Introduction to Symmetricom's SA.45s Chip Scale Atomic Clock (CSAC)

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Agenda

- What is the CSAC?
- How Does it Work?
- The Application Challenges Faced by SA.45s CSAC Customers
- Example Applications
- Ordering Information

The Chip Scale Atomic Clock

- The SA.45s Chip Scale Atomic Clock brings the accuracy and stability of an atomic clock to portable applications for the first time.
  - ±5.0E-11 accuracy at shipment
  - <3.0E-10/month aging rate
  - 115 mW Power Consumption
  - Only 16 cc in Volume

1 PPS for Calibration

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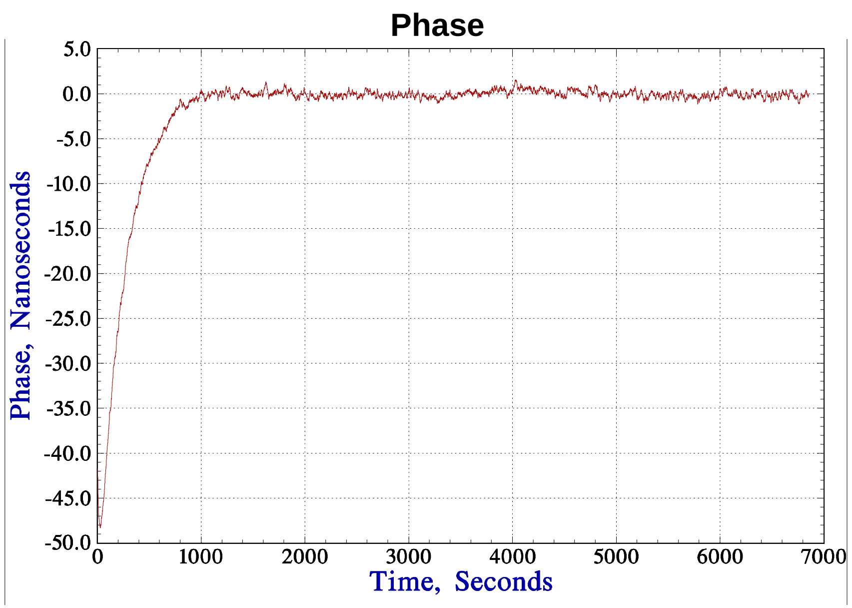
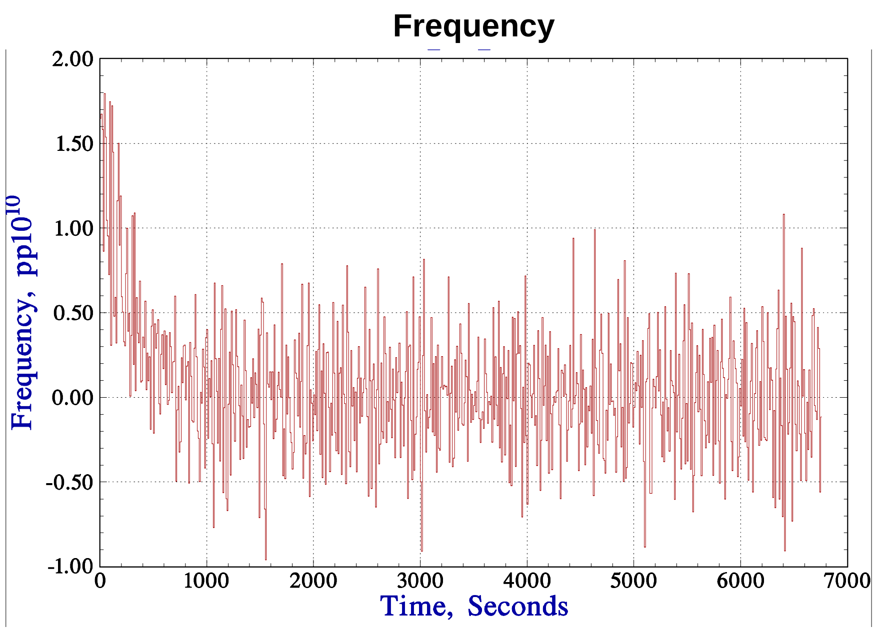
- Mission scenario: CSAC-based instrument has access to high-quality (cesium or GPS-steered Rb/CSAC) for 10-15 minutes prior to mission.
- Example:

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



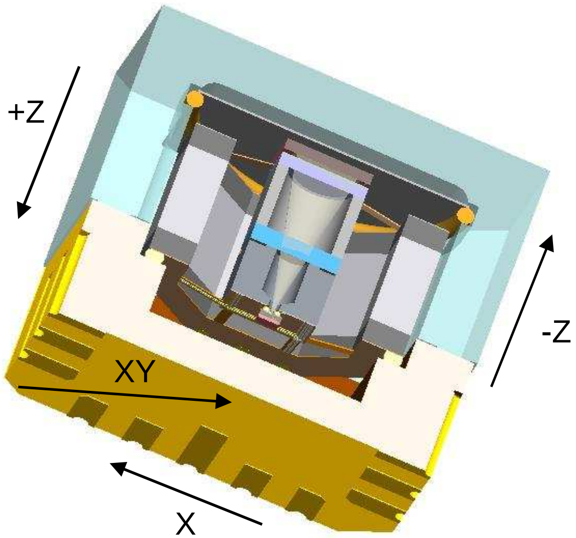


50 ns initial phase sync error is steered to < 1 ns within 1000 seconds

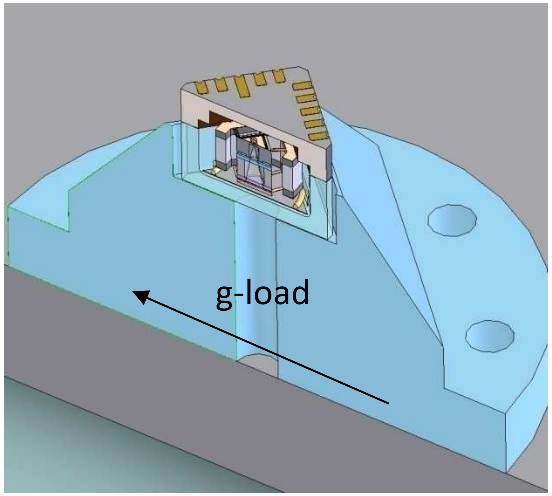
$+10^{-9}$ initial frequency error is steered out within 1000 seconds

Average frequency (1000-3000 seconds) = $+2x10^{-13}$

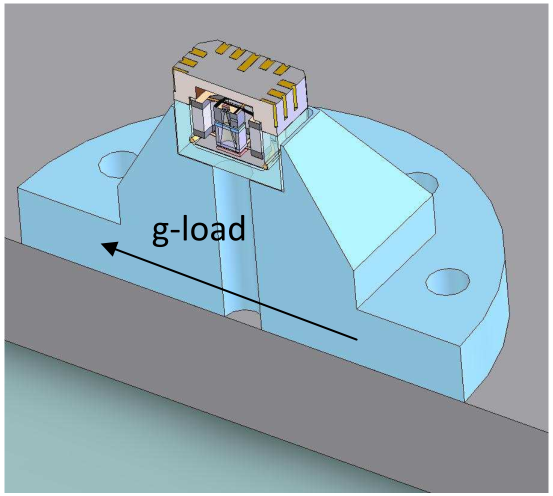
CSAC Environmentals – Shock



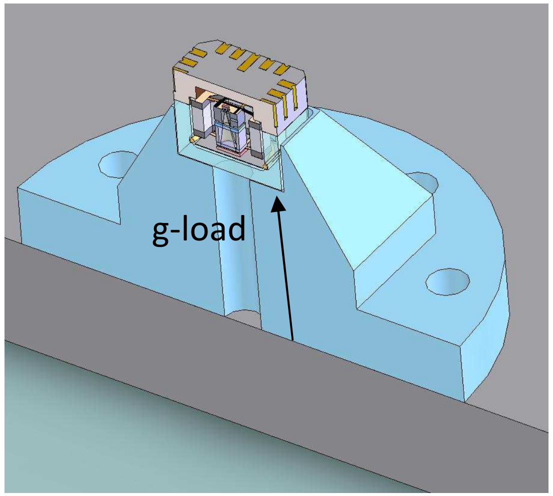
- CSAC will meet 500g 1 ms half-sine.
- After testing, spec may be changed to 1000g 1 ms half-sine.
- Early test data looks good.



X-Y shock



X shock



Z shock

CSAC Environmentals – Temperature & Vibration

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Temperature

- Two versions will be offered: Option 001 (-10℃ to +70℃; tempco = ±5.0 x 10^{-10}); and Option 002 (-40℃ to +85℃; tempco = ±1.0 x 10^{-9}).
- Tempco's on early units look solid.

Vibration

- Will meet Mil-STD-810, Method 514.5, procedure 1, category 24, minimum integrity, 7.7 g_{rms} @0.04 g/Hz, 20 Hz to 1 kHz, 15 min per axis.
- Early testing of random vibration up to 12 g_{rms} looks very good.
- Future tests will be to failure, and results published.

