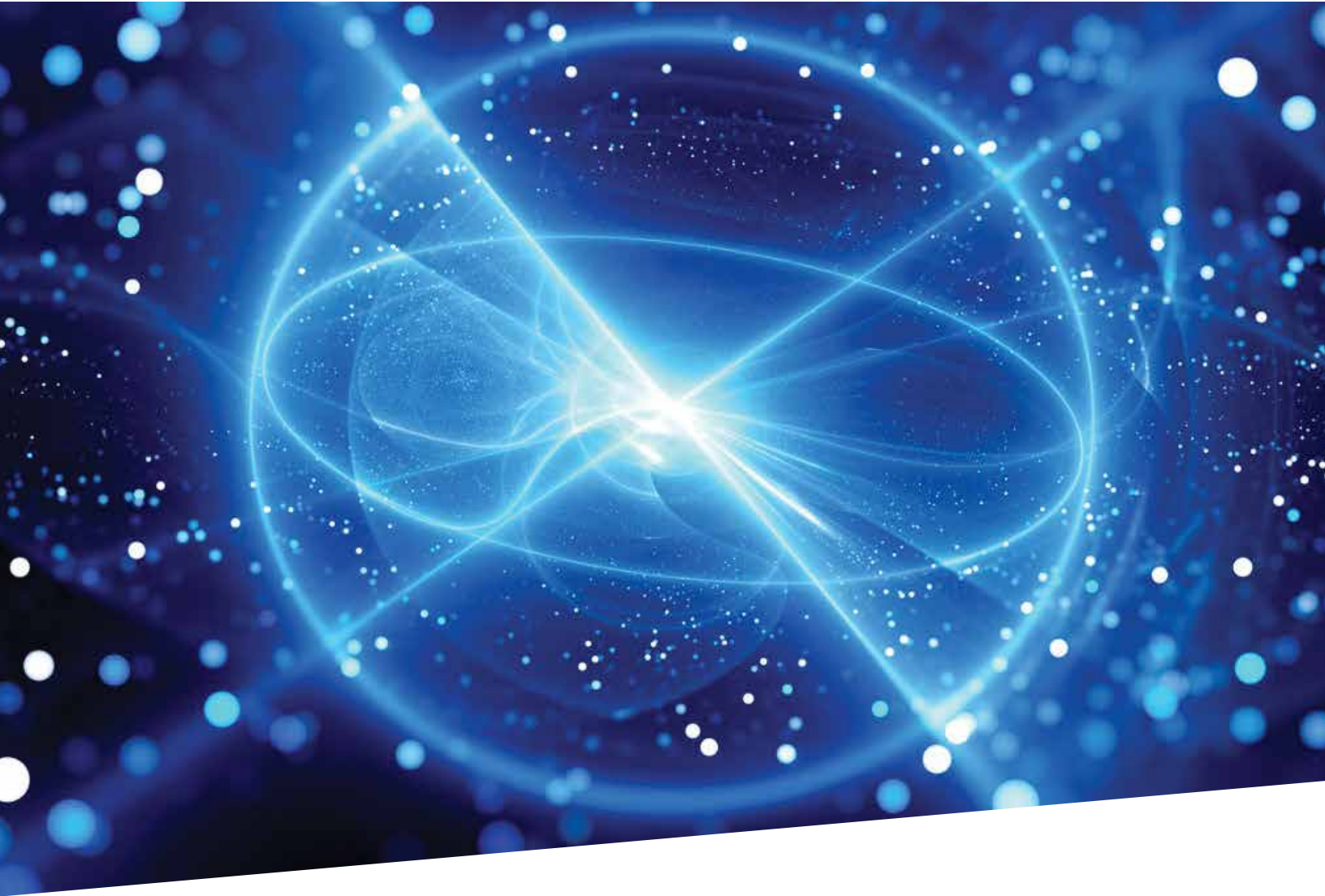




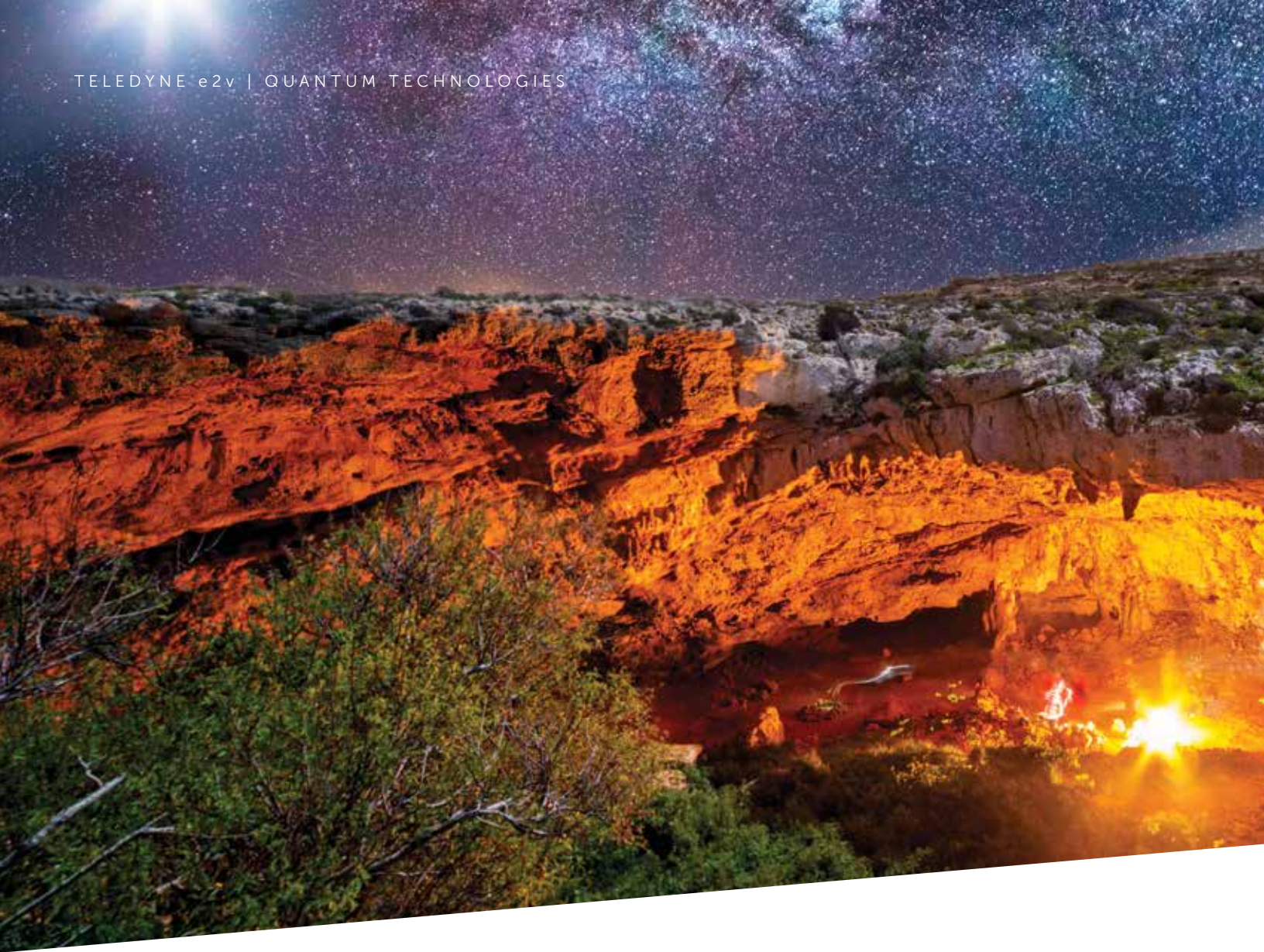
TELEDYNE e2V
Everywhereyoulook™

Part of the Teledyne Imaging Group



Quantum Technologies

Designing Solutions for the Impossible



Industrialising Quantum Technologies for Real-Life Applications

The engineering groups of Teledyne can draw on a remarkable portfolio of leading edge technology, unique expertise and decades of experience in sensing, signal generation and processing across a vast range of applications and industries. As a result Teledyne is well positioned to focus on the development and commercialisation of quantum technologies.

