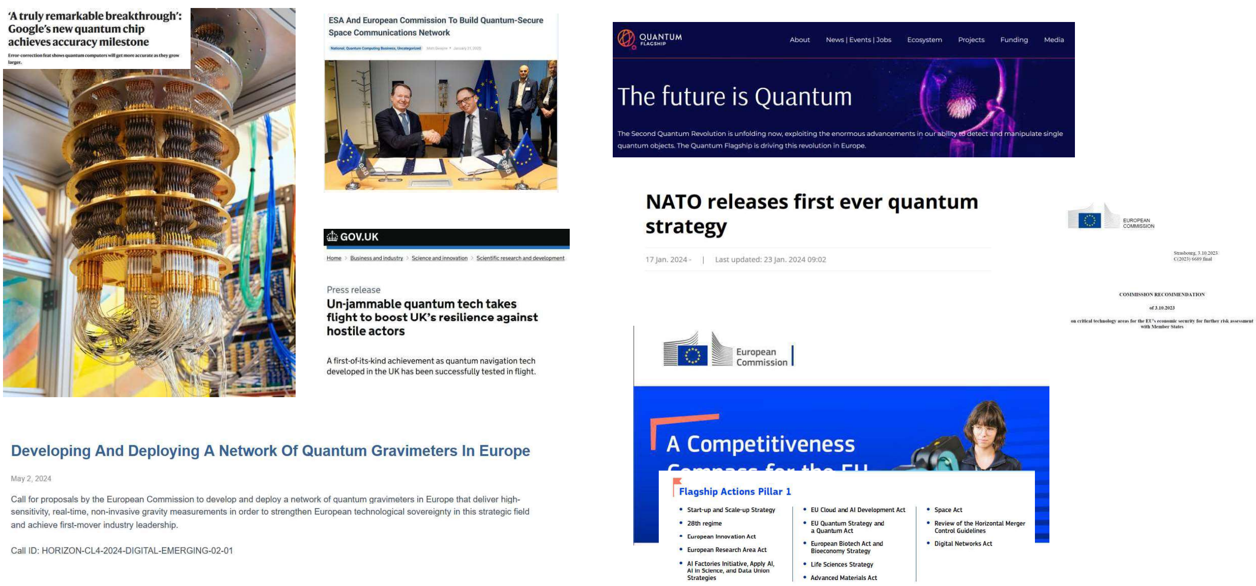
Prva kvantna revolucija…

… je omogočila t.i. informacijsko dobo, saj so polprevodniške tehnologije, laserji in kvantni modeli snovi osnova za vse sodobne elektronske naprave!

- **Tranzistorji (1947) –** osnova za sodobno elektroniko in računalnike
  - Polprevodmniki **-** osnova za integrirana vezja, diode, fotovoltaiko
- **Laserska tehnologija (1960) –** uporaba kvantnih prehodov za ojačanje svetlobe
- **Magnetna resonanca (MRI) (1977) –** kvantni pojavi v jedrskih spinih omogočajo slikanje v medicini

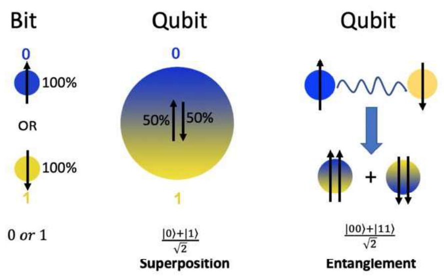
Danes?

INTERNATIONAL YEAR OF Quantum Science and Technology



Druga kvantna revolucija

- Prva revolucija: Razumevanje in pasivno izkoriščanje kvantnih pojavov.
- Druga revolucija: Aktivno upravljanje posameznih kvantnih stanj za razvoj novih tehnologij.



Uporaba qubitov v drugi kvantni revoluciji:

Kvantni računalniki
Kubiti so osnovni elementi kvantnih procesorjev.

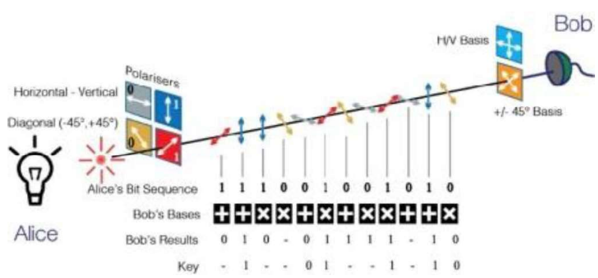
Kvantna komunikacija
Kubiti nosijo informacije, ki jih lahko varno prenašamo prek kvantnih kanalov.

Kvantni senzorji
Kubiti so izredno občutljivi na okolico - magnetna in/ali električna polja ipd.

Kvantne tehnologije

Kvantne tehnologije izkoriščajo kvantne pojave, kot so superpozicija, prepletenost in kvantna interferenca, za razvoj novih vrst senzorjev, računalnikov in komunikacijskih sistemov.

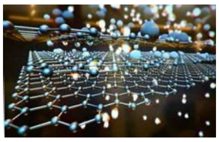
Kvantne komunikacije uporabljajo kvantne pojave, kot sta prepletenost in kvantna superpozicija, za varen prenos informacij, odporen proti klasičnemu prestrezanju.



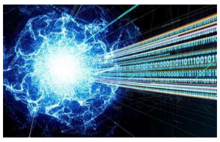
Kvantni računalniki lahko rešujejo probleme, ki jih s klasičnimi (super)računalniki ni mogoče

Quantum Chemistry
(new pharmaceuticals)

Quantum Simulation
(new materials)



Quantum Machine Learning
(artificial intelligence)



Quantum Communication
(cyber security)

+ optimization in logistics, financial modeling, climate modeling, fundamental physics, novel applications…

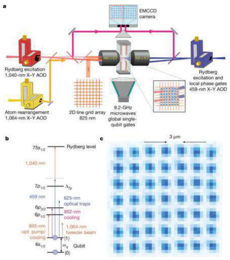
Kvantni senzorji nudijo občutljivost in natančnost, ki ni dosegljiva s klasičnimi predhodniki

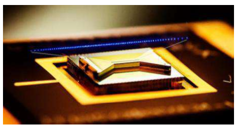
high precision magnetometers, gravimeters, accelerometers and gyroscopes

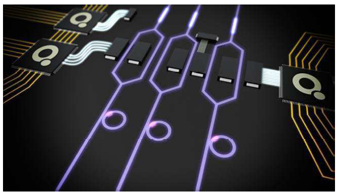
for applications in

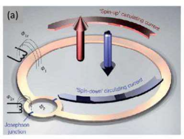
medical imaging, navigation, resource exploration, earthquake prediction…

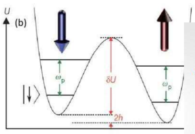
Realizacija kubita

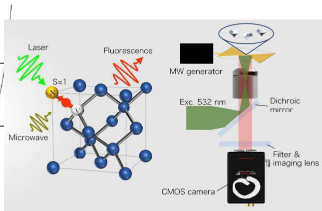










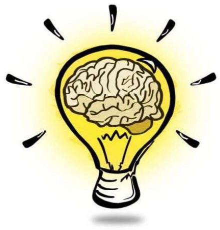


Platforme na osnovi:

- Superprevodna vezja
- Fotoni
- (Hladni) atomi
- Hladni ioni
- Polprevodniške kvantne pike
- NV centri v diamantu
- Topološki kubiti
- …

Dekoherenca

Koherenca kubitov opisuje, kako dolgo kvantni sistem ohranja svojo kvantno informacijo, preden jo zaradi interakcije z okoljem izgubi (dekoherenca).



občutljiva kvantna stanja interagirajo z okoljem, pri čemer njihova dekoherenca nosi informacijo o zaznanem pojavu **-> KVANTNI SENZORJI**

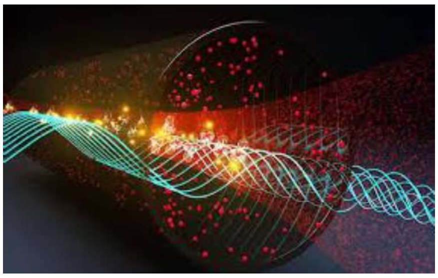
Kvantni senzorji

- Magnetometri
  - SQUID
  - NV-centri v diamantu
- Atomski interferometri za gravitacijske in inercijske meritve
- (RF) antene
- Optični senzorji
  - Kvantni radar / LIDAR
- Metrologija
  - Atomske ure

Kvantna (RF) antena

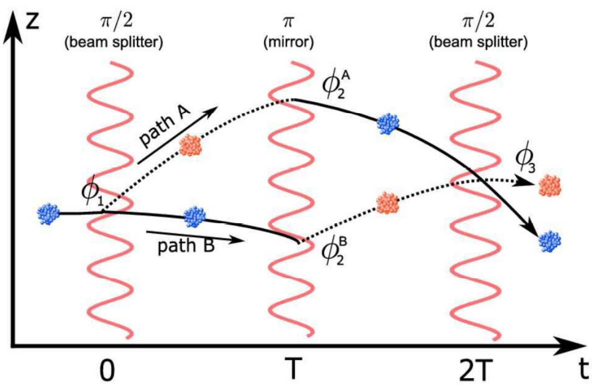
Prednosti:
- Visoka občutljivost
- Možnost zaznavanja signalov z izjemno visoko ločljivostjo in v širokem spektru (kHz – THz)

Izzivi:
- Minituarizacija
- Kompleksna oprema
- Integracija z obstoječo opremo



Atomski interferometer

- Priprava atomov
- Razdelitev na dve poti
- Združitev in interference
- Detekcija

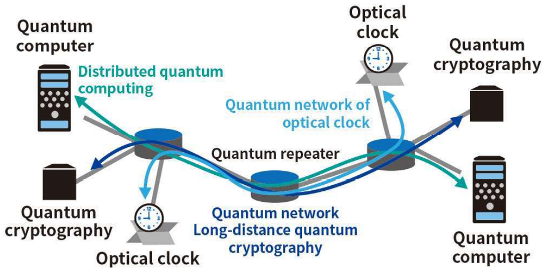


Gravitacijski senzorji

Prihodnost kvantnih senzorjev

- Ne potrebujejo kalibracije in se ne starajo
- Visoka občutljivost in natančnost
- Visoka prostorska in časovna ločljivost

- Uporaba kvantne prepletenosti med večimi/različnimi kvantnimi sistemi



Uporaba

- Merjenje gravitacijskih anomalij
  - Iskanje naravnih virov
  - Seizmologija

- Raziskave materialov
  - Npr. NV-magnetometrija

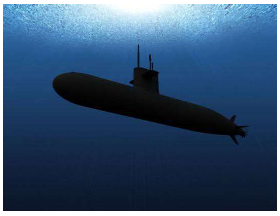
- Gravitacijski valovi (LIGO)

- Medicina (npr. MEG)

SQUID vs. Optically pumped

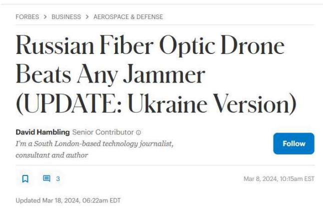
Uporaba

- Navigacija kjer ni GPS signala (pod vodo, pod zemljo…)



odstopanja klasične inercijske navigacije, odvisno od hitrosti in tipa, kot približno 1.8 kilometra na dan za ladje, podmornice in vesoljska plovila ter 1.5 kilometra na uro za letala.

- Motenje (jamming) in manipulacija (spoofing)
- GPS signal se uporablja tudi za časovno sinhronizacijo!



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Russian Fiber Optic Drone Beats Any Jammer (UPDATE: Ukraine Version)

David Hambling Senior Contributor
I'm a South London-based technology journalist, consultant and author

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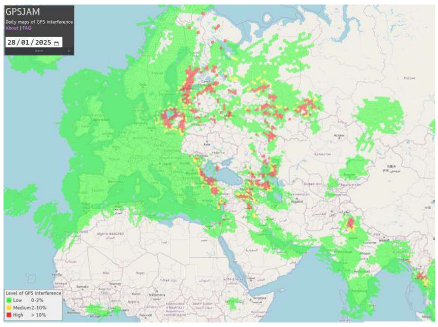
Mar 8, 2024, 10:15am EST

Updated Mar 18, 2024, 06:22am EDT



Kvantne tehnologije v SLO

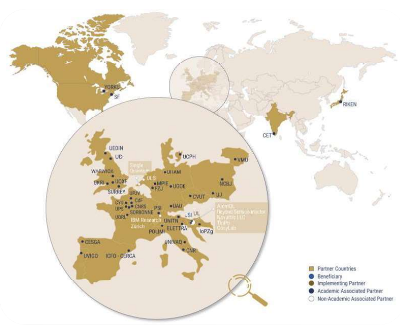
Kvantna tehnologija (QT) prepleta raziskovalne discipline (fizika, optika, elektrotehnika, računalništvo, uporabna matematika, kriptografija) **ter industrijske dejavnosti** (merjenje in testiranje, kontrolni sistemi, laserska tehnika, komunikacije, računalniška strojna in programska oprema).

Qutes

Slovene quantum science and technology community

- Physics of quantum technologies, Jozef Stefan Institut&University of Ljubljana
- Quantum Optics and Quantum Foundations group, University of Ljubljana
- Theoretical Physics department at Jozef Stefan Institute
- Condensed matter physics department at Jozef Stefan Institute
- Department of Complex matter at Jozef Stefan Institute
- Quantum Materials Group
- Department of Knowledge Technologies as Jozef Stefan Institute
- Faculty of Mathematics and Physics, University of Ljubljana
- Faculty of Mechanical Engineering, University of Ljubljana
- Faculty for Computer and Information Science, University of Ljubljana
- Rudolfovo – Science and Technology Center Novo mesto
- Center of Cryptography, FAMNIT, University of Primorska

SQUASH (Slovenian Quantum Science Hub)
https://squash.ijs.si



Funded by the European Union NextGenerationEU

NOO THE RECOVERY AND RESILIENCE PLAN

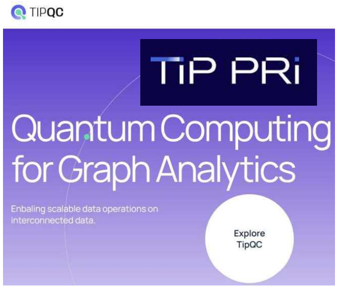
EuroQCI The European Quantum Communication Infrastructure Initiative

erc

QUANTERA

SiQUID Slovenian Quantum Communication Infrastructure Demonstration

Kvantne tehnologije v SLO



…

Kvantne tehnologije v SLO

- **Analiza koristi in tveganj, ki jih prinašajo kvantne tehnologije na področje varnosti**

- **Kvantni senzorji za zaznavanje časa in prostora**

Cilji:

- 1. Pregled trenutnega stanja in možnosti uporabe kvantnih senzorjev na področju varnosti
- 2. Razvoj in demonstracija laboratorijske kvantne naprave za zaznavanje radijskih valov
- 3. Ocena stanja in možnosti razvoja in izdelave različnih kvantnih senzorjev v Sloveniji
- 4. Organizacija delavnic in priprava končnih poročil

https://atomql.com/projects

REPUBLIKA SLOVENIJA
MINISTRSTVO ZA OBRAMBO

Zaključki

- Mnoge kvantne tehnologije prehajajo iz laboratorijev v resnične aplikacije.
- Kvantne tehnologije revolucionarno spreminjajo zaznavanje, računalništvo in komunikacijo.
- Kvantni senzorji omogočajo doslej nepredstavljivo natančnost in občutljivost.

Laboratorij za hladne atoma

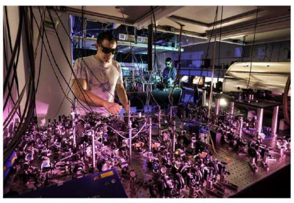


Photo credit: Arne Hodalič and Katja Bidovec, appeared in National Geographic Slovenija

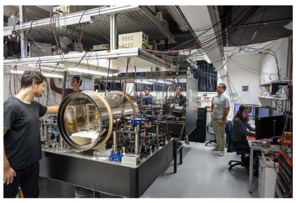
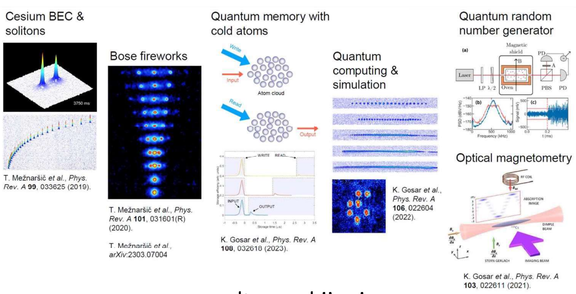
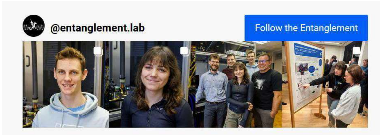


Photo credit: Marjan Verč

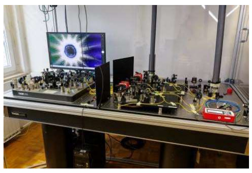


ultracool.ijs.si

Laboratorij za prepletenost



entanglement.ijs.si



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Igor Poberaj
Dušan Babič

PI Peter Jeglič ....

MR Katja Gosar ....
MR Jure Pirman ....

Injekcijska vklenitev v kvantnih komunikacijah
Injection entanglement in quantum communications

Vesna Eržen
Univerza v Ljubljani, Fakulteta za elektrotehniko
erzenvesna@gmail.com

Povzetek

Injekcijska vklenitev je metoda, ki bistveno izboljšuje zmogljivosti optičnih sistemov in ima velik potencial za uporabo na področju kvantnih komunikacij. Pri pojavu injekcijske vklenitve gre za frekvenčno in fazno sinhronizacijo dveh laserjev, pri čemer ima eden nadrejeno, drugi pa podrejeno vlogo. To je uporabno povsod tam, kjer je potrebna visoka koherentnost in stabilnost svetlobnega sevanja. Koherentni svetlobni viri omogočajo natančno merjenje polarizacijskih stanj fotonov, kar je še posebno uporabno na področju kvantnega šifriranja.

Abstract

Injection locking is a method that significantly improves the performance of optical systems and has great potential in quantum communications. The phenomenon of injection locking involves the frequency and phase synchronization of two lasers, with one playing a dominant role and the other a subordinate role. This is useful wherever high coherence and stability of light radiation is required. Coherent light sources enable precise measurement of the polarization states of photons, which is particularly useful in quantum encryption.

Biografija avtorja

Vesna Eržen je po končani gimnaziji študij nadaljevala na Visoki šoli za varnostne vede Univerze v Mariboru. Kasneje se je iz družboslovnih ved preusmerila na področje naravoslovja in se po končanem študiju varnostnih ved (l. 2006) vpisala na Fakulteto za elektrotehniko Univerze v Ljubljani. Leta 2012 je diplomirala iz področja optičnih komunikacij, njeno delo pa se je nanašalo na podaljševanje dosega zveze v pasivnih optičnih omrežjih. Od 2012 do 2016 je bila zaposlena kot raziskovalka na projektu v Laboratoriju za sevanje in optiko na Fakulteti za elektrotehniko. Od 2017 poučuje na srednji šoli za strojništvo. Leta 2020 si je na Filozofski fakulteti pridobila še pedagoško-andragoško izobrazbo. Trenutno poučuje strokovne predmete tudi kot predavateljica na Višji šoli za strojništvo Škofja Loka in je doktorska študentka na Fakulteti za elektrotehniko Univerze v Ljubljani. Je avtorica in soavtorica več strokovnih člankov s področja optičnih komunikacij in poučevanja strokovnih predmetov po principih reševanja problemov.

Author's biography

After finishing high school, Vesna Eržen continued her studies at the University of Maribor School of Security Sciences. She later switched from the social sciences to the field of natural sciences and after completing her studies in safety sciences (2006) enrolled at the Faculty of Electrical Engineering of the University of Ljubljana. In 2012, she graduated in the field of optical communications. Her work related to extending the communication range in passive optical networks. From 2012 to 2016, she was employed as a project researcher in the Radiation and Optics Laboratory at the Faculty of Electrical Engineering.

Since 2017, he has been teaching at a high school for mechanical engineering. In 2020, she obtained a pedagogic and andragogic education at the Faculty of Arts. She currently teaches professional courses as a lecturer at the Škofja Loka College of Mechanical Engineering and is a doctoral student at the Faculty of Electrical Engineering of the University of Ljubljana. She is the author and co-author of several professional articles in the field of optical communications and teaching professional subjects based on the principles of problem solving.

Injekcijska vklenitev v tehnologiji kvantnega razdeljevanja ključev

Vesna Eržen, Boštjan Batagelj

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E-pošta: vesna.erzen@ fe.uni-lj.si, bostjan.batagelj@fe.uni-lj.si

Vsebina:

- QKD (predstavitev, pomen)
- DV-QKD, CV-QKD
- Injekcijska vklenitev
- Pomen IL v QKD
- Fazno kodiran BB84
- Neposredno fazno moduliran oddajnik z injekcijsko vklenitvijo

Kvantno šifriranje

- **Kvantno razdeljevanje ključa – QKD**: varno izmenjavo kriptografskih ključev med strankama
- **Načela kvantne mehanike**: kvantni bit (qbit) za prenos informacij
  - kvantna superpozicija
  - kvantna prepletenost
- **BB84**: temelj QKD (C. Bennett, G. Brassard, 1984)
- **Varnost**: detekcija poskusov prestrezanja
- **Uporaba v praksi**: vojska, diplomacija, finančne ustanove....
- **Prednost pred klasičnimi kriptografskimi metodami**: matematične metode vs. fizikalni zakoni
- **Razvoj tehnologije**: vlaganja, novi pristopi in izboljšave za povečanje učinkovitosti, uporabnost v realnih okoljih.
- **Izzivi**: nadgradnja infrastrukture, povečanje prenosne sposobnosti, integracija QKD v obstoječe komunikacijske sisteme

QKD PROTOKOLI

Coherent One-Way
Measurement-device-independent
differential phase shift
twin-field
continuous-variable

	BB84	E91	SARG04	DPS-QKD	COW-QKD	TF-QKD	MDI-QKD	CV-QKD
Distance (km)	70	-	90	260	125	550	390	140
Star topology	Middle	Low	Low	Middle	Low	Low	High	High
Complexity	Middle	High	Middle	Middle	Middle	High	High	Low
Cost	Middle	High	High	Middle	Middle	High	High	Middle
Utilization	Low	Low	Low	Low	Low	Low	Low	High
Key rate	3×10^{-7}		5×10^{-7}	1×10^{-5}	1×10^{-38}	9×10^{-5}	2×10^{-6}	5×10^{-6}
Difficulty	Middle	High	Middle	Middle	Middle	High	High	High

vir: S. Pirandola, U. L. Andersen, L. Banchi, M. Berta, D. Bunandar, R. Colbeck, D. Englund, T. Gehring, C. Lupo, C. Ottaviani, J. L. Pereira, M. Razavi, J. Shamsul Shaari, M. Tomamichel, V. C. Usenko, G. Vallone, P. Villoresi, and P. Wallden, "Advances in quantum cryptography," Adv. Opt. Photon. 12, 1012-1236 (2020)

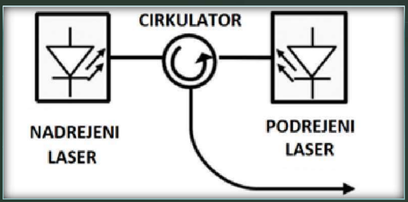
vir: K. Shim, Y. Kim, and W. Lee, "A Design of Secure Communication Architecture Applying Quantum Cryptography," Journal of Information Science Theory and Practice, vol.10, no.S, pp.123-134, Jun. 2022, doi:10.1633/JISTaP.2022.10.S.12 https://accesson.kr/jistap/v.10/S/123/11358

CV-QKD, DV-QKD

- Protokole QKD delimo glede na vrsto kvantnih stanj, uporabljenih za kodiranje informacij.
- Dva pristopa za kvantno razdeljevanje ključev:
  - CV-QKD (Continuous Variable – CV)
  - DV-QKD (Discrete Variable – DV)
- DV-QKD uporablja princip diskretnih kvantnih bitov (qbitov)
  - Informacije se prenašajo prek posameznih kvantnih stanj.
  - stanje qbitov se meri na osnovi polarizacije in faze fotonov.
- CV-QKD za šifriranje uporablja amplitudo moči svetlobe ali fazo svetlobnega vala:
  - zvezne (ali kontinuirane) spremenljivke.
  - Informacije se prenašajo s podatki, ki se nahajajo v kontinuiranih kvantnih stanjih svetlobnih impulzov

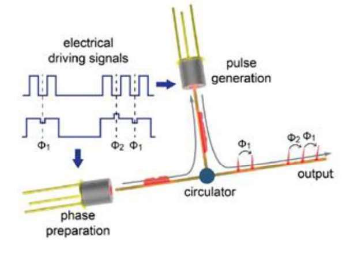
Injekcijska vklenitev

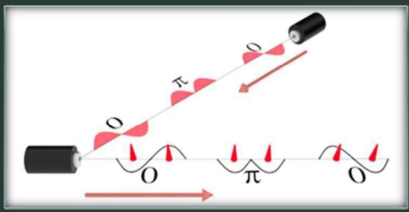
- Sinhronizacija: frekvenčna in fazna vklenitev dveh laserjev – nadrejenega (angl. master) in podrejenega (angl. slave)
- Lomni količnik polprevodniškega ojačevalnega medija se spremeni ob vstopu svetlobe nadrejenega vira v resonančno votlino podrejenega laserja
- Spremeni se dolžina optične poti med zrcali resonatorske votline
- Sprememeni se frekvenca in faza podrejenega laserja



IL za direktno fazno modulacijo v QKD:

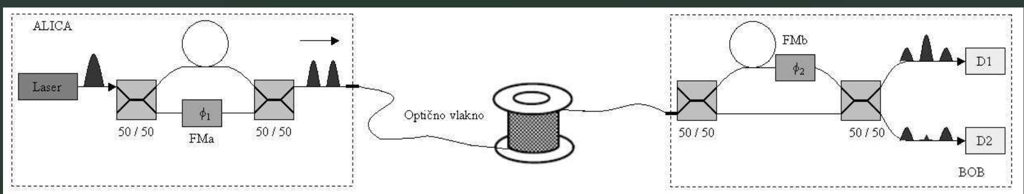
- manipulacija napajalnega toka nadrejenega laserja za naključno spremembo faze





Vir: Z. L. Yuan, B. Fröhlich, M. Lucamarini, G. L. Roberts, J. F. Dynes, A. J. Shields. „Directly Phase-Modulated Light Source", Phisical Revew, 2016. https://physics.aps.org/articles/v9/s102

Fazno kodiran BB84



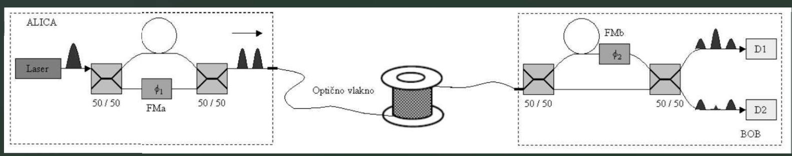
Fazna kodiranja: Alica kodira podatkovni niz s spremembo faze impulza (Fma).
- faza 0 za logično '0' in fazo π/2 za logično ‚1'
- Alica uporablja en optični vir (oddaja šibak laserski impulz, ki se v interferometru na delilniku 50/50 razdeli v dve poti: krajšo K in daljšo D)
- **Sprememba faze**: faza na poti K se spremeni z modulatorjem FMa, kar omogoča kodiranje informacije o ključu

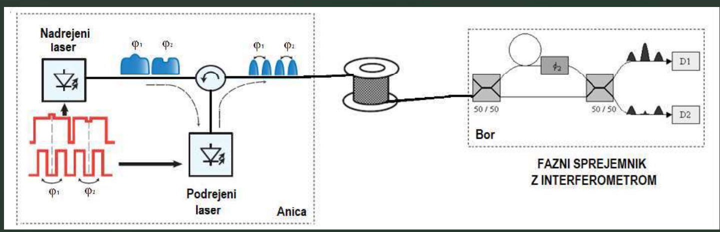
Bob uporablja fazni modulator FMb:
- za logično '0' nastavi fazo na 3π/2, za logično '1' na π
- z modulatorjem FMb se spreminja faza v daljši veji

Interferenca impulzov: na izhodu Bobovega interferometra nastanejo trije impulzi: KK, DD in KD/DK (različni interferenčni vzorci)
Močnostni nivoji: Bob se odloča na podlagi treh močnostnih nivojev (0, 0.5, in 1)
- nivoji določajo, katere bite sprejme in potrdi

Detekcija informacij: impulz (KD in DK) vsebuje ključne informacije:
- konstruktivna in destruktivna interferenca na detektorjih D1 in D2

Fazno kodiran BB84 z uporabo injekcijske vklenitve na oddajni strani





Prednosti:
- izboljšana stabilnost
- poenostavljena arhitektura
- manjše dimenzije
- nižja poraba energije
- izboljšana integracija
- univerzalnost

Vir:Nazarikov, G. »Optical Injection Locking for Enhanced Performance of Optical Communication Systems« [Phd Thesis 1 (Research TU/e / Graduation TU/e), Electrical Engineering]. Eindhoven University of Technology. 2023

Koraki izvedbe laboratorijskega testiranja:

1. Priprava opreme in povezava merilne opreme:
   - Oddajna stran: nadrejeni in podrejeni laser ustreznih lastnosti (valovna dolžina, moč), optični cirkulator, manipulacija toka nadrejenega laserja
   - Sprejemna stran: MZI, dva fotodetektorja z visoko občutljivostjo, osciloskop, OSA
   - Optika: SMF, 1550nm za povezavo med oddajno in sprejemno stranjo.
   - Programska oprema
2. Ustrezna nastavitev parametrov
3. Izvedba meritev in analiza pridobljenih podatkov
   - Stopnja napak (QBER)
   - Analizira vpliva različnih parametrov (moč laserjev, hitrost modulacije, dolžina optične poti, itd.) na stopnjo napak in učinkovitost prenosa.
4. Optimizacija eksperimenta:
   - Prilagoditev parametrov

Zaključek:

- Prednosti QKD
- Injekcijska vklenitev in njena uporaba v QKD
- Prednosti, tehnološki izzivi
- Stabilizacija in optimizacija oddajnika
- Cilj: Laboratorijska izvedba fazno kodiranega BB84 z injekcijsko vklenitvijo in neposredno fazno modulacijo

Kako optika pomaga v radarski tehniki?

How do optics help in radar technology?

Luka Podbregar

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Povzetek

Radarski sistemi, prvotno razviti v vojaške namene za zaznavanje sovražnika, so se v zadnjih desetletjih razširili na številna civilna in znanstvena področja, kot so avtomatizacija, avtomobilizem, meteorologija in astronomija. Sodobni radarski sistemi omogočajo natančno zaznavanje tarč, vendar se soočajo z omejitvami, kot so počasne hitrosti prenosa, omejena pasovna širina, omejena razdalja med porazdeljenimi sistemi in slaba ločljivost. Za premagovanje teh izzivov je potreben inovativen pristop, ki združuje elektronske in optične komponente v tako imenovanem mikrovalovno-fotonskem radarju.

Abstract

Originally developed for detecting enemies in military applications, radar systems have, in recent decades, found widespread use in various civilian and scientific fields, including automation, automotive technology, meteorology, and astronomy. Modern radar systems provide accurate target detection but face limitations such as slow transmission speeds, limited bandwidth, restricted range in distributed systems, and poor resolution. To address these challenges, an innovative approach is required that combines electronic and optical components in the so-called microwave photonic radar.

Biografija avtorja

Luka Podbregar je leta 2020 diplomiral iz elektrotehnike na Univerzi v Ljubljani, Fakulteti za elektrotehniko, kjer je leta 2023 tudi magistriral. Od leta 2023 je zaposlen kot mladi raziskovalec v Laboratoriju za sevanje in optiko, kjer se ukvarja z raziskavami sinhronizacijskih tehnik za porazdeljene radarske sisteme. Njegova raziskovalna področja vključujejo daljinsko zaznavanje, sinhronizacijske metode porazdeljenih radarskih sistemov in mikrovalovno fotoniko.

Author's biography

Luka Podbregar graduated in 2020 with a degree in electrical engineering from the University of Ljubljana, Faculty of Electrical Engineering, where he also completed his master's degree in 2023. Since 2023, he has been employed as a junior researcher at the Radiation and Optics Laboratory, focusing on research into synchronization techniques for distributed radar systems. His research areas include remote sensing, synchronization methods for distributed radar systems, and microwave photonics.

Kako optika pomaga v radarski tehniki?

Luka Podbregar

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Ljubljana, 7. 2. 2025

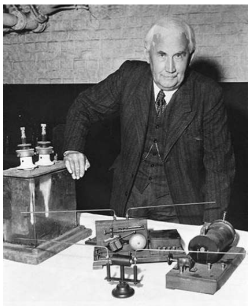
Pregled predavanja

- Zgodovina radarja
- Radar danes
- Dopplerjev radar
- Napredni radarski sistemi
- Mikrovalovna fotonika
- Mikrovalono-fotonski radar

Zgodovina radarja

1904 - Christian Hülsmeyer
Prvi radar - Telemobiloskop

1886-1888 - Heinrich Hertz
Dokaže odboj elektromagnetnih valov od kovine

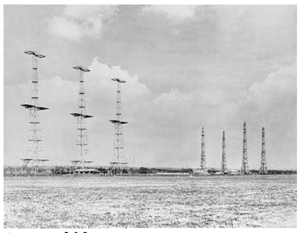


1921 - Albert Wallace Hull
Izumi magnetron

1922 - Guglielmo Marconi
Med eksperimenti opazi odboje od predmetov

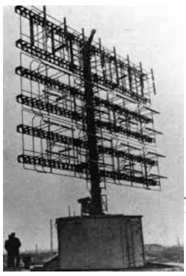
Zgodovina radarja

1933-1937
Impulzni radarji:
Freya (250 MHz)
Seetakt (370 MHz)
Würzburg (560 MHz)

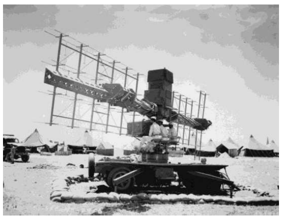


1935-1938 - Robert Watson-Watt
Impulzni radar:
Chain Home (20 - 30 MHz)

1930
Pojav težkih kovinskih bombnikov dolgega dometa

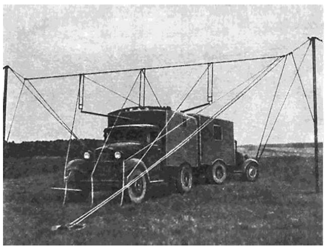


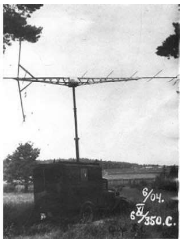
Zgodovina radarja




1922-1940
Radarja z neprekinjenim oddajanjem:
RUS-1 (75-83 MHz)
Impulzni radar:
RUS-2 (75-83 MHz)

1934-1940
Impulzni radarji:
SCR-268 (205 MHz)
SCR-270 (106 MHz)





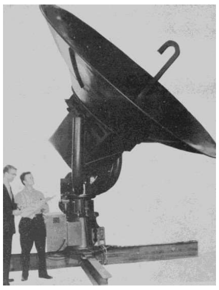
Zgodovina radarja

1940-1941
Razvijejo letalski radar **H2S**
zmožen zaznavanja periskopa podmornic

1939 - John Randall in **Henry Boot**
Radar z votlinskim magnetronom
(>6 kW moči pri 3 GHz)


Zgodovina radarja

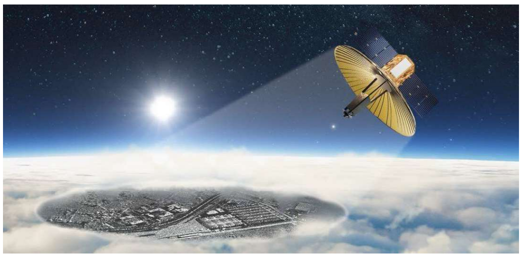
1947-1989 - Hladna vojna
- Dozoritev raznih radarskih sistemov
- Razširitev radarske tehnike na razna civilna področja

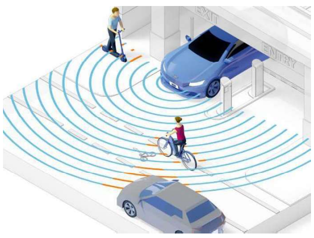


Radar danes

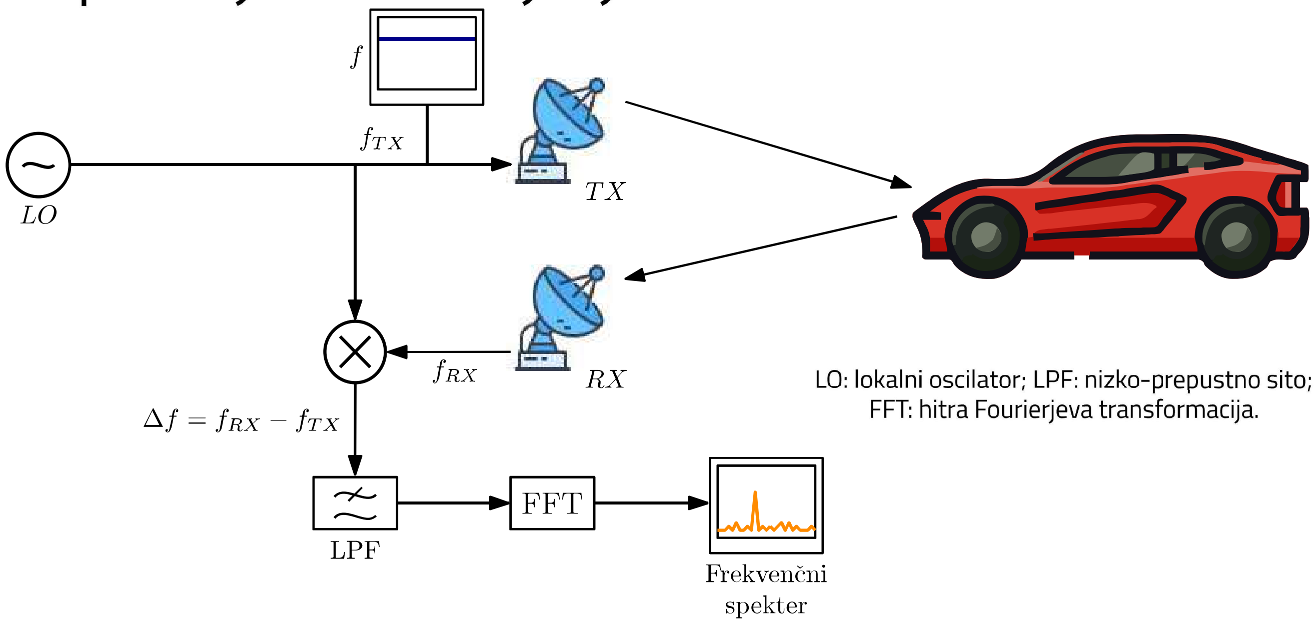
2025
Raznolika uporaba radarjev:
- Radarji za nadzor zračnega prometa
- Vremenski radar
- Radarji za kartografiranje
- Radarske pištole
- Astronomski radarji
- Avtomobilski radarji
...

- **Selitev na višja frekvenčna območja:**
  - območje milimeterskih valov (30-100 GHz)
  - pod-teraherčno območje (100-300 GHz)
  - teraherčno območje (0,3-10 THz)
- **Uporaba večjih pasovnih širin**
- **Energetsko učinkovitejši sistemi**
- **Povezovanje večih (porazdeljenih) radarskih sitemov**
- **Napredni radarski sistemi**



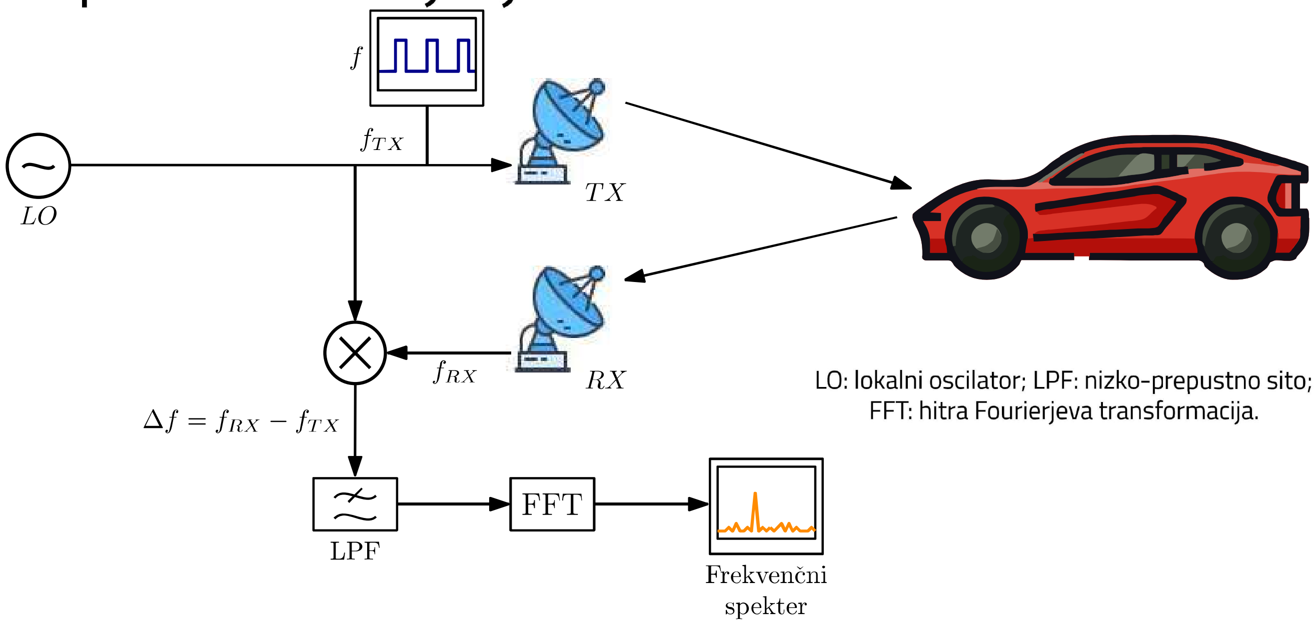


Dopplerjev radar z neprekinjenim oddajanjem



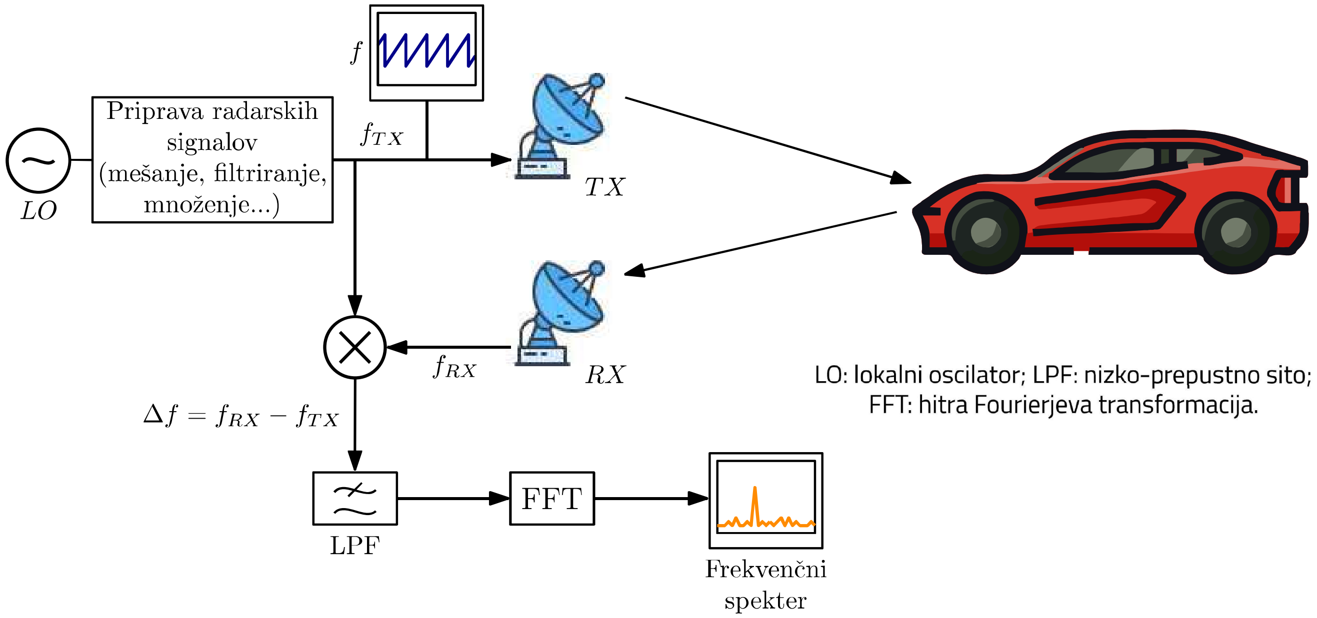
LO: lokalni oscilator; LPF: nizko-prepustno sito; FFT: hitra Fourierjeva transformacija.

Dopplerjev radar z impulznim oddajanjem



LO: lokalni oscilator; LPF: nizko-prepustno sito; FFT: hitra Fourierjeva transformacija.

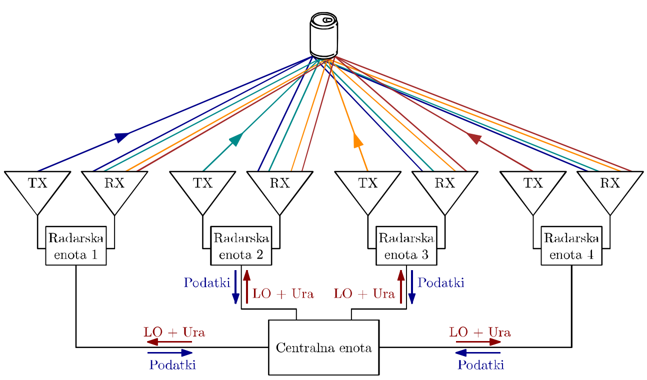
Frekvenčno moduliran Dopplerjev radar z neprekinjenim oddajanjem

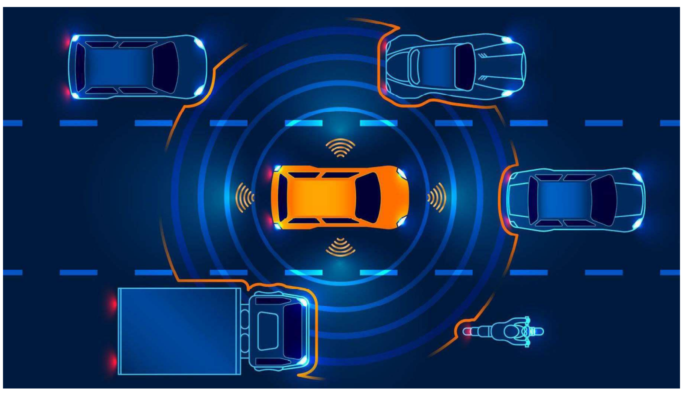


LO: lokalni oscilator; LPF: nizko-prepustno sito;
FFT: hitra Fourierjeva transformacija.