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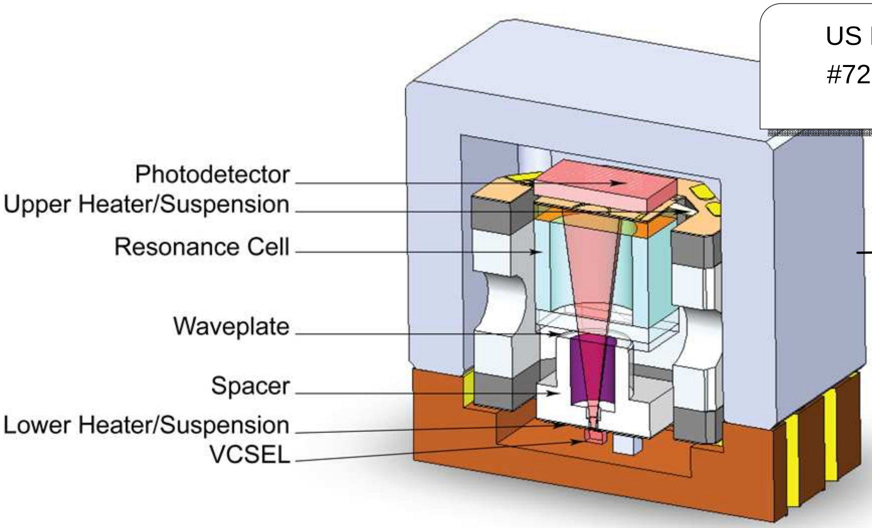
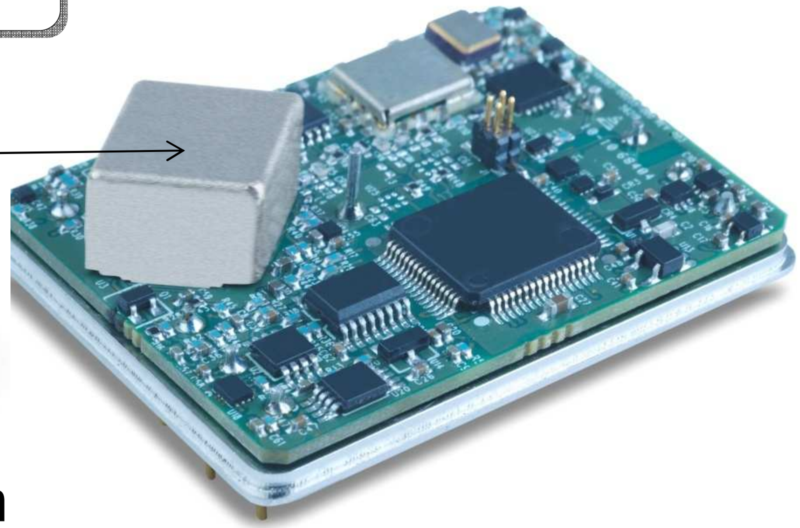
Miniaturizing the Physics Package



US Patent #7215213



- Tensioned polyimide suspension
- Microfabricated silicon vapor cell
- Low-power Vertical-Cavity Surface Emitting Laser (VCSEL)
- Vacuum-packaged to eliminate convection/conduction – overall thermal resistance of 7000°C/W
- Entire physics package can operate on 10 mW

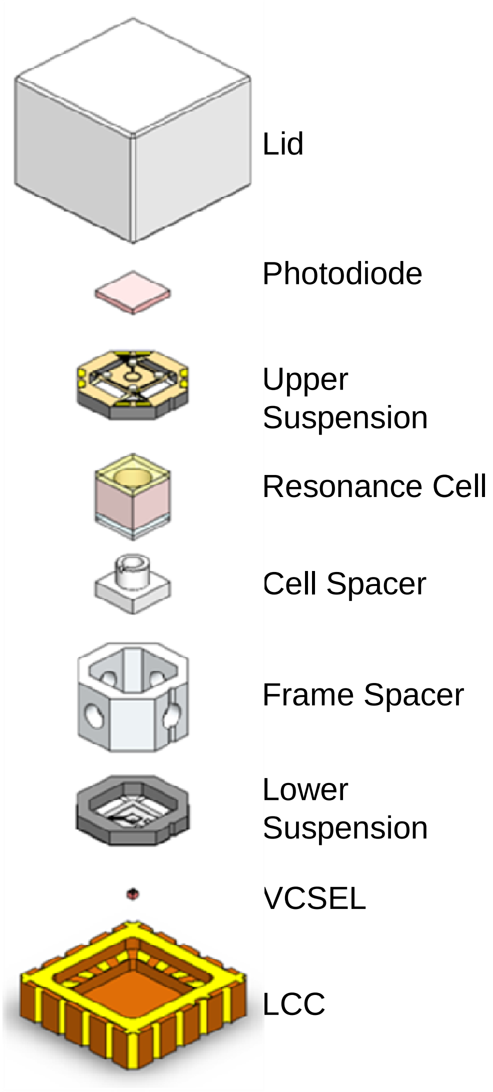
How It's Made

Suspensions
- Spin-on polyimide over Silicon
- Photodefine polyimide and lift-off
- Metallization on polyimide
- Backside etch to release

