OSCILLOQUARTZ
An ADVA Optical Networking Company

Optical cesium beam clock for ePRTC telecom applications

Michaud Alain, Director R&D and PLM Time & Frequency, Oscilloquartz

Dr. Patrick Berthoud, Chief Scientist Time & Frequency, Oscilloquartz

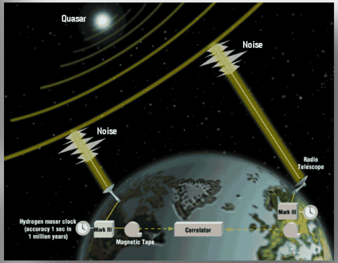
Workshop on Synchronization and Timing Systems, WSTS 2017, San Jose CA, USA, April 2017

Outline

- Motivation and applications
- Clock sub-systems development
- Clock integration results
- Conclusion and acknowledgment

Identified markets

- **Telecommunication** network reference
  - Telecom operators, railways, utilities, …
- **Science**
  - Astronomy, nuclear and quantum physics, …
- **Metrology**
  - Time scale, fund. units measurement
- **Professional mobile radio**
  - Emergency, fire, police
- **Defense**
  - Secured telecom, inertial navigation
- **Space** (on-board and ground segments)
  - Satellite mission tracking, GNSS systems




OSCILLOQUARTZ
An ADVA Optical Networking Company

Available Cs clock commercial products

- **Long life magnetic** Cs clock
  - Stability : **2.7^{E}-11 $\tau^{-1/2}$, floor = 5^{E}-14**
  - Lifetime : **10 years**
  - Availability : commercial product
- **High performance magnetic** Cs clock
  - Stability : **8.5^{E}-12 $\tau^{-1/2}$, floor = 1^{E}-14**
  - Lifetime : **5 years**
  - Availability : commercial product
- **High performance and long life optical** Cs clock
  - Stability : **3.0^{E}-12 $\tau^{-1/2}$, floor = 5^{E}-15**
  - Lifetime : **10 years**
  - Availability : coming soon

Motivation for an Optical Cs clock

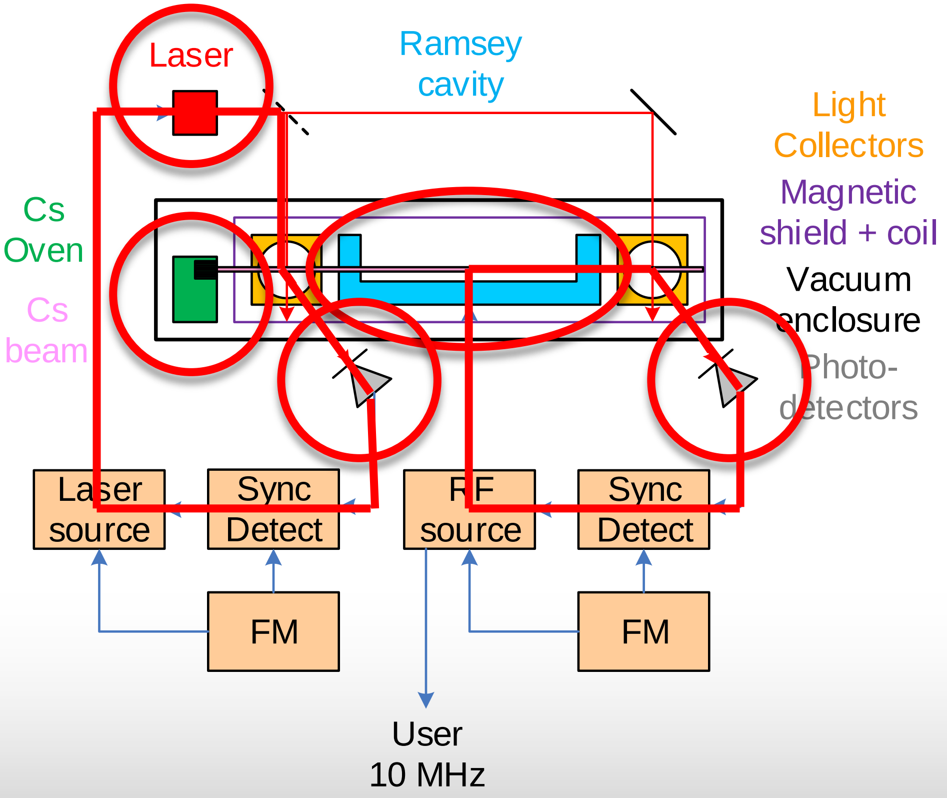
- **Improved performance (short and long-term stability)** for:
  - Metrology and time scales
  - Science (long-term stability of fundamental constants)
  - Inertial navigation (sub-marine, GNSS)
  - Telecom (ePRTC = enhanced Primary Reference Time Clock)