Napredni radarski sistemi

- Porazdeljeni radarski sistemi
- Radarski sistemi z več vhodi in več izhodi (MIMO)
- Radarski sistemi s koherentno obdelavo





Mikrovalovna fotonika

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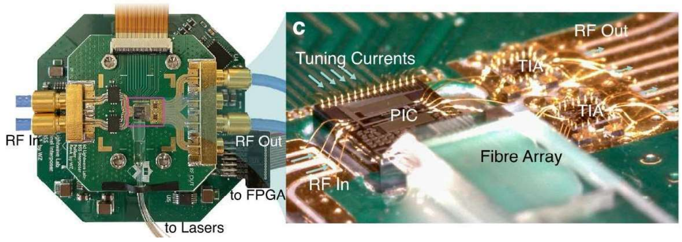
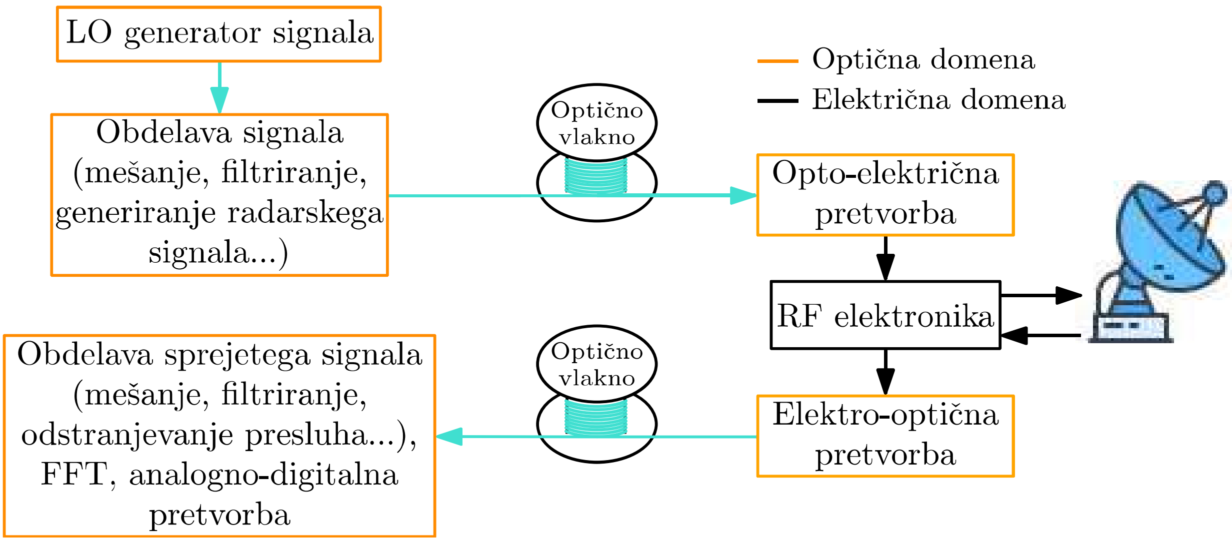


Zhang, W., Lederman, J.C., Ferreira de Lima, T. *et al.* A system-on-chip microwave photonic processor solves dynamic RF interference in real time with picosecond latency. *Light Sci Appl* 13, 14 (2024). https://doi.org/10.1038/s41377-023-01362-5

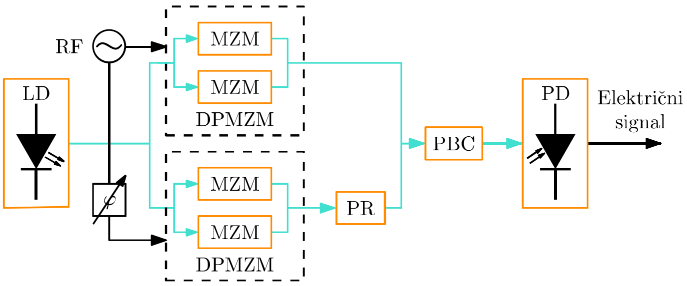
Mikrovalono-fotonski radar



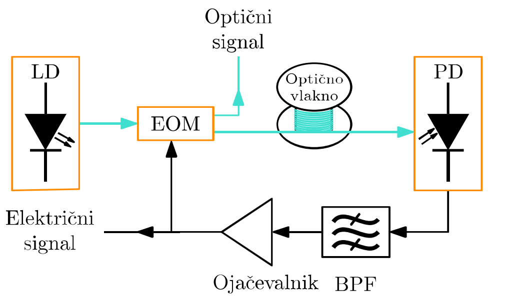
Mikrovalono-fotonski radar

Optični LO generator signala

- nizek fazni šum
- visoka spektralna čistost



Blokovni načrt generiranja signala LO na podlagi množenja frekvenc.
DPMZM: dvojni paralelni Mach-Zehnderjev modulator; MZM: Mach-Zehnderjev modulator; PR: rotator polarizacije; PBC: združevalnik polariziranih žarkov.
G. Qi, J. Yao, J. Seregelyi, S. Paquet, and C. Belisle, "Generation and distribution of a wide-band continuously tunable millimeter-wave signal with an optical external modulation technique," IEEE Transactions on Microwave Theory and Techniques, vol. 53, no. 10, pp. 3090–3097, 2005.

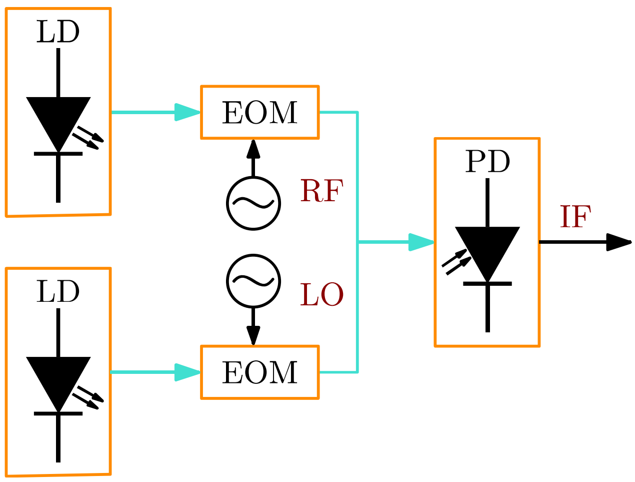


Blokovni načrt generiranja signala LO z elektro-optičnim oscilatorjem.
BPF: pasovno prepustno sito; EOM: elektro-optični modulator.
Z. Fu, Y. Ma, Z. Zeng, L. Zhang, H. Tian, W. Lyu, Y. Zhang, Z. Zhang, S. Zhang, H. Li, and Y. Liu, "Microwave local oscillator signal generation with low near-carrier phase noise based on cascaded optoelectronic oscillators," Optics & Laser Technology, vol. 181, p. 111628, 2025.

Mikrovalono-fotonski radar

Optični mešalniki

- lažje filtriranje nezaželjenih mešalnih produktov
- omogočajo uporabo signalov večjih pasovnih širin
- omogočajo skoraj neskončno izoliranost RF in LO vhodov

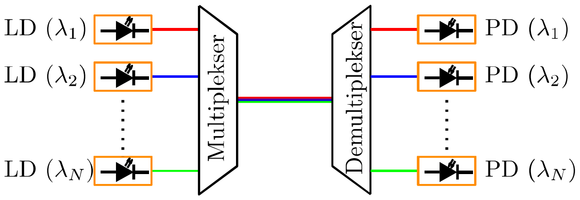


Blokovni načrt optičnega mešanja z uporabo vzporednih EOM.
R. A. Minasian, E. H. W. Chan, and X. Yi, "Microwave photonic signal processing," Opt. Express, vol. 21, no. 19, pp. 22 918–22 936, Sep 2013..

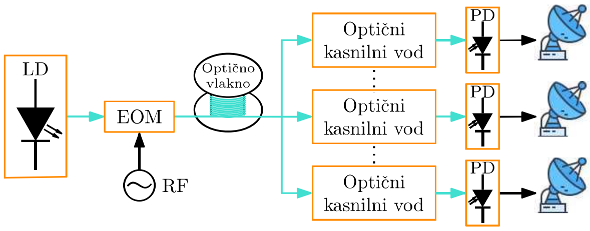
Mikrovalono-fotonski radar

Prenos signala - optična vlakna

- omogoča prenos visokofrekvenčnega signala z nizkimi izgubami (~0,2 dB/km)
- večja pasovna širina
- lažja kompenzacija zakasnitev v prenosu
- omogoča uporabo zakasnitvenih vodov - npr. v antenskih skupinah
- omogoča uporabo porazdeljenih sistemov
- omogoča večkanalno komunikacijo z multipleksiranjem



Blokovni načrt valovnodolžinskega multipleksiranja.

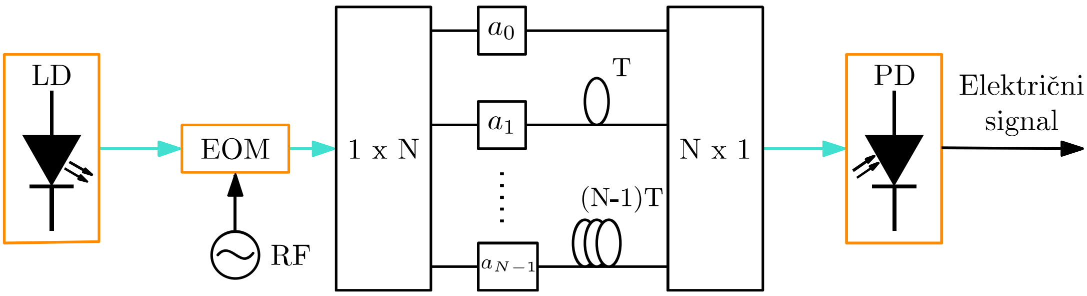


Blokovni načrt optične antenske skupine.
Y. Luan, T. Yang, J. Ren, R. Li, and Z. Zhang, "Broadband beam-scanning phased array based on microwave photonics," Electronics, vol. 13, no. 7, 2024.

Mikrovalono-fotonski radar

Optično filtriranje

- bolj prilagodljivi filtri kot električni
- možna implementacija sit s končnim (FIR) in neskončnim (IIR) odzivom.

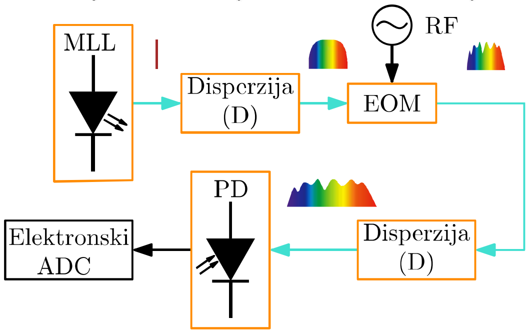


Blokovni načrt optičnega sita s končnim odzivom.
S. Pan and Y. Zhang, "Microwave photonic radars," Journal of Lightwave Technology, vol. 38, no. 19, pp. 5450–5484, 2020.
VUK BALIŽ, Kristjan. Izvedba visokofrekvenčnih sit s tehniko mikrovalovne fotonike : magistrsko delo. Ljubljana: [K. Vuk Baliž], 2019. XIX, 72 str., ilustr. https://repozitorij.uni-lj.si/IzpisGradiva.php?id=109650. [COBISS.SI-ID 12667220]

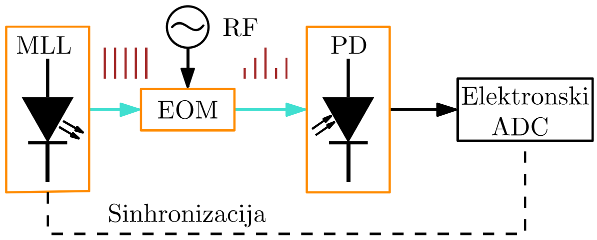
Mikrovalono-fotonski radar

Optični analogno-digitalni pretvorniki (ADC)

- omogočajo višje vzorčne frekvence in večje efektivno število bitov
- večina metod izkorišča MLL za generiranje časovno zelo kratkih impulzov
- možna uporaba več vzporednih sistemov za povečanje vzorčne frekvence



Blokovni načrt ADC z optičnim predprocesiranjem.
R. A. Minasian, E. H. W. Chan, and X. Yi, "Microwave photonic signal processing," Opt. Express, vol. 21, no. 19, pp. 22 918–22 936, Sep 2013..

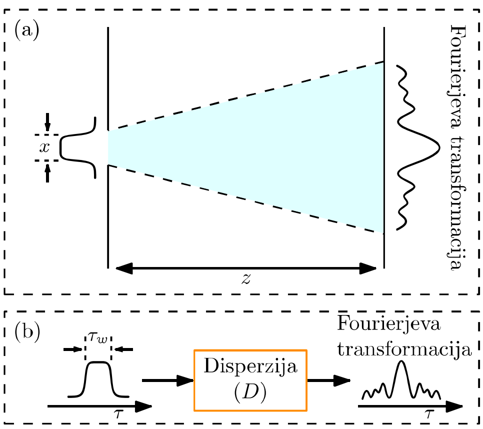


Blokovni načrt ADC z optičnim vzorčenjem.
P. Ghelfi, F. Laghezza, F. Scotti, G. Serafino, A. Capria, S. Pinna, D. Onori, C. Porzi, M. Scaffardi, A. Malacarne, V. Vercesi, E. Lazzeri, F. Berizzi, and A. Bogoni, "A fully photonics-based coherent radar system," Nature, vol. 507, pp. 341–345, 2014.

Mikrovalono-fotonski radar

Optična Fourierjeva transformacija v realnem času (RTFT)

- izkorišča lastnost prostorsko-časovne dualnosti
- vzorec v daljnem (Fraunhoferjevem) polju prikazuje Fourierjevo transformacijo
- nadomesti uporabo DSP modulov z ozkimi pasovnimi širinami



Princip delovanja optične Fourierjeve transformacije.

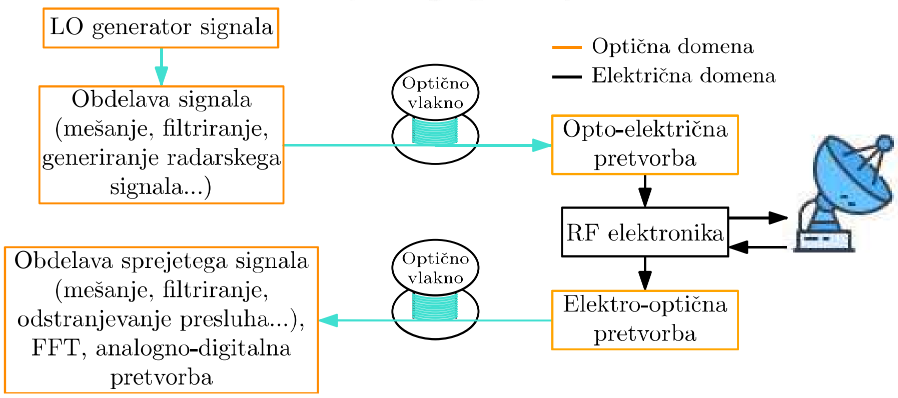
Povzetek

- Prvi radar 1904, začetek pospešenega razvoja pred 2. svetovno vojno, civilna uporaba po 2. svetovni vojni
- Moderni radarji:
  - ↑ osrednje frekvence
  - ↑ pasovna širina
  - ↑ natančnost
  - ↑ energetska učinkovitost
  - sodelovanje večih porazdeljenih radarskih sistemov
- Dopplerjev radar
- Mikrovalovna fotonika
- Mikrovalono-fotonski radar

sok.fe.uni-lj.si 2025

Vprašanja?

luka.podbregar@fe.uni-lj.si



Mikrovalovna fotonika za radarske aplikacije
Microwave photonics for radar applications

Mirco Scaffardi

National Inter-University Consortium for Telecommunications (CNIT)

mirco.scaffardi@cnit.it

Povzetek

Radarski sistemi so ključnega pomena v številnih civilnih aplikacijah, kot so spremljanje zračnega in pomorskega prometa, slikanje zemeljskega površja v visoki ločljivosti iz vesolja, opazovanje naravnih nesreč. Mikrovalovna fotonika je tehnologija, ki omogoča napredne radarske sisteme, ki zahtevajo prilagodljivo generiranje frekvence, programabilno oblikovanje snopa, več in široko porazdeljenih sprejemnikov, večpasovno delovanje, koherentno obdelavo signala za slikanje z visoko ločljivostjo. V tem prispevku se posvečamo zgoraj omenjenim funkcionalnostim s fotonskimi tehnikami, naslovimo pa jih tudi v luči napredka optičnih integriranih tehnologij.

Abstract

Originally developed for detecting enemies in military applications, radar systems have, in recent decades, found widespread use in various civilian and scientific fields, including automation, automotive technology, meteorology, and astronomy. Modern radar systems provide accurate target detection but face limitations such as slow transmission speeds, limited bandwidth, restricted range in distributed systems, and poor resolution. To address these challenges, an innovative approach is required that combines electronic and optical components in the so-called microwave photonic radar.

Biografija avtorja

Mirco Scaffardi je leta 2001 pridobil magistrski naziv iz elektrotehnike na Univerzi v Parmi, doktoriral pa je leta 2005 na Scuola Superiore Sant'Anna. Med letoma 2004 in 2007 je bil raziskovalni sodelavec na Scuola Superiore Sant'Anna, od leta 2007 pa je zaposlen pri CNIT v Pisi, kjer od leta 2018 opravlja funkcijo vodje raziskav. Kot gostujoči raziskovalec je deloval na Danskem, Japonskem in v Kanadi, kjer je leta 2009 prejel štipendijo province Quebec. Od leta 2011 predava na doktorskih in mednarodnih magistrskih programih na Scuola Superiore Sant'Anna. Njegove raziskave se osredotočajo na optično in elektro-optično procesiranje signalov, optično preklapljanje ter fotonske radarske sisteme, pri čemer je soavtor več kot 46 znanstvenih člankov, 87 konferenčnih prispevkov, 15 patentnih predlogov in dveh knjižnih poglavij.

Author's biography

Mirco Scaffardi received his M.S. degree in electronics engineering from the University of Parma in 2001 and his Ph.D. from Scuola Superiore Sant'Anna in 2005. He was a research fellow at Scuola Superiore Sant'Anna from 2004 to 2007 and has been with CNIT, Pisa, since 2007, serving as head of research since 2018. He has been a visiting researcher in Denmark, Japan, and Canada, receiving a Quebec state scholarship in 2009. Since 2011, he has lectured in Ph.D. and international *master's courses at Scuola Superiore Sant'Anna. His research focuses on optical and electro-optical signal processing, optical switching, and photonic-based radar systems, with over 46 journal papers, 87 conference papers, 15 patent proposals, and two book chapters.*

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PNTLab Photonic Networks&Technologies

INSTITUTE OF COMMUNICATION, INFORMATION AND PERCEPTION TECHNOLOGIES

Scuola Superiore Sant'Anna

Microwave photonics for radar applications

Mirco Scaffardi

National Inter-University Consortium for Telecommunications (CNIT)

CNIT-PNTLab– Pisa, Italy

27th Seminar on Optical Communications

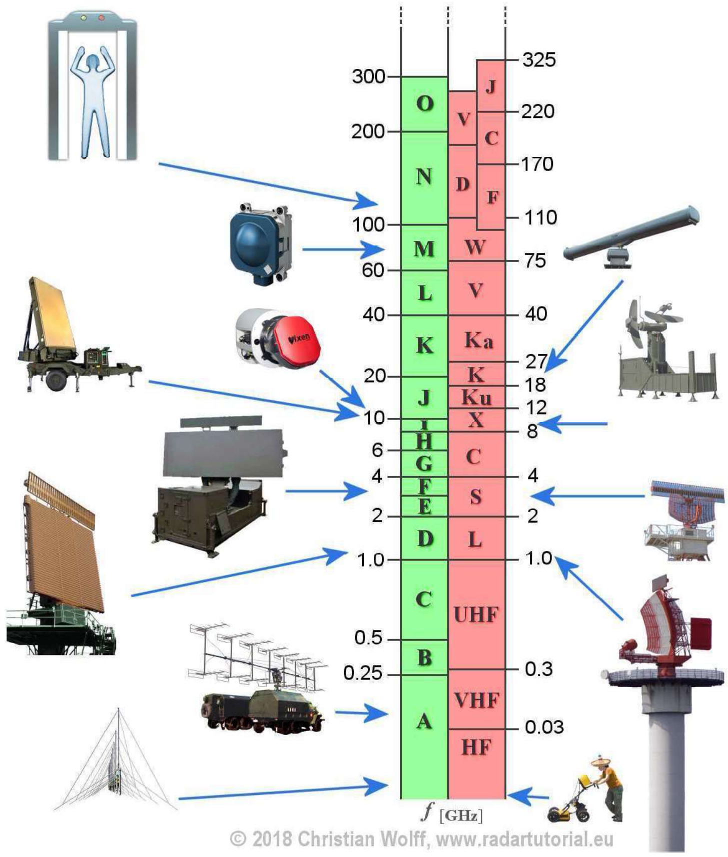
7 February 2025

Faculty of Electrical Engineering, Ljubljana

Radar system scenario

➢**Different functionalities could be exploited via different systems:**

- ✓**Different carrier frequency**
- ✓**Different waveforms**
- ✓**Different bandwidth**
- ✓**……**

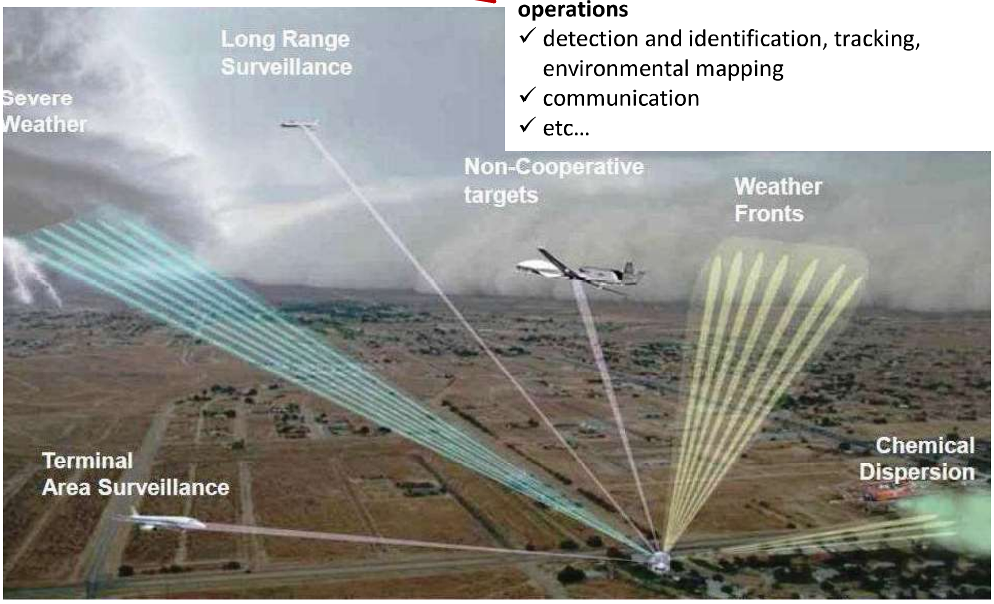


Future radar concept

MULTIFUNCTION ADAPTIVE and MINIATURIZED RADAR

a single RADAR unit performing multiple operations

- ✓ detection and identification, tracking, environmental mapping
- ✓ communication
- ✓ etc…

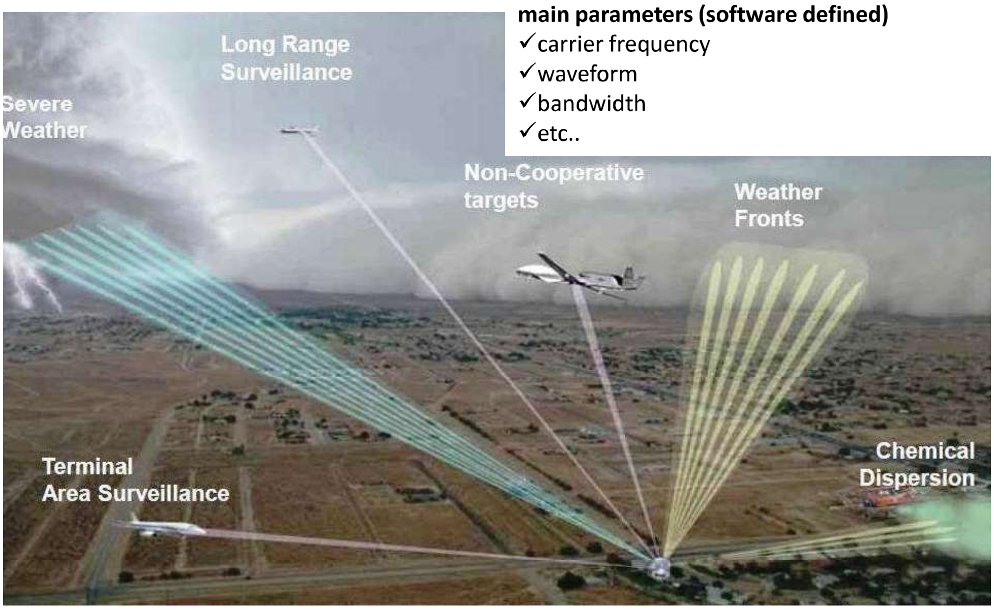


Future radar concept

MULTIFUNCTION ADAPTIVE and MINIATURIZED RADAR

a single RADAR unit able to adaptively change its main parameters (software defined)

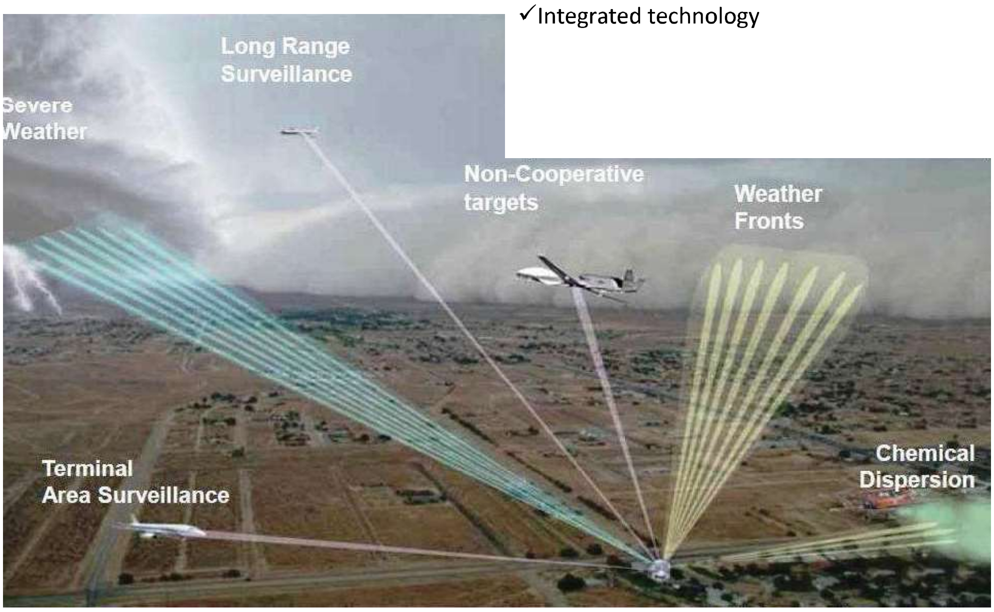
- ✓ carrier frequency
- ✓ waveform
- ✓ bandwidth
- ✓ etc..



Future radar concept

MULTIFUNCTION ADAPTIVE and MINIATURIZED RADAR

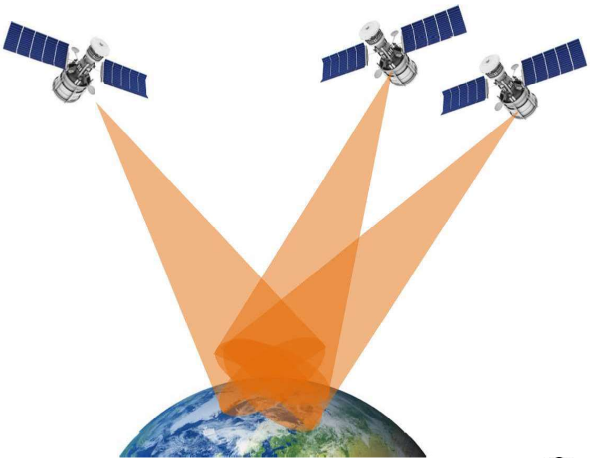
a single RADAR unit ideally on chip
✓Integrated technology

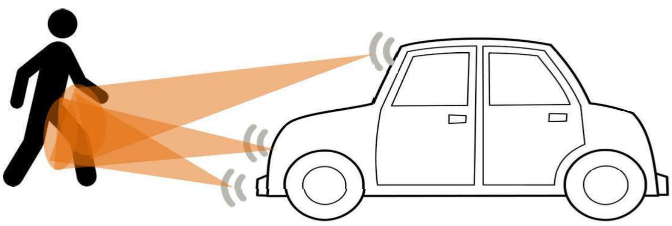


Future radar network concept

DISTRIBUTED RADAR

A network of spatially distributed RADARs coherent each other
✓simplified data fusion
✓Increased resolution





Key challenges with RF technology:

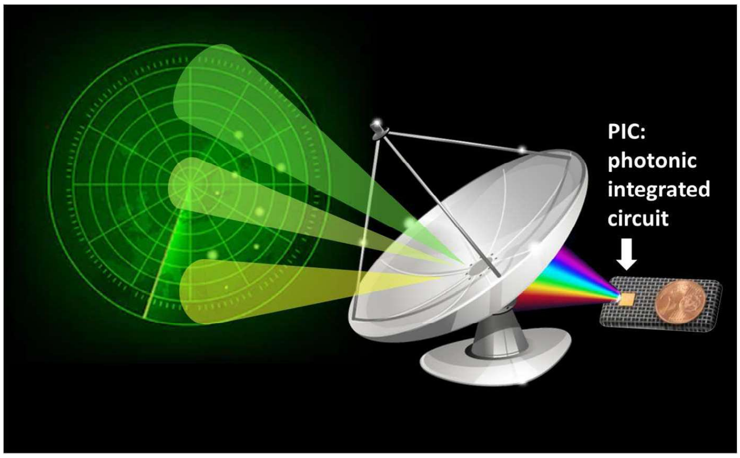
✓Frequency agility

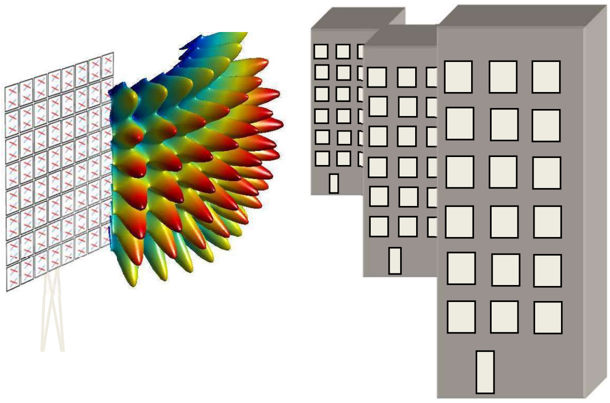
✓Coherent signal distribution

✓Fast and precise elaboration

Photonics-based radars

Photonics for radars





Radar (radio detection and ranging) and Lidar (light detection and ranging)

Laser

LIDAR

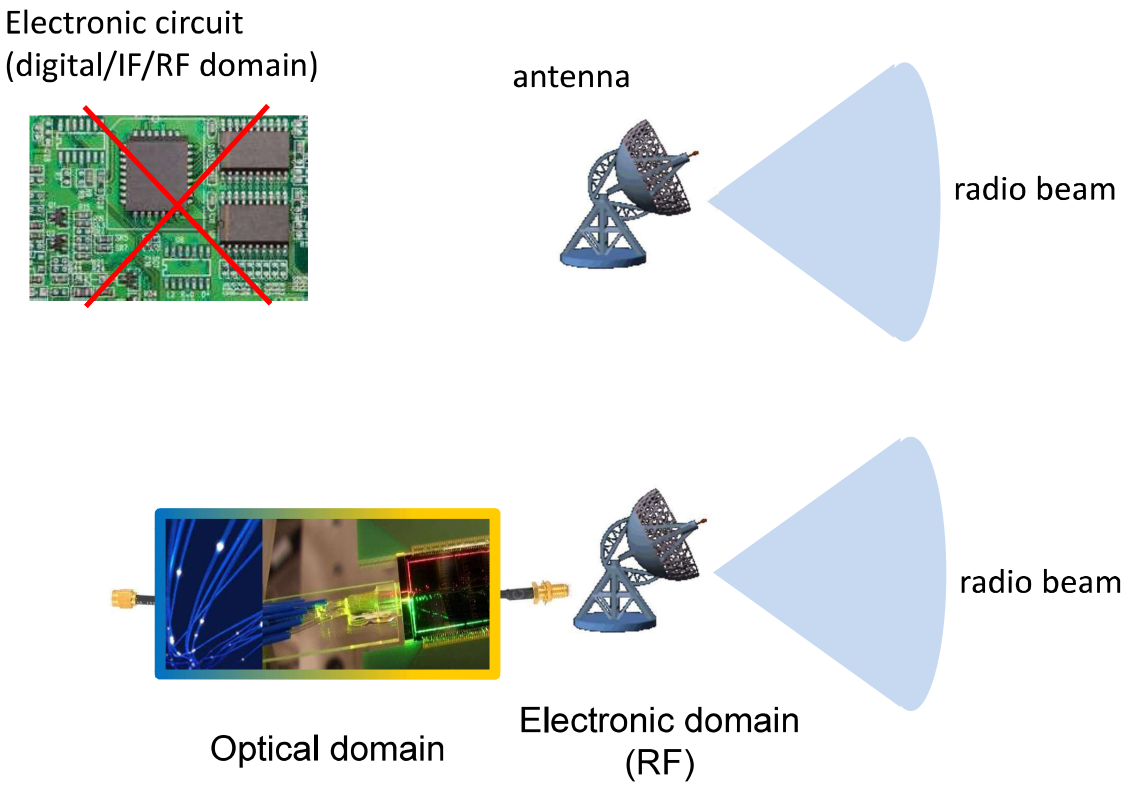
Light beam

Electronic circuit

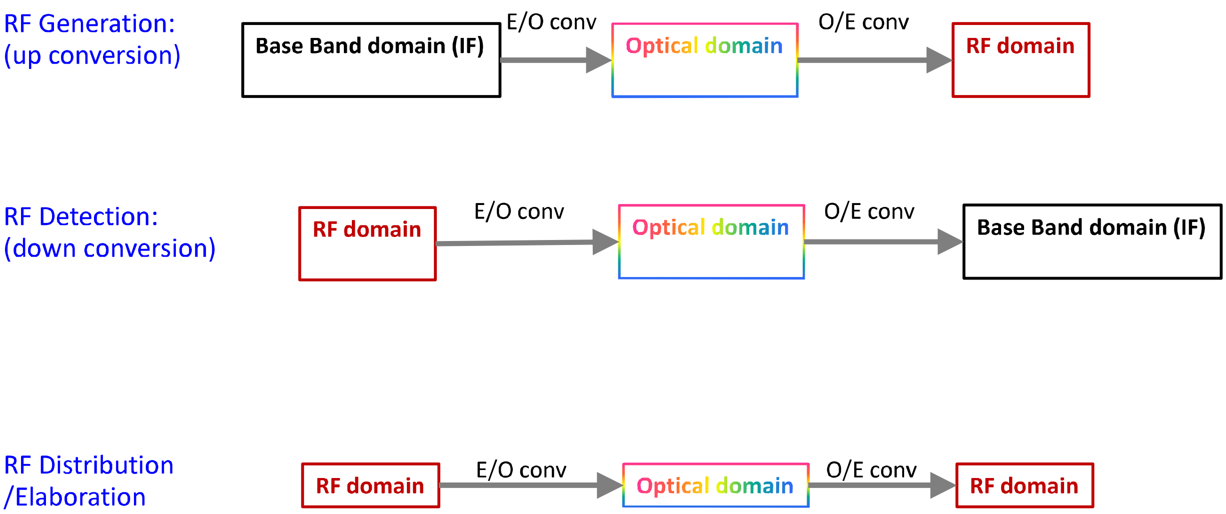
antenna

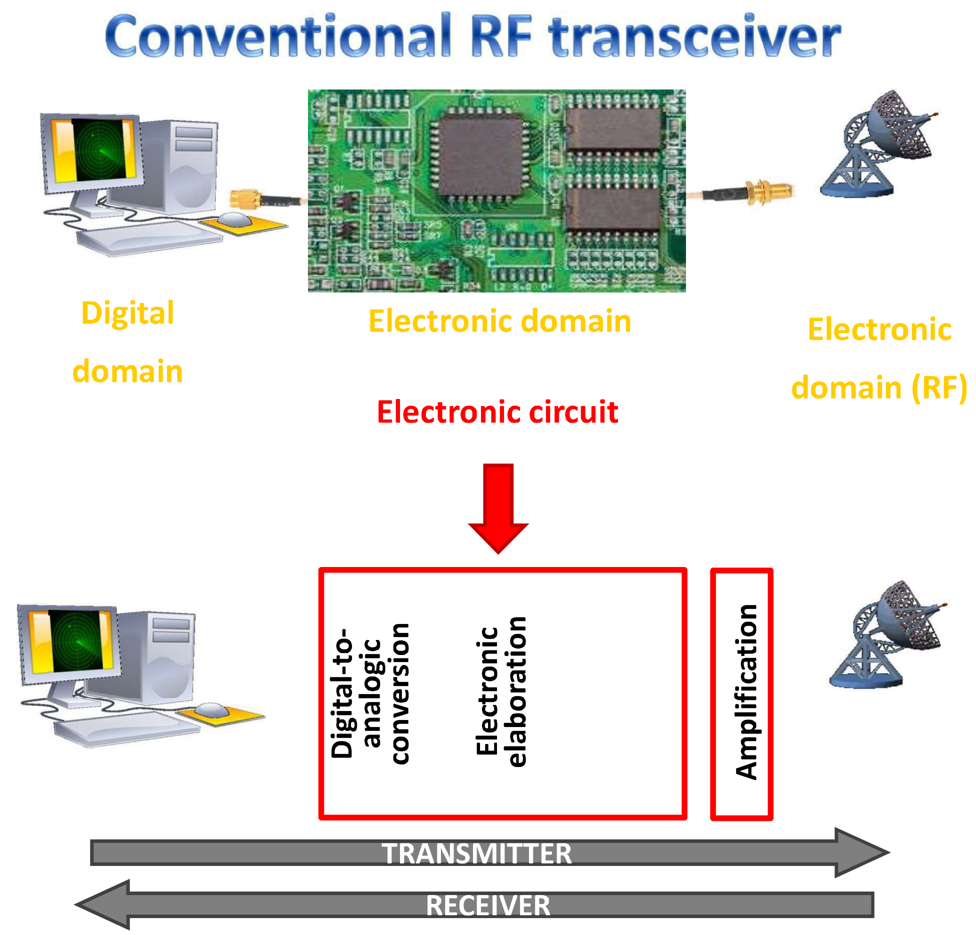
radio beam

Photonics-based radar

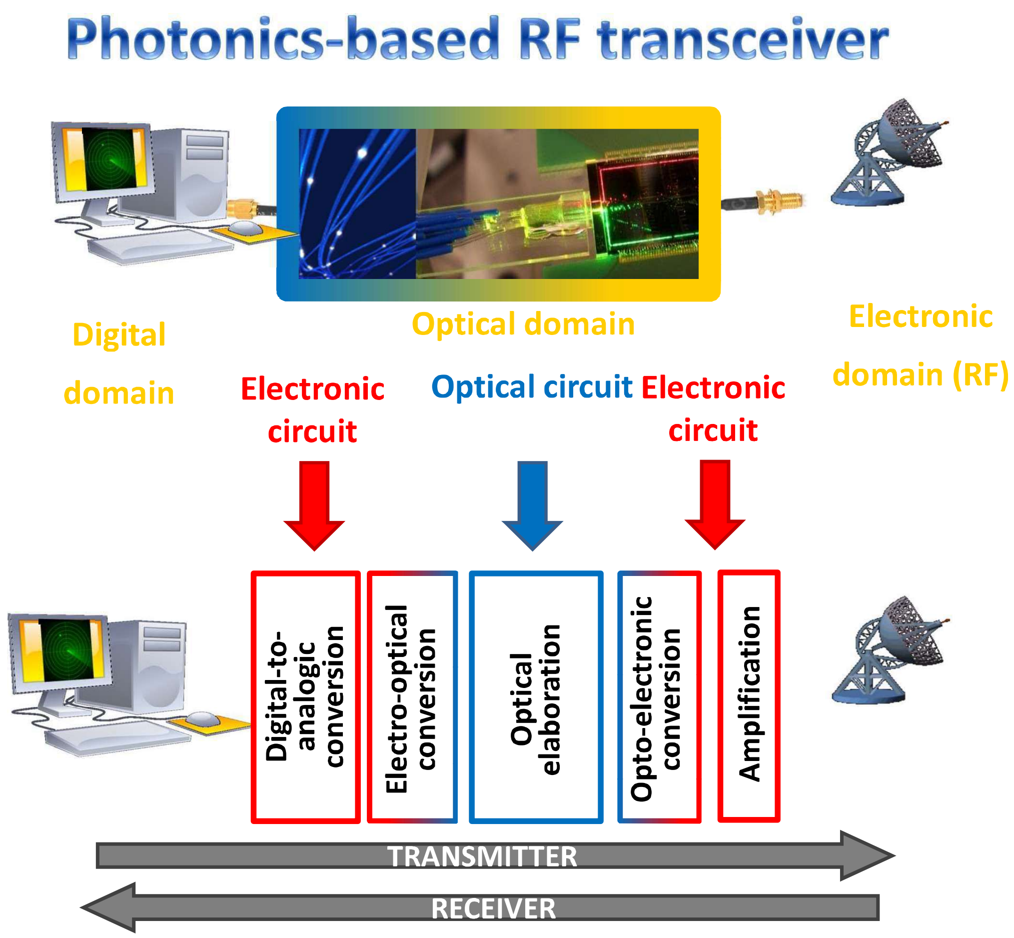


Photonics in radar



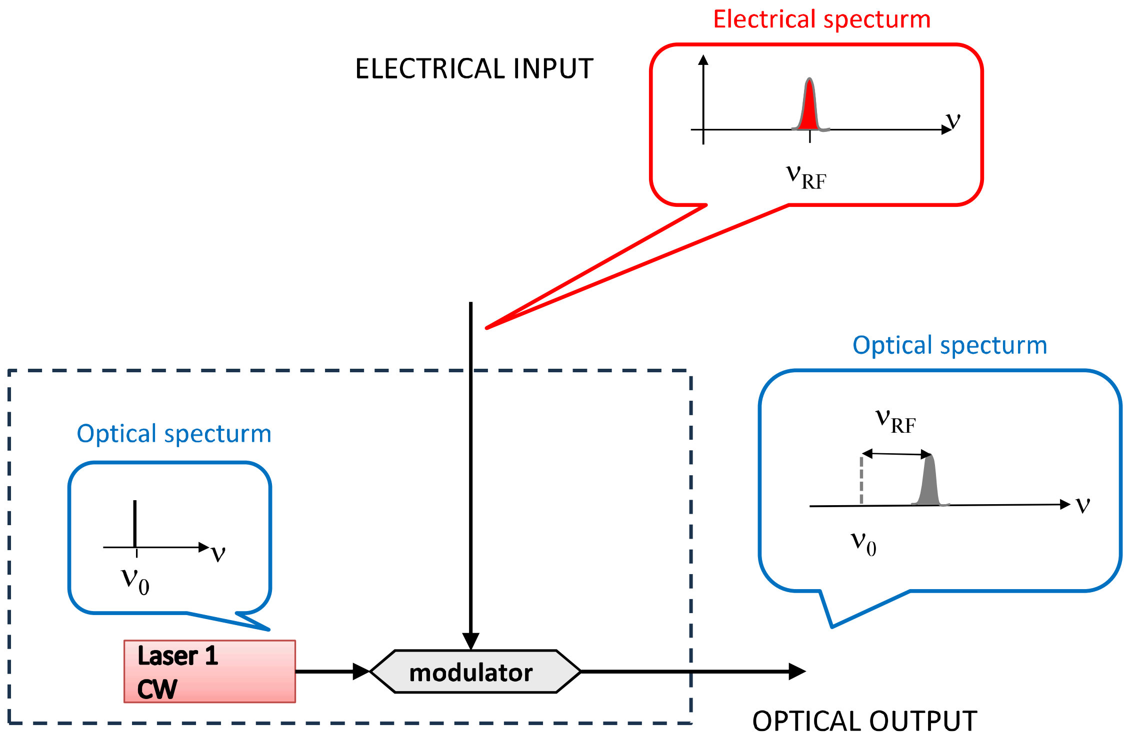


Conventional RF transceiver
Digital domain
Electronic domain
Electronic domain (RF)
Electronic circuit
Digital-to-analogic conversion
Electronic elaboration
Amplification
TRANSMITTER
RECEIVER

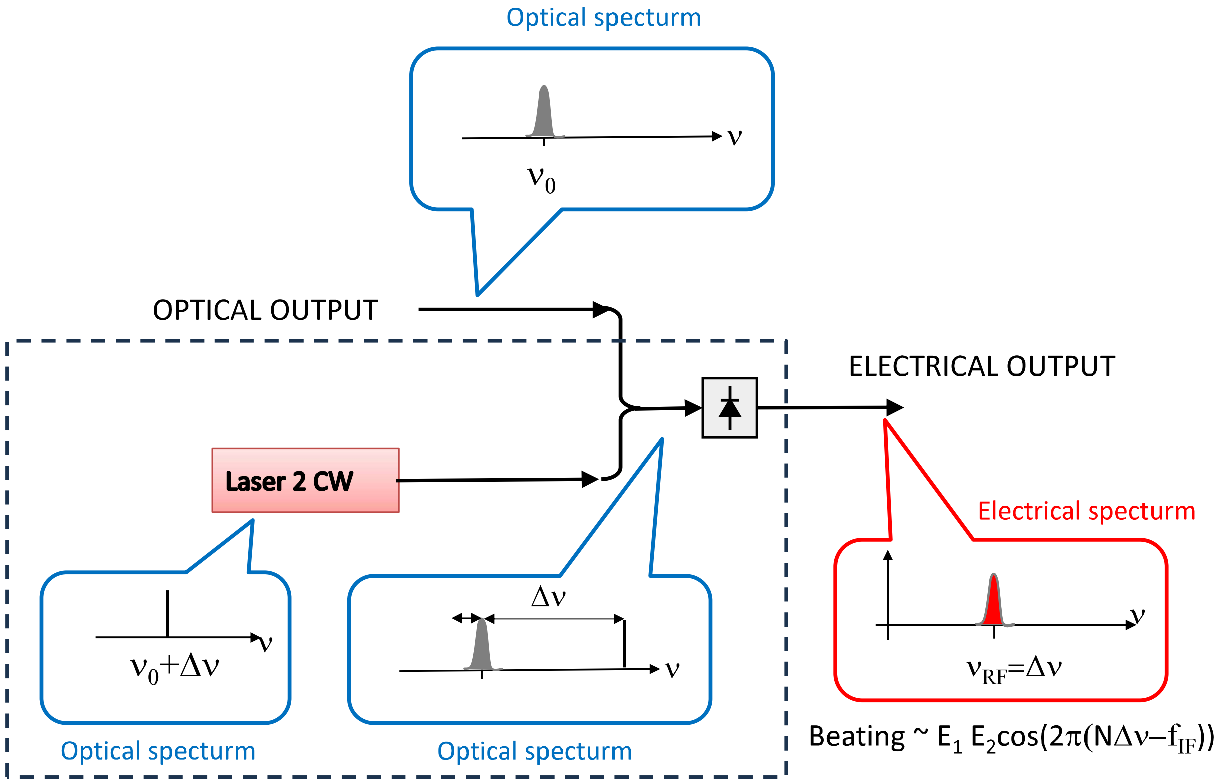


Photonics-based RF transceiver
Digital domain
Optical domain
Electronic domain (RF)
Electronic circuit
Optical circuit
Electronic circuit
Digital-to-analogic conversion
Electro-optical conversion
Optical elaboration
Opto-electronic conversion
Amplification
TRANSMITTER
RECEIVER

