QUBIG

EMPOWERING *LASER & QUANTUM* TECHNOLOGIES

Laser beam conditioning
EO & AO light modulators

Dr. Jackson Ang'ong'a | QUBIG

QuRIOUS | DN

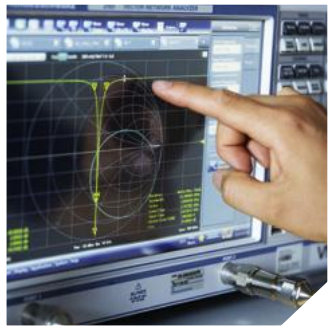
Quantum Research and Innovation in Optical clocks for Upcoming Scientists

Overview

In-house Crystal processing

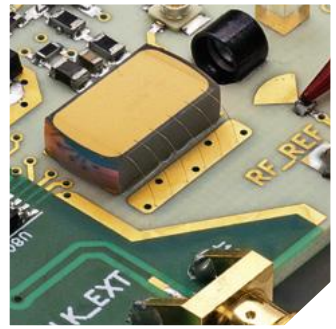
In-house HF/HV electronics development

In-house work shop & surface treatment



High-quality Equipment & Laser booths for testing

In-house Clean room



Miniaturisation & Integration (in progress)

Company:

- Head office: Munich, GERMANY | founded in 2008
- Focus: Active laser beam conditioning (via light modulators)
- State recognised research facility: since 2018 (AZ: 72A-9733-0287/24)
- Structure: Strong vertical integration
- Customers: >700, >45 nations
- Markets: QR&T, Industry (wafer inspection, LMP)

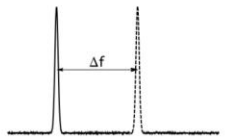
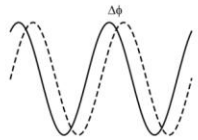
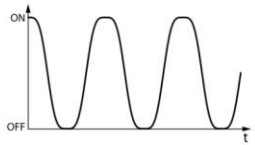
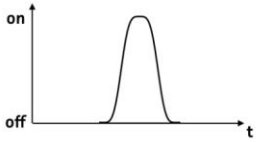
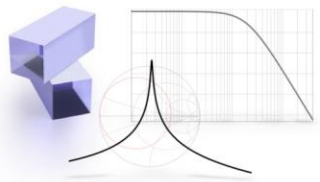
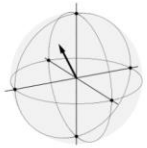
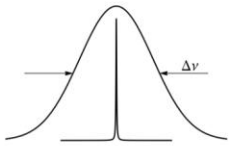
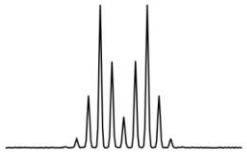
Expertise/Experience:

- Electro - & Acousto Optics / Devices
- HF|HV - Electronics: >20 GHz | >kV @ MHz
- Laser: 200nm – 11um | $\hbar\omega$ – kW | cw – ns/ps/fs
- Strong QT background

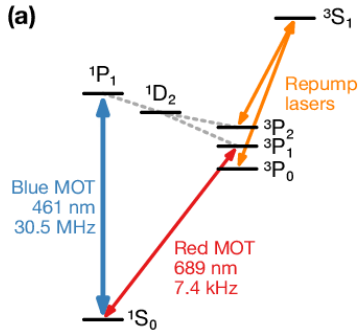
Laser beam modulation and conditioning

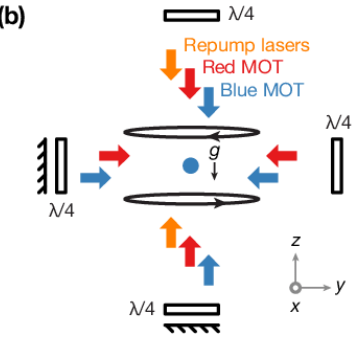
Laser

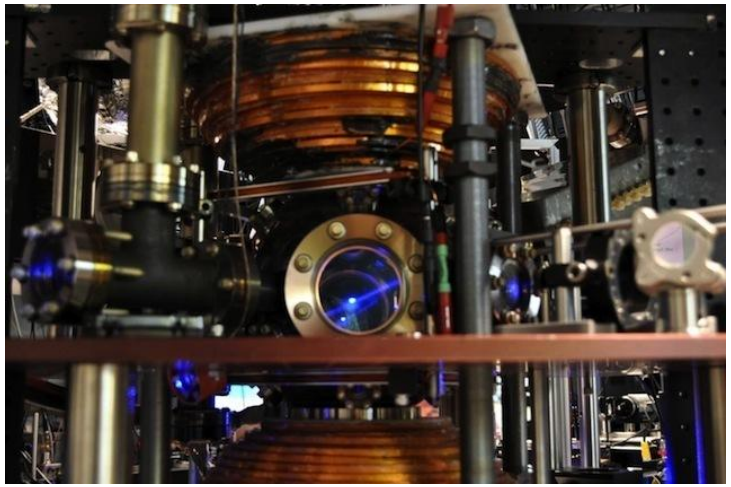
Laser beam conditioning

Frequency Δf	Phase Δφ	Amplitude ΔI
		
Ultra-short Pulses ΔT		**Position Δx**
		
Polarization Δp	**Linewidth Δν**	**Spectrum ωᵢ**
		

Science: neutral atoms, trapped ions, NV centers etc



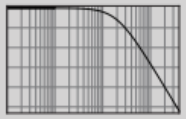
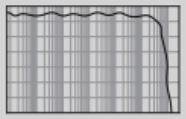
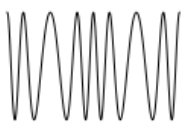
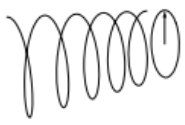
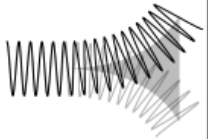
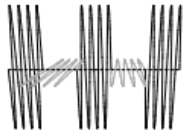
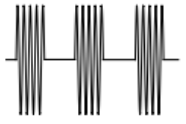
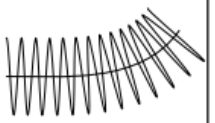
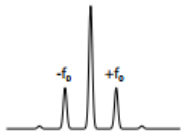
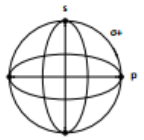
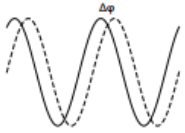
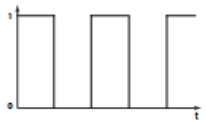
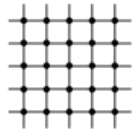
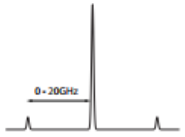
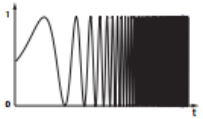




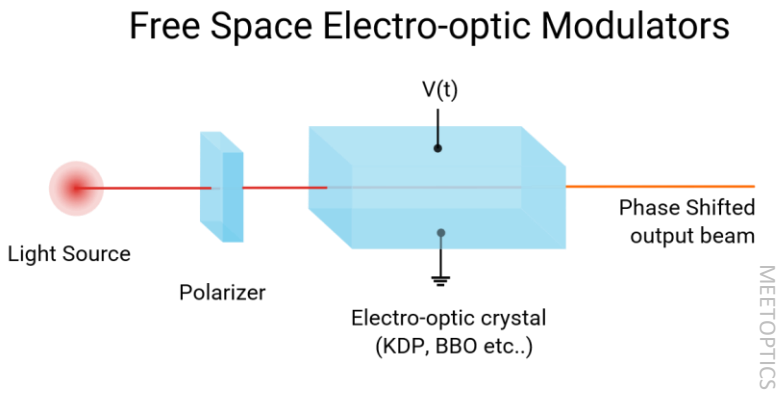
Product portfolio

Free-space light modulators and electronic drivers for high-precision applications.

- Frequency: DC – 20GHz
- Wavelength : 200nm - 10µm
- Power: $\hbar\omega$ – 100 W

EM-field coupling	resonantly enhanced				broadband/ DC-coupled (high Z) 				broadband/ Traveling Wave (50Ω) 	
Modulator Type	Phase Modulator	Polarisation Modulator	Amplitude Modulator	Electro-Optic Scanner	Phase Shifter	Polarisation Shifter	Pockels Cell	Electro-Optic Deflector	Traveling Wave Phase Modulator	Traveling Wave Amplitude Modulator
Product Series	**PM**	**AM**		**EOS**	**PS**	**PC**		**EOD**	**TWP**	**TWA**
Laser Property										
Optical Effect										

