TIME: It's Importance to Ham Radio

Frank M. Howell, PhD
K4FMH

"*Measurement is the process of making observations against some arbitrary standard or set of rules.* We create the appearance of absoluteness on the basis of arbitrary standards. Imagine the cave man running from one village to another with a torch to pass along fire, etc."

TIME, TIME INTERVAL, FREQUENCY

"Time and time interval are distinct concepts. **Time** is the marking of an event with respect to a reference origin. A **time interval** is a measurement of duration. The time of an event might be measured by hours, minutes, seconds, and a calendar date, while a time interval might be measured by the number of seconds between two events.

Frequency is the measure of the number of events that occur within a time interval, such as the number of oscillations of a voltage waveform within one second (George Kamas and Sandra L. Howe, Time and Frequency User's Manual, National Bureau of Standards Special Publication 559, U.S. Government Printing Office, Washington, DC, 1979; available online at https://www.scribd.com/document/297797230/NIST-Special-Publication-250-67).

Coordinated Universal Time (UTC) is a time system adopted by many countries in 1972. UTC is coordinated by the Bureau International des Poids et Mesures (BIPM) in France and is based on the weighted combination of atomic clocks located around the world. UTC occasionally changes by the addition of leap seconds. Other time systems are also used."
(https://ilrs.cddis.eosdis.nasa.gov/docs/timing/gpsrole.pdf)

TIME AND FREQUENCY USERS

Astronomic observatories use time to record celestial events and to perform simultaneous observations at distant locations. Very long base line interferometry uses time-synchronized recordings from widely separated radio astronomy observatories to map celestial radio sources as though from a *single enormous antenna*.

Electric power companies use frequency standards to maintain the 50 or 60 hertz line frequencies.

Computer networks need to synchronize distant nodes for billing and communications switching purposes.

Communications systems use both time and frequency to maintain carrier frequencies and data-bit phase timing.

Military and banking communications networks have special timing requirements for synchronization of data encryption and decryption equipment.

Frequency standards are required for radio and television stations, as well as for satellite communications transmitters. Tracking deep-space vehicles requires coordinated observations from synchronized ground stations.

All of these users require some combination of precise time, time interval, and frequency that attains accuracies measured in nanoseconds (10-9 or billionths of a second)."
(https://ilrs.cddis.eosdis.nasa.gov/docs/timing/gpsrole.pdf)

"The modern era of timekeeping began with the development of the quartz crystal oscillator.

In a 1918 patent application, Alexander M. Nicholson disclosed a piezoelectric crystal as the control element in a vacuum tube oscillator.

The first clock controlled by a quartz crystal was subsequently developed in 1927 by Joseph W. Horton and Warren A. Marrison." (Hackman and Sullivan, Resource Letter, Time and Frequency Measurement, 1996; available online at http://tf.nist.gov/general/pdf/616.pdf).

TIME AND AMATEUR RADIO

Most hams neglect the relationship between time and frequency. Hams might say "why do I need to be concerned about time when I'm simply operating my radio?"

So there's not much thought given to need for some sort of time reference to know that you're operating on the right frequency and staying in the bands. This explanation could lead right into some comments about time accuracy.

Let's get some definitions out of the way:

"Frequency is the rate of a repetitive event. If T is the period of a repetitive event, then the frequency f is its reciprocal, 1/T. Conversely, the period is the reciprocal of the frequency, T = 1/f." (Michael Lombardy NIST Fundamentals of Time and Frequency 2002 (CRC Press); available online at http://tf.nist.gov/general/pdf/1498.pdf).

Operating a radio might seem to be unrelated to the need for accurate time. My first rig, the Kenwood TS-830S, used time, but I was more concerned with tuning the grid! Frequency of the VFO involves time because frequency is the rate over a period of time.

But why is time and frequency increasing in importance to amateur radio operators and experimenters?

Mode is a key factor. Voice or CW in analog mode may not need a highly accurate time reference but digital modes do! Why? ***Phase measurement and its associated phenomena.***

Let's explore….