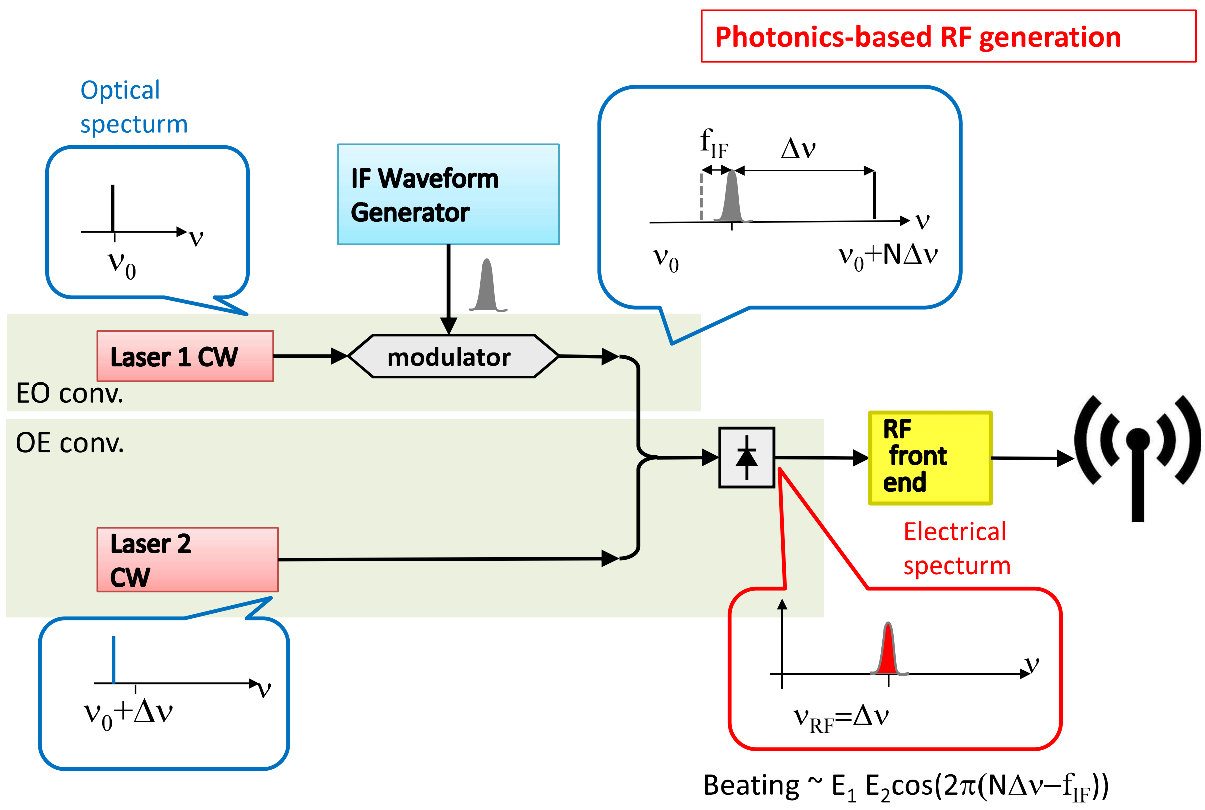
Electro-optical conversion



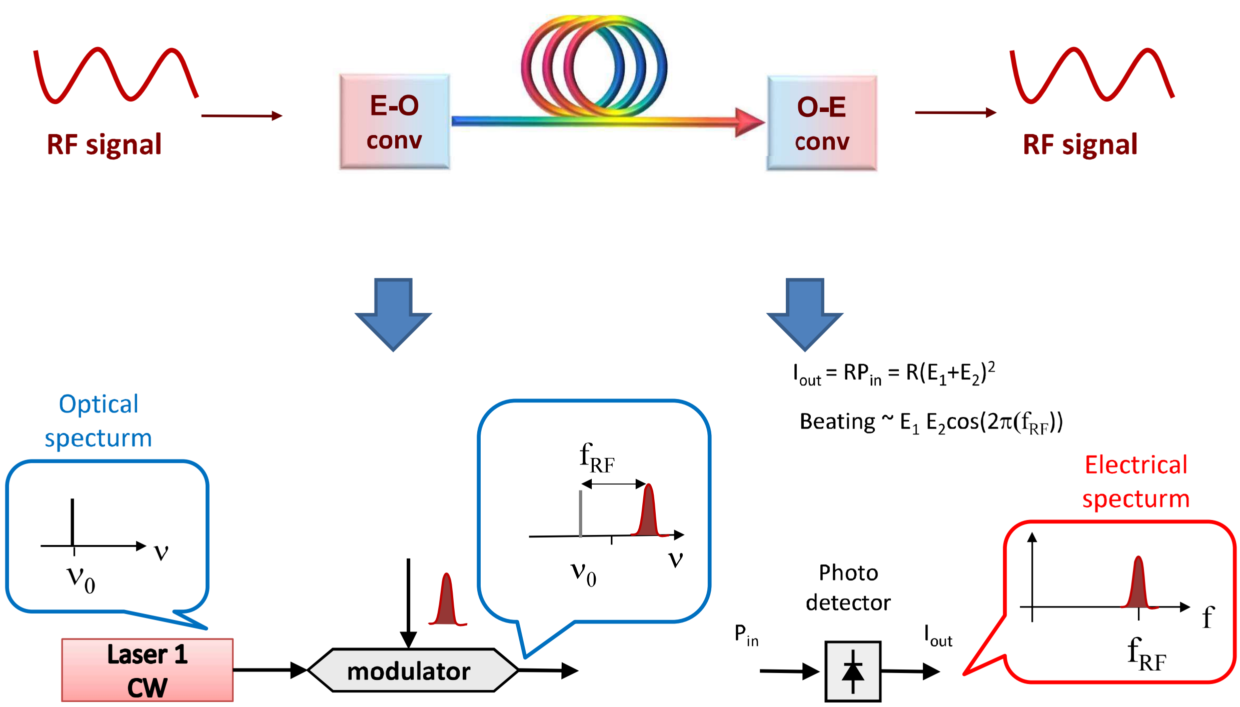
Opto-electrical conversion



Photonics-based up/down converison



Radar signal distribution



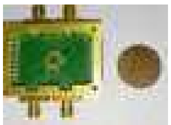
SoA of photonics-based radars

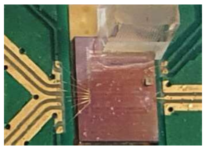
BULK

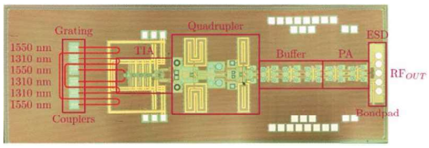
- P. Ghelfi et al., "A fully photonics-based coherent radar system", NATURE, 507, 2014
- Y. Li et al., "Photonic Radar for 3D Imaging: From Millimeter to Terahertz Waves", IEEE JSTQE, V.29, n.5, 2023
- Z. Ziqian et al., "Photonic radar for contactless vital sign detection", NaturePhotonics, 17, 2023
- …

ON CHIP:

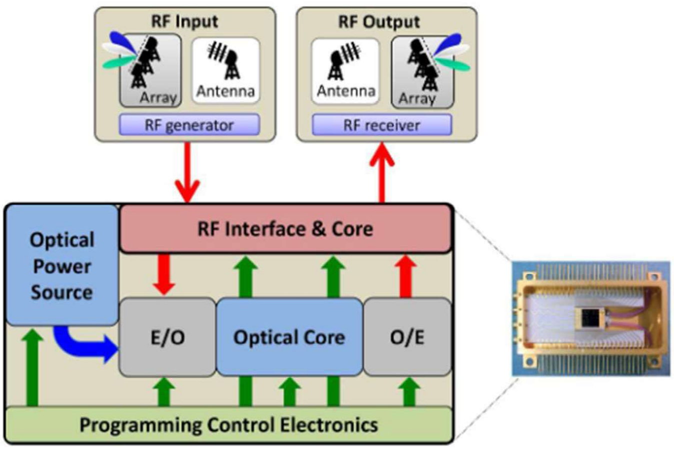
- S Li et al., "Chip-Based Microwave-Photonic Radar for High-Resolution Imaging", Laser&Photonics Reviews, 2020
- F. Falconi et al., "A Combined Radar & Lidar System Based on Integrated Photonics in Silicon-on-Insulator", IEEE JLT, V.39, n.1, 2021
- "Silicon Photonic Radar Transmitter IC for mm-Wave Large Aperture MIMO Radar Using Optical Clock Distribution", IEEE MWC Letters, V.31, n.6, 2021
- …







Photonic material platforms



Photonic IC

S. Iezekiel, "Integrated microwave photonics: a key enabling technologyfor radio-over-fiber," in Broadband Access Communication TechnologiesXI, Vol. 10128 (SPIE, 2017).

InP

Silicon photonics

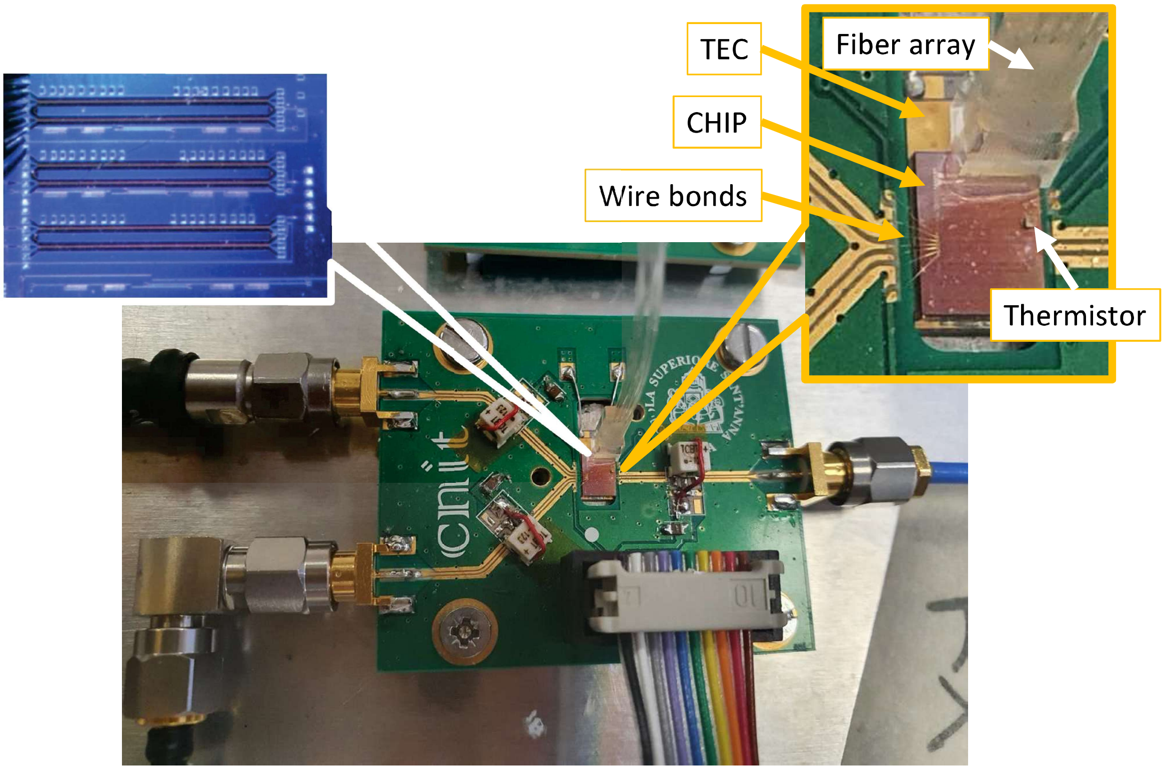
Silicon nitride

Lithium Niobate on Insulator (LNOI)

We used first SOI technology as the most mature photonics technology

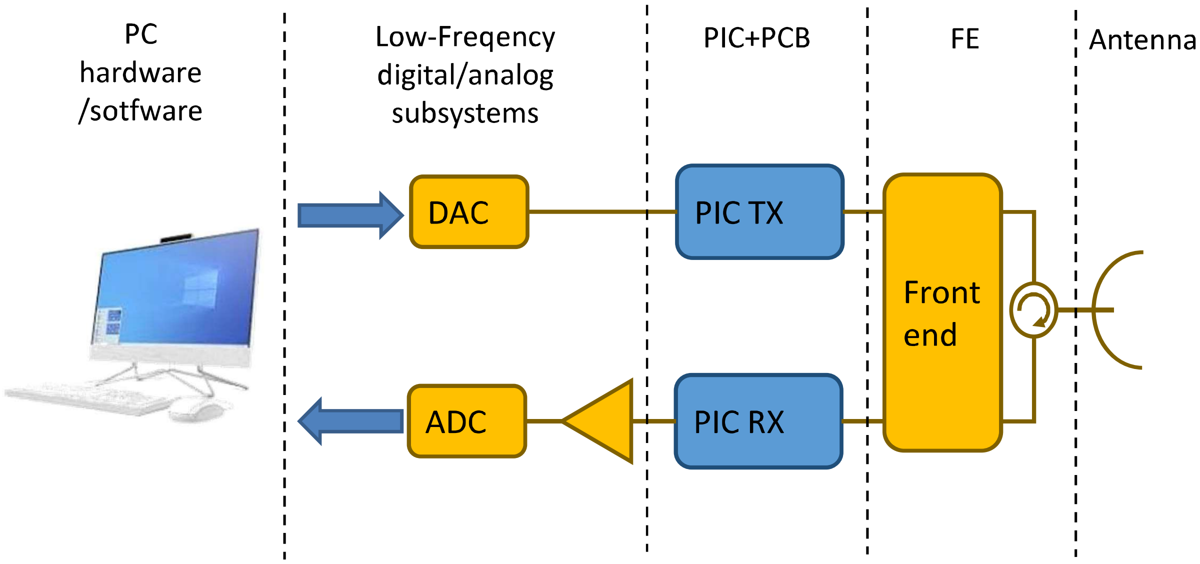
Falconi F., et al., IEEE J. of Lightwave Technology, Vol 39, n.1, 2021

Our first photonics-based radar on chip: SOI technology + external laser

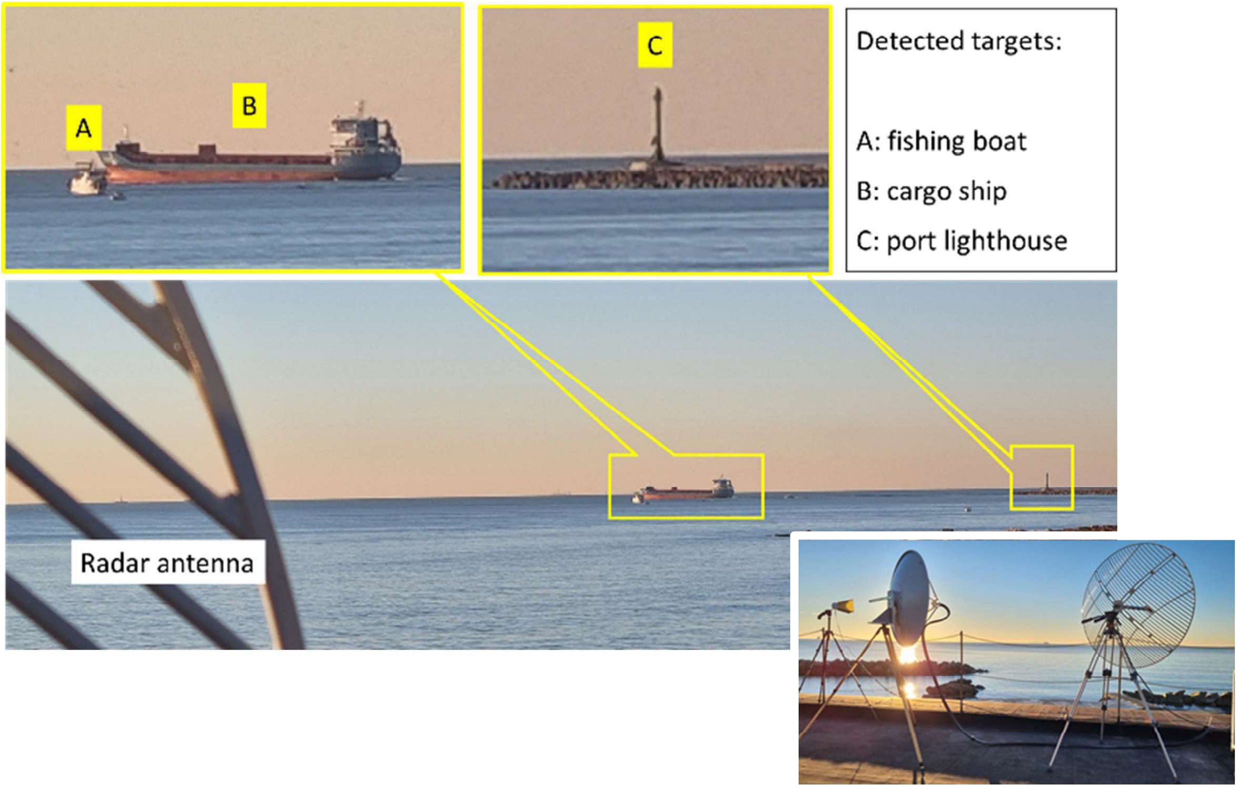


photonics-based radar on chip: system demonstration

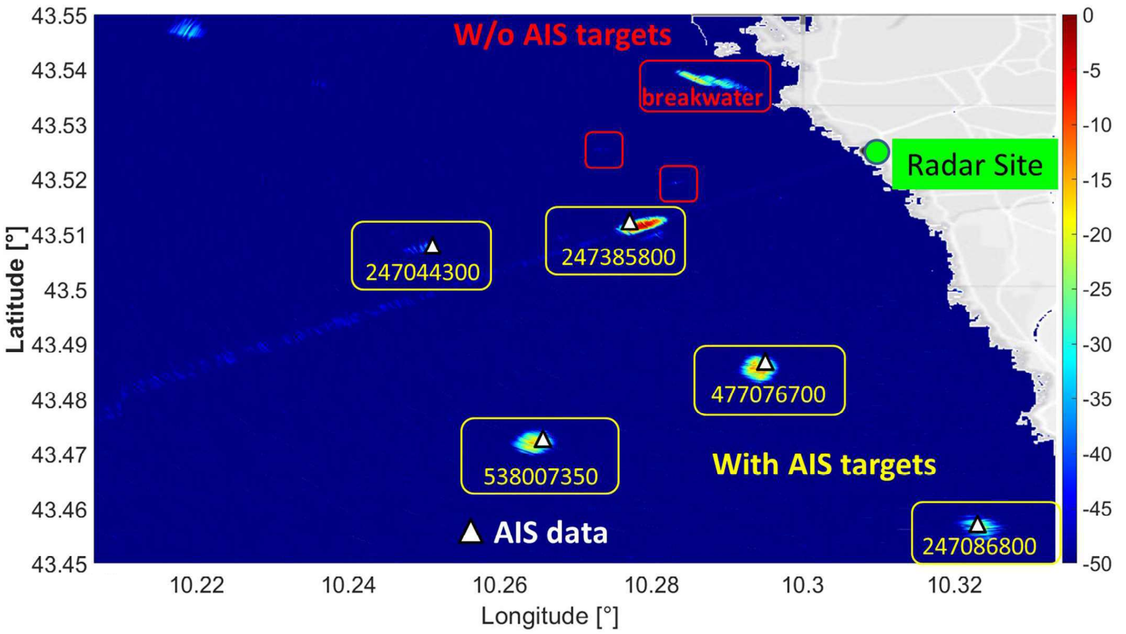
Complete radar system



Scenario for biband detection (X and S band)



Comparison between radar detection and AIS data



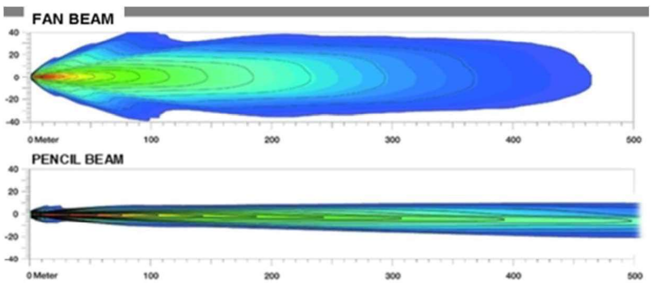
Prototype performance

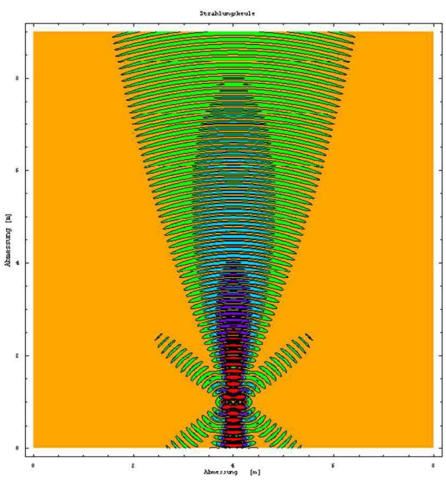
INTEGRATED RADAR TRANSCEIVER	Expected value	Reached value
Transmitter		
RF carriers	4 carriers (S, C, X, Ku)	4 carriers (S, C, X, Ku)
Signal max instantaneous band	500 MHz (total band to be distributed among the 4 RF carriers)	> 500 MHz (used 100 MHz due to available equipment)
Signal jitter	< 15 fs (10kHz-10MHz)	Independent on the chip Dependent on the used clock
SNR	> 70 dB/1MHz	56 dB/1MHz
Spurious free dynamic range	> 50 dBc	53 dBc
Receiver		
RF carriers	4 carriers (S, C, X, Ku)	4 carriers (S, C, X,Ku)
Signal max instantaneous band	500 MHz (total band to be distributed among the 4 RF carriers)	> 500 MHz (used 100 MHz due to available equipment)
SNR	> 70 dB/1MHz	56 dB/1MHz
Spurious free dynamic range	> 50 dBc	53 dBc

BeamForming

Beamforming = Beam Shaping + Beam Steering

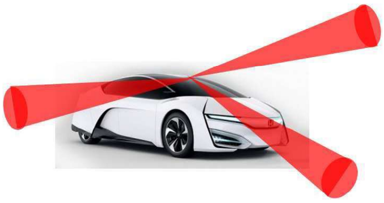
- Beam shaping consists in modeling an antenna radiation pattern to give it the desired shape



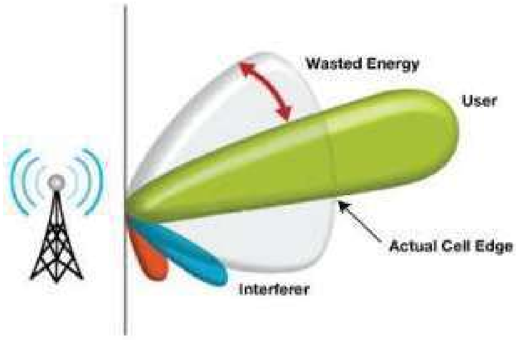


- Beam steering consists in a controlled variation of the antenna's pattern lobes direction

BeamForming benefits



- Optimization of resources allocation

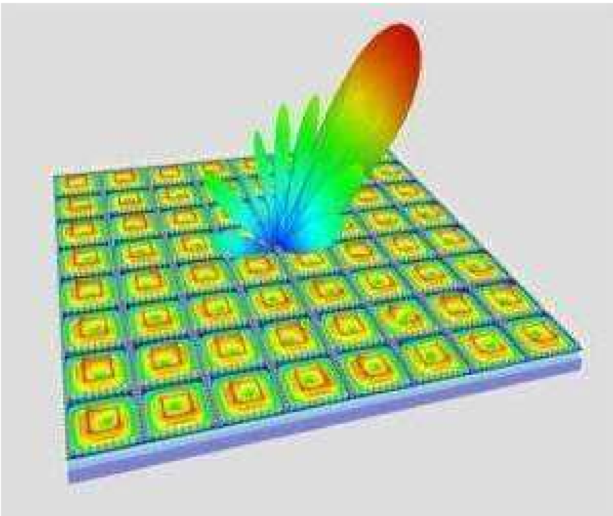


- Tracking of moving target

- Lower energy consumption

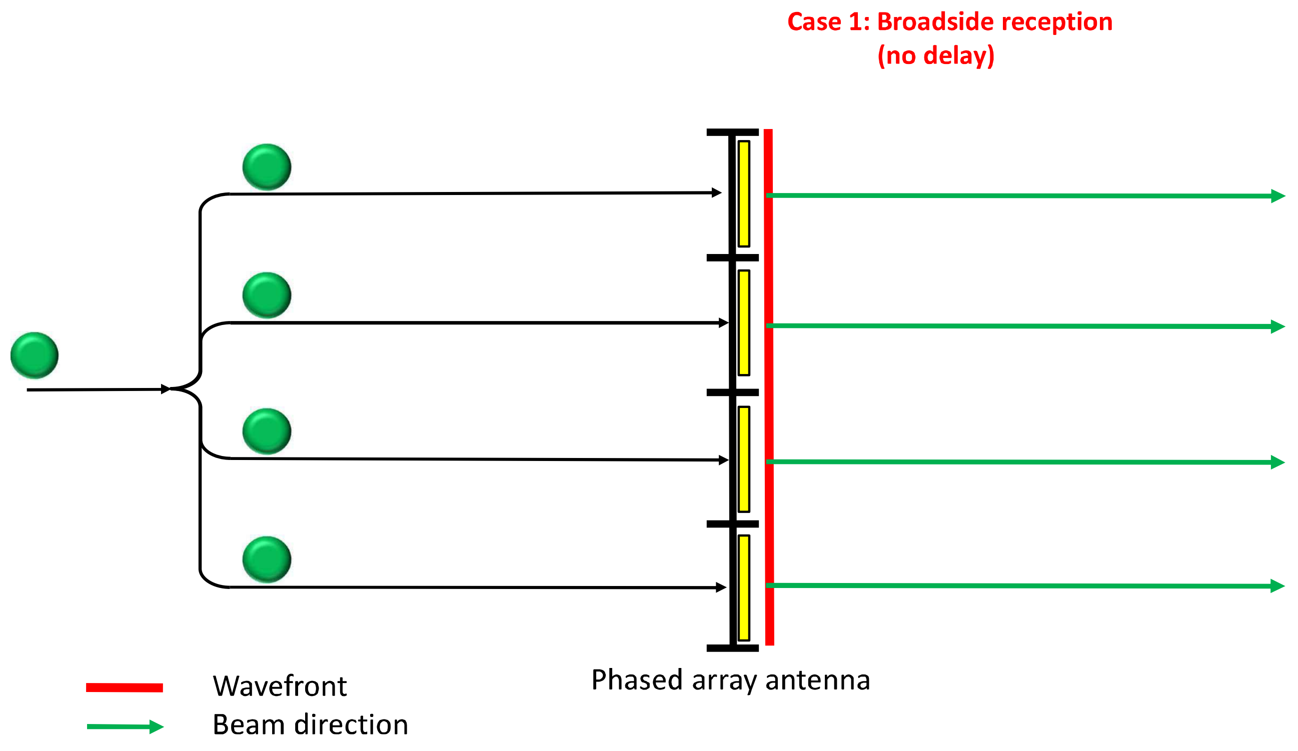
- 5G is considering using beamforming for giving all the BW to smaller areas

How to realize BeamForming

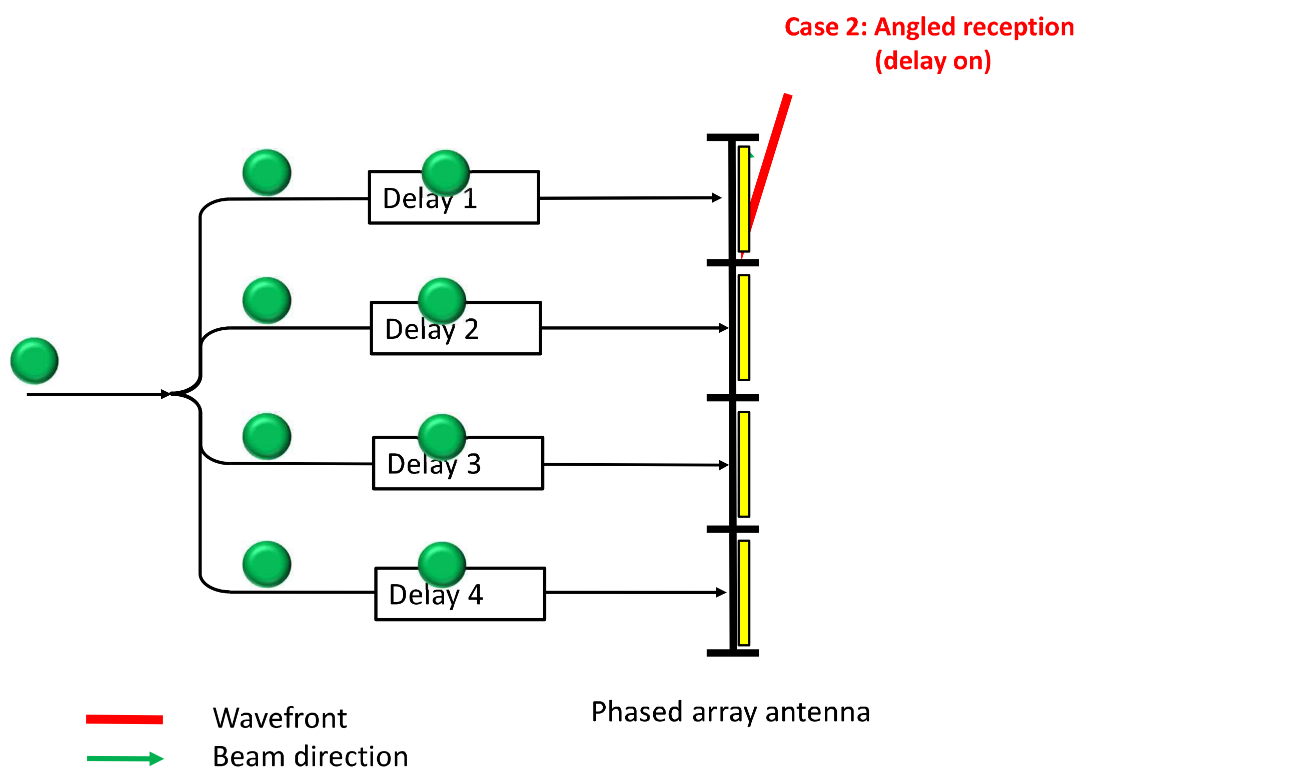


Arrays of antennas

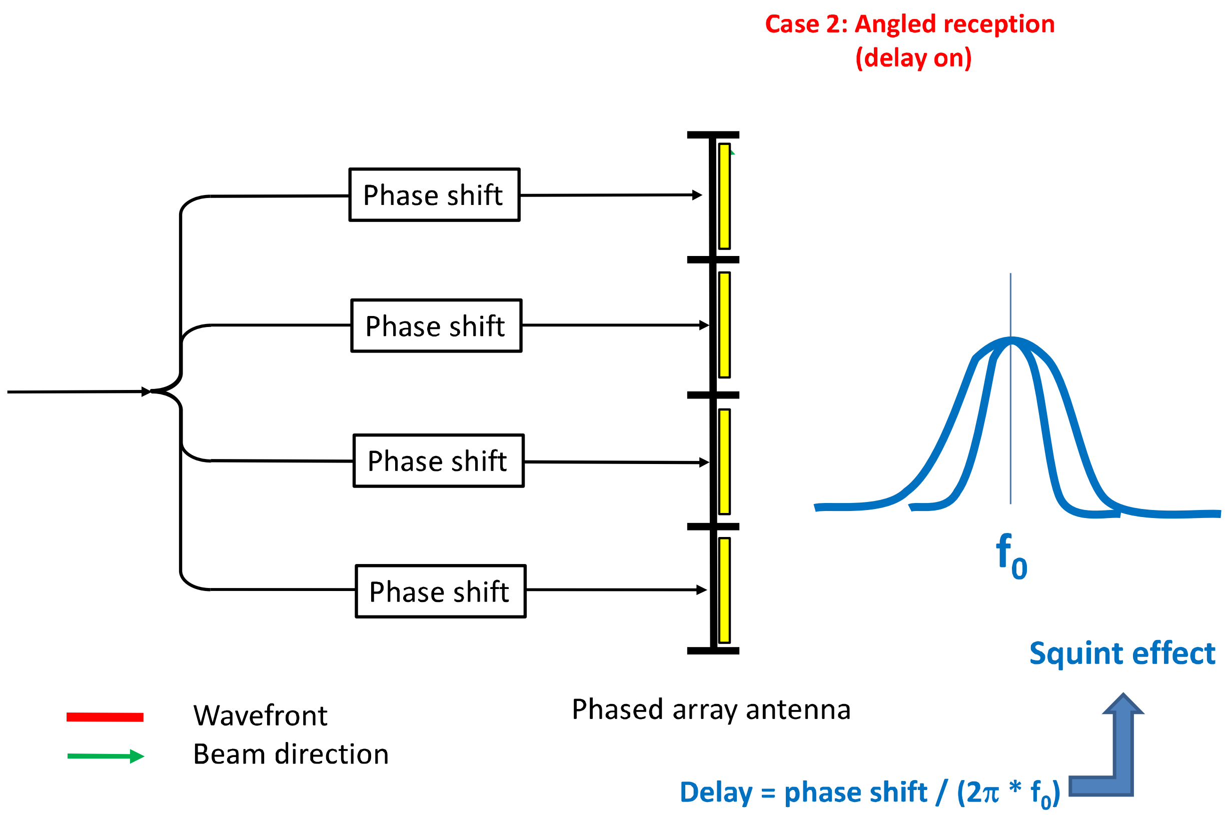
BeamForming concept



BeamForming concept



BeamForming concept



Electronics vs. optics

Electronic beamforming can not be based on true time delay (TTD)

Based on phase shift

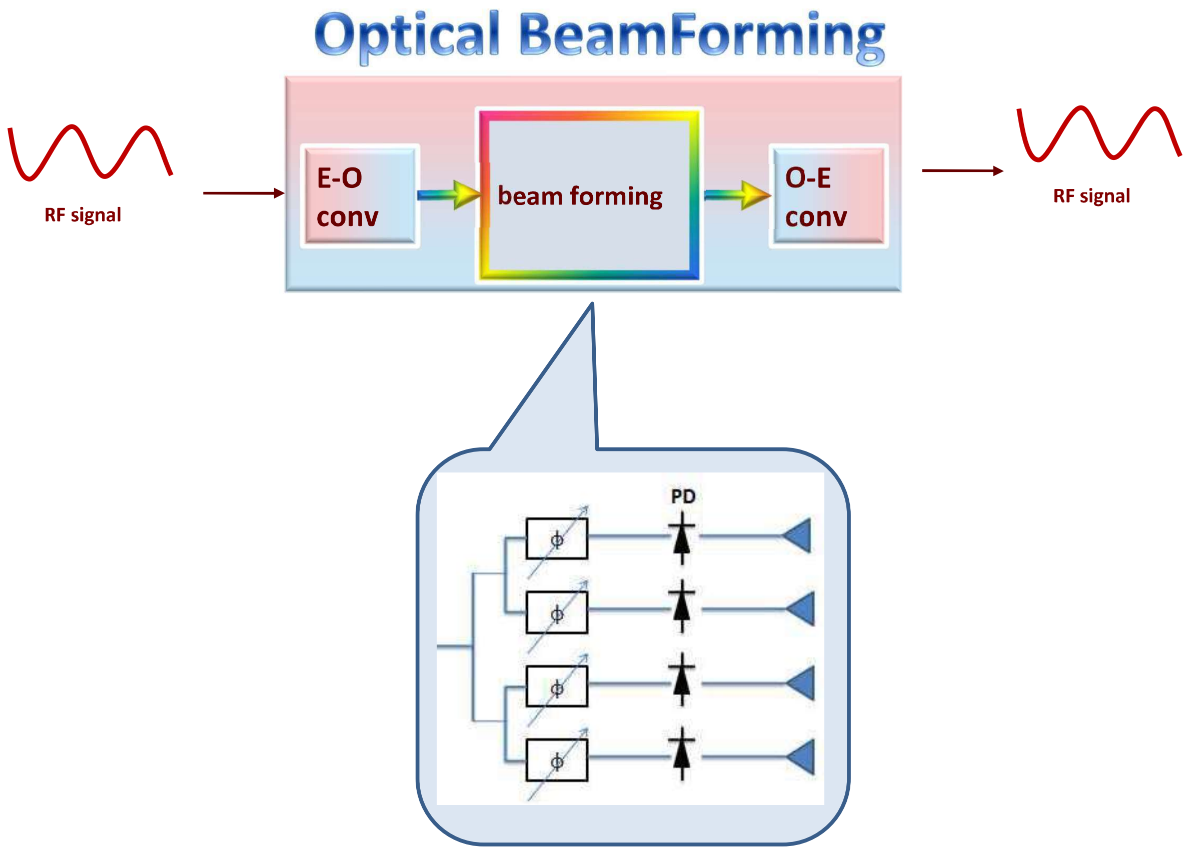
- ✓ Sensitive to Squint effect (that poses a limitation on signal bandwidth)
- ✓ Limited tunability speed
- ✓ Limited pointing precision
- ✓ High power consumption
- ✓ High footprint

Optical beamforming can be based on both TTD or phase shift:

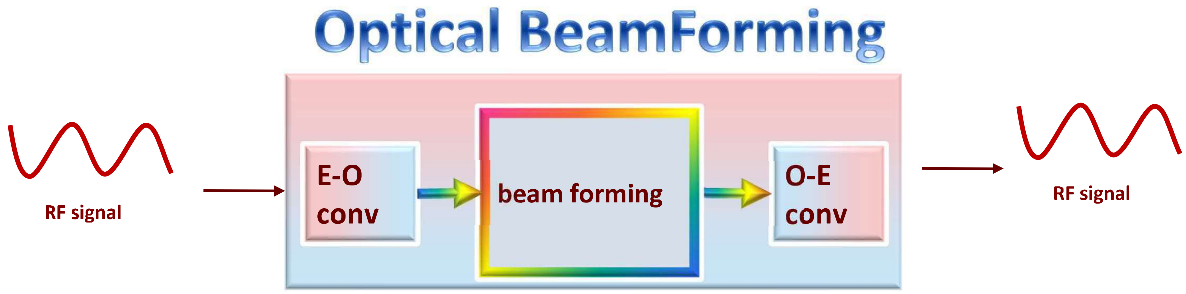
- ✓ faster beam tuning
- ✓ higher precision

TTD systems: squint-free ☺, complex, typically stepwise ☹

PS systems: simpler ☺, squint-limited ☹



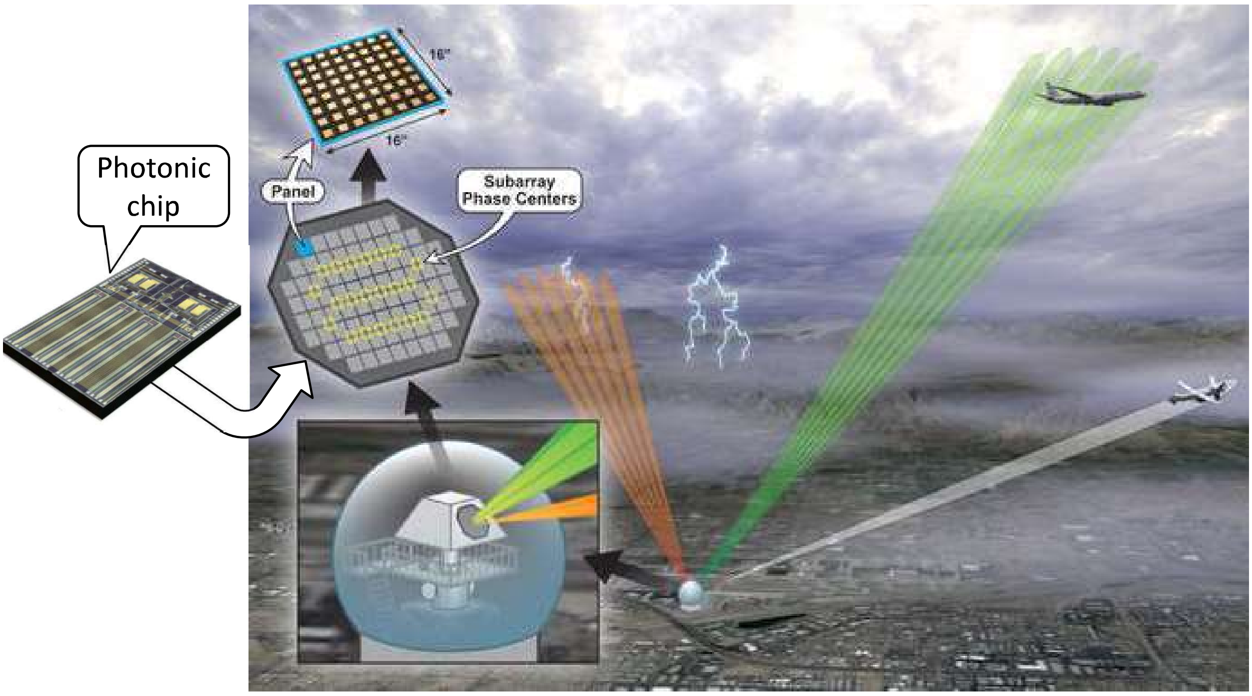
Principle: controlling **phase or delay** of sideband or carrier



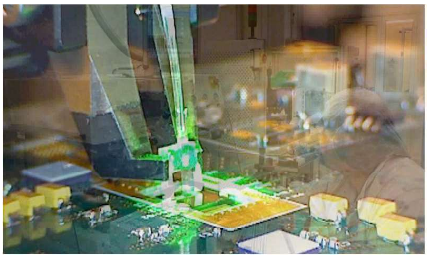
Benefits of optical beamforming

- ✓ **Based on True Time Delay (TTD) (independent on Squint Effect) or phase shifters (PS)**
- ✓ **Larger bandwidth (TTD)**
- ✓ **Fast tunability (Phase shifter)**
- ✓ **Higher precision**
- ✓ **EMI free**
- ✓ **Smaller footprint**

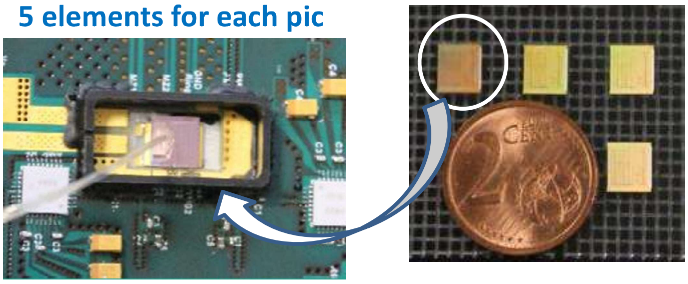
A photonics-based transceiver with BeamForming



Optical beamforming net



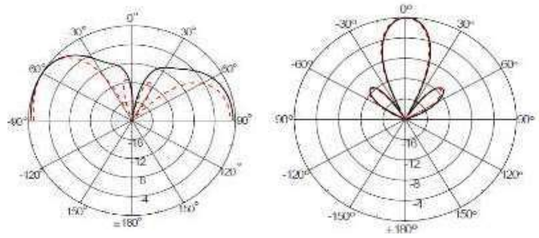
5 elements for each pic



Specs

RF frequency	**13 GHz and odd multiples**
Phase precision	**0.06° (SoA: >4°)**
Response time	**<1ns (SoA: >>1μs)**
3-dB bandwidth	**400MHz**
PIC loss (including 4dB for coupling)	**10 dB**
Total RF loss	**40dBm**
Output RF power	**-40dBm**

4 antenna elements system experiment



Serafino G., Porzi C., Falconi F., Pinna S., Puleri M., D'Errico A., Bogoni A., Ghelfi P., "Photonics-Assisted Beamforming for 5G Communications", IEEE Photonics Technology Letters, Vol. 30, n. 21, pp. 1826-1829, 2018

Main KPIs in MWP

- the RF/IF to IF/RF conversion loss (Lc)
- the spurious free dynamic range (SFDR)
- the noise figure (NF)

Photonic up/down conversion performance

Parameter	SFDR	NF	L_c
Requirement	>100 dB·Hz^2/3	<30dB	<10dB

Next steps to overcome the open issues

The limits demonstrated in the first prototype concerns the conversion loss Lc
Which resulted too high (>55 dB) for each down conversion. These high values are to be attributed:

1. to the high losses of silicon guides
2. the low efficiency of silicon optical modulators

These criticalities can be overcome with technological advances:

1. Introduce amplification stages to reduce losses in the photonic circuit. It is possible with a hybrid integration platform.

Toward the photonics-based radar on chip

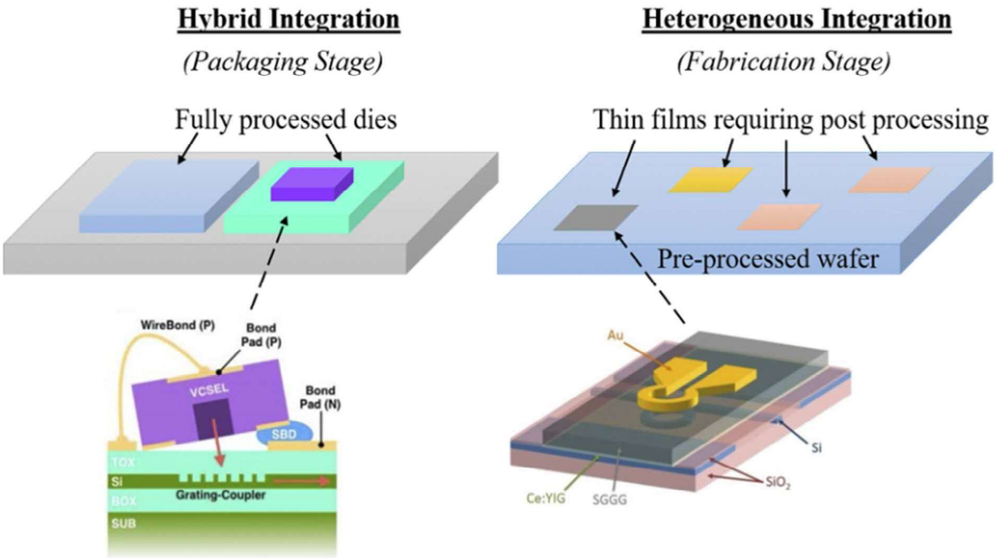
2. The best technology so far for implementing MODs is the bulk lithium niobate (LN) where the electro-optic Pockels effect ensures pure phase modulation, allowing the implementation of highly linear MODs even in SSB-CS configurations.

Very recently, the technology of lithium niobate on insulator (LNOI) is being developed gaining lot of attention for allowing LN modulators on chip with much lower Vπ per unit length and strongly reduced size

However, even LNOI does not provide gaining components as lasers and amplifiers. Consequently, a hybrid approach (i.e., several components separately realized on different materials, combined on the same substrate) is mandatory for implementing linear and efficient microwave photonic circuits.

A.M. Haimovich et al, IEEE Signal Processing Magazine, 2008.
T.Derham et al., IEEE Radar 2006.
P. Ghelfi, et al., Nature, vol. 507, no. 7492, 2014.
F. Scotti, et al., IEEE Trans. Microwave Theory Techn., vol. 63, no. 2, , 2015.

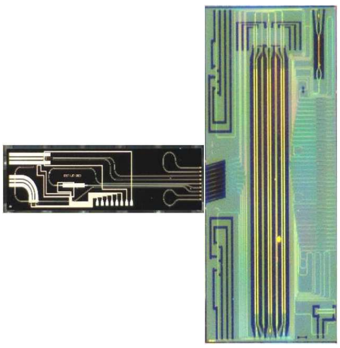
Hybrid and heterogeneous approach

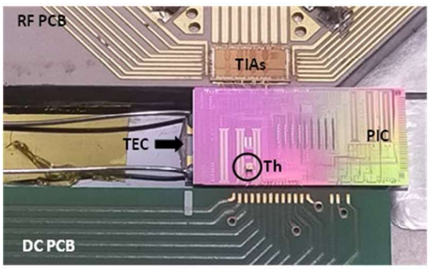


Kaur, A. Boes, G. Ren, T. G. Nguyen, G. Roelkens, and A. Mitchell,"Hybrid and heterogeneous photonic integration," 6, 061102 (2021).

