Bob’s TechTalk #36

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NIST

Buddy, Got the Time? Or:

The Adventure of the NIST Time Standard WWVB

Time is something we all take for granted unless we're late for an important event. However, for a ham in China and a ham in the US to schedule a QSO and show up on the same frequency and at the same time requires that time be universal around the world. This universality is so important countries of the world put politics aside and agreed on a standard, the **second**. Since frequency is the reciprocal of time, defining the second also defines the Hertz.

Originally the second was defined relative to the **mean solar day**. There are different types of **day** on earth, two being the **solar day** and the **sidereal day**. The solar day is the period between two successive points when the sun reaches its highest point in the sky. Since the earth's orbit is elliptical, and the earth's axis is tilted with respect to the sun's orbit, a solar day varies throughout the year. The **mean solar day** is the average of the solar days over the year. It is divided into the hours, minutes and seconds we are familiar with. **A sidereal day** is the time it takes the earth to make one complete rotation on its axis. Since the earth actually rotates on its axis a bit over 366 times in one year, a sidereal day is shorter than a solar day by about 4 minutes. Sidereal time is used extensively in astronomy as a reference for finding astronomical objects.

The Modern Second Defined

As science expanded, a more accurate way to measure a second was needed. Again the world's scientists agreed on a new standard. One second under the **International System of Units (SI)** is equal to 9,192,631,770 cycles of a specific radiation of the cesium atom at a specific temperature.

Highly accurate Cesium clocks are expensive. **NIST**, the **National Institute of Standard and Technology** is responsible for keeping the time standard in the US. NIST was formerly known as **The National Bureau of Standards (NBS)**. The NIST time and frequency laboratory is located in Boulder, Colorado. It averages multiple high precision Cesium clocks to define the second for the US. NIST also coordinates US time with other nations through the SI based in France. Time based on the coordinated cesium time standard is called **Universal Coordinated Time** or **UTC** (The strange abbreviations are because the French put the adjective after the noun.) UTC is the standard for civil time that we commonly use for day-to-day time. UTC is based on an atomic time scale, but it also has to have a celestial reference; otherwise, midnight may occur in the middle of the day!

Universal Time comes in at least four additional flavors. Two are **UT0** and **UT1**. **UT0** is determined by modern observation of the daily motion of astronomical bodies. It is uncorrected for the earth's polar motion that results in an error related to the observer's position on the earth. **UT1** is UT0 corrected for polar motion and is the same everywhere on the earth. Since the earth's rotation speed varies, it is accurate to within ± 3 milliseconds per day. Two other universal times are **UT1R** and **UT2**. They are used for special purposes and not of interest to the layperson.

Since UT1 has a celestial reference, it is used to reference UTC to the motion of the solar system. Over a period of time an error increases between UTC and UT1. To keep UTC coordinated with UT1 a leap second is added to UTC on occasion. This is done when needed to keep UTC within ±0.9 seconds of UT1. Determining when to add a leap second is the job of the **International Earth Rotation and Reference Systems Service (IERS**[1]). Leap seconds may also be subtracted, though this has never been needed. Currently about four leap seconds are added for every five years - usually on the last day of June or December. If one needs to know UT1 to an accuracy higher than about 1 second, NIST provides UT1 correction data along with its UTC time information.

WWV and WWVH

As the "keeper of time" for the United States, NIST provides services to calibration laboratories, broadcast stations, businesses and others who need varying degrees of accuracy of time and frequency. One such service is **WWV/WWVH** that transmits voice time signals on accurate frequencies in the HF band at 2.5, 5.0, 10, 15, and 20 MHz. Most hams are familiar with WWV and WWVH and use them to set their clocks and also as a frequency reference. One problem with the NIST HF standard transmissions is that propagation causes varying signal travel time over a fixed path, and that can result in significant time errors. While not critical for most ham use, this error can be intolerable for certain users. WWV is located in Fort Collins, Colorado. WWVH is located on Kauai, Hawaii.

