WHAT TIME IS IT?

We hams oft-times use the term **time** *without thinking about its meaning or definition. Our QSOs are logged with a specific time and date. Scheduling contacts, for example, allows us to arrange traffic nets, or individual contacts, at a specific time and frequency. Contesting requires us to make as many contacts as possible within a certain time duration. Propagation requires the knowledge of how various frequency radio waves, or bands, behave differently at various times-of-day. We hams all use time, but what is time? What time is it? Time is an ethereal concept and depends on a point of reference. First some history of timekeeping and standardization, then a few definitions explaining our modern timekeeping mechanisms. Finally, methods of measuring time shall be presented.*

Standardizing Time Across the Globe

Looking back for a moment, in 1840, the British Great Western Railway (GWR) became the first company to adopt a standard time and time-table for its trains, which it called "railway time". At that time, each railway company had its own system of timekeeping, which made it difficult to coordinate schedules and caused confusion for passengers. This was based on the time at the GWR's headquarters in London and was gradually adopted by other railway companies. However, only after 1880 was a standardized system of timekeeping introduced across the entire British railway system. The introduction of GMT allowed for greater coordination between British railway companies and also made it easier for passengers to plan their journeys, as they could rely on a consistent time across the entire country.

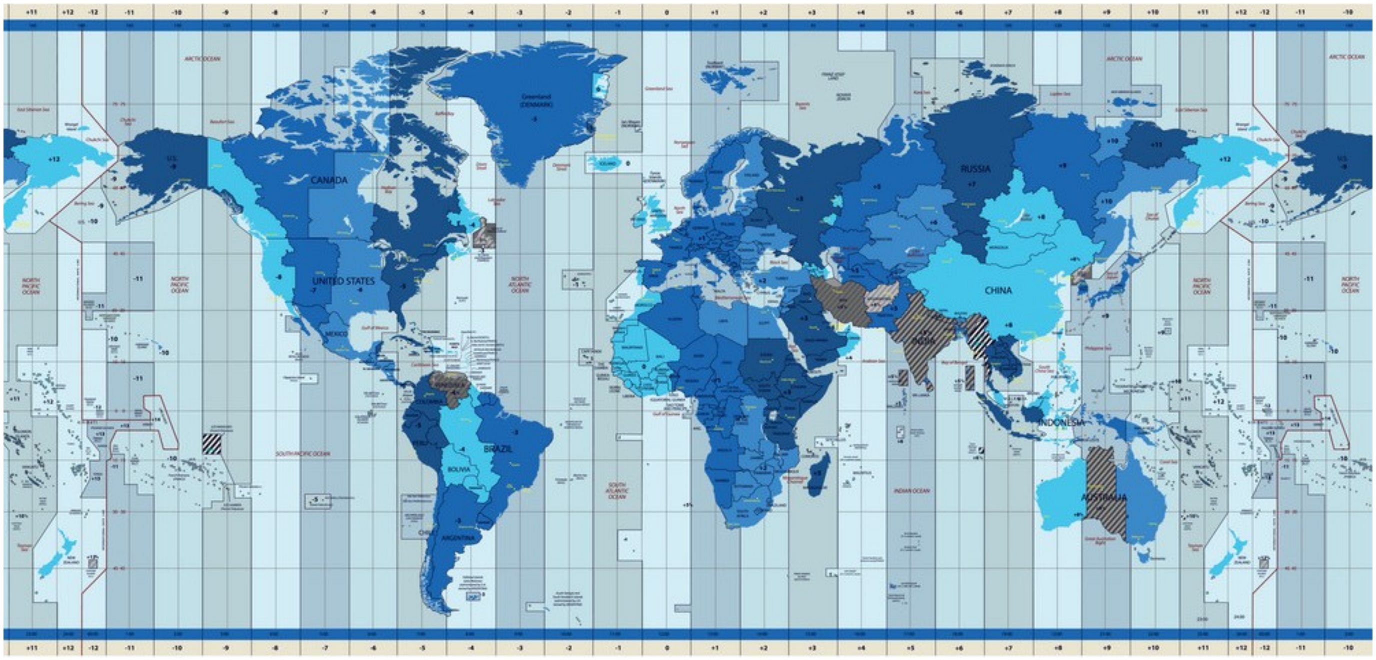
In the U.S. timekeeping was a purely local process, until the 1880's. Before 1883 there were over 144 local time zones in North America. Normally, each locale would set their clocks to Noon as the Sun reached its zenith. Each city had its own time standard and traveling between cities required resetting one's watch upon arrival. Once people began traveling large distances, via railroads, a uniform system of timekeeping was crucial for the efficient and safe operation of railroads.