Previous and in progress developments

- Monolitic InP
- Hybrid InP-SOI
- Hybrid InP-LNOI
- Heterogeneous InP-LNOI





- S. Vera et al., "Hybrid InP-LNOI photonic integrated frequency converter for microwave photonics applications " MWP2024, Pisa, Italy
- F. Camponeaschi et al., "Heterogeneously Integrated Multi-band Radar Transceiver Based on Micro-Transfer-Printing" MWP2024, Pisa, Italy

Photonic up/down conversion performance

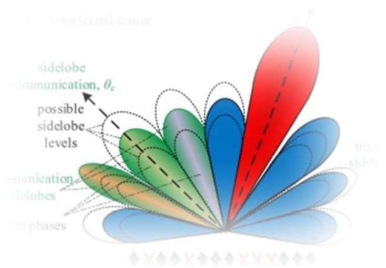
	Parameter	SFDR	NF	L_c
	Requirement	>100 dB·Hz^2/3	<30dB	<10dB
✗	Silicon Photonics (with external laser)	>95 dB·Hz^2/3	>55dB	>55 dB
✗	Monolitic InP	>80 dB·Hz^2/3	>50dB	>30 dB
✗	Hybrid InP -LNOI	>85 dB·Hz^2/3	>40dB	>25dB
?	Heterogeneous integration on LNOI	>85 dB·Hz^2/3	>34dB	>12dB

Simulated performance comparison of IMWP-based back-to-back RF distribution

	Parameter	SFDR	NF	L_c
	Requirement	>100 dB·Hz^2/3	<30dB	<30dB
✗	Monolithic InP	95 dB·Hz^2/3	>50dB	>34dB
✗	Hybrid InP-SOI	85 dB·Hz^2/3	>35dB	>28dB
?	Hybrid InP-LNOI	110 dB·Hz^2/3	>32dB	>25dB
✓	Heterogeneous integration on LNOI	110 dB·Hz^2/3	>30dB	>21dB

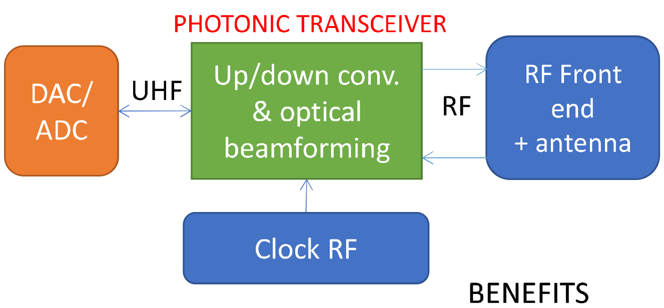
Simulated performance comparison analog IMWP beamforming networks

	Parameter	SFDR	NF	L_c
	Requirement	>100 dB·Hz^2/3	<30dB	<10dB
✗	Monolitic InP	83 dB·Hz^2/3	>56dB	>40 dB
✗	Hybrid InP-SOI	96 dB·Hz^2/3	>56dB	>56 dB
✗	Hybrid InP-LNOI	85 dB·Hz^2/3	>46dB	>31dB
?	Heterogeneous integration on LNOI	85 dB·Hz^2/3	>41dB	>26dB



Main radar scenarios enabled by microwave photonics

a) Monostatic radar with colocated antenna



Digital
Electrical
Optical

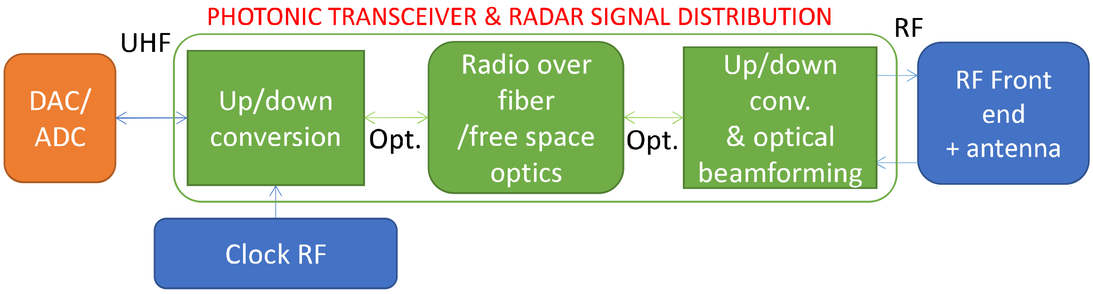
BENEFITS

- ✓ Multiband operation useful for
  - Stealth targets detection
  - Adaptive frequency agility
  - Facing the spectrum erosion by communications
- ✓ Fast and precise multibeam beamforming

Main radar scenarios enabled by microwave photonics

Digital
Electrical
Optical

b) Monostatic radar with remote antenna

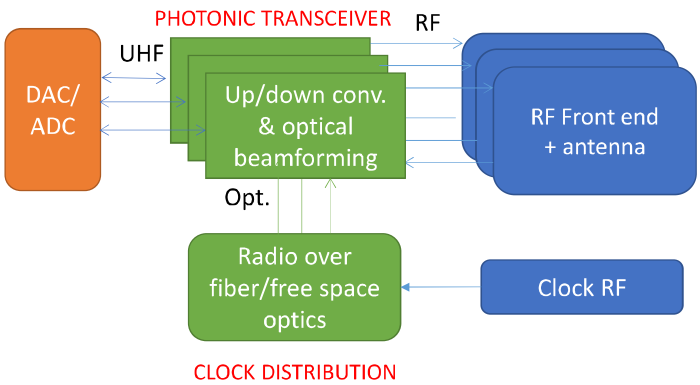


ADDITIONAL BENEFITS

- ✓ Antenna remotization

Main radar scenarios enabled by microwave photonics

c) Multistatic syncronized radar (several radars sharing the clock)

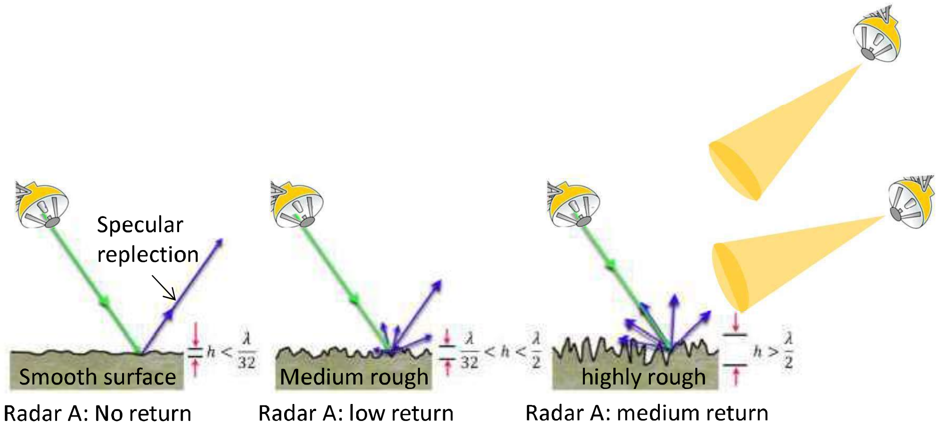


Digital
Electrical
Optical

ADDITIONAL BENEFITS

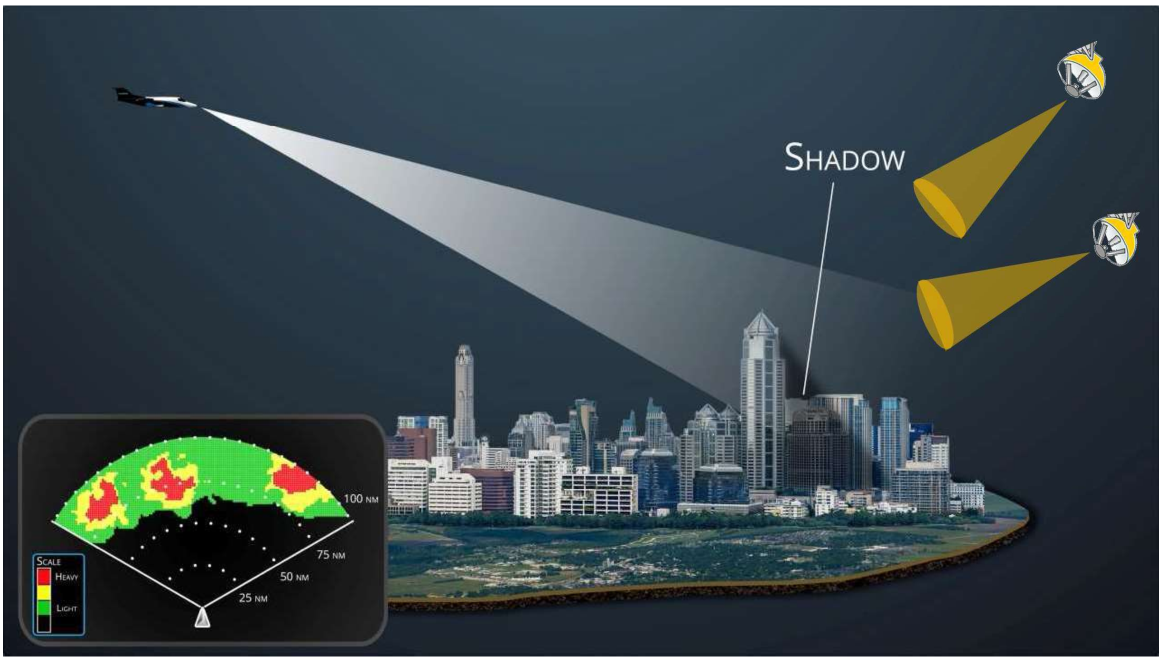
- ✓ Multiple synchronized points of view

Benefits of radar networks based on photonic: Higher received scattered power

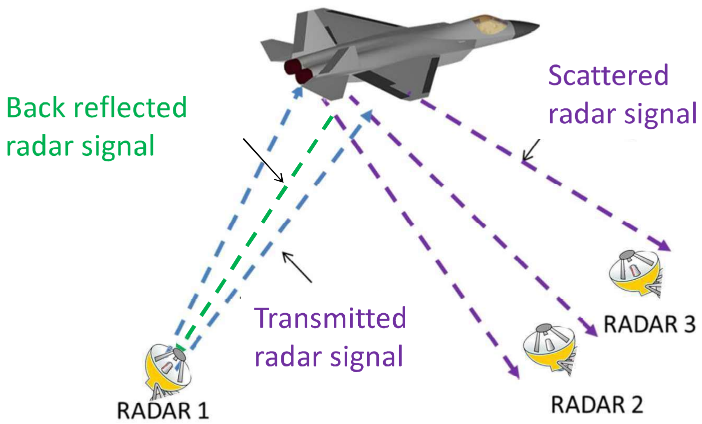


Reduced scintillation (depending on the target scattering in different directions)

Benefits of radar networks based on photonic: Lower shadow issues

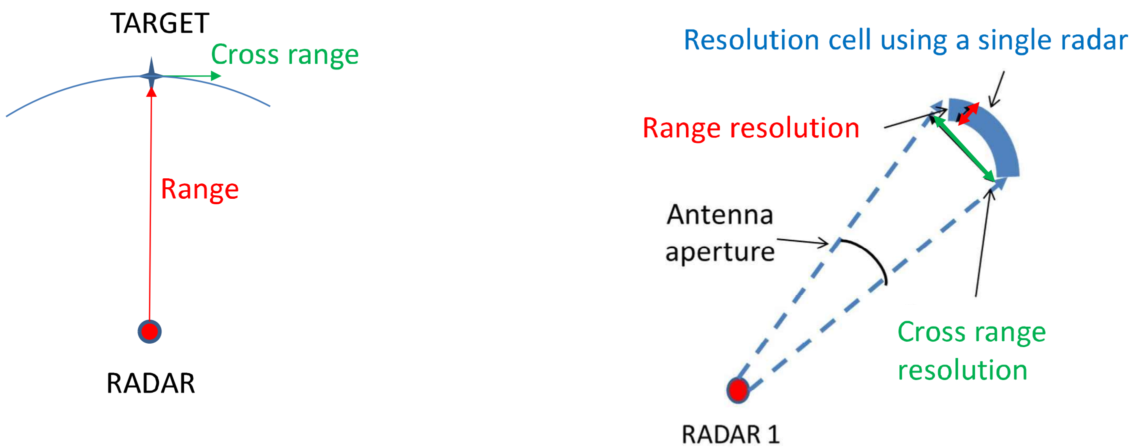


Benefits of radar networks based on photonic: stealth target detection



Higher efficiency in stealth target detection

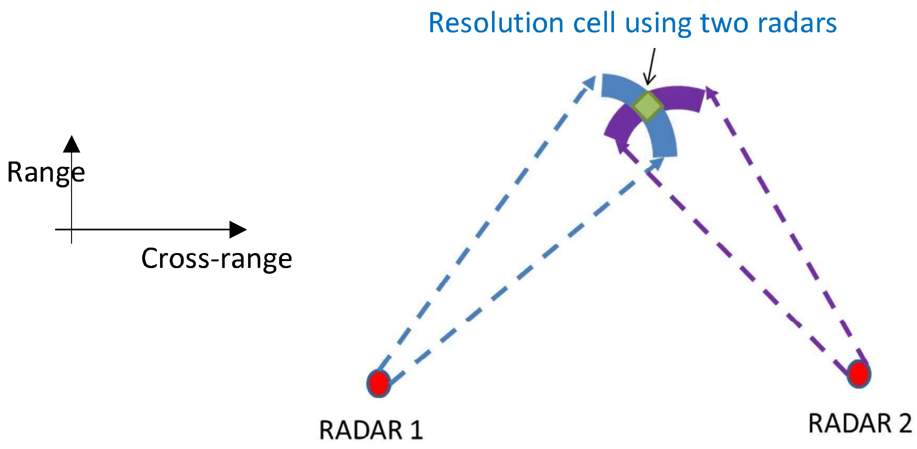
Benefits of radar networks based on photonic: cell resolution



MONOSTATIC RADAR: CELL DIMENSION = CROSS RES x RANGE RES

RANGE RESOLUTION depends on radar signal bandwidth
CROSSRANGE RESOLUTION depends on the antenna aperture

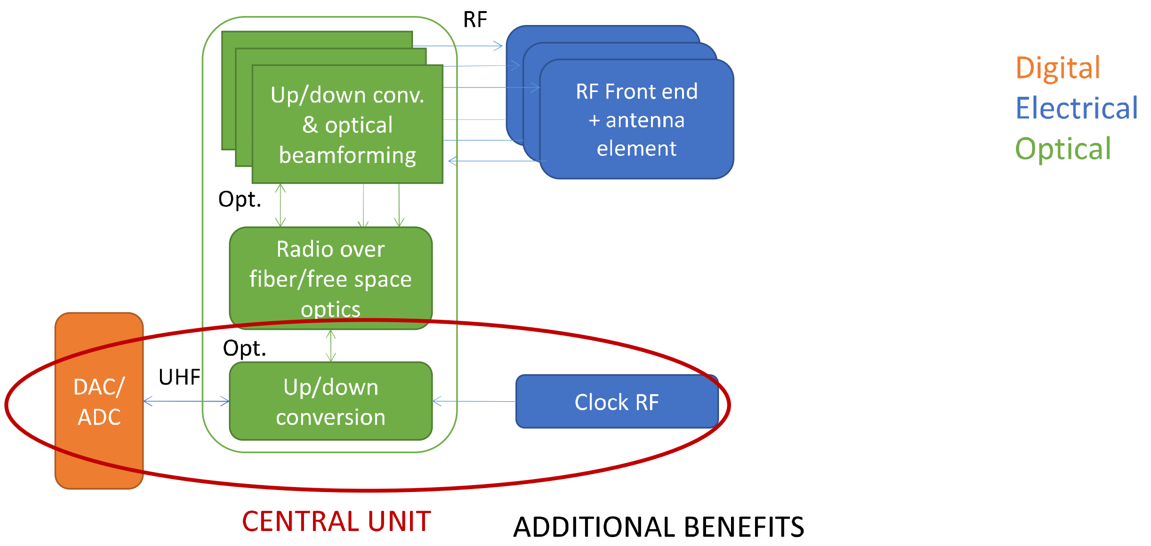
Benefits of radar networks based on photonic: cell resolution



MULTISTATIC RADAR: CELL DIMENSION = APPROX RANGE RES RADAR1 x RANGE RES RADAR2

Main radar scenarios enabled by microwave photonics

d) Distributed radar (single transceiver with distributed antenna elements)

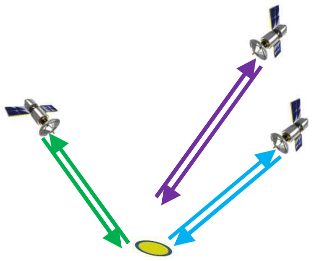


ADDITIONAL BENEFITS

- ✓ Coherent signal distribution and received data collection for centralized processing (i.e. max level of cooperation among radars)

Benefits of radar networks based on photonic: maximum level of cooperation

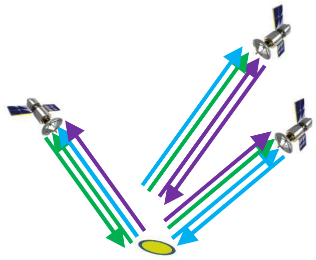
Multi Independent radars



target

Acquisitions: n=radar number

Coherent Multiple input-multiple output (MIMO) approach



target

Acquisitions: n^2=(radar number)^2

Conclusion

- ❑ Photonics in Radar systems has been already demonstrated
  - ✓ For providing wideband and frequency agile operations
  - ✓ Advanced performance radar networks
  - ✓ Beamforming
  - ✓ Integrated photonics for satisfying SWaP requirements
- ❑ Unfortunately, the available integrated photonics technologies are still inadequate to meet the Radar system requirements in terms of losses, noise and linearities for most of the applications
- ❑ The presented analysis highlights the RF signal distribution is feasible by hybrid/heterogeneous integration while emerging heterogeneous approaches could enable a real use of the other microwave photonics systems

Thank you!

email: mirco.scaffardi@cnit.it

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PNTLab Photonic Networks&Technologies

Občutljivost optičnih kablov na zvočne vibracije

Sensitivity of fiber optic cables to acoustic vibrations

Tomáš Horváth

Brno University of Technology

horvath@vut.cz

Povzetek

Ta predstavitev raziskuje razvijajoče se trende in izzive pri varnosti omrežij z optičnimi vlakni, pri čemer obravnava pogoste težave, kot je škoda, povezana z gradnjo, do naprednih tehnologij nadzora. Poudarek je na ocenjevanju razumljivosti govora tako v nadzorovanih okoljih kot v realni infrastrukturi z uporabo sofisticiranih metod, kot je STIPA. Preučuje vpliv različnih konfiguracij kablov, vrst stropnih plošč in postavitev kablov na občutljivost in jasnost.

Abstract

This presentation explores the evolving trends and challenges in the security of optical fiber networks, addressing from common issues like construction-related damage to advanced monitoring technologies. The focus lies on evaluating speech intelligibility in both controlled environments and real-world infrastructure using sophisticated methods such as STIPA. It examines the influence of different cable configurations, ceiling panel types, and cable placements on sensitivity and clarity.

Biografija avtorja

Tomas Horvath se je rodil leta 1989 v Havirovu na Češkem. Je raziskovalec na Tehnološki univerzi v Brnu in pri CESNET-u. Leta 2017 je doktoriral iz komunikacij in informatike na Univerzi za tehnologijo v Brnu. Njegova bibliografija vsebuje več kot 90 strokovno pregledanih zbornikov in člankov v revijah. Njegovi trenutni raziskovalni interesi vključujejo pasivna optična omrežja, zaščito perimetra z zaznavanjem vlaken in kvantno distribucijo ključev.

Author's biography

Tomas Horvath was born in Havirov, Czech Republic in 1989. He is a researcher at Brno University of Technology and at CESNET. He received his PhD degree in communications and informatics from Brno University of Technology in 2017. His record shows more than 90 peer reviewed proceedings and journal papers. His current research interests include passive optical networks, perimeter protection with fiber sensing, and quantum key distribution.

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

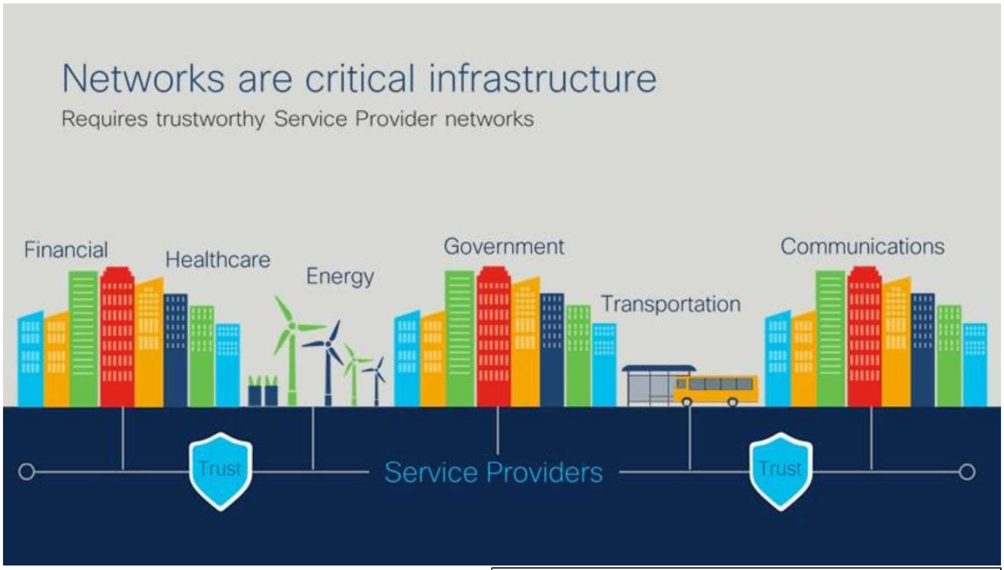
Sensitivity of fiber optic cables to acoustic vibrations

Tomas Horvath, Petr Munster, Adrian Tomasov, Petr Dejdar, Ondrej Klicnik, Pavel Zaviska

Friday, January 31, 2025

26th Seminar on Optical Communications

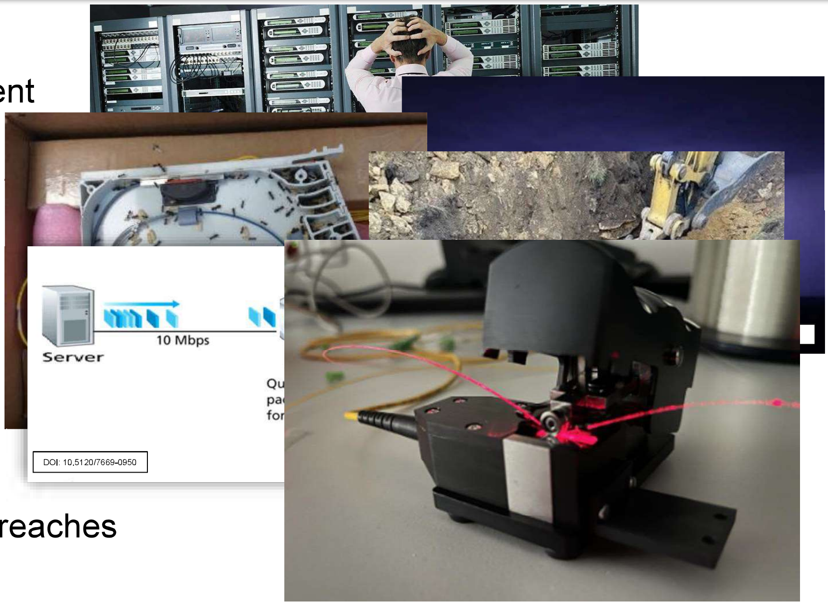
Optical Networks



https://www.cisco.com/c/en/us/solutions/service-provider/service-provider-security-solutions/index.html#~innovations

What Causes Internet Outages?

- Malfunctioning Equipment
- Inclement weather
- Animals
- Construction work
- Network Congestion
- Hacking and Security Breaches



Weather

- Optical cable can survive the most detrimental weather conditions!
- But…
  - Hurricane Sandy, which hit the Americas in 2012, disrupted services on several important transatlantic cables.
  - The Fukushima earthquake that happened in 2011 in Japan caused several outages, including parts of the fibre optic network in the region.
- Icing
  - The only situation where problems arise is if water infiltrates the fiber optic cable.
  - Once water is in the cable and the temperatures drop below freezing, the water will expand as it turns into ice and break the fiber cables.

https://www.cisco.com/c/en/us/solutions/service-provider/service-provider-security-solutions/index.html#~innovations

Weather

- Storm
  - Fiber optic cables are not affected by rain since data is transmitted underground.
  - The impact of lightning strikes on aerial fibers was long considered a non-issue, based mainly on the experience of insensitive 10-Gbps transmission.
  - However, with the move to polarization-multiplexed 100-Gbps transmission, aerial transmission cables began to experience recurring, signal-affecting events.

Construction Work

- In our increasingly connected world, fiber optic lines are the backbone of high-speed internet, telecommunications, and data transmission.
- There are countless cases of municipal workers damaging fiber while digging their way to a burst public water supply pipe or homeowners severing cables while installing a fence around their property.
- What can help – if underground installation of optic fiber is clearly mapped, recorded and marked with visual cues, such as poles or plaques.

https://www.bcsatellite.net/blog/fiber-line-cut-leads-to-utah-outage/

Construction Work

Utah Blacked Out After Fiber Optic Cable Cut

Sep 30, 2023

Share this post:

Just days before the school year began, a major broadband outage struck Northern Utah's Cache County School District. Phone and internet services went down without explanation, leaving officials uncertain when connectivity would resume. It soon became clear this was no ordinary outage.

A construction crew had accidentally cut through 1,300 fiber optic cables while boring under a Logan, Utah road. The extensive damage caused a two-day internet blackout affecting thousands of residential and business customers. Even county government offices and major local employers JBS Foods lost service.

https://www.bcsatellite.net/blog/fiber-line-cut-leads-to-utah-outage/

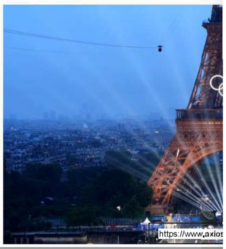
Hacking and Security Breaches

AXI

Jul 29, 2024 - World

French fiber optic c
latest Olympics sal

Ivana Saric



https://www.axios

NATO Wants
Undersea De

Officials fear Russia could cut the
undergirds much of the global ec

By Jack Detsch and Keith Johnson

An employee lays an undersea fiber optic cable at Arrie
Sopelana, on June 13, 2017. ANDER GILLENEA/AFP VIA GETTY

My FP: Follow to https://foreignpolicy.com/2024/0

JUNE 24, 2024, 2:45 PM

The

Sacramento airpo
internet cable snip

Police say this appears to be a 'de

Brandon Vigliarolo

Sacramento International Airport (SMF) suffer
what appears to be an intentional cutting of ar

The airport notified passengers of an issue wit
and Delta airlines facilities at SMF yesterday r
Sheriff's Office (SCSO) later confirming that ar
airport was cut in what appeared to be a 'delib

SCSO spokesperson Sergeant Amar Gandhi t
office, which provides security services for SM
time yesterday. Repair crews noticed the delib
arrived on scene.

"It looks like someone who knew what they we
KCRA. "So this wasn't just a couple of teenag
looks very deliberate."

An SMF spokesperson told *The Register* that
that no additional damage was caused. The ai
threats at this time.

SMF listed flight delays of over two hours yest
KCRA said. Service was restored by 1135, the

https://www.theregist...

Someone deliberately cut cabl
causing $40K in damage on Co
Island

Police are investigating a fibre-optic cable sabotage on Cortes Island.

Alanna Kelly
Mar 26, 2024 8:00 PM

The City West cables were cut in 17 different spots, according to police. | City West

Listen to this article
00:01:15

Police on Cortes Island have reason to believe a person purposely slic
internet and data networks causing tens of thousands of dollars in da

A manager at a fibre-optic service called City West reported the incide
March 21.

https://www.bowenislandundercurrent.com/highlights/person-deliberately-cut-cables-causing-40k-in-damage-on-cortes-island-8514166

Houthis may sabotage western internet cables in Red Sea, Yemen telecoms firms warn

UN-recognised government and telecoms firms speak of threat to digital infrastructure, with some cables lying 100m below surface

Houthi fighters at a rally in Gaza on Sunday. The UN-recognised Yemen government and telecoms firms have said Houthis may seek to damage submarine internet cables in the Red Sea. Photograph: Mohammed Hamoud/Getty Images

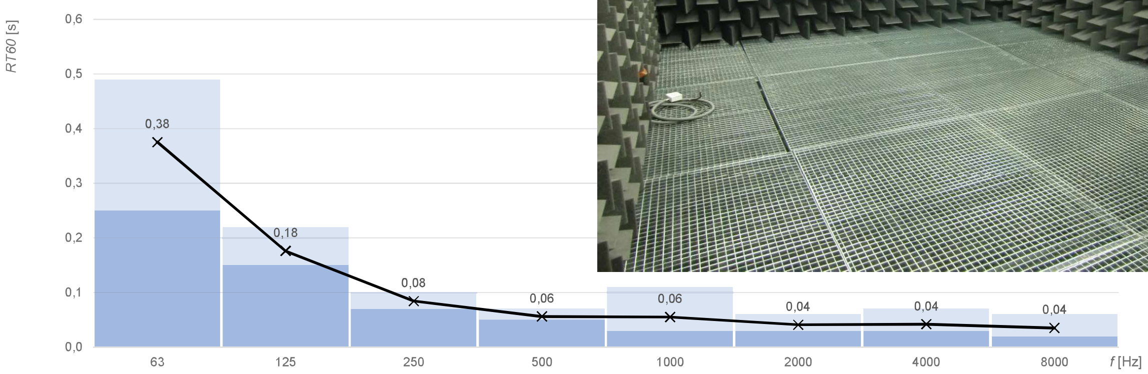
Telecom firms linked to the UN-recognised Yemen government have said they fear Houthi rebels are planning to sabotage a network of submarine cables in the Red Sea critical to the functioning of the western internet and the transmission of financial data.

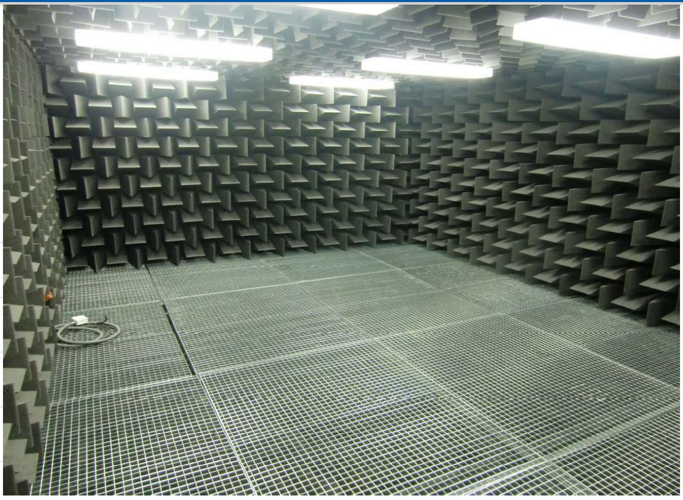
The warning came after a Houthi-linked Telegram channel published a map of the cables running along the bed of the Red Sea. The image was accompanied by a message: "There are maps of international cables connecting all regions of the world through the sea. It seems that Yemen is in a strategic location, as internet lines that connect entire continents - not only countries - pass near it."

https://www.theguardian.com/world/2024/feb/05/houthis-may-sabotage-western-internet-cables-in-red-sea-yemen-telecoms-firms-warn

Introduction to the Measuring Setup

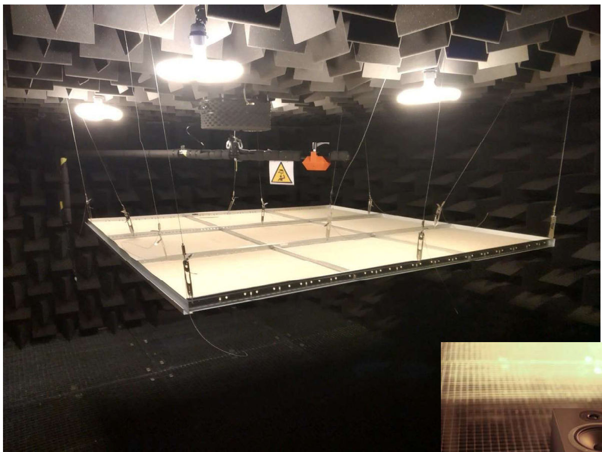
- Volume: 90 m^3
- Critical frequency: 105 Hz
- Background noise including measurement chain noise: < 7 dB(A) (1 Hz – 50 kHz)



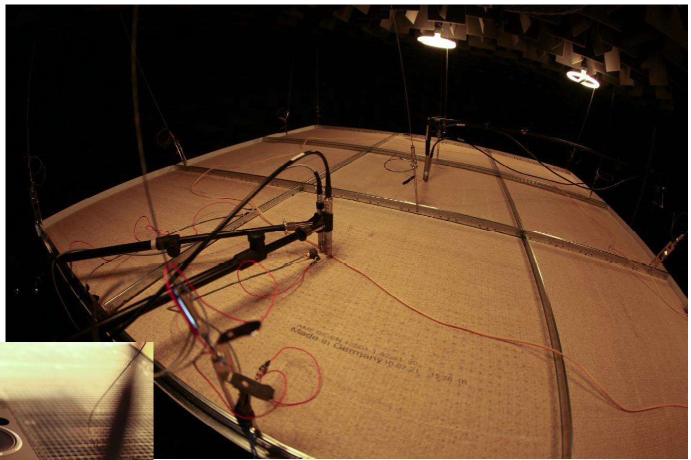


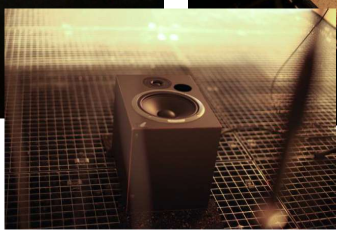
Introduction to the Measuring Setup

Placement of the ceiling into the anechoic chamber



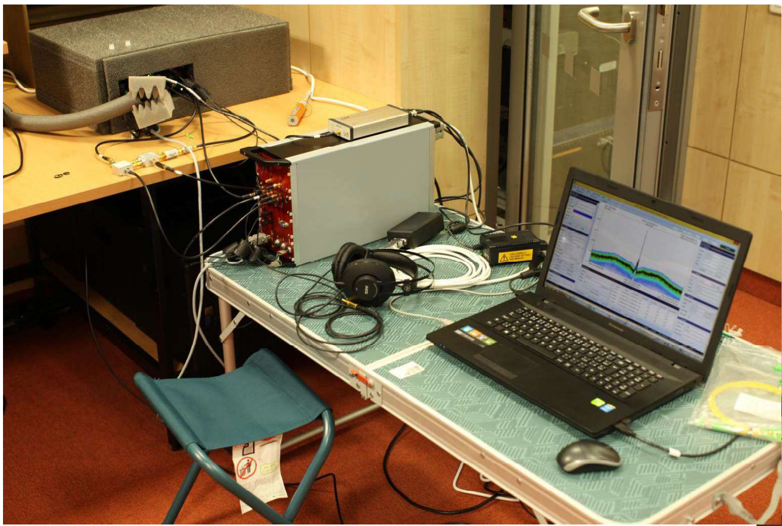
Microphones, accelerometers, and optical cable



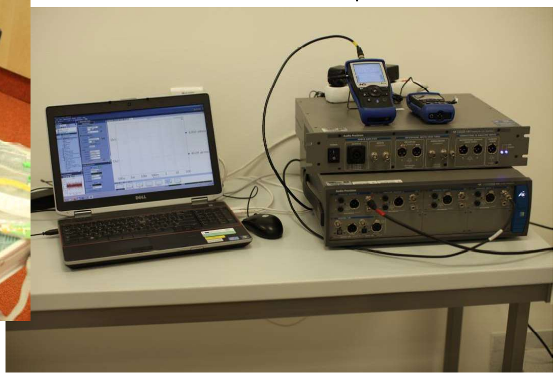


Speaker for vibration excitation

Introduction to the Measuring Setup



Speaker control

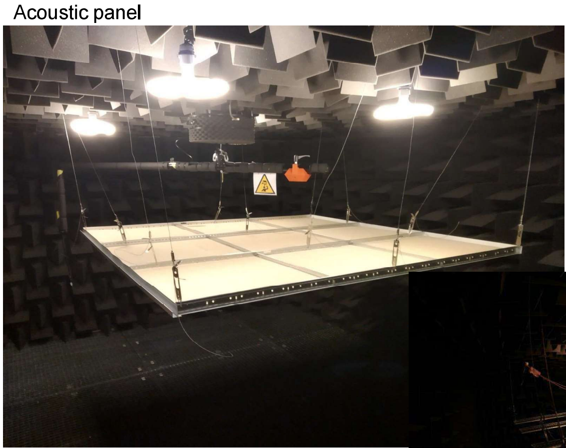


Detection system outside the chamber

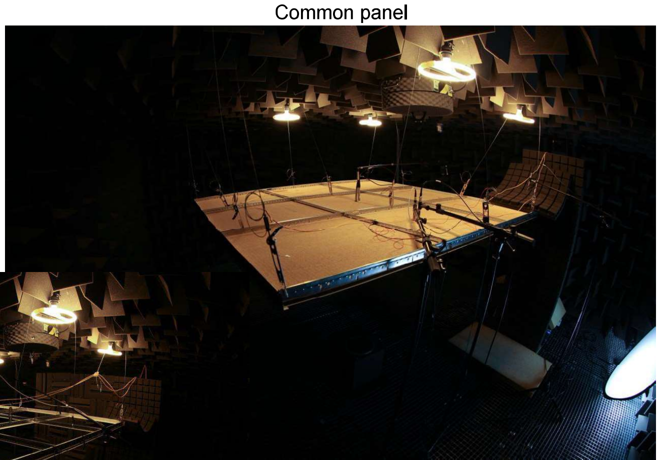
Remote access

Measuring the Dependence of the Recorded Signal on the Type of Ceiling Used

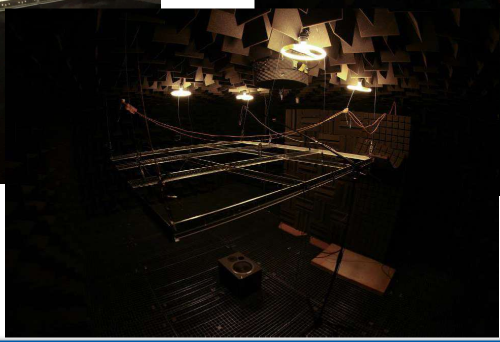
Acoustic panel



Common panel

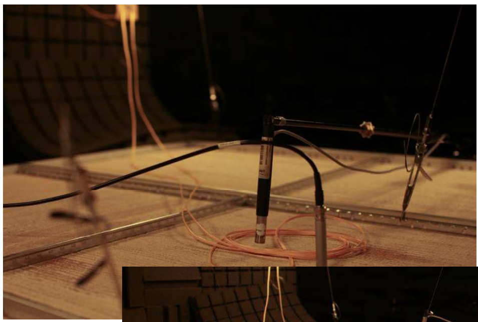


Without panel

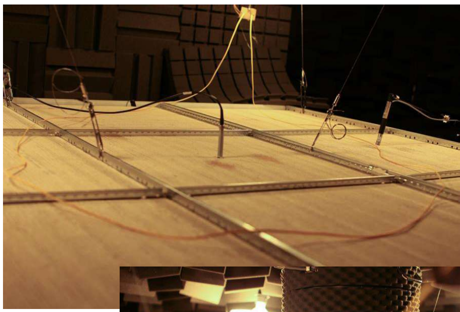


Measuring the Dependence of the Recorded Signal on Cable Placement

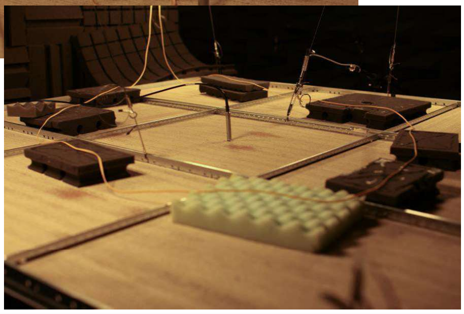
Coiled cable



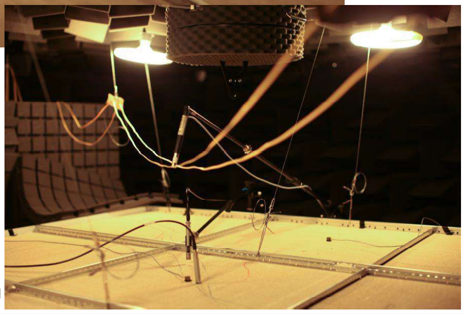
Large loop



Foam

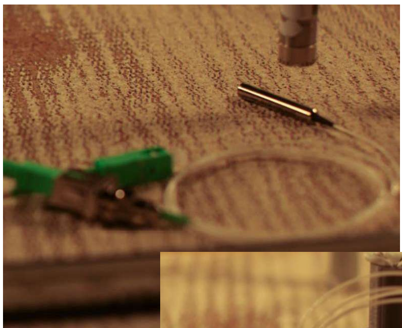


Hanging

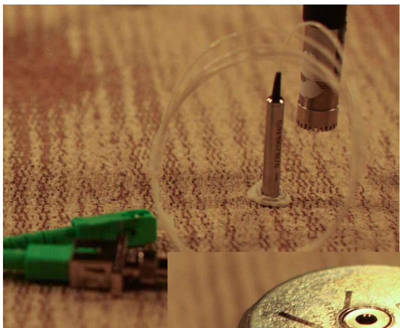


Measuring the Dependence of the Recorded Signal on the Placement of the Mirror

Lying horizontally



Lying vertically

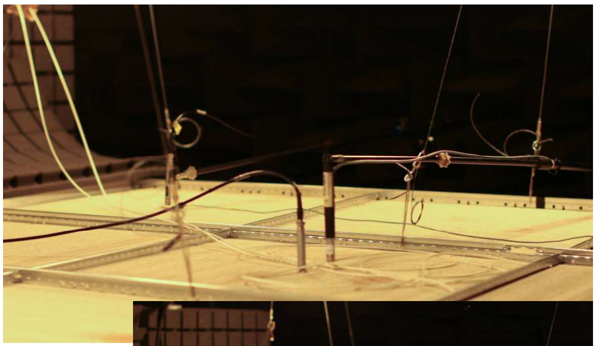


In the bell

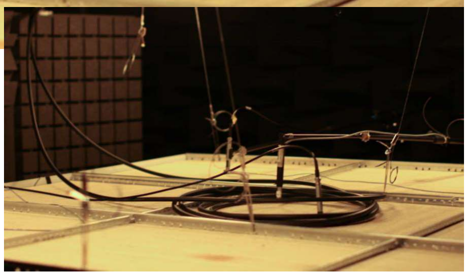
On the speaker

Measuring the Dependence of the Recorded Signal on the Cable Type

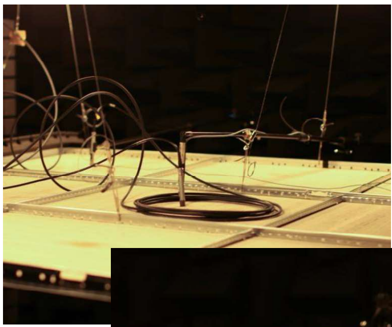
FTTx 2-fiber



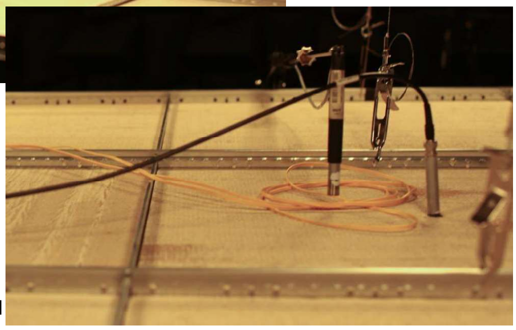
Excel 24-fiber



KDP 24-fiber with thinner cladding

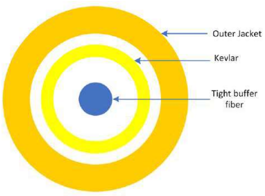


Patch cord

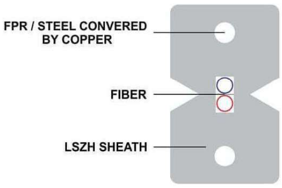


Cables Used

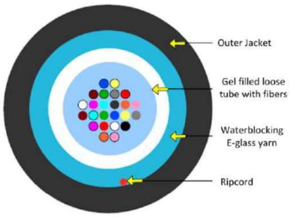
Patch cord



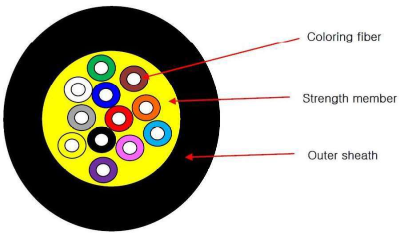
KDF



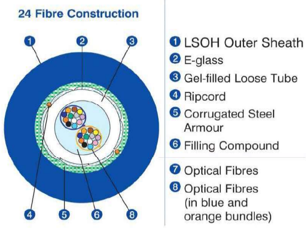
KDP



FTTX

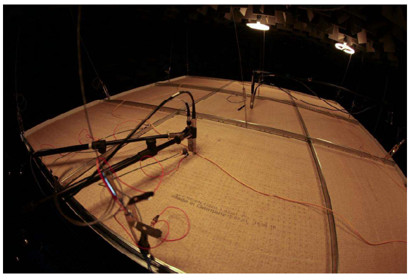


Excel



Introduction to the Measuring Setup

- Detection of acoustic vibrations in a defined environment
  - Anechoic chambre
  - Real infrastructure
- Measurement across the entire audible spectrum
- Focus on speech intelligibility
  - Evaluation using the STIPA method
  - Quantification of intelligibility for individual measurement setups
- Possibilities of effective measures against eavesdropping



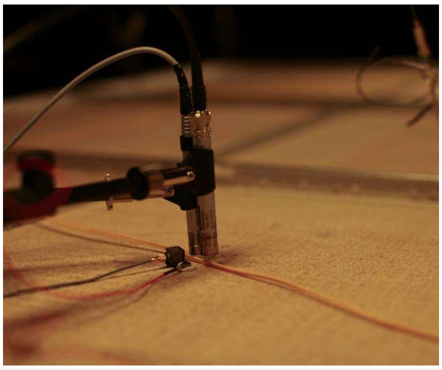
Test Sounds and Their Source

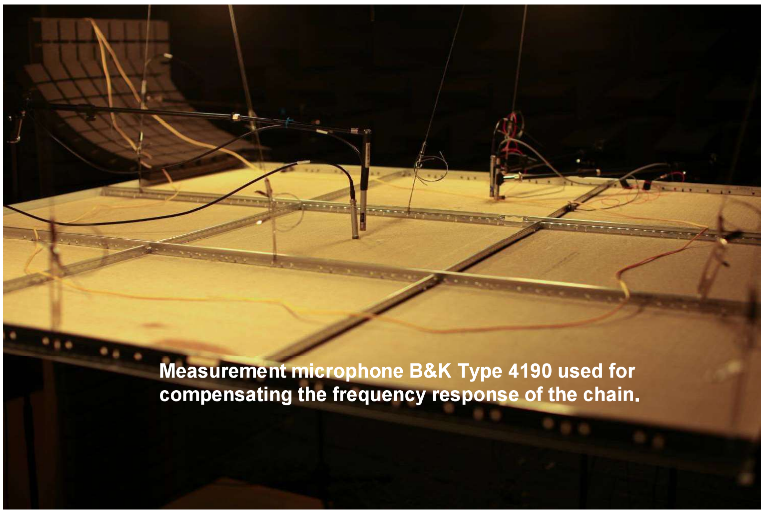
- Speaker Event 20/20 (50 až 20 000 Hz)
- Amplifier Bittner

- „Silence“
- Continuously modulated sine wave (logarithmic chirp, 50 to 20 000 Hz)
- Stepwise modulated sine wave (50 to 20 000 Hz, 53 logarithmic frequencies), steady states
- STIPA signal, a statistical imitation of a speech signal

Signal Capture

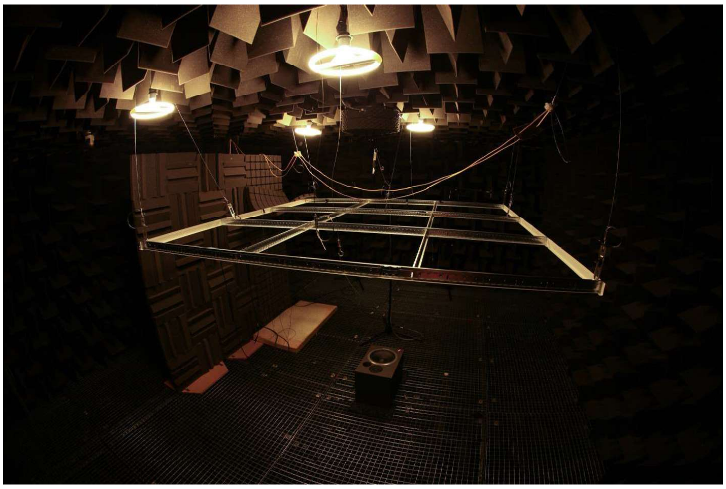
- Fiber (IQ signal – phase demodulation),
- Microphones
  - Under the center of the ceiling
  - Above the center of the ceiling
  - Near the measurement location





Signal Processing and Evaluation

- How do demodulated signals from the optical cable sound (interferometer)?



- Background
- Chirp
- Step
- STIPA

STI = 0.60 **without panels**.

