Silicon MEMS Oscillators for High Speed Digital Systems

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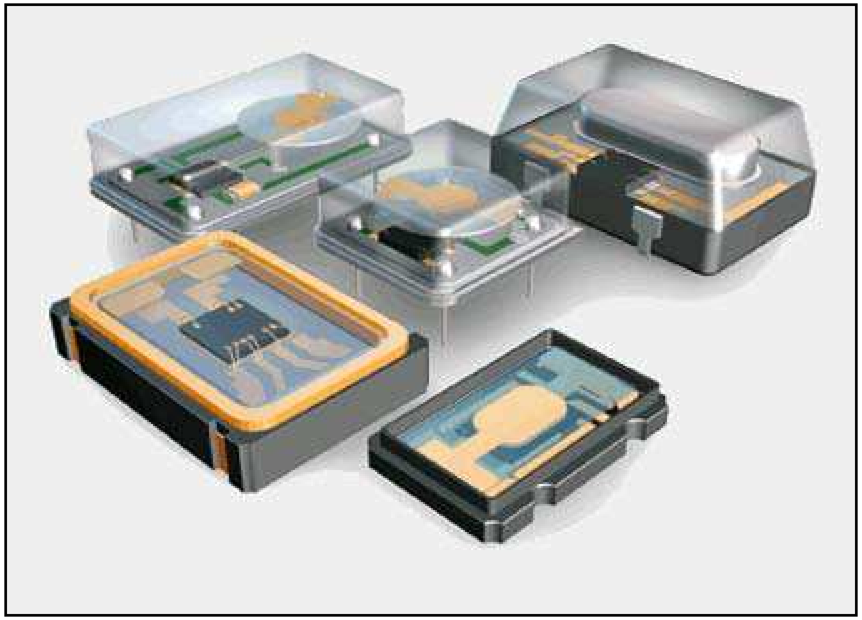
It's About Time

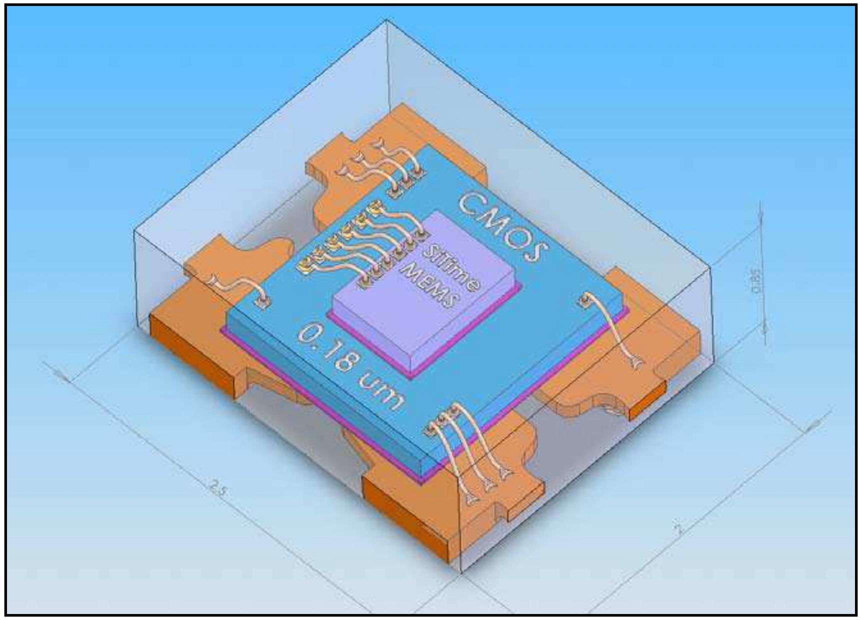
SiTime™

Questions This Talk Will Answer

- What are MEMS oscillators, and why do they matter?
- What is their history, and how are they made?
- How will they impact high speed digital systems?
- When and where can I get some?

Quartz and MEMS Oscillators





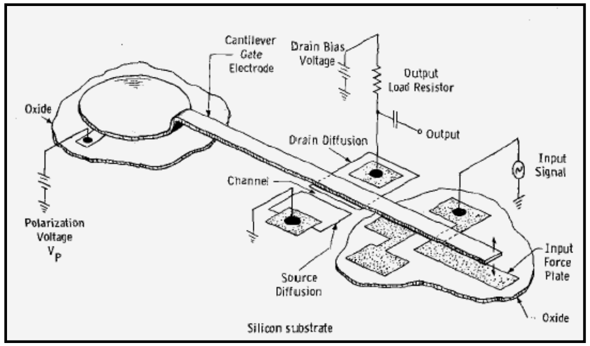
Quartz Oscillators:

- Ceramic or metal package
- Quartz plate above driver circuit
- Built with special dedicated processes in dedicated factories

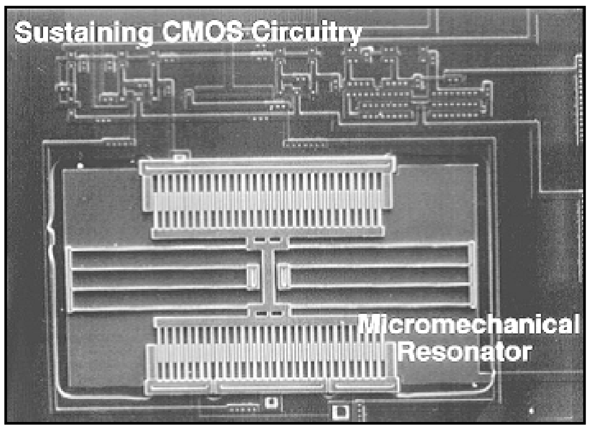
MEMS Oscillators:

- Plastic QFN package
- Silicon MEMS die on CMOS die
- Built with standard processes in standard IC fabs