A system of world-wide time zones was proposed by Canadian, Sir Sanford Fleming, and the system is still in use today. Fleming divided the world into 24 time zones each spaced apart by 15 degrees of longitude. Rail-roads in the U.S. began using Fleming's time zone standardization on November 18, 1883. Originally, the federal organization charged with railroad regulation, the Interstate Commerce Commission, proposed five time zones in the continental U.S. Standardized by Congress, in the Standard Time Act of 1918, the time zones in the U.S, were drawn to avoid populated areas, and sometimes moved to avoid complications. There are now, by law, nine time zones in the U.S. and its territories: Atlantic - Puerto Rico & Virgin Is.; Eastern; Central; Mountain; Pacific; Hawaiian; Guam and Wake Island.

An International Prime Meridian Conference was held in Washington, D.C. in October 1884 to standardize global time and select a prime meridian. A meridian is an imaginary longitudinal line running from North Pole to South Pole, along the Earth's surface. The Prime Meridian, 0° longitude, was selected as the longitude of Greenwich, England, home of the Royal Greenwich Observatory, thus Greenwich Mean Time (GMT). Why England and why Greenwich? In the 19th century, England had more shipping and ships using the Greenwich meridian than the rest of the world combined. Ship navigation, at that time, relied upon the data produced by the Royal Greenwich Observatory, based upon celestial and solar observation, and the Royal Greenwich Observatory produced the highest quality data available.

Interestingly, French maps showed zero degrees (0° longitude, the Prime Meridian) on Paris, in spite of the International Meridian Conference results of 1884. The French continued to treat Paris as the Prime Meridian until 1911. In 1967, Coordinated Universal Time (UTC – *Universel Temps Coordonné,* to satisfy the French) replaced GMT as the world's time standard. GMT is a time zone, while UTC is a time standard. UTC is sometimes referred to as "Zulu" time. Since world time zones are defined as so many hours 'ahead' or 'behind' the Greenwich timezone, UTC + 0. "Z" for zero and in the NATO phonetic alphabet "Z" is "Zulu".

WORLD TIME ZONES MAP



Time Standards

Universal Coordinated Time

UTC is a global standard used for scientific and technological purposes such as navigation and communication. It is based on atomic clocks and is kept in sync with the rotation of the Earth through the addition of leap seconds.

Two components determine Universal Coordinated Time (UTC):

- International Atomic Time (TAI) – A time scale determined by a network of some 400 highly precise atomic clocks (Cesium[1]-133 atom) worldwide.

  Atomic clocks deviate only 1 second in up to 100 million years. This high level of precision achieved by atomic clocks is both a blessing and a curse. Firstly, accurate timekeeping is a necessity in time-sensitive technology such as air traffic control (ATC) and satellite navigation systems. Secondly, TAI does not consider variations in the Earth's rotational speed, which determines the true length of a day.

- Universal Time (UT1) – Also known as astronomical time or solar time, referencing the Earth's rotation. UT1 is defined as the time that has elapsed since the last passage of the vernal equinox (the point at which the Sun crosses the celestial equator, marking the beginning of spring in the Northern Hemisphere over the Prime Meridian. It is measured in units of mean solar time, which is the average length of a day over a year.

  Since TAI does not consider the variation in Earth's rotation velocity, TAI is constantly compared to UT1. Once the difference reaches 0.9 seconds, a leap second is added to UTC. On average, Earth's rotational speed has been slowing over the past few decades and is currently running 37 seconds behind TAI.

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1 Cesium (Chemical element "Cs", atomic number 55 on the periodic table of elements) is the American language spelling. Caesium is the IUPAC spelling.

Modern timekeeping defines a day as the sum of 24 hours but this is not entirely accurate. The Earth's rotation is not constant, therefore in terms of solar time (UT1), most days are a little longer or a little shorter than 24 hours. Earth's moon is very gradually slowing the Earth's rotation due to its gravitational pull. The moon's gravitational pull causes changes to the earth's shape resulting in greater orbital friction, resulting in a slower rotational speed. In addition, the distance between Earth and moon changes continuously make daily variations in the Earth's rotational speed.

Over the course of a century, the length of a day increased by several milliseconds (ms). December 18, 2022, for example, was predicted to be 0.3592 ms, or 0.0003492 seconds longer than a standard 24-hour day.

- Local Mean Time

  Local Mean time (LMT) is a type of solar time, references the Sun's movement across the sky, and is based on the *average* length of a solar day. Local Mean Time is composed of two components:

  - Apparent Solar Time

    A sundial shows the true or apparent Solar Time. The variation in the length of an apparent solar day is the effect of two factors: 1.) The Earth's orbit is slightly elliptical; and, 2.) The Earth's axis is tilted. Both factors affected how quickly the Sun moves across our sky over the course of a year. Since the Earth's rotation is not constant, solar days vary lightly in length. Thus apparent solar time is not constant.