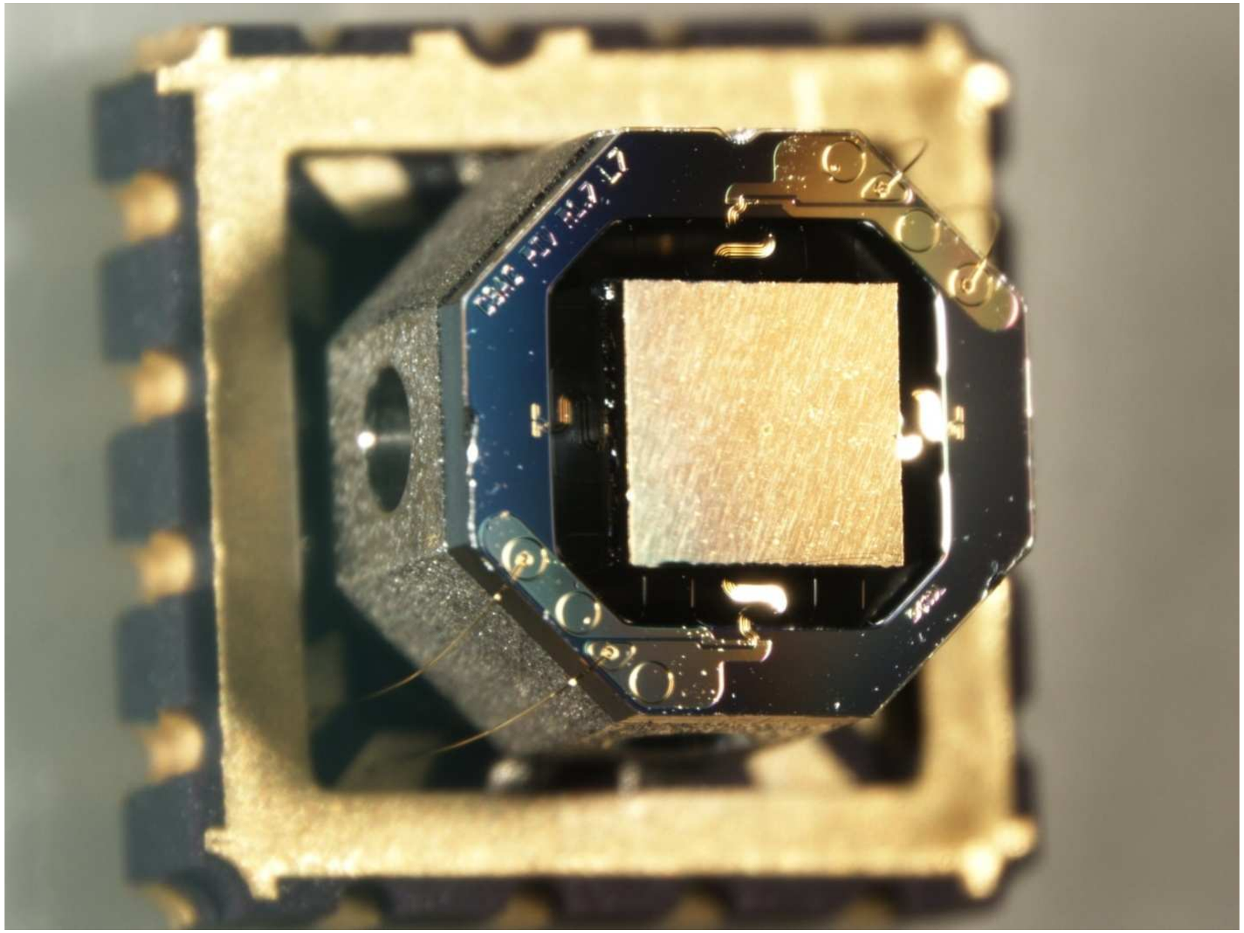
Resonance Cell
- DRIE holes in silicon
- Load cesium and buffer gas
- Anodic bond windows

Stack-up
- Bond VCSEL/Photodiode to suspensions
- Stack up and epoxy on pick-and-place machine