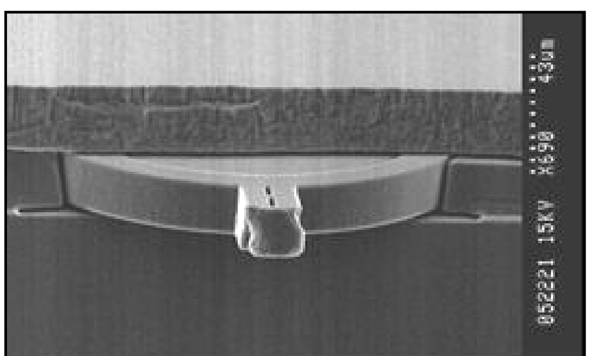
MEMS Resonator and Packaging History



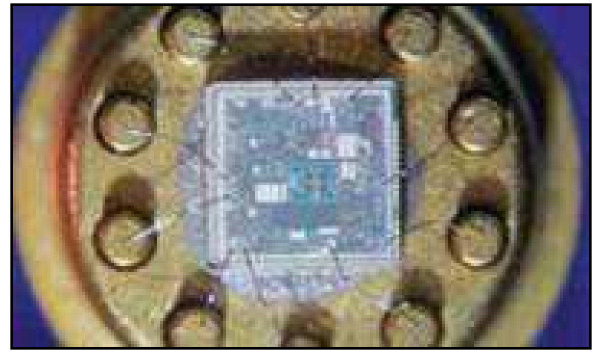
H.C. Nathanson 1967



C.T.C. Nguyen, R. Howe 1999

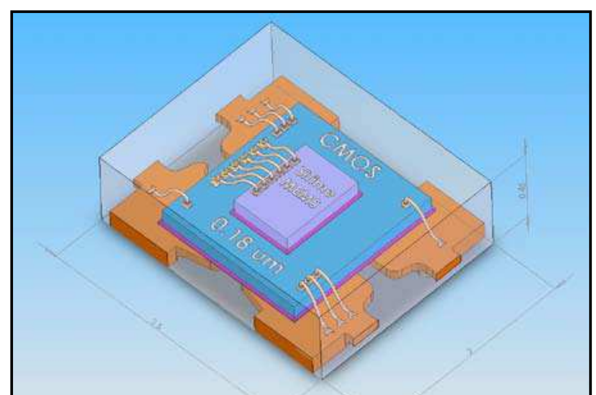


Bosch 2003



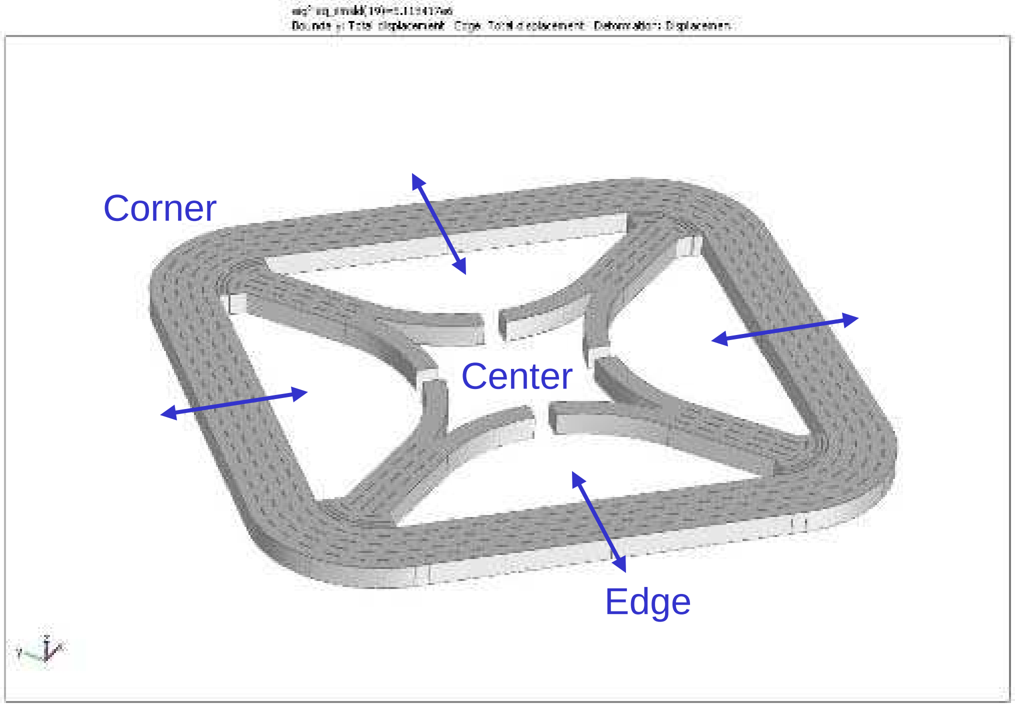
Analog Devices ADXL-50 1995

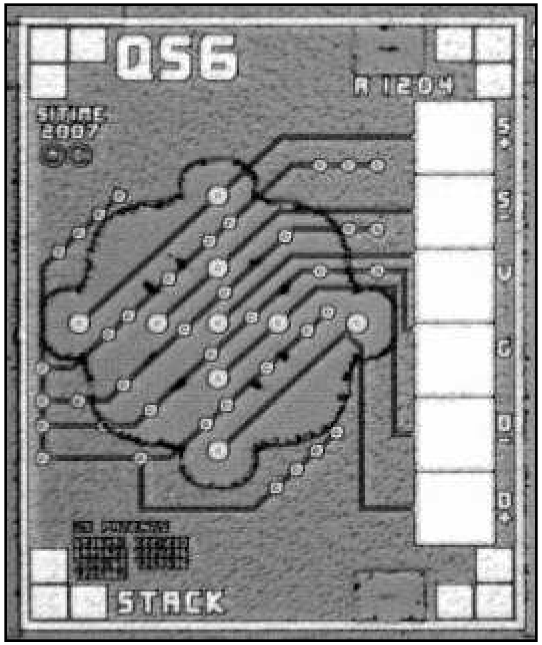
Bosch Resonant gyro 2006

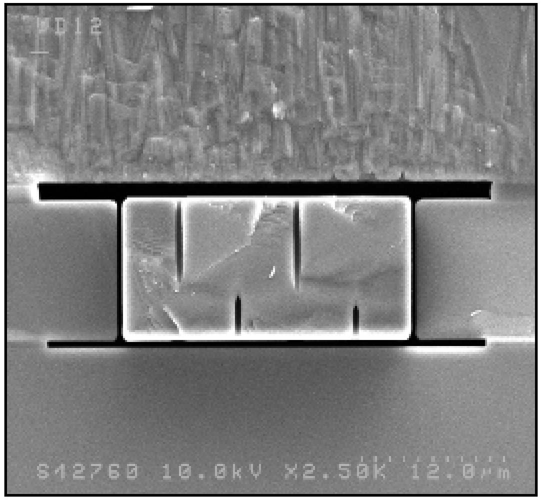


SiTime QFN Package 2006

5 MHz Resonator

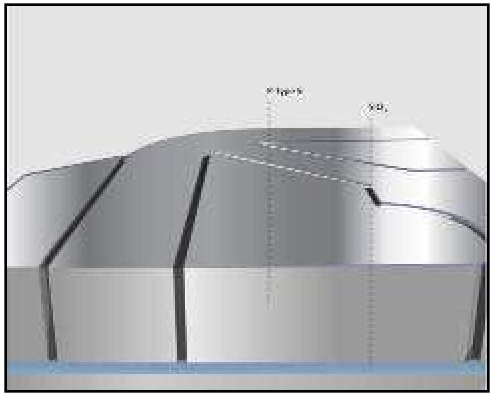




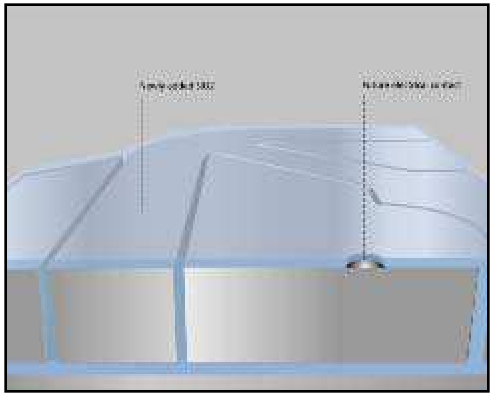


- Like a 2D bell – held in the center with its outer edges ringing. Motion is a few nanometers.
- Quad with center anchor and motionless corners keeps Q high and stress sensitivity low.
- Four resonant beams are driven and sensed capacitively by eight electrodes.

