COMPONENTS FOR OPTICAL AND QUANTUM COMMUNICATIONS

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TÜV NORD GROUP

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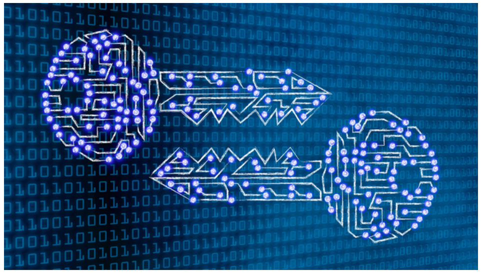
AGENDA

Components for Optical and Quantum Communications

1. Optical Communications in Space
   - Classical Communication
     - Optical transceivers
   - Quantum communication
     - QKD

2. Testing Quantum
   - Certification of Quantum Communication

3. Quantum & Classical Comm Products
   - Already available
   - ALTER portfolio of Optical & Quantum Products



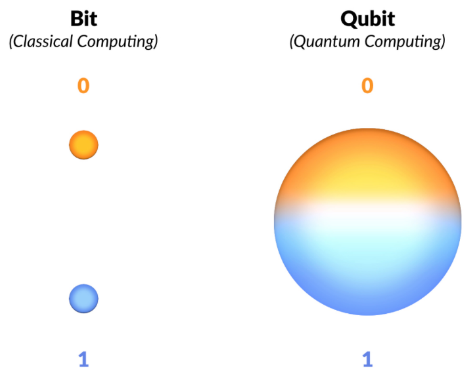
4. Quantum Conclusions

OPTICAL COMMUNICATIONS IN SPACE

Classical CHANNEL

Components
- Optical Modulators
- Optical Cross-connects
- Optical Transceiver

Characterization
- BER < 1e-12
- Rates > 25GBs
- Eye diagram



Quantum Key Distribution QKD

Components
- Entangled photon emitters
- Quantum Number Generator
- Complete system on a PIC

Characterization
- QBER ≈ 1-5%
- Raw Key Creation Rate
- Rates ≈ from 250Bs to MBs
- QKD Protocols
- Adversarial system

A classical channel is needed for coordinating the quantum communication

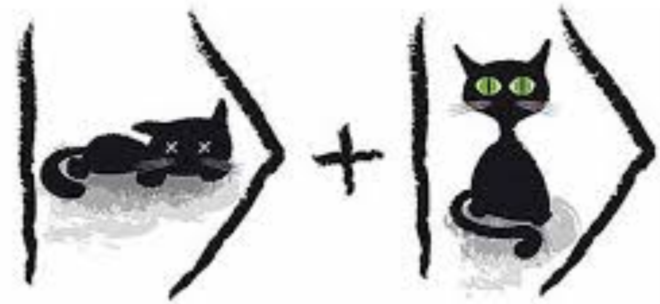
to transfer signals, like start, stop, sending a bit, etc., and it has to be authentic.