Note: transceivers with an optional crystal module. Who has one?

(**TXCO**, **Temperature Compensated Crystal Oscillator**) is the most common here. TXCO's are used to assist in various digital modes. As we get more involved with even voice being digital, time becomes increasingly important for frequency measurement.

For instance, FT8, Joe Taylor's newest digital mode for weak signal work requires highly similar time references on each end of a QSO. "Check your computer's clock. Timing is important for FT8: if your PC clock is a second or more wrong, you will have transmission and reception problems (i.e. signals won't decode reliably, if at all)." (Gary Hinson, ZL2IFB; see http://www.physics.princeton.edu/pulsar/K1JT/FT8_Operating_Tips.pdf).

Temperature is a key element in the stability of a crystal oscillator. An improvement over the TXCO is an **OXCO, Oven Controlled Crystal Oscillator** which shapes the temperature characteristics of the crystal.

This device is sometimes called a "crystal oven" (https://en.wikipedia.org/wiki/Crystal_oven):

"The oven is a thermally-insulated enclosure containing the crystal and one or more electrical heating elements. Since other electronic components in the circuit are also vulnerable to temperature drift, usually the entire oscillator circuit is enclosed in the oven. A thermistor temperature sensor in a closed-loop control circuit is used to control the power to the heater and ensure that the oven is maintained at the precise temperature desired. Because the oven operates above ambient temperature, the oscillator usually requires a warm-up period after power has been applied.[1] During this warm-up period, the frequency will not have the full rated stability."

The Wikipedia article on the crystal oven contains greater detail on various standards.
An even greater improvement is having a monitor in the mix which adjusts the oven: a **GPS-Disciplined Oscillator**.

How many use a Flex or other SDR transceiver? Often, an option is an external GPSDO to improve performance. The stock Flex 6500 transceiver comes with a TXCO but can be upgraded with a GPSDO module. From the Flexradio Systems website on the 6500 transceiver specifications:

- **10 MHz Reference Clock Stability:** 0.5ppm TCXO
- **GPSDO Frequency Stability (GPS locked):**[1] 5 x 10 (-12) over 24 hours

From the FLEX-6000 Hardware Reference Manual:

The FLEX-6700 and FLEX-6500 Signature Series radios have the ability to attain extremely precise frequency control through the use of an optional Global Positioning System Disciplined Oscillator (GPSDO) module. After satellite acquisition and synchronization, the GPSDO is capable of maintaining frequency accuracy to <5.0 x 10-12 in a stable temperature environment.

…

15.1 FREQUENCY CALIBRATION

The FLEX-6000 incorporates high quality low phase noise TCXOs and OCXOs for frequency accuracy and stability. However oscillators undergo a slow gradual change of frequency with time, known as aging and may require periodic frequency calibration using a known frequency standard.

The FLEX-6000 without an installed GPSDO can be calibrated by the user utilizing the automated routine provided in the SmartSDR for Windows client software. Before running this calibration routine, allow for the radio to temperature stabilize for at least 30 minutes before calibrating the frequency. Also refrain from frequency calibrating the radio in extreme high, low or fluctuating ambient temperatures as this will introduce error into the calibration process. Please refer to the SmartSDR for Windows Software User's Guide for detailed frequency calibration instructions.

(https://www.gpscentral.ca/manuals/FLEX-6000%20Hardware%20Reference%20Manual.pdf)

Now, other SDR transceivers (and receivers) may use a GPSDO as well but I use the Flex here as just an example.

Let's discuss how GPS signals work and how they're useful for frequency control.

"A **radio clock or radio-controlled clock** (RCC) is a clock that is automatically synchronized by a time code transmitted by a radio transmitter connected to a time standard such as an atomic clock. Such a clock may be synchronized to the time sent by a single transmitter, such as many national or regional time transmitters, or may use multiple transmitters, like the **Global Positioning System**. Such systems may be used to automatically set clocks or for any purpose where accurate time is needed.