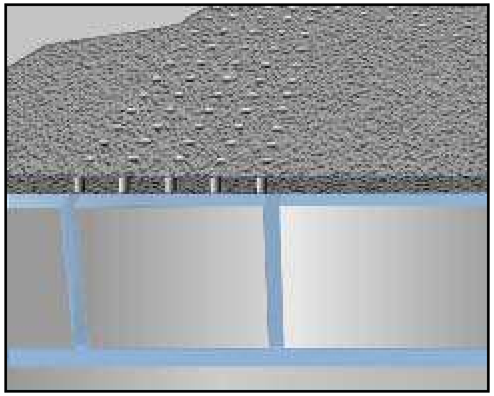
MEMS Resonator Fabrication



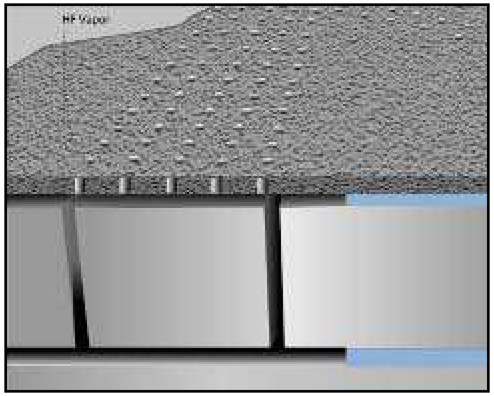
1. Etch SOI wafer



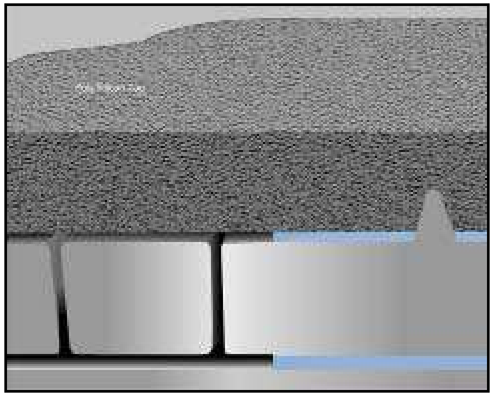
2. Protect under oxide



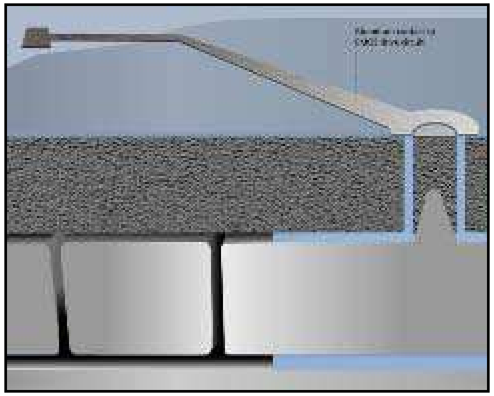
3. Cover and perforate



4. Remove oxide

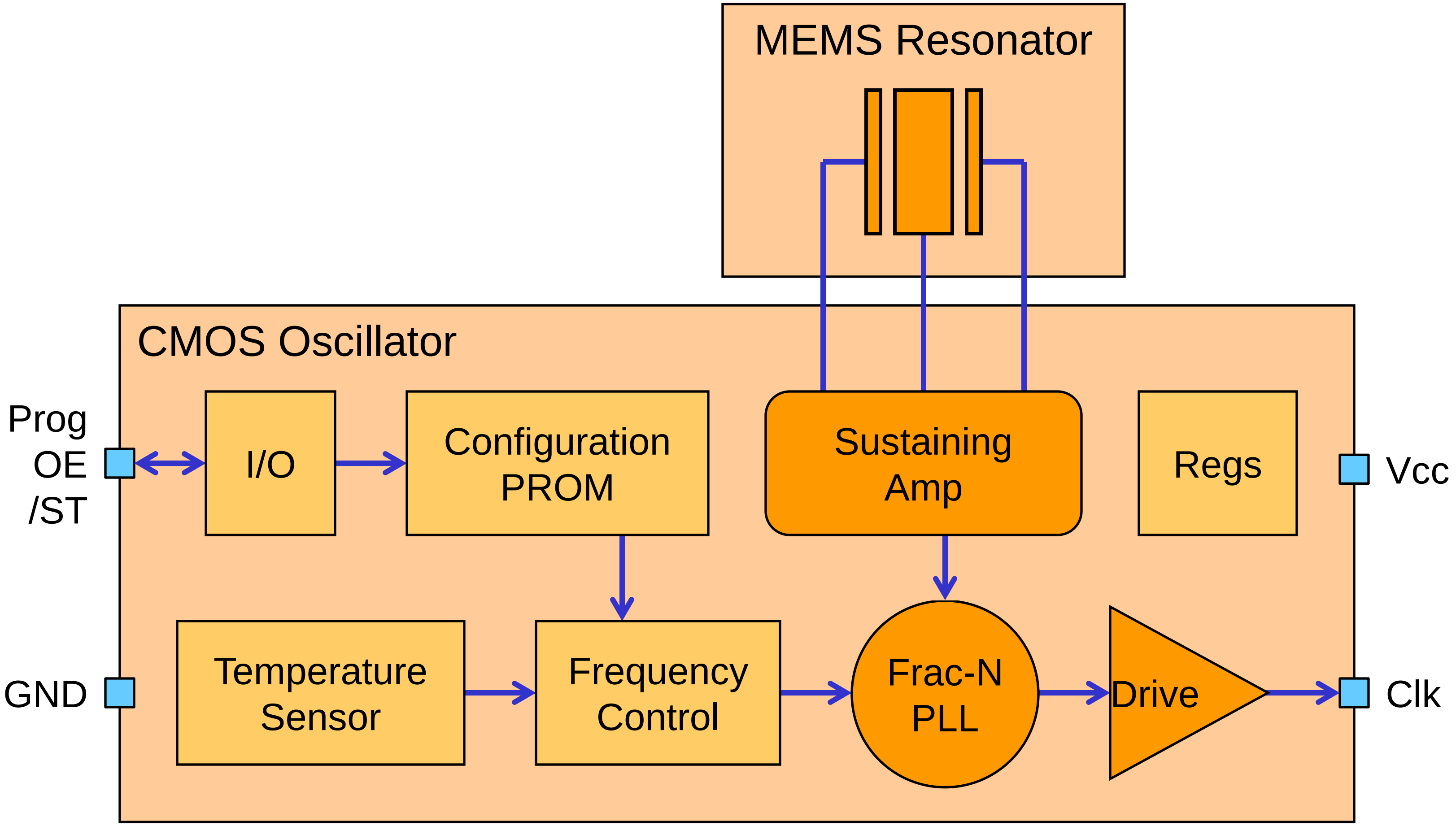


5. Deposit thick silicon



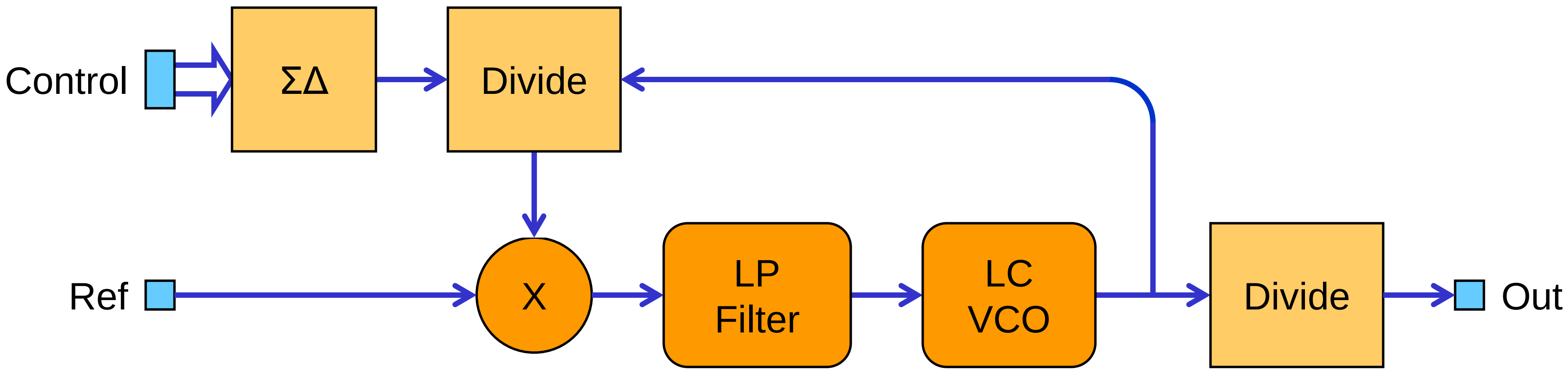
6. Finish interconnects

Oscillator System Architecture



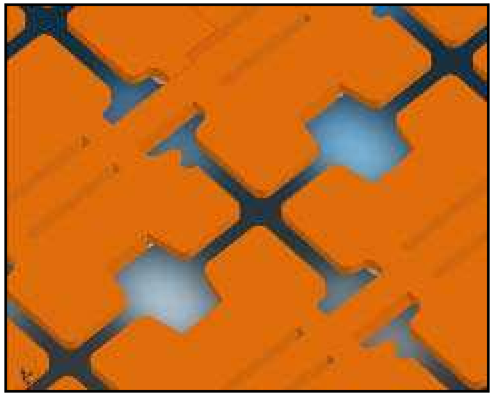
MEMS Oscillator System Architecture

PLLs Are Your Friends

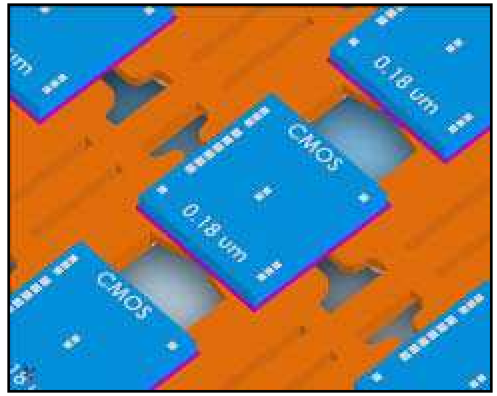


- Engineers are sometimes afraid of PLLs
  - Designing PLLs correctly is difficult and requires specialized tools.
  - Poorly designed PLLs can “peak” or degrade the signal or fail.
