



Microsemi's Frequency & Timing Space Products Space Forum 2017



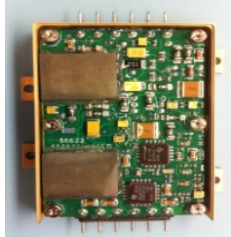
Peter Cash
Director, Clocks Business Unit
Microsemi Frequency and Time Division

Company Overview



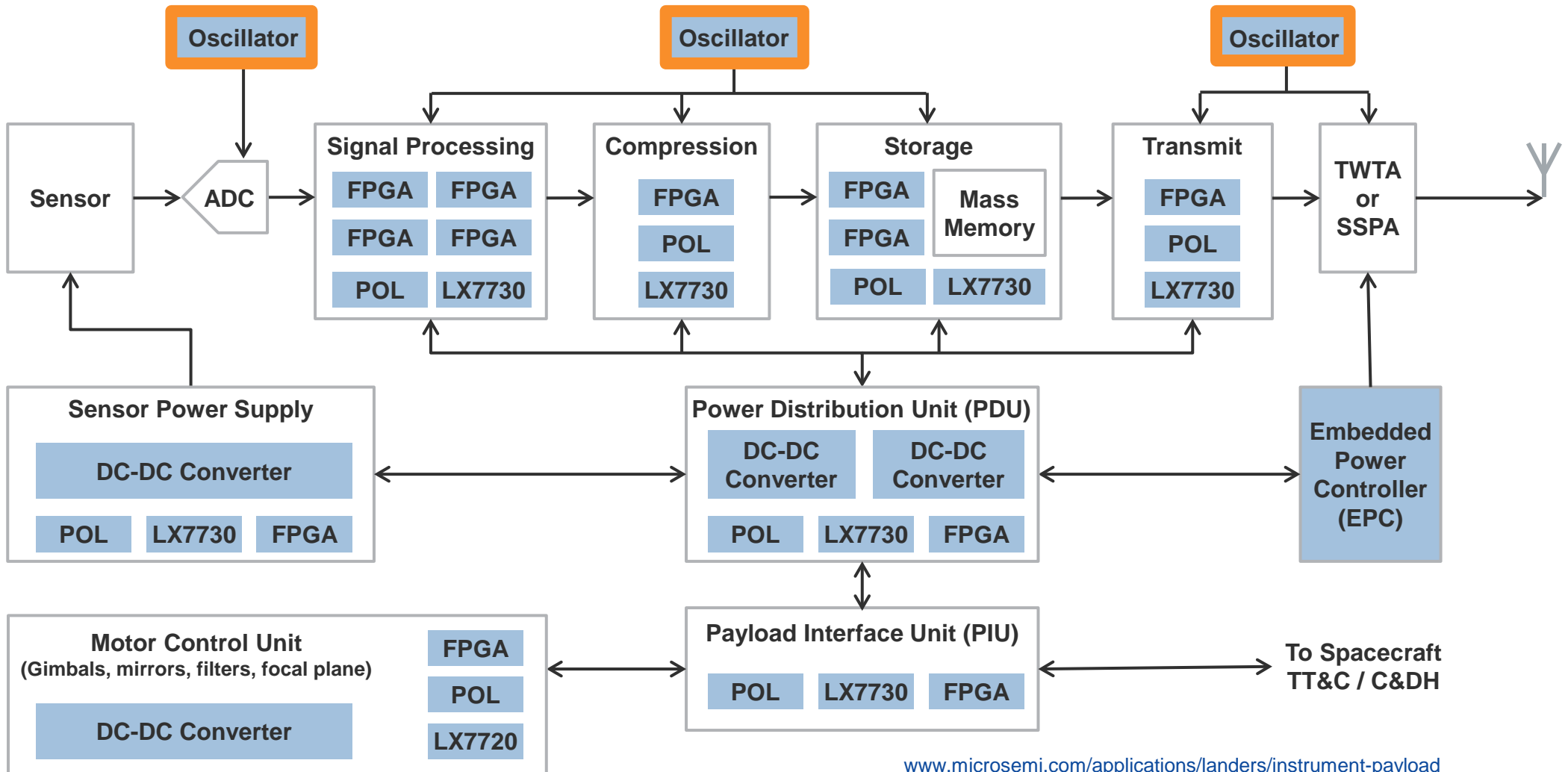
- Leading-Edge Semiconductor Solutions Differentiated by:
 - Performance
 - Reliability
 - Security
 - Power
- Solid Financial Foundation
 - FY2016 Revenue: \$1.6B
 - 4800 employees today
- Major Focus Products
 - FPGA and ASIC
 - Timing and OTN
 - Mixed-Signal and RF
 - Switches and PHYS
 - Storage Controllers
 - Discretes and integrated power solutions