Beyond the microscopic level, quantum technologies concern an even smaller scale and seek to exploit the fundamental properties of individual atoms or photons. As the science behind these quantum properties has become better understood we are now close to being able to harness these effects. Quantum-based devices hold the promise of exciting advances in timing, sensing and measurement, electronics, imaging, computing and simulation, and communications.



Teledyne e2v

Teledyne e2v's innovations lead developments in healthcare, life sciences, space, transportation, defense and security, and industrial markets. Teledyne e2v's unique approach involves listening to the application challenges of customers and partnering with them to provide innovative standard, semi-custom or fully-custom imaging solutions, bringing increased value to their systems. In combination with its sister companies, Teledyne DALSA and Teledyne Imaging Sensors, three imaging powerhouses together represent a new paradigm in the delivery of innovative imaging solutions built on unrivalled expertise and a deep technological heritage that includes capabilities across the spectrum, from infrared to x-ray imaging.

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Quantum Time and Frequency Solutions

Taking Timing and Synchronisation to Another Level

Precision Timing and Synchronisation is ubiquitous, and integral to our daily lives. In today's world, time is typically received from Global Navigation Satellite Systems (GNSS), however, the vulnerabilities of GNSS to natural terrain interference, along with accidental or malicious air/ground-based jamming and spoofing is widespread.

Teledyne e2v, in conjunction with NPL, is developing a family of low Size, Weight and Power/Cost (SWAP-C), environmentally rugged, caesium frequency standard atomic clocks.

These clocks have a wide range of applications, including as a holdover backup to GNSS provided timing, and provision of local/distributed timing and synchronisation capabilities in GNSS denied environments.

The **MINAC** range of atomic clocks will be available in a variety of form factors and interfacing options, including the ability to synchronise to an external timing source, and the option of multiple frequency outputs.

The MINAC atomic clocks are designed, manufactured and all key components sourced in the UK, and therefore free of ITAR or EAR restrictions.

KEY BENEFITS & FEATURES

- » High accuracy/stability caesium reference standard
- » Developed with NPL, who define and disseminate the UK's national time scale (UTC)
- » 1PPS input for synchronisation to an external timing source
- » 1PPS & 10 MHz outputs (other frequencies available as an option)
- » Wide range of environmental operating conditions
- » Low SWAP-C
- » RS-422 or USB interface for monitoring & control

APPLICATIONS

- » Aerospace & Defence — C4I, Comms Systems, ECM, Situational Awareness & Radar
- » Air Traffic Management
- » Autonomous Systems
- » Banking/Financial Markets
- » Critical National Infrastructure (CNI) Protection
- » Cyber Security
- » Energy Distribution
- » Fixed & Mobile Communications Networks (including 5G)
- » Oil & Gas Exploration
- » Science & Technology
- » Transport Infrastructure Networks
- » Utilities



Quantum for Space

Taking Quantum to Another World

Teledyne e2v has over 30 years of heritage, putting advanced and technically demanding instrumentation into space. We have sent instruments to every planet in the solar system, and have never had a failed mission in space.