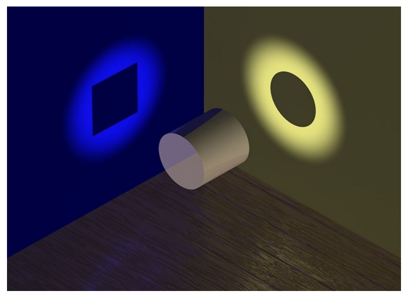
OPTICAL COMMUNICATIONS IN SPACE

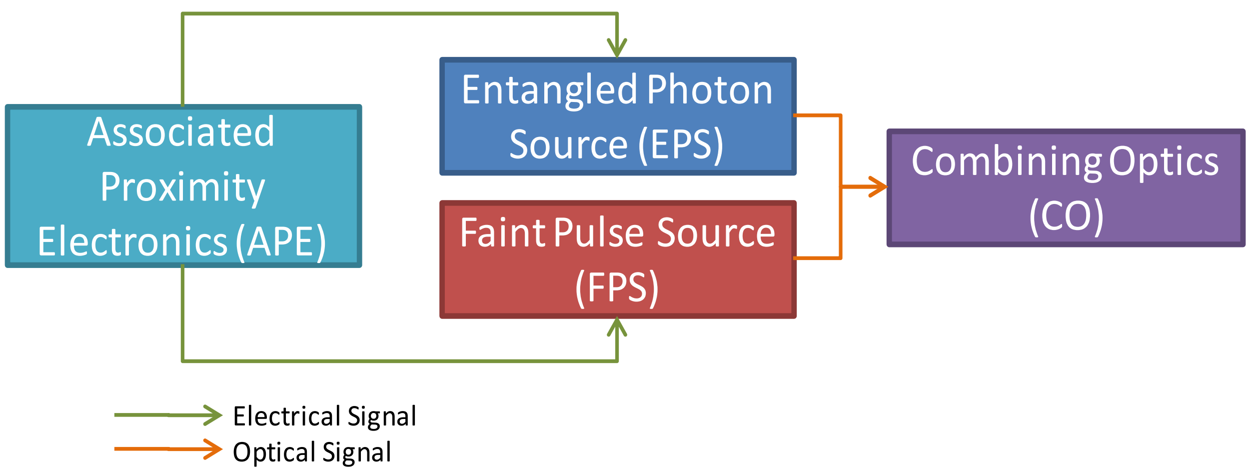
Quantum Key Distribution

- Schrödinger equation
- Heisenberg Uncertainty Principle
- <u>Entanglement</u>

$$\Delta\chi\Delta\rho \geq \frac{\hbar}{2}$$





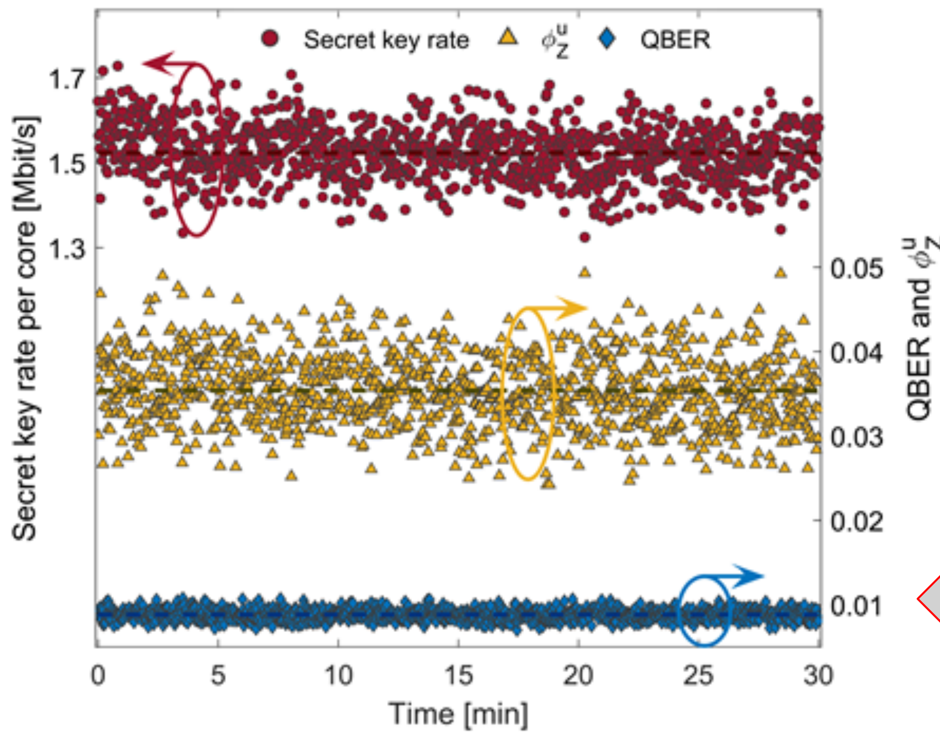


QBER: A STATE OF THE ART EXAMPLE

Boosting the secret key rate in a shared quantum and classical fibre communication system

Davide Bacco*[1▹], Beatrice Da Lio*[1▹], Daniele Cozzolino[1], Francesco Da Ros[1], Xueshi Guo[2], Yunhong Ding[1], Yusuke Sasaki[3], Kazuhiko Aikawa[3], Shigehito Miki[4], Hirotaka Terai[4], Taro Yamashita[5], Jonas S. Neergaard-Nielsen[2], Michael Galili[1], Karsten Rottwitt[1], Ulrik L. Andersen[2], Toshio Morioka[1], Leif K. Oxenløwe[1]

[1] *CoE SPOC, Dep. Photonics Eng., Technical University of Denmark, Kgs. Lyngby 2800, Denmark*



QBER, Phase error and QKD rate

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CLASSICAL & QUANTUM

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Table 1: Comparison with state of the art experiments. CC: classical channel; RX: receiver; QC: quantum channel; MUX: multiplexing; BB84: Bennet and Brassard 1984 protocol; SNSPD: superconductive nanowire single photon detector; CW: continuous wave; WDM: wavelength division multiplexing; SPD: single photon detector; ch.: channel; SDM: space division multiplexing.

