Frequency (and Time) Standards

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Why do you need a frequency Standard?

• Need to know what frequency you are on.
• Licence conditions
• Use of narrower bandwidths
• Also increasingly accurate timing is required for many of the newer digital modes.
History of Frequency Accuracy

- Early pioneers used spark and the bandwidth was large; frequency accuracy was 1 – 10%.
- Presently digital modes at microwave frequencies require accuracies of the order of $1 \text{ in } 10^9 - 10^{10}$. 
# History of Timekeeping

<table>
<thead>
<tr>
<th>Standard</th>
<th>Resonator</th>
<th>Date of Origin</th>
<th>Timing Uncertainty (24 h)</th>
<th>Frequency Uncertainty (24 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sundial</td>
<td>Apparent motion of the sun</td>
<td>3500 B.C.</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Verge escapement</td>
<td>Verge and foliet mechanism</td>
<td>14th century</td>
<td>15 min</td>
<td>$1 \times 10^{-2}$</td>
</tr>
<tr>
<td>Pendulum</td>
<td>Pendulum</td>
<td>1656</td>
<td>10 s</td>
<td>$1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Harrison chronometer (H4)</td>
<td>Spring and balance wheel</td>
<td>1759</td>
<td>350 ms</td>
<td>$4 \times 10^{-6}$</td>
</tr>
<tr>
<td>Shortt pendulum</td>
<td>Two pendulums, slave and master</td>
<td>1921</td>
<td>10 ms</td>
<td>$1 \times 10^{-7}$</td>
</tr>
<tr>
<td>Quartz crystal</td>
<td>Quartz crystal $^{87}$Rb resonance (6,834,682,608 Hz)</td>
<td>1927</td>
<td>10 µs</td>
<td>$1 \times 10^{-10}$</td>
</tr>
<tr>
<td>Rubidium gas cell</td>
<td>$^{133}$Cs resonance (9,192,631,770 Hz)</td>
<td>1958</td>
<td>100 ns</td>
<td>$1 \times 10^{-12}$</td>
</tr>
<tr>
<td>Cesium beam</td>
<td>$^{133}$Cs resonance (9,192,631,770 Hz)</td>
<td>1952</td>
<td>1 ns</td>
<td>$1 \times 10^{-14}$</td>
</tr>
<tr>
<td>Hydrogen maser</td>
<td>Hydrogen resonance (1,420,405,752 Hz)</td>
<td>1960</td>
<td>1 ns</td>
<td>$1 \times 10^{-14}$</td>
</tr>
<tr>
<td>Cesium fountain</td>
<td>$^{133}$Cs resonance (9,192,631,770 Hz)</td>
<td>1991</td>
<td>100 ps</td>
<td>$1 \times 10^{-15}$</td>
</tr>
</tbody>
</table>
# Measurement Uncertainties

<table>
<thead>
<tr>
<th>SI Base Unit</th>
<th>Physical Quantity</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candela</td>
<td>Luminous intensity</td>
<td>$1 \times 10^{-4}$</td>
</tr>
<tr>
<td>Kelvin</td>
<td>Temperature</td>
<td>$3 \times 10^{-7}$</td>
</tr>
<tr>
<td>Mole</td>
<td>Amount of substance</td>
<td>$8 \times 10^{-8}$</td>
</tr>
<tr>
<td>Ampere</td>
<td>Electric current</td>
<td>$4 \times 10^{-8}$</td>
</tr>
<tr>
<td>Kilogram</td>
<td>Mass</td>
<td>$1 \times 10^{-8}$</td>
</tr>
<tr>
<td>Meter</td>
<td>Length</td>
<td>$1 \times 10^{-12}$</td>
</tr>
<tr>
<td>Second</td>
<td>Time interval</td>
<td>$1 \times 10^{-15}$</td>
</tr>
</tbody>
</table>
Measurement Uncertainties and Alan Deviation

• All frequency sources have some degree of frequency variation. This can take the form of:
  1. Phase noise
  2. Amplitude noise
  3. Slow drifts or instability
Measurement Uncertainties and Allan Deviation

- Short term fluctuations will show up with short sample times but average out over long sample times.
- Long term variations will only show over long sample times.
- A plot of this variability versus sample time is referred to as an Allan deviation plot. These are widely used to characterise oscillator stability.
Hardware – What are the options?

<table>
<thead>
<tr>
<th>Oscillator Type</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Oscillator (XO)</td>
<td>$10^{-4} - 10^{-6}$</td>
</tr>
<tr>
<td>Temperature compensated XO (TCXO)</td>
<td>$10^{-7} - 10^{-8}$</td>
</tr>
<tr>
<td>Oven Controlled XO (OCXO)</td>
<td>$10^{-8} - 10^{-9}$</td>
</tr>
<tr>
<td>Double Ovened XO (DCOXO)</td>
<td>$10^{-9} - 10^{-10}$</td>
</tr>
<tr>
<td>Rubidium Locked (Rb)</td>
<td>$10^{-10} - 10^{-11}$</td>
</tr>
<tr>
<td>GPS Disciplined XO (GPSDO)</td>
<td>$10^{-10} - 10^{-12}$</td>
</tr>
<tr>
<td>Cesium Based Oscillators/Clocks</td>
<td>$10^{-12} - 10^{-15}$</td>
</tr>
</tbody>
</table>
# Hardware – What Does it Cost?