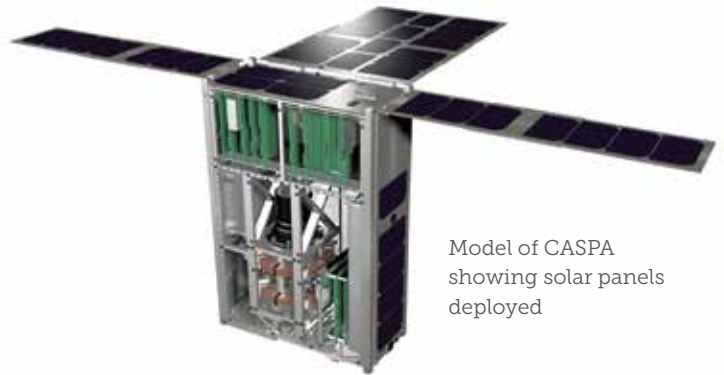
Over the last three years, Teledyne e2v have been leading Europe's efforts to industrialise quantum systems for space. Quantum systems in space offer a new generation of extremely sensitive sensors for measuring gravity, acceleration, rotation and time. Gravity sensors can be used to discover and monitor Earth resources.

CASPA (Cold Atom Space PAYload) is Teledyne e2v's flagship quantum space programme. This 6U CubeSat is a fully automated unit that will generate and test cold atom systems in space. As with all of our space systems, it has been through the rigorous modelling and test processes that are needed to make sure that it works. CASPA will be ready from March 2019, and we are actively exploring viable opportunities for launch as well as opportunities for larger instruments.

QUANTUM SENSING IN SPACE

With our expertise in both space and quantum technology we are exploring the design and build of a space based gravity sensor with a range of applications including:

- » **Earth Science:** Monitoring ice sheets melting, aquifer depletion & sea level
- » **Commercial:** Water reserves for mining, oil & gas exploration & geothermal energy sources
- » **Non-gravity applications:** Inertial navigation, timing references (atomic clocks) & attitude detection



Model of CASPA showing solar panels deployed

CASPA FEATURES

- » Payload weighs <4kg
- » Compact: 4U autonomous Magneto Optical Trap (MOT) system
- » Engineered for space

PHYSICS PACKAGE

- » Ruggedized miniature vacuum chamber
- » Pressure in chamber $\sim 10^{-11}$ mbar
- » Ready to generate MOTs
- » Fitted with atom dispenser
- » Portable

EXPERTISE

- » Space proven > 5,000 instrument-years in orbit
- » Concept development through to full systems design
- » Supply at component to full system level
- » Custom UHV system design & manufacture
- » Low SWAP
- » Complete design, assembly, integration & test capability for space

