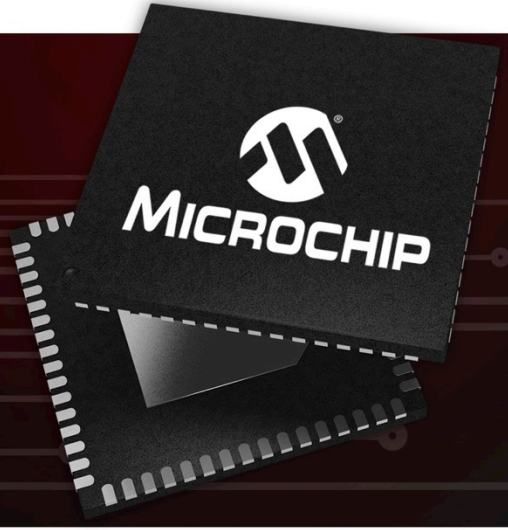
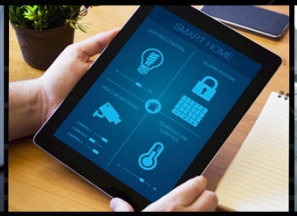
MICROCHIP



A Leading Provider of Microcontroller, Security, Mixed-Signal, Analog & Flash-IP Solutions






Space Timing Products
Peter Cash
Space Forum 2019

Agenda

- Space Qualified Oscillators & Clocks
- Frequency & Timing Division
- New Product: Chip Scale Atomic Clock for Space
- Space Qualified Crystal Oscillators
- Oscillator subsystems & atomic clocks for space
- Summary

Complete Timing (I)

	Market Position & Products
ZARLINK SEMICONDUCTOR	#1 supplier of IEEE1588, SyncE & GNSS network synchronization **PLL IC** and **software** Timing since 1992
maxim integrated. Comms Timing & Sync	Supplier of low phase noise/jitter **PLL IC** Clock synthesis, rate conversion, jitter attenuation and fan-out buffers
MICREL	Oscillators (TCXO), Timers
discera	Oscillators (MEMS, Normal), Clock Generators (Normal, PCIe)
PLL PhaseLink Corporation	Oscillator Die, Clock Generators (Normal, PCIe, VCXO), Clock Conditioning, Buffers (Zero Delay)
SYNERGY SEMICONDUCTOR	Clock Synthesizers, Buffers (PCIe), Multiplexers & Cross Point Switches, Logic Translators, Skew Management
Vectron a Knowles company	Timing since 1938 XO, VCXO, VCSO TCXO, OCXO - SAW & BAW technology GPS Disciplined **Oscillators**
Symmetricom	Precision Crystal (OCXO, TCXO) Embedded Atomic **Clocks** (CSAC, MAC) GPS Disciplined **Oscillators**
VITESSE	Leader in high-precision IEEE1588 timestamping and SyncE **PHY IC**. Full support for precise MACSec
Actel	Integrated Time Synchronization Module for IEEE1588 and SyncE SmartFusion2 **SoC/FPGA IC** complete **software** solution & reference design

Complete Timing (II)

	Hydrogen Maser	Cesium	Rubidium	Rubidium CPT	CSAC	OCXO	EMXO	TCXO			VCXO/XO	MEMS
Model Number	MHM 2010	5071A	XPRO	SA.35	SA.45s	OX-208	EX-421	TX-503	VT-803	MXT57	VC-840	DSC6100
Dimensions (cc)	500E+3	20E+3	338.4	45	17	13.3	1.521	506E-3	23E-3	15E-3	4E-3	2E-3
Temperature stability (0 to 50 °C)	1E-14	1E-13	3E-10	7E-11	5E-10	4E-10	1E-08	2E-08	1E-07	2E-06	1E-05	1E-05
Aging per month	6E-15	0	1E-11	1E-10	1E-09	1E-09	1E-08	1E-07	5E-08	1E-07	5E-07	5E-07
Aging per day	2E-16	0	1E-12	3E-11	1E-10	6E-11	1E-09	1E-08	5E-09	1E-08	5E-08	5E-08
24 hour holdover(s)	1E-10	5E-09	1E-07	1E-06	4E-06	3E-06	4E-05	4E-04	2E-04		2E-03	2E-03
ADEV 1s	8E-14	5E-12	1E-11	3E-11	3E-10	5E-12	2E-11	5E-11	1E-10		1E-09	1E-07
ADEV 10000s	2E-15	1E-13	1E-12	6E-12	5E-12	5E-11	1E-09	1E-09	5E-09		1E-07	1E-06
Phasenoise 10 Hz (dBc/Hz)	-150	-130	-90	-70	-70	-125	-95	-93	-91	-76	-70	-40
Phasenoise 100 kHz (dBc/Hz)	-160	-154	-155	-140	-140	-145	-165	-156	-157	-143	-150	-120
Power (W)	68.2	45	13	5	0.12	1.5	0.25	4E-02	5.0E-03	3E-03	4.5E-03	5.0E-03
Costs	$$$,$$$	$$,$$$	$,$$$	$,$$$	$,$$$	$$	$$	$$	$	$	cc	cc

Frequency & Timing Div.

