The Chip Scale Atomic Clock and Satellite Navigation

*Presented to the China Satellite Navigation Conference*

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Agenda

• What is the QUANTUM SA.45s CSAC?
• The Questions Everybody Asks
• The Big Benefit of CSAC in GNSS Systems – Holdover with Low SWaP
• Other Benefits of Using CSAC in GNSS Systems
What is the QUANTUM™ SA.45s CSAC?
The QUANTUM™ Chip Scale Atomic Clock

The QUANTUM™ SA.45s Chip Scale Atomic Clock brings the accuracy and stability of an atomic clock to portable applications for the first time.

Key Specifications

– ±5.0E-11 accuracy at shipment
– <3.0E-10/month aging rate
– 120 mW Power Consumption
– Less than 17 cc in Volume
The Questions Everybody Asks
CSAC Environmental Specifications – Shock

• At introduction, spec was **500g** 1 ms half-sine
• After spec validation, spec was changed to **1000 g** 1 ms half-sine
• Driving towards 2000 g
• Test results published as a Symmetricom whitepaper

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CSAC Environmental Specifications – Temperature & Vibration

• Temperature
  – Two versions offered
    • Option 001 (-10°C to +70°C; tempco = ±5.0 x 10^{-10})
    • Option 002 (-40°C to +85°C; tempco = ±1.0 x 10^{-9})

• Vibration
  – Units meet Mil-STD-810, Method 514.5, procedure 1, category 24
    • minimum integrity, 7.7 gms @0.04 g/Hz, 20 Hz to 1 kHz, 15 min per axis
  – In verification testing, all units meet twice this level
  – Visit www.symmetricom.com/csac to view ‘Test’ results
Calibration For 1 PPS

Mission scenario: CSAC-based instrument has access to high-quality cesium or GPS-steered Rb/CSAC for 10-15 minutes prior to mission

Example:

- CSAC cold-started with $+10^{-9}$ frequency error, initial sync -50 ns. (worst-case)

50 ns initial phase sync error is steered to < 1 ns within 1000 seconds

$+10^{-9}$ initial frequency error is steered out within 1000 seconds
Average frequency (1000-3000 seconds) = $+2\times10^{-13}$
SA.45s CSAC Licensing and Export Control

• SA.45s CSAC is **NOT** under ITAR control!!

• ECCN code = EAR99

• Eligible for export to most end users as NLR (No License Required)
Statement on CSAC RoHS Compliance

• CSAC is RoHS 5/6 compliant
• CSAC does not contain any Mercury, Hexavalent Chromium, PBB, or PBDE above the 0.1% RoHS threshold
• CSAC does not contain Cadmium above the 0.01% RoHS threshold
• CSAC can be used in assemblies using either lead-based or lead-free based solder when our manufacturing guidelines are followed
• CSAC does make use of lead in solders
• CSAC can be used in any product shipping to the European Union
  – that makes use of EU RoHS exemption 7b, “Lead in solders for network infrastructure equipment, or
  – used in Category 9 equipment, “Monitoring and control instruments,” as defined by the EU WEEE Directive
### Symmetricom’s Portfolio of Atomic Clocks

<table>
<thead>
<tr>
<th>Spec/Type</th>
<th>X72 Precision Rubidium Oscillator</th>
<th>XPRO High-Performance Rubidium Oscillator</th>
<th>SA.35m Miniature Atomic Clock</th>
<th>Quantum™ Chip Scale Atomic Clock (CSAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions (cm)</td>
<td>8.9 x 7.6 x 1.8</td>
<td>12.7 x 9.2 x 3.9</td>
<td>5.1 x 5.1 x 1.8</td>
<td>4.06 x 3.53 x 1.15</td>
</tr>
<tr>
<td>Volume</td>
<td>122 cm³</td>
<td>456 cm³</td>
<td>47 cm³</td>
<td>&lt; 17 cm³</td>
</tr>
<tr>
<td>Power @25°C</td>
<td>10 W</td>
<td>13 W</td>
<td>5 W</td>
<td>&lt; 120 mW</td>
</tr>
<tr>
<td>ADEV @ 1 sec</td>
<td>&lt; 3 x 10^{-11}</td>
<td>&lt;1 x 10^{-11}</td>
<td>&lt;3 x 10^{-11}</td>
<td>&lt;2.5 x 10^{-10}</td>
</tr>
</tbody>
</table>