  - SiTime’s PLLs are of course well designed and don’t cause problems.
- SiTime’s low jitter clocks and oscillators use LC Frac-N Sigma-Delta PLLs
  - Are among the most advanced PLLs in any product.
  - Provide high frequencies / low jitter / low power.
  - Compensate MEMS fab and temperature variations.
  - Support programmable frequencies, spread and voltage control.

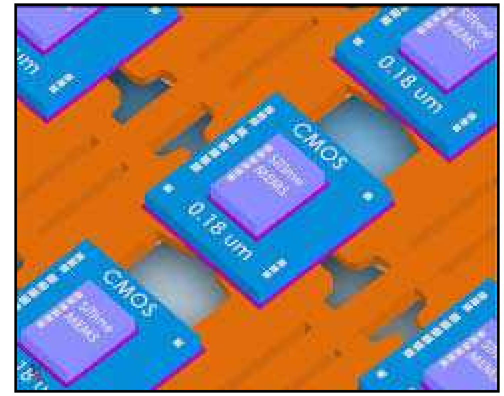
MEMS Oscillator Packaging is Similar to IC Packaging



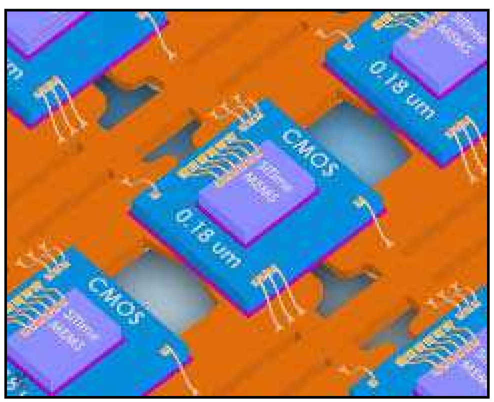
1. Etch lead frame



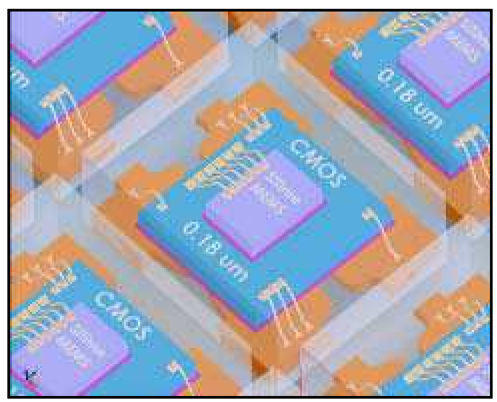
2. Mount CMOS



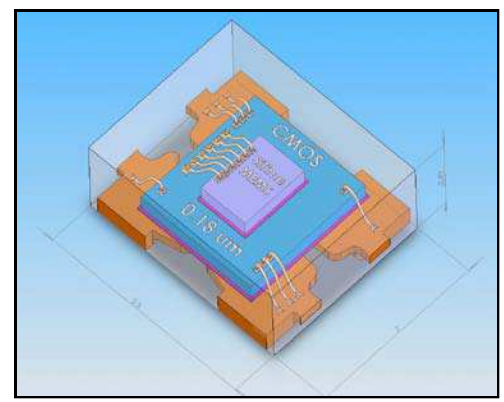
3. Mount MEMS



4. Attach wire bonds

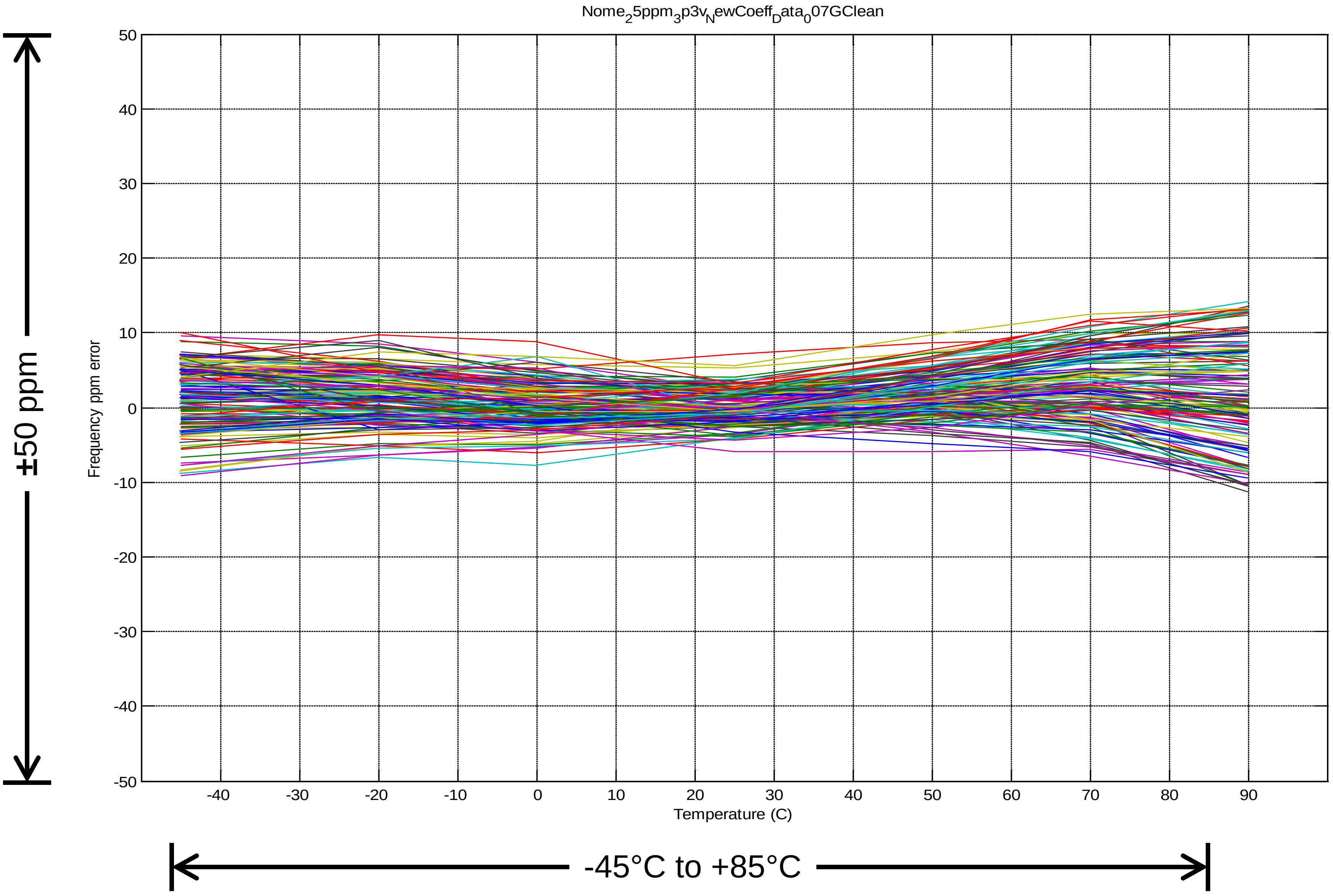


5. Mold and singulate



6. Test and calibrate

Frequency Stability Over Temperature (110 Example Parts)