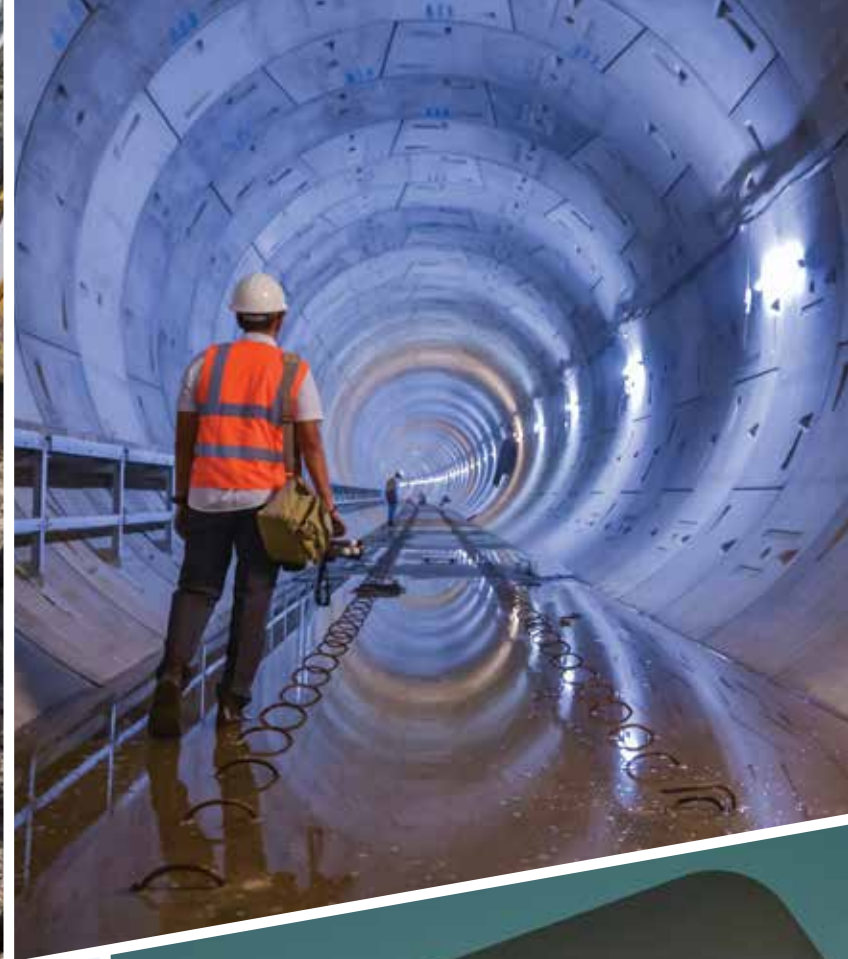


Assembled engineering model of CASPA



In Partnership with

UNIVERSITY OF
BIRMINGHAM



Quantum Gravity Sensors

Seeing the Invisible

Gravity is emerging as a new frontier in sensing, bringing the ability to passively detect objects and voids, through difficult to penetrate materials such as soil, rock, lead and water.

Teledyne e2v is developing a quantum gravity gradient sensor that is based on cold atom interferometry technology. These technologies are inherently referenced to the properties of an atom and therefore possess an unparalleled stability. Due to noise rejection, brought about by the gradient measurement, the measurement speed can be orders of magnitude faster than conventional methods.

These devices are exploiting Teledyne e2v's long heritage in advanced engineering to enable field measurements and in other hostile environments.

KEY BENEFITS & FEATURES

- » Highly penetrating sensing capability
- » Sensitive to changes in nearby density or mass
- » Gravity gradient sensor for advanced environmental resilience, & faster measurement time
- » Engineered for robustness & environmental stability

APPLICATIONS

Detect natural or artificial variations in ground conditions, revealing:

- » Tunnel workings
- » Sink holes & other voids
- » Oil, gas & water mixtures in oil fields
- » Heavy materials, such as radioactive substances or lead
- » Certain geologies
- » Changes in Earth-scale masses— ocean currents, volcanology, glaciers etc.
- » Navigation