	Rate CC, Rx power	Rate QC	Distance, loss	Protocol	Decoy	Operation	Classical MUX	Detector
This work (only QC)	-	105.7 Mbit s^{-1}	7.9 km, 3.75 dB	3-states BB84	1-decoy	finite key	-	SNSPDs
Ref. [57]	-	26 Mbit s^{-1}	4 dB	4-D BB84	2-decoy	finite key	-	SNSPDs
Ref. [11]	CW light, -23 dBm	10 kbit s^{-1}	100 km, 18 dB	BB84	2-decoy	finite key	WDM C-band	Self-differencing InGaAs SPDs
Ref. [41]	20 Gbit s^{-1}, -13.5 dBm per ch.	605 kbit s^{-1}	53 km, 13.5 dB	BB84	2-decoy	real-time	SDM+WDM C-band	Self-differencing InGaAs SPDs
Ref. [42]	200 Gbit s^{-1}, -36 dBm per ch.	1.9 Mbit s^{-1}	35.5 km, 6.8 dB	BB84	2-decoy	finite key	WDM C-band	Self-differencing InGaAs SPDs
This work (QC+CC)	370 Gbit s^{-1}, -34 dBm per ch.	62.8 Mbit s^{-1}	7.9 km, 3.75 dB	3-states BB84	1-decoy	finite key	SDM+WDM C-band	SNSPDs
Ref. [43]	3.6 Tbit s^{-1}, 8.7 dBm	4.5 kbit s^{-1}	66 km, 19.83 dB	BB84 (O-band)	2-decoy	real-time	WDM C-band	Self-differencing InGaAs SPDs
Ref. [44]	6.38 Tbit s^{-1}, -1 dBm	14.8 kbit s^{-1}	50 km, 16.5 dB	BB84 (O-band)	2-decoy	real-time	WDM C-band	Self-differencing InGaAs SPDs

QKD PROTOCOLS

QKD Vulnerability

Cases	*Quantum Key Distribution Protocols*								
	BB84	**B92**	**SARG04**	**COW**	**KMB09**	**EPR**	**DPS**	**S13**	**AK15**
Properties	Heisenberg	Heisenberg	Heisenberg	Entanglement	Heisenberg	Entanglement	Entanglement	Heisenberg	Heisenberg
Number of States	4 states	2 States	4 States	Time slots	2 states	Entangled 2 of photons	4 States	4 States	*n* states
Detection of presence	QBER	QBER	QBER	Break of coherence	ITER	Bell's inequality	Time-instance	Ran. Seed Asymmetric	QBER + Parity Cell
Polarization Situation	2 orthogonal	1 non-orthogonal	coded bits	No, using DPS	No	No	4 non-orthogonal	2 orthogonal	2 Orthogonal
Probability of each state	Various	50%	50%	equal	50%	equal	equal	Various	Various
Qubit case	DV	DV	DV	DV	DV	DV	DV	DV	DV
Classical channels	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Decoy States	No	No	No	Yes	No	No	No	No	Yes
Sifting phase	Revealing Bases	Alice = 1 - Bob	Revealing non-orth. state	revealing the times 2k+1	determining the error rate	Bell's Inequality	No	Revealing Bases	No
Bell's inequality	No	No	No	No	No	Yes	No	No	Yes
PNS attack	Vulnerable	Vulnerable	It's better than BB84	Robust	Robust	N/A	Robust	N/A	Robust
IRUD attack	Vulnerable	Vulnerable	Vulnerable	Under Test	Under Test	Vulnerable	N/A	N/A	Robust
Beam-Splitting attack	Vulnerable	Vulnerable	Robust	Robust	Robust	Vulnerable	Robust	N/A	Robust
Denial of Service attack	Vulnerable	Vulnerable	Vulnerable	Vulnerable	Vulnerable	Vulnerable	Robust	N/A	N/A
Man-In-The-Middle attack	Vulnerable	Robust	Robust	Robust	Robust	Robust	Robust	N/A	Robust
IRA attack	Vulnerable	Vulnerable	Robust	Robust	Robust	Bell's inequality	Robust	N/A	Robust

QUANTUM CERTIFICATION

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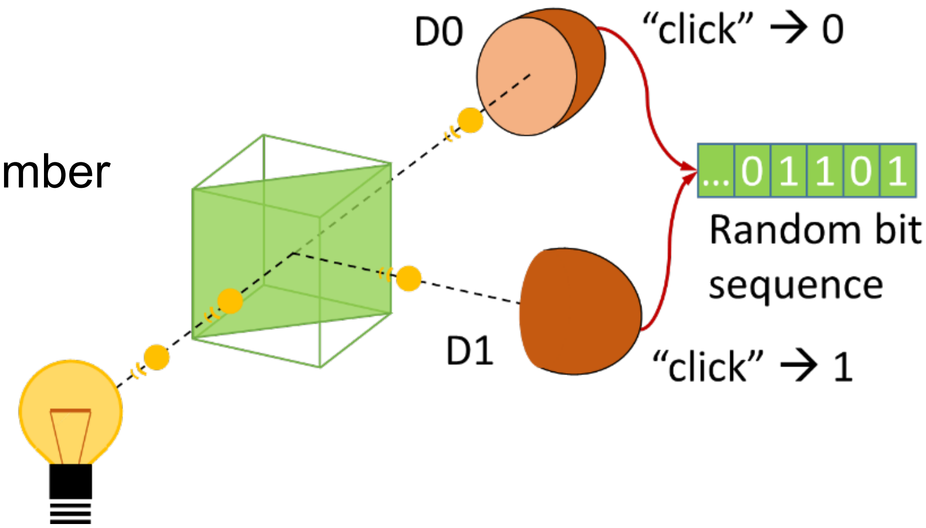
How do I know the results I am getting are showing the quantum nature of the experiment?