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  - Mean Solar Time

    Mean Solar Time is based on the length of a *mean, or average,* solar day, which is 24 hours long. Mean Solar Time is constant. UT1 is the Local Mean Time at the prime meridian at the Royal Observatory, Greenwich, UK.

    The difference between Apparent Solar Time and Mean Solar Time is called the **equation of time.**

- Sidereal Time

  Sidereal Time is based on the Earth's rate of rotation measured relative to fixed stars, and is a system astronomers use to locate celestial objects. A Sidereal Day, on Earth, is approximately 86,164.0905 seconds, or 23 hours, 56 minutes, 4.0905 seconds. While Mean Solar Time is measured using the Sun as a reference, Sidereal Time is referenced to distant celestial objects, and used by astronomers to measure the position of celestial objects in the sky. It is based on the Earth's rotation relative to fixed stars, and is therefore a more accurate measure of the Earth's rotation than other forms of timekeeping that are based on the Sun's position in the sky.

- Ephemeris Time

  Ephemeris Time is based on the motion of the Earth and other planets in the solar system. It is defined as the time it would take for the Earth to complete one orbit around the Sun, if the Sun were stationary. Ephemeris Time is used to calculate the positions of planets and other solar system objects, and is used as a standard time scale for astronomical observations. Ephemeris time is used by astronomers and space agencies to calculate the positions of planets and other celestial bodies. Since it is based on the motion of the Earth and other planets in the solar system, and is therefore more accurate than other forms of timekeeping based on the Earth's rotation.

Why is the confusing multiple system of timekeeping important? Various methods of measuring time is important because each method is suited to a particular purpose or application, and provides a unique perspective on the concept of time. Each method of measuring time has its own strengths and weaknesses, and is suited for it's specific application. By having multiple methods of measuring time, we can better understand and appreciate the complex nature of time and its role in our lives and the universe. As will be explained, precise timekeeping is imperative for measuring electromagnetic wave frequency.

Measuring Time

Man first used sticks in the ground, or stone monuments, to observe the Sun's shadow progress as a primitive clock. Sun dials, water clocks and 'hour-glasses' of sand were next step in timekeeping. By the mid-17th century, mechanical pendulum clocks were developed, but celestial observation of the Earth's rotational period remained the standard reference for timekeeping.

Time can be used to determine navigational longitude by comparing the local time of a specific location with the time at a known location, such as the prime meridian. The Earth rotates once every 24 hours, and therefore, there is a 15° difference in longitude between each hour of the day. This means for every passing hour, local time at a specific location will be one hour ahead or behind the time at the prime meridian, depending on whether the location is east or west of the prime meridian. This method of determining longitude is known as the "method of lunar distances" and was first used by the British astronomer, Nevil Maskelyne, in the late 18th century. Navigation by longitudinal determination, however, requires accurate timekeeping.

With the development of accurate marine chronometers by the English clockmaker John Harrison in the mid-18th century, navigators could accurately determine their longitude using the method of dead reckoning. Harrison's chronometers were used on several important voyages of discovery, including James Cook's voyages to the South Pacific in the 1760s and 1770s. By the end of the 18th century, marine chronometers became widely adopted by navigators, and revolutionized the field of navigation.

First built in 1927, the first quartz crystal derived clock was developed by Warren Marrison and Joseph Horton,[i] bringing us into the "electronic age". The accuracy of the Marrison's and Horton's crystal clock was very high and was capable of keeping time to within one second per day, which was a significant improvement over the existing mechanical clocks. Since then, the technology of quartz crystal clocks has improved significantly, and modern quartz clocks can keep time with an accuracy of better than one second per year. Atomic clocks, which are the most accurate timekeeping devices currently available, are based on the same fundamental technology as quartz crystal clocks.

Louis Essen and J.V.L. Parry, scientists working at the National Physical Laboratory (NPL) in the United Kingdom in the mid-1940's, are best known for developing the first practical atomic clock based on the resonance of atoms of cesium-133, which they called the "cesium clock". Essen started work at the National Physical Laboratory (NPL) at Teddington in Middlesex the following year as a Junior Scientific Officer, under D. W. Dye, investigating the potential of tuning forks and quartz crystal oscillators for precise time measurement. His research led to his development of the quartz ring clock in 1938, which used the electrically induced vibrations of a quartz crystal to measure time.[ii] Dye had already developed an annular ring oscillator which Essen later transformed by substituting circumferential for radial oscillation into a practicable standard of high stability. The clock soon becoming a standard for time measurement at observatories throughout the world.[iii] It was the first device accurate enough to measure the minute variations in the Earth's speed of rotation, prior to Essen's work, scientists had thought that the speed was constant.