Vacuum Seal
- Bake-out and activate getter in lid before braze



Completed Physics Package



Physics Package in LCC Before Sealing

The Clock is More Than Just the Physics Package

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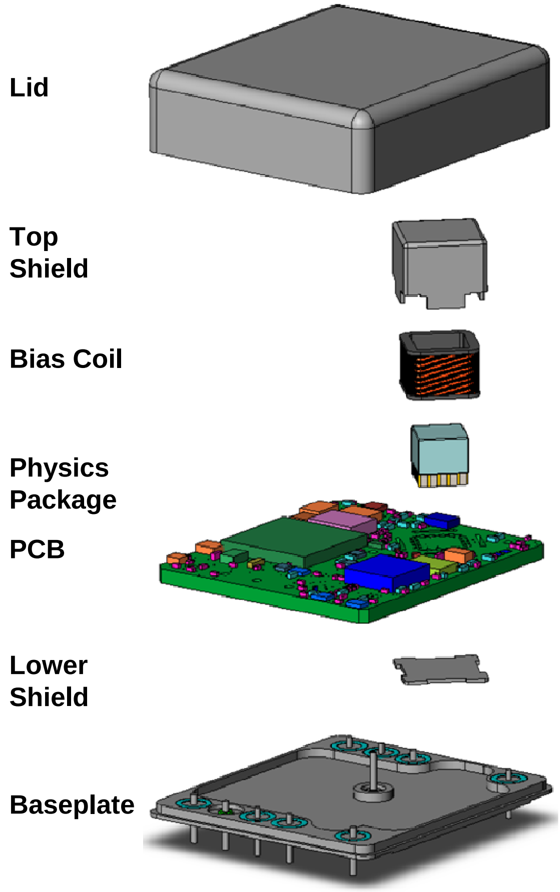
- All electronics on single PCB
- Low-power DSP and other electronics, controlled by power-efficient proprietary algorithms
- Double-layer magnetic shield
- Hermetically sealed



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Symmetricom Atomic Clock Comparison

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	X72 Precision Rubidium Oscillator	XPRO High-Performance Rubidium Oscillator	SA.35m Miniature Atomic Clock	Chip-Scale Atomic Clock ("CSAC") 2010
Dimensions (cm)	8.9 x 7.6 x 1.8	12.7 x 9.2 x 3.9	5.1 x 5.1 x 1.8	4.1 x 3.3 x 1.0
Volume	122 cm^3	456 cm^3	47 cm^3	**16 cm^3**
Power at 25°C	10 W	13 W	5 W	**115 mW**
ADEV at 1 sec.	<3E-11	<1E-11	<3E-11	<3E-10

What Application Challenges are CSAC Customers Trying to Address?

- Applications which benefit from CSAC
  - Require precise time for synchronization without direct connection
  - Require ability to hold precise time even in absence of GPS
  - Need to minimize size, weight, and power (SWaP)
- Examples include:
  - Portable "man-pack" equipment for the military
  - Distributed geophysical sensors, underground or underwater

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Geophysical Sensors – Marine

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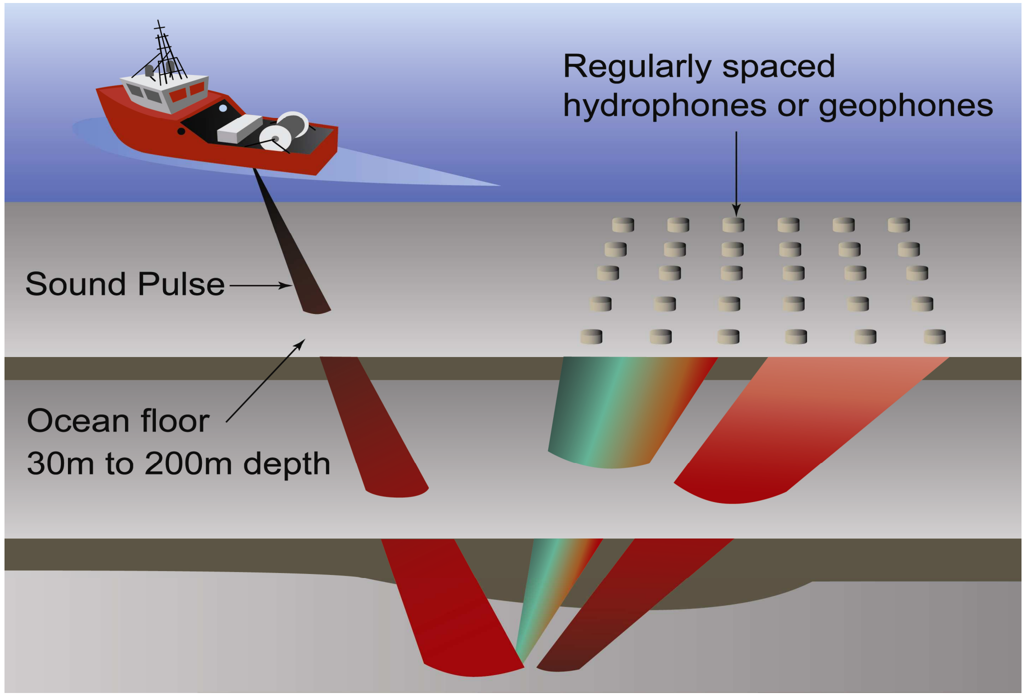
- Acoustic pulse hits and penetrates ocean floor.
- Sound travels thru different materials at different speeds.
- Sensors time-stamp when pulse is received.
- Post-processing of sensor data shows likely places to drill for oil.