- **OPTION#1: BY DESIGN**
  - For example QRNG

Classical Pseudo Random Number
01101….



https://qt.eu/discover-quantum/underlying-principles/qrng/

QUANTUM CERTIFICATION

How do I know the results I am getting are showing the quantum nature of the experiment?

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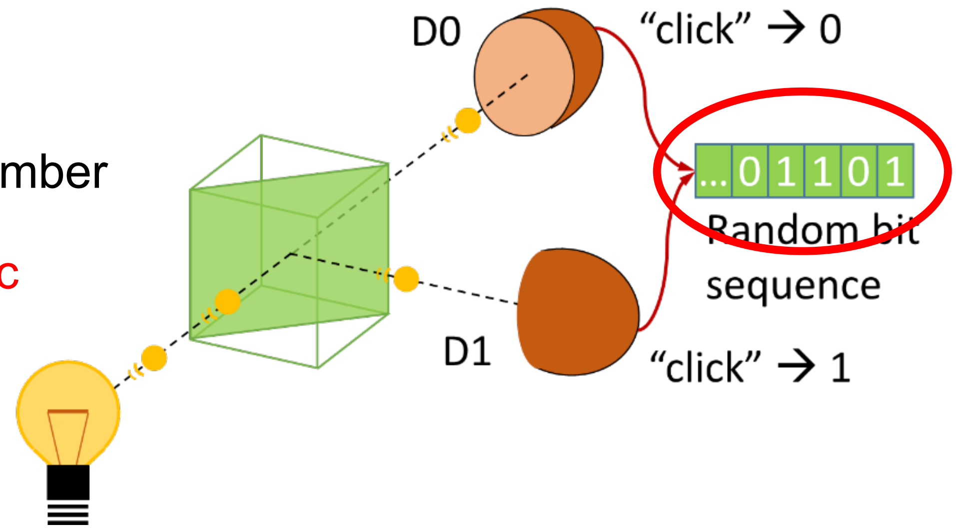
Classical Pseudo Random Number
01101….

Deterministic
Predictable
algorithms



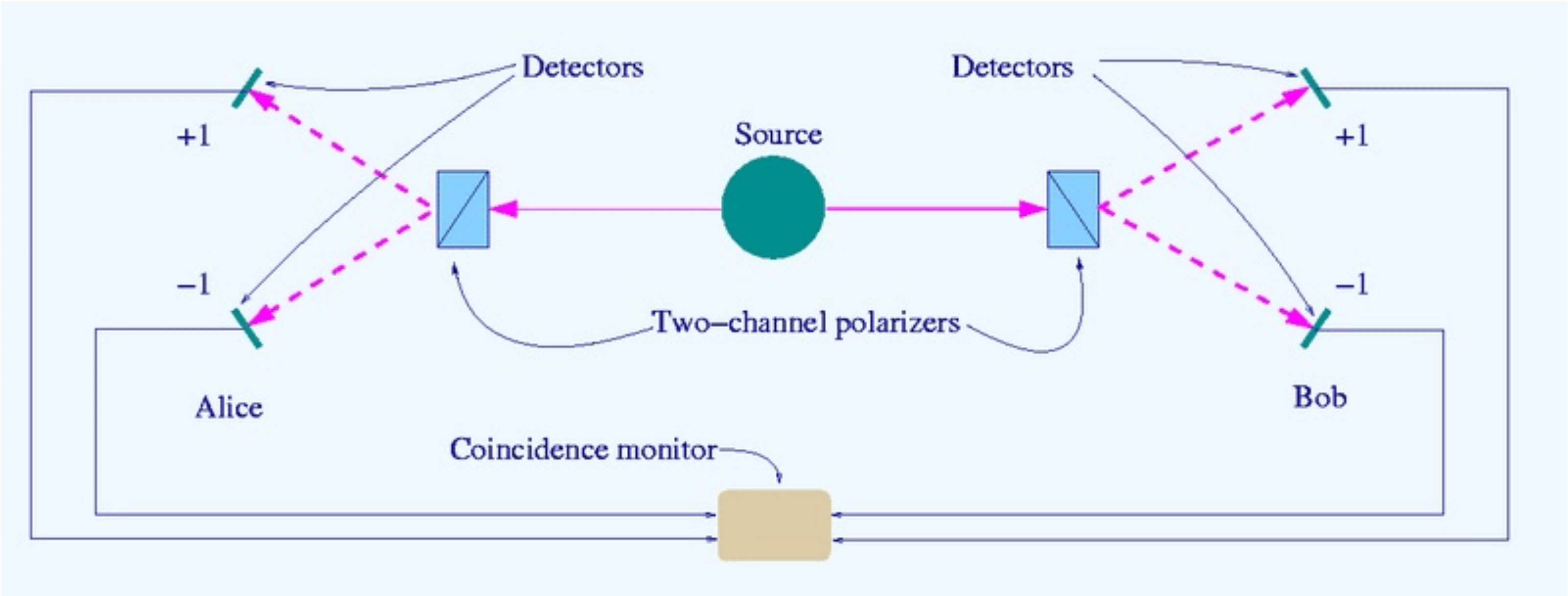
https://qt.eu/discover-quantum/underlying-principles/qrng/