Signal Processing and Evaluation

- Background
- Chirp
- Step
- STIPA

STI = 0.46
after covering the ceiling.

Speech Transmission Index (STI)

- Measure of speech transmission quality (standard IEC-60268-16)
- Measures some physical characteristics of a transmission channel and expresses the ability of the channel to transmit speech-signal
- Influences on speech intelligibility
  - The speech level
  - Frequency response of the channel
  - Non-linear distortions
  - Background noise level
  - Quality of the sound reproduction equipment
  - Echoes
  - The reverbation time
  - Psychoacoustic effects (masking effects)

History

- The method for speech intelligibility measurement dates back to 1970s
- Original method introduced by Tammo Houtgast and Herman Steeneken
- STI became IEC standard in 1988
- Since then it has undergone several modifications, corrections and extensions
- STIPA became part of the standard in the third edition in 2003
- The currently valid standard is 5th edition from 2020

STI Concept

- Speech signal level varies rapidly with time producing variations (fluctuations) in the intensity envelope of the sound
- These fluctuations (intensity changes) in speech signal carry the most relevant information relating to speech intelligibility
- Preservation of the intensity envelope is the utmost important
- Time-domain distortions within a transmission channel along with noise can degrade the fluctuating speech signal and reduce the intelligibility
- The STI model measures the degree to which the fluctuations are preserved

STI vs STIPA

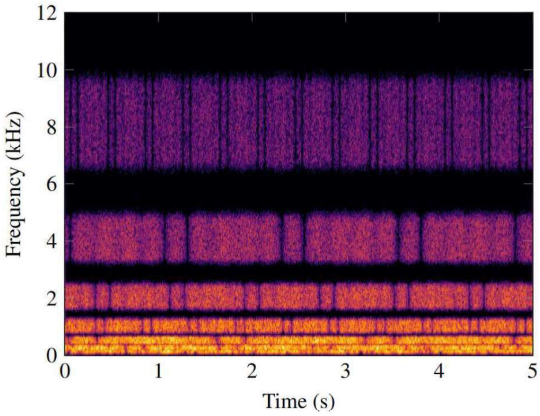
- STI (full STI)
  - Consists of 98 separate test signals
  - 14 different modulation frequencies ranging from 0.63 Hz to 12.5 Hz
  - 7 different octave bands from 125 Hz to 8 kHz
  - With 10 seconds per test signal takes approx. 15 minutes
- STIPA
  - Simplified measurement of STI
  - Only one test signal with a predefined set of two modulation frequencies in each band
  - 14 modulations are generated simultaneously
  - One measurement takes between 15 and 25 seconds

Direct vs Indirect Method

- Direct method
  - Utilizes a speech-like measurement signal
  - No further post-processing needed
  - Convenient also for non-linear distortions
  - Typically used when also „electro-acoustic“ components are present in the chain
- Indirect method
  - Based on the system‘s impulse response
  - Requires strict synchronization
  - Only applicable to linear time-invariant systems
  - Usually used for studying speech intelligibility based on „pure room acoustics“

STIPA Signal

- Artificial signal emulating speech-like characteristics
- Broadband pink noise modulated by two amplitude modulations in each band
- 14 different modulation frequencies
- Divided into 7 frequency bands (125, 250, 500, 1000, 2000, 4000 and 8000 Hz)
- Generated using ½ octave filter bank



STIPA Computation

- Band-filtering
  - The signal is fed into a filterbank to split it to seven frequency bands
  - Minimum of 42 dB attenuation at the center of each frequency band
- Envelope detection
  - Detection of the intensity envelope
  - Raise the output of filter-bank to the power of 2
  - Low-pass filtering with a cut-off frequency of ~100 Hz
- Calculation of modulation depths
  - Estimation of modulation depths for each octave band and modulation frequency
  - Calculation of modulation transfer ratio, given as output modulation depts divided by input modulation depth (default 0.55)

STIPA Computation

- Limiting the modulation transfer ratio
  - To avoid complex values in the further computation, max value is limited to 1
- Adjustments (optional)
  - Adjustment for ambient noise
    - Requires intensity of signal and noise (measured separately)
    - This step can be omitted when STIPA measurement is carried out in noisless conditions
  - Adjustment for auditory effect
    - Compensate the absolute threshold of hearing and masking effects
    - This compensation is taken into account when the signal is obtained acoustically and intensities in octave bands are known
- SNR computation
  - SNR is computed from the limited and adjusted modulation transfer ratios
  - SNR is ranging between –15 and 15 dB

STIPA Computation

- Transmission index
  - Transmission index ranging between [0,1] is computed from the obtained SNR values
- Modulation Transfer index (MTI)
  - Calculated as an average value over modulation frequencies
- Final STI value
  - Calculated from the MTI values
  - Takes into account the intra-band modulations and MTIs of adjacent bands
  - Weighted using α and β factors, which are gender-specific factors for each octave band
  - The result STI value is ranging between 0 and 1
  - In case of exceeding 1, the value is simply clipped to 1

Interpretation of STI Scale

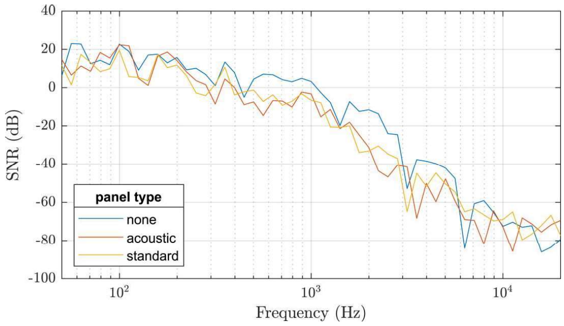
Quality according to IEC 60268-16	Intelligibility of syllables in %	Intelligibility of words in %	Intelligibility of sentences in %
Bad	0 – 24	0 – 67	0 – 89
Poor	34 – 48	67 – 78	89 – 92
Fair	48 – 67	78 – 87	92 – 95
Good	67 – 90	87 – 94	95 – 96
Excellent	90 – 96	94 – 96	96 – 100

Interpretation of STI Scale

Category	Nominal STI	Examples
A+	> 0.76	Recording studios
A	0.74	Theaters, speech auditoria, parliaments, courts, Assistive Hearing Systems (AHS)
B	0.7	
C	0.66	Theaters, speech auditoria, teleconferencing, parliaments, courts
D	0.62	Lecture theaters, classrooms, concert halls
E	0.58	Concert halls, modern churches
F	0.54	PA (Public Addressing) systems in shopping malls, public building offices, VA (Voice Alarms) systems
G	0.5	Shopping malls, public building offices, VA systems
H	0.46	VA and PA systems in difficult acoustic environments
I	0.42	VA and PA systems in very difficult spaces
J	0.38	Not suitable for PA systems
U	<0.36	Not suitable for PA systems

Sensitivity Measurement Results

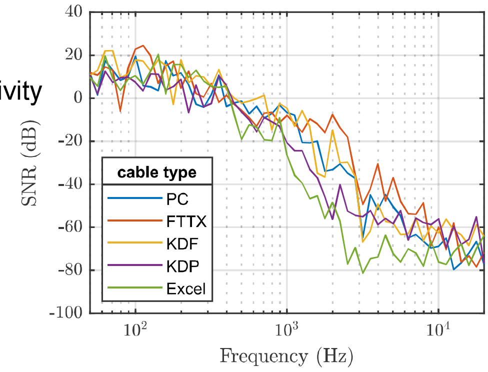
- The best position for sensitivity is a coiled cable
- Foam dampens vibrations best
- Panels improve sensitivity as resonators
  - They have the opposite effect on intelligibility.



Type of panel	STI
Without panel	0.60
Acoustic	0.49
Standard	0.46

Sensitivity Results

- Highest sensitivity above 1 kHz with FTTX cable,
- also most sensitive to speech,
- more insulation layers = lower sensitivity

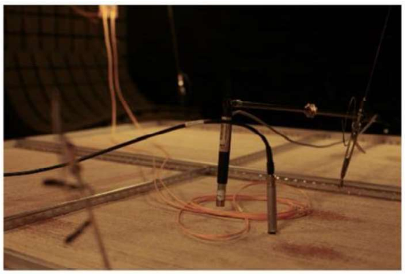


Type of cable	STI
PC	0.46
FTTX	0.66
KDF	0.31
KDP	0.23
Excel	0.20

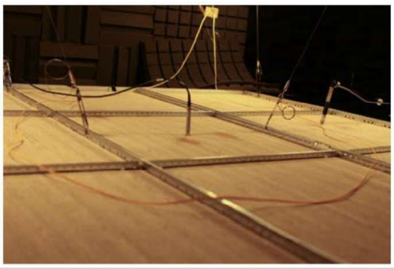
Results by Conditions

Without panel

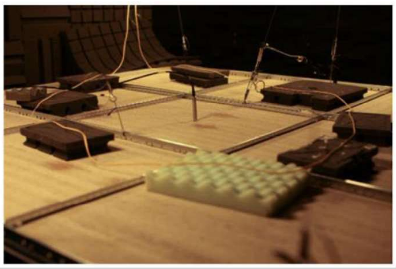
Coil



Circle

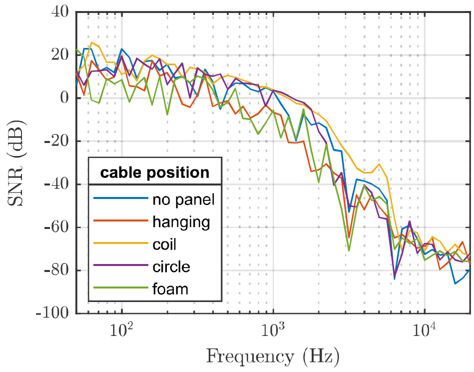


Foam



Sensitivity results

- Best position for sensitivity is coiled cable,
- foam dampens vibrations best,
- panels improve sensitivity as resonators.

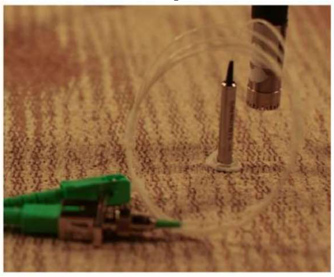


Cable position	STI
Without panel	0.60
Hanging	0.46
Coil	0.67
Circle	0.66
Foam	0.44

Sensitivity Results by Position

Lying

Vertically

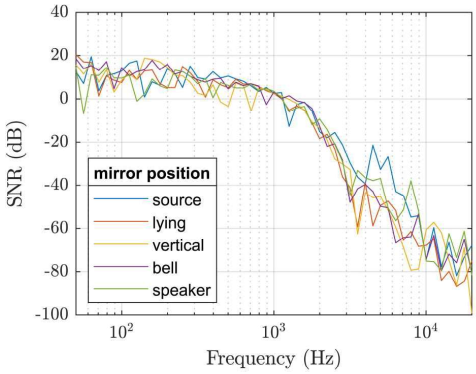


Bell

Speaker

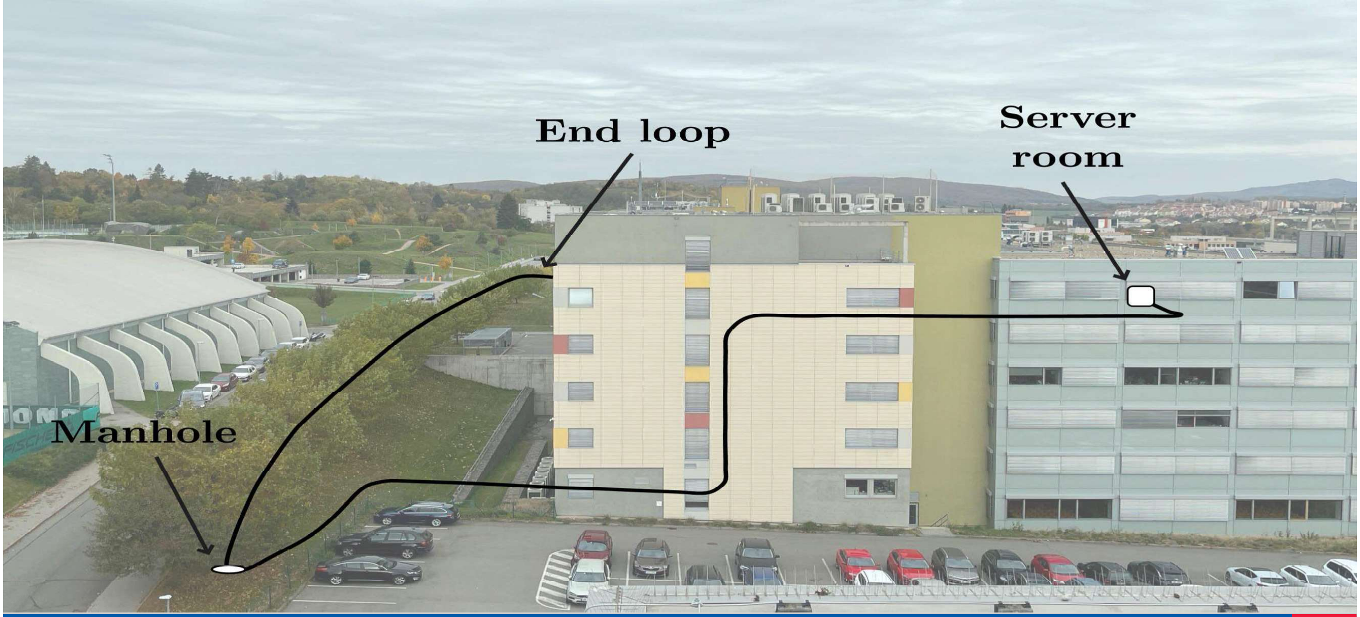
Sensitivity Results

- Best position for mirror is directly lying on the panel,
- verification of optical mirror use,
- various positions including dummy speaker.



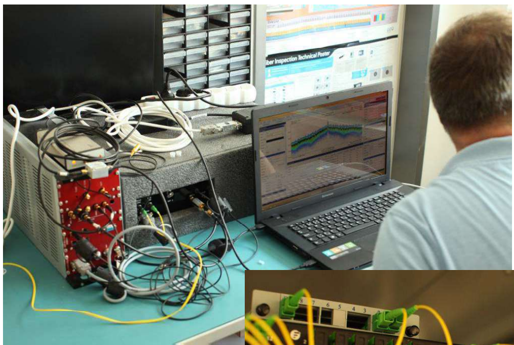
Mirror	STI
Source	0.62
Lying	0.65
Vertically	0.54
Bell	0.47
Speaker	0.59

Measurement on a Pilot Link

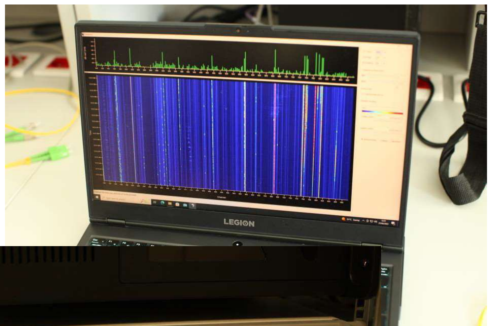


Measuring Setup

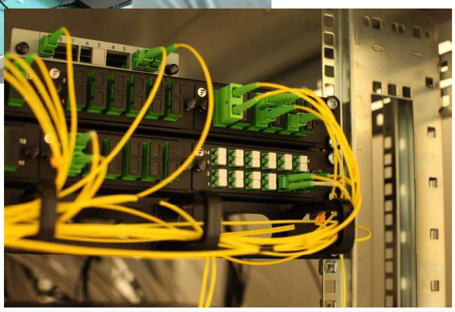
Measuring workstation



DAS system



Connection in the server room



Detail of the Chamber with Optical Cables

Chamber cover

Open chamber

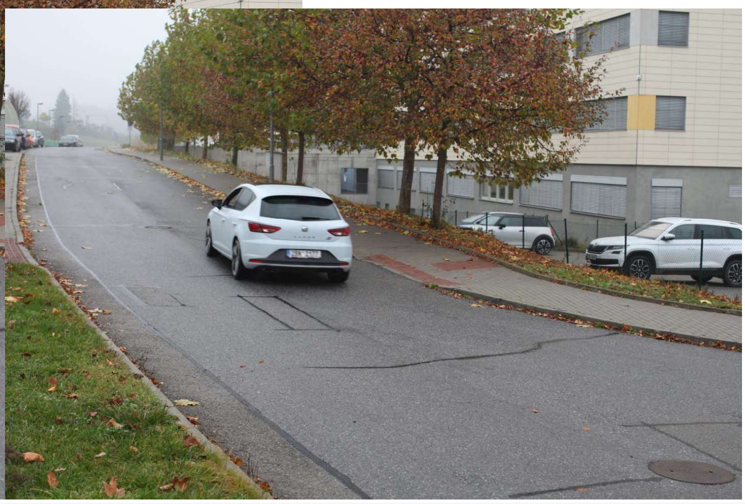
Chamber location

Detail of the splice

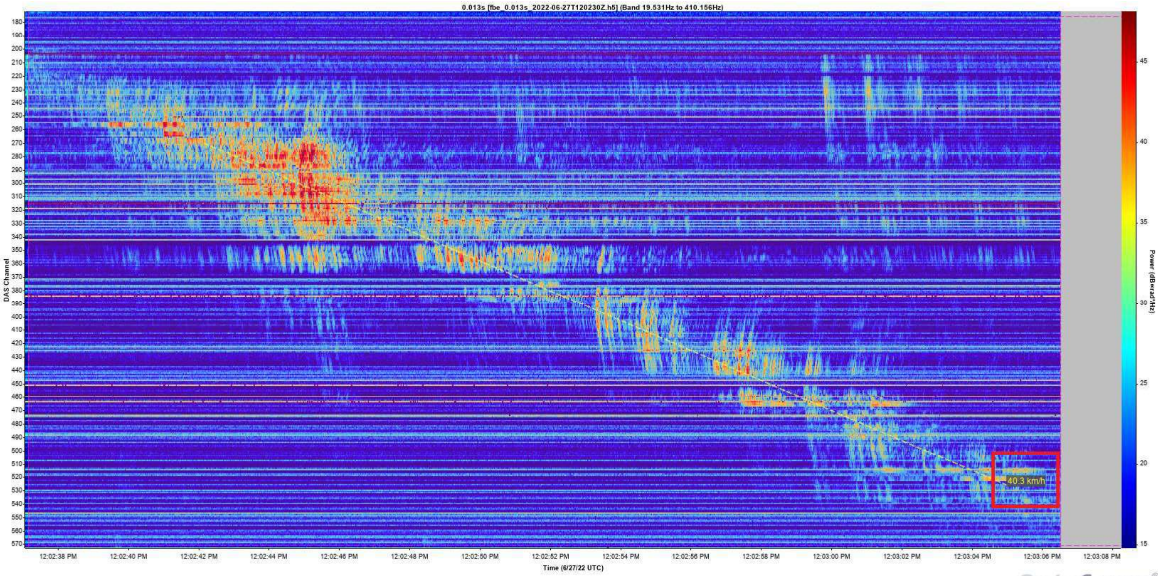
Measurement of Vehicle Passage

Passage along the fiber at different speeds

Both directions

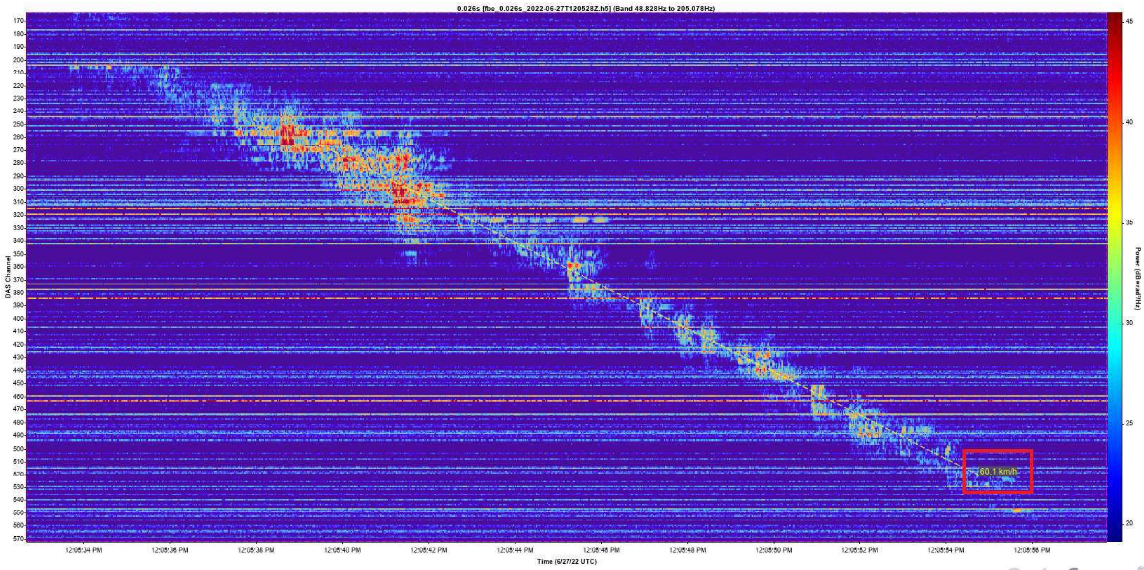


Measurement of Vehicle Passage at 40 km/h



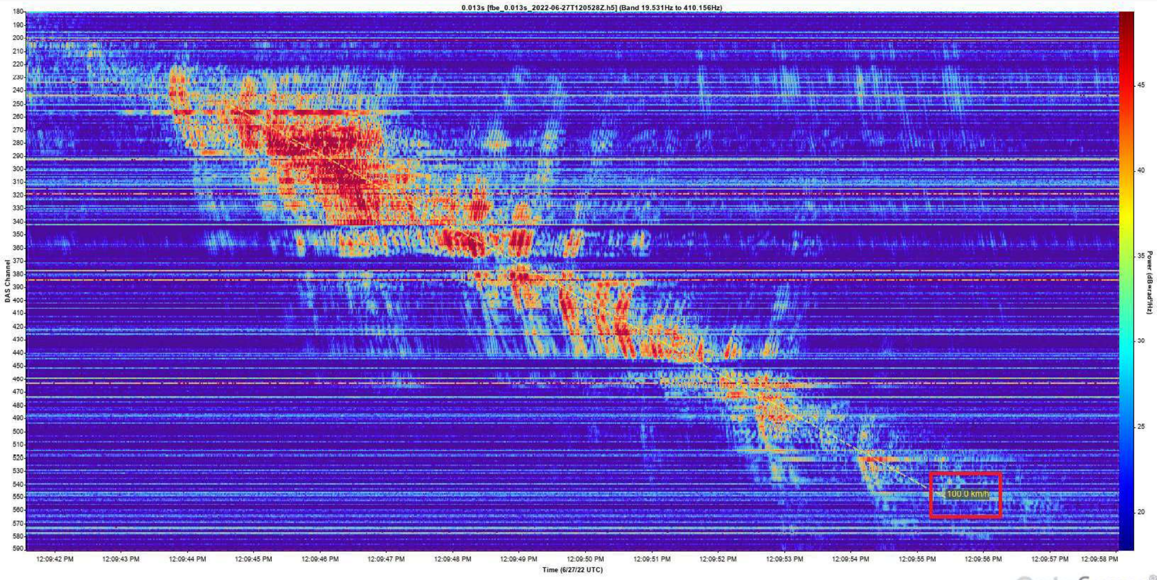
OptaSense®

Measurement of Vehicle Passage at 60 km/h



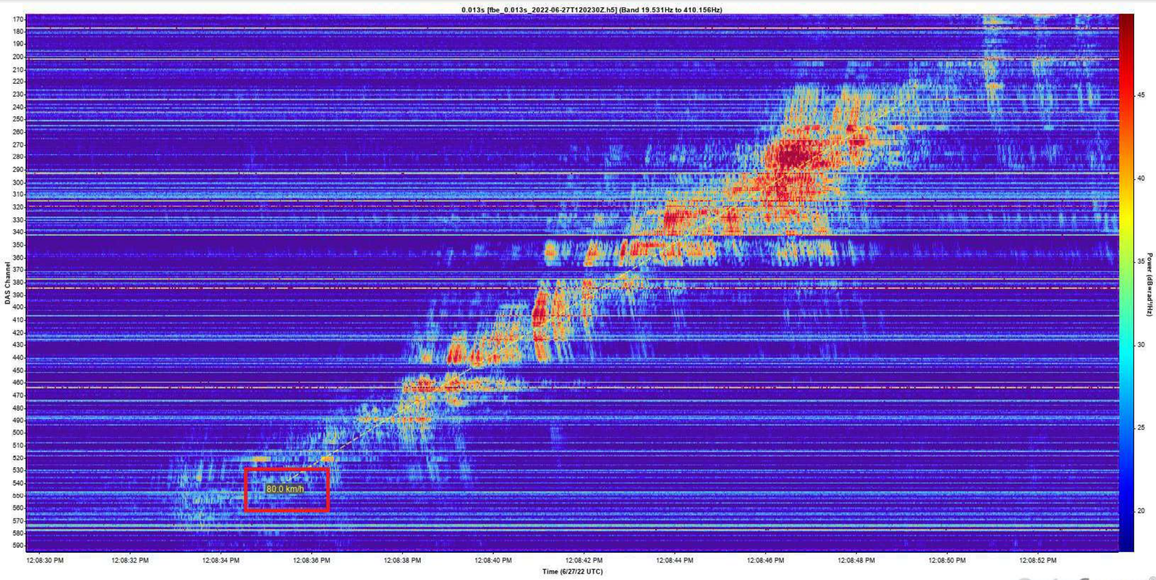
OptaSense®

Measurement of Vehicle Passage at 100 km/h



OptaSense®

Vehicle Passage at 80 km/h in the Opposite Direction

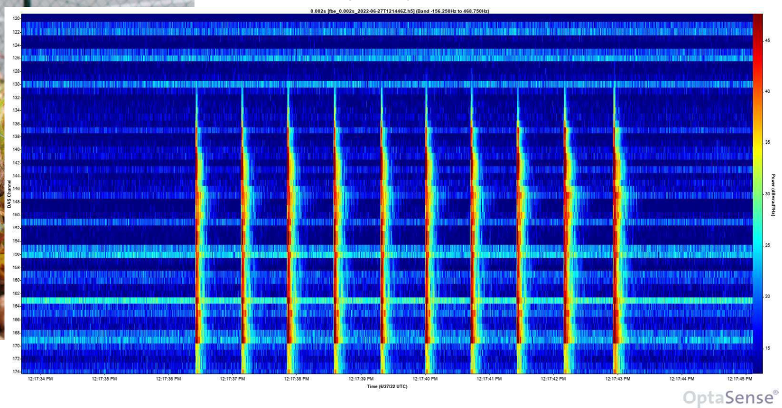


OptaSense®

Knocking on the Chamber Cover

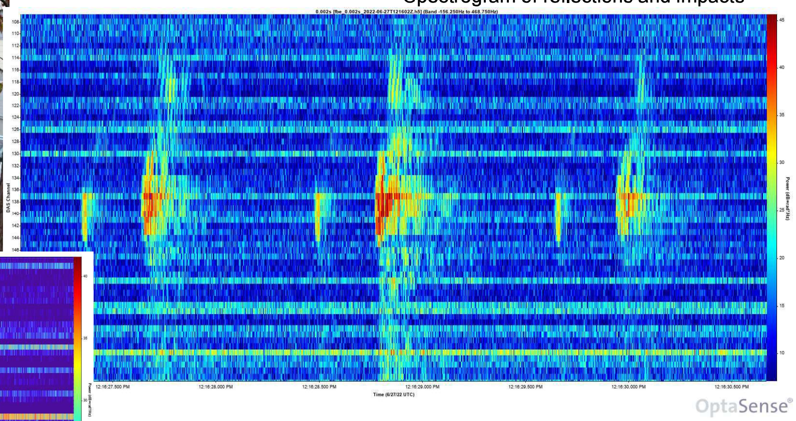
Detection of possible outdoor chamber integrity disruption

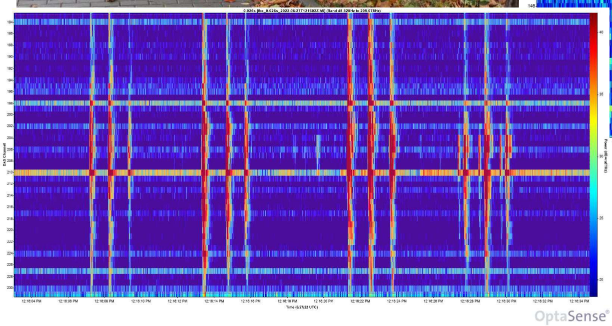
Spectrogram of individual knocks



Jumps Near the Chamber

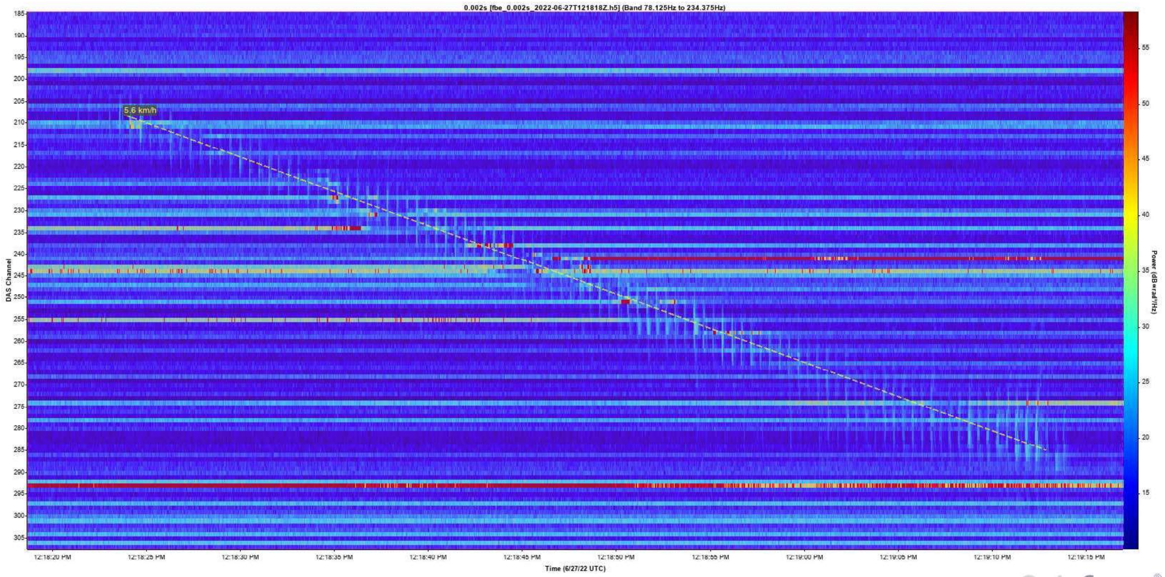
Spectrogram of reflections and impacts





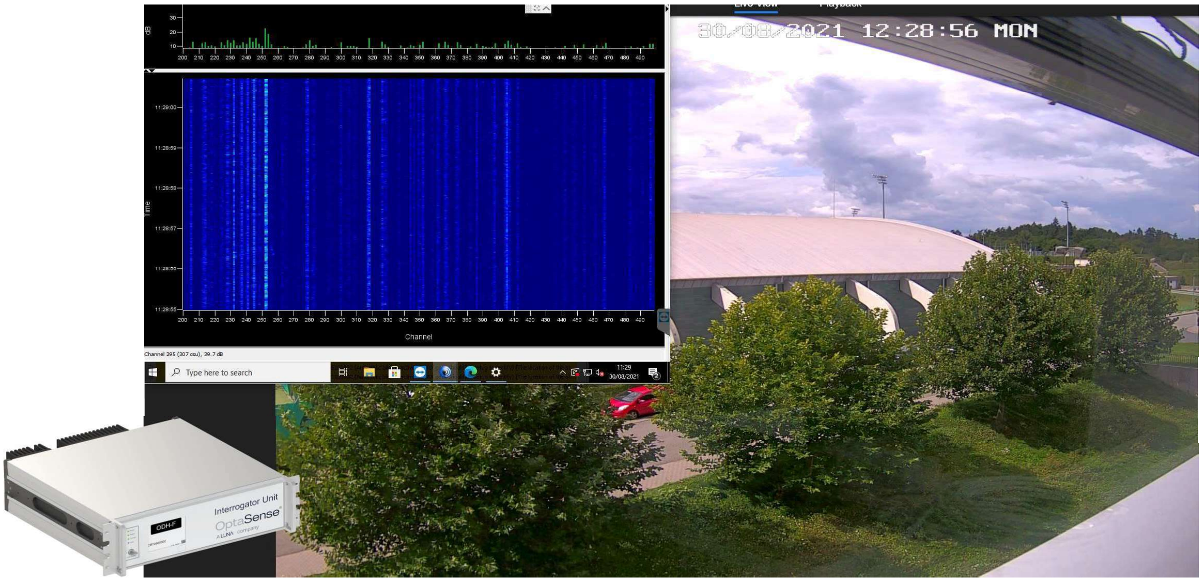
Spectrogram of all jumps

Spectrogram of Walking on the Pavement



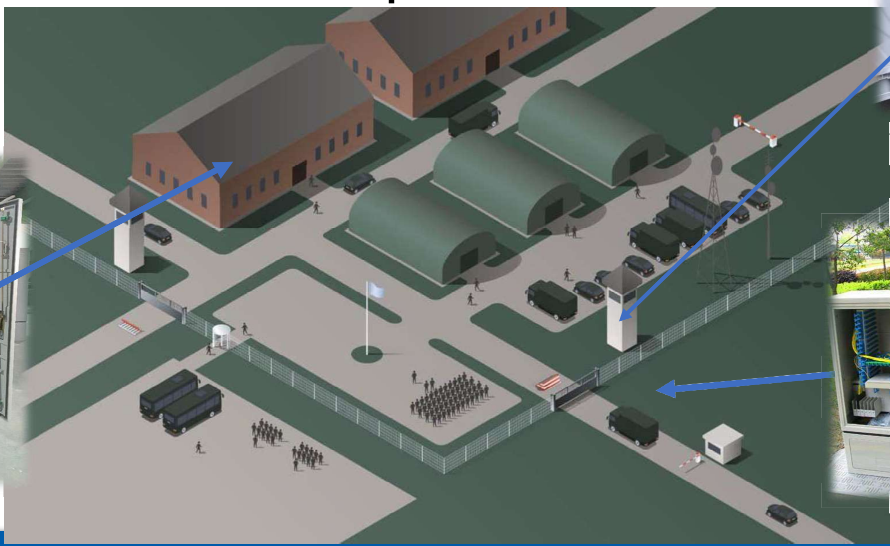
OptaSense®

Distributed Acoustic Sensing



Distributed Acoustic Sensing

- **Do you know where the operator fiber ends?**



Thank you for your attention!

horvath@vutbr.cz

This work was supported by the Ministry of the Interior of the Czech Republic, program IMPAKT, under grant Using machine learning in photonic network security – SMILIES, no. VJ03030012.

BRNO UNIVERSITY OF TECHNOLOGY | FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

Optolab FIBER OPTICS GROUP

Uporaba optičnega vlakenskega senzorja v elektroenergetiki
Application of fiber optic sensor in energy industry

Andrej Souvent

Operato

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Povzetek

Integracija optičnega vlakenskega senzorja je revolucionirala zmogljivosti nadzora v elektroenergetskih sistemih, saj ponuja natančen zajem podatkov linijskih infrastrukturnih objektov v realnem času. V okviru predavanja bosta predstavljeni ključni metodologiji zaznavanja z optičnimi vlakni: porazdeljeno merjenje temperature (Distributed Temperature Sensing - DTS) na osnovi Ramanovega sipanja in porazdeljeno akustično zaznavanje (Distributed Acoustic Sensing - DAS). DTS omogoča neprekinjeno temperaturno profiliranje vzdolž optičnih vlaken. To se uporablja predvsem za merjenje temperaturnega profila kritičnih infrastrukturnih komponent, kot so nadzemni daljnovodi in kabli. Predavanje bo predstavilo nekaj empiričnih podatkov iz testnega poligona za dinamično ocenjevanje prenosne zmogljivosti vodnikov (Dynamic Line Rating - DLR). Tehnologija DAS pretvarja standardna optična vlakna v obsežno mrežo akustičnih senzorjev, sposobnih zajemanja vibracijskih podatkov na velikih razdaljah. Ta funkcionalnost je posebej koristna za merjenje vetra, saj zagotavlja podrobne vpoglede v hitrost in smer vetra za vsak razpon nadzemnega voda, kar je ključno za aplikacije dinamičnega ocenjevanja prenosne zmogljivosti vodnikov.

Abstract

The integration of fiber-optic sensing technologies has revolutionized monitoring capabilities within power systems, offering precise real-time data acquisition for linear infrastructure assets. This lecture delves into two pivotal fiber-optic sensing methodologies: Distributed Temperature Sensing (DTS), and Distributed Acoustic Sensing (DAS). By leveraging the Raman scattering phenomenon, DTS enables continuous temperature profiling along optical fibers. This capability is instrumental in detecting hotspots and assessing the thermal behavior of critical infrastructure components such as overhead power lines and cables. The lecture will present some empirical data from a Dynamic Line Rating (DLR) testing facility. DAS technology transforms standard optical fibers into extensive arrays of acoustic sensors, capable of capturing vibrational data across vast distances. This functionality is particularly advantageous for wind measurement, providing detailed insights into wind speed and direction for every overhead line-span , which are crucial for the Dynamic Line Rating applications.

Biografija avtorja

Andrej Souvent je direktor podjetja Operato, hčerinske družbe slovenskega kombiniranega operaterja prenosnega in distribucijskega sistema Eles. Preden se je pridružil Operatu, je 15 let deloval na Elektroinštitutu

Milan Vidmar, kjer je sedem let vodil Oddelek za vodenje in obratovanje elektroenergetskih sistemov. Z več kot 25-letnimi izkušnjami na področju procesnih tehnologij, zlasti v aplikacijah za elektroenergetske sisteme, ima Andrej bogate izkušnje pri integraciji rešitev in tehnologij pametnih omrežij v obratovanje elektroenergetskega sistema. Diplomiral in magistriral je iz elektrotehnike na Fakulteti za elektrotehniko Univerze v Ljubljani ter je član organizacij IEEE, CIGRE in IEC.

Author's biography

Andrej Souvent is the CEO of Operato, a subsidiary company of the Slovenian Combined Transmission and Distribution System Operator Eles. Prior to joining Operato, he spent 15 years at the Milan Vidmar Electric Power Research Institute, where he served as the head of the Power System Control and Operation department for seven years. With over 25 years of experience in operational technologies, particularly in power system applications, Andrej has extensive expertise in integrating smart grid technologies and solutions into power system operations. He holds Bachelor's and Master's degrees in Electrical Engineering from the University of Ljubljana and is a member of IEEE, CIGRE, and IEC.

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Uporaba optičnega vlakenskega senzorja v elektroenergetiki

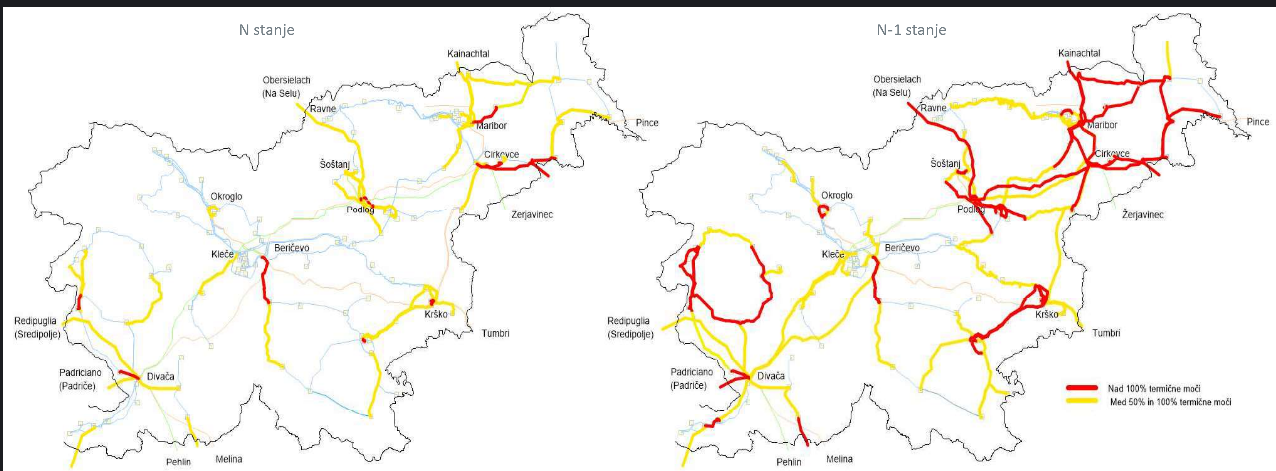
mag. Andrej Souvent

Februar 2025

ELES

Predvidene obremenitve omrežja

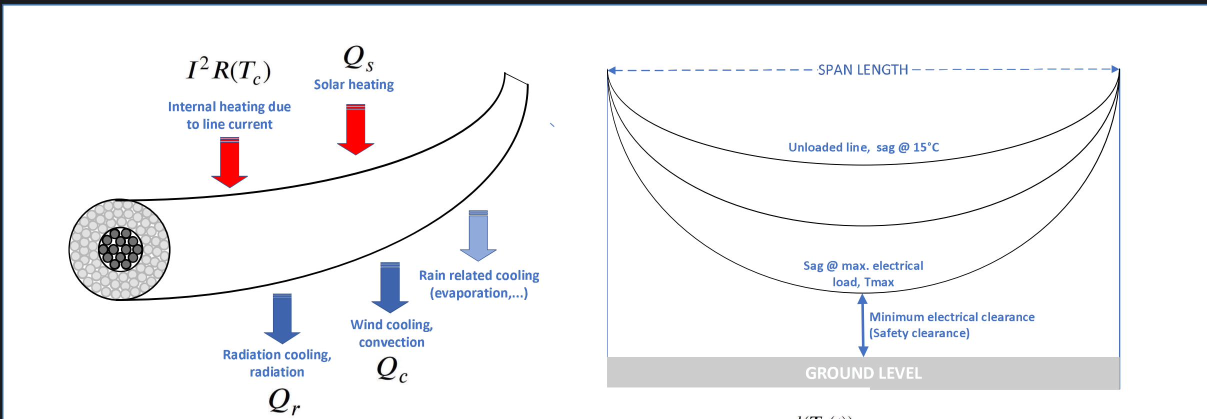
Integracija velikih količin OVE v prihodnosti bo predstavljala velike izzive tudi v slovenskem EES. Spodaj primer možnega scenarija za prenosno omrežje 2030:



Vir: dr. Jurij Klančnik, ZAGOTAVLJANJE VARNEGA IN ZANESLJIVEGA DELOVANJA EES, 14. Höflerjevi dnevi, november 2022, Portorož

Dynamic Thermal | Line Rating (DTR/DLR)

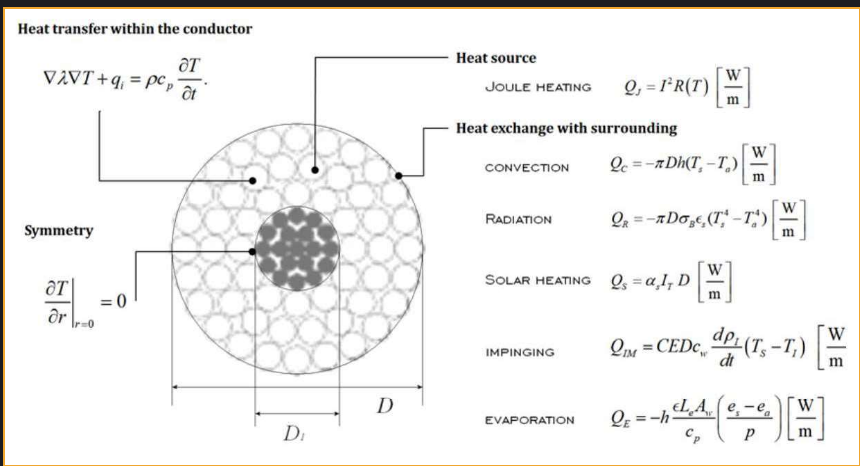
DTR/DLR je koncept obratovanja elektroenergetskega sistema, ki maksimira prenos energije skozi daljnovode/kablovode in transformatorje v času za hlajenje ugodnih vremenskih razmer, brez ogrožanja varnosti obratovanja in brez škodljivega vpliva na življensko dobo opreme.



$$I^2R(T_c) + Q_s = Q_r + Q_c + MC_p\frac{d(T_c(t))}{dt}$$

Izračun

- Izboljšan CIGRE (TB 601) model
- CIGRE (TB 601)
- IEEE (738-2023)

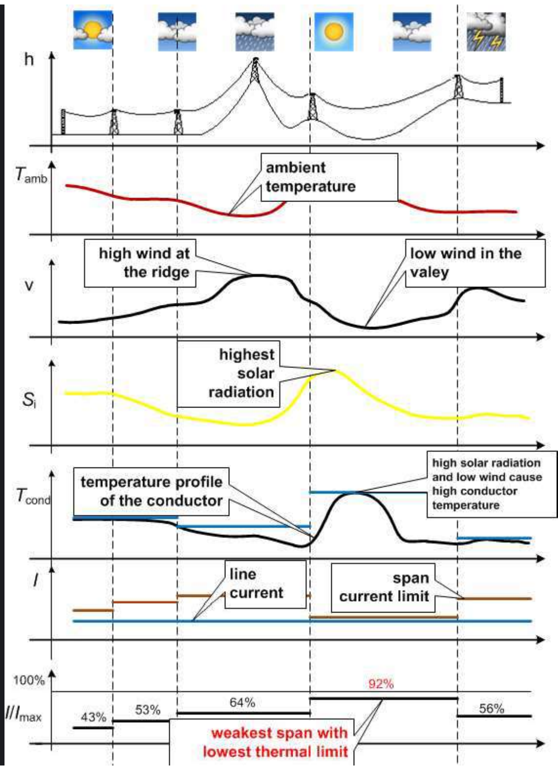


[1] M. Maksić, V. Djurica, A. Souvent, J. Slak, M. Depolli, and G. Kosec, '**Cooling of overhead power lines due to the natural convection**', *Int. J. Electr. Power Energy Syst.*, no. 113, p. str. 333-343, 2019.
[2] G. Kosec, M. Maksić, and V. Djurica, '**Dynamic thermal rating of power lines : model and measurements in rainy conditions**', *Int. J. Electr. Power Energy Syst.*, vol. 91, p. str. 222-229, 2017.

Računanje DLR

Spremenljive vremenske razmere vzdolž daljnovoda!

DLR računamo za vsako razpetino.



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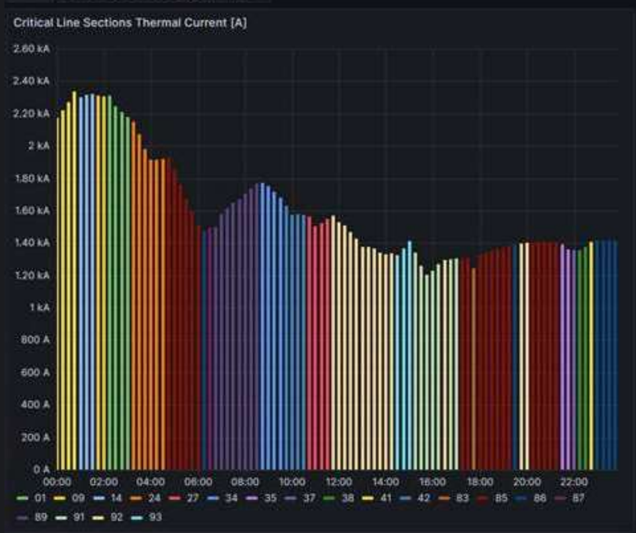
Potovanje kritične razpetine vzdolž daljnovoda

Primer obratovanja v 24 urah.