Synchronization Systems

- Frequency & Time Distribution Systems
- 1588 Grand Masters
- NTP Servers
- GPS Instruments
- Custom and Configurable systems (Gov't Systems)
- Software
- Contract Support services
- Engineering & Installation Services

Clocks

- Chip Scale Atomic Clock (CSAC)
- Rubidium Clocks
- Cesium Clocks
- Hydrogen Masers
- Space Qualified and Military Oscillators

Markets

- Communications, Defense, Space, Infrastructure, Datacenters

Customers

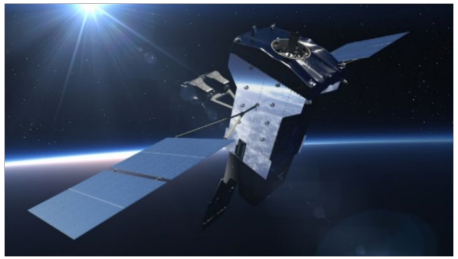
- Critical Infrastructure (Utilities, Rail, Public Safety, Telecom Operators), Satcom, System Integrators/NEMs, Defense prime contractors and Government agencies, Geophysical survey operators, Datacenters, Enterprise IT, Test & Measurement, Medical, Energy

Applications

- Precise timing and frequency references
- Holdover for GPS vulnerability

Space Qualified Oscillators & 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



Space Capabilities

- Design and manufacture high-performance space VCXOs, 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
- 2 Vibration tables and Shock system

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	8.95“ x 3.87“ x 3.27"	<2382 g	<2.9 W (in vacuum)

9600 / 9700 (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.

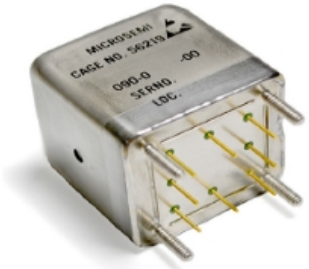
Connectorized Package

PCB Mount Package

- **High stability and low phase noise**
- **Allan Deviation of < 1 x 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 in^2**
- **300 Krad (Si) hard and SEL immune**

9800 (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



9800 OCXO

- **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**

9500 USO (OCXO)

- USO: 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

9500B OCXO

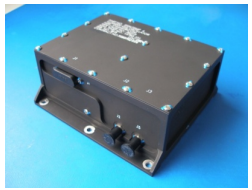
- **Temperature Stability < 3 x 10^{-12}/ °C**
- **Frequency Stabilities < 1 x 10^{-13} for τ=1-100 seconds**
- **Phase Noise <-145 dBc/10 Hz**
- **<3.6 W @ 25 °C in thermal vacuum**
- **Frequency range of 4 MHz to 100 MHz**
- **Grade 1 or 2 EEE parts**
- **MTBF of ten million hours**
- **Size: 8.95”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

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

Atomic Clocks and Oscillator Subsystems

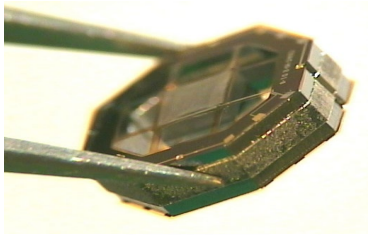
- 4410 Cesium Atomic Frequency Standard
  - GPS block IIF

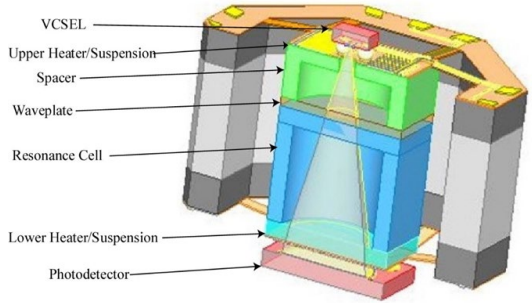
- Sub-systems have been delivered that include:
  - Multiple and/or redundant oscillators
  - Power supplies
  - Frequency multipliers and synthesizers
  - Integrated thermal baseplate controllers for improved performance
- Mechanical Survivability
  - 3000 g's pyroshock
  - Greater than 20 grms



CSAC

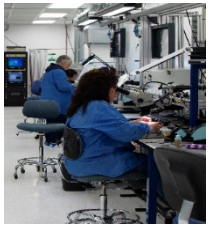
- Chip Scale Atomic Clock (CSAC)
- 120 mW Atomic Clock with 16 cm^3 volume
- <1 ppb Frequency Accuracy, ± 5 x 10^{-10} temperature stability
- < 3 x 10^{-10} Allan Deviation at 1 second
- 1 PPS steering option, <50ns 1 Hr holdover
- Extremely low sensitivity to acceleration
- Rugged physics package by design
- >1000g shock resistant
- Vacuum-packaged physics package to eliminate convection/conduction – 7000˚ C/W
- Entire physics package can operate on 15 mW