Modulators relevant to QuRIOUS

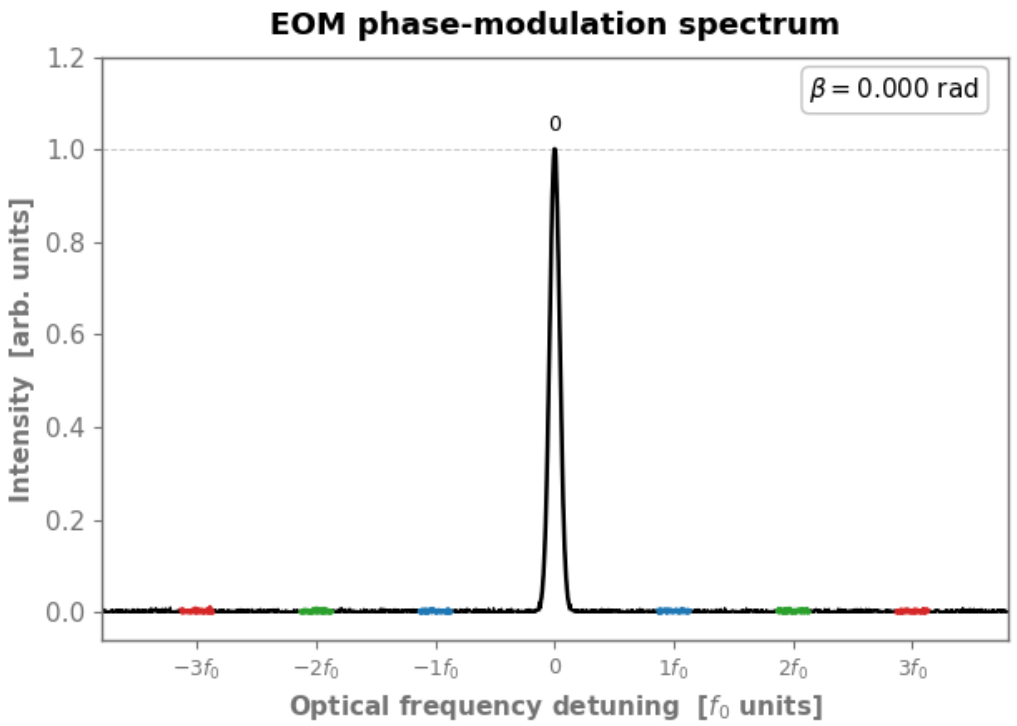


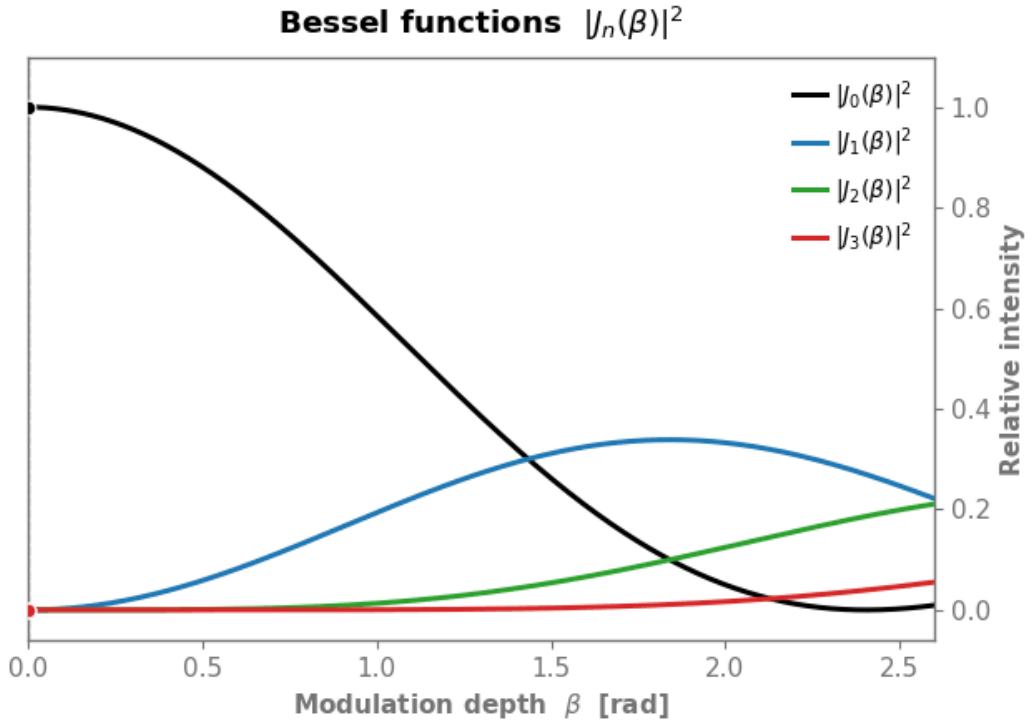
$$Ae^{i\omega t} \longrightarrow Ae^{i\omega t + i\beta \sin(\Omega t)}$$

$$Ae^{i\omega t} + \frac{A\beta}{2i}\left(e^{i(\omega+\Omega)t} - e^{i(\omega-\Omega)t}\right)$$

Modulators relevant to QuRIOUS

Figure of merit: how much power for 1 rad modulation depth

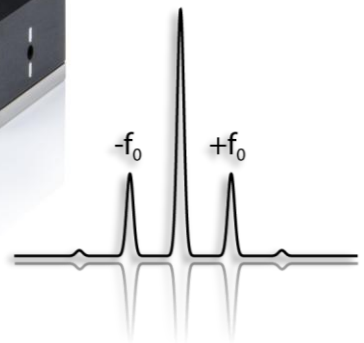




$$Ae^{i\omega t} + \frac{A\beta}{2i}\left(e^{i(\omega+\Omega)t} - e^{i(\omega-\Omega)t}\right)$$

Modulators relevant to QuRIOUS

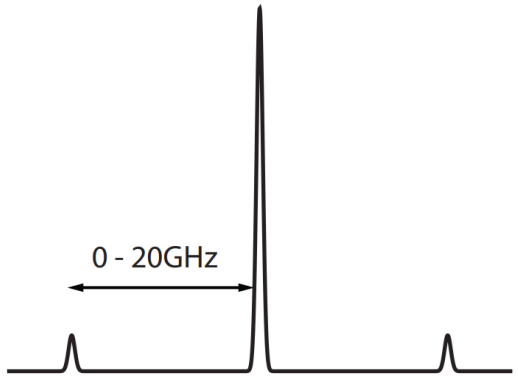
Resonantly enhanced



Key features:

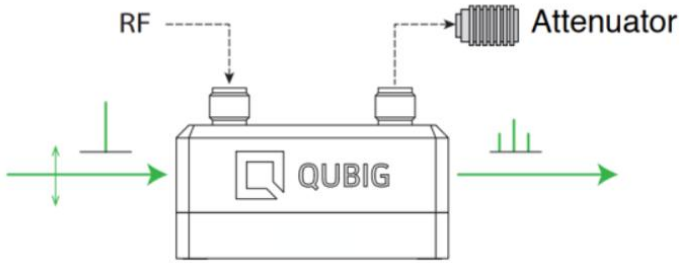
- Speed: >30GHz
- Spectral bandwidth: UV - IR
- Optical Transmission (AR coated)
- Power handling
- Low RAM

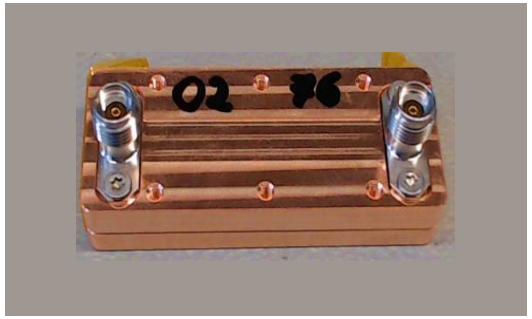
Broadband



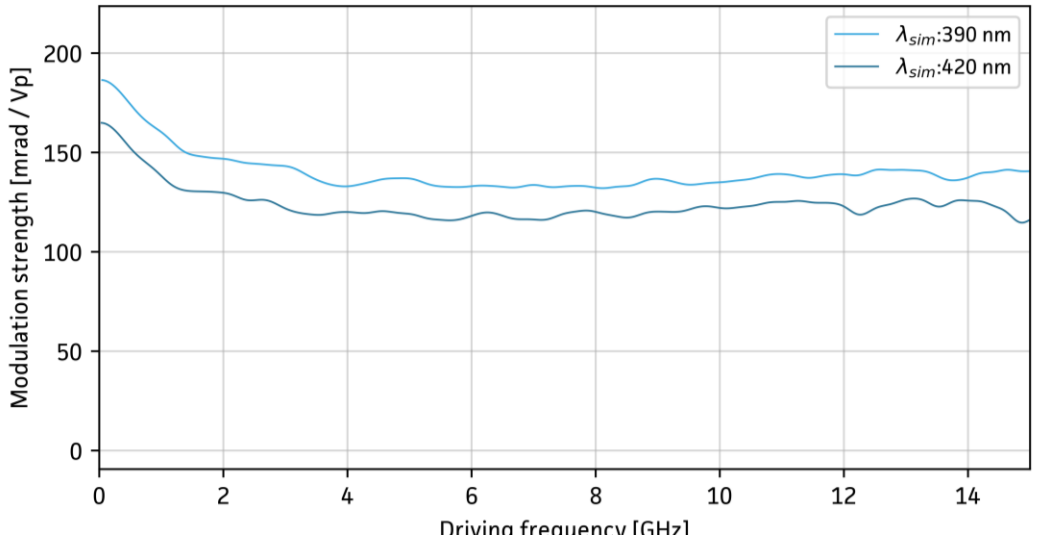
- **Laser cooling & trapping**
- **Laser frequency stabilisation**
- **Quantum state manipulation and Quantum gate operations**
- **…**

Traveling wave broadband EOM



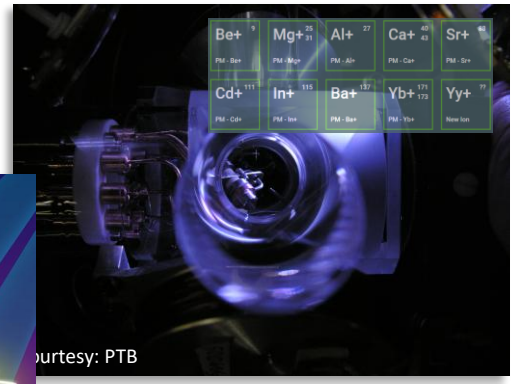


- High efficiency : 120mrad /V
- Optimized Bandwidth 14 GHz
- Dimensions: 10 x20 x45 mm^3
- 30dBm for 1 rad



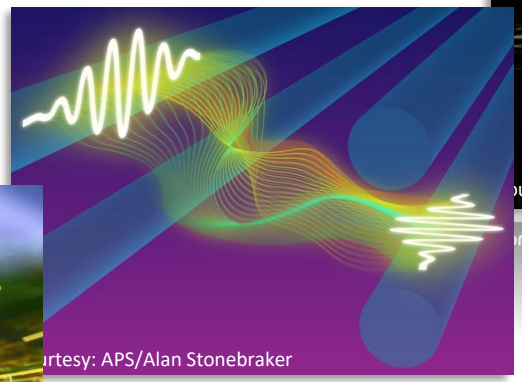
Why free-space light modulators

UV (>200nm)



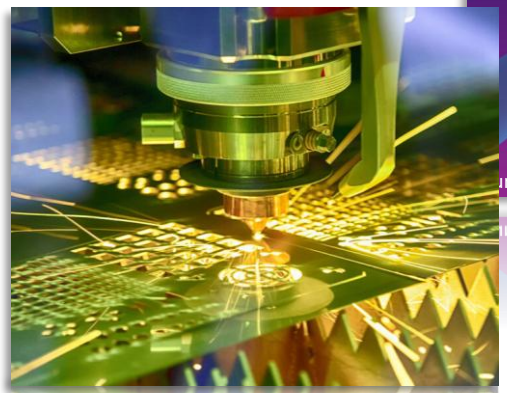
Courtesy: PTB

Low optical losses



Courtesy: APS/Alan Stonebraker

High optical power



vs.