Device 924L OHL 240 kV Langdon - Milo



Critical Line Sections

section	name	duration [hh:mm:ss]	conductor
85	TF-924L238-924L262	04:45:00	ACSR SD Type 6.4 Alloy 5005
92	TF-924L280-924L294	03:30:00	ACSR SD Type 6.4 Alloy 5005
89	TF-924L269-924L270	02:00:00	ACSR SD Type 6.4 Alloy 5005
91	TF-924L271-924L280	01:45:00	ACSR SD Type 6.4 Alloy 5005
24	TF-924L58-924L69	01:30:00	ACSR SD Type 6.4 Alloy 5005
86	TF-924L262-924L265	01:30:00	ACSR SD Type 6.4 Alloy 5005
41	TF-924L140-924L158	01:15:00	ACSR SD Type 6.4 Alloy 5005
42	TF-924L158-924L160	01:00:00	ACSR SD Type 6.4 Alloy 5005
34	TF-924L92-924L106	01:00:00	ACSR SD Type 6.4 Alloy 5005
01	TF-924L0B-924L4A	01:00:00	ACSR Hornbill
27	TF-924L79-924L80	01:00:00	ACSR SD Type 6.4 Alloy 5005
93	TF-924L294-924L302	00:45:00	ACSR SD Type 6.4 Alloy 5005

From	To	Observed hours
03/18/2023 12:00:00 am	03/18/2023 11:59:59 pm	24

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Primer daljnovoda 220 kV Podlog – Obersilach

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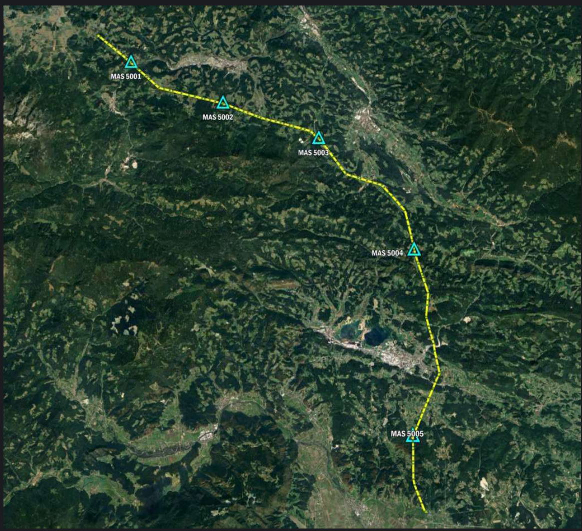

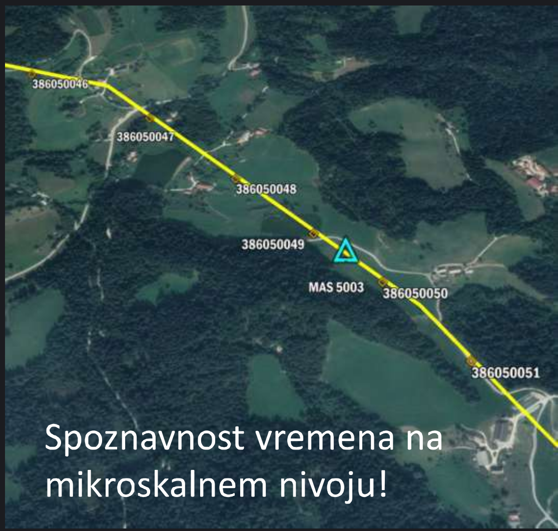

Lokalne vremenske postaje in mikroskalno procesiranje vremena

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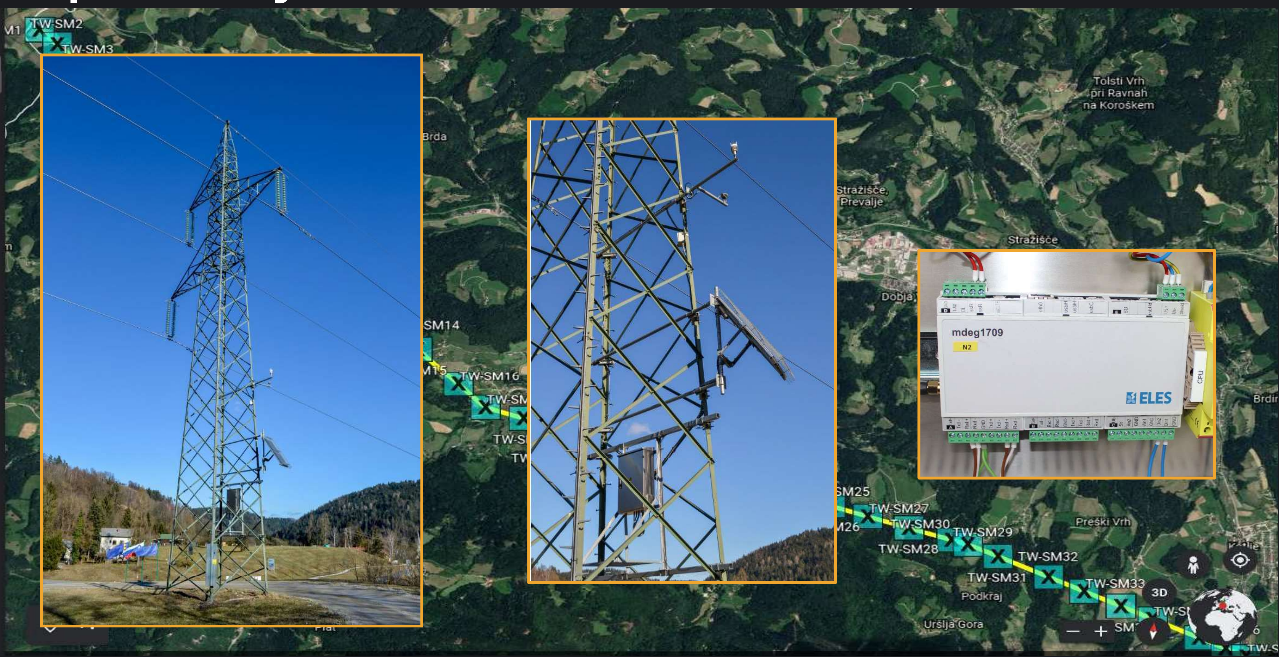
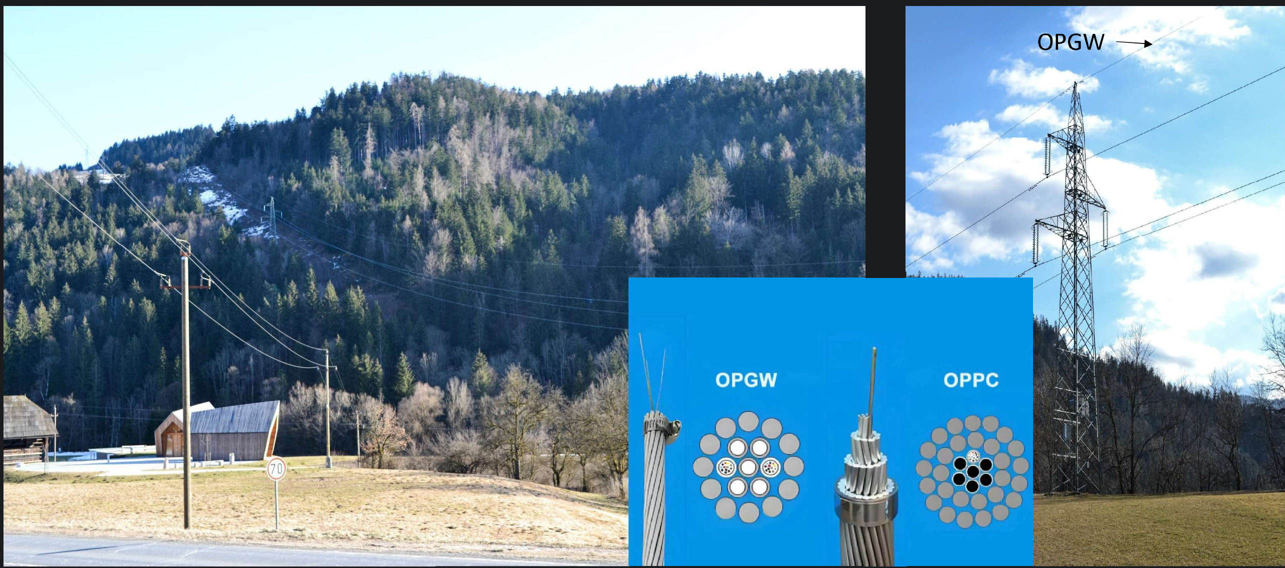
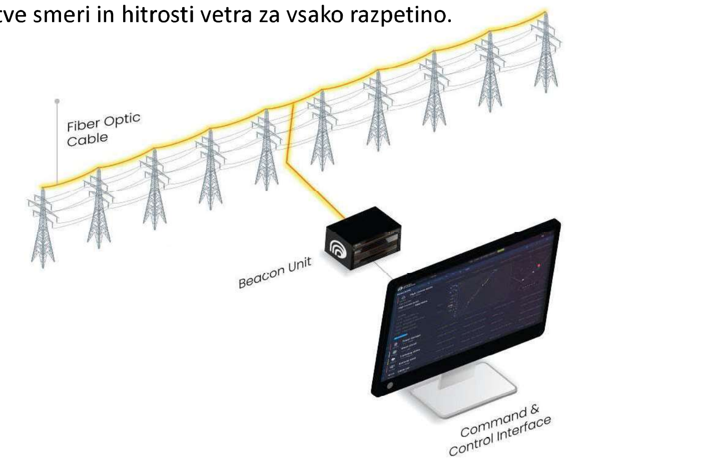


Uporaba optičnega vlakenskega senzorja za meritve vremena

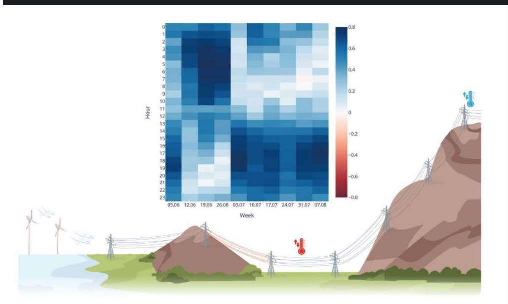


Uporaba porazdeljenega akustičnega zaznavanja za merjenje vetra

Meritve smeri in hitrosti vetra za vsako razpetino.



Uporabi se optična vlakna v zaščitnem vodniku (OPGW).



Uporaba porazdeljenega akustičnega zaznavanja

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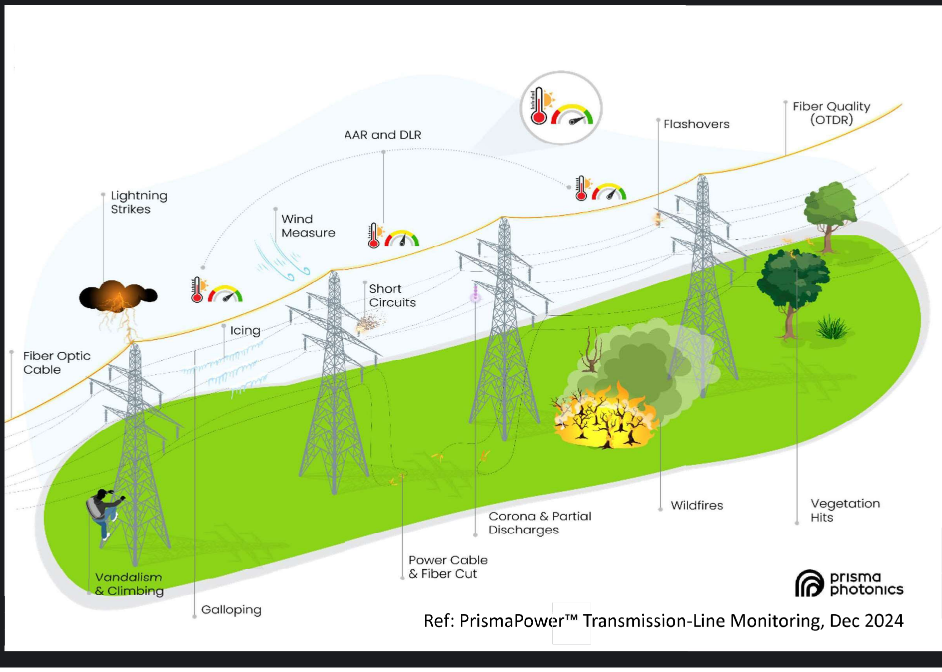
Številne druge aplikacije v elektroenergetiki:



Ref: PrismaPower™ Transmission-Line Monitoring, Dec 2024

Verifikacija DLR izračunov – merjenje temperature vodnika

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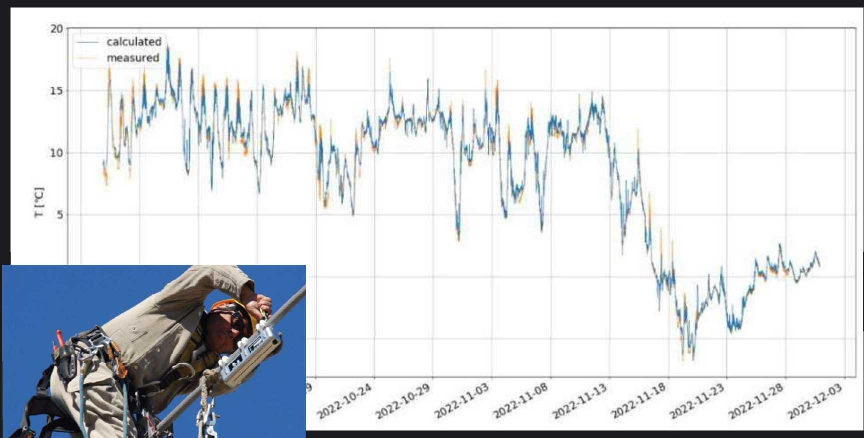
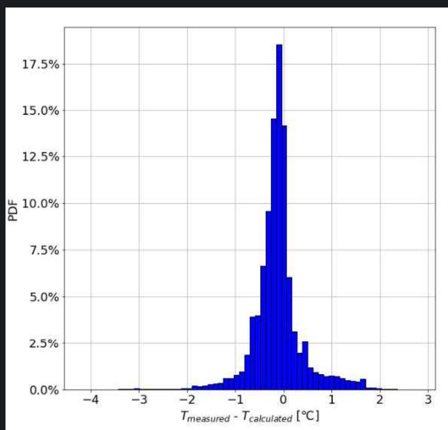
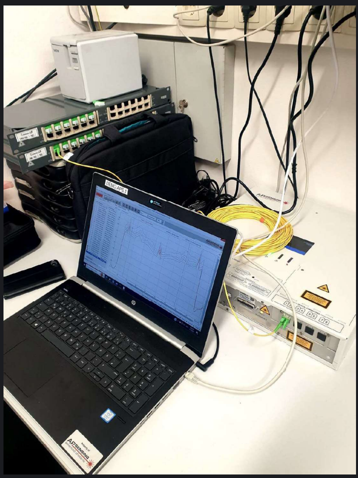
Izmerjene temperature primerjamo z izračunanimi temperaturami površine vodnika.

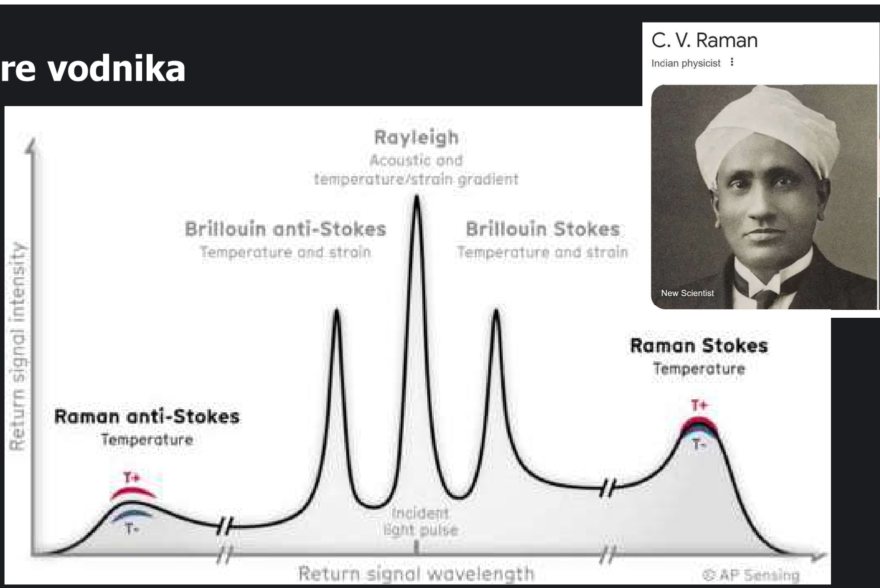




Primer: napaka izračuna temperature površine vodnika ±2°C.

Merjenje temperature vodnika





Vzdolžna ločljivost: 0,5 m
Temperaturna ločljivost: 0.3 °C

Ramanovo (povratno) sipanje v optičnih vlaknih na nadzorovanih strukturah omogoča kvantitativno merjenje temperature vzdolž celotne dolžine vodnika (daljnovoda/kablovoda).

DLR senzorji

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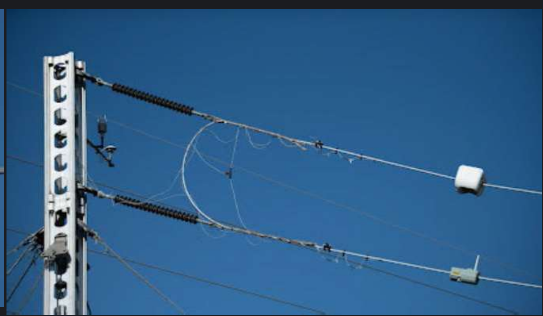
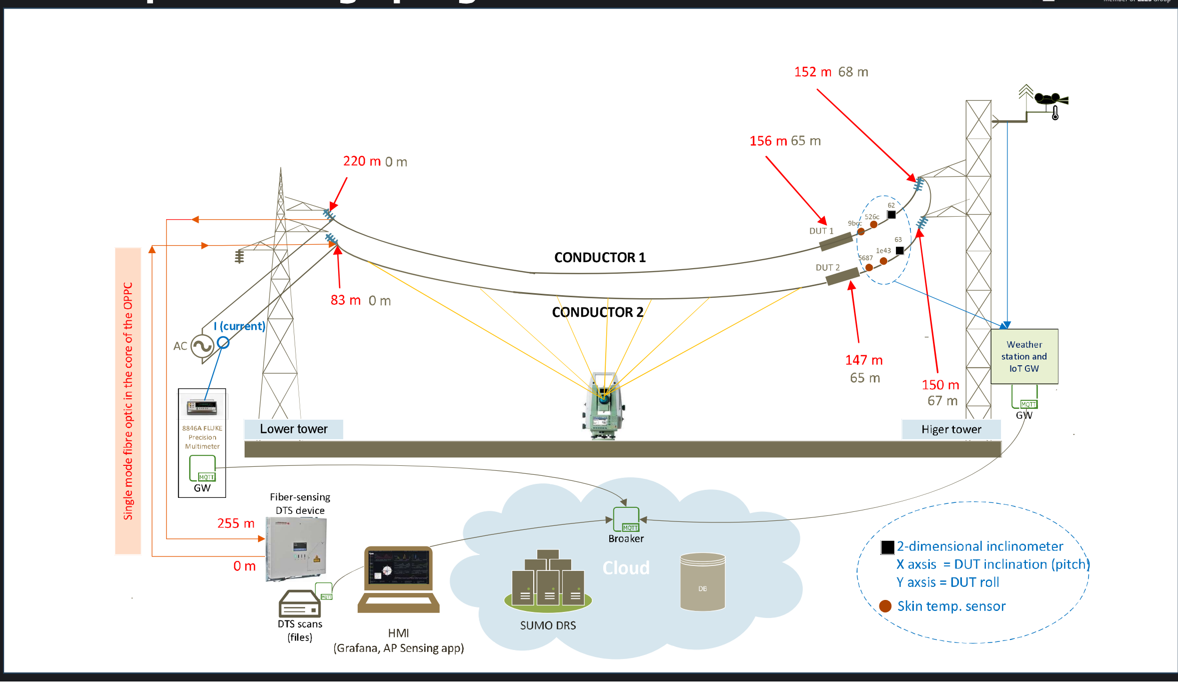


- Temperatura na mestu merjenja
- Povprečna temperatura vodnika
- Nagib
- Poves

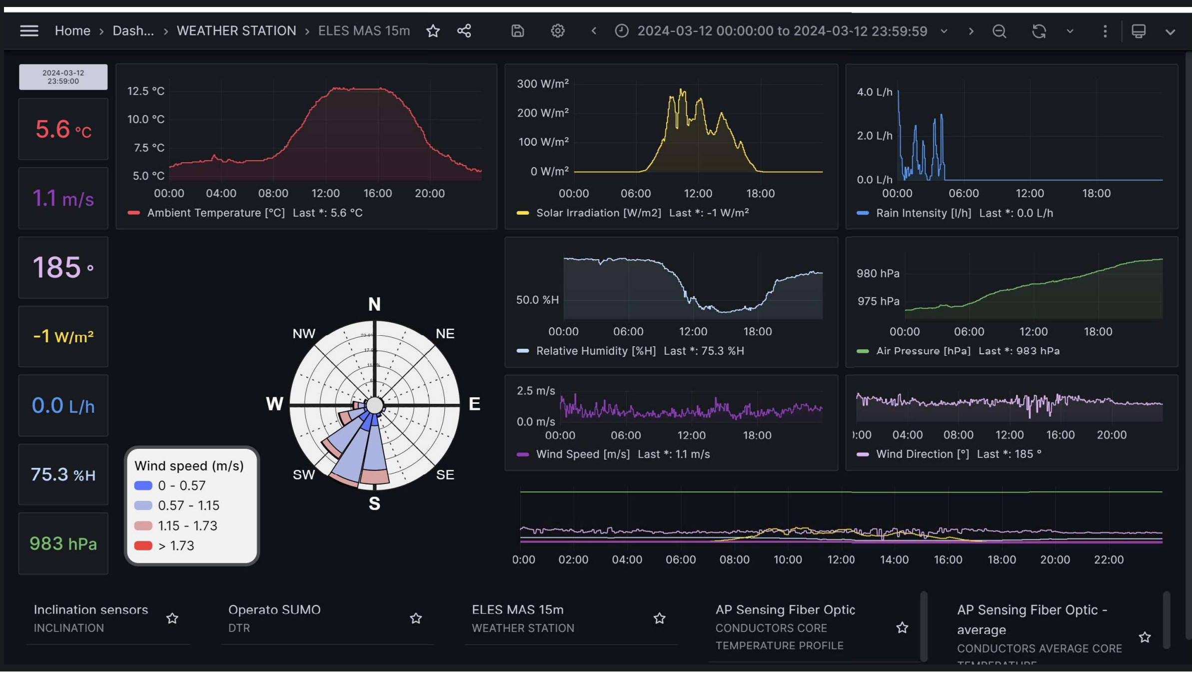
— Preizkusni poligon – aplikacija DTS

— Shema preizkusnega poligona

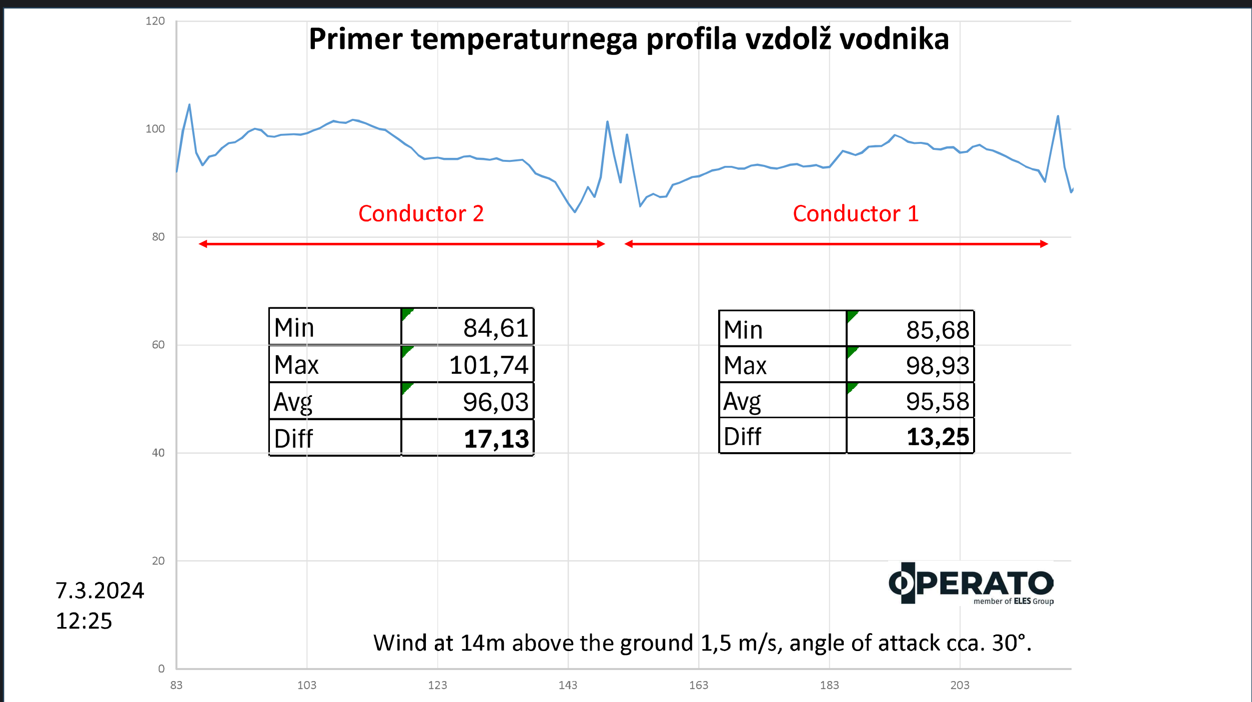


Izračun toka glede na vreme za doseganje želene temperature vodnika

Vremenski podatki



DTS meritve



Min	84,61
Max	101,74
Avg	96,03
Diff	**17,13**

Min	85,68
Max	98,93
Avg	95,58
Diff	**13,25**


Vroča mesta zaradi načina vpetja vodnika
Conductor 2
Conductor 1
Min 75,61
Max 103,75
Avg 88,64
Diff 28,14
7.3.2024
14:50
Dead end guy-grip
Spray-sanded helical wire
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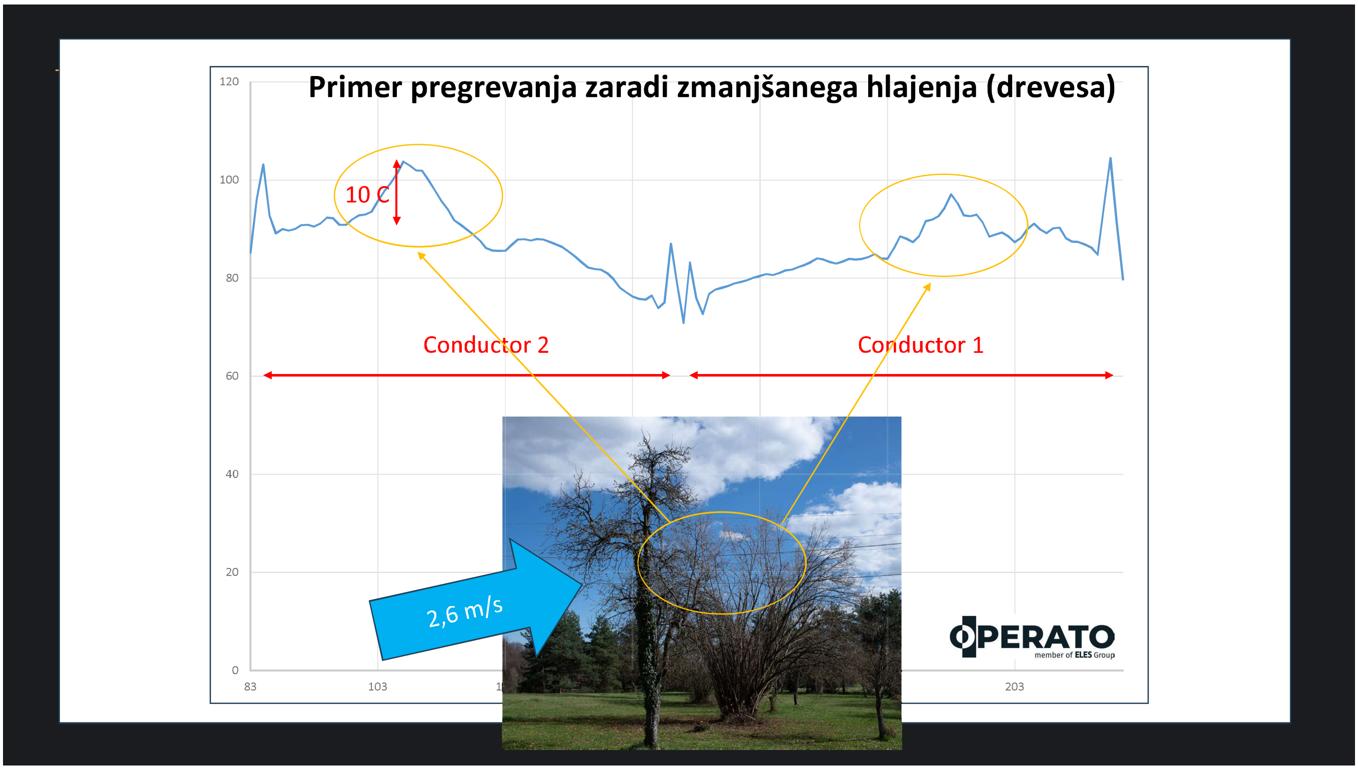
120
100
80
60
40
20
0
83
103
123
143
163
183
203


Primer pregrevanja zaradi zmanjšanega hlajenja (drevesa)
10 C
Conductor 2
Conductor 1
2,6 m/s
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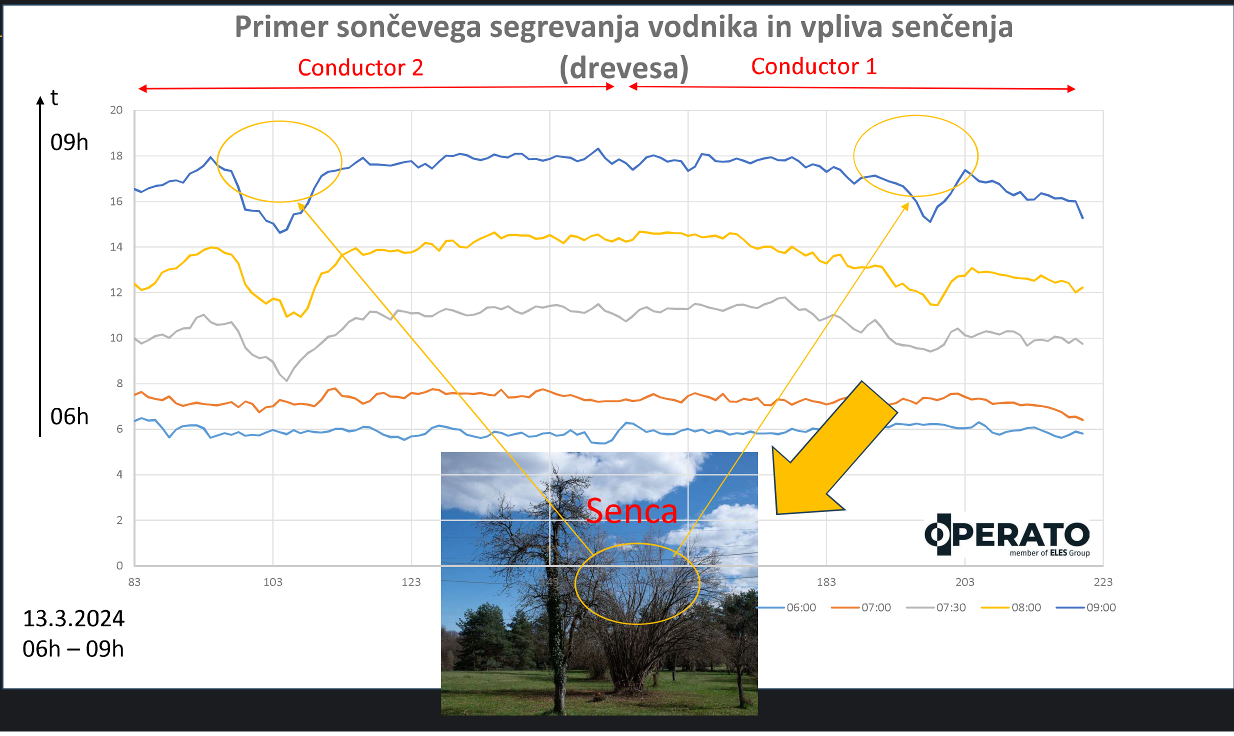
120
100
80
60
40
20
0
83
103
203



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Razvoj tehnologije FTTH od 10G do 50G in naprej

FTTH Technology trends from 10G to 50G and beyond

Igor Plevnjak

IBIS Instruments

igor.plevnjak@ibis-instruments.com

Povzetek

Tehnologija FTTH se nenehno razvija v smeri povečanja pretoka do končnega uporabnika. Da bi zadovoljili naraščajoče zahteve, je potrebno upoštevati standarde in izmeriti (oceniti) zmogljivost in kakovost omrežja. Predstavitev podaja pregled trenutnih in prihodnjih trendov razvoja FTTH ter priporočeno metodologijo merjenja, ki je potrebna za množično implementacijo.

Abstract

The FTTH technology is constantly evolving towards increasing throughput to the end user. To meet the growing demands, it is necessary to consider standards and measure (estimate) the performance and quality of the network. The presentation provides an overview of current and future trends in FTTH development and the recommended measurement methodology required for mass implementation.

Biografija avtorja

Igor Plevnjak je diplomirani inženir telekomunikacij in diplomirani ekonomist. Različne smeri šolanja so mu omogočile širok nabor znanja, ki ga je nadgradil z delom v različnih delovnih okoljih. Trenutno dela kot tehnični svetovalec pri testiranju žičnih in brezžičnih komunikacij ter rešitvah kakovosti storitev. Igor verjame, da je za dobro poznavanje sistema pomembno razumeti vse njegove vidike, od osnov, kot je varjenje optičnih vlaken, do kompleksnih nalog, kot so meritve na optičnih vlaknih, kar je v svetu optičnih komunikacij izkusil tudi sam.

Author's biography

Igor Plevnjak holds degrees in telecommunications engineering and economics. His diverse educational background has provided him with a broad range of knowledge, which he has further enhanced through work in various professional environments. He currently works as a technical consultant in the testing of wired and wireless communications and service quality solutions. Igor believes that a deep understanding of a system requires familiarity with all its aspects, from the basics, such as fiber optic splicing, to complex tasks like fiber optic measurements, an experience he has gained firsthand in the field of optical communications.

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FTTH New Trends

from 10G to 25, 50G and beyond…

Igor Plevnjak
Technical support
Ibis Instruments International
February 2025

Agenda

- XGS-PON is now a mainstream
- 25/50-GPON and beyond
- NG-PON2 deployment blockers
- The only way is to test

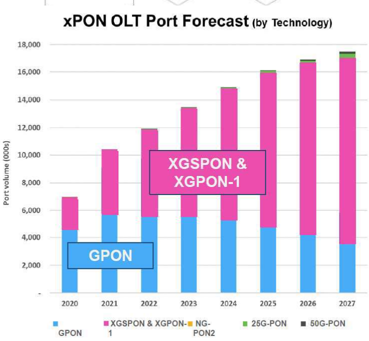
XGS-PON is now a mainstream

PON technology options for a multi gigabit future

XGS-PON has propelled us in the multi-gigabit era, but what comes after XGS-PON?
What is the status of standardization and market readiness of next-generation technologies?
How can service providers prepare today to be able to monetize their PON infrastructure for these new use cases in the future?
Is speed the only important driver or there are others?

	Standard \ Speeds (Gbps)	Up	Down
GPON	ITU-T G.984.5	1.25	2.5
XGS-PON	ITU-T G.9807.1	10	10
25GS-PON	25GS-PON Specification 2.0 MSA	25	25
50G-PON	ITU.T G.9804.3	50	50
VHSP	*ITU.T G.sup.VHSP (draft)*	*> 50*	*> 50*

	Upstream	Downstream
GPON	1290-1330	1480-1500
XGS-PON	1260-1280	1575-1581
25GS-PON	1260-1280 (UW0) 1290-1310 (UW1) 1284-1288 (UW3)	1356-1360 (DW0)
50G-PON	1260-1280 (option 1) 1290-1310 (option 2) 1284-1288 (option 3)	1340-1344
VHSP	*Proposed 1284-1288 (option 3 from 50G)*	*Proposed in 1310-1340 range*



Source: OmdiaFiber & Copper Access Equipment Forecast Report 2021 –2027, February 2022

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Demand for higher bitrates is growing

	The past		The future	
PHOTO	12 MP smartphone photo	3MB	30-50 MB	180 degree photo digital sculpture
WEB	Average web page size in 2017	3MB	30-50 MB	3D web scene
VIDEO CALL	Video chat apps	1-5 Mbps	25-50 Mb/s	Holo-chat 1 person
VIDEO	4K, 8K	5-20 Mbps	100 Mb/s – 1 Gb/s	Free viewpoint video

Source: Nokia

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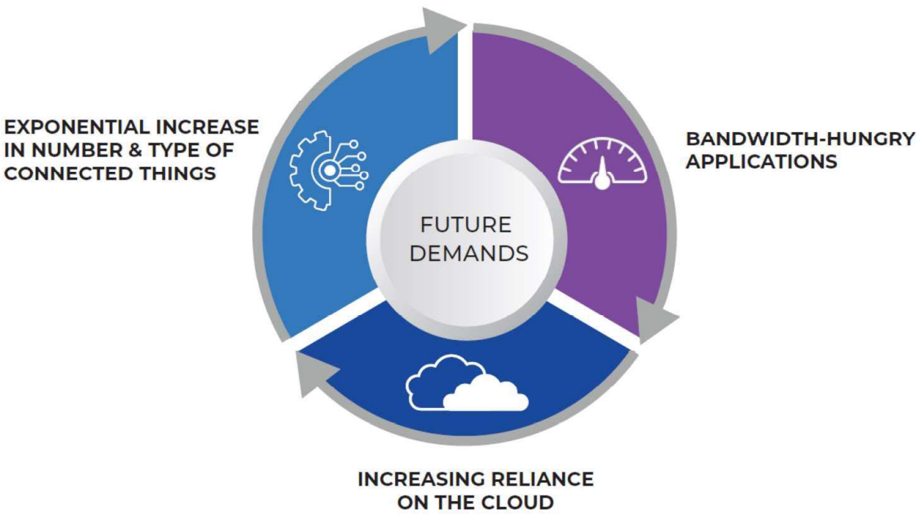
Future Demands on Network Driven by …



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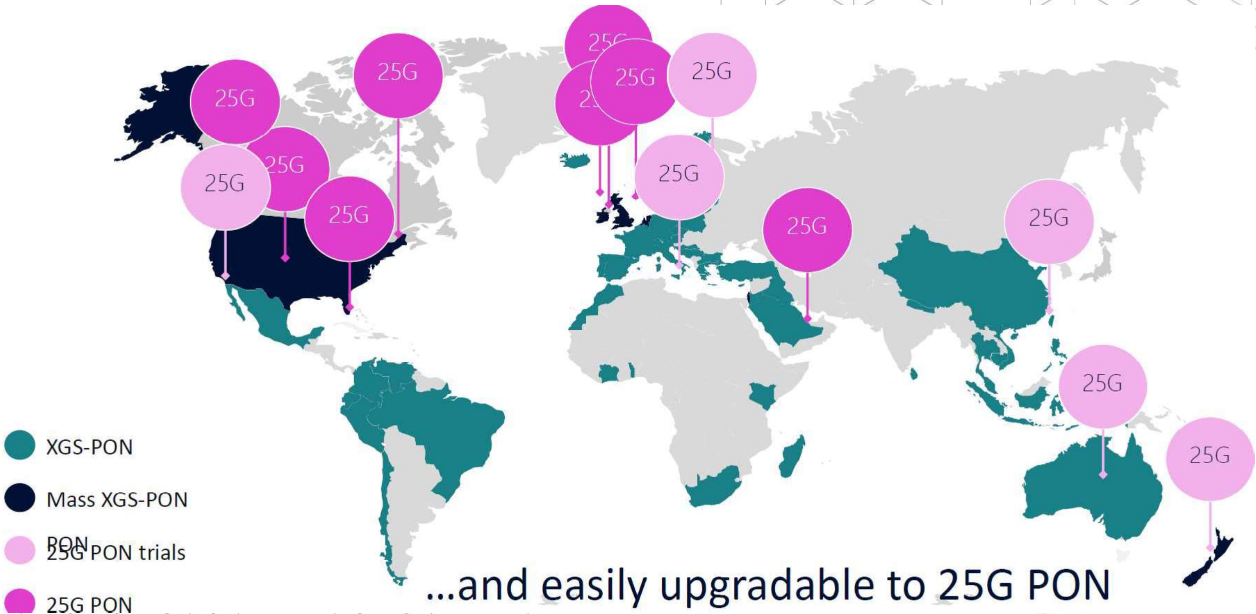
XGS-PON is now a mainstream



...and easily upgradable to 25G PON

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Introduction to higher speed PON takes time

3 to 10 years	2 to 5 years	4-5 years	10+ years
Technology proof of concept	Initial products	Early adoption	Mass adoption
Prototypes Standardization Early demos	Eco-system creation Performance optimization Cost optimization	Field trials Tactical deployments	Volume deployments Market demand

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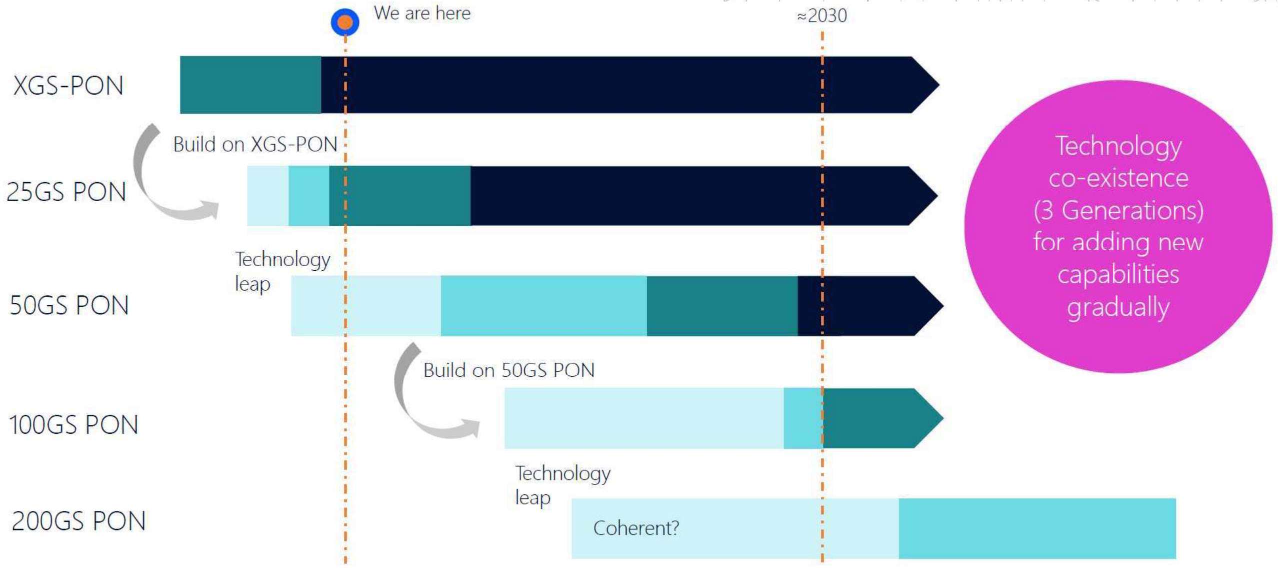
Reality check #1: from technology innovation to deployment



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25/50-GPON and beyond

Next-Generation PON Standards

- Limitations with current G-PON/GE-PON standards
- Standards have been defined by ITU-T & IEEE:

	GPON	XGS-PON	NG-PON2	25G PON	50G PON	GE PON	10G EPON	25G EPON	50G EPON
Standards	ITU-T G.984 (2003)	ITU-T G.987.1 (2016)	ITU-T G.989 (2015)	Follows ITU-T G.987.1 with Deltas (2020)	ITU-T (G.984.3) (2021)	IEEE 802.3ah (2004)	IEEE 802.3av (2009)	IEEE 802.3ca (2020)	IEEE 802.3ca (2020)
Downstream Upstream	2.4 GB/s 1.2 GB/s	10 GB/s 10 GB/s	4(8)x10 GB/s 4(8)x2.5 GB/s	25 GB/s 10/25 GB/s	50 GB/s 12.5/25/50GB/s	1.25 GB/s 1.25 GB/s	10 GB/s 10 GB/s	25 GB/s 10/25 GB/s	50 GB/s 10/25/50 GB/s
Splitting Ratio (Typ.)	1:64 (128)	1:64 (128)		1:64 (256)	1:64 (256)	1:32	1:64	1:32	1:32
Distance / Max. Loss	20 km 32 dB	60 km 35 dB	60 km 35 dB	20 km 24/29 dB	20/40 km 29/32/35 dB	20 km 29 dB	20 km 29 dB	20 km 24/29 dB	20 km 24/29 dB
Fiber Type	G.652	G.652 / G.657 (for new inst.)		G.652 / G.657	G.652 / G.657	G.652	G.652 / G.657	G.652 / G.657	G.652 / G.657

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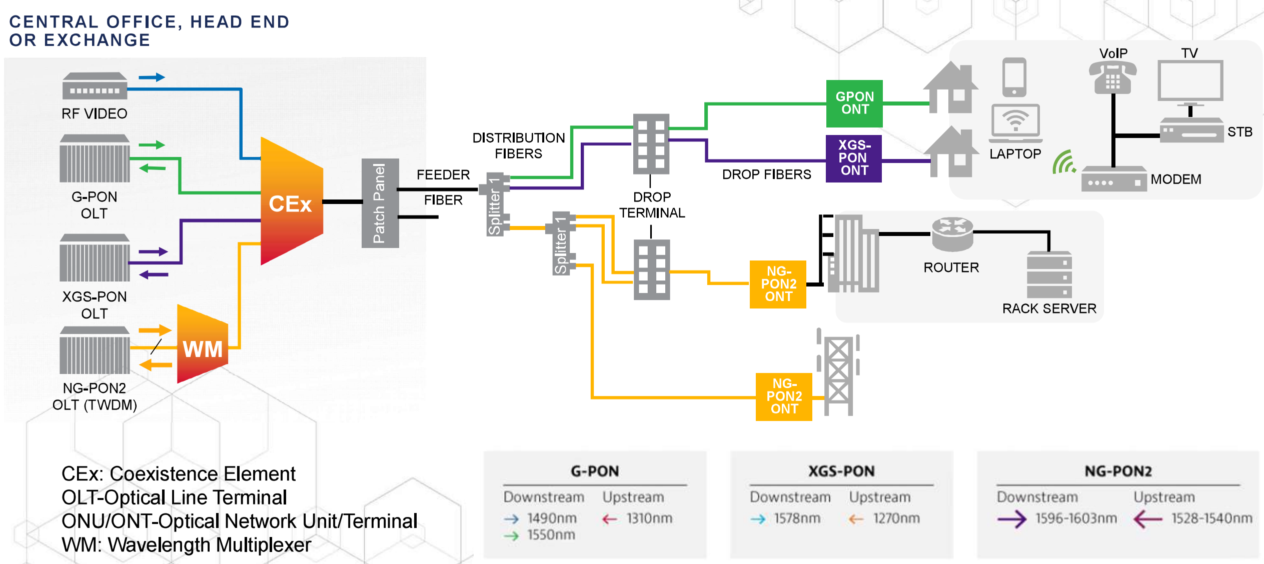
PON Coexistence Architecture



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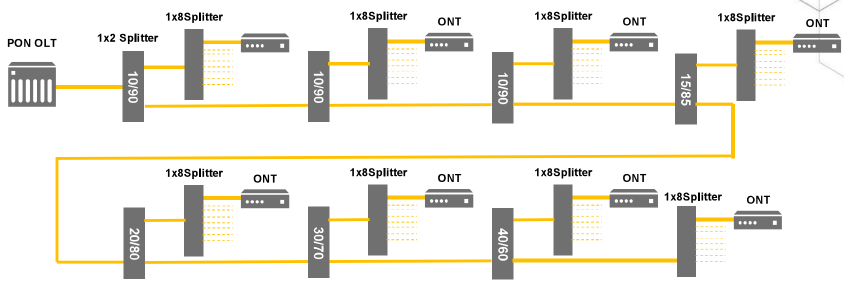
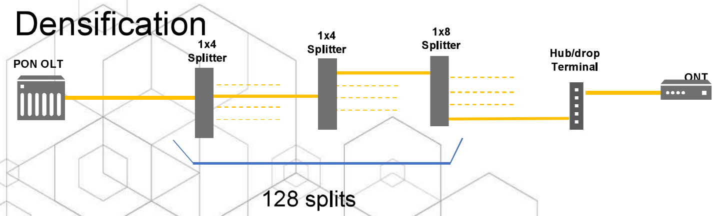
New Architectures

Unbalanced



Uneven splitting ratio to increase cascading capability and scalability. South America

Densification



Increase densification in standard PON architectures

but limited bit rate per customer.