- **No compromise between lifetime and performance**
  - Low temperature operation of the Cs oven
  - Standard vacuum pumping capacity
  - Large increase of the Cs beam flux by laser optical pumping

Outline

- Motivation and applications
- Clock sub-systems development
- Clock integration results
- Conclusion and acknowledgment

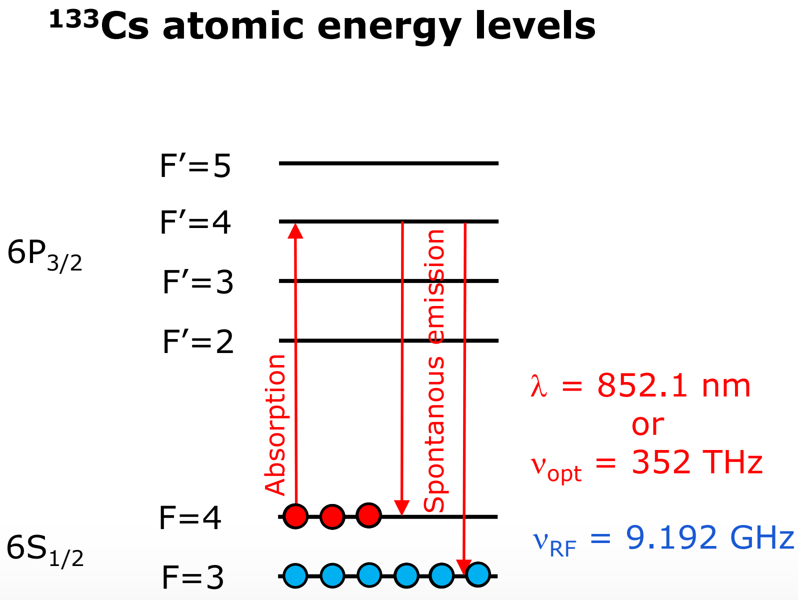
Optical Cesium clock architecture



- **Cs beam** generated in the Cs oven (vacuum operation)
- Cs atoms state selection by **laser**
- Cs clock frequency probing (9.192 GHz) in the **Ramsey cavity**
- Atoms detection and amplification by **photodetector** (air)
- Laser and RF sources servo loops using **atomic signals**

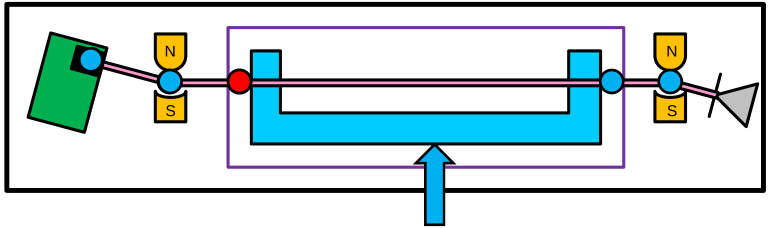
OSCILLOQUARTZ
An ADVA Optical Networking Company

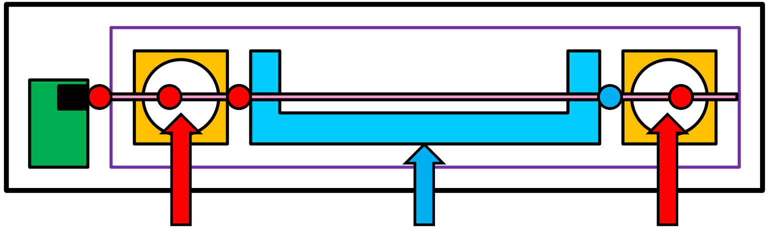
Optical Pumping vs Magnetic Selection



- Atomic energy states
  - **Ground states** (F=3,4) equally populated
  - **Excited states** (F'=2,3,4,5) empty
- Switching between ground states F by **RF interaction 9.192 GHz** without atomic selection (no useful differential signal)
- Atomic preparation by **magnetic deflection** (loss of atoms)
- Atomic preparation by **optical pumping** with laser tuned to F=4 →F'=4 transition (gain of atoms)

