GPS AND RADIO-CONTROLLED TIME

Primex Wireless, Inc.

OVERVIEW

Since the days of the Industrial Revolution, American businesses have recognized the importance of accurate time. Several new technologies emerged in the 20th century to help improve time-measurement techniques. Each is based on atomic time generation: both radio waves and global-positioning-system (GPS) satellites distribute precise atomic time to clocks and other timekeeping devices. This paper explores the similarities and differences between radio-controlled and GPS-based clocks.

GENERAL INTRODUCTION

Before about 1949, astronomical sightings determined absolute time. But because these sightings were not very accurate, scientists began to look for a universally repeatable method for standardizing time. The time standard for the United States is known as "Mean Solar Time." Our clocks use Mean Solar Time, which is a uniform measure averaged out over a year (365.243... days). The local Mean Solar Time on the Greenwich meridian is called "Greenwich Mean Time" (GMT).

People sometimes use the term "Greenwich Mean Time" to refer to Corrected Universal Time (UT1). UT1 is not actually a measure of time but rather a reference to the orientation angle of the earth. When we talk about time using space as its reference, it is important to realize that time is not predictable because of the slight wobble in the earth's axis, which is called "rotational precession." This imperfect rotation has led scientists and mathematicians to find a way to correlate these angles to time. Different places view time through different meridians. For example, Eastern Standard Time (EST) is the Mean Solar Time of the meridian at 75 degrees W.

The actual standard of time that scientists track and control is often called "Coordinated Universal Time" (UTC). UTC is a compromise between the highly stable atomic time and the irregular Earth rotation. A connection with UT1 is necessary to keep Earth rotational values accurate. That's why scientists depend on leap seconds—by adding or subtracting them from time to time, they maintain a link with UT1. It is important to note that UTC is not a physical realization but only a prediction based on time in a laboratory, and that differences between labs can vary by as much as 10 nanoseconds. There are many labs throughout the world that predict time for correlation purposes.

ATOMIC CLOCKS

Today, atomic clocks represent the standard for highly accurate timekeeping devices, and the term "atomic time" is commonly used to connote the most precise time available. But "time," in the case of atomic clocks, is actually developed from an atomic frequency standard. A "frequency standard" generally refers to anything that generates a periodic signal, and a "clock" is a device that displays a time interval relative to a period of oscillation. The time on an atomic clock at the U.S. Naval Observatory in Washington, D.C., determines the time we set on our clocks. The National Institute of Standards and Technology (NIST) also maintains atomic clocks that are calibrated to the U.S. Naval Observatory's clock.

Just as the Celsius temperature scale is calibrated to the freezing and boiling points of water at sea level, time is synchronized to the natural orbiting rhythms of electrons in such elements as cesium 133, hydrogen, or rubidium. When a specific frequency of microwaves bombards these electrons, their orbits resonate and release energy. The microwave frequency at which this occurs is divisible down to an exact second and becomes the time base for an atomic clock. Cesium, which resonates at a frequency of 9,192,631,770 Hz, is the most common type of atomic clock.

Atomic clocks are extremely accurate. Some atomic clocks now claim to have an accuracy of plus or minus one second in 20 million years! An atomic clock must be calibrated to the standard at the U.S. Naval Observatory (or a NIST standard).

RADIO-CONTROLLED CLOCKS

Some clocks on the market that are labeled "atomic" really are not. Rather, they are synchronized by a radio signal to an atomic clock located at a NIST facility in Fort Collins, Colorado, and thus are more accurately described as "radio-controlled" clocks.

At the NIST facility in Colorado, the government operates a 23-kW transmitter at a low frequency of 60 kHz. This transmitter, licensed as station WWVB, continually broadcasts the time and date as a series of slow data pulses. At 60 kHz, the WWVB signal consists of mostly magnetic waves that, like an insect flittering on the surface of a pond, generate ripples in the earth's magnetic field. Through an array of long antennas at the NIST site, this time signal is broadcast throughout most of the North American continent. Transmitters similar to this are located in different areas of the world, such as London, England, where the British Broadcasting Company transmits at a different frequency of 198 kHz. Although these low frequency waves do an adequate job of conforming to the terrain of the earth, the waves have a difficult time penetrating some metal structures, and they are sharply polarized.

Being "polarized" means that invisible flux lines striate the magnetic field, similar to the grain in a piece of wood. These flux lines, which run perpendicular to the direction that the waves are traveling, can twist due to aberrations in the environment. One detriment of a polarized signal is that it requires the receiving antenna (located inside clocks or watches) to be oriented properly for best signal detection. This isn't a big problem for watches since the wearer moves about during the day, allowing the watch to be properly oriented often enough to receive the signal and update the time.

Physical orientation becomes more of an issue with fixed wall clocks. Once they're mounted, these clocks don't move, so it is imperative that they be mounted in a position that allows the internal antenna to receive the WWVB signal. The need to properly orient the clock imposes limitations on where the user can mount it, and these clocks must also be kept away from sources of low-frequency electrical or magnetic interference such as motors or computer screens.

GPS-BASED CLOCKS

The Global Positioning System consists of a network of 24 orbiting satellites, each with its own cesium or rubidium atomic clock on board. The purpose of this network of satellites is to facilitate an electronic means of determining the longitude and latitude coordinates of any place on Earth. This is possible through a technique called 3-D trilateration, which measures the distance to several satellites.