One common style of radio-controlled clock uses time signals transmitted by dedicated terrestrial longwave radio transmitters, which emit a time code that can be demodulated and displayed by the radio controlled clock. The radio controlled clock will contain an accurate time base oscillator to maintain timekeeping if the radio signal is momentarily unavailable. Other radio controlled clocks use the time signals transmitted by dedicated transmitters in the shortwave bands. Systems using dedicated time signal stations can achieve accuracy of a few tens of milliseconds.

GPS satellite navigation receivers also internally generate accurate time information from the satellite signals. Dedicated GPS timing receivers are accurate to better than 1 microsecond; however, general-purpose or consumer grade GPS may have an offset of up to one second between the internally calculated time, which is much more accurate than 1 second, and the time displayed on the screen.

Other broadcast services may include timekeeping information of varying accuracy within their signals." (https://en.wikipedia.org/wiki/Radio_clock)

GPS Clocks

"Many modern radio clocks use the Global Positioning System to provide more accurate time than can be obtained from terrestrial radio stations. These GPS clocks combine time estimates from multiple satellite atomic clocks with error estimates maintained by a network of ground stations. Due to effects inherent in radio propagation and ionospheric spread and delay, GPS timing requires averaging of these phenomena over several periods.

No GPS receiver directly computes time or frequency; rather they use GPS to discipline an oscillator that may range from a quartz crystal in a low-end navigation receiver, through oven-controlled crystal oscillators (OCXO) in specialized units, to atomic oscillators (rubidium) in some receivers used for synchronization in telecommunications. For this reason, these devices are technically referred to as GPS-disciplined oscillators.

Note that GPS units intended primarily for time measurement as opposed to navigation can be set to **assume the antenna position is fixed**. In this mode, the device will average its position fixes. After approximately a day of operation, it will know its position to within a few meters. Once it has averaged its position, it can determine accurate time even if it can pick up signals from only one or two satellites." (https://en.wikipedia.org/wiki/Radio_clock)

For Use in Amateur Radio:

SDRs can use an external time reference for enhanced operation as just described. Recall the phase quadrature (I-Q) manipulation of RF signals once the Analog to Digital Converter (ADC) has transformed them. Analyzing the phase of the two signals need as accurate a time reference as available, especially for digital modes, since the difference between I and Q will have time-reference measurement error that is inherent. An external GPSDO as a reference signal for more precise frequency control reduces this error.

There is another use of frequency (and voltage, current, etc.) reference signals: **the experimenter's workbench**.

Here, there is a fork in the road: just wanting a good frequency reference so that test equipment results are as accurate and consistent with one another as possible OR become a "time nut".

ASK: *who has a watch? Who has more than one watch?*
"The man with one watch knows what time it is. The man with two is never sure" (Unknown).
(Relative error vs. absolute error)

For precise measurement of time without regard to amateur radio workbench issues, see the very well-known website maintained by John Miles KE5FX at http://k3fx.com. Very good resource!

I use GPSDO by a Chinese company (amoj1010; http://stores.ebay.com/no1equipment?_trksid=p2047675.l2563) and a British company, Leo Bodnar (https://www.leobodnar.com).

The Chinese GPSDO is in a standard metal project box, runs on 12 vdc and it about the size of a bar of soap. (see below) It's based upon a repurposed Trimple GPS unit that likely came from the cellular telephone industry.

The Leo Bodnar unit has a more professional finish (see below).

The antenna is an inexpensive radome style antenna (see specs below).

It feeds my test equipment external references (all from the same reference frequency of 10 mhz. This 3 freq counters, 1 signal generator, 1 Vector Network Analyzer. I have an inexpensive GPS radome antenna sitting on a shelf in my workbench area but will relocate it to the peak of my roof very soon so I can get a "clear sky" view of satellites.

My workbench has a rolling IT rack with most of my test equipment rack-mounted. This includes an HP 5334B 1.3 ghz Freq Counter, HP 8657B2 ghz Freq Gen, HP 5386a 1.2 ghz Freq Counter, Tek FC504 Counter/Timer, HP 3586C Selective Level Meter, and an SDR-KITS Vector Network Analyzer.