"We know it is quantum because the method is quantum"

QUANTUM CERTIFICATION

How do I know the results I am getting are showing the quantum nature of the experiment?

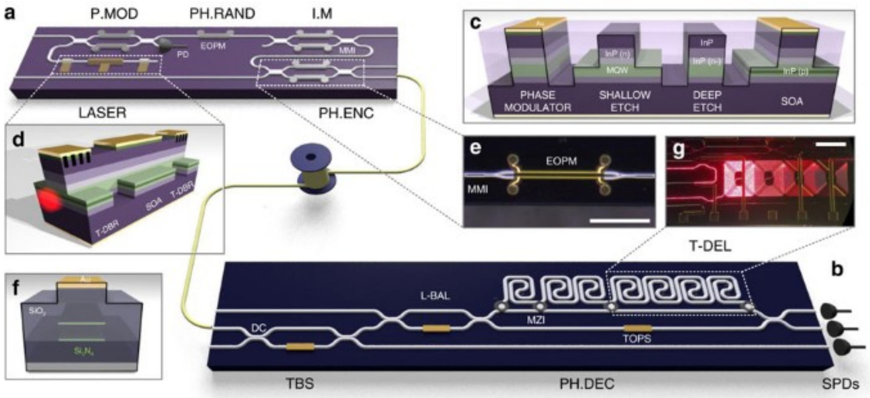
- OPTION#2: Bell Inequality – No Local hidden variables



"If [a hidden-variable theory] is local it will not agree with quantum mechanics, and if it agrees with quantum mechanics it will not be local."[

QUANTUM PRODUCTS

- **Entangled photon sources**
- **QRNG Chip**
- **Quantum Sensing:**
  - Photon counter
- **Precision Timing electronics**
- **QKD equipment**
  - Commercial products are already available
  - PIC Integrated QKD



Chip-based quantum key distribution

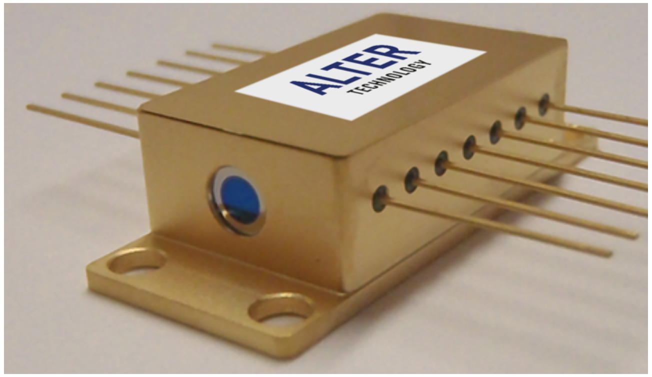
P. Sibson[1], C. Erven[1], M. Godfrey[1], S. Miki[2], T. Yamashita[2], M. Fujiwara[3], M. Sasaki[3], H. Terai[2], M.G. Tanner[4], C.M. Natarajan[4], R.H. Hadfield[4], J.L. O'Brien[1] & M.G. Thompson[1]

NATURE COMMUNICATIONS | 8:13984 | DOI: 10.1038/ncomms13984 | www.nature.com/naturecommunications

ALTER QUANTUM PRODUCTS

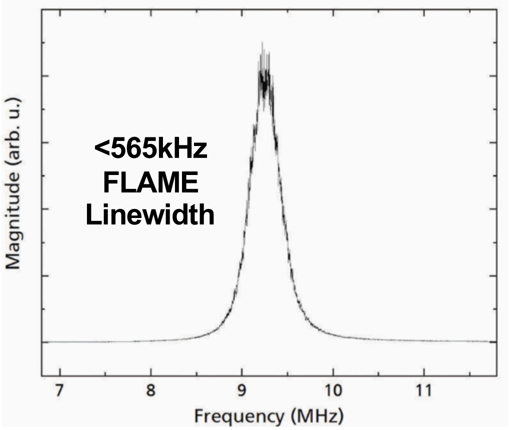
<u>**FLAME**</u> is a compact, frequency-stabilised laser module with integrated vapour cell that allows locking to spectral features of an atomic reference. This first FLAME product addresses **transitions of Rubidium** around 780 nm that are key to applications in Quantum Technologies.