Cesium clock: Magnetic vs. Optical

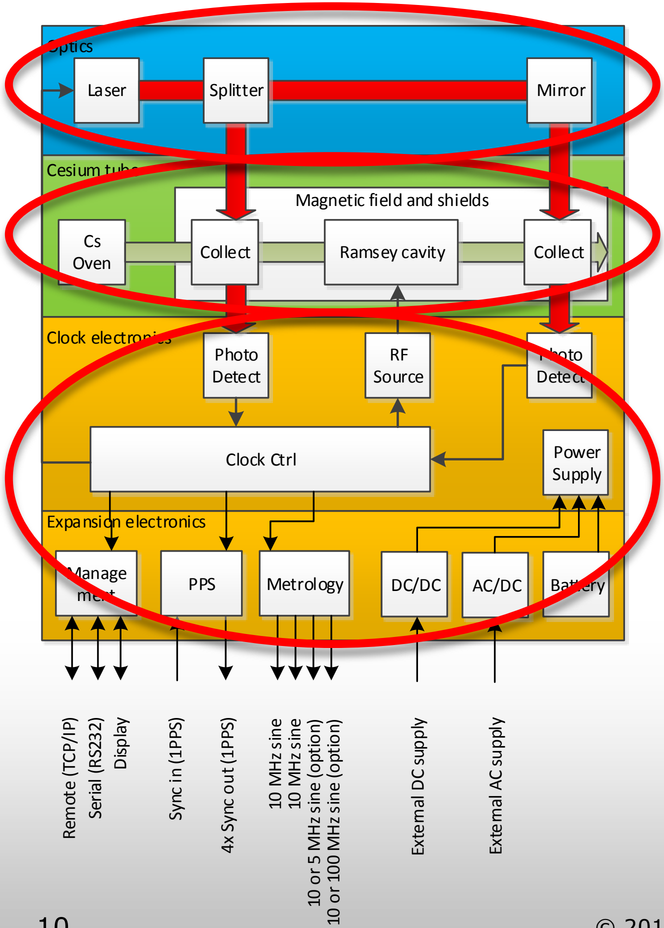




- Weak flux
  - Strong **velocity selection** (bent)
  - Magnetic deflection (**atoms kicked off**)
- Typical performances:
  - **2.7^{E}-11** $\tau^{-1/2}$
  - 10 years
- **Stringent** alignment (bent beam)
- Critical component **under vacuum** (electron multiplier)

- High flux (x100)
  - **No velocity selection** (straight)
  - Optical pumping (**atoms reused**)
- Typical performances:
  - **3^{E}-12** $\tau^{-1/2}$
  - 10 years
- **Relaxed** alignment (straight beam)
- Critical component **outside vacuum** (laser)

Clock functional bloc diagram



- Cs tube
  - Generate **Cs atomic beam** in ultra high vacuum enclosure
- Optics
  - Generate **2 optical beams** from 1 **single frequency laser** (no acousto-optic modulator)
- Electronics
  - **Cs core electronics** for driving the Optics and the Cs tube
  - **External modules** for power supplies, management, signals I/O