Optical waveguide-based EOMs

- Optical transmission*: **>>99%**
- Spectral range: **200nm – 11um**
- Power handling*: **>>W | cw - ns/ps/fs**
- Stability: **RAM**

Why free-space light modulators

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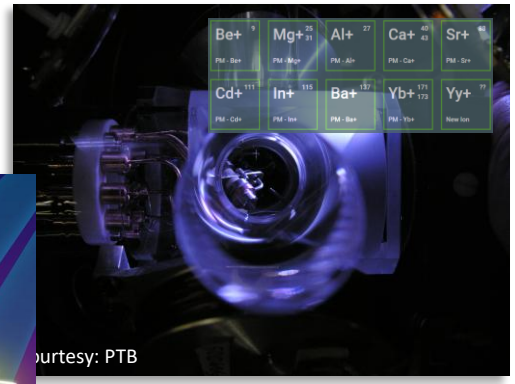

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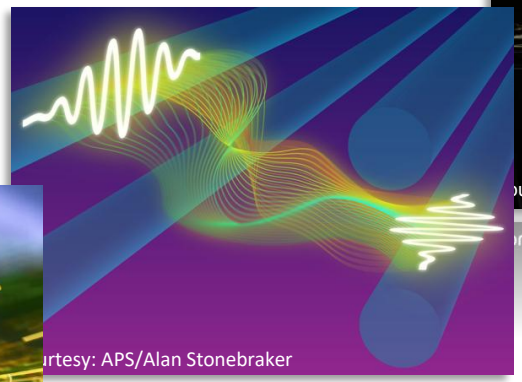

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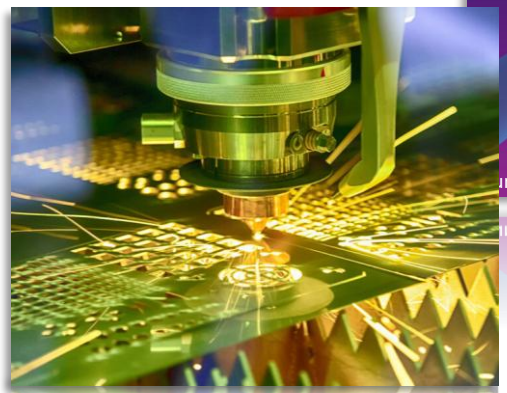


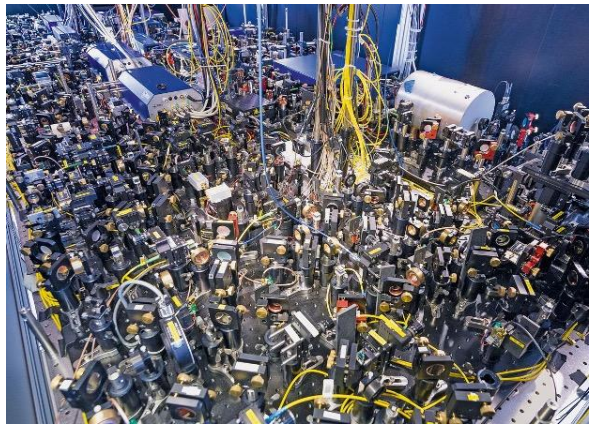
vs. Optical waveguide-based EOMs

- Optical transmission ✓
- Spectral range ✓
- Power handling ✓
- Stability ✓
- Size | Integration

Pushing quantum technologies out of the lab

via

opto-electronic Integration



Pushing quantum technologies ~~out of the lab~~

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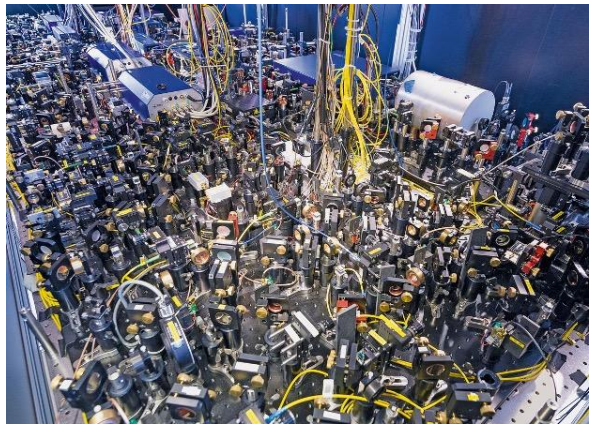


Quantum technologies are out of the lab

Sensing

... many more not mentioned

Memory

Quantum Key Distribution

Networking

Software

... many more not mentioned

Computing

... many more not mentioned

Quantum technologies are out of the lab but still complex

IONICS

ZABRE

... many more not mentioned

SINGLE QUANTUM
Excellence in photon detection

Image: Nasdaq

atom computing

IONQ

QUANTINUUM

Computing

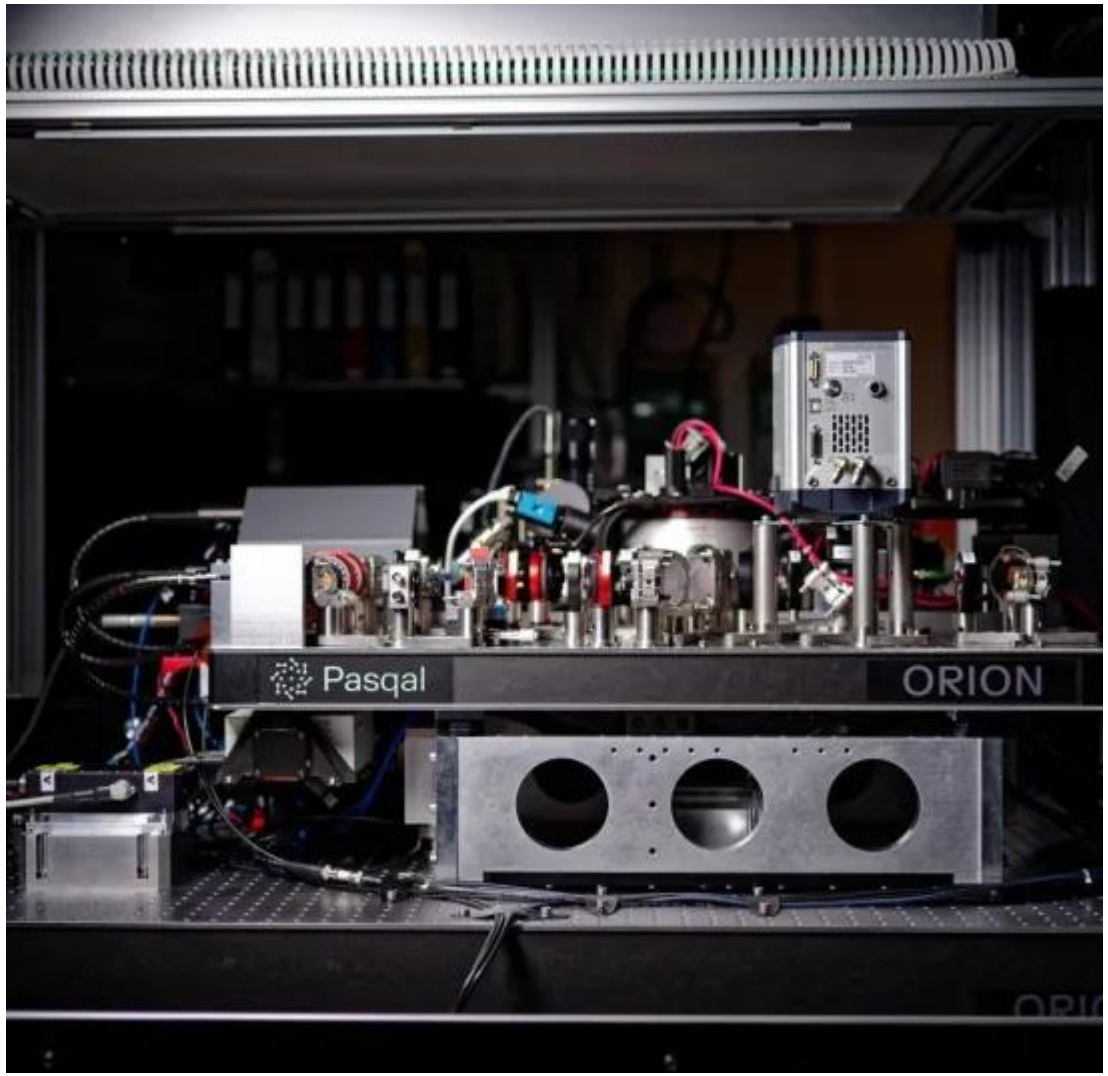
planqc

Pasqal

AQT

Most prominent: quantum computers

- QC systems are for example still at the human scale
- We need to scale up by getting more compact



Most prominent: quantum computers

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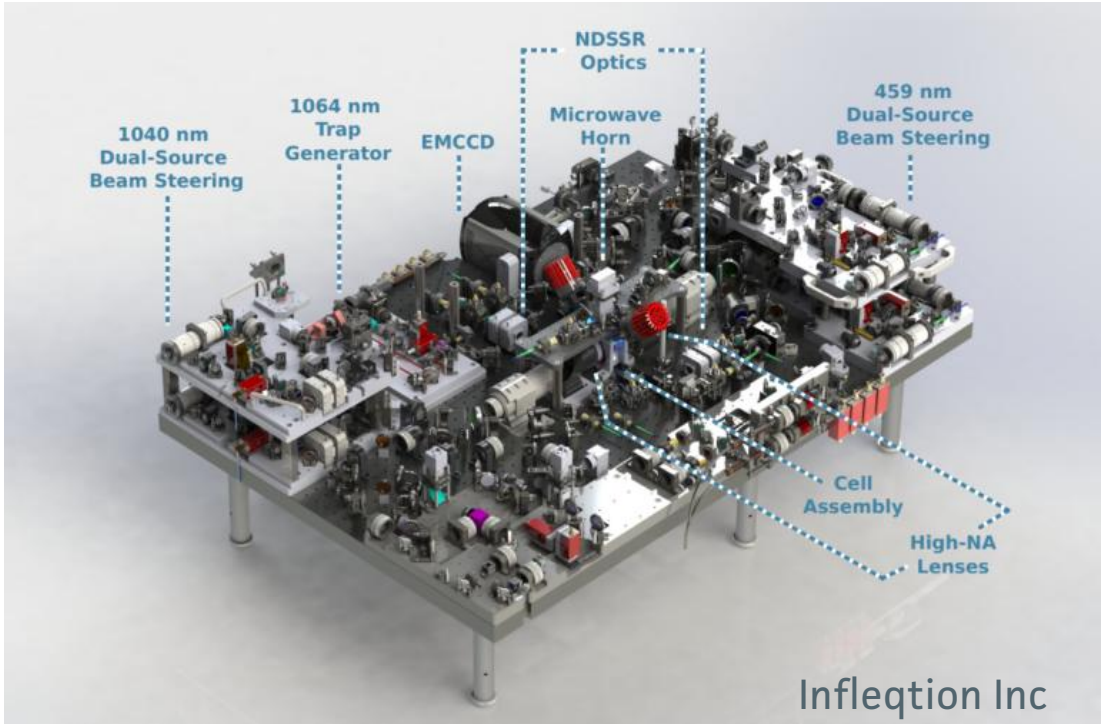
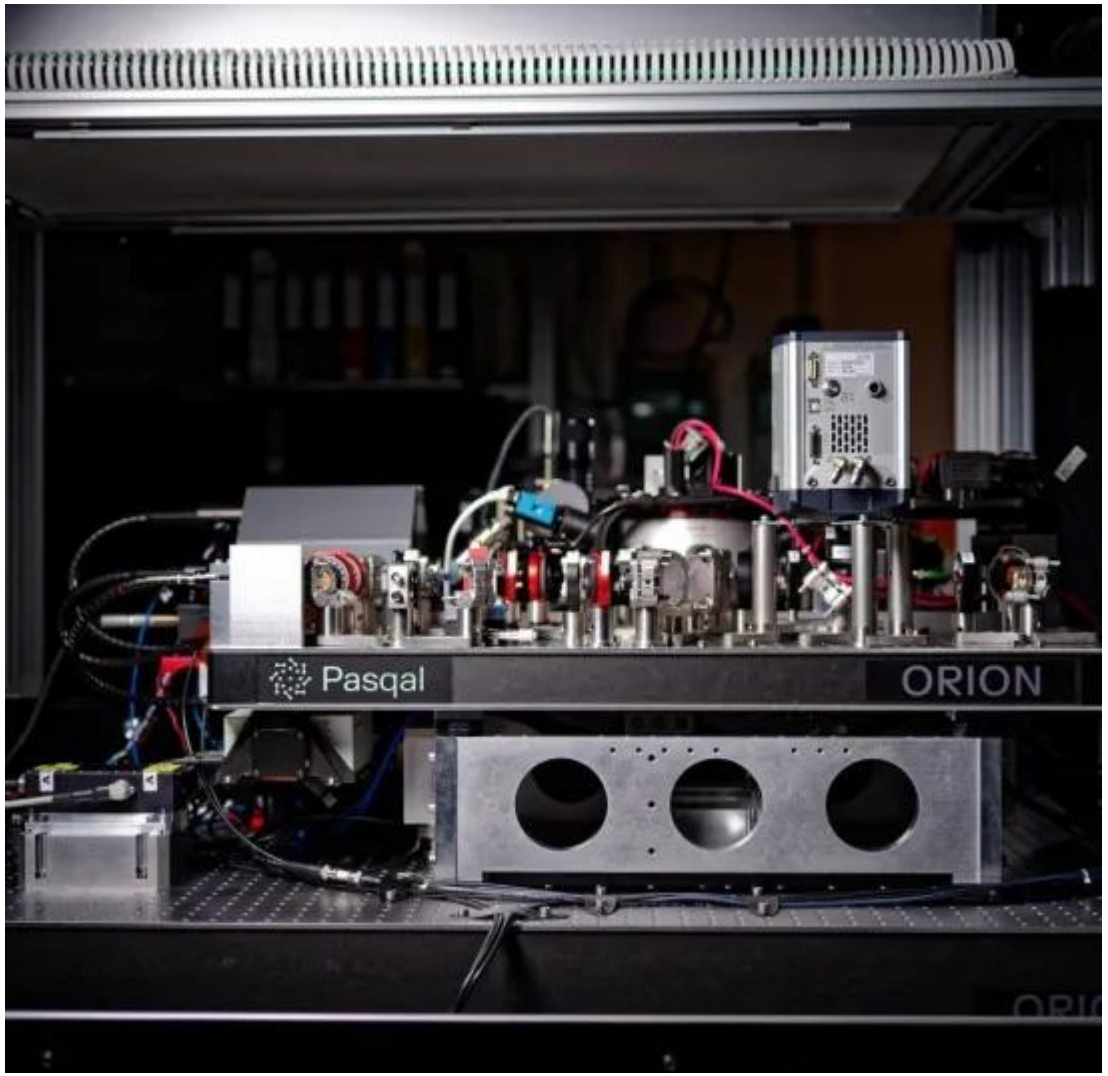