<u>**REMOTE**</u> is a rugged micro-ECDL technology in a hermetic package for **cold atom applications**. It offers ¬ 80 kHz stable linewidth with tunability across Rb 87 and Rb 85 lines



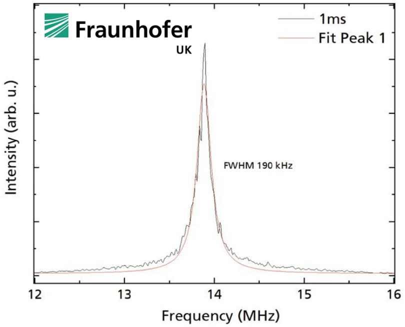
FLAME 780 – Key Benefits

- SWAP-C frequency stabilised laser module with integrated Rb reference cell (hermetic ready).
- Manufactured using space & telecoms qualified processes
- Coefficient of Thermal Expansion (CTE) matched materials
- Alignment-free, vibration immune: short cavity laser diode, in addition to no moving parts or piezos
- Fast current tuning (~40 GHz) without mode-hops across all of the hyperfine spectral features of Rb^{87} and RB^{85} lines
- Narrow Linewidth, typical: [1ms – 600 kHz (1ms, 100ms), 150 mW output power



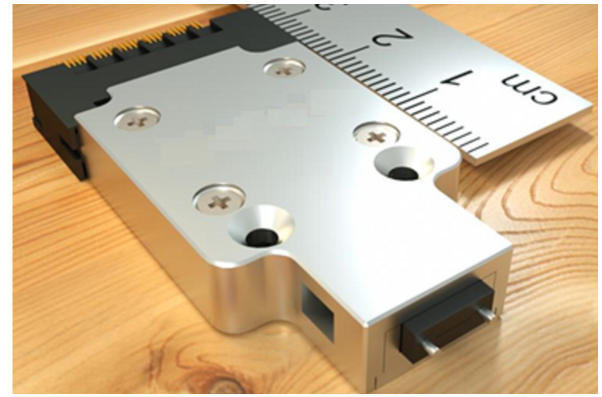
REMOTE-780 Specifications

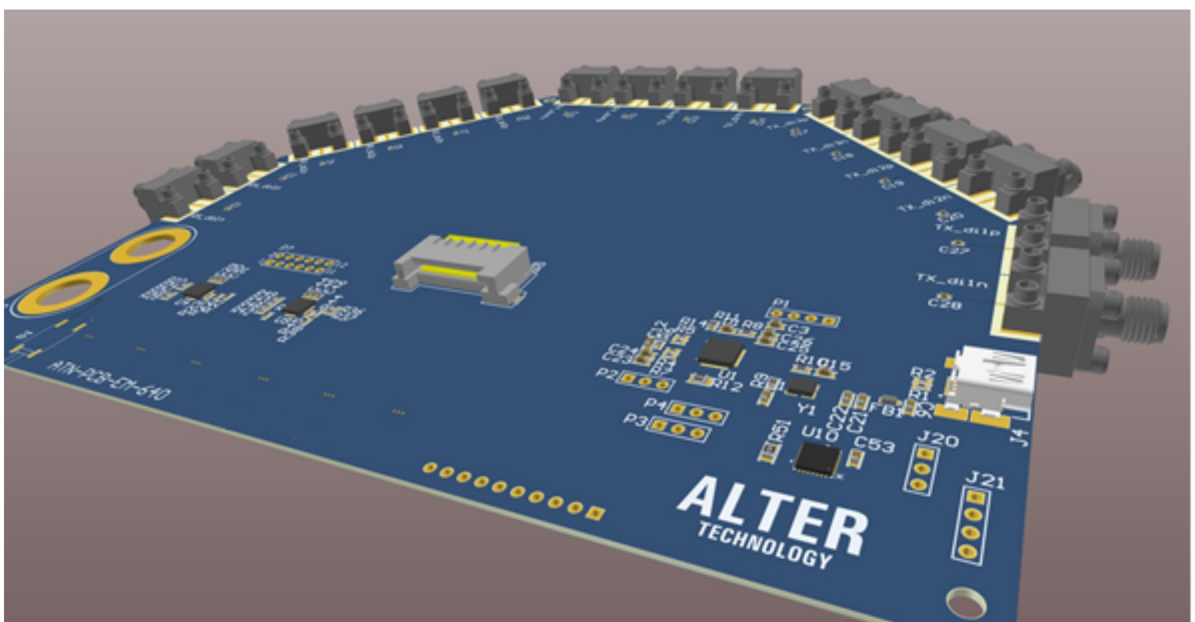
- Butterfly packaged μ-External Cavity Diode Laser (μ-ECDL)
- Hermetically sealed, robust, reliable and miniaturised laser module with integrated passive grating technologies
- SWaP-C optimised: only 30 x 12.7 x 8.9 mm^3
- Optimised for 780.24nm with 100mW of output power
- Alignment-free, high vibration stability: short cavity, in addition to no moving parts or piezos
- Rapid current frequency tuning: across all of the Rb 87 and Rb 85 lines ~10 GHz wide hyperfine spectral features
- Typical linewidth: 80 kHz (1ms, 100ms) (when locking to Fabry–Pérot interferometer, >200 finesse 1.5GHz FSR)