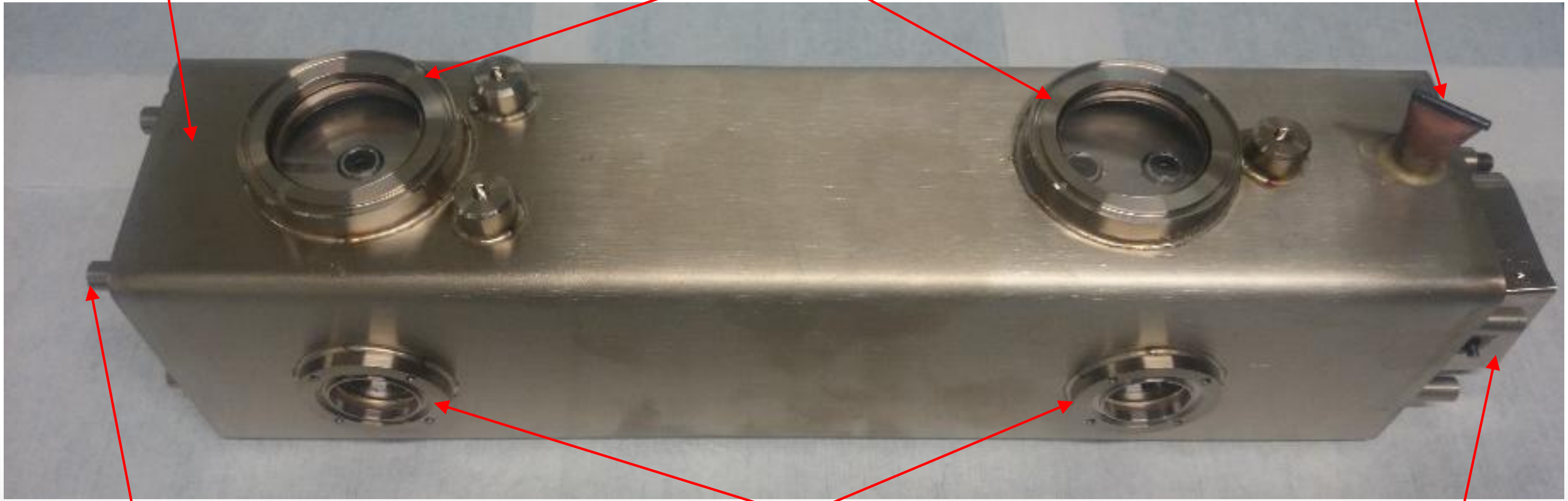
OSCILLOQUARTZ An ADVA Optical Networking Company

Cs tube sub-assembly

Vacuum enclosure

Laser viewports

Pinch-off tube



Tube fixation

Photo-detectors viewports

Ion pump

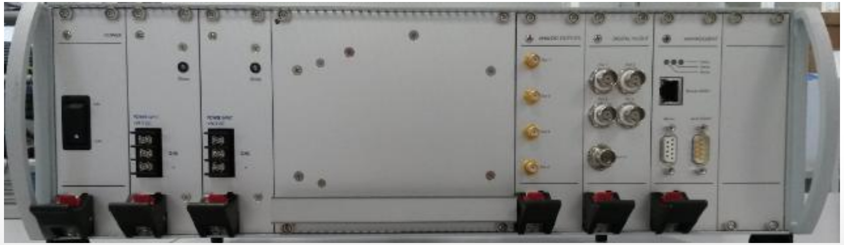
OSCILLOQUARTZ
An ADVA Optical Networking Company

Optics sub-assembly

- Optical sub-system
  - **Free space** propagation
  - **Single optical frequency** (no acousto-optic modulator)
  - **Redundant laser** modules (2)
  - **No optical isolator**
  - Ambient light protection by cover and sealing (not shown here)
- Laser module
  - **DFB 852 nm**, TO3 package
  - **Narrow linewidth** (<1MHz)