WWVB

To provide a more accurate time standard, NIST also operates a transmitter on VLF. Station **WWVB** is located in Ft. Collins, Colorado. WWVB transmits at 50KW ERP on 60 KHz (yes – 60,000 hertz) simultaneously using two separate 36 KW transmitters and two separate but nearly identical antennas. Each antenna consists of a wire top-hat suspended between four 400' towers and a vertically radiating down-lead that drops from the center of the top-hat to a building that contains an automatic helix antenna tuner. Unlike WWV and WWVH, WWVB doesn't transmit voice or tones. Instead it transmits a pulse width coded time signal. VLF signals are more accurate because signal travel time is less variable, especially when in ground-wave range. An observer who knows the distance between his station and the WWVB transmitter can correct for transmission time.

WWVB Modulation

WWVB transmits a steady 60 KHz carrier that is modulated by dropping the level by 10 dB at the beginning of each second. The carrier remains low for 0.2, 0.5 or 0.8 seconds before returning to full power. These times correspond to a zero bit, a one bit or a frame reference (or position marker) bit. One bit is sent per second. See Figure one. There are seven frame reference or position marker bits sent each minute. The frame reference bits occur at 0 and 59 seconds to mark the beginning of the minute. The position marker bits occur at 9, 19, 29, 39, and 49 seconds to synchronize the data. The other bits are binary coded decimal values (see sidebar) and give the current minutes, hours, day of year (1 to 366), sign2 of UT1 time correction, UT1 time correction, year (last two digits only), leap year indicator, leap second pending indicator3, and daylight savings time4 indicator. Table 1 gives the details. Reserved bits are not currently in use and are sent as a zero bit. In addition to its unique time code, WWVB identifies by shifting its carrier phase 45° at 10 minutes past the hour and returning it to normal five minutes later. The WWVB time code is represented in Figure 2.

Self-Setting Atomic Clocks

The WWVB signal is used by many consumer 'self-setting' atomic clocks. Their performance varies with location, propagation and nearby interference sources. In 1999 WWVB power was increased, as was the antenna size, to improve performance. This made the use of 'self setting' clocks a lot more reliable. Usually these clocks set themselves only once a day, though they may try more often if their last attempt was unsuccessful. The rest of the time they rely on an internal crystal oscillator that should keep the clock accurate to less than a second over a 72-hour period (but as the wise ones say; "your mileage may vary".)

Listening for WWVB

Few ham receivers receive below 100 or 150 KHz. However, with a simple VLF converter you can receive almost down to DC. Heathkit and Palomar both made VLF converters that convert 10 - 500 KHz up to a ham band such as 3.51 to 4.0 MHz. If you have the capability to receive 60 KHz, give it a try. Put your receiver on CW, tune to 60 KHz and then slowly tune off frequency. If you hear a carrier that seems to change in level once a second you are hearing WWVB. For best results listen at night. On one of the recent two-meter nets I was able to retransmit the signal for a few seconds so others on frequency could hear it. Remember, since the modulation is happening only once per second your receiver's audio and AGC circuits are doing their best to make it hard for you to hear the signal modulation.

WWVB as a Frequency Standard

If you have a good VLF receiver and VLF antenna in the open and clear of interference sources, chances are you can receive WWVB reliably most of the time. Some people use large loop antennas since they are less sensitive to LF noise than wire antennas. The 60 KHz carrier frequency of WWVB is very accurate. It can be used as a reference to control a phased-locked crystal oscillator at a standard frequency such as 10 MHz. As long as the loop remains locked, the resulting standard frequency will be of laboratory quality. WWVB keeps its UTC time accurate to within 100 nanoseconds at the station site. The carrier frequency is accurate to a few parts in 1013 or about 2 ten-billionths of a hertz. Depending on the quality of the signal and equipment in use, a reference oscillator locked to WWVB can be accurate with an uncertainty of less that one part in 1012 when averaged over a couple of days!