These are just the ones with an external frequency reference input. My venerable HP 8640B uses 5mhz as a reference input but is not GPIB addressable. I have a frequency divider to use the GPSDO's 10mhz signal for that input.

All have the "same error" by virtue of the daisy chain 10 mhz reference signal from the GPSDO from China. The Leo Bodnar is reference frequency agile and outputs two separate reference signals. I bought it for the VNWA but have not put it online yet.

This common reference signal keeps this test equipment in sync with each other and, while not completely accurate, gives the same relative error among the test units. The GPSDO yields very high accurate frequency output once it has achieved a good position lock and disciplining over a day or two. I keep it running 24/7 in my workbench area. The Leo Bodnar unit has yet to be put into use but it will soon with the Vector Network Analyzer.

Questions?

Note: See HamRadio 360 Workbench, Episode 32 for additional notes (http://hamradio360.com/index.php/2017/09/12/ham-radio-360-workbench-32-gps-disciplined-oscillators-and-frequency-references/).

Chinese GPSDO from eBay seller amoj1010:

Leo Bodnar Frequency-Agile GPSDO:

GPS Antenna:

GPS-TMG-20N, 20 dB Internal Amplifier

The GPS-TMG-20 timing reference antennas are specifically designed for long-lasting, trouble-free deployments in congested cell-site applications. Their 20 dB high gain amplifier is well suited to address attenuation issues associated with applications requiring longer cable runs.

The proprietary quadrifiliar helix design, coupled with multistage filtering provides superior out-of-band rejection and lower elevation pattern performance than traditional patch antennas.

Their unique radome shape sheds water and ice, while eliminating problems associated with bird perching. The antenna may be purchased by itself or with pipe mounting hardware. Custom models or site kits options are also available.

This antenna is made of materials that fully comply with provisions stipulated by EU directives RoHS 2002/95/EC.

This antenna also features ESD, reverse polarity protection and transit voltage suppression.

GPS-TMG-20N

Antenna Electrical Specifications

Frequency Band	Antenna Gain	Nominal Impedance	VSWR	Polarization
1575.42 +/- 10 MHz	3.5 dBic	50 ohms	< 1.5:1	Right hand circular

Connector	Input/Output
N, female (one - bottom fed)	• ESD protected • Reverse polarity protection • Transient voltage suppression on output

Mechanical Specifications

Antenna Dimensions	Shipping Dimensions	Antenna Weight	Shipping Weight	Radome Color
5" H x 3.2" D (126 H x 81 mm)	7.5" L x 4.4" W x 3.8" D (190 x 112 x 96 mm)	0.6 lbs (0.3 kg)	1.9 lbs (0.9 kg)	White

Environmental Specifications

Temperature Range	Humidity
- 40°C to + 85°C	95%

Mounting

All mounting options fit pipes of 1"-1.45" (25 mm-37 mm) maximum diameter.

Model	Options
GPS-TMG-20N	Does not include mounting hardware.
GPS-TMG-20NMS	Includes universal mounting hardware consisting of collar (part #540438A000) and pipe clamp (part #39A000).
GPS-TMG-20NCS	Includes economy collar mount (part #13315-1).

MAXRAD

Low Noise Amplifier Specifications

Frequency Band: 1575.42 center frequency 3 dB bandwidth +/- 10 MHz
Amplifier Gain: 20 dB +/- 3 dB
Nominal Impedance: 50 ohms
Output VSWR: < 2.0:1
Maximum Noise Figure: ≤ 2.5 dB @ +25°C including pre-selector
DC Voltage: 3.3 - 6.0 V (regulated)
DC Current: 20 mA, 30 mA max @ 5V
Polarization: Right hand circular
Filtering: 3 stage filters including pre-selector
Out of band rejection: -60 dB @ 1575.42 +/- 50 MHz