Today Most Marine Geophysical Sensors Use OCXO's as Clocks!

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Critical Parameter	Why	OCXO	CSAC
Battery Lifetime	Key determinant of how long sensor can stay underwater.	~1 W to 3 W	115 mW
Tempco	Sensor calibrated on boat deck; then goes into very cold water.	±1.0E-8	±5.0E-10
Aging	Produces an error that varies as square of time underwater.	<3.0E-8 per month	<3.0E-10 per month

SA.45s CSAC can often be selected on economics alone (battery savings); but tempco and aging advantages are also important, especially in longer-term deployments.

CSAC Ultralow-Power Mode

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- Only operate physics periodically to recalibrate TCXO
- TCXO short-term stability ↔ CSAC long-term drift
- Average power consumption < 30 mW
  - < 20 mW in TCXO-only mode
  - < 110 mW during physics warmup (≈ 2 minutes)
  - < 100 mW during full operation interval

Example:

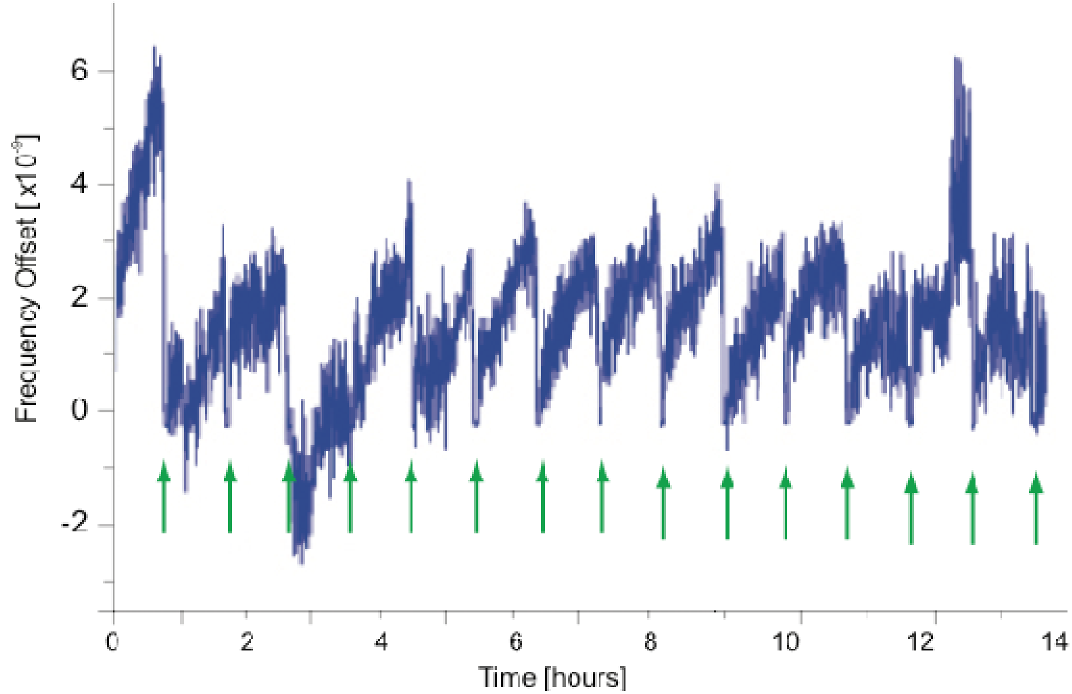
1-hour period

55 minutes TCXO-only

2-minute warm-up

3-minute calibration

Average power < 30 mW



IED Dismounted (Backpack) Jammers

- Problem:
  - Need to jam wireless signals used to detonate Improvised Explosive Devices (IEDs)
  - First jammers were vehicle-mounted, but ~70% of all patrols in Afghanistan are on foot.
  - Dismounted jammers must be synchronized to allow friendly communications, while blocking detonation signals.