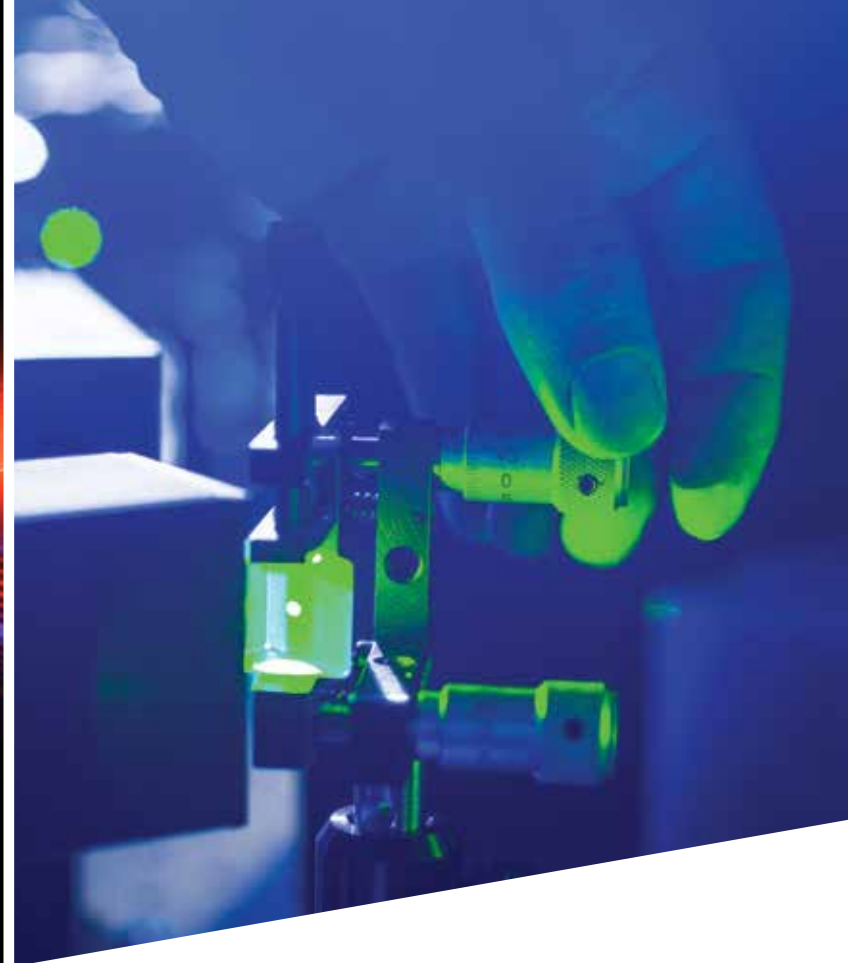
First generation quantum gravity gradient sensor

In Partnership with



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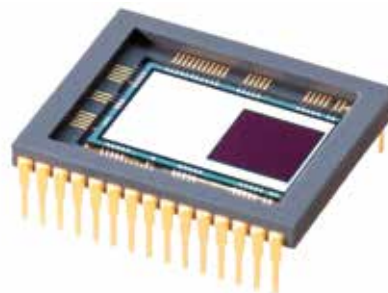


Quantum Communication and Imaging Sensors

Volume-Manufacturing of Imaging and Photon Counting

Teledyne is the world's largest manufacturer of imaging sensors for scientific research across both CCD and CMOS technology.

We are currently investing in new types of imaging and photon counting sensors for QKD and other applications.



Quantum Components and Services

Quantum Research Made Easier

Teledyne e2v have developed a family of products and services that help you get your quantum lab up and running quicker and more efficiently — in weeks rather than years. These include miniature vacuum systems and control electronics. All of our devices are designed to take the hassle out of quantum research, helping you concentrate on cutting-edge science.

We supply standard components and subsystems as well as bespoke devices. All of our devices are made in the UK and are ITAR free.

BENEFITS & FEATURES

- » Industrial & miniaturised vacuum systems, electronics & other components, designed to take the hassle out of your research
- » Develop a cold atom lab in weeks, not years
- » Free up the time of your PhD students & post-docs for the research that really matters

MINIATURE VACUUM SYSTEMS

- » Small volume <600mL
- » High numerical aperture, 2 inch BK7 window with anti-reflection coating options at a variety of wavelengths
- » Simple glass to metal sealed window design for robust operation
- » Miniature ion pump, suitable to UHV/ 10^{-11} mBar pressure
- » Very high window flatness < $\lambda/10$ to maintain low optical wave-front distortion
- » Rubidium dispenser supplied as standard, other species available on request

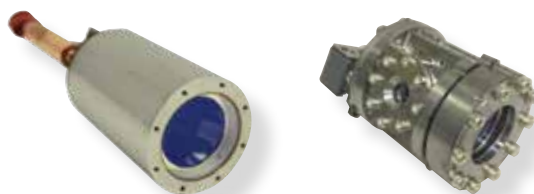


Control Electronics

- » Additional options include:
 - » Optical prism package for easy production of cold atoms
 - » Side windows
 - » RF/DC Electrical feedthroughs for atom/ion chips