Delivering Comprehensive Space Portfolio

<p>Radiation-Tolerant FPGAs</p>	<p>High Performance, High Density, Low Power TID up to 300 Krad, SEL Immune RTG4 FPGAs up to 300 MHz and 150K LE RTProASIC3, RTAX and RTSX-SU QML Qualified</p>	  
<p>Rad-Hard Mixed Signal Integrated Circuits</p>	<p>Telemetry and Motor Control Space System Managers High Side Drivers Regulators and PWMs Extensive Custom IC Capability</p>	
<p>Space Qualified Oscillators</p>	<p>Ovenized Quartz Oscillators Hybrid Voltage Controlled and Temperature Compensated Crystal Oscillators Cesium Clocks</p>	 
<p>Rad-Hard Power Solutions</p>	<p>Rad-hard JANS Diodes, Bi-Polar Small Signal Transistors, and MOSFETs Rad-hard Isolated DC-DC Converter Modules Custom Power Supplies 2 W to > 5 KW Linear and POL Hybrids Electromechanical Relays</p>	   








Portfolio Breadth: Example Signal Processing Payload

- Clocks and Oscillators



www.microsemi.com/applications/landers/instrument-payload

Space-Qualified Crystal Oscillators

Type	Family	Image	Output Frequency	STS @10s	Phase Noise @100 Hz	Aging (per year)	Volume (WxLxH)	Weight	Steady State Power
OCXO	9600		4 MHz -60MHz	<5.0E-12	<-145 dBc/Hz	<4.0E-8	1.33" x 1.33" x 1.33"	<100 g	<1.3 W (in vacuum)
	9700			<2.0E-12	<-150 dBc/Hz	<1.5E-8			
	9800B		40 MHz -125 MHz	<1.0E-11	<-135 dBc/Hz	<2.0E-7			
	9500B		4 MHz -100 MHz	<3.0E-13	<-155 dBc/Hz	<1.0E-8			
TCXO	9960		10 MHz -225 MHz	<1.0E-11	<-125 dBc/Hz	<5.0E-7	1.39" x 0.82" x 0.50"	<30 g	220 mW
VCXO	9940		10 MHz -250 MHz		<-90 dBc/Hz	<2.0E-6	1.4" x 1.38" x 0.28"		
	9942		10 MHz -600 MHz		<-80 dBc/Hz				
XO	9920		10 MHz -500 MHz		<-110 dBc/Hz	<1.0E-6			
	9922		10 MHz -1.2 GHz		<-118 dbc/Hz				

Agenda

- New product development
 - Space CSAC
 - Satellite timing module
- Space timing products
 - Space qualified oscillators
 - Oscillator subsystems & atomic clocks for space
- Summary