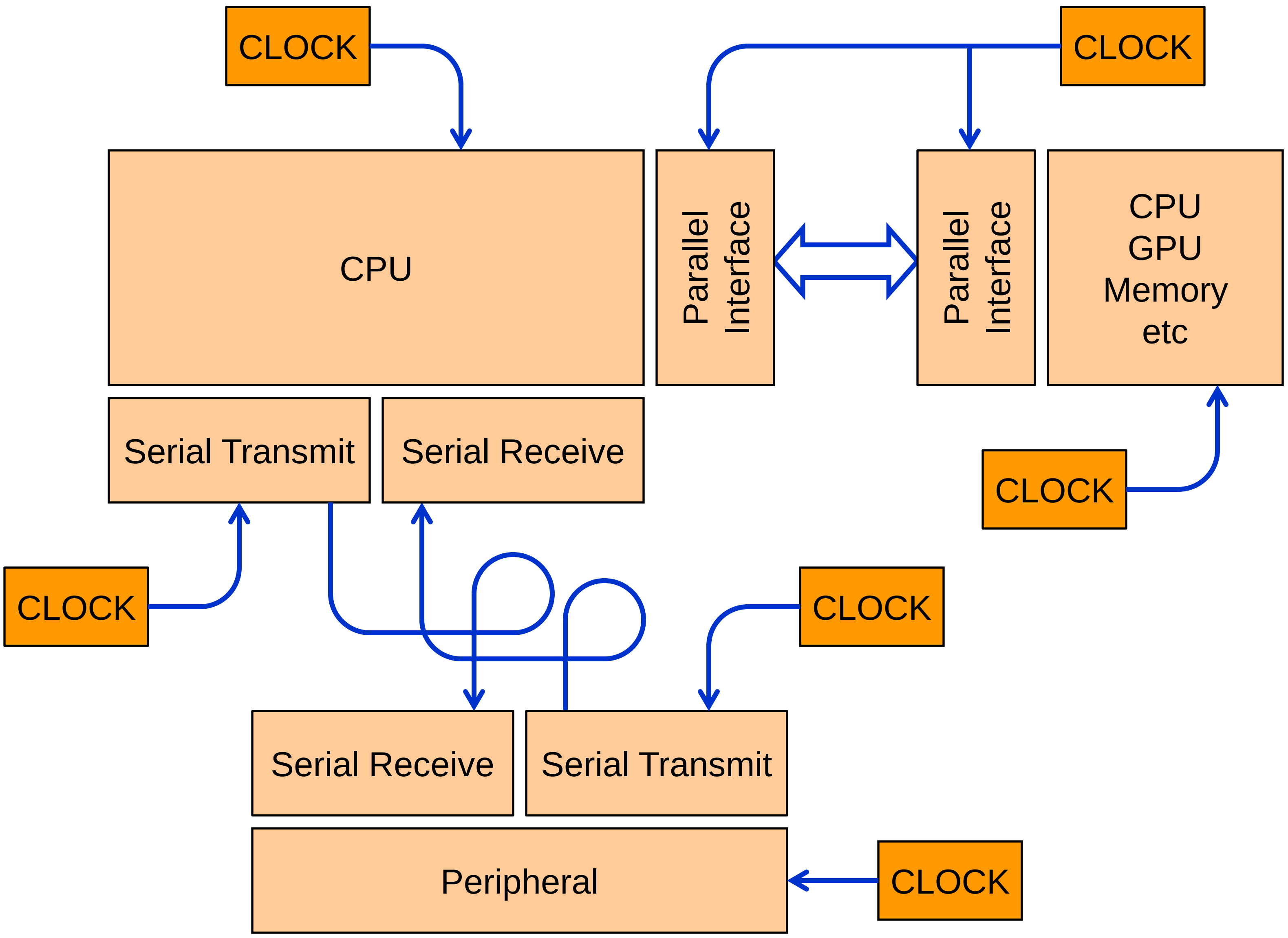


IC-Level Reliability

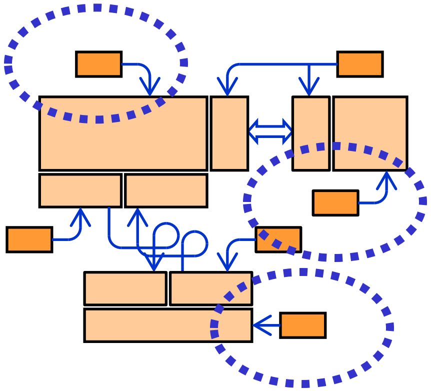
- MEMS oscillators pass all standard CMOS quals and additional tests

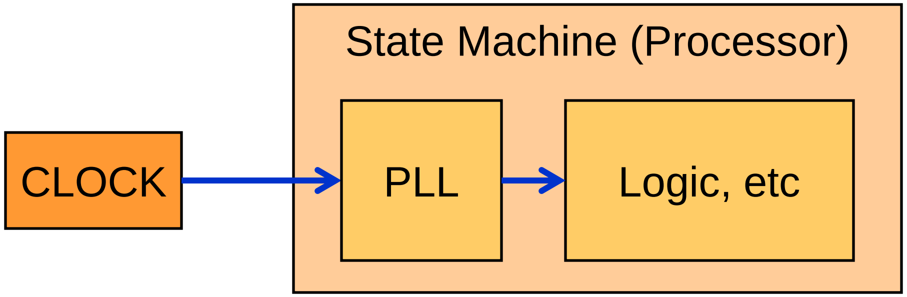
Test	Description	Quantity	Fails
EFR	Early Life (125C 168 hrs dynamic)	4771	0
HTOL	Operating Life (125C 2000 hrs dynamic)	320	0
ESD	Electrostatic Discharge (HBM, MM, CDM)	30	0
LU	Latch Up (85C 150mA)	18	0
DRB HTS	Data Retention Bake (150C 1000 hrs)	80	0
DRB HTOL	Data Retention Bake (125C 1000 hrs dynamic)	80	0
HAST	Biased Temp and Humidity (85 hrs 130C 85% RH)	320	0
TC	Temp Cycle (MSL1 + 1000 cycles, -65C -- 150C)	319	0
QA	Quartz Style Aging (30 days 85C dynamic)	240	0
MS	Mechanical Shock (50kg shock multi-axis dynamic)	60	0
VFV	Variable Frequency Vibration (70g dynamic)	60	0
VF	Vibration Fatigue (20g 30 hrs dynamic)	120	0
CA	Constant Acceleration (30kg dynamic)	120	0
HTS	High Temperature Storage (125C 1000 hrs)	240	0
PCT	Pressure Cooker Test (120C 100% RH 2atm 96 hrs)	240	0
TS	Temp Shock (-55C -- 125C 100 cycles)	180	0
MSL1	Moisture Sensitivity Level 1 (JEDEC)	900	0

Clocks in High Speed Digital Systems



State Machine (Processor) Clocking





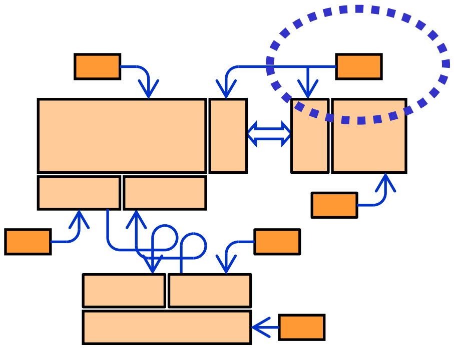
- The system cares about the product of two filters: The PLL loop response and the period jitter filter response.
- Mostly a function of the internal PLL and the clocking strategy, not the clock.
- However, a high frequency reference simplifies the PLL.
- Faster cleaner edges help in noisy environments.
- Differential clock signals advantageous for both high frequency and low noise.