1:32 78Mbps down
1:64 39Mbps down
1:128 19Mbps down

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25/50 G-EPON according to IEEE 802.3ca

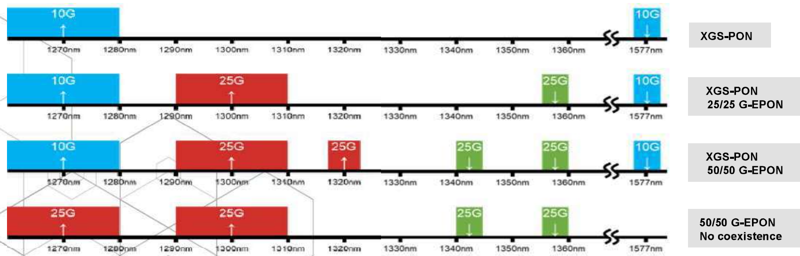
Approved in June 2020

Standard	Terminology	Bandwidth	Wavelengths	Core applications
25G/50G -EPON IEEE 802.3 ca	**High Speed EPON**	2 x 10G Up 2 x 25G Up 2 x 25G Down	Low O band Up High O band Down	Business services/MDU 5G Transport

Allows symetrical operation 25/25 or 50/50 Gbps as well as asymetrical 25/50 Gbps.

Used fixed wavelengths, instead of tunable wavelengths, and wideband optics in O-band without dispersion compensation are main advantages in comparison with NG-PON2.

25/50 G-EPON is designed to enable symmetrical 10G to coexist with either symmetrical 25G or 50G traffic on the same fiber as well. See various coexistence scenarios.



MDU **M**ultiple **D**welling **U**nit

Source: Calix

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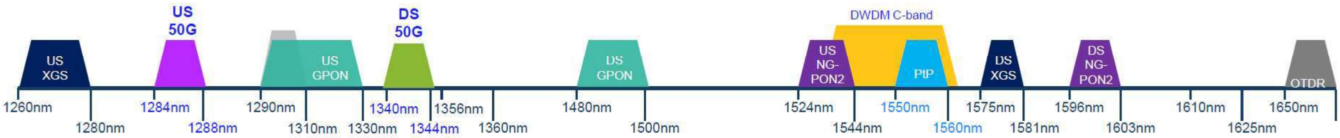
50G PON Wavelength Plan

- Wavelengths defined in ITU-G G.9804.3
  - o Option 3 has been added with ITU-T G.9804.3 (2021) / Amd.1 (02/2023)
    - 1284-1288nm US
    - 1340- 1344nm DS
  - o Option 3 allows coexistence of 50G PON with GPON, XGS PON as well as PtP / DWDM C band

	Upstream	Downstream
GPON	1290-1330	1480-1500
XGS-PON	1260-1280	1575-1581
25GS-PON	1260-1280 (UW0) 1290-1310 (UW1) 1284-1288 (UW3)	1356-1360 (DW0)
50G-PON	1260-1280 (option 1) 1290-1310 (option 2) 1284-1288 (option 3)	1340-1344
VHSP	*Proposed 1284-1288 (option 3 from 50G)*	*Proposed in 1310-1340 range*



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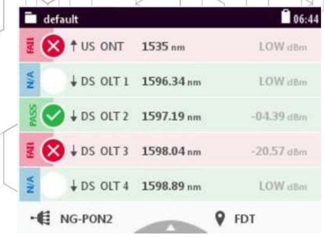
NG-PON2 deployment blockers

NG-PON2 Spectrum

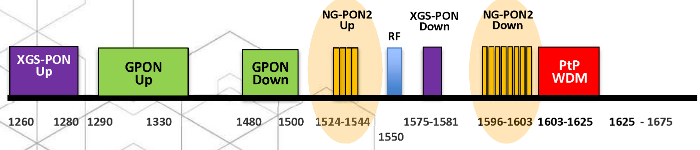
NG-PON2 supports multiple 10 Gbps wavelengths

- Downstream 4/8 x 10 Gbps at 4/8 TWDM wavelengths between 1596 – 1603 nm
- Upstream 4/8 x 2,5 Gbps at 4/8 TWDM wavelengths between 1524 – 1544 nm



NG-PON2 blockers:

- Multi-wavelength NG-PON2 requires **tunable optics** at the ONU (Optical Network Unit) endpoint.
- NG-PON2 is very sensitive to macrobendings mainly in house cabling. It requires G.657B/C cabling instalations. Upgrade of older G-PON networks to NG-PON2 **requires also upgrade of in house cabling (from G.652 to G.657B/C)!**



Source: FTTH EMEA D&O Committee FTTH Poland 2015

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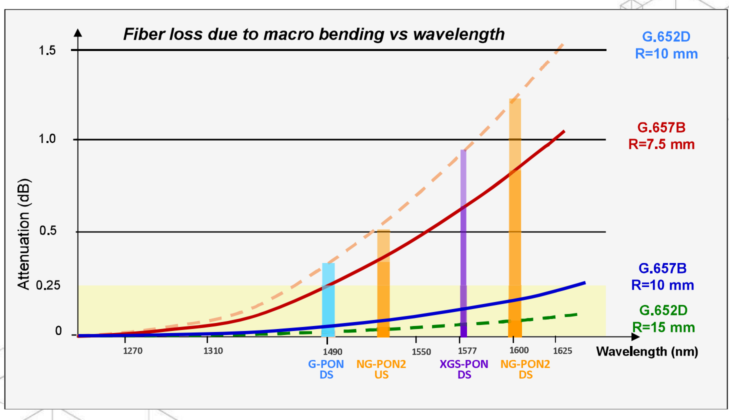
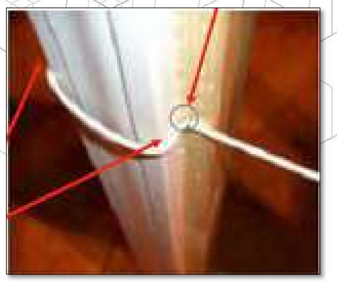
Bending Constraints – Impact on NG-PON





According to Verizon, radius around corners can go down <10 mm

- XGS-PON or NG-PON2 new construction is similar to G-PON with a special focus on loss induced by fiber bending
- Longer wavelengths > higher sensitivity to macrobend (in house cabling!)
  - Use of G.657B bend insensitive fiber (works down to 10 mm radius)
- **Characterization at 1625/1650 nm will become a strong requirement**

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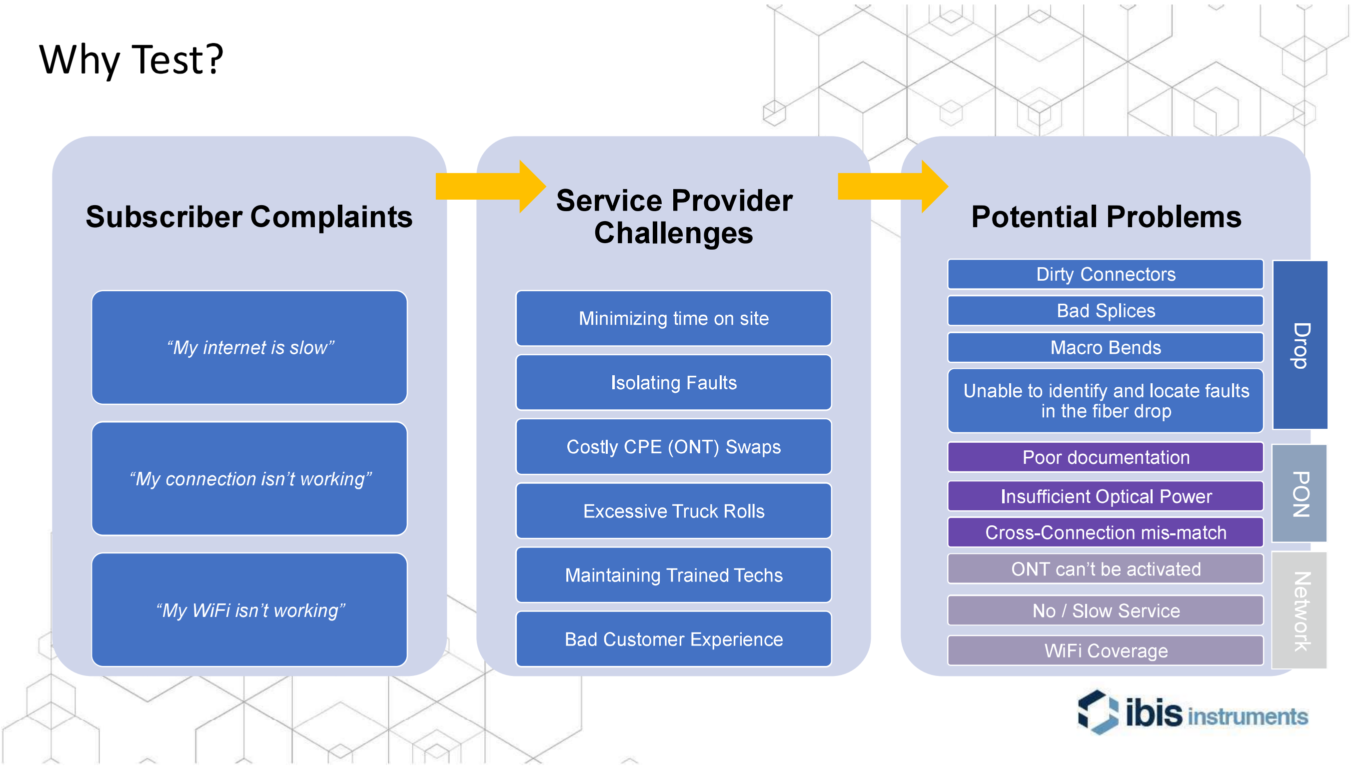
The only way is to test


Why Test?
Subscriber Complaints
"My internet is slow"
"My connection isn't working"
"My WiFi isn't working"
Service Provider Challenges
Minimizing time on site
Isolating Faults
Costly CPE (ONT) Swaps
Excessive Truck Rolls
Maintaining Trained Techs
Bad Customer Experience
Potential Problems
Dirty Connectors
Bad Splices
Macro Bends
Unable to identify and locate faults in the fiber drop
Poor documentation
Insufficient Optical Power
Cross-Connection mis-match
ONT can't be activated
No / Slow Service
WiFi Coverage
Drop
PON
Network
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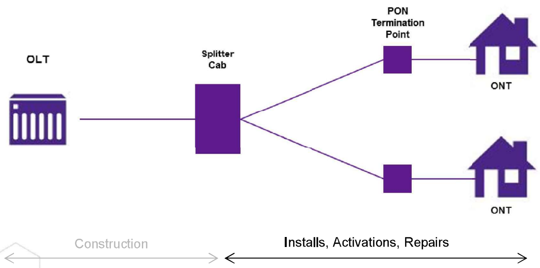
Last Mile FTTx

Best Practice Test Checklist (IPQT)

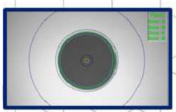


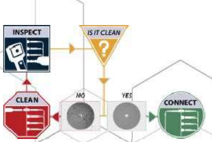
Inspection & Cleaning
for both fiber cable and bulkhead connectors

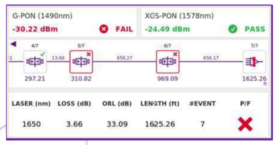
Power Measurement
to verify the right light to ONT

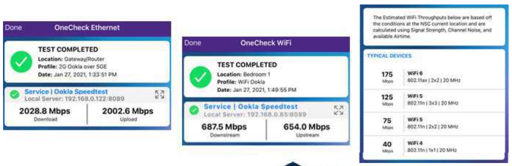
Qualification of the Fiber and Its Elements
up to the first splitter (connectors, splices)

Throughput to ONT/Gateway and WiFi
in the home









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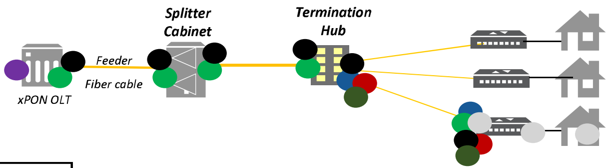
Where Do Measuring Tools Suite Fit into the Network?

Fiber test Suite
- Bi-Directional IL/ORL/OTDR
- End-to-end Continuity check
- Qualify Feeder cable and/or complete PON network
- Generate birth certificate

True PON Analyzer (G/XGSPON)
- λ-sel. / through mode PM
- ONT- and OLT-identification
- Verification of service activation status
- Alien/Rogue-ONU detection
- In-service loss testing

Power Meters
- Broadband or λ-selective
- Terminal PON meter option
- G-XGSPON

RFTS PON
- Centralized OTDR testing
- End-to-End loss and distance
- Construction certification
- Turn-up validation



Network & Service certification
- Speed Test 2G, layer 1-4
- WiFi coverage & performance
- Optical level reading
- OLT ID & ONU emulation

Inspection scopes
- Pass/Fail indication
- Validate connector integrity throughout the network

Classic OTDRs
- Build 1310/1550nm -OTDR
- PON 1650nm
- In-Service troubleshooting

PON OTDR
- Test through cascaded PON splitters
- E2E validation from ONT

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Test Process Automation Tools

Expert OTDR

- One-button test
- Sequence of expert measurements / tests encapsulated as a single test operation

Manage jobs

- Sequence of individual test tasks grouped together to form a single job
- Web tool for defining & customizing job templates
- Can coordinate tasks & results across instruments
- Instrument UI displays step-by-step task instructions, progress and results

Mobile connect

- Mobile App for IOS and Android
- Auto syncs jobs and results to/from the instrument
- Enriches instrument test results
  - Geolocation data
  - Multimedia attachments (pictures, signature capture)

Cloud connect

- Centralized Management
  - Organize and push job assignments & test configurations to instrument
  - Auto collection and organization of Test Results
- KPI Dashboards, Analytics, Backoffice integration of Test process/data

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Questions?

For more information contact us
igor.plevnjak@ibis-instruments.com

Napredne rešitve za taktična omrežja v zahtevnih okoljih
Tactical Networks in Harsh Environments: Advanced Solutions

Jiri Štefl
Optokon
stefl@optokon.com

Povzetek

Taktična omrežja so ključna za vojaške in nujne operacije, saj zagotavljajo varno komunikacijo v dinamičnih okoljih. Omogočajo prenos podatkov, zvoka in videa med mobilnimi in stacionarnimi enotami, tudi v ekstremnih pogojih. Njihova odpornost zagotavlja neprekinjeno povezljivost, kar je ključno za uspeh misije. Napredne rešitve vključujejo najsodobnejšo tehnologijo za hitro, varno in zanesljivo komunikacijo. Ta omrežja ponujajo izboljšano mobilnost, fleksibilnost in brezskrbno interoperabilnost v različnih operativnih scenarijih. Visoka raven varnosti se zagotovi z naprednimi šifrirnimi tehnologijami in varnimi protokoli, ki ščitijo občutljive podatke in ključne operacije.

Abstract

Tactical networks are crucial for military and emergency operations, providing secure communication in dynamic environments. They enable data, voice, and video transfer between mobile and stationary units, even under extreme conditions. Their resilience ensures uninterrupted connectivity, essential for mission success. Advanced solutions integrate cutting-edge technology for high-speed, secure, and reliable communication. These networks offer enhanced mobility, flexibility, and seamless interoperability across various operational scenarios. High-level security is maintained through advanced encryption and secure protocols, protecting sensitive data and critical operations.

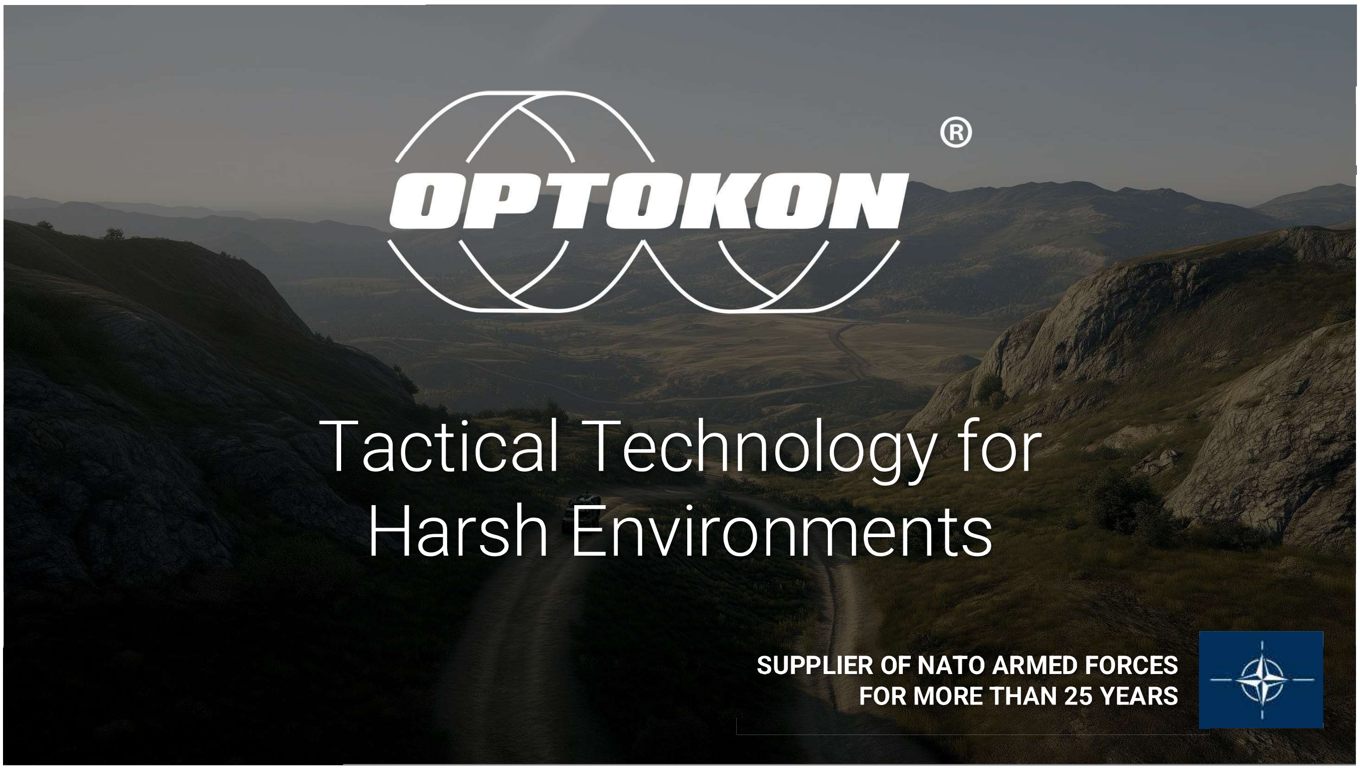
Biografija avtorja

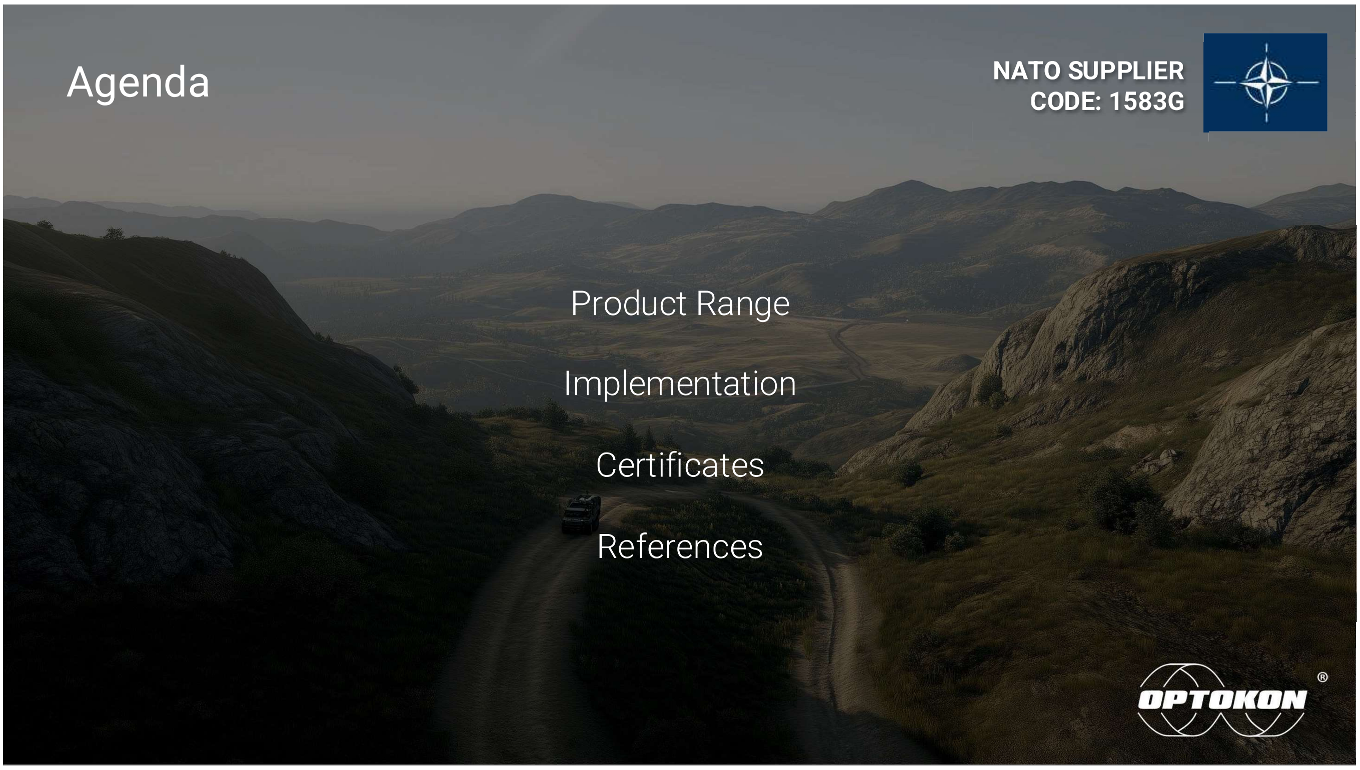
Jiří Štefl je leta 1985 diplomiral na Češki tehnični univerzi v Pragi, s poudarkom na tehnologiji in telekomunikacijah. Pet let je delal kot razvojni inženir v podjetju Tesla Jihlava, nato pa se je leta 1991 pridružil podjetju OPTOKON, najprej kot vodja tovarne in kasneje kot direktor prodaje. Od leta 1996 je bil direktor podjetja OPTOKON, kjer je vodil vse dejavnosti skupine, vključno z akreditiranimi kalibracijskimi laboratoriji v Maleziji in podjetjem OPTOKON KABLE v Sloveniji. Od leta 2000 predstavlja Češko v CENELEC-u, kjer se osredotoča na optične konektorje in pasivne komponente. Od leta 2021 je predsednik uprave podjetja OPTOKON, kjer vodi skupino in njene podružnice po vsem svetu, vključno s podjetjem OPTOKON Kable in kalibracijskimi laboratoriji v različnih državah.

Author's biography

Jiří Štefl graduated in 1985 from the Czech Technical University in Prague, specializing in technology and telecommunications. He worked as a development engineer at Tesla Jihlava for five years and then joined OPTOKON in 1991, initially as a factory manager and later as Sales Director. From 1996, he served as CEO of OPTOKON, overseeing all group activities, including calibration laboratories in Malaysia and the company

OPTOKON KABLE in the Czech Republic. Since 2000, he has represented the Czech Republic in CENELEC, focusing on optical connectors and passive components. Since 2021, he has been the Chairman of the Board at OPTOKON, overseeing the group and its subsidiaries worldwide, including OPTOKON Kable and calibration laboratories in various countries.


OPTOKON®
Tactical Technology for Harsh Environments
SUPPLIER OF NATO ARMED FORCES
FOR MORE THAN 25 YEARS


Agenda
NATO SUPPLIER
CODE: 1583G
Product Range
Implementation
Certificates
References
OPTOKON®

Computing Platform – Server

NATO SUPPLIER
CODE: 1583G

LMCP-7H

Compact, ultra-durable server

6x Gigabit Ethernet ports

Operates from -32°C to +75°C

MIL-STD-810G certified

- Equipped with Intel® CPU, M.2 onboard storage, and removable SSD
- Supports up to 64 GB DDR4 memory for efficient power use
- Dust- and debris-sealed for use in harsh conditions

OPTOKON®

Rugged Rugged Display Assistant

NATO SUPPLIER
CODE: 1583G

AIRDA / *XARDA*

Airforce / Land Forces

Operates from – 500m to 16 800m altitude

Operates from -55°C to +85°C

MIL-STD-810G IP54 certified

- 10” High-resolution, 1,5 Kg Rugged Display with Screen Brightness 1100cd/m2
- Ideal for mission-critical operations where durability and functionality are paramount
- Supports DVI / VGA video inputs, ensuring compatibility with variety of systems

OPTOKON®

Ruggedized routers

NATO SUPPLIER
CODE: 1583G

LMSR-R63

Ruggedized Next Gen Gigabit Router

- 6 Gigabit Ethernet ports (2 WAN, 4 LAN with PoE)
- Operates from -40°C to +70°C
- Built for harsh conditions, IP65 certified

- Built for secure data, voice, and video in tactical networks
- Onboard encryption ensures secure, scalable communications
- Low power consumption: 12 W (up to 150 W with PoE)

OPTOKON®

Ruggedized phones

NATO SUPPLIER
CODE: 1583G

LMIPT-41

High-class Rugged IP Phone

- Gigabit Ethernet, PoE, D38999 connectors
- Operates from -25°C to +55°C
- MIL-STD-810G certified

- 5-inch high-resolution display, with localized language support
- Cisco EnergyWise™ technology for energy efficiency
- MIL-STD-461G EMC compatibility, MIL-STD-810G environmental testing

OPTOKON®

Ruggedized switches

NATO SUPPLIER
CODE: 1583G

LMSW-E33

Rugged 1/10G Layer 2/3 PoE Switch

10G fiber optic HMA connectors.

Operates from -40°C to +70°C

Compact, robust, 19” rack-mountable.

- Cisco IOS® software with L2/L3 network functionality
- 8/24 PoE-enabled ports, 360 W total power budget
- Flexible 20–40 V DC input power supply

OPTOKON®

Ruggedized switchboards

NATO SUPPLIER
CODE: 1583G

LMES

Power supply 230 V AC / 24 V DC

8x 24 V DC outputs, D38999 connectors

Operates from -25°C to +70°C

3U aluminum, 19” rack-mountable

- Total output current of 20 A, split across two groups
- Front panel display shows output voltage status
- Short-circuit and surge protection, 93% efficiency

OPTOKON®

Ruggedized UPS

NATO SUPPLIER
CODE: 1583G

LMUPS-80S-24V-AC

Ruggedized Uninterruptible Power Supply

5x 24 V DC outputs, hot-swappable battery

Operates from -25°C to +70°C

2.5 RU box, built for durability

- DC UPS provides uninterrupted power and independent battery charging
- Dual modules: 24 V DC UPS and 220 V AC power supply
- EMC compliant, MIL-STD-461F and EN 60950-1 certified

OPTOKON®

Ruggedized Convertors

NATO SUPPLIER
CODE: 1583G

LMC-02.GF

Gigabit Ethernet Media Converter

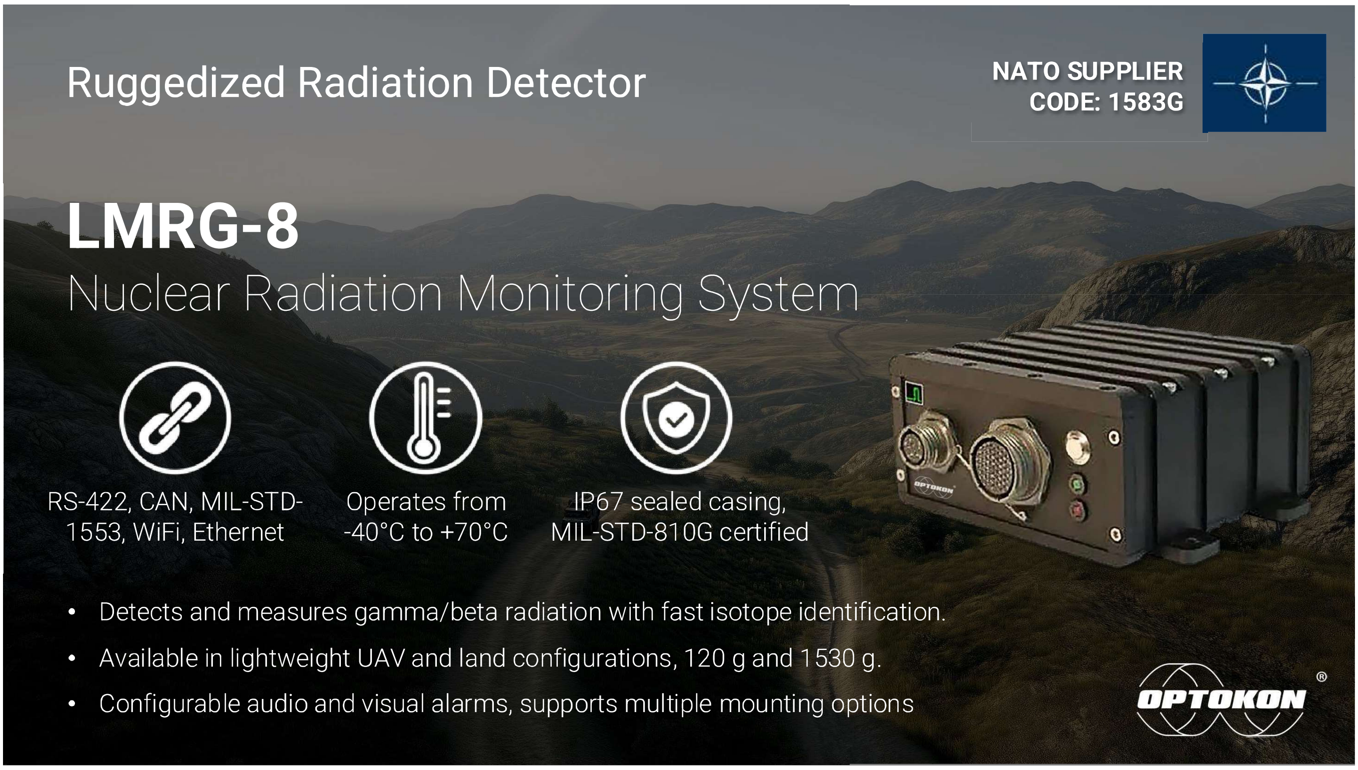
Supports fiber optic and copper Ethernet ports

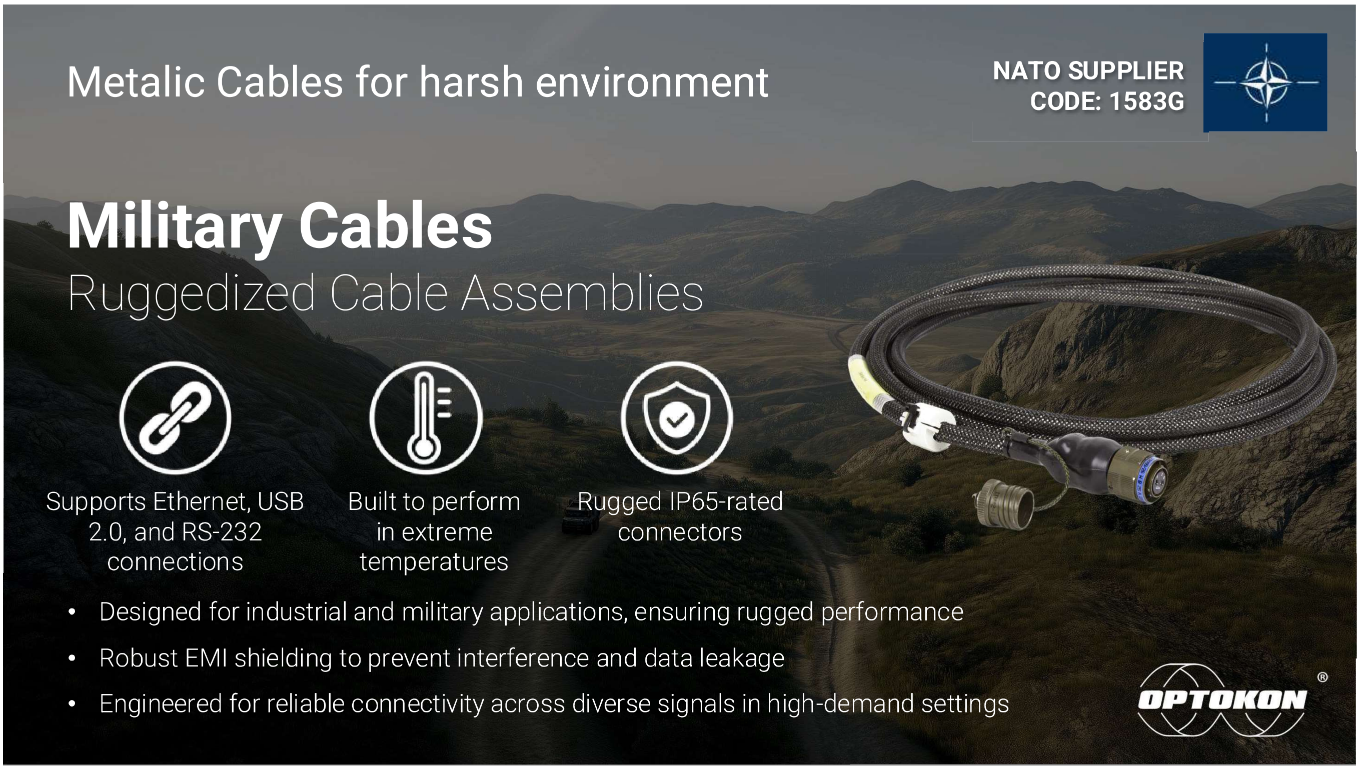
Operates from -30°C to +70°C

IP65 protection, MIL-STD 810G

- Expands Ethernet capabilities with connectivity up to 50 km on single-mode fiber
- Two independent 1G media converters in a single rugged metal box
- Web-based management, remote power failure detection, and firmware upgrades

OPTOKON®


Ruggedized Radiation Detector
NATO SUPPLIER
CODE: 1583G
LMRG-8
Nuclear Radiation Monitoring System
RS-422, CAN, MIL-STD-1553, WiFi, Ethernet
Operates from -40°C to +70°C
IP67 sealed casing, MIL-STD-810G certified
• Detects and measures gamma/beta radiation with fast isotope identification.
• Available in lightweight UAV and land configurations, 120 g and 1530 g.
• Configurable audio and visual alarms, supports multiple mounting options
OPTOKON®


Metalic Cables for harsh environment
NATO SUPPLIER
CODE: 1583G
Military Cables
Ruggedized Cable Assemblies
Supports Ethernet, USB 2.0, and RS-232 connections
Built to perform in extreme temperatures
Rugged IP65-rated connectors
• Designed for industrial and military applications, ensuring rugged performance
• Robust EMI shielding to prevent interference and data leakage
• Engineered for reliable connectivity across diverse signals in high-demand settings
OPTOKON®

Ruggedized Fiber Optic Connectors

NATO SUPPLIER
CODE: 1583G

HMA Series Connectors

Expanded Beam technology

Single mode, multimode, and hybrid fiber connections.

Operates from -55°C to +85°C

Water, mud, dust, and oil-resistant, field-installable.

- Features advanced expanded beam technology for reliable signal transmission
- Hermaphroditic connectors for quick deployment and easy field repairs
- Suitable for military, broadcast, industrial, and petrochemical applications

OPTOKON®

Implementation

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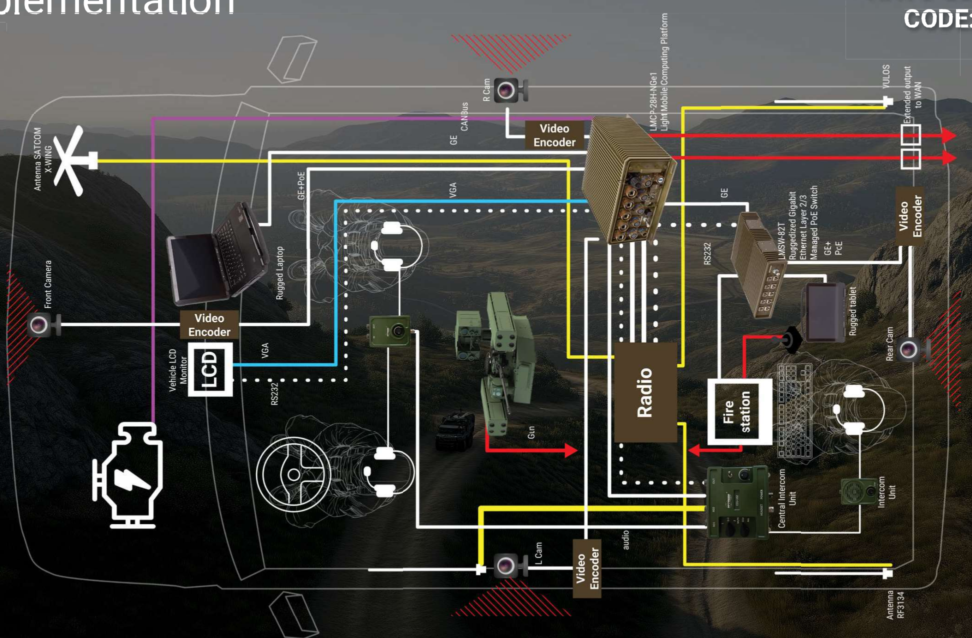
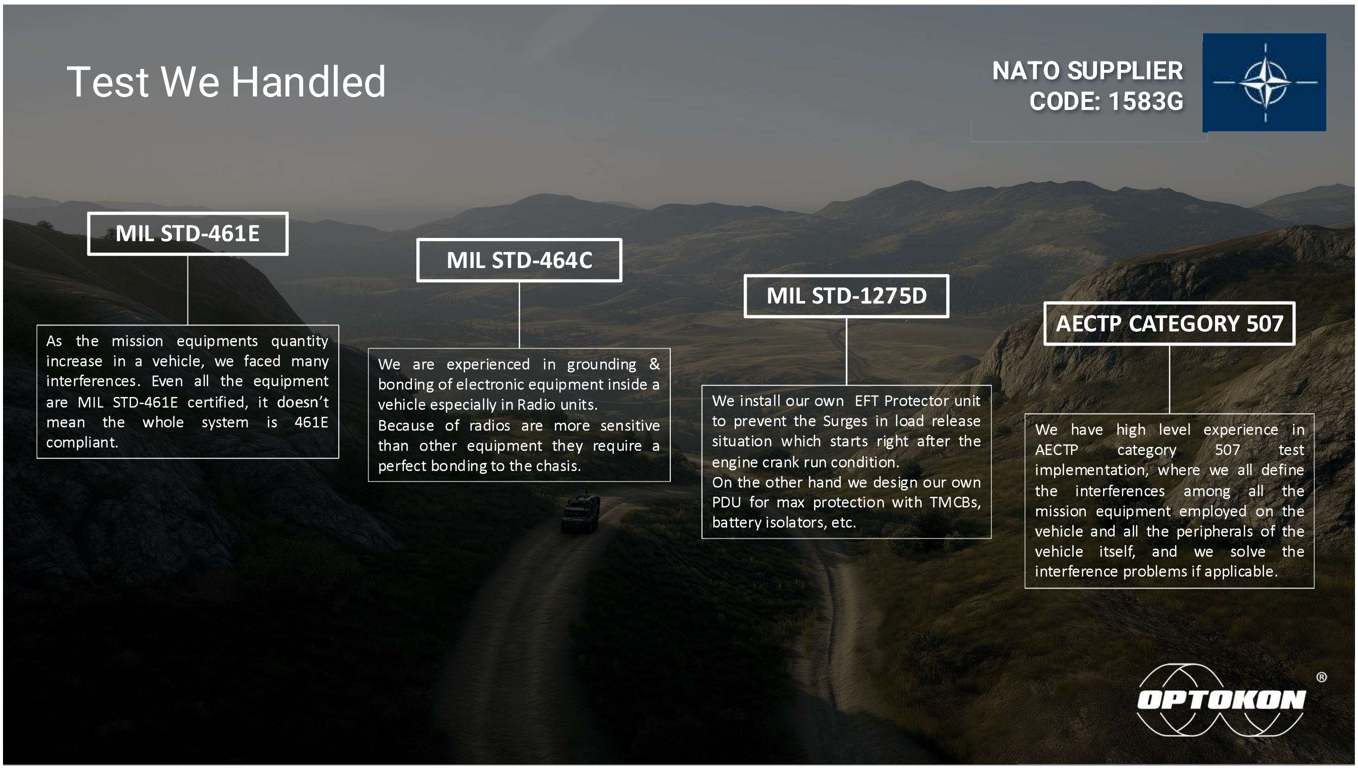
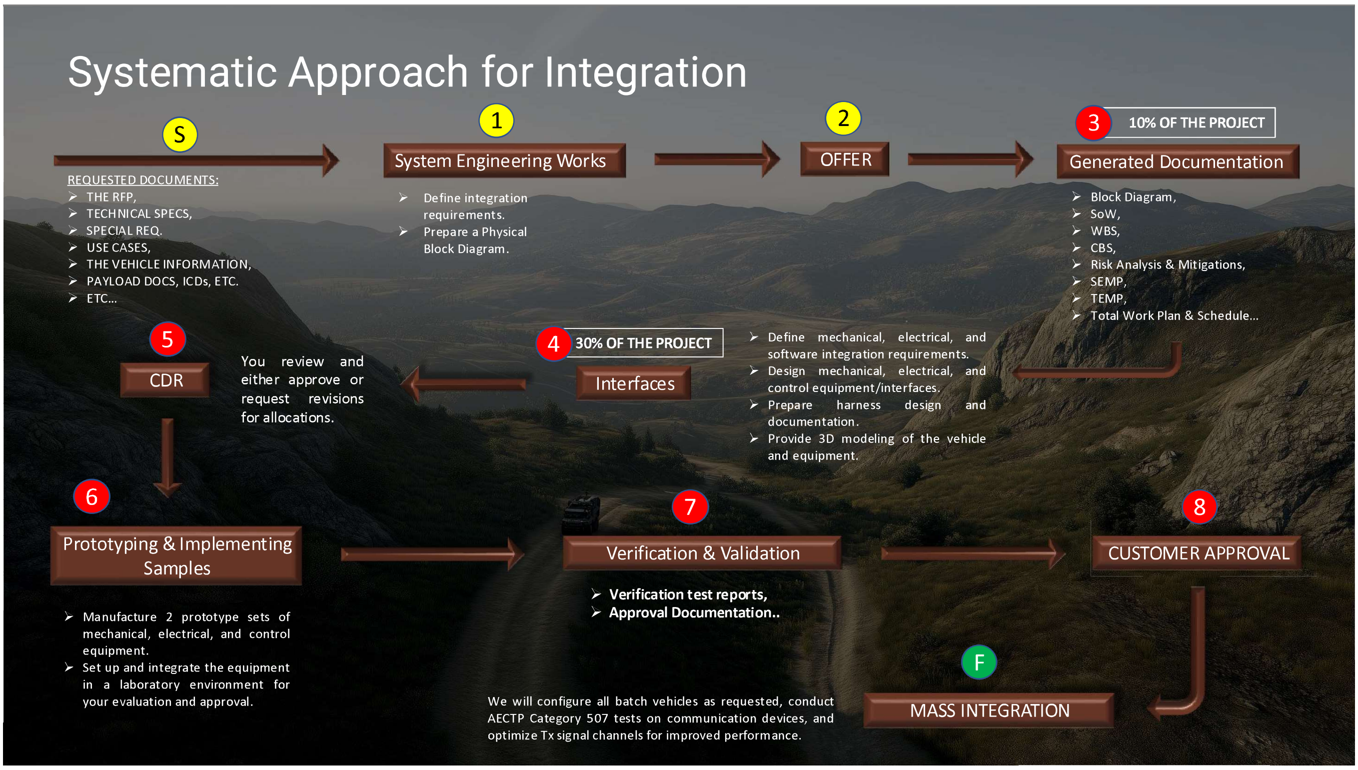
CODE: 1583G

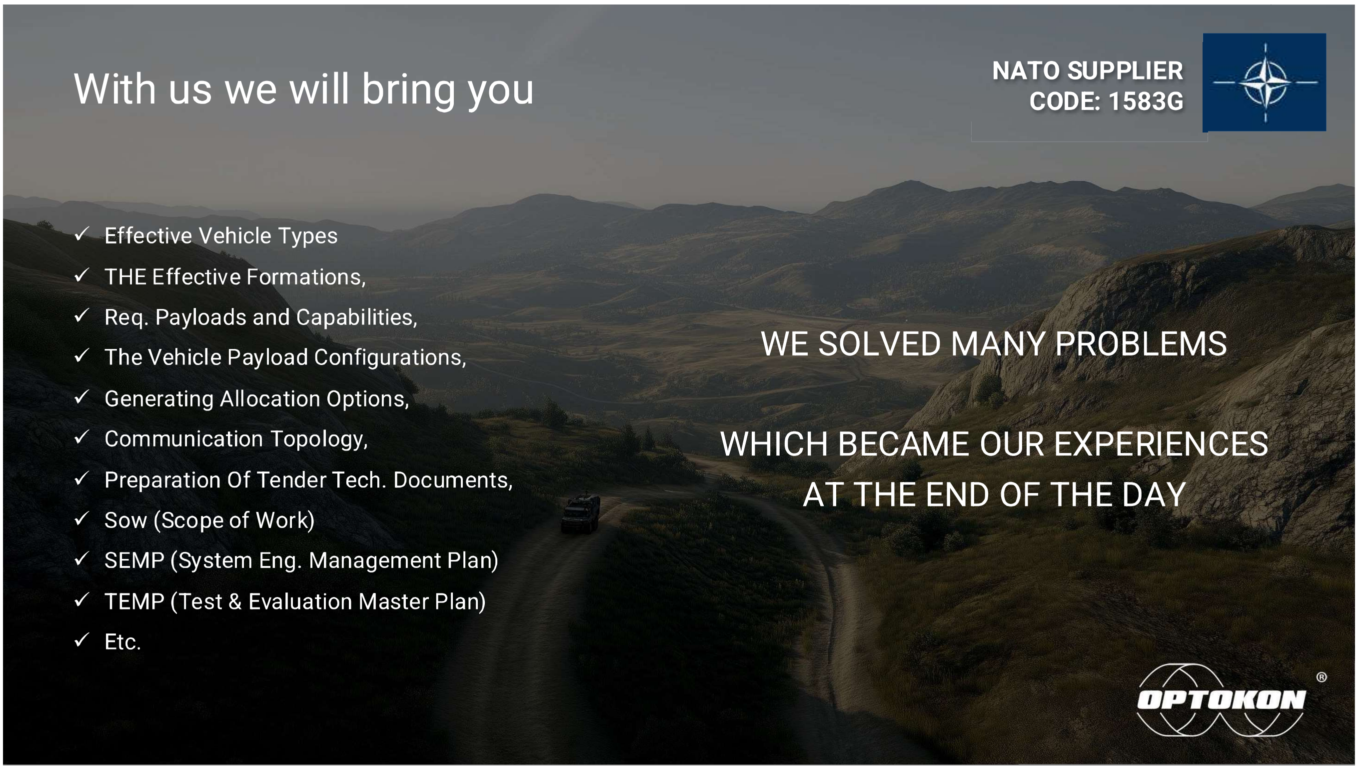


OPTOKON®


THE COMPLETE SOLUTION
FOR C4 ISR
OPTOKON®
LMRS-TD
Nuclear Radiation Monitoring Sensor
The LMRS Sensors are integral to the LMRG-8 Nuclear Radiation Monitoring System, suitable for both civil and defense applications. These sensors can be installed inside or outside vehicles and mounted externally.
LMIPT-41
Provides secure phone communication over a data network with all standard call features.
High-Class Rugged IP Phone
Drone Fiber
Lightweight optical fiber for drone control, weighing only 0.3 kg per kilometer.
Ultra Lightweight Optical Fiber
LMSW-E33-82P
Provides network connections between devices, allowing fast and secure data transfer.
Ruggedized Managed PoE Switch
LMSR-R63
Secure, high-performance router for mobile networks, optimized for data, voice, and video.
Ruggedized Next-Gen Gigabit Router
LMRG-8
Detects and measures radiation levels, quickly identifying dangerous isotopes.
Rugged Radiation Detector
LMRG-8A
Nuclear Radiation Monitoring Sensor
BOUNCER
DRONE
LMCP-7H
A multifunctional computing device combining server that through virtualization can act as a router, file server, a remote desktop server and much more, all at once, providing a comprehensive solution for managing and distributing data in a military environment.
Light Mobile Computing Platform
OPK-U-BRFTAC-4(4X2,0)
Provides reliable data transmission in harsh conditions for temporary military and industrial use.
Breakout Tactical Cable
LMUPS-80S-24V-AC
Provides reliable DC power and battery charging, ensuring optimal performance in harsh conditions.
Ruggedized Uninterruptible Power Supply
HMA-J Series Connector
Connects tactical networks and devices using optical fibers in tough environments.
Expanded Beam Connector
KIM1
A communication node that securely manages data exchange between classified and unclassified networks.
Communication Node
LMC-02.GF
Converts between fiber and Ethernet, extending network reach in tough environments.
Ruggedized Media Convertor
LMDS
Portable data switch with battery backup for reliable mobile network use.
Light Mobile Data Switch


Test We Handled
NATO SUPPLIER
CODE: 1583G
MIL STD-461E
As the mission equipments quantity increase in a vehicle, we faced many interferences. Even all the equipment are MIL STD-461E certified, it doesn't mean the whole system is 461E compliant.
MIL STD-464C
We are experienced in grounding & bonding of electronic equipment inside a vehicle especially in Radio units.
Because of radios are more sensitive than other equipment they require a perfect bonding to the chasis.
MIL STD-1275D
We install our own EFT Protector unit to prevent the Surges in load release situation which starts right after the engine crank run condition.
On the other hand we design our own PDU for max protection with TMCBs, battery isolators, etc.
AECTP CATEGORY 507
We have high level experience in AECTP category 507 test implementation, where we all define the interferences among all the mission equipment employed on the vehicle and all the peripherals of the vehicle itself, and we solve the interference problems if applicable.
OPTOKON®


Systematic Approach for Integration
S
REQUESTED DOCUMENTS:
THE RFP,
TECHNICAL SPECS,
SPECIAL REQ.
USE CASES,
THE VEHICLE INFORMATION,
PAYLOAD DOCS, ICDs, ETC.
ETC...
1
System Engineering Works
Define integration requirements.
Prepare a Physical Block Diagram.
2
OFFER
3
10% OF THE PROJECT
Generated Documentation
Block Diagram,
SoW,
WBS,
CBS,
Risk Analysis & Mitigations,
SEMP,
TEMP,
Total Work Plan & Schedule...
4
30% OF THE PROJECT
Interfaces
Define mechanical, electrical, and software integration requirements.
Design mechanical, electrical, and control equipment/interfaces.
Prepare harness design and documentation.
Provide 3D modeling of the vehicle and equipment.
5
CDR
You review and either approve or request revisions for allocations.
6
Prototyping & Implementing Samples
Manufacture 2 prototype sets of mechanical, electrical, and control equipment.
Set up and integrate the equipment in a laboratory environment for your evaluation and approval.
7
Verification & Validation
Verification test reports,
Approval Documentation..
8
CUSTOMER APPROVAL
F
MASS INTEGRATION
We will configure all batch vehicles as requested, conduct AECTP Category 507 tests on communication devices, and optimize Tx signal channels for improved performance.