Symmetricom’s atomic clocks meet a variety of application needs
The Big Benefit of CSAC in GNSS Systems – Holdover with Low SWaP
Everyday GNSS Outages (Unintentional)

**Mechanical, Human Error**
- Antennas are easily damaged and can interfere with each other
- Human error in GNSS system operations
- GPS cable conduit dangling in the wind
- Harmonics or radiation from nearby electronics, failures or misaligned transmission equipment

**Natural, Environmental**
- Lightning hits and high winds take out antennas, antenna icing
- Solar flares, atmospheric phenomena
- Foliage causes signal masking
Examples of Holdover Requirements and Performance

• **Power Substation LANs**
  – Smart Grid Substations require ±1 µsec timing accuracy (IEC 61850)
  – OCXO: about 10 minutes
  – Rubidium: about 8 hours

• **Wireless Networks: 3G and LTE-FDD**
  – 3G base stations require 16 ppm accuracy at the network interface (3GPP)
  – OCXO: about 1 month
  – Rubidium: about 5 years

• **Wireless networks: LTE-TDD and LTE-A**
  – ±1.5 µsec to ±5 µsec: standards are still works-in-progress (3GPP)
  – OCXO: about 30 minutes (±1.5µsec)
  – Rubidium: about 24 hours (±1.5µsec)

• **Enterprise: Data Center LANs**
  – No standard, but let’s say ± 1 millisecond is the objective (using NTP)
  – OCXO: about 1 day
  – Rubidium: over 60 days

• **Enterprise: High Frequency Trading Network LANs**
  – No standard, but let’s say ± 1 microsecond is the objective (using PTP)
  – OCXO: about 10 minutes
  – Rubidium: about 8 hours

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Actual performance will vary widely depending on the quality (cost) of the oscillator and environmental conditions.
Rb or CSAC -- Atomic Clock Holdover

Rb or CSAC versus OCXO
time error over temperature changes

Service continuity
Fewer truck rolls
Fewer off-hour repair calls

Atomic Clock performance is 5 to 8 times better than OCXO.
GPS-2700 and GPS-2750 GPS Disciplined Oscillators Feature the SA.45s CSAC

- A complete solution for portable timing card applications
- The smallest size, lowest power consumption, and highest performance available
- The flagship offering in a full line of GPSDO’s now offered by Symmetricom

• Typical holdover of ±1 µs over a 24-hr. period
• Power consumption <1.4W
• Fast warm-up time, <110 s
• 1 PPS accuracy ±15 ns to UTC RMS (1-sigma) when GPS-locked
• Low profile, <0.7” in total height
Other Benefits of Using CSAC in GNSS Systems
Other Benefits of Using CSAC in GNSS Systems

• **Operation with only three space vehicles (SV’s) in view**
  – Useful in “urban canyon” situations

• **Greatly improved Time to Subsequent Fix (TTSF)**
  – Can lead to improved anti-jam immunity in military applications
  – Can lead to improved battery life in all applications
Extended Battery Life

- Power down GPS receiver to save power, with the security of knowing that TTSF is quick.
Summary

• Symmetricom’s Chip Scale Atomic Clock (CSAC) represents a breakthrough in low-power, small-size atomic clocks.
• For GNSS receivers, the CSAC can provide excellent holdover performance with no SWaP penalty.
• The CSAC can also enhance GNSS receivers by enabling longer battery life and better performance in urban canyon settings.
Thank You

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