Oscillator Frequency Performance Measurements

By Bertrand Zauhar, VE2ZAZ
ve2zaz@amsat.org
http://ve2zaz.net
THIS PRESENTATION

- Oscillator Performance Definitions
- Frequency Offset Measurement Methods
- Anatomy of:
  - Frequency Counter
  - Time Interval Analyzer
- Types of Crystal Oscillators
- Concept of Stability
- Stability Measurement (Short, Long term)
  - Practical Setups
  - Results
- Web References
Oscillator Performance Definitions

- **Very Short Term Variations**
  - Occur within a second or less. They usually manifest themselves as frequency (or phase) modulation (or amplitude modulation), and they are usually measured in the frequency domain using spectrum analyzers or phase noise meters.

- **Short Term Variations**
  - Occur between one second and several minutes to an hour. Usually we consider short term variations to include the effects of temperature variation, but to exclude the effects of aging for instance.

- **Long Term Variations**
  - Go from minutes to hours or days, sometimes months or more. Aging is the prime cause.
Oscillator Performance Definitions

- **Stability**
  - indicates how well an oscillator can produce the same time or frequency **offset** over a given time interval.

- **Accuracy**
  - is the degree of conformity of a measured or calculated value to its definition. Accuracy is related to the offset from an ideal value.

The relationship between accuracy and stability.
**Frequency Offset:**

**Oscilloscope Method**

Two sine waves with a changing phase relationship.

Phase comparison using an oscilloscope.

\[ f(\text{offset}) = \frac{-\Delta t}{T} \]
Frequency Offset: Frequency Counter Method

\[ f(\text{offset}) = \frac{f_{\text{measured}} - f_{\text{nominal}}}{f_{\text{nominal}}} \]
Anatomy of Basic Frequency Counter
Some Suitable Frequency Counters

HP 5334A / B

HP 5386A

HP 53131A / 53132A

HP 5335A / B

HP 5345A
Frequency Offset: 
**Time Interval Counter Method**

Measurement using a time interval counter.

\[ f(\text{offset}) = \frac{-\Delta t}{T} \]
Anatomy of Time Interval Analyzer
Some Suitable T.I. Counters / Analyzers

- Stanford Research SR620
- HP 5370A / B
- HP 5371A / 5372A
Types of Crystal Oscillators

- Crystal Oscillator (XO)

- Temperature Compensated XO
Types of Crystal Oscillators (Cont.)

- Oven-Controlled XO

SWEET SPOT

~75°C
# Oscillator Comparison

## Table 1: Comparison of frequency standards' salient characteristics

<table>
<thead>
<tr>
<th></th>
<th>Quartz Oscillators</th>
<th>Atomic Oscillators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TCXO</td>
<td>MCXO</td>
</tr>
<tr>
<td><strong>Accuracy</strong> (per year)</td>
<td>$2 \times 10^{-6}$</td>
<td>$6 \times 10^{-8}$</td>
</tr>
<tr>
<td><strong>Aging/year</strong></td>
<td>$5 \times 10^{-7}$</td>
<td>$2 \times 10^{-8}$</td>
</tr>
<tr>
<td><strong>Temp. Stab.</strong> (range, °C)</td>
<td>$5 \times 10^{-7}$ ($-55$ to $+85$)</td>
<td>$3 \times 10^{-8}$ ($-55$ to $+85$)</td>
</tr>
<tr>
<td><strong>Stability, $\sigma_f(t)$ (1s)</strong></td>
<td>$1 \times 10^{-9}$</td>
<td>$3 \times 10^{-10}$</td>
</tr>
<tr>
<td><strong>Size (cm$^2$)</strong></td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td><strong>Warmup time (min.)</strong></td>
<td>0.1 (to $1 \times 10^{-6}$)</td>
<td>0.1 (to $2 \times 10^{-5}$)</td>
</tr>
<tr>
<td><strong>Power (W) (at lowest temp.)</strong></td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Price (~$)</strong></td>
<td>100</td>
<td>1,000</td>
</tr>
</tbody>
</table>

*Including environmental effects (note that the temperature ranges for Rb and Cs are narrower than for quartz).*

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**Best of Both Worlds: GPS-Disciplined OCXO!**
Illustration of Short Term Stability