With us we will bring you
NATO SUPPLIER
CODE: 1583G
Effective Vehicle Types
THE Effective Formations,
Req. Payloads and Capabilities,
The Vehicle Payload Configurations,
Generating Allocation Options,
Communication Topology,
Preparation Of Tender Tech. Documents,
Sow (Scope of Work)
SEMP (System Eng. Management Plan)
TEMP (Test & Evaluation Master Plan)
Etc.
WE SOLVED MANY PROBLEMS
WHICH BECAME OUR EXPERIENCES
AT THE END OF THE DAY
OPTOKON ®

Certificates

NATO SUPPLIER
CODE: 1583G

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References

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CODE: 1583G

Defense Sector

- Albania
- Bulgaria
- Croatia
- Czech Republic
- Denmark
- Estonia
- Egypt
- France
- Germany
- Greece
- Hungary
- Italy
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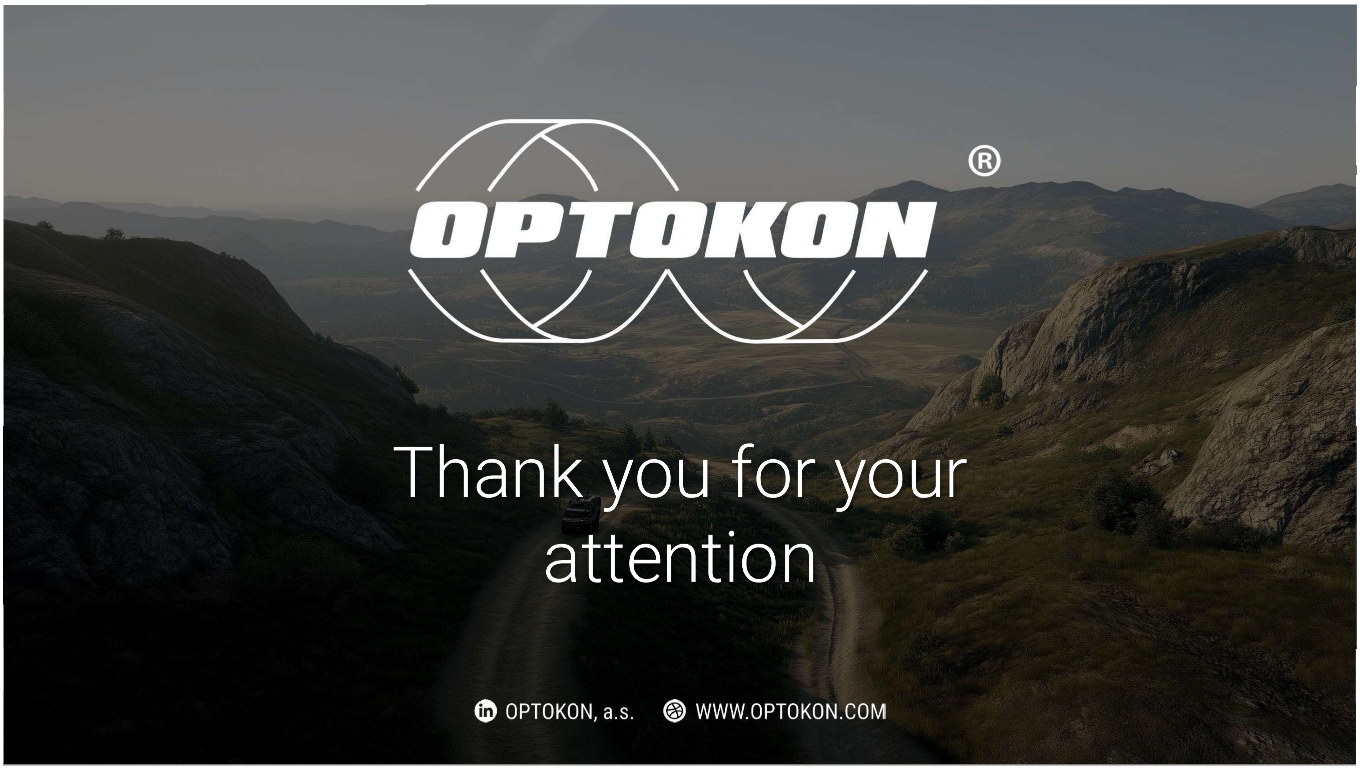
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Idejna zasnova kvantnega radarskega senzorja na osnovi kvantne prepletenosti

Vid Vrh, Andrej Lavrič, Boštjan Batagelj

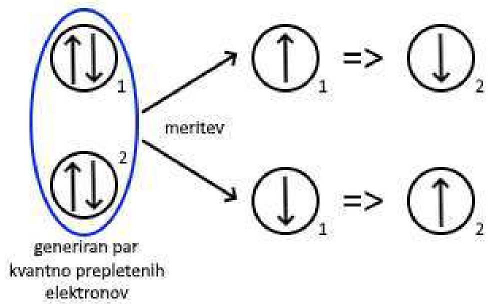
Uvod

Kvantne tehnologije se že dobro uvajajo na področja računalništva, zaznavanja in komunikacij, kar bo pripomoglo tudi na področju transportnih sistemov, ki bodo v prihodnosti okoljsko sprejemljivi, varni, razpoložljivi in robustni [1]. Na področju zaznavanja kvantne tehnologije prinašajo izredno občutljive senzorje, ki delujejo tudi v bolj zahtevnih razmerah [2]. Transportna industrija kvantne pojave trenutno že izkorišča za natančno merjenje časa preko cezijevih atomov v atomskih urah. Najnovejši napredek pri uporabi kvantne mehanike pa obeta tudi vedno bolj varne sisteme za pozicioniranje na osnovi kvantnega radarja [3].

Kvantna prepletenost

Pri na motnje in ponarejanje odpornih signalih je ključnega pomena koncept kvantne prepletenosti. Kvantna prepletenost predstavlja medsebojno vplivanje dveh delcev v t. i. kvantnem sistemu na tak način, da ob meritvi lastnosti enega delca (npr. spin elektrona ali polarizacija fotona) hkrati izmerimo tudi isto lastnost drugega delca iz para. Prav tako velja, da se ob spremembi lastnosti enega delca spremenijo tudi lastnosti drugega. Takšen medsebojni vpliv je mogoč ob neomejeni medsebojni oddaljenosti delcev.

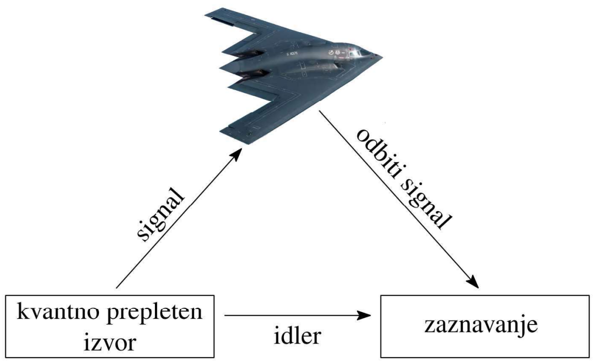
Ena glavnih metod za generiranje kvantno prepletenih signalov je spontana parametrična pretvorba navzdol (angl. *Spontaneous parametric down conversion* - SPDC), pri kateri z uporabo nelinearnih kristalov žarek fotonov razcepimo na dva žarka fotonov nižjih frekvenc.



Idejna zasnova kvantnega radarja

Ideja kvantnega radarja je ta, da na napravi ustvarimo dva kvantno prepletena signala. Enega od njiju (imenujemo ga kar "*signal*") pošljemo proti tarči, od katere se odbije, drugi signal (imenovan "*idler*") pa zadržimo na radarski napravi. Ko sprejmemo od tarče odbit signal, lahko na radarski napravi preverimo, ali je kvantno prepleten s signalom, ki ni bil oddan proti tarči. Če ugotovimo, da sta signala med seboj kvantno prepletena, potem smo potrdili, da gre za odbiti signal. Če signala med seboj nista kvantno prepletena, potem smo sprejeli šum oziroma ponarejen signal [4, 5].

Glavne težave koncepta kvantnega radarja izhajajo iz tega, da želimo enega od signalov zadržati na radarski napravi. Zaradi ustreznega časa zakasnitve je potrebno poznati oddaljenost tarče od radarja, kar je ravno tisto, kar z radarjem poskušamo izmeriti. Prav tako se težave pojavljajo tudi pri shranjevanju signala na napravi, saj izgube, ki se pri tem pojavljajo, pomembno vplivajo na domet radarja. Če radar deluje na mikrovlovnem področju, je naprava občutljiva tudi na termični šum, kar zahteva kirogene razmere v sami napravi.



Ker klasična definicija ob prehodu v kvantne tehnologije postane teoretsko nekonsistentna, je potrebno na novo definirati tudi kvantno radarsko odmevno površino. Definicija je analogna definiciji klasične radarske odmevne površine in odraža vidnost tarče za radar, predpostavlja ohranitev energije ob zanemarjenih absorbcijskih pojavih, je odvisna od geometrije in materiala tarče in ni odvisna od lastnosti radarskega sistema [6].

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Uporaba kompenzacijskega vlakna za merjenje faznega šuma

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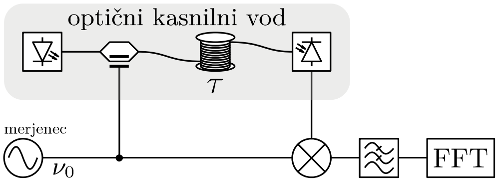


Postopek s kasnilnim vodom

Postopek merjenja faznega šuma s kasnilnim vodom za praktično meritev zahteva zakasnitev v velikostnem razredu 10 µs. Izvedbo tako dolgih zakasnitev omogoča nizko slabljenje optičnega vlakna. Želenih 10 µs ustreza 2 km optičnega vlakna. Glavna prednost merilnik na osnovi optičnega kasnilnega voda je odsotnost potrebe po referenčnem oscilatorju. Za pravilno delovanje takega merilnika je potrebno zagotoviti kvadraturo na vhodu mešalnika.

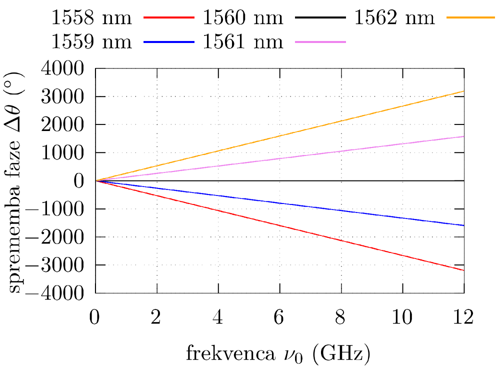
Kvadraturo lahko zagotovimo z nastavljanjem zakasnitve. Barvna razpršitev je ena od lastnosti optičnega vlakna. Njena posledica je odvisnost zakasnitve od valovne dolžine λ svetlobe

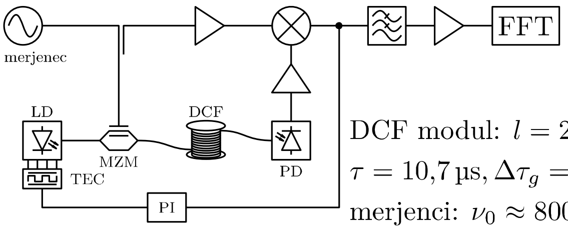
$$\tau(\lambda) = \frac{ln}{c} + \Delta\tau_g$$

S spreminjanjem valovne dolžine laserja po območju $\Delta\lambda$ lahko fino nastavimo zakasnitev in z njo fazo signala.

$$\Delta\tau_g = l\widehat{D}\Delta\lambda$$

Izbira vlakna z velikim koeficientom barvne razpršitve $\widehat{D}$ omogoča večjo nastavljivost faze $\Delta\theta$.





Vlakna za kompenzacijo barvne razpršitve (DCF) imajo visok koeficient barvne razpršitve $\widehat{D}$, ki so dostopna v modulih za kompenzacijo v standardnih zvezah.

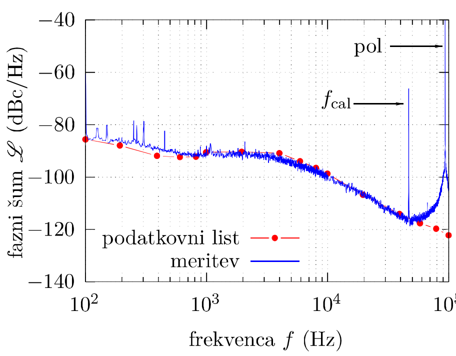
DCF modul: $l = 2{,}2\,\mathrm{km}$, $\widehat{D} = -160\,\mathrm{ps/(km\,nm)}$ pri 1560 nm

$\tau = 10{,}7\,\mu\mathrm{s}$, $\Delta\tau_g = 1{,}4\,\mathrm{ns}$ → dosegljiv fazni zasuk: 0,5 °/MHz pri $\Delta\lambda = 4\,\mathrm{nm}$

merjenci: $\nu_0 \approx 800\,\mathrm{MHz} \ldots 12\,\mathrm{GHz}$ zgornja meja uporabljenih fotodiod

Pri praktičnem preizkusu smo ovrednotili fazni šum komercialnega signalnega generatorja Agilent E4438C pri frekvenci 2,2 GHz. Umerjanje je bilo izvedeno z znanim kalibracijskim tonom f_{cal}. Meritev se ujema z specifikacijami, ki jih podaja proizvajalec. Neoptimalna dolžina vlakna v kompenzacijskem modulu potisne pol prenosne funkcije merilnika v opazovano področje in pokvari merilni rezultat.

$$\mathscr{L}(f) = \frac{S_v(f)}{8k_\phi^2|\sin\pi\tau f|^2}$$



Z izbiro krajšega vlakna se ognemo polu v merilnem območju.

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Zasnova kvantnega generatorja naključnih števil

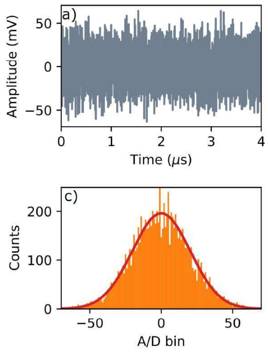
Nejc Bertoncelj, Andrej Lavrič, Boštjan Batagelj

Potreba po naključnih številih

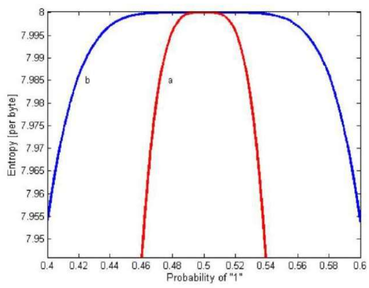
Naključna števila so prisotna v mnogih področjih, ki zajemajo znanstvene raziskave, domačo rabo, poslovna okolja in industrijo. Pojavljajo se v panogah, kot so:

- Kriptografija,
- varne komunikacije,
- loterija, igre na srečo,
- računalniške simulacije in Monte-Carlo metode,
- stohastično modeliranje,
- računalniške igre,
- sinteza glasbe,
- operacijske, fizikalne in kemijske raziskave,
- preizkušanje integriranih vezij.

Za tvorbo naključnih števil se pogosto uporabljajo cenovno in časovno učinkoviti generatorji, velikokrat izvedeni v okviru računalniške programske opreme, ki ustvarjajo t.i. psevdonaključna števila. To so števila, ki so sicer na videz naključna in tudi imajo enakomerno porazdelitev, a so vnaprej predvidljiva [1].



Slika 1 – primer izvedbe s štetjem dogodkov pri posameznih napetostih [5]



Slika 2 - demonstracija porazdelitve verjetnosti enega od stanj pred (a) in po (b) procesiranju v sistemu z možnima stanjema '0' in '1' [6]

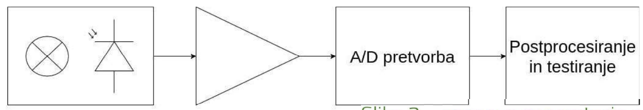
Ker številni primeri uporabe, kot so kriptografija, komunikacije, igralništvo in druge zahtevajo, da imajo števila dobre statistične lastnosti in jih hkrati ne moreta napovedati niti uporabnik generatorja niti opazovalec sistema, se pojavi potreba po izdelavi generatorja, ki vire naključnosti išče v fizikalnih, nepredvidljivih procesih [2].

Zasnova generatorja s plazovno fotodiodo

Izbran vir naključnosti za generator je bila plazovna fotodioda – polprevodniški fotodetektor, ki vpadne fotone zaznava prek mehanizma plazovne multiplikacije nosilcev naboja [3]. Z njo zadostimo pogoju fizikalnega ozadja, saj delovanje fotodiode temelji na kvantnih pojavih. Z njo je bil sestavljen merilni sistem, shematsko prikazan na sliki 3.

Pri vzorčenju signala s fotodiode se lahko poslužujemo metode zaznavanja in štetja impulzov, ki predstavljajo vpade fotonov (slika 1) [4]. Izbrana metoda, pa je vzorčenje šuma na izhodu fotodiode, ki vsebuje različne potencialno ustrezne komponente. To so med drugimi [3, 4]:

- šum temnega toka,
- šum sevanja ozadja,
- plazovni multiplikacijski šum,
- termični (Johnson-Nyquistov) šum,
- fotonski šum.



Slika 3 – zasnova generatorja s plazovno fotodiodo

Ker signal fotodiode ni nemudoma primeren za uporabo, potuje še prek pretvorbenih stopenj: ojačevalnega vezja, analogno-digitalnega pretvornika in programske opreme, ki ga predela v želen format. Vsi te koraki, združeni z materialnimi lastnostmi diode, dodajo svoj šumni prispevek, ki lahko negativno vpliva na končno stanje in ga je zato potrebno evalvirati in po potrebi s postprocesiranjem odstraniti (primer na sliki 2).

Testiranje sistema

Po zanesljivem vzorčenju in obdelavi signala fotodiode se nastala naključna števila preizkuša z različnimi programskimi paketi, kot so NIST STS, TestU01 in DieHarder [1], hkrati pa se meri še količina časa, potrebnega za generacijo določene količine naključnih števil, ki je poleg kakovosti naključnih števil še drugi dejavnik, ki odloča, če je izdelan sistem smiseln za uporabo v realnih primerih.

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Sinhronizacija radarjev z uporabo optičnih vlaken

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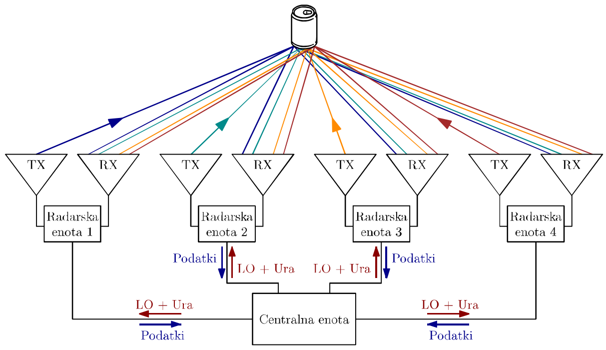
Motivacija

Prenos visokofrekvenčnih signalov igra ključno vlogo v radarskih sistemih, zlasti v porazdeljenih radarskih sistemih, antenskih skupinah in sistemih, ki zahtevajo oddaljeno obdelavo signalov. Napredni radarski sistemi, kot so sistemi z več vhodi in več izhodi (MIMO), uporabljajo več radarskih čipov na različnih lokacijah, kar omogoča zaznavanje tarč iz večih zornih kotov.

Za doseganje največje natančnosti radarskega sistema je ključna koherentna obdelava podatkov, ki zahteva izjemno natančno časovno in fazno sinhronizacijo med posameznimi čipi. To je mogoče zagotoviti z metodami za prenos fazno stabilnega signala, pri čemer optične komponente omogočajo najučinkovitejšo in najbolj zanesljivo izvedbo teh metod. Radar, ki uporabljaja tako optične kot mikrovalovne komponente imenujemo mikrovalovno-fotonski radar.



Slika 1: Blokovni načrt radarskega sistema z več vhodi in več izhodi s koherentno obdelavo podatkov.

Prednosti uporabe optičnih vlaken

- **Širokopasoven prenos podatkov -** Prostorska ločljivost in prilagodljivost radarskih sistemov sta odvisni od pasovne širine radarskega signala. Optična vlakna omogočajo širokopasovni prenos radarskih signalov, kar prispeva k boljši zmogljivosti in natančnosti sistema.
- **Majhne izgube v prenosu -** Optična vlakna omogočajo nizkoizguben prenos visokofrekvenčnih signalov. To omogoča izvedbo porazdeljenih radarskih sistemov, kjer so lahko posamezni elementi radarskega sistema bolj oddaljeni med seboj kot pri uporabi drugih prenosnih medijev. Zaradi nizkih izgub omogočajo tudi izvedbo dolgih kasnilnih vodov, ki so lahko uporabljeni v filtrih ali pa v antenskih skupinah.
- **Prenos več neodvisnih signalov preko enega vlakna -** Optična vlakna omogočajo uporabo različnih vrst multipleksiranja, ki omogočajo nemoteno večkanalno komunikacijo. Najpogosteje uporabljene metode so valovno-dolžinsko multipleksiranje (WDM), polarizacijsko multipleksiranje (PDM) in prostorsko multipleksiranje (SDM). Z multipleksiranjem je hkrati mogoče prenašati več neodvisnih signalov, ki so ključni za delovanje radarskega sistema.
- **Lažja kompenzacija zakasnitev v prenosu -** Optična vlakna so lahko podvržena različnim okoljskim vplivom, kot so temperaturna nihanja, mehanske obremenitve in vibracije. Ti dejavniki lahko povzročijo zakasnitve v prenosu, ki vplivajo na fazo prenešenega signala. Z uporabo optičnih komponent je mogoče kompenzirati vnešene zakasnitve in tako zagotoviti prenos fazno stabilnega sinhronizacijskega signala.

Sinhronizacijske tehnike

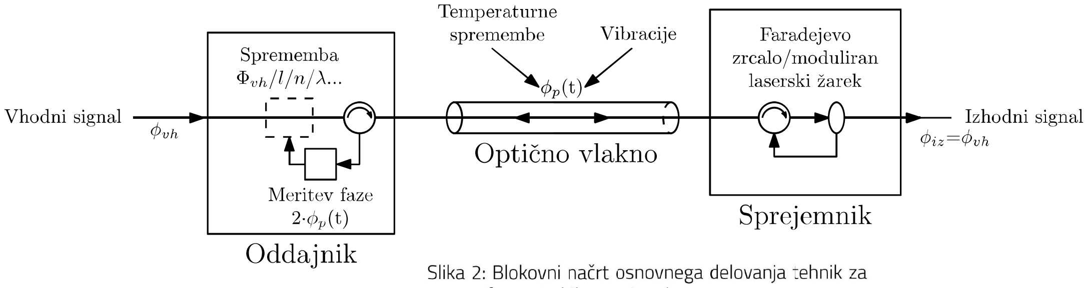
V literaturi večina najnatančnejših sinhronizacijskih tehnik temelji na meritvi faze med vhodnim signalom in signalom, ki je prepotoval pot od oddajnika do sprejemnika in nazaj. Na sprejemni strani je signal lahko ponovno moduliran na laserski žarek ali odbit s Faradejevim zrcalom, kot prikazuje slika 2. Sinhronizacijske tehnike lahko razvrstimo glede na način doseganja fazne stabilnosti prenesenega signala:

Tehnike, kjer spreminjajo fizikalne lastnosti prenosnega medija ali laserja

- Spreminjanje dolžine zveze l in lomnega količnika n optičnega vlakna [1]
- Spreminjanje valovne dolžine laserja λ [2]

Tehnike, kjer spreminjanjajo fazo vhodnega signala Φ_{vh}

Pasivno spreminjanje faze [3] ← → Aktivno spreminjanje faze [4]



Slika 2: Blokovni načrt osnovnega delovanja tehnik za prenos fazno stabilnega signala

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Optični instrument na NEMO-HD

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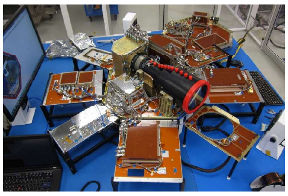
Misija NEMO-HD

NEMO-HD je prvi slovenski mikrosatelit. Izstreljen je bil 2. 9. 2020 iz Francoske Gvajane z raketo Vega v s soncem sočasno nizko Zemljino tirnico na višini 520 km. Misijo je razvil Center odličnosti Vesolje-SI v sodelovanju s kanadskim UTIAS SFL. NEMO-HD je kompakten satelit z maso 60 kg. Zasnovan je okrog glavnega optičnega instrumenta, ki predstavlja skoraj polovico mase satelita. Glavna misija satelita NEMO-HD je raziskati nov koncept opazovanja Zemlje s kombiniranim zajemom večspektralnih posnetkov ter HD videa s sledenjem poljubni vnaprej nastavljeni krivulji ali izbrani točki na Zemlji realnem in skoraj realnem času.



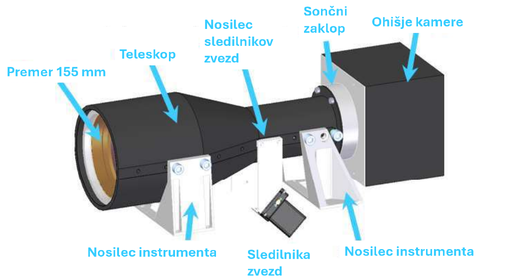
Glavni optični instrument

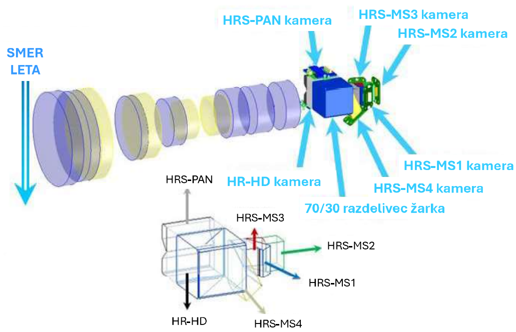
Glavni optični instrument zajema posnetke v pasu širine 10 km v 4 spektralnih kanalih (R, G, B, NIR). Isti instrument omogoča tudi zajem barvnega HD video posnetka v visoki ločljivosti. Poleg glavnega optičnega instrumenta ima NEMO-HD še sekundarno video kamero, ki zajame širše območje z nižjo prostorsko ločljivostjo.

	MS	PAN	HR-HD	LR-HD
Tirnica	520 km, SSO, 10:30 LTDN			
Širina opazovanega pasu	10 km	9 km	5 km	75 km
Prostorska ločljivost	5,6 m	2,8 m	2,8 m	40 m
Časovna ločljivost	3 – 13 dni (odvisno od kota opazovanja)			
Prostorska pokritost	Podatke lahko zajema globalno			
Časovna pokritost	Podatke zajema od 2. 9. 2020			
Talna hitrost	7,7 km/s			

Svetlobo zbira s teleskopom s premerom 155 mm in svetlobno močjo f/2,3. Vpadna svetloba je z razdelivcem žarka preusmerjena na tri dele, od katerih je eden usmerjen na PAN senzor, drugi na HR-HD video senzor, tretji pa je s pomočjo prizme razdeljen na štiri spektre različnih valovnih dolžin (420–520 nm, 535–607 nm, 634–686 nm, 750–960 nm), vsak od njih pa vpada na svoj senzor. Ločeno beleženje posameznih spektrov je pri daljinskem opazovanju Zemlje ključnega pomena, saj omogoča izračun in prikaz različnih indeksov, s katerimi lahko karakteriziramo različne lastnosti posnetega okolja, kot so stanje vegetacije, vrsta rastja, vlažnost tal ipd., česar na RGB posnetkih ne bi bilo mogoče zaznati.

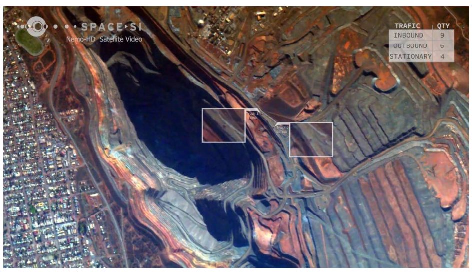
Elektroniko glavnega koristnega tovora sestavlja pet vgrajenih računalnikov, eden za vsakega od senzorjev za zajem slik. Video kamera lahko v času kontakta z zemeljsko postajo video s kodekom H.264 prenaša na Zemljo v realnem času. Ko satelit ni v vidnem območju zemeljske postaje, lahko video posname na kateregakoli od petih računalnikov optičnega instrumenta. Shranjeni posnetki se na zemljo prenesejo po frekvenčnem pasu X.



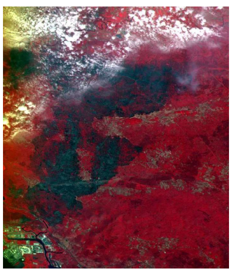


Aplikacije

Večspektralni posnetki so uporabni za širok nabor aplikacij, od kmetijstva, urbanizma, spremljanja naravnih nesreč in vodarstva. Video iz vesolja med drugim omogoča spremljanje pomorskega prometa ter ekonomskih aktivnosti v rudnikih, pristaniščih, letališčih ter logističnih centrih.



Video posnetek rudnika zlata v Avstraliji z video analitiko.



Večspektralni posnetki požara na Krasu leta 2022.

Pomorski promet v Istanbulu.

High - Bandwidth Quantum Communication Protocols Using Field Programmable Gate Arrays

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Motivation

SiQUID (Slovenian Quantum Communication Infrastructure Demonstration): BB84, BBM92, MDI

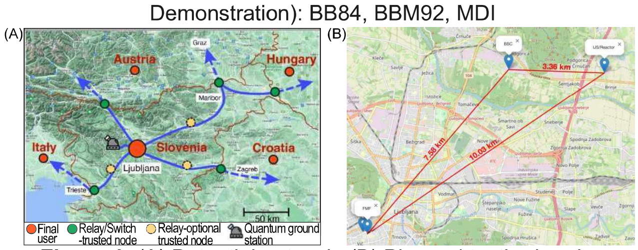

Figure 1: (A) Potential network (B) Planned testbed nodes

Using FPGAs

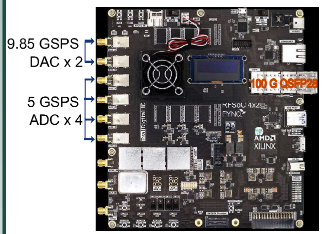

Figure 2: RFSoC 4x2 Board

Crucial for:

- GHz signal generation (~1-2.5GHz using RFDAC or > using QSFP28).
- Generating short laser pulses for prepare-and-measure QKD.
- Randomly (security measure) modulating the laser drive current for specific phase shift between pulses at GHz speed.

Experimental Setup

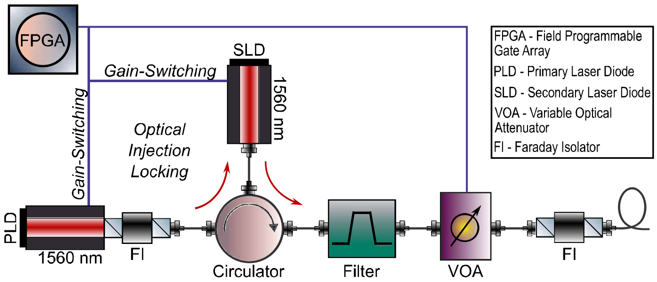

Figure 3: Sender module for BB84

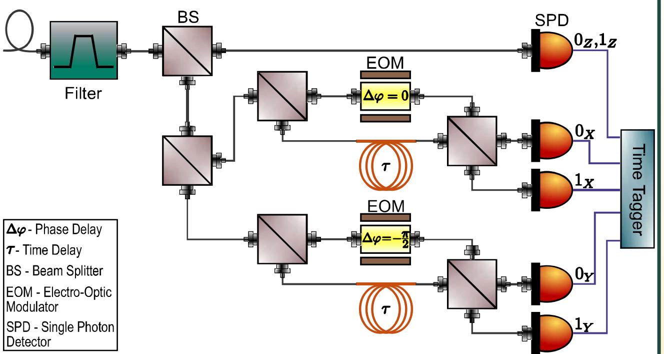

Figure 4: Receiver module for BB84

BB84 Protocol

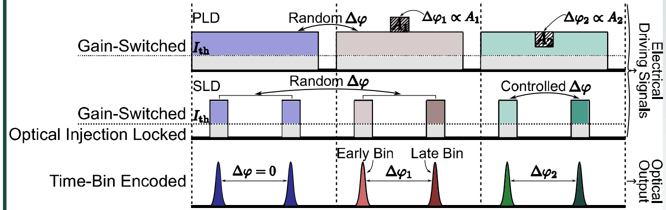

Figure 5: Laser dynamics and encoding process

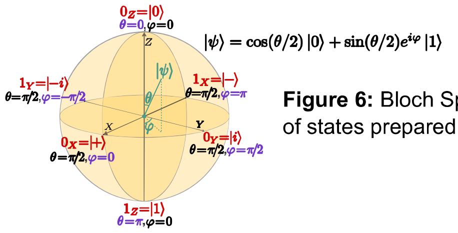

Figure 6: Bloch Sphere representation of states prepared for BB84 protocol

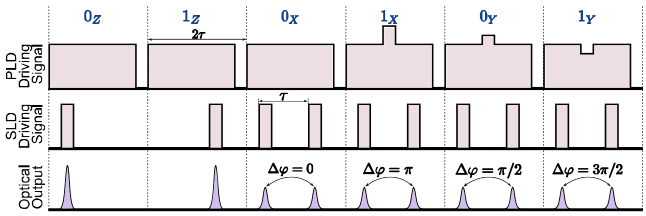

Figure 7: State preparation (Bit_{Basis})

Ongoing Work and Challenges

- Checking for gainswitching with our laser diodes.
- Different bandwidth and frequency spectrum of different equipments affect significantly, specially at such high frequency requirements.
- Measuring the pulse shapes and confirming phase randomization due to gainswitching.

Future Work

- Observe Optical Injection Locking.
- Determine optimal PLD modulation to add desired phase delay between two bins of SLD.
- Design receiver module and post processing of Time Tagger data.
- Decoy state implementation.

Funded by:

EuroQCI
The European Quantum Communication Infrastructure Initiative

Univerza v Ljubljani
Fakulteta za matematiko in fiziko

Funded by the European Union
NextGenerationEU

NOO
THE RECOVERY AND RESILIENCE PLAN

Group Website

SiQUID Project

Group Instagram

Generating and Teleporting Entanglement for Quantum Networks & Quantum Internet

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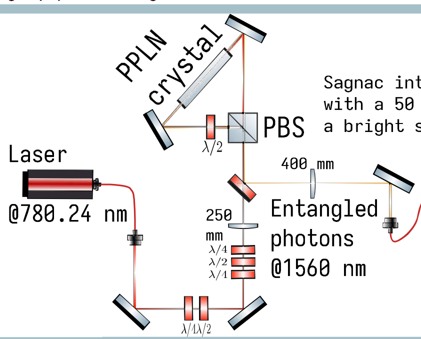
UNIVERZA V LJUBLJANI | FMF Fakulteta za matematiko in fiziko

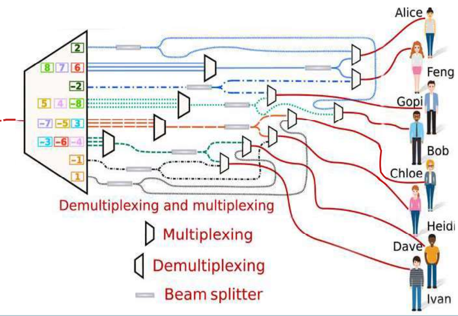
Entanglement is a key resource for quantum technologies of the future quantum networks, and the development of the quantum internet. Having the ability to efficiently distribute it between distant parties is essential. We implement a Sagnac source of polarization entangled photons around 1560 nm for use in already existing fiber infrastructure. The source will be characterized in our lab at the Faculty of Mathematics and Physics in Ljubljana, and later will be used for entanglement distribution over large distances. An identical source will be built by partners at the Jozef Stefan Institute, allowing us to demonstrate teleportation and entanglement swapping by performing Bell state measurements.

Motivation

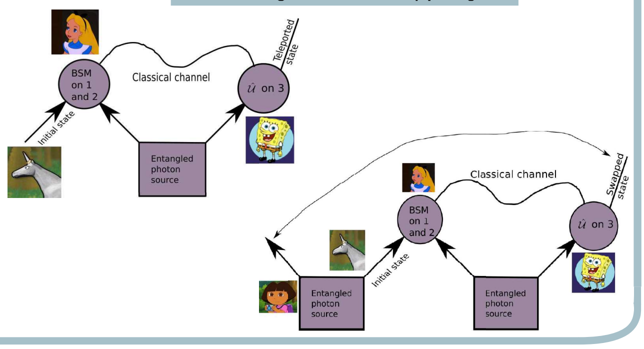


Sagnac interferometer in a minimal configuration with a 50 mm Type-0 PPLN crystal to create a bright source of entangled photons for many users.

By pumping the crystal bidirectionally we generate one of four maximally entangled states: $|\phi\rangle = |HH\rangle + e^{i\theta}|VV\rangle$



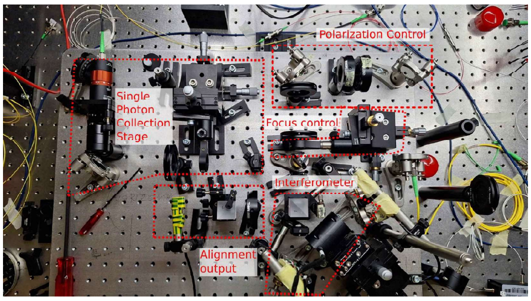
Quantum Teleportation and Entanglement Swapping



Current status

Optimizing alignment and coupling, testing various automation code, and tinkering with postprocessing for entanglement swapping.

Photo of the current source design



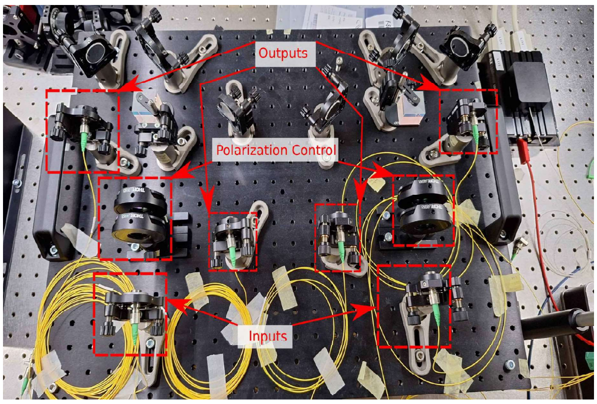
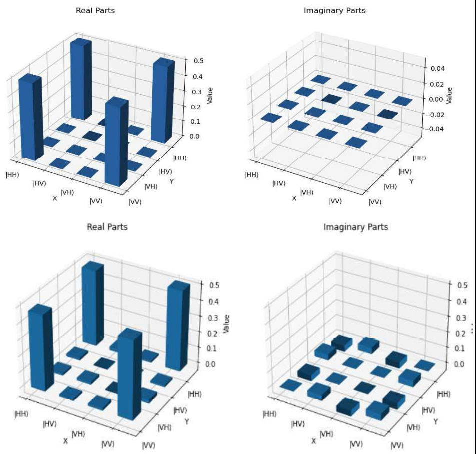


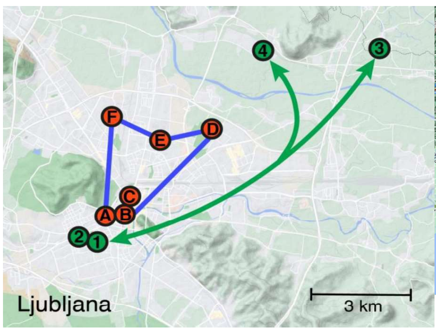
Photo of the analysis stage design

Tomography measurements

Currently succesfully able to produce the entangled state $|\phi\rangle = |HH\rangle + \quad |VV\rangle$ This has been done with a fidelity of $\approx$ 97.76% Currently in the process of maximizing the source brightness and heralding efficiency



Plans for the future



Ljubljana experimental and government network

Proposed Slovenian Quantum Network

Our group

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O seminarju
The seminar

Strokovni seminar Optične komunikacije se je razvil iz izobraževalne dejavnosti, ki jo je pod okriljem projekta TEMPUS JEN-04202 v letih 1993 do 1997 izvajala Fakulteta za elektrotehniko Univerze v Ljubljani. Seminar je namenjen strokovnemu izpopolnjevanju strokovnjakov optičnih komunikacij in drugih, ki jih to področje zanima. Vključen je v program izvajanja vseživljenjskega izobraževanja na Fakulteti za elektrotehniko v Ljubljani. Njegov namen je osveževanje, razširjanje izpopolnjevanje in poglabljanje znanja ter dvig strokovnosti zaposlenih strokovnjakov na področju optičnih komunikacij. Seminar obsega uvodni del, namenjen obnavljanju in razširjanju znanja, ter strokovni del, namenjen seznanjanju in poglabljanju v strokovna vprašanja o sistemih in njihovih sestavnih delih. Izvedenski del seminarja, ki ga izvajajo priznani vabljeni strokovnjaki, obsega nekatera pomembnejša razvojna vprašanja.

Seminar on Optical Communications evolved from the activities running at the Faculty of Electrical Engineering University of Ljubljana, during the period from 1993 to 1997 under the auspices of the European project TEMPUS JEN-04202 granted for the same period. The seminar si intended to communication professionals and other involved into the field of optical communications. It is part of the continuing education programme at the Faculty of Electrical Engineering in Ljubljana. Its primer porpuse is to enhance the expertise of professionals in the field of optical communications. The seminar consists of two parts: one part is dedicated to basic technical topics aiming to refresh fundamental knowledge in optical communications, and the second part is intended to the latest research and development achievements and trends from spectrum regulation, standardization, systems and solutions, all from international and national experts.

Ključna gesla
Keywords

100Gbps, 1.6T, 800G, adiabatni sklopniki, akustične vibracije, diagnostika, dostopovno omrežje, električna energija, erbijeva vlakna, fotonska vezja, injekcijska vklenitev, izzivi diagnostike, izzivi vlaken, količina podatkov, koherentna tehnologija, kvantna enofotonska viri, kvantna informacija, kvantna komunikacija, kvantna varnost, kvantno omrežje, merjenje, mikrovalovna fotonika, nova generacija, optika, optična komunikacija, optična vlakna, optična omrežja, pasivno optično omrežje, poraba energije, preizkušanje, prihodnost povezljivosti, podatkovni promet, radar, radarska tehnika, regulacija, senzorske tehnologije, SiN fotonika, SiQUID, širokopasovne povezave, taktična omrežja, telekomunikacije, testiranje, vpliv XGS-PON, vlakenski senzorji, zmogljivosti omrežja, umetna inteligenca, kvantni senzorji, laserska tehnologija, razvoj kvantnih omrežij, kvantno šifriranje.

100Gbps, 1.6T, 800G, Adiabatic couplers, Acoustic vibrations, Artificial intelligence, Diagnostics, Distributed fiber sensor, Electric power, Erbium fibers, Fiber optics, Fiber optics networks, Fiber photonic circuits, Injection entanglement, Measurement, Microwave photonics, Network access, Network capacity, Network development, Network optimization, Quantum communication, Quantum information, Quantum networks, Quantum security, Quantum sensors, Quantum entanglement, Quantum encryption, Quantum photonic sources, Radar technology, Regulatory aspects, Sensor technologies, SiN photonics, SiQUID, Test equipment implementation, Testing, XGS-PON impact, Wideband connectivity, Future connectivity, Future optical technologies, Optical communications, Optical fiber, Optical network, Passive optical network, Photonic technologies, Radar, Telecommunications, Data traffic, Laser technology, Energy consumption, Quantum network development.

Avtorji
Authors

Allott Graeme, Batagelj Boštjan, Bertalanič Blaž, Bertoncelj Nejc, Buffa Marta, Debevc Andraž, Dejdar Petr, Eržen Vesna, Goluža Tomislav, Golja Mitja, Gupta Shreya, Hobbs Neil, Horváth Tomáš, Klicnik Ondrej, Krč Janez, Krüger Sven, Lavrič Andrej, Ljubotina Miloš, Lukan Peter, Meža Matej, Mousavi Faezeh, Munster Petr, Mustafa Luka, Penko Gorazd, Plevnjak Igor, Podbregar Luka, Praček Pavel, Rodič Tomaž, Sarić Milorad, Scaffardi Mirco, Štefl Jiří, Souvent Andrej, Taškov Stanko, Tomasov Adrian, Topič Marko, Ulčakar Lara, Udovičić Adrian, Urbas Ana, Vidmar Matjaž, Vrh Vid, Zaviska Pavel, Zupanič Erik.