State Machine (Processor) Clocking

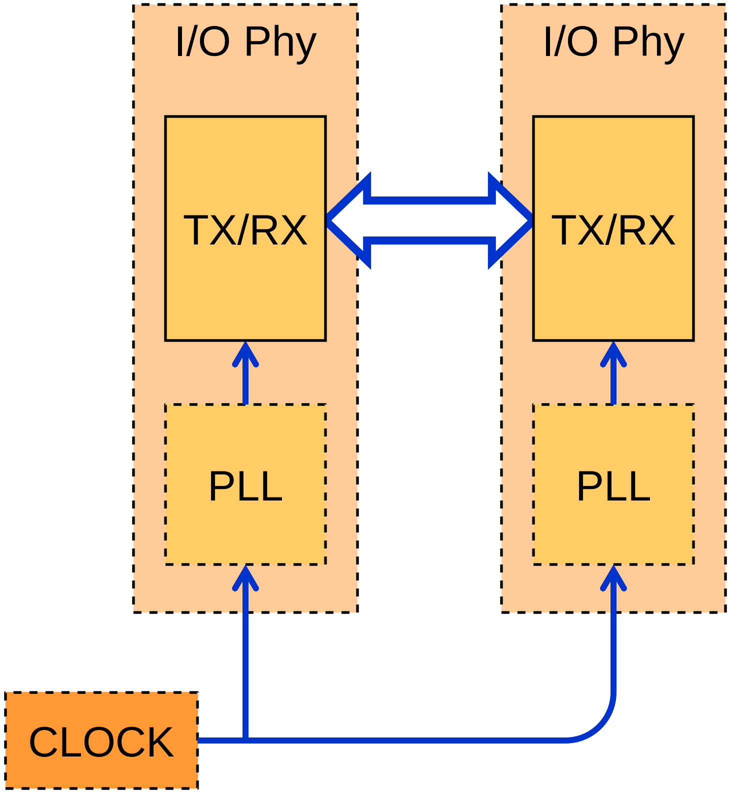
- Processors, microcontrollers
- Application processors (graphics, network, etc)
- State-machines, DSP

Parameter	Application Requirements	MEMS Timing Solutions
Frequency range	1 MHz to 600 MHz	1 MHz to 800 MHz
Frequency Stability	25 ppm to 50 ppm	10 ppm to 50 ppm
Period Jitter	4 ps to 100 ps (RMS)	1.5 ps to 15 ps
Cycle-to-cycle (C2C) jitter	20 ps to 500 ps	8 ps to 100 ps
IDD	10 mA to 200 mA	3 mA to 100 mA
Start-up time	5 ms to 50 ms	3 ms to 30 ms
Spread Spectrum clocking (for EMI reduction)	Down-spread, Center-spread 0.5%, 1%, 2%, 4%	All option readily available

Parallel Communication Clocking



- Similar filter function as state machines.
- However, specs are not discretionary to IC design team.
- Must meet industry standards.
- Might not own both ends of data path.
- Again, high frequency and differential signaling are advantageous.

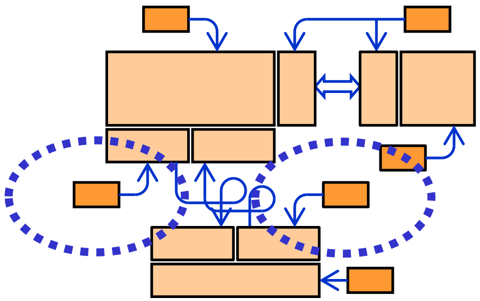


Parallel Communication Clocking

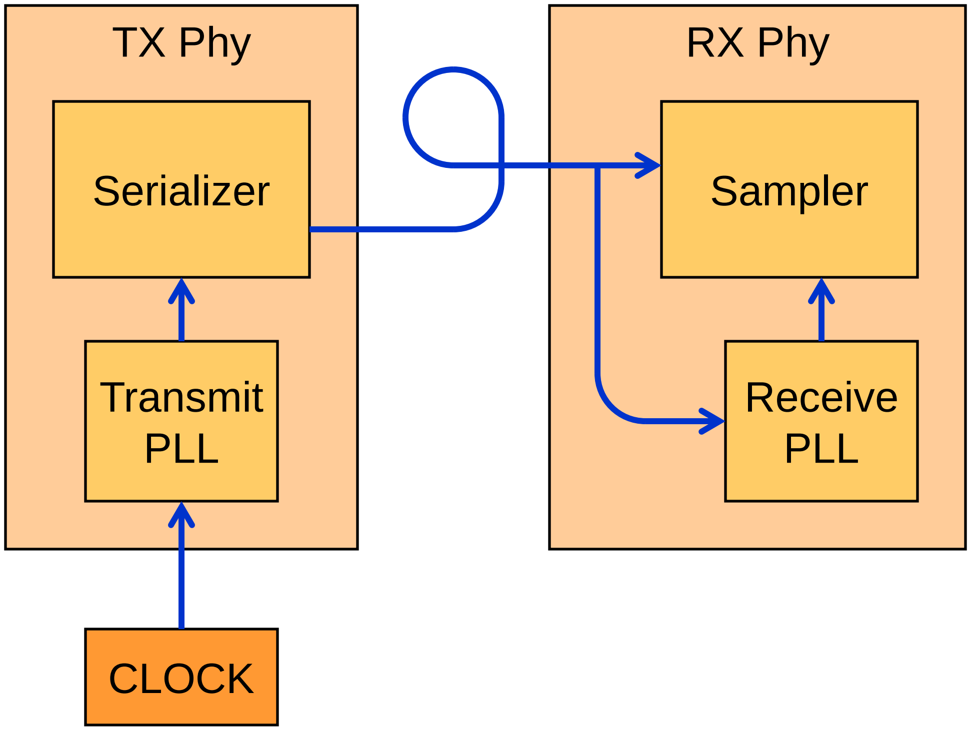
- DDR, DDR2, DDR3
- HyperTransport

Parameter	Application Requirements	MEMS Timing Solutions
Frequency range	33 MHz to 400 MHz	1 MHz to 800 MHz
Frequency Stability	50 ppm	10 ppm to 50 ppm
Period Jitter	4 ps to 100 ps (RMS)	1.5 ps to 15 ps
Cycle-to-cycle (C2C) jitter	20 ps to 500 ps	8 ps to 100 ps
Multi-cycle jitter (50 cycle)	75 ps to 500 ps	40 ps to 120 ps
Spread Spectrum clocking (for EMI reduction)	Down-spread, Center-spread 0.5%, 1%, 2%, 4%	All options readily available

Serial Communication Clocking



- Filter function a product of transmit PLL and receive PLL.
- Must meet industry standards, some of which are stringent.
- Usually will not own both sides of the data path.
- High frequency and differential signaling are often required.