Still a long way to go

What system size do we need for practical quantum advantage?

Hundreds of thousands to millions of physical qubits

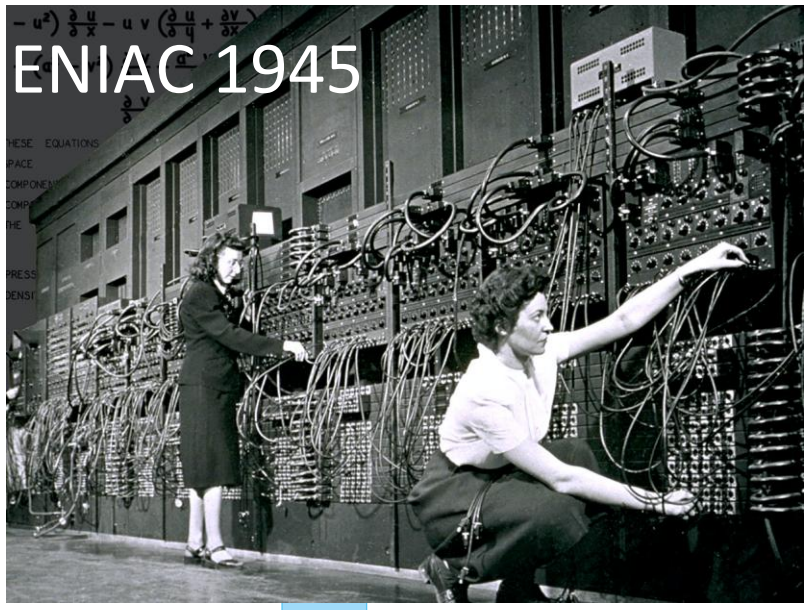
Beverland et al. arXiv 2211.07629v1 (2022)

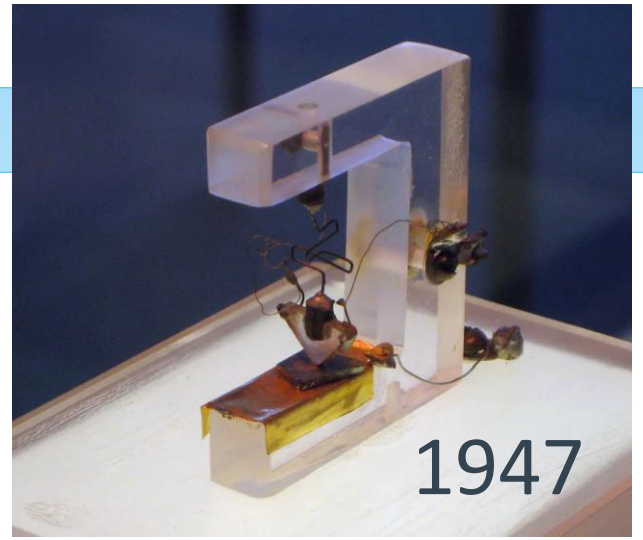
10,000 to 1,000,000 physical qubits if you cleverly chose your algorithm

Katabarwa, Amara, et al. Early fault-tolerant quantum computing. *PRX quantum* 5.2 (2024): 020101.

https://www.desmos.com/calculator/jlmbygcqrp?lang=de

Still a long way to go



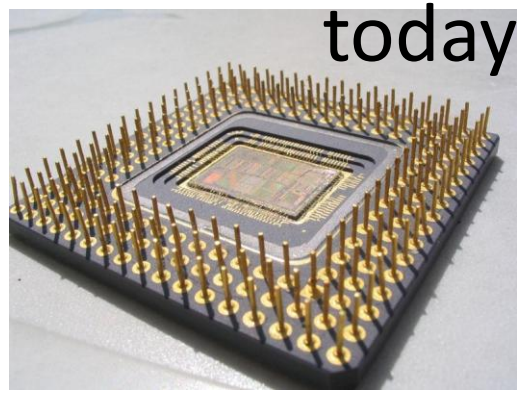


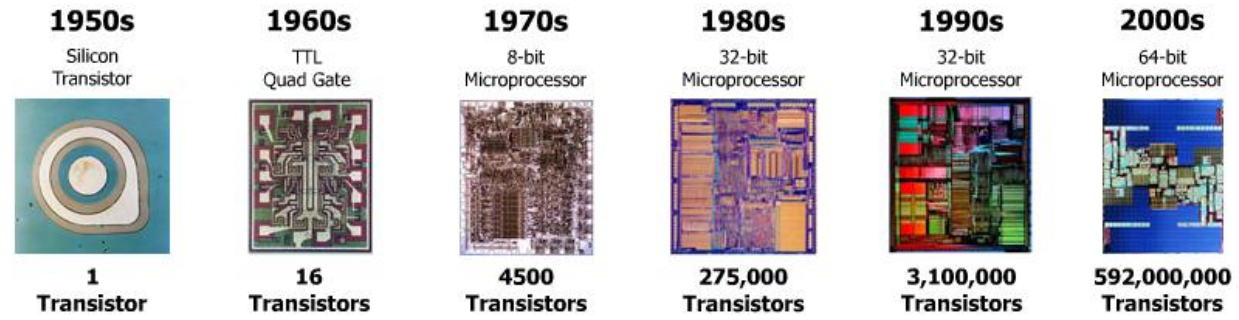
Hundreds of thousands to millions of physical qubits are needed to achieve practical quantum advantage

Beverland et al. arXiv 2211.07629v1 (2022)

10,000 to 1,000,000 if you cleverly chose your algorithm

Katabarwa, Amara, et al. "Early fault-tolerant quantum computing. " *PRX quantum* 5.2 (2024): 020101.





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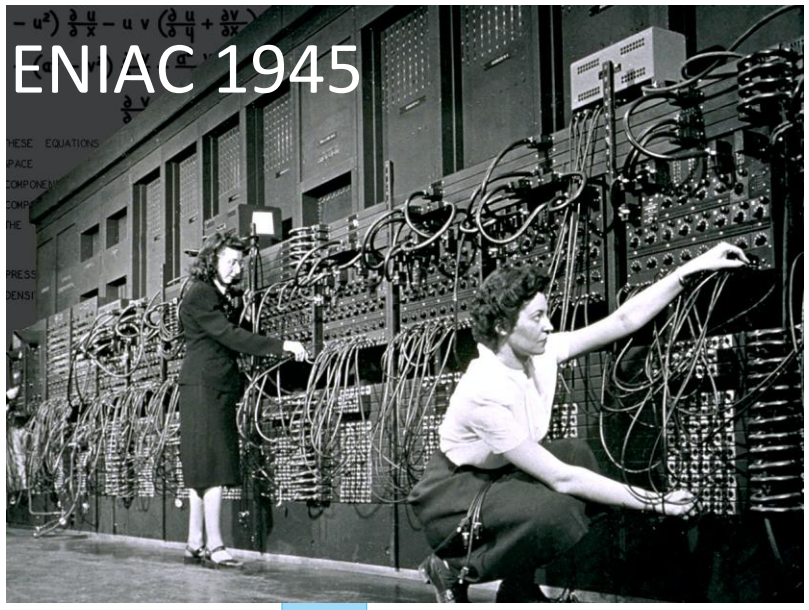

