A Comparison of Frequency Calibration Techniques for High Stability Oscillators
by K6JEY Doug Millar

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Doug Millar K6JEY

2791 Cedar Ave.

Long Beach, Ca. 90806

dmillar@moonlink.net

The growing use of the upper microwave bands and high stability oscillators such as rubidium controlled ones, has necessitated the exploration by amateurs of means of calibrating those oscillators. There are a variety of means of calibration and a wide variety of techniques used with them. This presentation will cover most of the more available ones with an eye toward which equipment is readily available and ease of use.

First a few basics:

In frequency calibration, one compares the drift of a signal over a period of time. The drift is called the delta t and the time period is called t.

(t is the Greek Tau) Thus if you are watching an oscillator drift 1 microsecond over a period of an hour, or 3600 seconds, the resulting stability is .000001/3600 = 2.7 x10-10. The answer is said, "2.7 parts in ten to the minus tenth". It should be noticed that the more stable an oscillator is the more need there is to see fine differences in stability, down to nanoseconds. The other option is to see differences in microseconds, but watch that difference over a long period. Here are two examples:

1.A rubidium oscillator is monitored by a reference that can resolve 10ns. Over a one-hour time, the monitor can see changes as little as 2.7x10-13.

2. In contrast, another monitor can only resolve down to one microsecond. If the oscillator is monitored for an entire day, (000001/86,400) it can only resolve 1.1x10-11.

Test Setup Types

In looking at different test set ups and their applicability I would like to offer the following suggestions. One should have a high stability oscillator such as a rubidium and a monitor that can establish and track its accuracy. From and oscillator such as rubidium, or some type of disciplined oscillator, frequency comparisons can be most easily made by the use of an oscilloscope, a time interval counter, or frequency difference meter.

There are a number of frequency monitors available. An older unit is the Austron 2100f, which locks on to a Loran C signal and compares it to a local standard. It can resolve down to 10ns. Although very accurate, it takes about an hour to make a good measurement. Another system is to use the venerable VLF Comparator with a chart recorder. They use the signal from WWVB at 60khz and do a phase comparison with a local source. These are available cheaply, as is the paper, and if one is patient a rubidium can be adjusted and monitored with one. They are good for averaging at about 1microsecond. For that reason high stability oscillators can take one, or several, days to calibrate. Both the LoranC at 100khz and WWVB at 60Khz signals are affected by changes in the ionosphere and variations can confuse measurements.

The GPS system has offered another technique. By using either a dedicated comparator such as the Trimble 4000ax unit or the Synergy Systems UT+ kit one can compare one's frequency to the GPS system. The Trimble unit does direct comparison. The UT+ provides a 1pulse per second output that, using a time interval counter can be compared to another 1pps output. There are also a variety of "disciplined oscillator" commercial units and several amateur level kits. The GPS system is stable to about 40ns for measurement when the receiver is in a position lock mode. This means that frequency measurements for high stability oscillators will take several hours to get a good settled reading. While inexpensive to build, there is a significant learning curve to contend with to get them working well. Nevertheless, disciplined oscillators represent a very cost effective way to provide a very stable reference source. As can be seen, having a master oscillator with a monitor that is able to track its stability over a long period provides a very high level of confidence for further measurement. By the same token, using these monitors for direct calibration can be cumbersome and at least very time consuming.

Comparison Techniques

Once one has a calibrated master high stability source, then one is able to adjust other oscillators to frequency very quickly. There are three main techniques that can accomplish this.

The first is a "Frequency Difference Meter" such as the Tracor 537A. It uses 1mhz inputs from a reference source and a unit to be tested and displays the difference directly in x times 10&endash;x. For instance, the range switch selects decades of 10 &endash;7,-8,-8,-10 and &endash;11, and the meter reads out the parts in that range. It is a very quick system and easy to use. However, it uses 1mhz inputs. Units are also fairly rare and can be expensive.

The second is to use a time interval counter such as the HP 5370A. The TIC can resolve down to 20ps and reads frequency at 100 mhz to 12 digits. One simply plugs the reference into one channel and the device to be tested in the other and adjusts for minimum difference. The TIC even has limited math abilities. However, this level of equipment must have a good internal oscillator and units can be expensive.

The third method is to use an oscilloscope. Using a Tek475 scope, the trigger is switched to external and the horizontal sweep is set to 1ns. The reference is connected as the trigger and the device to be adjusted is connected to channel one. With the input sensitivity set quite high, it is easy to see parts of the sine wave traveling across the screen. The oscillator to be tested is moved so that the trace slows down as much as possible. The time it takes for the trace to cross one major division (1ns) divided into 1ns is the stability of the oscillator. It is very fast, reliable and inexpensive. Of course one can change the horizontal sweep speed to suit the range of stability of the oscillator.

Other Factors Effecting Stability

Oscillator stability can be affected by a number of factors such as magnetic fields, temperature and vibration. The greatest effect is that of temperature both for crystal and rubidium oscillators. In terms of using them in the field for microwave work, it would be wise to install either type of oscillator where either the ambient equipment heat or sunlight did not adversely affect the stability of the oscillator.

Having adjusted an oscillator to frequency it is then important to characterize the equipment so that when one is in the field, one has some idea of what to expect. In the Los Angeles are we have several 10ghz beacons with known accuracies that provide a meaningful reference for frequency. Our microwave club, the San Bernardino Microwave Society, regularly holds meetings to do frequency calibration and has a "get ready" session in the field to check out the equipment in the summer.

A Club Approach to Frequency Calibration

It is probably too much to think that everyone in a microwave group will have the resources to do frequency calibration, but it is not unrealistic for a club to pool its resources so that a frequency calibration set up is available to members when needed. It is hoped that this presentation and paper might act as a guide for those wishing to set up a frequency calibration system.

There are a wide variety of resources available for the study of time and frequency calibration. A few are listed at the end of the article. I will be happy to correspond by email on the subject with those interested in pursuing the subject.

A SpectraCom receiver and FRS rubidium source:

My equipment rack with a Tracor 537 a Frequency Difference Meter, Austron 2100f Loran Receiver, and a Trimble 4000ax GPS receiver.

Web Resources:

US Naval Observatory

http://tycho.usno.navy.mil/

Brook Shera's Disciplined Oscillator

http://www.rt66.com/~shera/index_fs.htm

Doug Horgath's Site on Time

http://www.niceties.com/time.html

Datum makes Rubidium Oscillators and has data sheets

http://www.datum.com/

Synergy Systems sells a plug-n-play GPS receiver for time comparison.

http://www.synergy-gps.com/

Hewlett Packard has published two application notes on time and frequency that are quite informative they are #51-1 and 2.

back to SBMS homepage