- Depends on Integration (Averaging) Time

**Frequency Noise and \( \sigma_y(\tau) \)**

- Graphs showing frequency noise with different averaging times
- \( \Delta \tau \) and \( \Delta f \) with averaging times of 0.1 s and 1.0 s
- \( \sigma_y(\tau) \) plotted against averaging time (\( \tau \), s)
The Allan Deviation

- Allan Deviation
  - A statistical tool that calculates how accurately you can predict the occurrence of the next pulse, transition or event, based on measurements made on previous pulses, transitions or events.
  - For instance, you may have an oscillator that drifts in a predictable way, and it's Allan Deviation would be good (low), or you may have an oscillator that has little drift on average, but wanders a lot around its nominal frequency (phase noise), and its Allan Deviation would be bad (high).

\[
\sigma_y(\tau) = \sqrt{\frac{1}{2(M-1)} \sum_{i=1}^{M-1} (y_{i+1} - y_i)^2}
\]
The Allan Deviation

- Typical Allan Deviation Curves
Oscillator Comparison (cont.)

- Relative Allan Deviation of Various Oscillator Technologies
Method 1: Frequency Measurements using a Time Interval Counter

Note: Reference Oscillator must be more stable than Device Under Test!

Good Counter Candidates:
HP 5370A/B, HP 5334A/B, HP 5345A, HP 5386A, HP 5371/72A.
GPIB (IEEE-488) option required!

Some Useful Software:
Labview, KE5FX Utilities, DF6JB's Plotter, Spreadsheet
Method 1: Short Term Results

Short Term Stability of Various OCXOs vs. VE2ZAZ GPS_Standard

- HP 70310A
- HP 8644A
- HP 5370B
- HP 5350B
- Isotemp mini-OCXO
Method 2: Frequency Measurements using a Receiver / Sound I/F / PC

Note:
Reference Oscillator must be more stable than Device Under Test!

Receiver Candidates:
HP 3586A/B/C,
Rhode & Schwartz,
General Coverage Receivers (Free Running)

Some Useful Software:
Spectrum Lab,
DF6JB's Plotter,
Spreadsheet
Method 2: Short / Long Term Drift
Method 2: Effects of Temperature

Heat Gun!
Method 3: Frequency Measurements
Freq Mult. / Mixing / Sound I/F / PC (VE2AZX)

![Diagram of Method 3](image)

- SMHU Sig Gen
- Reference clock
- HP 5334B Counter
- Scope
- Isolation Xfrm
- Computer Sound Card
- Running Spectrum Lab
- Noise x200
- HP 5254A Multiplier
- DUT
Method 4: Time Interval Measurements using a Time Interval Counter

Note:
Reference Oscillator must be more stable than Device Under Test!

Good Counter Candidates:
HP 5370A/B, HP 5334A/B, HP 5345A, HP 5371/72A.
GPIB (IEEE-488) option required!

Some Useful Software:
Labview, KE5FX Utilities, DF6JB's Plotter, Spreadsheet
Some Facts of Stability Measurement

• **Short Term Measurements**
  – Need a **clean and stable** reference, not an accurate reference.
  – Mix-and-Match measurement of various OCXOs will reveal the best units.

• **Long Term / Very Long Term Measurements**
  – Need a **stable** reference, not an accurate reference.
    • Free running OCXO References will drift if not disciplined.
  – Averaging math will remove short term stability components.
  – GPS disciplining or Atomic clock best.

• **All Cases**
  – Need to let Instruments and PC (Sound Card) warm up a few hours.
  – Be prepared to purchase several OCXOs and/or Instruments equipped with OCXOs.
    • Ebay: ~ 20$ to $80 each OCXO.
Some References

- **Spectrum Lab Software**
  - [http://www.qsl.net/dl4yhf/spectra1.html](http://www.qsl.net/dl4yhf/spectra1.html)
- **DF6JB's Plotter Software**
- **HP: Fundamentals of Time Interval Meas. (AN 200-3)**
- **NIST: Fundamentals of Time and Frequency**
- **KO4BB: FAQ#1: Measuring Oscillators Stability**
- **VE2ZAZ's Website**
  - [http://ve2zaz.net](http://ve2zaz.net)
- **VE2AZX's Website**
  - [http://ve2azx.net](http://ve2azx.net)