Atomic Clock and Atomic Magnetometer

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Abstract**—**Todaythe Battery-operated clocks (quartz clock) with frequency instabilities of 10^{-11} can be used for time interval up to a day, and the package is not larger than 1 cm^3, it could be widely used in portable electronic devices. In certain military and civilian applications, such as global positioning systems (GPS) and synchronization of mobile communication and navigation networks which demands timing precision and stability, that cannot be achieved with low-power quartz crystal technology which takes time intervals of more than a few minutes. Atomic clocks can provide these stabilities. Atomic magnetometer has extremely high sensitivity so along with atomic clock atomic magnetometer can also sense extremely low magnetic field so this device can also use in biomedical as well as defense field.

Keywords*-Atomic Clock, Atomic Magnetometer.*

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I.INTRODUCTION

Now a days Small commercial atomic frequency references with volumes around 100 cm^3 are currently widely used in modern cellular telephone networks and GNSS devices (Global Navigation Satellites Systems). In many areas their use in portable communication and navigation systems is limited by their power consumptions of a few watts. Small and inexpensive quartz crystals, on the other hand, show poor frequency stability over time periods longer than a few seconds. As electronic devices become increasingly mobile and data rates grow, more severe requirements are being placed on the frequency references that synchronize distributed networks, in terms of stability, power consumption, and size. Furthermore, smaller, lower-power atomic clocks installed in GPS could enable direct acquisition of the military GPS code and hence enhance the resistance of the receiver to jamming.

For achieving better stability, lower power consumption, and precision it is needed to develop a faster Atomic clock and Magnetometer. During the last few decades, considerable scientific and technical advances have not only led to better stability of frequency standards, but also reduced their physical dimensions and energy consumption. The possibility of using micro-electromechanical systems (MEMS) techniques for instruments based on atomic spectroscopy is leading to a new generation of atomic clocks and magnetometers. This fabrication methodology not only allows for smaller sizes and more robust structures, but at the same time makes lower power consumption possible, and devices attractive for portable applications.

A. Atomic Clock

An atomic clock is a clock device that uses an electronic transition frequency in the microwave, optical, or ultraviolet region of the electromagnetic field of atoms as a frequency standard for its timekeeping element. Atomic clocks are the most accurate time and frequency standards known, and are used as primary standards for international time distribution services, to control the wave frequency of television broadcasts, and in global navigation satellite systems such as GPS. The accuracy of an atomic clock depends upon two factors. The first factor is temperature of the sample, atoms colder atoms move much more slowly, allowing longer probe times. The second factor is the frequency and intrinsic width of the electronic transition. Higher frequencies and narrow lines increase the precision. The simplest atomic frequency standards are passive devices based on microwave transitions in a room-temperature vapor of atoms confined in a cell. The smallest physics packages for an atomic frequency reference have a volume of about 1 cm3 and dissipate several watts of electrical power. In contrast, the most precise type of frequency reference that might be considered generally suitable for portable applications is a temperature-compensated quartz-crystal oscillator. These devices dissipate tens of milli-watts of power and have fractional frequency instability at 1s of about 10-9, degrading to the 10-7 range over longer time periods due to environmental perturbations and aging. This long-term instability makes these devices largely inadequate for applications such as anti-jam GPS.

National standards agencies in many countries maintain a network of atomic clocks which are kept synchronized to an accuracy of 10-9 seconds per day (approximately 1 part in 1014). These clocks collectively define a continuous and stable time scale, International Atomic Time (TAI).

B. Atomic Magnetometer

Atomic magnetometer is a device that measures extremely low magnetic field using atom and LASER light. Atomic magnetometers work by detecting how the energy levels of atoms are modified by an external magnetic field. This is the famous Zeeman Effect, a quantum effect whereby the magnetic spin states in an atom split in the presence of an external magnetic field. This interaction between the atomic magnetic moment and external field is used to measure the field. This is normally done by using a pump laser to polarize the atoms by populating specific spin states, while a probe laser measures the spin precession, which is proportional to the magnetic field.