Atomic Clocks

Designed to measure the precise length of a second, atomic clocks are the fundamental unit of modern timekeeping. Currently, the global atomic clock time-keeping system consists of hundreds of atomic clocks strewn about the world, integrated to form a very consistent counter. In 1949, Louis Essen, at the National Physical Laboratory built the first cesium clock. This clock was the first device to achieve an accuracy of better than one part in 10^{-10}, or one second in 300 years.

In 1955, the first atomic clock using a beam of ammonia molecules, was built by researchers at the National Bureau of Standards (now NIST) in the United States. Also in 1955, the first commercial cesium clock was produced by the U.S.-based, National Company, and it quickly became the standard for timekeeping around the world. Since then, cesium clocks have become even more accurate, with modern versions able to keep time to within one second in 30 million years. Today, cesium clocks are used in a variety of applications, including satellite navigation systems, telecommunications networks, and scientific research.

The cesium clock was used to redefine the second in 1967, when the International System of Units (SI) adopted it as the basis for measuring time. The International System of Units (SI) defines a second as the time it takes a Cesium-133 atom, in a precisely defined state, to oscillate 9 billion, 192 million, 631 thousand, 770 times. The official SI definition provides more detail: *"The second is the duration of 9,192,631,770 period of the radiation corresponding to the transition between two hyperfine levels of the ground state of the Cesium-133 atom. This definition refers to a Cesium atom at rest at a temperature of 0° Kelvin."* Currently, the global atomic clock time-keeping system consists of hundreds of atomic clocks strewn about the world, integrated to form a very consistent counter.

The history of the rubidium clock dates back to the 1950s, when researchers began exploring the use of atomic resonance as a means of keeping time. In the early 1960s, researchers began exploring the use of rubidium as an alternative to the ammonia molecule used in the first atomic clocks. Rubidium has a simpler electronic structure than ammonia, making it easier to work with and more stable. In 1964, the first rubidium atomic clock was built by Louis Essen and J.V.L. Parry at the National Physical Laboratory (NPL) in the United Kingdom.

The rubidium clock became commercially available in the late 1960s, and has since become one of the most widely used types of atomic clock. Rubidium clocks are used in a variety of applications, including GPS satellites, telecommunications networks, and scientific research. They are known for their high stability and accuracy, and their relatively low cost and small size make them a popular choice for many applications.

Rubidium clocks are less accurate than cesium clocks but still offer very precise timekeeping. Rubidium clocks typically have an accuracy of about 1 part in 10^{-11}, meaning they may gain or lose one second every 10 million years. Conversely, modern Cesium clocks are even more precise, with an accuracy of about 1 part in 10^{-14}, meaning they may gain or lose one second every 100 million years.

Despite being less accurate, Rubidium clocks are smaller, more portable, and less expensive than cesium clocks. They are often used in applications where high accuracy is not required, such as in telecommunications, navigation, and scientific experiments.

Mentioned earlier, UTC is a global standard for scientific and technological purposed such as navigation and communications. Cellular telephone systems and satellite navigation systems, such as GPS, GLONASS, and Galileo rely upon precise time measurements to calculate geographic positions accurately. Each satellite in the GPS constellation carries multiple Cesium clocks which are continuously synchronized with other, ground-based, atomic clocks. The National Standards and Technology (NIST) laboratory Cesium Fountain Atomic Clock, NIST-2, time measurement accuracy approaches 1.5 parts in 10 to the 16^{th} (1.5×10^{-16}) or stated another way, this clock will not lose or gain a second in at least 300 million years.

The most precise chronometer currently available, today, is the optical lattice clock, which uses a lattice of lasers to trap and measure the vibrations of atoms. These clocks are capable of measuring time with an accuracy of about one second in *15 billion* years, which is several orders of magnitude more precise than even the best atomic clocks with a demonstrated accuracy at the 1 part per 10^{-18} level. However, it's worth noting optical lattice clocks are still in the experimental stage and are not yet widely used for practical applications.

Frequency & Time

Once time is measured precisely, Hertzian wave frequency can be measured almost as precisely. We know, for example, frequency is the reciprocal of time:

$$f_{Hertz} = \frac{1}{t_{seconds}}$$

A GPS corrected, Rubidium disciplined master oscillator, at N1XP consistently provides a standard 10 MHz signal with an accuracy of 2×10^{-11}, equivalent to 10,000,000 ±0.0002 Hertz. This 10 MHz source supplies a reference to several modified radios, increasing their frequency tuning accuracy. A frequency counter is also locked to this source. However, the discussion of frequency measurements using a time standard is a discussion for another ***...time!***

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i Margolis, Helen, Fellow, National Physical Laboratory, Teddington, UK, "A brief history of timekeeping" *Physics World,* November 2018

ii Louis Essen, British physicist, at Britannica Online

iii https://royalsocietypublishing.org/doi/pdf/10.1098/rspa.1936.0115