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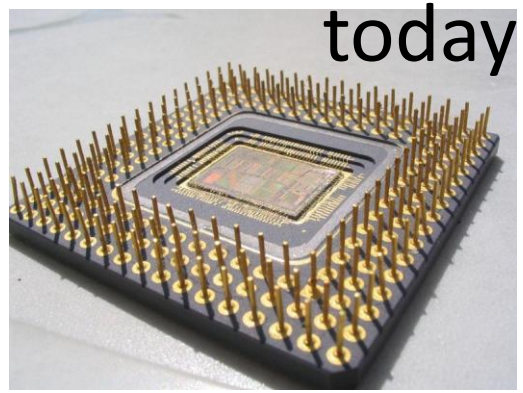
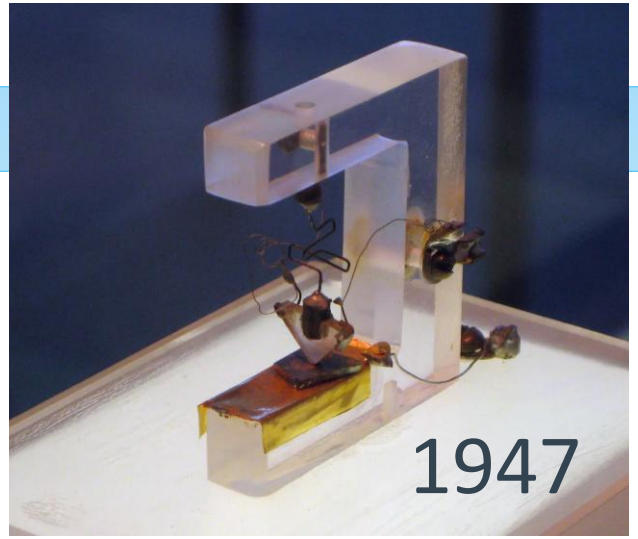
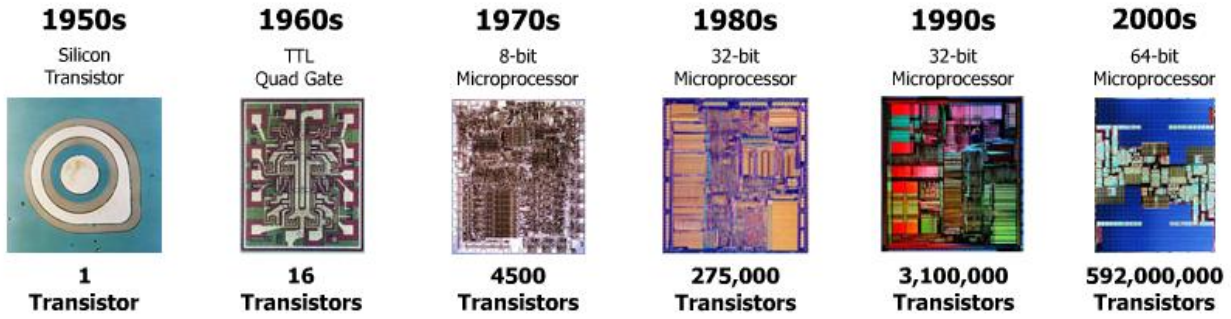
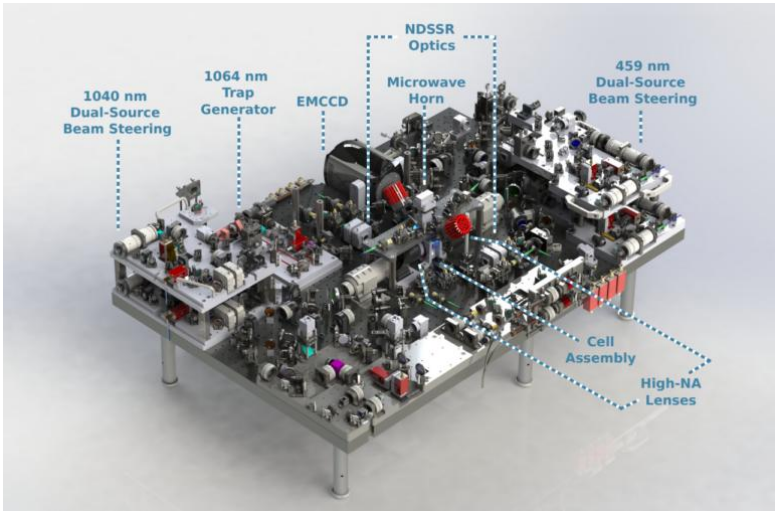


Quantum hardware is here





Quantum technologies are out of the lab but still complex



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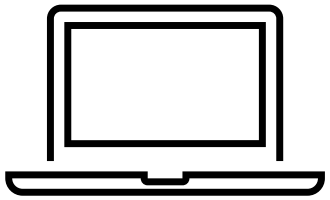
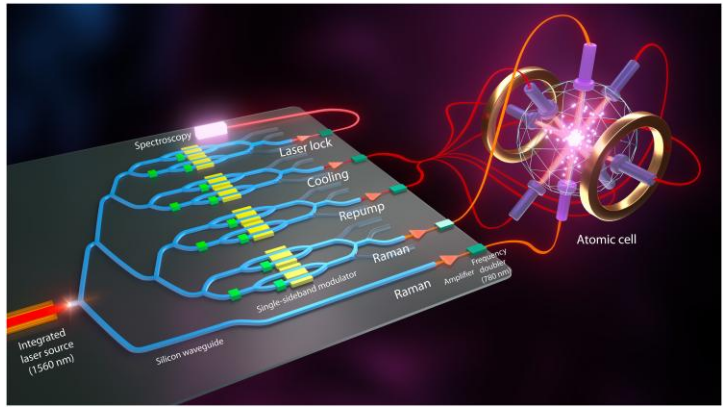


Scaling up by scaling down

- Photonic integrated circuits (PIC)

Ashok Kodigala *et al.* ,High-performance silicon photonic single-sideband modulators for cold-atom interferometry.*Sci. Adv.***10**,eade4454(2024)



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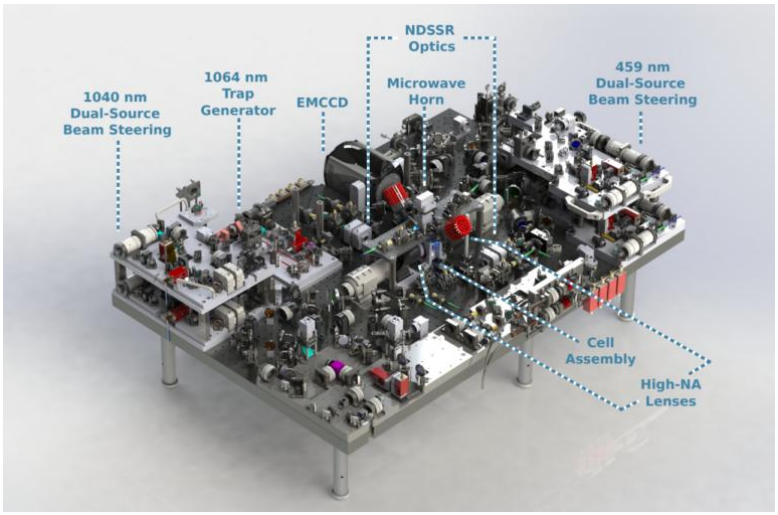

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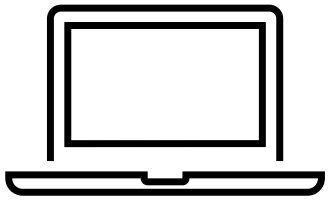
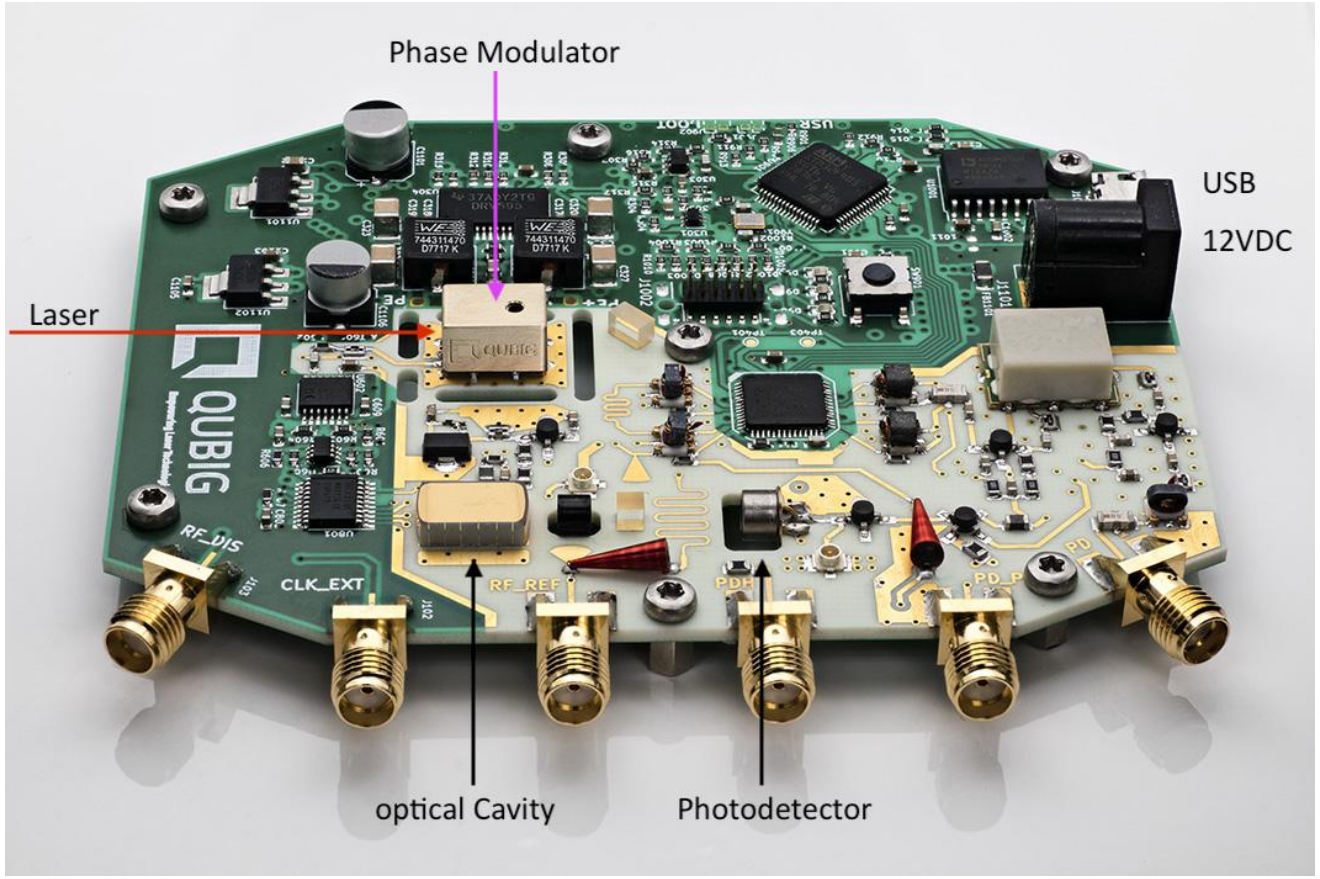
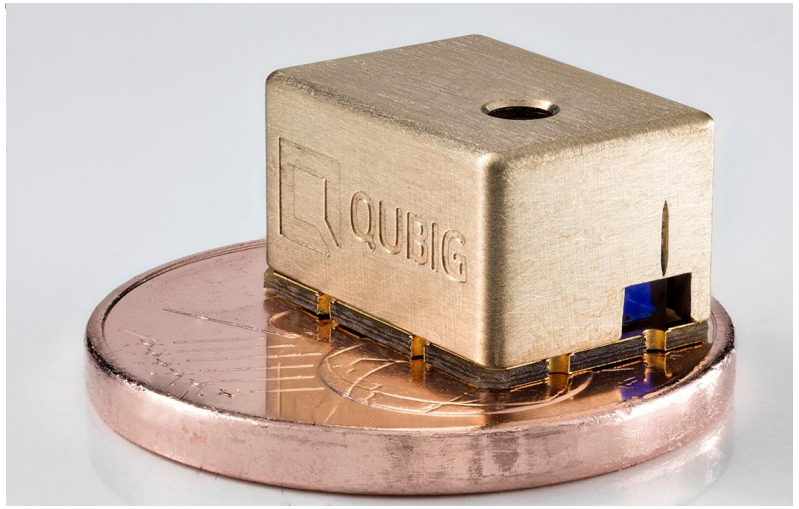