Magnetometers are measurement instruments used for two general purposes: to measure the magnetization of a magnetic material like a ferromagnet, or to measure the strength and, in some cases, the direction of the magnetic field at a point in space. Magnetometers are widely used for measuring the Earth's magnetic field and in geophysical surveys to detect magnetic anomalies of various types. They are also used militarily to detect submarines. Magnetic fields are everywhere in the world around us and are generated most commonly by electrical currents or by permanently magnetized ferromagnetic materials. Sensing these fields enables a characterization at some level of the source in a non-invasive, remote manner. Existing magnetic field sensors exploit a wide range of physical phenomena and include inductive pick-up coils, Hall probes, magneto-resistive elements, magneto-optic devices. For practical operation at finite fields, atomic magnetometers require a feedback loop to keep the frequency of the excitation locked to resonance as the magnetic field is changing. One approach is to use a phase-sensitive detector with an external feedback loop and a voltage-controlled oscillator. Another approach, which is oft en simpler, is a self-oscillating magnetometer that uses the measured spin-precession signal to directly generate the radiofrequency field in a positive feedback loop5Applications range from industrial, for example, the sensing of the position of a moving metallic component in a machine, to the detection of exquisitely weak fields produced by biological systems.

II.LITERATURE REVIEW

This section gives knowledge about history and further developments in atomic clock and magnetometer.

A. Developments in Atomic Clocks

The idea of using atomic transitions to measure time was first suggested by Lord Kelvin in 1879. Magnetic resonance, developed in the 1930s by Isidor Rabi, became the practical method for doing this. In 1945, Rabi first publicly suggested that atomic beam magnetic resonance might be used as the basis of a clock. The first atomic clock was an ammonia maser device built in 1949 at the U.S. National Bureau of Standards (NBS, now NIST). It was less accurate than existing quartz clocks, but served to demonstrate the concept. The first accurate atomic clock, a caesium standard based on a certain transition of the caesium-133 atom, was built by Louis Essen and Jack Parry in 1955 at the National Physical Laboratory in the UK. Calibration of the caesium standard atomic clock was carried out by the use of the astronomical time scale ephemeris time (ET). This led to the internationally agreed definition of the latest SI second being based on atomic time. Equality of the ET second with the (atomic clock) SI second has been verified to within 1 part in 1010.

Since the beginning of development in the 1950s, atomic clocks have been based on the hyperfine transitions in hydrogen-1, caesium-133, and rubidium-87. The first commercial atomic clock was the Atomichron, manufactured by the National Company. More than 50 were sold between 1956 and 1960. This bulky and expensive instrument was subsequently replaced by much smaller rack-mountable devices, such as the Hewlett-Packard model 5060 caesium frequency standard, released in 1964.

In the late 1990s four factors contributed to major advances in clocks:

- Laser cooling and trapping of atoms
- So-called high-finesse Fabry–Pérot cavities for narrow laser line widths
- Precision laser spectroscopy
- Convenient counting of optical frequencies using optical combs.

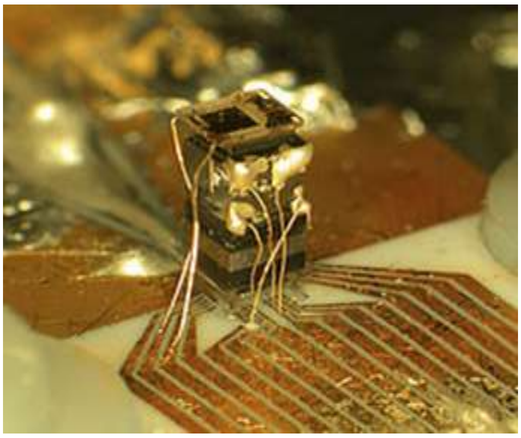

Fig 2.1 Chip-scale atomic clocks, such as this one unveiled in 2004, are expected to greatly improve GPS location.

In August 2004, NIST scientists demonstrated a chip-scale atomic clock. According to the researchers, the clock was believed to be one-hundredth the size of any other. It requires no more than 125 mW, making it suitable for battery-driven applications. This technology became available commercially in 2011. Ion trap experimental optical clocks are more precise than the current caesium standard.

B. Developments in Atomic Magnetometer

The first magnetometer was invented by Carl Friedrich Gauss in 1833 and notable developments in the 19th century included the Hall Effect which is still widely used. Magnetometers can be used as metal detectors: they can detect only magnetic (ferrous) metals, but can detect such metals at a much larger depth than conventional metal detectors; they are capable of detecting large objects, such as cars, at tens of meters, while a metal detector's range is rarely more than 2 meters. In recent years magnetometers have been miniaturized to the extent that they can be incorporated in integrated circuits at very low cost and are finding increasing use as compasses in consumer devices such as mobile phones and tablet computers.