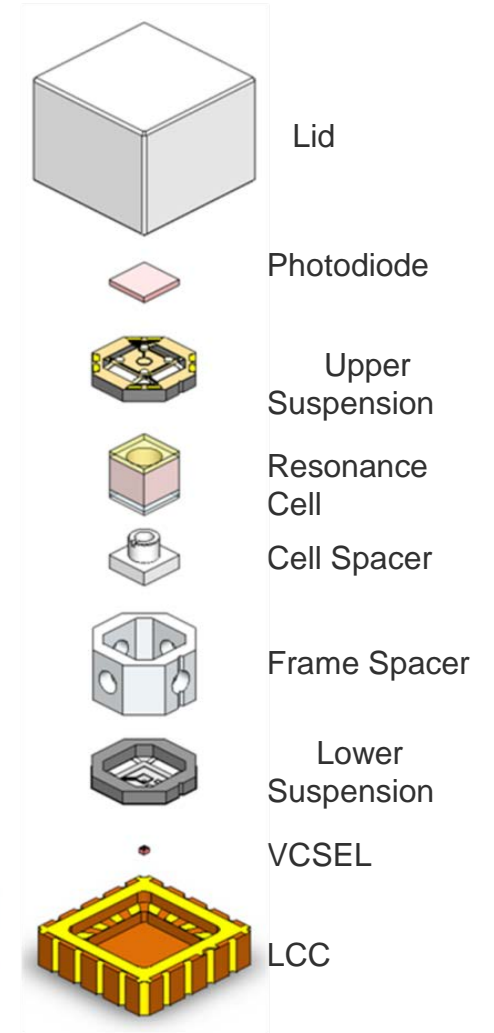
New Timing Products for Space

Space Chip Scale Atomic Clock (CSAC)

- Microsemi has developed the first radiation tolerant chip scale atomic clock for use in low earth orbit (LEO) applications.
- Space CSAC Advantages
 - Satellite timing and frequency control
 - Has better than 10 times accuracy performance vs. crystal oscillators of 5 times higher power
 - Satellite clock reference
 - Hold-over performance clock that can continue to provide accurate time during a GNSS outage or degradation due to receiver interruption or jamming
 - Achieves much higher performance than most existing GPSDO solutions for space
 - Enables crosslinking capabilities
 - Assured PNT– link cannot be detected or jammed from the ground
 - Reduces or eliminates ground station timing upload requirements
 - SWaP & affordability
 - Pricing much lower than most of today's high-precision space oscillators of comparable size & weight

Space CSAC – Chip Scale Atomic Clock

- Cesium MEMS gas cell
- Low power consumption, <120 mW
- Small form-factor/low volume
 - Size: 1.6" x 1.39" x 0.45"
- CMOS-compatible output
- 1PPS output and 1PPS input for synchronization
- RS-232 interface for monitoring and control
- Short term stability (Allan Deviation) of $3.0E-10$ at TAU = 1 sec
- Radiation tolerant: 20Krad (SEE to be tested 2017)
- Weight: <35 g
- MTBF >100,000 hours
- Operating temperature: -10°C to 70°C



Space CSAC Schedule

Milestone	Completion Date
Sample Production Lot (with new TCXO)	End of July '17
Qualification Testing (Including SEE & TID)	End of August '17
Flight Product Available	October '17

- For more information please contact Peter Cash at peter.cash@microsemi.com

Satellite Timing Module

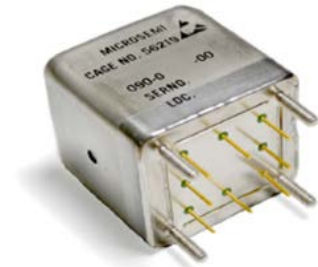
Satellite Timing Module (STM)

- STM provides autonomous and accurate local frequency and time for individual or constellations of satellites
 - Reduced dependency of ground station support/ or on-board atomic clock
 - Significant improvement to current system's capabilities and security
 - Enables the possibility of crosslinking among satellites
- The Satellite Timing Module uses the 1PPS output of a spacecraft GPS receiver to optimally steer a ovenized crystal controlled oscillator (OCXO) using a proprietary Kalman filtering called KAS-2
- Precision frequency sources are required for timekeeping and metrology in communication, navigation, reconnaissance, and scientific satellites
 - Source are typically quartz oscillators, and in some cases, atomic clocks
- Drift associated with these clocks requires that the frequency and time be adjusted by ground stations
 - Process can be costly, and results in undesired dependencies

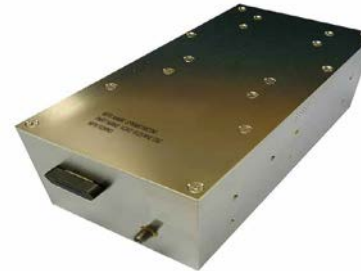
STM Design

- STM is a flexible design that allows for a miniature OCXO or ultra-stable oscillator to trade off performance vs. power/weight.

