Application Note: GPS Disciplined Sources

The Problem with Frequency Sources & Generators

There are many frequency sources commercially available in the market place. Many frequency sources are in the class of Function Generators, Sweep Generators, and the like. These frequency sources are very flexible and should be part of any electronic developer's tools. However, if one is in the business of telecommunications, Cellular or RF engineering, a frequency source with a higher degree of accuracy is needed.

A frequency standard is a stable oscillator used for frequency calibration or reference. A frequency standard generates a fundamental frequency with a high degree of accuracy and precision. A frequency reference is an instrument used for providing a stable frequency of some kind.

Among the most stable frequency references in the world are cesium standards and rubidium standard or rubidium atomic clocks. However, these can be expensive. Since the 1980's, the GPS satellite system has been in use and provides the means for obtaining, not only position and altitude information, but very accurate timing information. By monitoring the GPS system, one can compute the frequency error from any frequency source. Once this error is known, corrections can be applied to adjust the frequency output.

Severity of the Frequency Error

Today's RF and Cellular systems require very accurate frequency settings due to narrowing and precisely controlled bandwidths. A typical crystal oscillator may be specified at having a 100 ppm, 50 ppm, or even 25 ppm error. A typical frequency reference value is 10 MHz and is commonly used in almost all commercial test equipment. This frequency error translates to 1000 Hz, 500 Hz, or 250 Hz error for a 10 MHz source.

While this is generally not a problem for typical electronics development, this is catastrophic for Cellular or RF engineering applications. This error propagates throughout the entire design. That is, if one has a Cellular system that is operating at 881.5 MHz (center of the GSM band), the resulting error is 88,150 Hz, 44,075 Hz, and 22,038 Hz, respectively for the above errors. The GSM channel bandwidth is 200 kHz. Thus, one could be off by as much as 88 kHz error.

This error is due to four major sources:

- Environmental temperature
- Load variations
- Voltage variations
- Inherent Frequency error (crystal cut)

There are various means to control the errors. One of the more common ways is to use a temperature-compensated crystal oscillator (TCXO) or an oven-controlled crystal oscillator (OCXO). While these oscillator types provide a significant improvement in the temperature stability, there is still the issue with the inherent frequency accuracy.

Frequency Stability vs. Frequency Accuracy

While both the TCXO and OCXO oscillator can provide frequency stability on the order of 100's of parts per billion (ppb), the frequency accuracy is still in error due to the ability to precisely cut the crystal. A typical TCXO may have a frequency accuracy of 5 ppm to 1 ppm with stabilities on the order of 300 ppb. This may still be too ambiguous for Cellular or RF Engineering applications. Using the above GSM example, this would translate to 4408 Hz and 882 Hz error, respectively. Still, too much for most Cellular or RF applications.

Low-cost Approach for Stable, Accurate Frequency

Since frequency stability is extremely important in any Telecommunications, Cellular or RF Engineering application, the solution must begin with a highly stable solution. A well-designed OCXO will guard against temperature, voltage and load variations. But there is still the fundamental problem of frequency accuracy.

By comparing the frequency output from the OCXO oscillator against a known, highly accurate frequency source, corrections can be applied to the OCXO so that the frequency can be corrected to within 1 ppb. For the above GSM example, this would translate to 0.88 Hz frequency error. So now we have the means to correct environmental and inherent errors in a well-designed OCXO oscillator. This is the basis for our DS-1000 and FR-1000 series Frequency Standards.

However, what if one needs a frequency other than 10 MHz? That's where our DS-2000 and FR–2000 series Frequency Standards come in. At the time of manufacture, we can calibrate and adjust the frequency output to any frequency desired in the 4 MHz to 35 MHz range to within, typically, 1 Hz of your desired output.