ALTER COMMUNICATION PRODUCTS

<u>4x4 25 Gb/s Transceiver</u> is a fast, compact, multiport Tx/Rx device designed for intra-satellite communication, to enable HTS/VHTS and other applications requiring rapid communication of large volumes of data





ALTER CLASSICAL COMM TESTING

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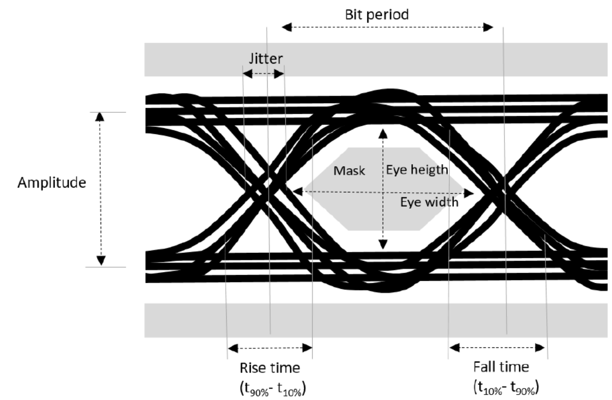
Digital RF Characterization ALTER SP Tres Cantos



Up to 28Gbs

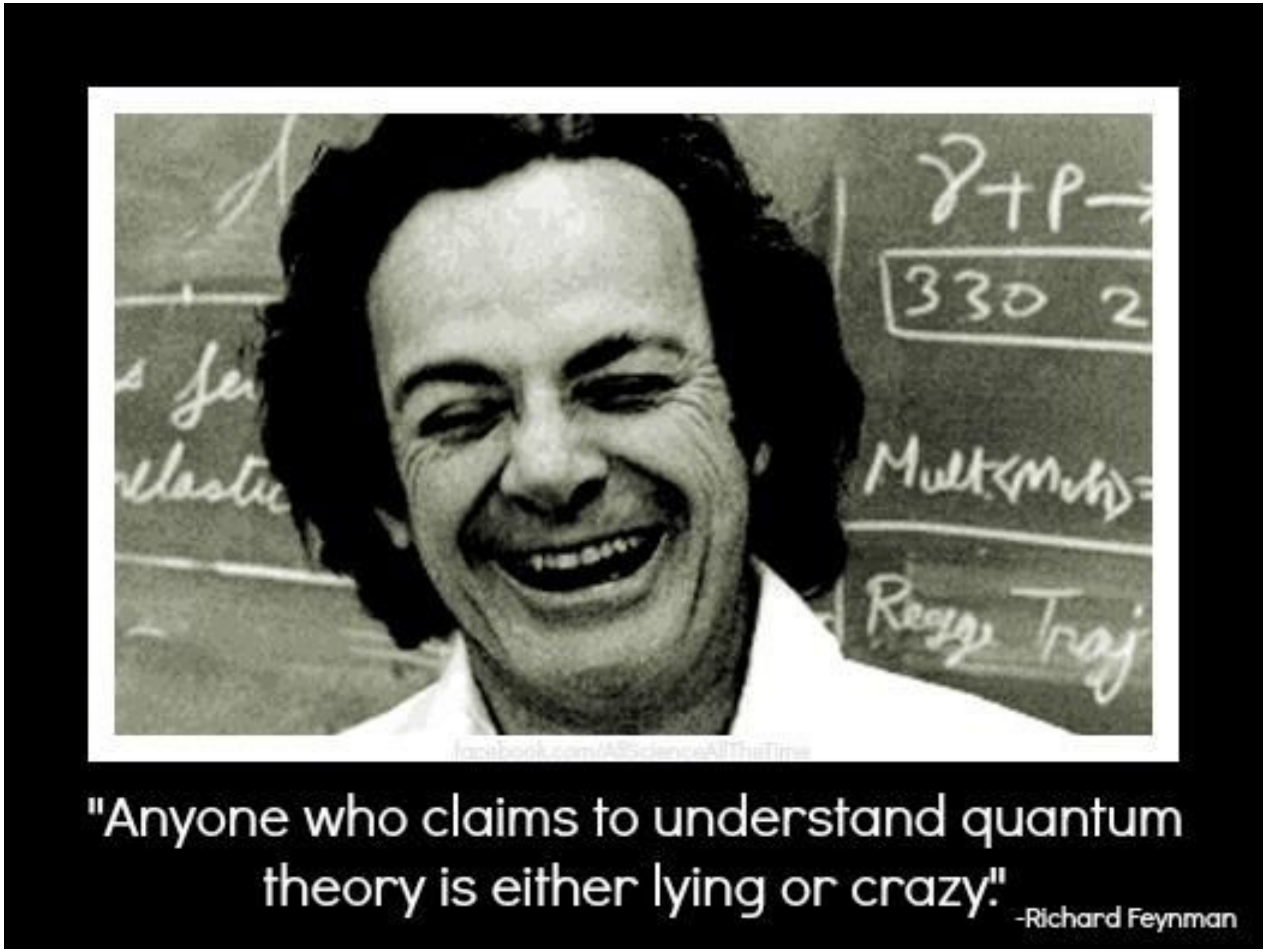
MP2110A	BERTWave
MP2110A-011	1CH BERT
MP2110A-021	Dual Electrical Scope
MP2110A-024	Precision Trigger
MP2110A-054	Clock Recovery (Electrical/Optical)
MP2110A-093	PPG/ED Bit Rate Extension
MP2110A-095	PAM4 Analysis Software
MP2110A-096	Jitter Analysis Software