Scaling up by scaling down

- Photonic integrated circuits approach
- Integrated opto-electronics

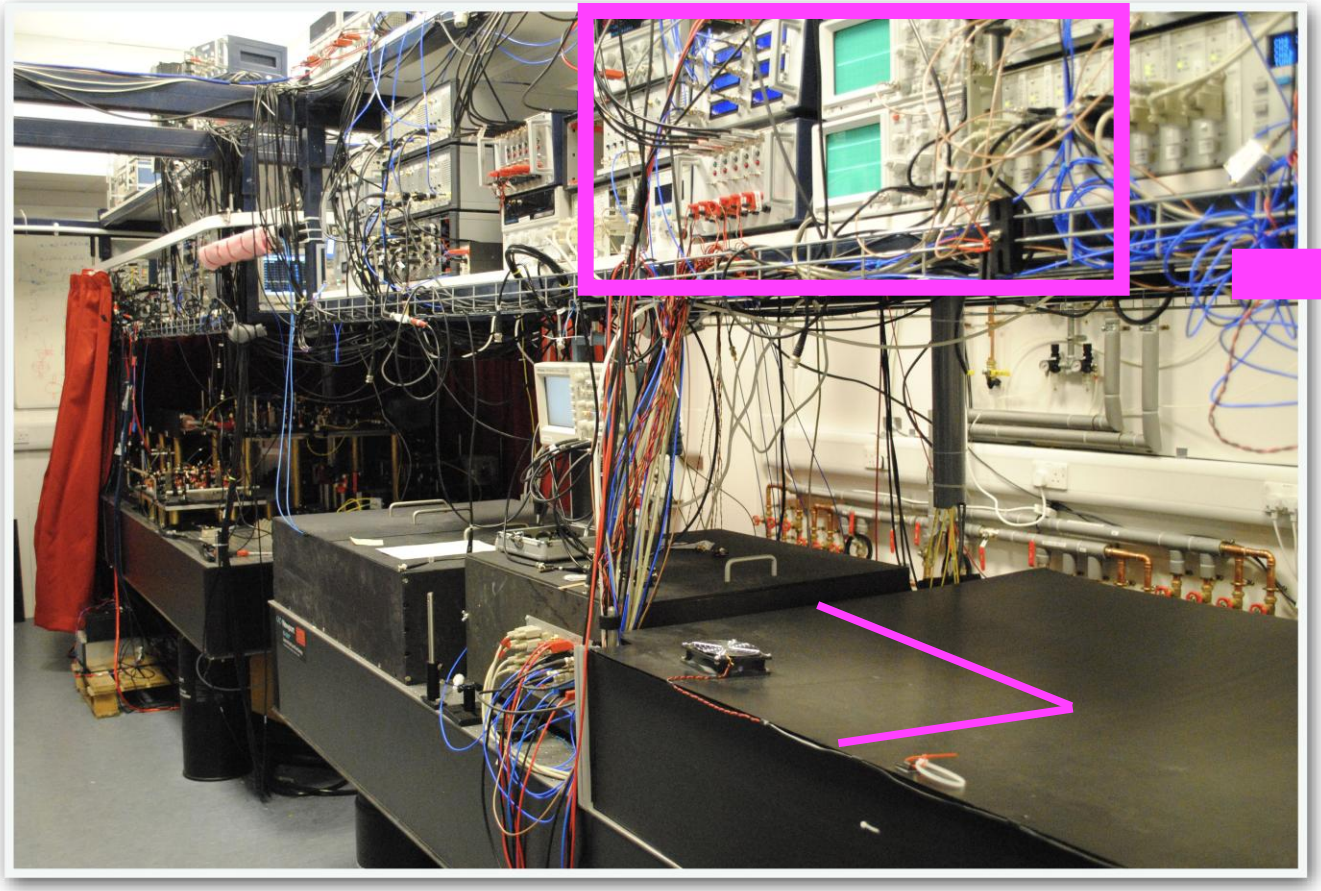
Opto-Electronic Integration

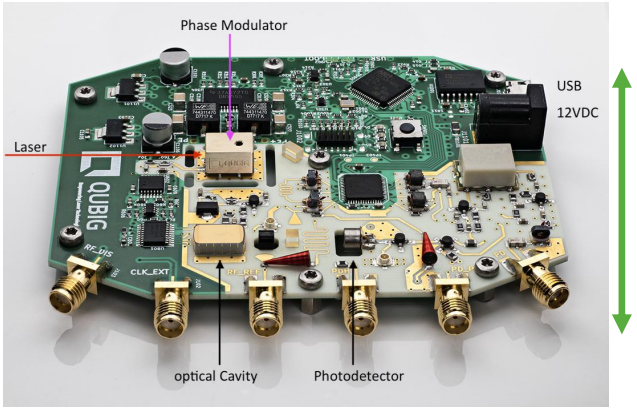




Execution example: **Pound-Drever-Hall Module**

Pushing quantum technologies outside the lab





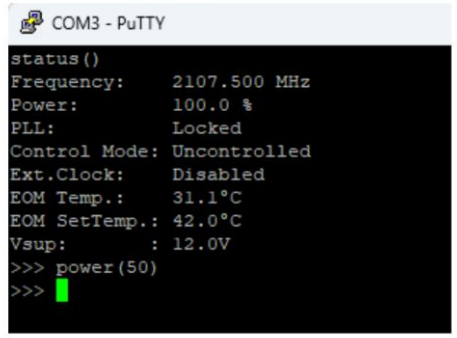
Goal: shrink down!

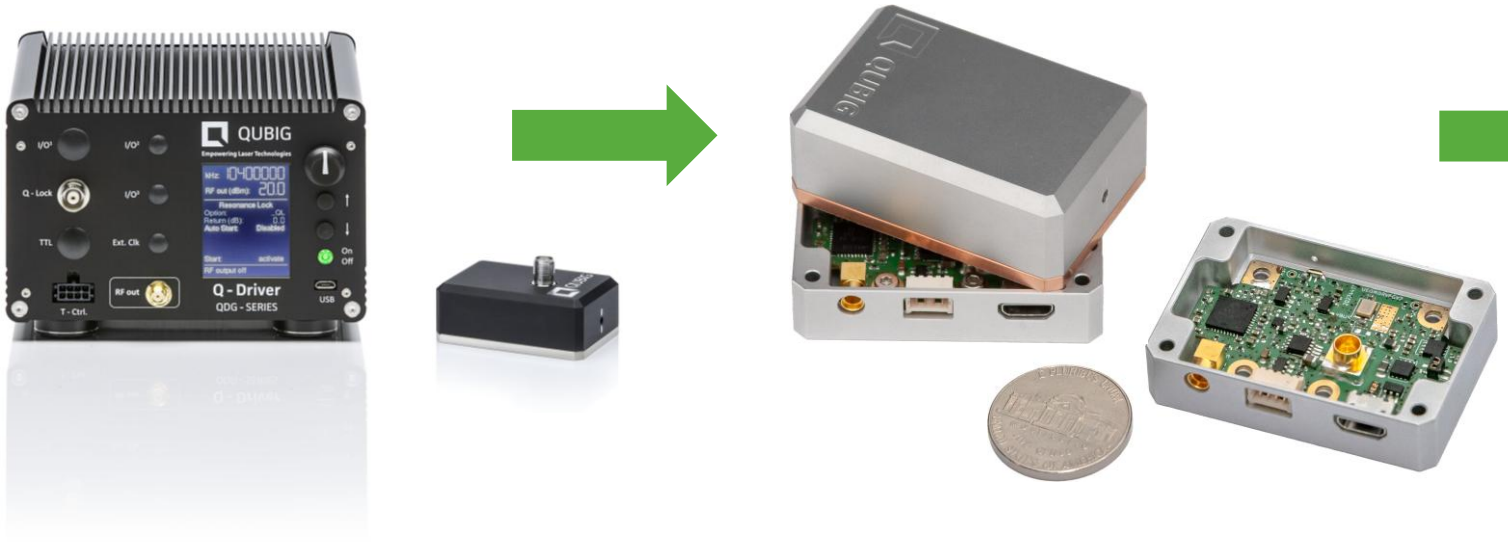
Execution examples

1. Phase Modulation Module - PMM:

Key features:

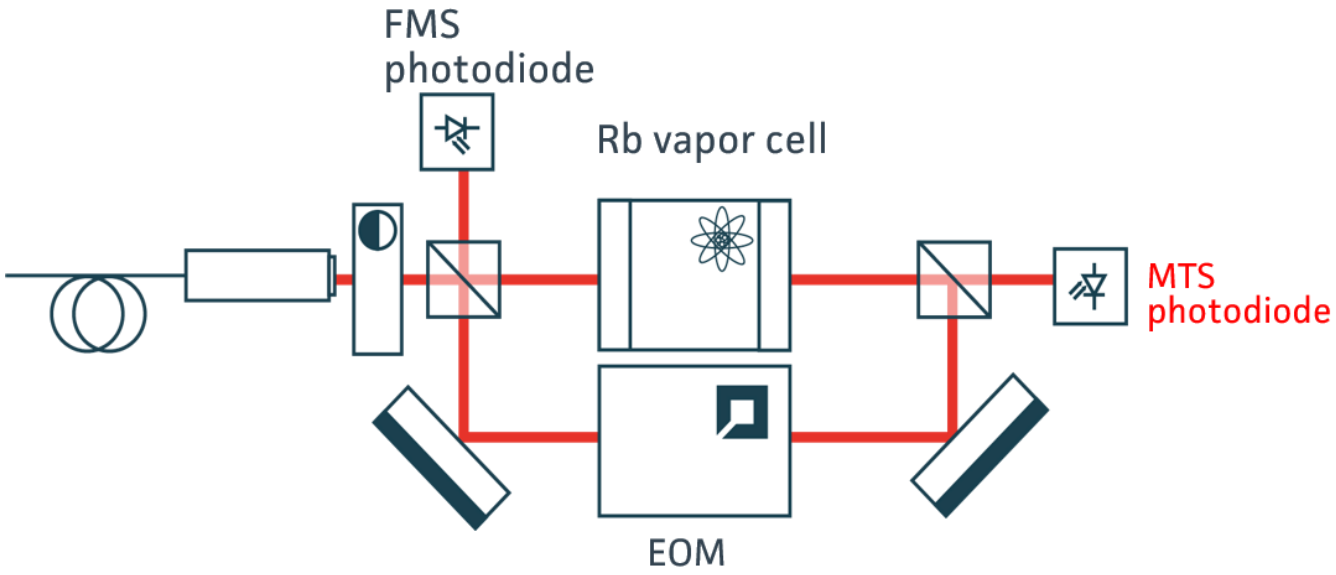
- Freely selectable work frequency up to 20GHz
- **Integrated Driver electronics**: signal generation & amplification, active feedback loops, I/O, etc.
- Fiber coupling: single mode, PM fibers with FC/APC | high stability | low insertion loss (typ. < 1.5dB @ 780nm)
- Interfaces: ext. **Clock** input (phase noise < -110dBc/Hz, MMCX), **RF on/off** (TTL, MMCX), **USB-C** (data I/O)
- Power supply: just +12VDC - **no additional driver elctronics required**