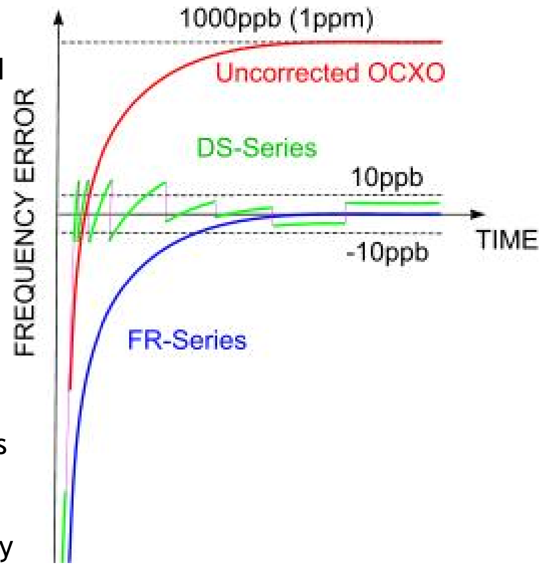
Different Solutions to a Common Problem

The GPS system provides the means for obtaining the frequency error in any oscillator. However, the GPS system is not always as accurate as it claims to be at all times during the day. This is due to various reasons but primarily it is due to the satellite constellation used to obtained a timing solution at a given time.

The GPS system accuracy is further degraded by a poorly located GPS antenna and other radio interference from nearby sources. While an indoor GPS antenna can be used to obtain signals from the GPS system, the resulting solution is not suitable for making frequency error corrections. Thus, in our proprietary error correcting algorithm, we monitor the GPS health status and make error corrections only when certain conditions are available, most notably, the position of the GPS constellation to give a timing solution. Further, since the GPS constellation is always changing, the timing solution is also going to change. Thus, one can envision different strategies to achieve the desired error so the OCXO oscillator's frequency can be corrected.

Frequency Error Correction

If one were to monitor a typical Signal Generator output from a cold start to thermal steady-state conditions, one would see a significant frequency shift (many kilohertz). Even with a stable OCXO Source, the frequency error over time would look something like the red trace shown here. Although the OCXO warms up quickly, the absolute error can still be off from 5 ppm to 1 ppm depending on the model. At a 1 ppm error, the frequency error is still too large to be used in RF communication systems.



Our FR-Series Frequency Standards “shift” this error by calibrating the various errors seen by the oscillator as shown in the blue trace. This “correction factor” is stored within each unit and is unique to each system. Thus, every time the FR-Series Frequency Standard is turned on, the unit’s STBY LED is active to indicate to the user that the internal circuitry is still in the “warm-up” phase.

The only error that remains after calibration of an FR-Series Frequency Standard is the aging of the internal OCXO. This error is common to all oscillator systems. However, the error is bounded by the specifications of the OCXO, typically less than 4.5 ppm over a 10 year period. Thus, depending on the application, the FR-Series may not need recalibrating. However, if it does, Diarcy Technologies can re-calibrate the unit for a nominal cost.

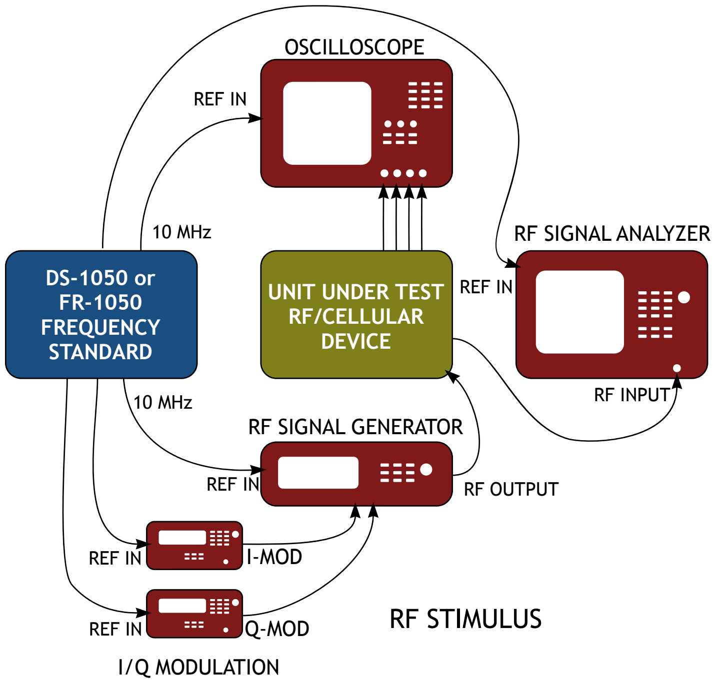
Our DS-Series Frequency Standards take a different approach as shown in the green trace. Since GPS signals are available, the DS-Series Frequency Standards are constantly computing the error in the oscillator system. Every time a new correction factor is computed, it is applied to the oscillator system and also stored in memory. This stored value is used on subsequent power-ups. This can also be useful if the GPS system is not active since the latest correction factor has already been applied. Any long-term aging of the internal OCXO is accounted for in the constantly updating algorithm. Even after 10 years, the internal oscillator system continues to be updated as long as the GPS signals are available.