OSCILLOQUARTZ
An ADVA Optical Networking Company

Typical System Integration view

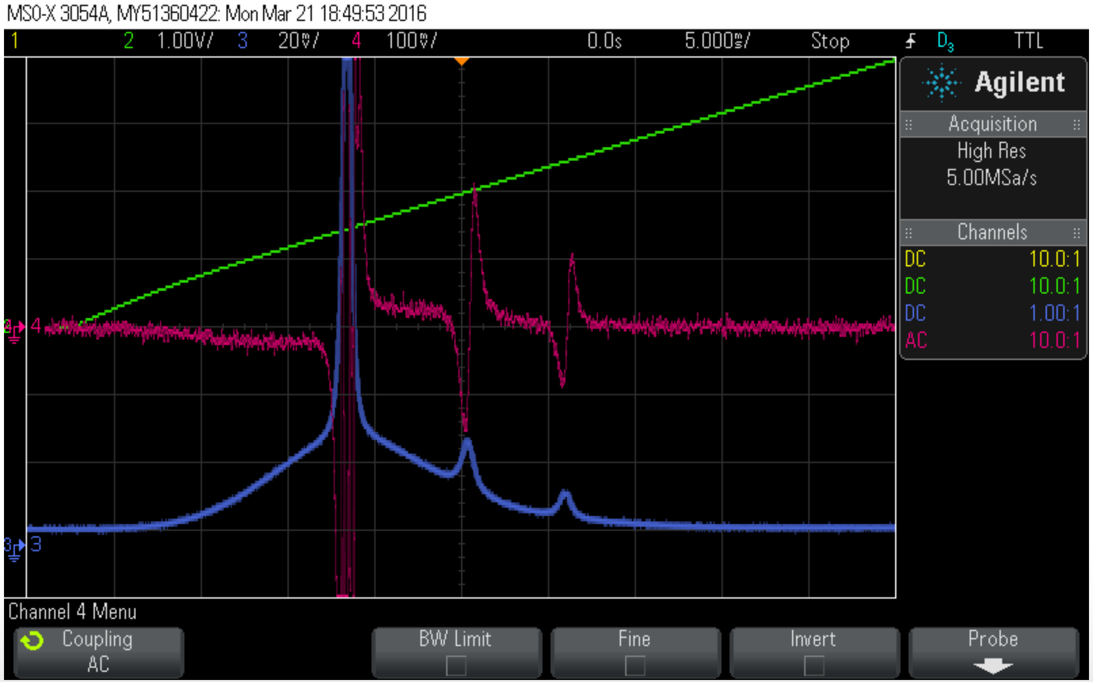


OSCILLOQUARTZ
An ADVA Optical Networking Company

Outline

- Motivation and applications
- Clock sub-systems development
- Clock integration results
- Conclusion and acknowledgment

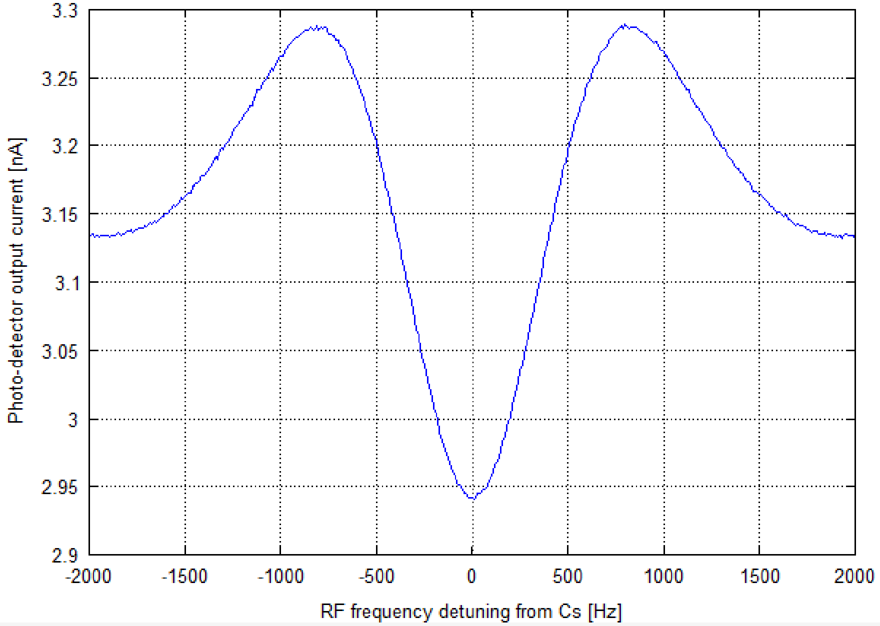
Laser frequency lock



- Green curve: **laser current** (ramp + AM modulation)
- Blue curve: modulated atomic **fluorescence zone A** (before Ramsey cavity)
- Pink curve: **demodulated** atomic fluorescence in zone A
- **Automatic** laser line **identification** and laser **lock** (micro-controller)