<table>
<thead>
<tr>
<th>Oscillator Type</th>
<th>Accuracy</th>
<th>$/£</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Oscillator (XO)</td>
<td>$10^{-4} - 10^{-6}$</td>
<td>1 - 30</td>
</tr>
<tr>
<td>Temperature compensated XO (TCXO)</td>
<td>$10^{-7} - 10^{-8}$</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Oven Controlled XO (OCXO)</td>
<td>$10^{-8} - 10^{-9}$</td>
<td>10 - 30</td>
</tr>
<tr>
<td>Double Ovened XO (DCOXO)</td>
<td>$10^{-9} - 10^{-10}$</td>
<td>25 - 100</td>
</tr>
<tr>
<td>Rubidium Locked (Rb)</td>
<td>$10^{-10} - 10^{-11}$</td>
<td>70 - 150</td>
</tr>
<tr>
<td>GPS Disciplined XO (GPSDO)</td>
<td>$10^{-10} - 10^{-12}$</td>
<td>45 - 400</td>
</tr>
<tr>
<td>Caesium Based Oscillators/Clocks</td>
<td>$10^{-12} - 10^{-15}$</td>
<td>5K – 10K</td>
</tr>
</tbody>
</table>
TCXOs

• Widely available on the surplus market.
10 MHz OCXOs

- Trimble
- Symmetricom
- Rakon
- Isotemp
- HP 10811
- Buckets of them on Ebay from China
10 MHz DOCXOs

- Morion MV89A – excellent performer
Rubidium Standard
GPSDOs  HP Z3801A and Cousins
GPSDOs Trimble Thunderbolt
Ex-Telco Trimble GPSDO

Trimble GPS Receiver GPSDO 10MHz 1PPS GPS Disciplined Clock

Item condition: Used
Quantity: 1
5 available
Sold / See feedback

Price: US $129.99
Buy It Now
Add to cart

31 watching
Add to watch list
Add to collection

100% buyer satisfaction
Limited quantity remaining
More than 76% sold

Shipping: FREE Economy International Shipping |
International items may be subject to customs processing and additional charges.
Item location: HONGKONG, Hong Kong
Ships to: Worldwide

Delivery: Estimated between Fri, Sep. 22 and Mon, Oct. 23
Please note the delivery estimate is greater than 10 business days.
Ex-Telco Symmetricom GPSDO
Cesium Beam Standards – Ouch!

HP 5061B Cesium Beam Frequency Standard, Fully Tested and Guaranteed Working

Condition: Seller refurbished

US $11,995.00
Approximately £9,098.15

Buy it now
Add to basket

Make offer

100% positive Feedback

Collect 3,000 Nectar points
Redeem your points

Postage: US $721.10 (approx. £546.95) UPS Worldwide Expedited | See details

Click to see seller
Follow this seller

Visit Shop: Midwest ATE
See other items

Capacitive Pinch-Zoom-Swipe Touchscreen
Get deeper into your signals

See it in action

Have one to sell? Sell it yourself
“Spares and Repairs” !!

HEWLETT PACKARD HP / AGILENT CESIUM BEAM FREQUENCY STANDARD 5061B - SOLD AS IS

Condition: For parts or not working

US $2,499.99
Approximately £1,886.23

Buy it now

Add to basket

Make offer

Seller information
dockguys (38004)
98.9% Positive Feedback

Follow this seller

Visit Shop: SURPLUS SELECT/D

Have one to sell? Sell it yourself

EDINBURGH to BIRMINGHAM each way
£43 → BOOK
OCXO Pros and Cons

• ++ No settle time.
• ++ Simple
• ++ Low cost
• -- Accuracy ??
OCXO and DOCXO - Pros and Cons

- ++ Accuracy can be very good
- ++ Self contained
- -- Warm up / settling time
- -- Power consumption
Rubidium – Pros and Cons

• ++ Very accurate
• ++ Quick warm up ~ 2 to 4 minutes
• ++ Self-contained
• -- Power consumption
• -- Lamp Life decidedly finite
GPSDO – Pros and Cons

• ++ Very accurate
• ++ Moderate cost
• -- Power consumption
• -- requires an antenna with a sky view
• -- Settling time
Caesium Beam – Pros and Cons

• ++ Ultimate accuracy
• -- Complexity
• -- Power consumption
• -- Cost ... Ouch!!
Lady Heather control of GPSDOs
Lady Heather

- Written by Mark Sims (TexasPyro)
- Available on John Miles website (KE5FX)
- Desktop Icon!
Conclusions ??

• Shack standard - 10 MHz GPSDO
• Portable – Good TCXO or Rb