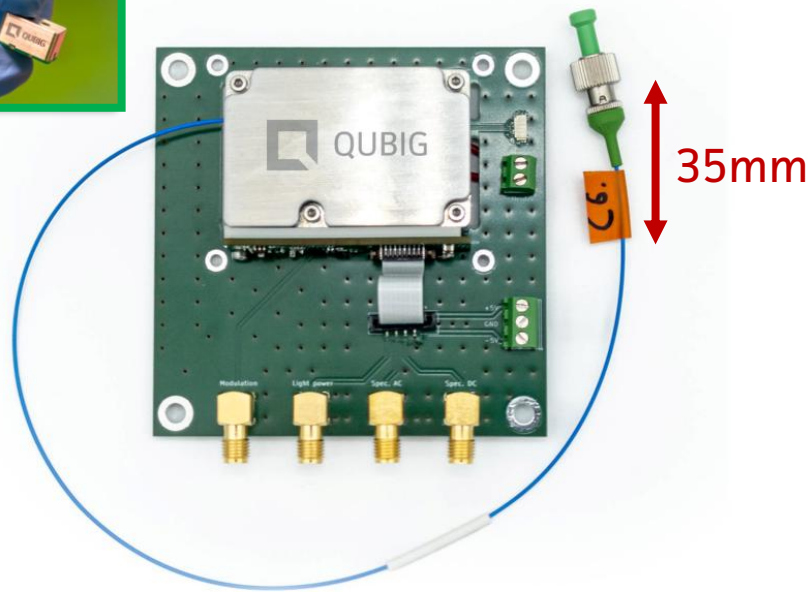




Execution examples

2. Laser Frequency Stabilization Module - LFS:
   - Frequency Modulation Spectroscopy (FMS)
   - Modulation Transfer Spectroscopy (MTS)





- Compact size
- stability: < 100kHz
- PDH, FMS, MTS, Cs, Rb…

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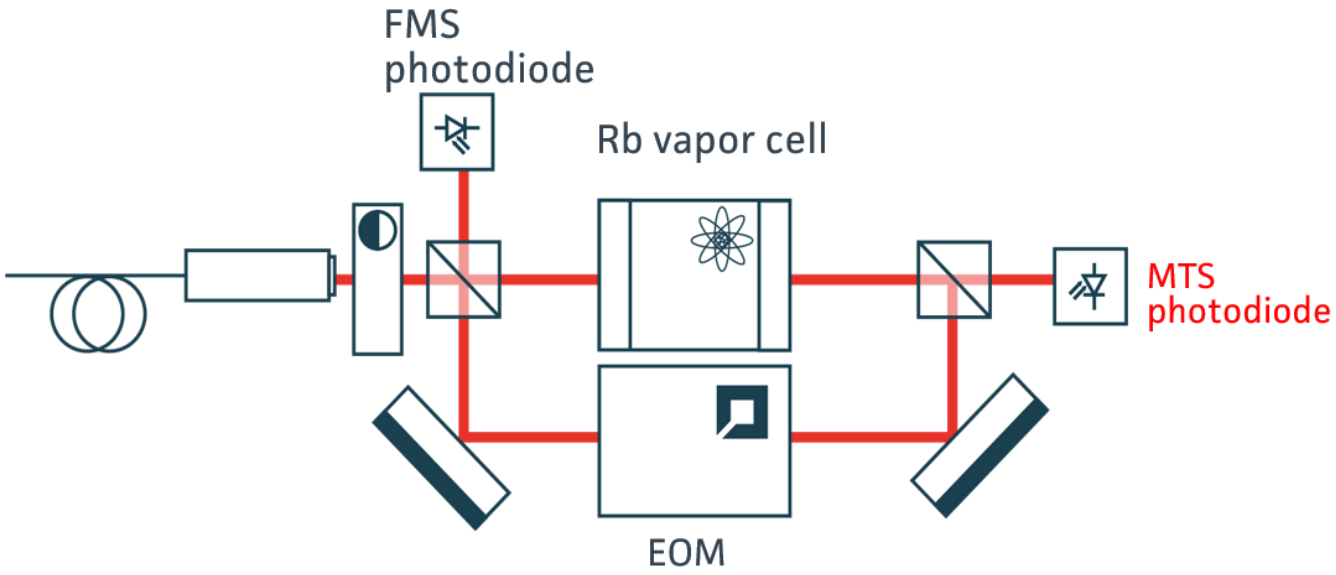

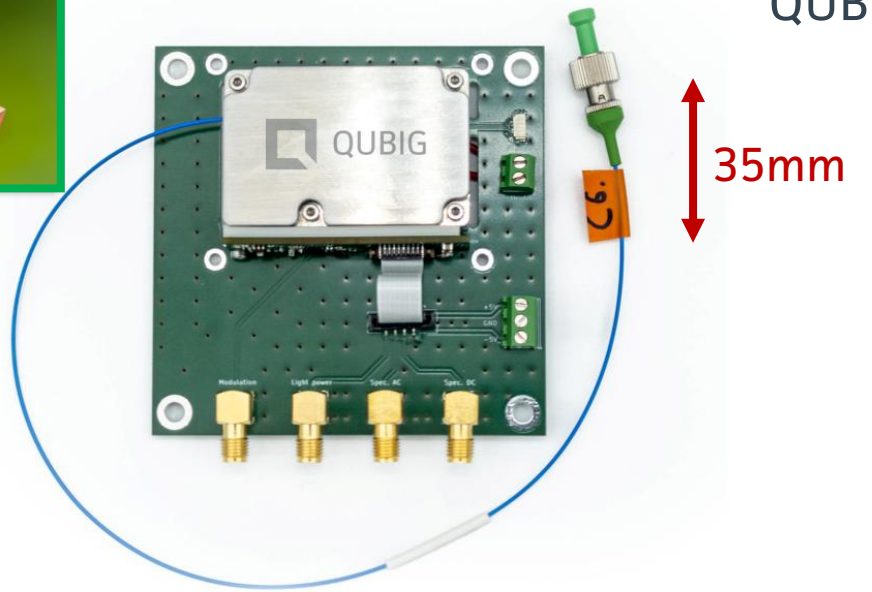

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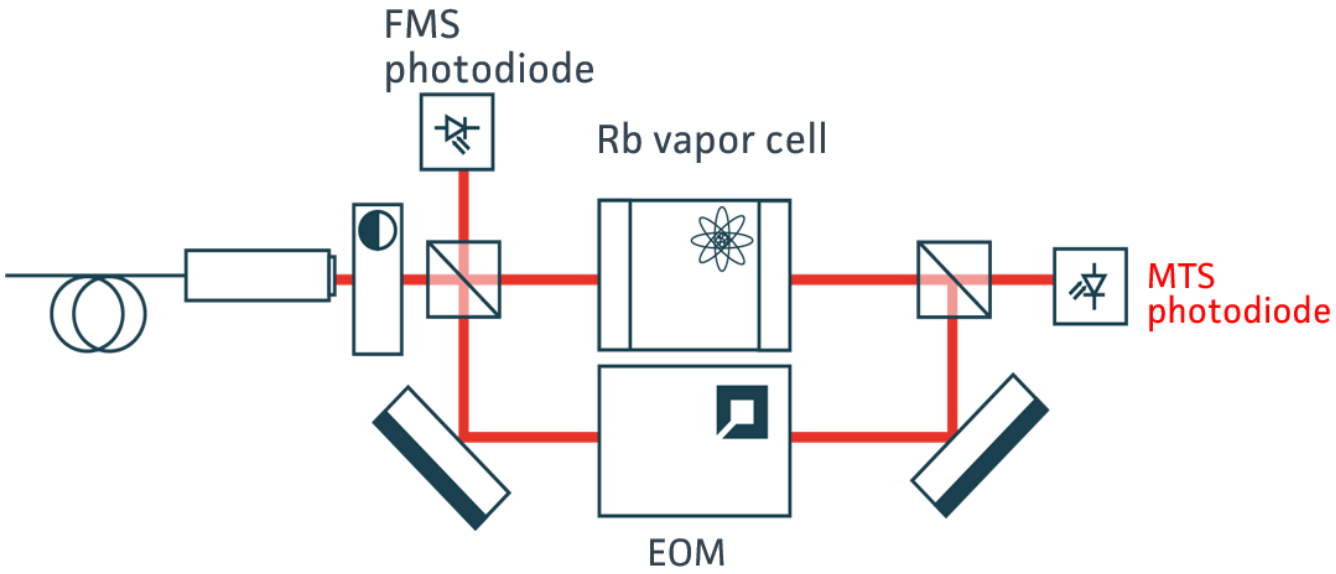