OSCILLOQUARTZ
An ADVA Optical Networking Company

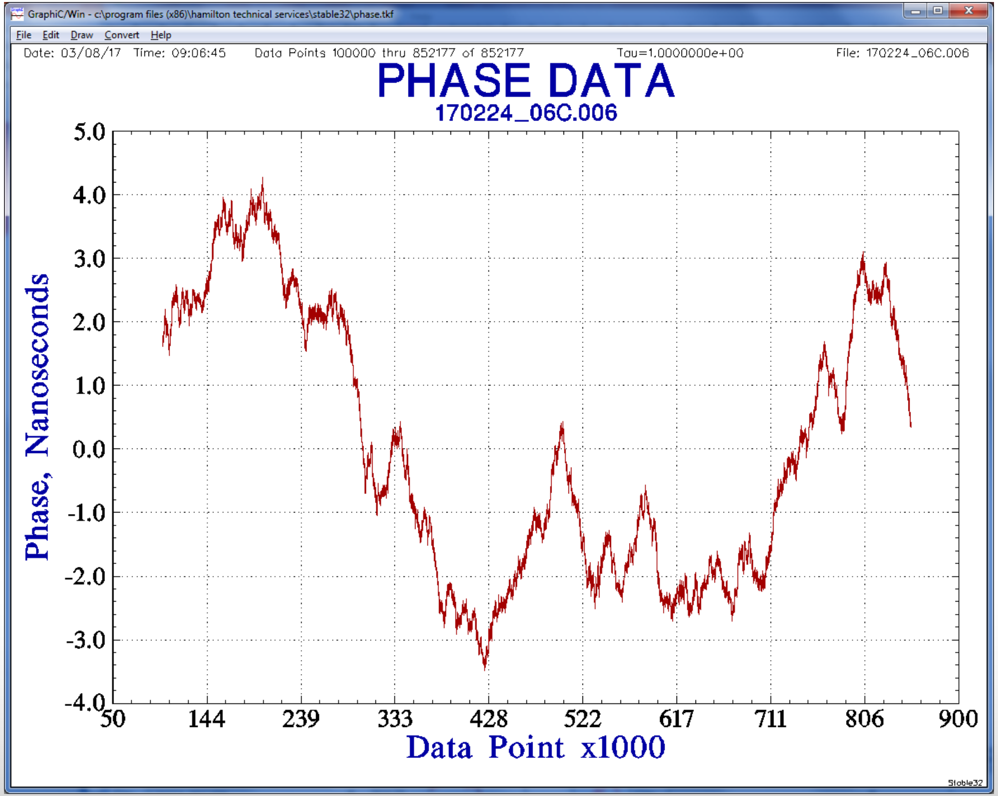
Ramsey fringes



- **Dark fringe** behavior (minimum at resonance)
- **Central fringe**
  - Amplitude = **350 pA**
  - Linewidth = **730 Hz** (FWHM)

OSCILLOQUARTZ
An ADVA Optical Networking Company

Time Interval Error



- Recording of 10 MHz phase output vs H-maser reference clock
- Holdover mode
- Maximum Time Interval Error (Peak-to-Peak): **7 ns over 9 days**
- **No** evidence of **frequency drift**
- Ready to be used for **ePRTC**

OSCILLOQUARTZ
An ADVA Optical Networking Company

Outline

- Motivation and applications
- Clock sub-systems development
- Clock integration results
- Conclusion and acknowledgment

Conclusion and acknowledgment

- Development of an **industrial Optical Cesium Clock** for ground applications
- Design using **laser** instead of magnets
  - **Better performance**
  - **No compromise on Cs tube lifetime**
- MTIE measured in holdover: **7 ns over 9 days**
- Ready to be used for **ePRTC**

- **Acknowledgment**: this work is being supported by the **European Space Agency**

OSCILLOQUARTZ
An ADVA Optical Networking Company

OSCILLOQUARTZ

An ADVA Optical Networking Company

Thank You

IMPORTANT NOTICE

ADVA Optical Networking is the exclusive owner or licensee of the content, material, and information in this presentation. Any reproduction, publication or reprint, in whole or in part, is strictly prohibited.

The information in this presentation may not be accurate, complete or up to date, and is provided without warranties or representations of any kind, either express or implied. ADVA Optical Networking shall not be responsible for and disclaims any liability for any loss or damages, including without limitation, direct, indirect, incidental, consequential and special damages,
alleged to have been caused by or in connection with using and/or relying on the information contained in this presentation.