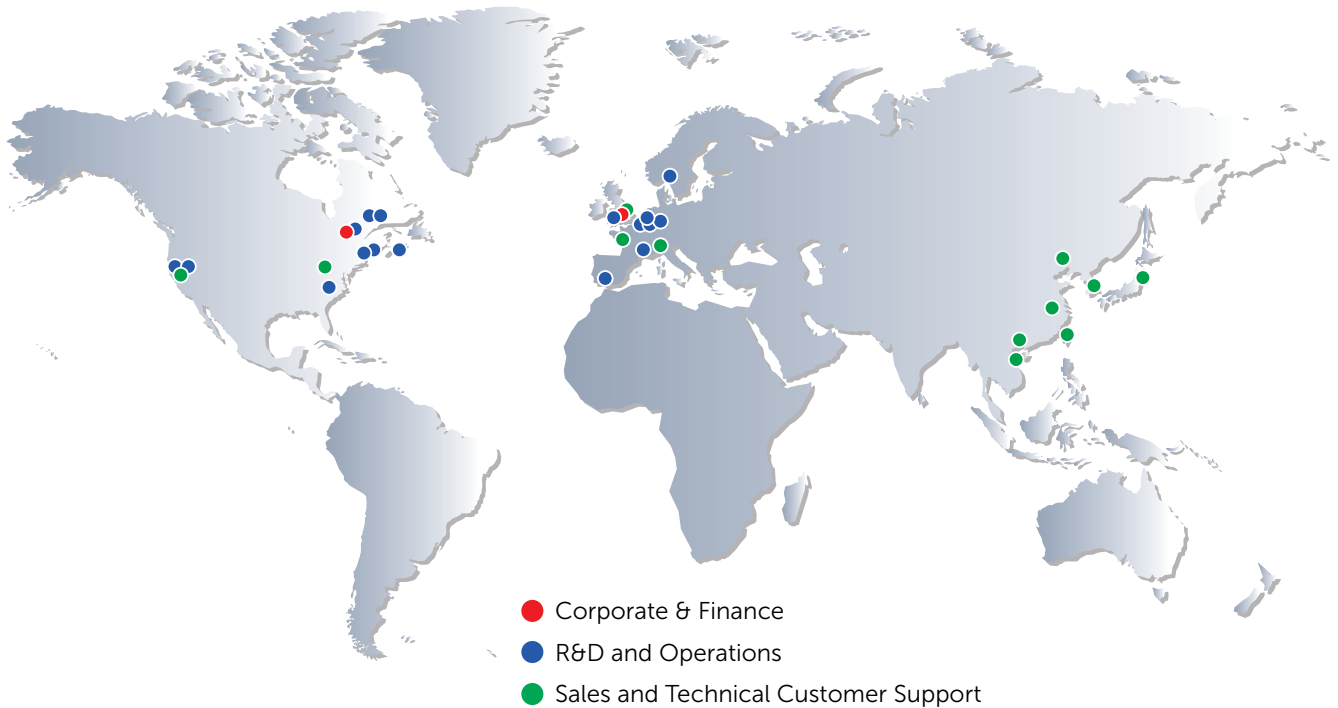
CONTROL ELECTRONICS

- » High performance FPGA architecture
- » Precision DDS waveform generation & timing control up to 5 GHz
- » Buffered / isolated high speed I/O
- » Flexible analogue & digital channels
- » Reconfigurable & upgradable through software updates
- » LabVIEW & Simulink custom drivers provided
- » USB device support — E.g. Laser Temperature controller
- » Future PID support (for frequency locking)
- » Control all functionality via Ethernet or USB
- » In-built security
- » Uninterruptable power supply (UPS) support
- » Expandable



Miniature vacuum chambers for use in laboratory (left) or space environments (right)

Everywhere You Look



Office Locations

We have offices across North America, Europe, and Asia. Find details at:

teledyne-e2v.com/about-us/e2v-offices

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