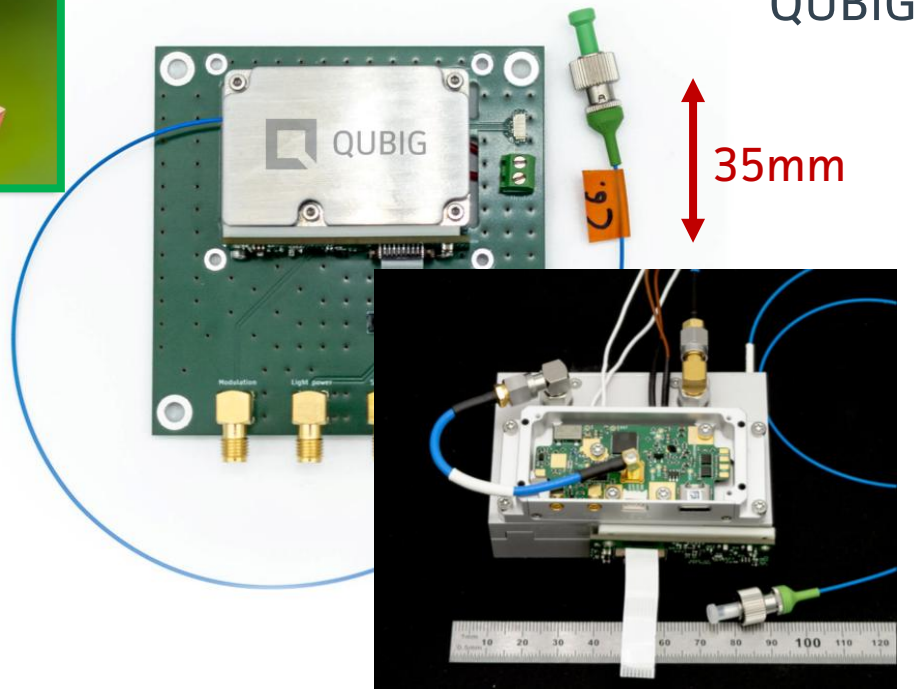

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Execution examples

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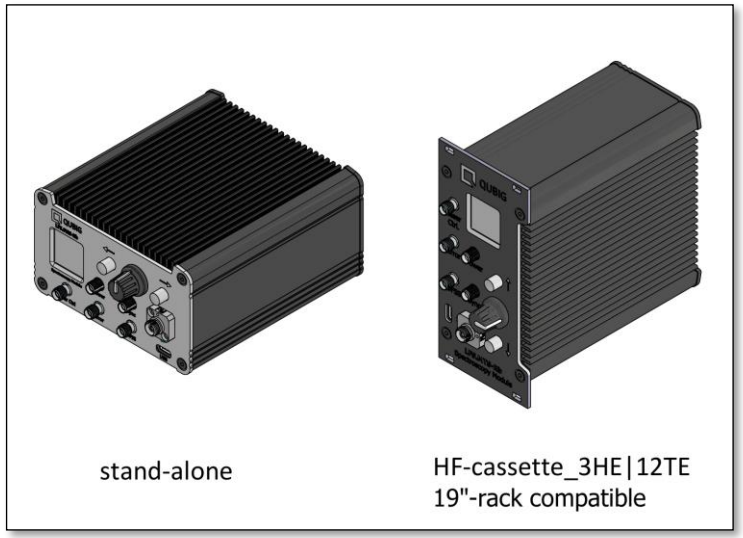
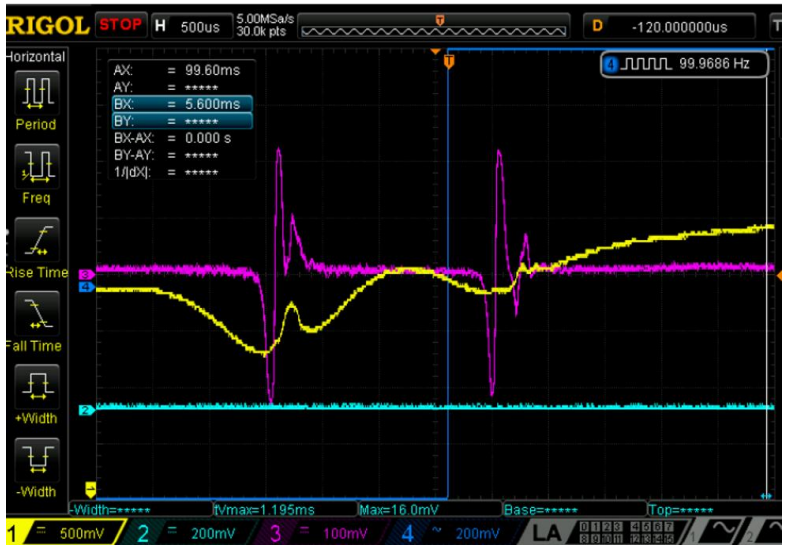




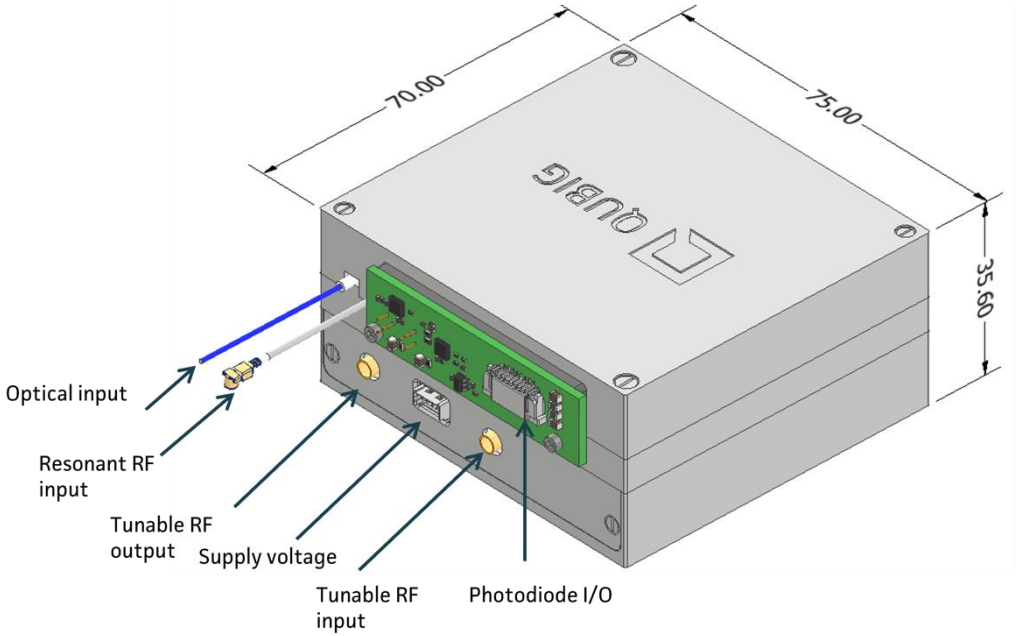
Electronics included

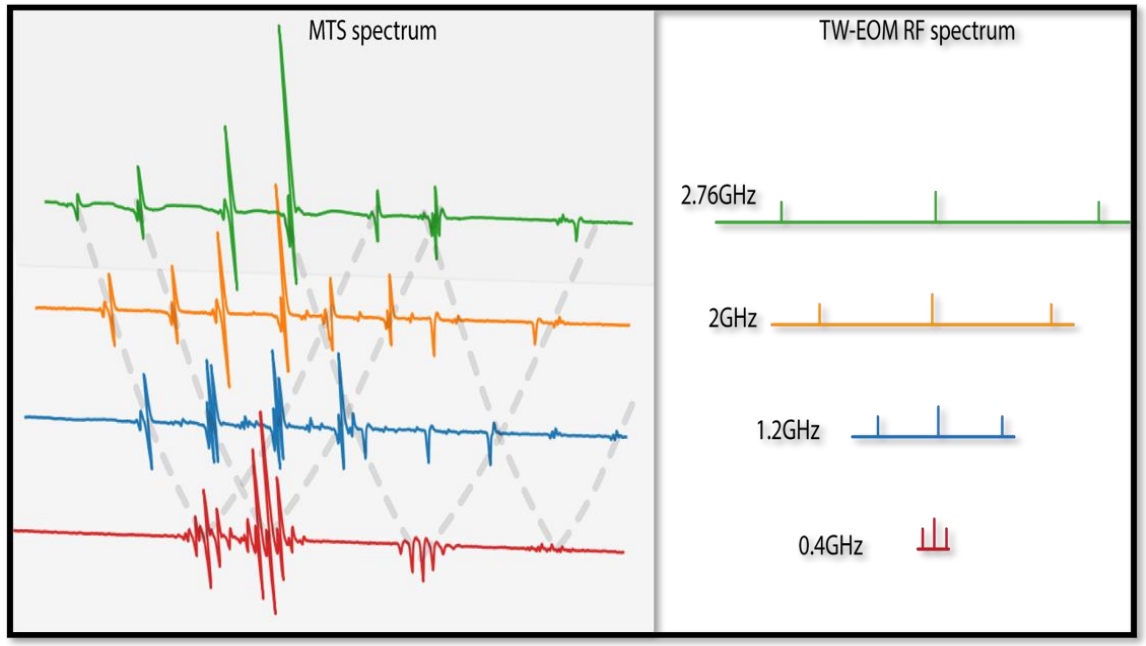
- Laser in, piezo ctrl signal out
- Error signal, DFSS and optical power monitoring
- Autolock feature
- 12V power supply

Execution examples

3. Dynamic Laser Frequency Stabilization Module: DLFS

- Allows for tuning of lock point up to 10 GHz





Execution examples: QuRIOUS

3. Compact intensity stabilized LFS module for Sr atoms

This module is the subject of the QuRIOUS project
We have two options

- Use atoms as reference (FMS/MTS module)
- Use a cavity as reference (PDH module)

Components for FMS/MTS module

1. SMD resonantly enhanced EOMs technology
2. Broadband EOMs to be integrated
3. Laser intensity control feature based on AOMs
4. Atomic references eg vapor cells or hollow-cathode lamps

Components for PDH module

1. SMD resonantly enhanced EOMs technology
2. Broadband EOMs to be integrated
3. Laser intensity control feature based on AOMs
4. Stable low expansion cavity with a small form factor

Deliverables List

Table 3.1 c Deliverables List

Scientific Deliverables

No.	Deliverable Title	Short description	WP	Lead Beneficiary	Type	Diss Level	Due Date
D2.10	Comb spectroscopy of hot Rb atoms	Demonstration of direct comb spectroscopy of hot Rb atoms in a breadboard model	WP2	MEN	R	SEN	M18
D3.12	Superradiance enhanced readout scheme	Generalized and optimized superradiance enhanced readout scheme	WP3	UIBK	R	SEN	M18
D1.3	Transportable clock validation	Validation of the transportable optical clock demonstrating stability better than $1x10^{-16}$	WP1	UoB	R	SEN	M24
D1.1	Compact vacuum chamber	Realisation of a compact vacuum chamber suitable for a transportable optical lattice clock operating at $5x10^{-18}$	WP1	UoB	R	SEN	M30
D1.8	Compact light modulators	Development of extremely compact broadband light modulators	WP1	QUBIG	R	SEN	M30
D2.1	CW cavity-enhanced	Demonstration of continuous loading of Sr atoms into ring cavity	WP2	UvA	R	SEN	M30
	system						
D1.9	Laser frequency reference for Sr atoms	Tunable laser frequency reference for Sr atoms (461nm) with integrated control electronics	WP1	QUBIG	R	SEN	M36
D2.6	Non-destructive detection	Implementation of improved non-destructive detection	WP2	CNRS-SYRTE	R	SEN	M36
D3.2	CW superradiant lasing of	Continuous superradiant lasing on Yb clock transition	WP3	CNRS-FE	R	SEN	M36
	transportability and field deployability	deployability					
D1.7	Integration of laser system into clock	Integration of laser system in experimental setup for coherent coupling of narrow atomic transitions	WP1	NKT	R	SEN	M42
D1.10	Demo light conditioning modules in clock	Usage demonstration of light conditioning modules in clock at UvA	WP1	QUBIG	R	SEN	M42
D2.3	Non-demolition readout	Non-demolition readout for zero-deadtime clock	WP2	UvA	R	SEN	M42
D2.5	generation of entangled states	Generation of entangled states with potentially lower uncertainty than coherent (classical) collective states	WP2	INRIM	R	SEN	M42

QUBIG

THANK YOU FOR YOUR ATTENTION!

Dr. Enrico Vogt | CEO QUBIG