If you have an Atomic clock, now you can be amazed at the system behind it. If you haven't bought one, they're very reasonably priced at Costco.

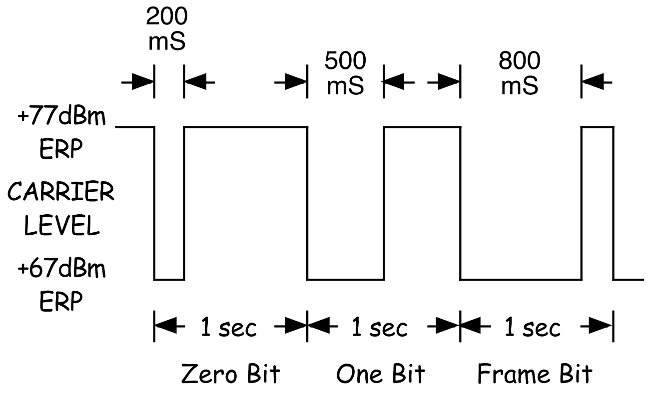
Notes:

The organization’s name recently changed from the International Earth Reference Service and they decided to keep the original abbreviation when the name was changed.

A plus sign for the UT1 correction value is indicated by bits 36 and 38 being one, and bit 37 being zero.

When this bit is a one it indicates that a leap second will be added to UTC at the end of the current month. The bit goes back to zero after the second is added.

The daylight savings time bits (bits 57 and 58) are zero during standard time (ST) and one during daylight savings time (DST). On the day the time changes from ST to DST bit 57 goes to one at 0000 hours and bit 58 follows 24 hours later. On the day the time changes from DST to ST bit 57 goes to zero at 0000 hours and bit 58 follows 24 hours later.



Bit #	Bit Description
0	Frame Ref. Bit, Pr
1	Minutes, 40
2	Minutes, 20
3	Minutes, 10
4	Reserved
5	Minutes, 8
6	Minutes, 4
7	Minutes, 2
8	Minutes, 1
9	Position Marker 1, P1
10	Reserved
11	Reserved
12	Hour, 20
13	Hour, 10
14	Reserved
15	Hours, 8
16	Hours, 4
17	Hours, 2
18	Hours, 1
19	Position Marker 2, P2
20	Reserved
21	Reserved
22	Day of Year, 200
23	Day of Year, 100
24	Reserved
25	Day of Year, 80
26	Day of Year, 40
27	Day of Year, 20
28	Day of Year, 10
29	Position Marker 3, P3
30	Day of Year, 8
31	Day of Year, 4
32	Day of Year, 2
33	Day of Year, 1
34	Reserved
35	Reserved
36	UT1 Sign, +
37	UT1 Sign, –
38	UT1 Sign, +
39	Position Marker 5, P5
40	UT1 Correction, 0.8 s
41	UT1 Correction, 0.4 s
42	UT1 Correction, 0.2 s
43	UT1 Correction, 0.1 s
44	Reserved
45	Year, 80
46	Year, 40
47	Year, 20
48	Year, 10
49	Position Marker 5, P5
50	Year, 8
51	Year, 4
52	Year, 2
53	Year, 1
54	Reserved
55	Leap Year Indicator
56	Leap Second Warning
57	Daylight Savings Time
58	Daylight Savings Time
59	Frame Ref. Bit, P0

Table 1 – Bit Description for the 60 bits sent each minute

Binary Coded Decimal:

Binary Coded decimal is a simple way of expressing a decimal digit using four bits. The four bits represent a weight of 8, 4, 2 and 1 respectively. (Usually the left-most bit is the eight). By adding the bits that are one you get the decimal number. For instance if the bits are 0010 then the number is a two. 0111 equals seven, 0100 equals eight, 1001 equals nine and 0000 equals zero. Combinations, like 1100, where the bits add to greater than nine are illegal.

73, from AF6C

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