Atomtronics

Internet electronics and photonics

Quantum computers and atomic clocks

Atomtronic concepts and devices

Image: E. Edwards, JQI
Internet

Is it just a flash in the pan . . .

. . . or could it be REALLY BIG, someday?
Internet

Is it just a flash in the pan . . .

. . .or could it be REALLY BIG, someday?

**ARPANET 1980**
Computers connected by telephone lines and satellite links

*Image: E. Edwards, JQI*
Internet

Is it just a flash in the pan . . .

. . . or could it be REALLY BIG, someday?

ARPANET 1980
Computers connected by telephone lines and satellite links
Internet

Is it just a flash in the pan . . .

. . . or could it be REALLY BIG, someday?

ARPANET 1980

Computers connected by telephone lines and satellite links

A printed directory of the 4,000 users
Internet

Is it just a flash in the pan . . .

. . .or could it be REALLY BIG, someday?

ARPANET 1980

Computers connected by telephone lines and satellite links
Internet

Is it just a flash in the pan . . .

. . . or could it be REALLY BIG, someday?

ARPANET 1980
Computers connected by telephone lines and satellite links
Internet

Is it just a flash in the pan . . .

. . .or could it be REALLY BIG, someday?

ARPANET 1980
Computers connected by telephone lines and satellite links

Enabling technology of electronics:
The Transistor
Bell Laboratories 1947

ARPANET GEOGRAPHIC MAP, OCTOBER 1980

NOTE: THIS MAP DOES NOT SHOW ARPA’S EXPERIMENTAL SATELLITE CONNECTIONS
NAMES SHOWN ARE IMP NAMES, NOT (NECESSARILY) HOST NAMES
Internet today

The Electronic Age
Internet today

Vast global flow of data requires high-speed optical communication: *Photonics*

Global reach requires precise network synchronization: *Atomic clocks*

2 billion smartphones worldwide; *each contains ~ 1 billion transistors = 10^{18}*

Image: TeleGeography
Internet today

1.3 million kilometers of submarine fibre-optic cables

2 billion smartphones worldwide; each contains \( \sim 1 \text{ billion transistors} = 10^{18} \)

The Electronic Age

Vast global flow of data requires high-speed optical communication: Photonics

Global reach requires precise network synchronization: Atomic clocks

Image: TeleGeography

Atomic clock timing
Vast global flow of data requires high-speed optical communication: Photonics

Global reach requires precise network synchronization: Atomic clocks
Vast global flow of data requires high-speed optical communication: **Photonics**

Global reach requires precise network synchronization: **Atomic clocks**

**Constellations of Atomic Clocks Aboard Earth Satellites**

Global Navigation Satellite Systems (GNSS):
- Global Positioning System GPS (USA)
- GLONASS (Russia)
- Galileo (Europe)

Regional coverage:
- BeiDou (China)
- NAVIC (India)
Atomic Clocks
The original atomtronic devices
Atom – most precise oscillator
– sets the standard of time

Global reach requires precise network synchronization:
Atomic clocks

The clock in the control room of the Laser
Interferometer
Gravitational-Wave
Observatory at Hanford,
WA, displays PST and
GPS Time (in seconds).
Shown on a GPS-enabled smartphone.
Atomic Clocks

The original atomtronic devices

Global reach requires precise network synchronization: Atomic clocks

Get your own atomic clock on eBay for about a hundred bucks (plus shipping)
Quantum Computers and Atomic Clocks

Quantum Computers and Atomic Clocks

D. J. WINELAND, J. C. BERQUIST, J. J. BILLINGER, B. E. DURKLING, AND W. M. ITANO
NIST, Time and Frequency Division, Boulder, CO, 80305-3338, USA
david.wineland@boulder.nist.gov

Recent developments in quantum information processing may be applicable to future atomic clocks. In this paper we discuss two potential applications to trapped ion frequency standards. In the first, quantum-mechanical entanglement can provide a resource for increased measurement precision in spectroscopy. In the second, we indicate how a simultaneously trapped auxiliary ion species can be used to provide cooling and as a quantum measuring device this could be used to increase the number of ion species than can be used as frequency standards.

1 Introduction

The subject of quantum information processing (QIP) has recently received attention because quantum computers could provide a substantial speedup in factoring numbers and in searching databases. In spite of considerable interest in these goals, it is generally agreed that a quantum computer capable of useful factorization or searching (beyond what is possible with classical computers) will, at best, be extremely difficult to achieve in any currently proposed implementation. Nevertheless, it is highly likely that other, more tractable applications of QIP will be found and implemented. This paper cites two possible applications of QIP to frequency standards based on trapped ions. Although the basic ideas for these applications emerged before the tidal wave of interest in QIP appeared (cn. 1995), these ideas have matured more rapidly due to advances in QIP. The first application, which we only summarize here, is to use entanglement to reduce frequency instability $\sigma_f(\tau)$ to the minimum level allowed by quantum mechanics. The second application uses the ideas of QIP to remove the functions of cooling and detection from the ion that is used for the frequency standard and place those functions on a second, simultaneously trapped ion species.

Atoms

- Identical
- Stable
- Quantum
- Diverse
Atoms

- Identical
- Stable
- Quantum
- Diverse
- Electronic “vibrations”
- Light excitations

The “virtual orchestra” of atomic oscillators in the Sun’s atmosphere.

Alfred Landé
1888-1976

Image: N.A.Sharp, NOAO/NSO/Kitt Peak FTS/AURA/NSF
Atomtronics timeline

Image: E. Edwards, JQI
Atomtronics timeline

- 1970: Ion cooling and trapping
- 1980: Cooling/trapping of neutral atoms, Optical lattices
- 1990: Shor’s algorithm, Experimental quantum logic, Bose-Einstein condensation
- 2000: Atom laser, Commercial products
- 2010: Nobel Prizes in Physics
- 2020: 

Image: ILLA
New Journal of Physics Focus on Atomtronics-enabled Quantum Technologies

http://j.mp/At0mtr0nics

- Precision measurement – quantum-enhanced clocks, matter-wave interferometry
- Sensing: magnetometry, gravity/gradiometry, rotation, acceleration
- Novel scanning probe microscopy
- Novel superconductivity and superfluidity
  - Experimental quantum logic
- Novel magnetism and synthetic magnetic fields
- Simulating complex quantum systems

Atomtronics applications
Recent atomtronic devices

Portable BEC chamber (2014)

Diode (2015)

Battery (2017)

Atom SQUID (2014)

Tank Circuit (2016)
Atomtronics today
First Bose-Einstein condensate in space

MAIUS 1 Sounding Rocket Mission

- MAIUS: Matter-Wave Interferometry in Microgravity
- Launched 23 January 2017 in northern Sweden
- Produced Bose-Einstein condensate on board
- Performed 100 experiments in matter-wave interferometry

Images: DLR