CSAC Capabilities

- Manufacturing location, mid-volume, flow based manufacturing
- CSAC (Chip Scale Atomic Clock) Product Line
- Quality Management system Registered to ISO-9001:2008, and TL-9000 Standards
- Class 10K clean Room, CL 100 Bench
- Vacuum cleaning and processing
- Semi-automated precision micro assembly
- Soldering, bonding, wiring, PCBA, vacuum firing/cleaning, aging, thermal cycling, Cs cell processing & assembly, final test, inspection, system test



Space CSAC

- Space Chip Scale Atomic Clock (CSAC)
- Released in April 2018
- Identical performance to CSAC
- EAR-99 component (commercial – no restrictions)
- Radiation Tolerance: 20Krad and no SEL to 64 MeVcm^2/gm
- Optimal for LEO applications
- Radiation lot acceptance testing for commercial device susceptibility
- “New Space” type of product that leverage commercial state of the art technology
- Initial units flying on NASA missions – results published
- Multiple customer orders including Harris Space

Space CSAC

Space CSAC

Space CSAC

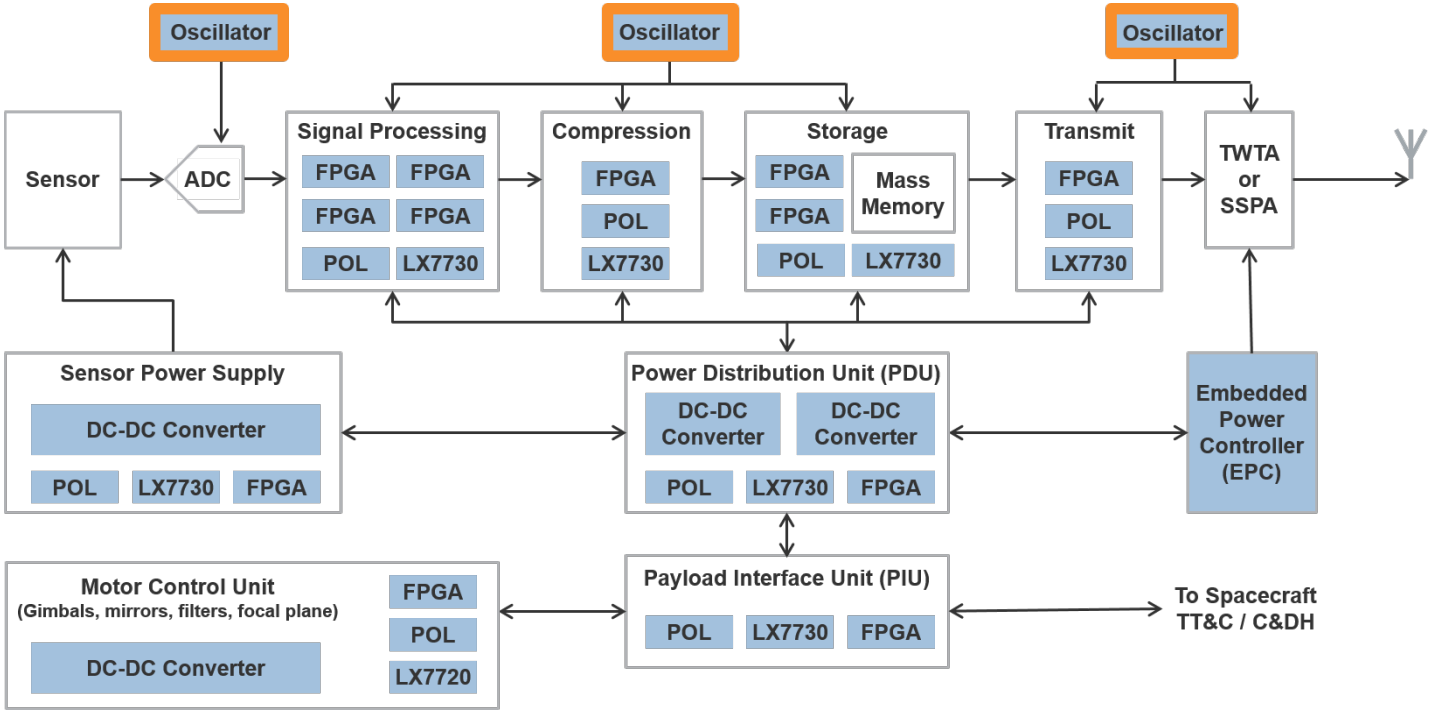
- Shorter more frequent lower cost missions in LEO (<1,200mi, 2,000km)
- Atomic Accuracy at Low SWaP
- Rad tolerant COTS parts
- Lot control / rad testing
- Parts in Stock, Short lead times
- Lower cost / cutting edge technology
- Medium risk / redundancy may be required

Traditional Space Oscillator

- Long Mission Duration (10+)
- 100 krad + radiation hardened
- Hermetic packaging
- Mature technology
- Limited suppler stock / build to order
- Longer lead times
- Higher component cost
- Lower risk

Signal Processing Payload

Example:



Summary

- 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 / test
- FTD and Vectron together offer the broadest array of Space Qualified Oscillators

Thank you