- Solution:
  - CSAC precision enables synchronization, while its low power consumption reduces the amount of batteries needed to power the jammer.

Today Most Dismounted Programs Use OCXO's!

Critical Parameter	Why	OCXO	SA.45s CSAC
Power Consumption	Batteries determine mission life; but battery weight **must** be minimized.	~1 W to 3 W	125 mW
Size	Space at a premium in backpack.	Various sizes; most much larger than CSAC.	16 cc
Tempco	Extreme temp swings in desert climates.	±1.0E-8	±1.0E-9
Aging	Critical to maintain time during GPS outages; enable sync for "blue force comms"	<3.0E-8 per month	<3.0E-10 per month

Dismounted (Backpack) Military Radios

- Today Use TCXO's, OCXO's
- Sometimes too much drift for GPS-denied scenarios.
- Problem will get worse with new, higher-bandwidth waveforms.

- Excellent future application for SA.45s CSAC as these new waveforms get rolled out

Tactical UAV's

- Payloads are always stretched on Size, Weight, and Power ("SWaP").
- SA.45s CSAC helps in all three areas! (16 cc, 35 g, 125 mW)
- The CSAC also provides excellent holdover performance in GPS-denied environments.

Enhanced Military GPS Receiver

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- Greatly improved TTSF.
- Holdover of ~ 24 hours with rapid reacquisition of GPS signal.
- Improved jamming immunity.
- Possibility of lower-power operation.
- Operate with 3 satellites in view rather than 4 (only 2 satellites if altitude not needed).

Image © Rockwell Collins, Inc.

Enhanced Military GPS Receiver

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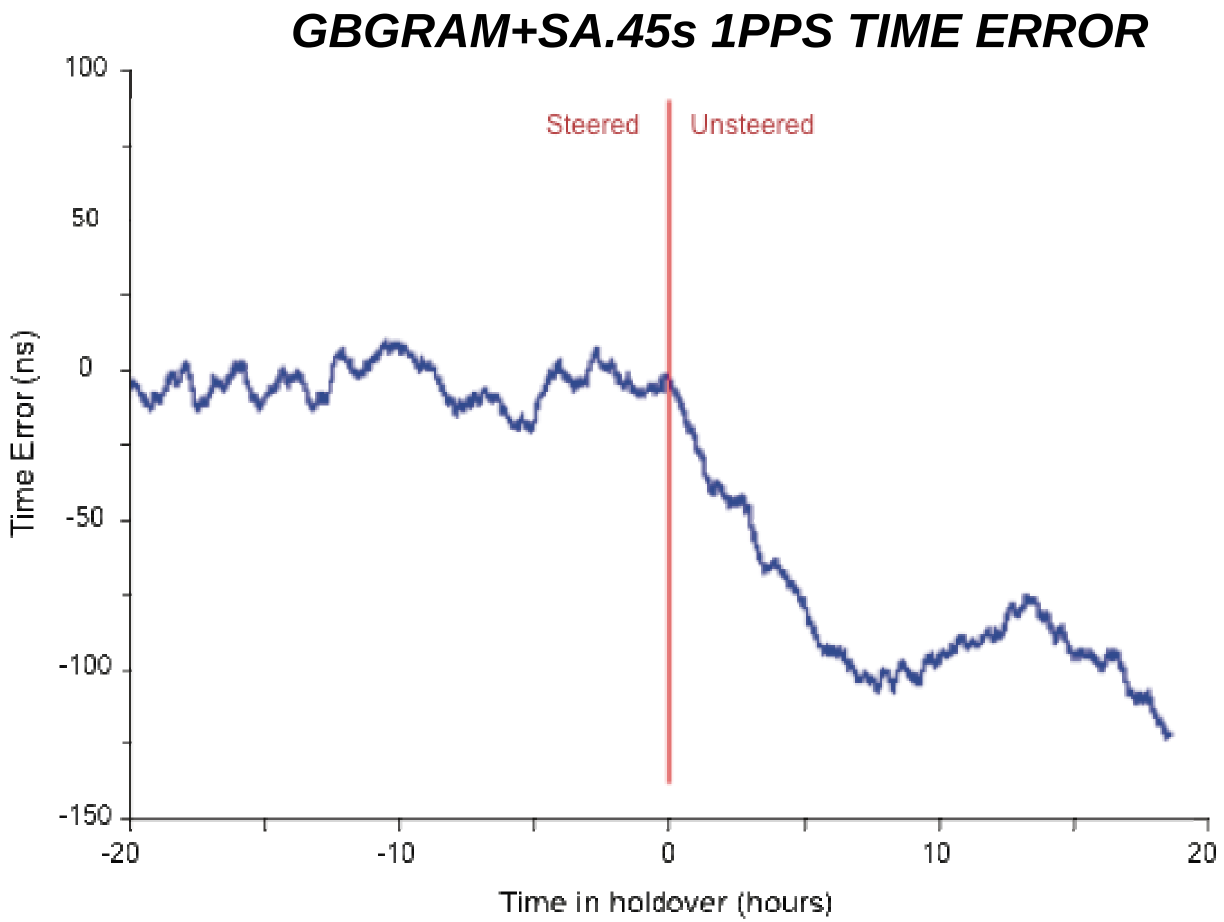