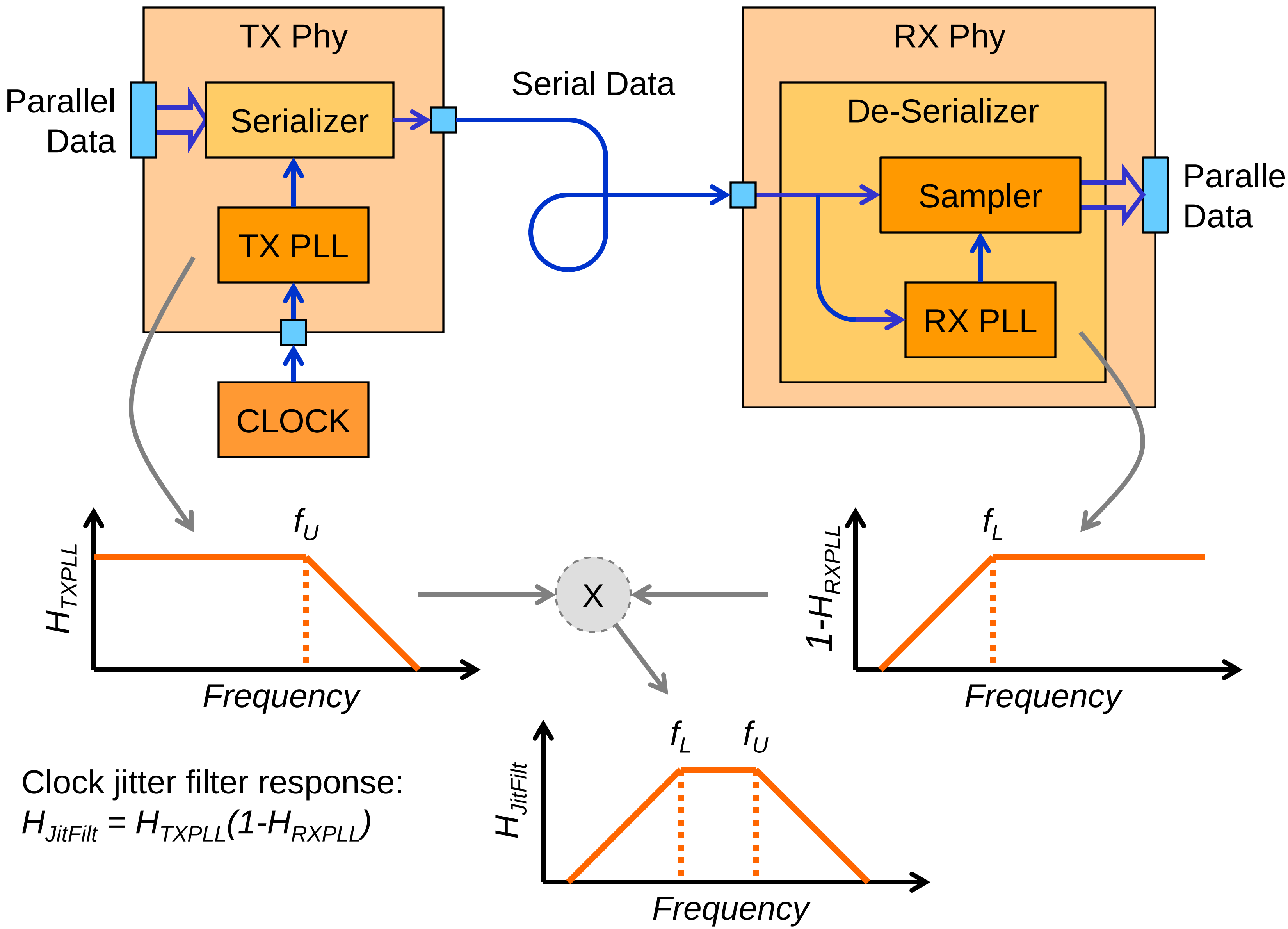


Serial Communication Clocking

- Computing: PCI-Express, FireWire, USB2.0, USB3.0, Infiniband
- Storage: SATA, SAS, FibreChannel
- Networking: Ethernet, GbE, 10GbE, XAUI
- Consumer: EPON, GPON, Mobile Industry Processor Interface (MIPI), HDMI

Parameter	Application Requirements	MEMS Timing Solutions
Frequency range	12 MHz to 666 MHz	1 MHz to 800 MHz
Frequency stability	25 ppm, 50 ppm	10 ppm to 50 ppm
Phase jitter budget	~30% of total system budget	10% typical for most widely used applications – see next slide
Spread Spectrum clocking (for EMI reduction)	Down-spread 0.5%	Readily available

Serial Communication Clocking



Clock jitter filter response:

$H_{JitFilt} = H_{TXPLL}(1-H_{RXPLL})$

Serial Communication Clocking

Application	Jitter Margin Consumed by MEMS Oscillators
FiberChannel	9% (1 Gbps), 12% (2 Gbps), 20% (4 Gbps)
GPON, EPON	14%, 21%
10GBE	9% (XAUI), 26% (Optical, XFP)
USB2.0, USB3.0	3% (USB2.0 Device), 7% (USB2.0 Hub), 8% (USB3.0)
PCI-Express	5% (Embedded clock), 7% (C. RefClk), 12% (CC. Gen-II)
SATA	4% (1.5 Gbps), 6% (3 Gbps), 12% (6 Gbps)
IEEE1394b (FireWire)	7% (400 Mbps), 11% (800 Mbps), 13% (1600 Mbps)
Infiniband	15% (device), 8% (slot)

Features that Quartz Generally Does Not Provide

High frequencies, unusual frequencies, and differential outputs:

- MEMS oscillators have internal PLL's so they easily supply high frequencies.
- Available to 220 MHz single ended, 800 MHz differential, highly programmable.
- SiTime's PLL's are differential, so they easily supply differential outputs.

Spread spectrum and voltage control (VCXO functionality):

- Spread and voltage controlled oscillators available in each product family.
- SiTime offers the world's only single chip differential spread oscillator.

Multi-outputs:

- Additional circuits readily supply multiple outputs.
- Up to three independent frequencies, formats, and supply voltages.
- Differential and single-ended or combinations.

Low defect rates, short lead times:

- Defect rates in the parts per millions, and sub-3 FIT (Failures In Time).
- Same day samples, two week production quantities.

A Few Additional Examples

Extreme shock survival

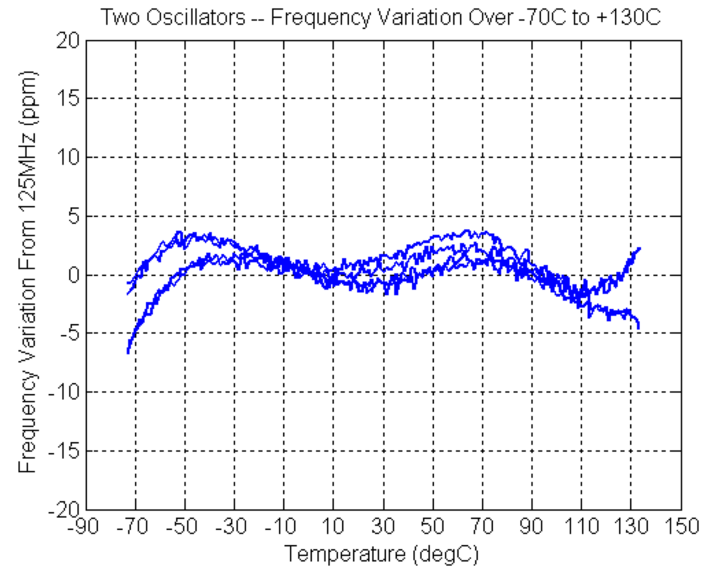
- We have tested to 50 kG shock, vibration, acceleration etc, with no failures.
- Our parts have survived customer shock tests in which <u>all</u> quartz failed.

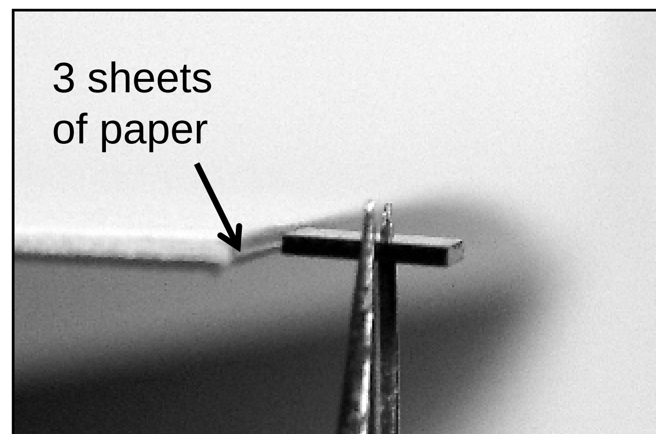
Wide temperature operation

- -70 to +130 C with only 5 ppm frequency variation – quartz doesn't do this.
- Applications in defense.