Microsemi 9800 Oscillator



Microsemi 9500 Ultra-Stable Oscillator



- Design includes a power supply, the voltage controlled OCXO, 100MHz PLL circuit, and the controller assembly that contains the FPGA.
- 100 MHz PLL contains a OCXO that is required for high performance applications
- STM design was evolved from an already delivered custom platform timing module.
- STM will use RTG4 to meet performance, radiation, and flexibility goals.

Microsemi RTG4



STM Next Steps

- Complete feasibility study using RTG4 and analyze performance data to target specification
- For more information please contact Peter Cash at peter.cash@microsemi.com

Space Qualified Oscillators and Clocks

- 70+ Cesium atomic clocks and 800+ crystal oscillators for space
- Key programs such as GPS, SBIRS, multiple NASA missions
- Strong technical skills in quartz oscillators, ruggedized atomic clocks, frequency, and time sub-systems
 - 9600/9700/9800 models offer an unsurpassed combination of small size, low power, and performance
 - 9500 models provide the world's best performance for frequency stability and phase noise
- Our oscillators are designed for use in multiple satellite applications
 - Spaceborne GPS receivers
 - Down and up Converters
 - Synthesizers
 - Transponders
 - Navigation
 - Board calculator



Strengths and In-House Capabilities

- Microsemi designs and manufactures high-performance space VCXOs, TCXOs, and OCXOs
- We specialize in providing precise time and frequency solutions for customers with the most demanding performance requirements
 - Separate manufacturing capability focused on additional environmental controls, hi-reliability materials control, and enhanced process tolerances
 - Stock of standard Class S and Class B electronic components
 - Well established source of supplies for critical components such as hybrids and crystals
 - In-house 100% sampling of all parts for prohibited materials such as pure tin
 - Certified J-STD space addendum soldering instructors on staff
 - 6 thermal vacuum chambers
 - 6 thermal chambers
 - 2 vibration tables and shock system



9600 and 9700 Ovenized Crystal Oscillators (OCXO)

- Hybrid circuitry allows for greatest possible reduction in size without compromises in performance or reliability
- Features a SC-cut quartz resonator that enables excellent short term stability, phase noise, and aging characteristics
- Backed by an extensive space heritage (300+ delivered into space)
 - CloudSat, MESSENGER, Cosmo IV, LRO, DSAC, WorldView III, MUOS, STEREO, GPS Spaceborne receivers
- Can be customized in output frequency, warm-up time, g-sensitivity, and other characteristics.



Connectorized Package

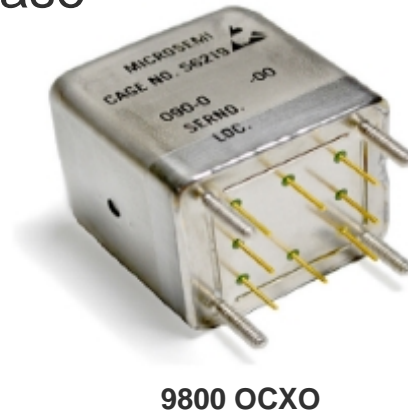


PCB Mount Package

- High stability and low phase noise
- Allan Deviation of $< 1 \times 10^{-12}$ 1-10 seconds typical for 5 MHz unit
- Phase Noise < -110 dBc/Hz @ 1 Hz typical for 5 MHz Unit
- 1.3 W @ 25 °C in thermal vacuum
- Frequency range of 1 MHz to 25 MHz
- Grade 1 or 2 EEE parts
- MTBF of six million hours
- 300+ oscillators delivered for space missions
- Volume of 2.25 in²
- 300 Krad (Si) hard and SEL immune