- Time error must be < 200 ns for rapid GPS acquisition.

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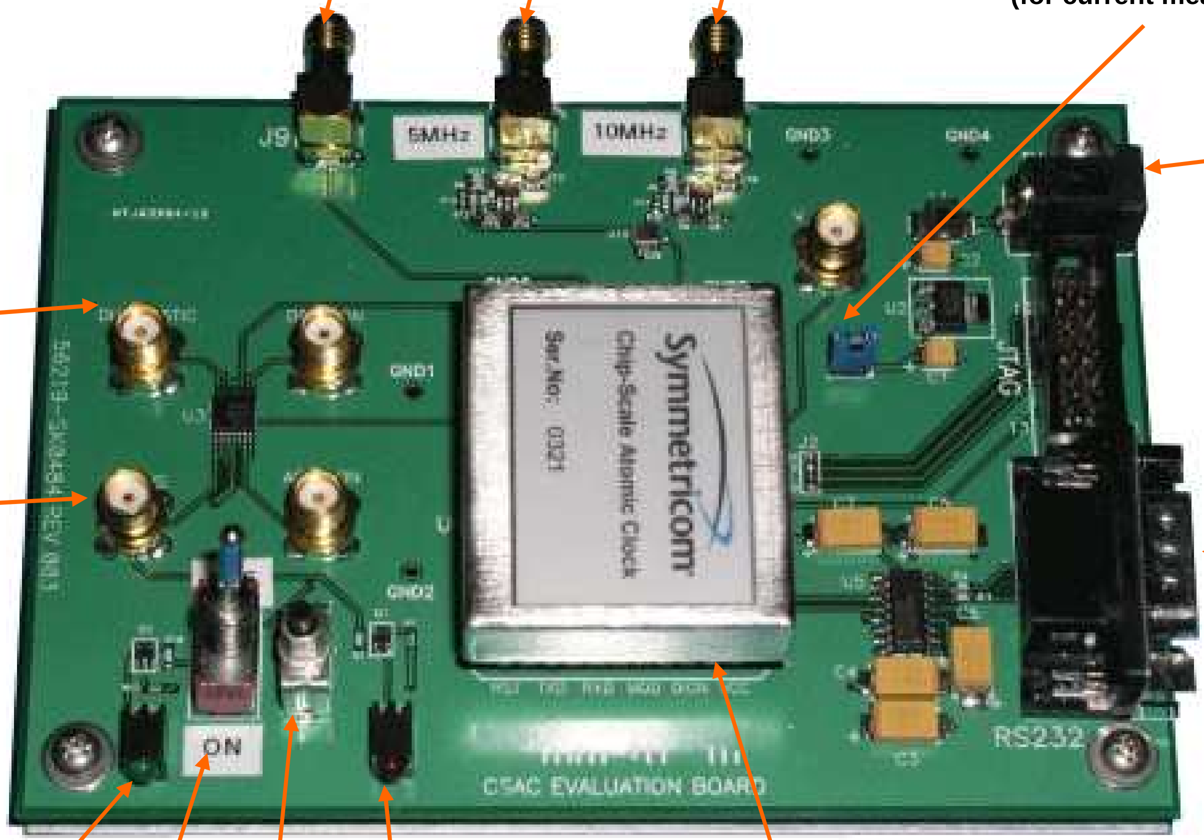
Developer’s Kit Evaluation Board



Product Information

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- The SA.45s CSAC is available in two versions:
  - Option 001 (090-00218-001) is aimed at geophysical sensors and other commercial applications.
    - -10°C to +70°C operating temperature, <115 mW
  - Option 002 (090-00218-002) is aimed at military applications.
    - -40°C to +85°C operating temperature, <125 mW
- Output is 10 MHz square wave; frequency customization is possible for high-volume applications.

SA.45s CSAC Licensing

- SA.45s CSAC is **not** under ITAR control!!
- ECCN code = EAR99.
- Eligible for export to most end users as NLR.
  (No License Required)