A certain distance from a satellite, in all directions, defines a sphere. If you can measure the distance to three satellites, you have defined three intersecting spheres. The intersection of two spheres is a circle and the intersection of three spheres is two points. A fourth intersecting sphere is required to define a single point. Ignoring altitude, the globe of the earth can be this fourth sphere. If four satellite signals are received, it's possible to calculate elevation as well.

We measure distance to a satellite by the time it takes a microwave signal to travel from a satellite to a specific point on Earth. Here is a brief analogy of how one can calculate distance by knowing the delay time. Let's say you work at a factory where they always blow the noon whistle just as the second hand on your watch passes 12. One day you are home from work and you hear the factory whistle in the distance just as the second hand on your watch is 10 seconds past noon. You can calculate the distance to the factory based on the knowledge that sound travels at 770 miles per hour (mph) and the sound arrived at your home 10 seconds late by your watch. A speed of 770 mph equals 0.214 miles per second, so calculations indicate the factory is 2.14 miles away.

A GPS receiver works in a way similar to the above scenario, except that it calculates the distance to orbiting satellites by measuring the delay in the arrival of microwave signals it receives from the satellites. Microwave signals travel at nearly the speed of light. Atomic clocks on all the orbiting GPS satellites initiate a precisely simultaneous series of data transmissions. On Earth, the signals from three or four of these satellites arrive at a GPS receiver at slightly different times, depending on the distance the signal traveled from each satellite.

In the factory example above, if you didn't know exactly what time the whistle actually blew, you couldn't measure the delay to make the distance calculation. Likewise, a GPS receiver needs to know the exact time the signals left the satellites in order to measure the time delay of each satellite's signal. The GPS receiver must derive the exact time in order to calibrate its internal quartz clock to true atomic time. The information required to do this comes from the delayed signals being received from at least three satellites.

The synchronizing signals from GPS satellites experience time delays due to the long distances they travel as they come to Earth. However, the GPS receivers carry what is called a firmware "almanac," which enables them to determine the location of each satellite at any time, and thus calculate the actual distance to each satellite. This enables the GPS receiver to compensate for the known signal delay. It uses this correction data to reconstruct the actual time that is in the atomic clocks aboard the satellites. In other words, the GPS time signal is adjusted to correct for propagation delay.

The GPS receiver adjusts its own clock until the signal arrival times make sense compared to position data reported by each satellite. Once the GPS receiver acquires signals from at least three satellites, its internal clock is set to near-perfect agreement with the atomic clocks aboard the satellites. The satellite clocks are calibrated to the time standard at the NIST and the U.S. Naval Observatory.

It may take some time for three or more satellites to orbit into view of the GPS receiver. This is why it sometimes takes several minutes to extract the time from a GPS receiver. After the GPS receiver's clock is set, it can then determine the time delays and calculate the distance to each satellite.

RADIO-CONTROLLED VS GPS TIME

As discussed earlier, the physical orientation of radio-controlled wall clocks and proximity to metal structures or sources of interference can affect reliability. Also, the distance of the receivers from the WWVB source can be thousands of miles away. This distance causes slight delays in the time registered on radio controlled clocks. The WWVB signal also weakens with distance from Fort Collins making signal reception more unreliable. Reception is also affected by weather and ground moisture conditions.

The Primex GPS Wireless Clock System overcomes most of the disadvantages of radio-controlled clocks. The system corrects signal propagation delays to yield exact time anywhere on Earth. The GPS receiver is not sensitive to orientation, other than that it needs a view of the sky. With the Primex Wireless system, the GPS signal is locally rebroadcast in a building at a 72.1- to 72.4 MHz frequency that is less prone to noise signals than the WWVB broadcast frequency of 60 kHz and more easily penetrates walls and metal structures. The GPS signal is also less affected by weather conditions, and the receiver can pick it up anywhere in the world.

Since the WWVB signal is amplitude-modulated (AM), it is susceptible to electrical noise, both man-made and weather-related. This interference can mask synchronizations of WWVB clocks. Primex Wireless clocks are synchronized by an FM signal, which is less prone to interference. Furthermore, GPS clocks can receive synchronization six times a day, whereas most WWVB clocks only look for a signal four times a day. GPS clocks will be inherently more accurate just because they synchronize more often and won't drift as far.

Finally, during midday hours WWVB sky waves cannot be detected beyond 500 miles of Fort Collins, Colorado. Outside this radius WWVB clocks may only see three synchronizations per day compared to a GPS clock's six synchronizations.

CONCLUSION

While both methods provide accurate ways to derive time, radio-controlled clocks have more limitations due to their inherent design. These clocks may be acceptable for typical residential and consumer applications, but they are not a good fit in commercial buildings. The materials used in the construction of schools, hospitals, and office buildings often interfere with the radio transmission required to synchronize radio-controlled clocks.

GPS-based systems, on the other hand, function well in commercial building applications. The locally broadcast time signal penetrates every type of construction material. The signal is not affected by weather conditions. Users can locate clocks virtually anywhere in a building. As long as they are in range of the local transmitter, they'll always be synchronized and perfectly accurate.