Reliability assurance guideline for digital optical transmitter, receiver and transceiver modules

ISROS_GL_002_V01

High Frequency Photodetector to be used as reference to test emitters.

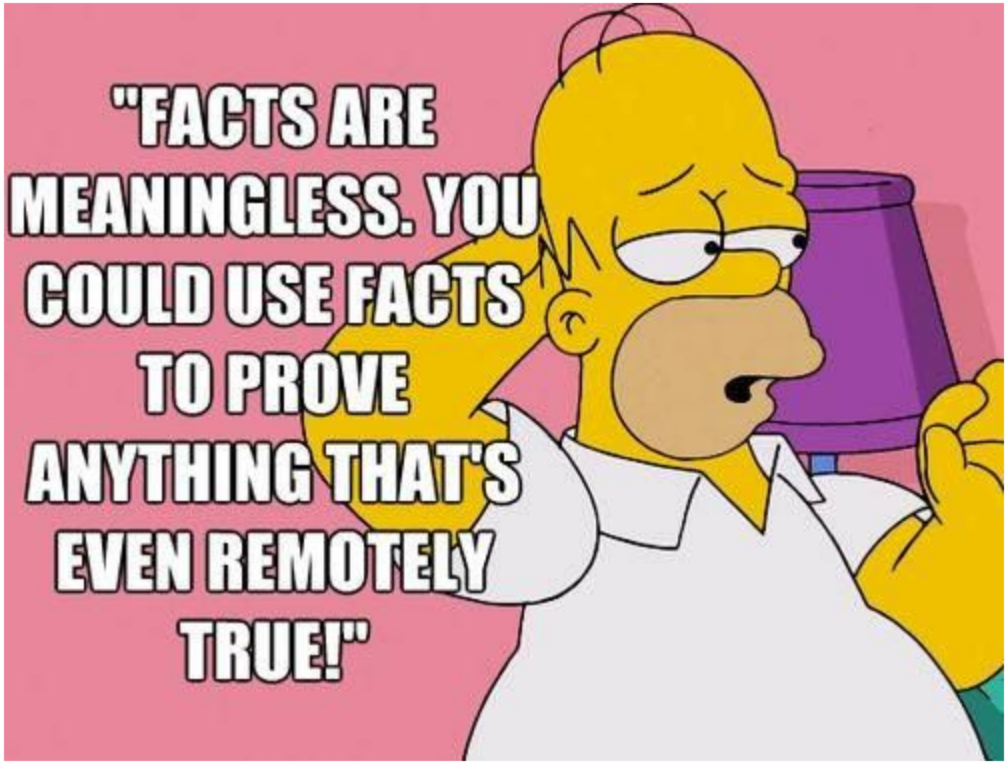
QUANTUM CONCLUSIONS



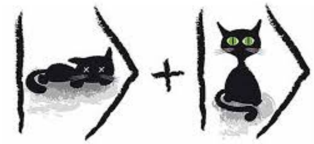
<u>We need to base our quantum results on facts (classical)</u>

QUANTUM CONCLUSIONS

But,…



QUANTUM CONCLUSIONS



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- CLASICAL & QUANTUM Communication will live together for many years to come. And each one needs the other.
- QKD needs classical channel to confirm it.
- Quantum is key for secure communications, but quantum is probabilistic (no hidden variables)
- QBER is quite high compare to classical BER.
- ALTER UK capabilities are also producing components for Quantum applications
- Increasing complexity leads to more difficult testing. ALTER goal is to **continuously improve the lab capabilities** to be ready for future test challenges.

THANK YOU!

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