Alkali atoms enclosed within a vapor cell were first developed in the 1950's, In 1969, Dupont-Roc and coworkers developed a zero-field version of this AM with nearly 10 fT/√Hz level sensitivity. In 1973, Tang and coworkers discovered a phenomenon, which led to suppression of spin-exchange relaxation in alkali atoms, opening a pathway to miniaturization of highly sensitive AMs operating in a low magnetic field. In 2003, Romalis and coworkers used this discovery to demonstrate an ultra-sensitive AM with sub-femtotesla level sensitivity. The AMs operating in this regime are now referred to as Spin-Exchange Relaxation-Free (SERF) magnetometers.

III. APPLICATIONS

The Atomic clock and atomic magnetometer has wide range of applications in various fields such as defense, biomedical etc. some of applications are given as follows:

A. Applications of an Atomic Clock

The development of atomic clocks has led to many scientific and technological advances such as a worldwide system of precise position measurement (the Global Positioning System and Global Navigation Satellite System), and applications in the Internet, which depend critically on frequency and time standards. Atomic clocks are installed at sites of time radio transmitters. They are used at some long wave and medium wave broadcasting stations to deliver a very precise carrier frequency. Atomic clocks are used in many scientific disciplines, such as for long-baseline interferometry in radio astronomy.

1) Global Navigation Satellite Systems

The Global Positioning System (GPS) provides very accurate timing and frequency signals. A GPS receiver works by measuring the relative time delay of signals from a minimum of four, but usually more, GPS satellites, each of which has at least two onboard caesium and as many as two rubidium atomic clocks. The relative times are mathematically transformed into three absolute spatial coordinates and one absolute time coordinate. GPS Time (GPST) is a continuous time scale and theoretically accurate to about 14 ns. However, most receivers lose accuracy in the interpretation of the signals and are only accurate to 100 ns. GPST remains at a constant offset with TAI (TAI – GPST = 19 seconds) and like TAI does not implement leap seconds. Periodic corrections are performed to the on-board clocks in the satellites to keep them synchronized with ground clocks. The GPS navigation message includes the difference between GPST and UTC. As of July 2015, GPST is 17 seconds ahead of UTC because of the leap second added to UTC on June 30, 2015. Receivers subtract this offset from GPS Time to calculate UTC and specific time zone values.

2) Time signal radio transmitters

A radio clock is a clock that automatically synchronizes itself by means of government radio time signals received by a radio receiver. Many retailers market radio clocks inaccurately as atomic clocks although the radio signals they receive originate from atomic clocks; they are not atomic clocks themselves. They are inexpensive time-keeping devices with an accuracy of about a second. Instrument grade time receivers provide higher accuracy.

3) High speed telecommunication network

Using atomic clock the speed of the telecommunication network will be increased to great extent and one of the main advantages is that there will be very less delay and better signal receiving accuracy, precision as compare to telecommunication network that we are using now a day.

4) Underground and underwater detection

Atomic clock can be used in defense for underwater and underground detection of enemies. It is very useful device in navy and defense areas where we have to detect submarines and other underground enemies using RADAR, SONAR etc.

B. Applications of an Atomic Magnetometer

Atomic magnetometers range from large, highly precise laboratory apparatus to smaller, but less sensitive instruments that can be used in the field. Magnetometers are typically characterized by their sensitivity, but also by a range of other features such as vector or scalar operation, bandwidth, heading error, size, weight, power, cost and reliability. These characteristics determine the range of applications for which the magnetometer is suitable. Recently, new applications for atomic magnetometers have emerged in research laboratories, including the detection of bio-magnetic signals, the detection of nuclear magnetization and the detection of magnetic particles.

1) Detection of magnetic anomalies

Commercial atomic magnetometers are used most frequently for the detection of magnetic anomalies produced by metallic objects such as unexploded ordinance, geophysical structures, vehicles, and ships.

2) Detection of biomedical signals

As atomic magnetometer can detect extremely low magnetic field, Human body has very low electric as well as magnetic field in heart and brain, so it can be used for medical diagnostics such as MCG (Magneto-cardiograph) and MEG (Magneto-encephalograph) like ECG (Electro-cardiograph) and EEG (Electro-encephalograph).

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