Since the DS-Series and FR-Series take different approaches to removing the frequency and thermal errors, different calibration algorithms are used within each series. In both cases, the GPS system error must also be taken into account. This error is inherent in the GPS system, usually dominated by the satellite geometry at a given time. However, over a long period of time (hours or days), the GPS system is very accurate.

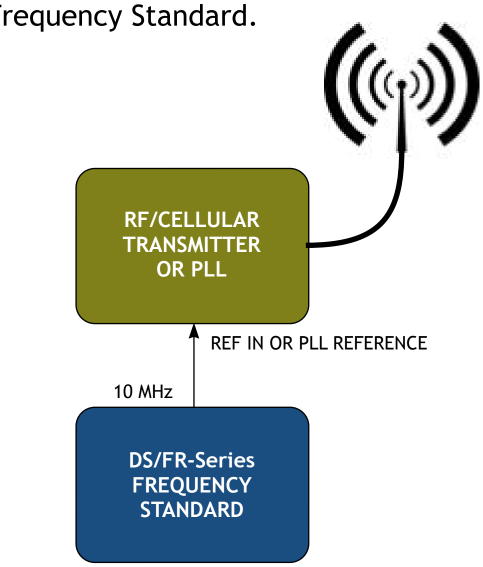
Thus, in the FR-Series Frequency Standard, the calibration used takes many hours, sometimes up to 5 to 10 hours. Whereas in the DS-Frequency Series Frequency Standard, the integration time is less.

Applications

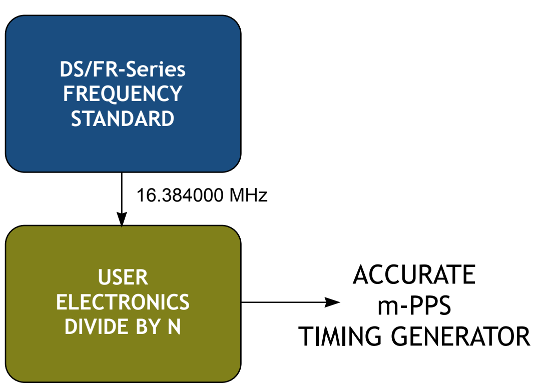
Here are some examples of using either the DS-Series or FR-Series Frequency Standard.



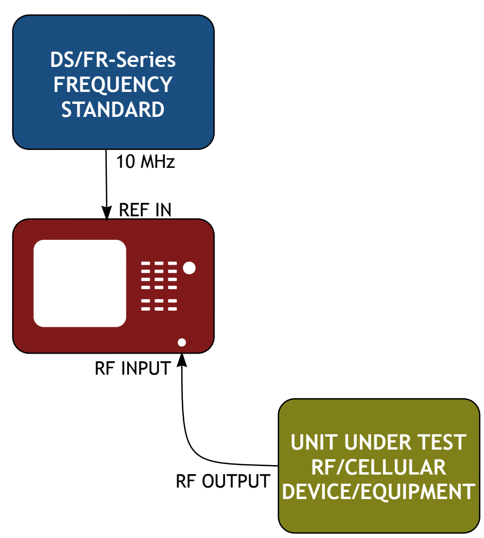
COMPLETE FREQUENCY SYNCHRONIZATION WITH UNIT UNDER TEST AND ALL YOUR TEST EQUIPMENT



ACCURATELY CONTROLLER YOUR BASE STATION RF TRANSMITTER



MAKE AN ACCURATE TIMING REFERENCE



NOW MAKE ACCURATE FREQUENCY MEASUREMENTS WITH YOUR TEST EQUIPMENT