9800 Ovenized Crystal Oscillator (OCXO)

- Superior long term stability
 - Low frequency aging extends the period of time needed between synchronization, contributing to the simplification of system design
- Features a SC-cut quartz resonator that enables excellent short term stability, phase noise, and aging characteristics
- Strong space heritage
 - PAN, INTELSAT, EchoStar 21, CLIO
- Can be customized in output frequency, warm-up time, g-sensitivity, and other characteristics.
- All discrete components are manufactured and tested to Class S standards



- 40 MHz - 200 MHz output frequency
- Low power consumption <1.3 W at 25° C in thermal vacuum
- Low phase noise: < -105 dBc / Hz at 10 Hz for 50 MHz
- Superior ADEV: < 5e⁻¹² at 1 second for 50 MHz
- Aging of less than 1PPM over 20 years
- MTBF of six million hours
- 300 Krad (Si) hard and SEL immune
- Fixed frequency

9960 Temperature Controlled Oscillator (TCXO)

- These space qualified hybrid TCXOs and VCXOs are based on heritage designs and manufacturing techniques proven for reliability in numerous space applications
 - Manufactured at a Class K-qualified facility
- Microsemi has developed and delivered oscillators from 10 MHz to 100 MHz
- Vacuum sealed vs. open blank crystals result in low aging, excellent phase noise, and short term stability
- Best-in-class phase noise at 10 MHz based on overtone crystal design



9960 TCXO

- Aging < +/- 0.5 PPM 1yr
< +/- 3 PPM 10 years
- Short term stability <5E-10 @ 1 sec
- Phase noise < -108 dBc/10Hz
- Frequency range of 10 MHz to 225 MHz
- MTBF of twenty million hours
- 24-pin DDIP package
- 100 Krad (Si) hard and SEL immune

Microsemi 9500 Ultra Stable Oscillator

- Best stability performance available in a commercial product
- Key programs
 - GPS III – navigation payload master reference oscillator
 - SBIRS High – master reference oscillator
 - Lunar Reconnaissance Orbiter
 - EOS – AM
 - Custom platform timing module
- Capability for digital frequency control using an FPGA
- Multiple output frequency
 - Suitable for space craft primary or secondary supplies
- Internal vibration and isolation system
- Environmentally rugged design

- Temperature Stability $< 3 \times 10^{-12}/^{\circ} \text{C}$
- Frequency Stabilities $< 1 \times 10^{-13}$ for $\tau=1-100$ seconds
- Phase Noise $< -145 \text{ dBc}/10 \text{ Hz}$
- $< 3.6 \text{ W}$ @ 25°C in thermal vacuum
- Frequency range of 4 MHz to 100 MHz
- Grade 1 or 2 EEE parts
- MTBF of ten million hours
- Size: 8.95" x 3.87" x 3.27"
- 100 Krad (Si) hard and SEL immune



9500B Measure Allan Deviation

	Adev - Typical Performance
T=1 second	1.1×10^{-13}
T=10 seconds	1.3×10^{-13}
T=100 seconds	1.5×10^{-13}

Atomic Clocks and Oscillator Subsystems

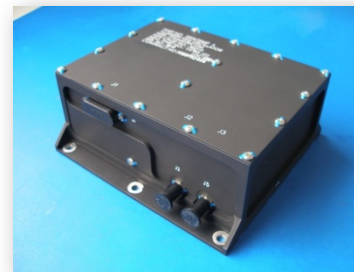
- 4410 Cesium Atomic Clock

- GPS block IIF



- Sub-systems have been delivered that include:

- Multiple and/or redundant oscillators
- Power supplies
- Frequency multipliers and synthesizers
- Integrated thermal baseplate controllers for improved performance



- Mechanical Survivability

- 3000 g's pyroshock
- Greater than 20 grms



Microsemi Frequency and Timing Core Capabilities

- Extensive experience in precision quartz oscillators for space applications
- Low-noise circuit design and frequency synthesis
- Advanced timing capabilities
- Atomic clock development for space
- Expertise in radiation characterization, analysis and testing

Thank You



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