Ultra thin packaging

- SiTime 8003XT is only 0.25 mm thick – thinner than 3 sheets of paper.
- Design wins in smart SIM cards.





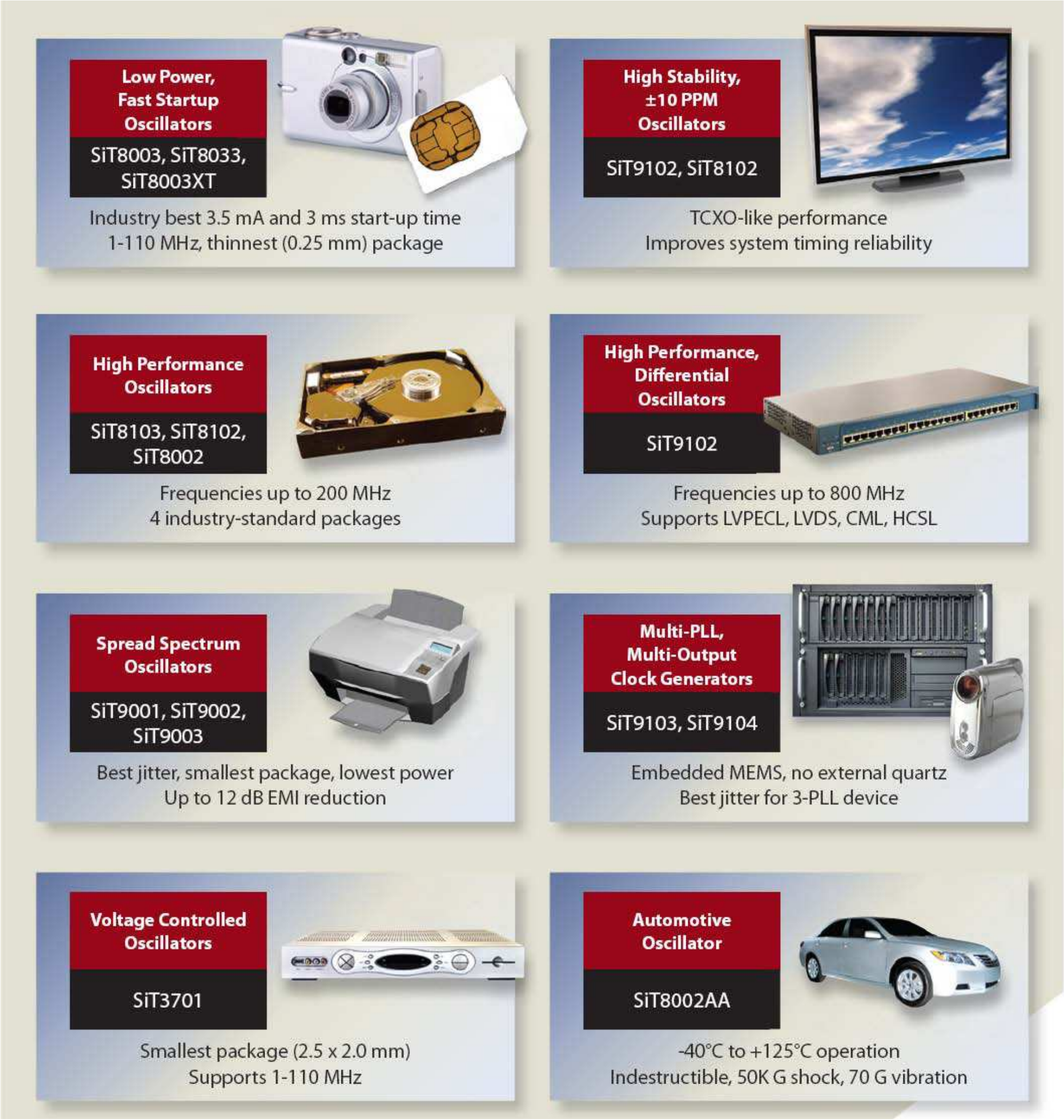
Available Now From SiTime

Low power, high stability:
8003, 8033, 9102, 8102

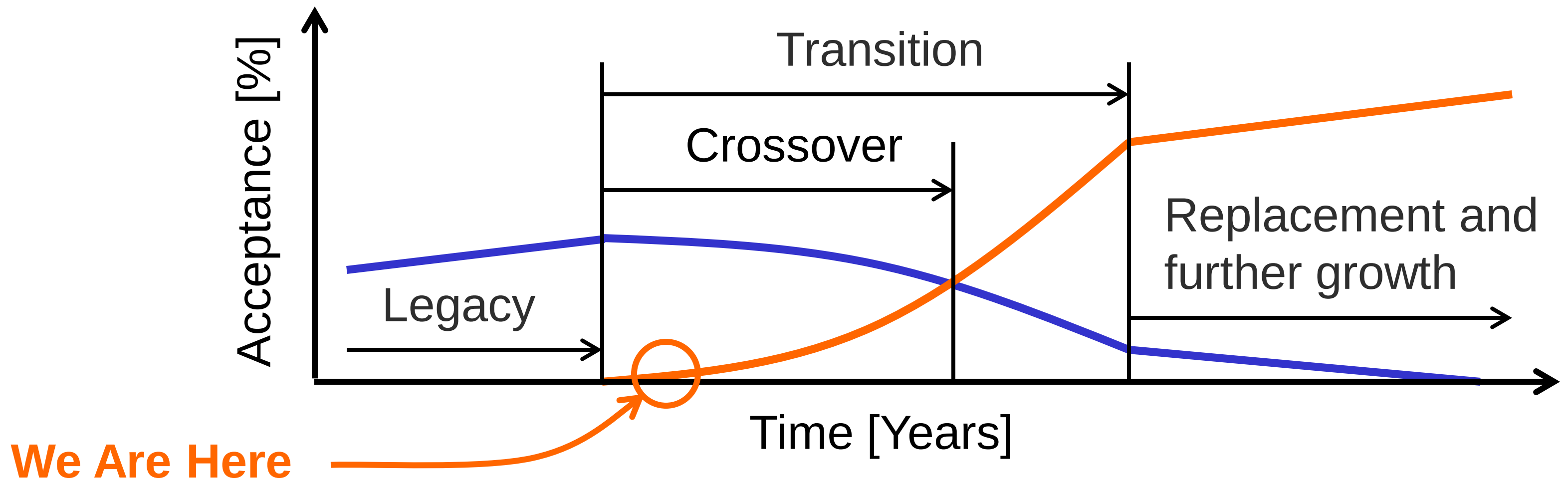
Performance, differential:
8103, 8102, 8002, 9102

Spread, multi-output:
9001, 9002, 9003, 9104

Voltage control, automotive:
3701, 8002AA



Technology Transitions



OLD	NEW	YEARS	WHY REPLACED
Analog cell phones	Digital cell phones	6	Spectrum efficiency, features
CRT displays	LCD displays	8	Size, image, weight, cost
Film cameras	Digital cameras	8	Ease of use, sharing, cost
Balls in tubes	MEMS accelerometers	5	Reliability, accuracy
Quartz gyroscopes	MEMS gyroscopes	6	Cost, size
Electrets	MEMS microphones	4	Size, PCB assembly
Quartz timing	**MEMS timing**	**?**	**Size, reliability, lead time, new functions, cost**

Years = introduction to crossover

Thank you

Questions?