High Temperature Frequency Control Solutions

White Paper
HIGH TEMPERATURE FREQUENCY CONTROL SOLUTIONS

The demand for frequency references with higher operating temperature range capability is rapidly growing across all marketplaces. The range -40°C to +105°C is replacing -40°C to +85°C as the de facto industrial temperature range, partly due to system designers downsizing application boards and eliminating cooling fans from their systems. The expansion of electronic controls in automobiles is further pushing maximum operating temperatures to +125°C and beyond. There is also a growing acceptance of using commercial-type components for military, aerospace, and rugged industrial applications, driving the need for devices that can survive in their respective operating environments.

Harsher operating environments bring new demands and challenges to improve performance for frequency reference devices functioning in today’s applications. These include integrated circuits [IC] used in oscillators operating at higher temperatures with concerns for thermal resistance such as junction temperature, quartz resonators and oscillators maintaining lower stability numbers over wider temperature ranges, Coefficient of Thermal Expansion [CTE] mismatches creating stresses in the resonator mounting structure that can accelerate aging and cause frequency perturbations [jumps] in oscillators.

CTS has an extensive portfolio of frequency references and timing solutions developed to operate at higher temperatures that specifically address the needs for automotive grade components, military and aerospace applications, as well as a variety of industrial environments.

AUTOMOTIVE GRADE COMPONENTS

In today’s automobiles there can be up to 100 electronic control units [ECUs] used to perform various functions. The “connected car” is advancing communication protocols used within the vehicle and is increasing the need for multiple frequency references to support the timing requirements for technologies used.

Operating environments that electronic components will be subjected to are varied whether under the hood, within the drivetrain, or in cabin applications. Each environment requires a different operating temperature range. The automotive industry has developed test standards that control component/system compliance to provide excellent durability, quality, and consistency in the supply chain.
Beyond the automobile, automotive grade components are being widely accepted for use in medical, industrial, and military/aerospace [mil/aero] applications. These components meet the industry standards for high-quality devices, give excellent performance, are cost-effective, and are readily available - all essential characteristics to meet application requirements for these demanding industries.

Optimized for non-safety applications with wide temperature ranges, to +150°C, CTS has an array of standard crystal and oscillator products compliant to AEC-Q200 standards and manufactured on certified TS 16949 production lines. Additionally, CTS has developed timing solutions that support Advanced Driving Assistance Systems [ADAS] using radar/LIDAR technologies.

**AEC-Q200**

In the 1990’s representatives from Chrysler, Ford, and General Motors came together and formed a consortium called the Automotive Electronics Council [AEC]. The AEC established common part-quality system standards, AEC-Qxxx, and the most commonly referenced documents are:

- AEC-Q100 “Failure Mechanism Based Stress Test Qualification for Integrated Circuits”
- AEC-Q101 “Failure Mechanism Based Stress Test Qualification for Discrete Semiconductors”
- AEC-Q200 “Stress Test Qualification for Passive Components”

The AEC component technical committee’s role is to establish and maintain global standards for reliable, high-quality electronic components. Components meeting these standards are suitable for use in the harsh automotive environment, with the intent of no additional component-level qualification testing necessary by the end user.

The reliability standard most applied to the frequency and timing products used in automotive applications is AEC-Q200. This standard details the stress tests applicable to passive electrical components to ensure reliable use in the automotive industry. AEC-Q200 also defines 5 component grades that categorize automotive application temperature environments that a product must function in, shown in the table below. The testing standards defined in the AEC-Qxxx documents use a combination of MIL-STD and JEDEC test procedures. A typical test procedure for quartz crystal products is shown in Table 11 in the Appendix.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Minimum Temperature</th>
<th>Maximum Temperature</th>
<th>Passive Component Type [maximum capability unless otherwise specified and qualified]</th>
<th>Typical/Example Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-50°C</td>
<td>+150°C</td>
<td>Flat Chip ceramic resistors, X8R ceramic capacitors</td>
<td>All Automotive</td>
</tr>
<tr>
<td>1</td>
<td>-40°C</td>
<td>+125°C</td>
<td>Capacitor Networks, resistors, Inductors, Transformers, Thermistors, Resonators, Crystals and Varistors, all other ceramic and Tantalum Capacitors</td>
<td>Most Underhood</td>
</tr>
<tr>
<td>2</td>
<td>-40°C</td>
<td>+105°C</td>
<td>Aluminum Electrolytic Capacitors</td>
<td>Passenger Compartment Hot Spots</td>
</tr>
<tr>
<td>3</td>
<td>-40°C</td>
<td>+85°C</td>
<td>Film Capacitors, Ferrites, R/R-C Networks and Trimmer Capacitors</td>
<td>Most passenger Compartment</td>
</tr>
<tr>
<td>4</td>
<td>0°C</td>
<td>+70°C</td>
<td></td>
<td>Non-Automotive</td>
</tr>
</tbody>
</table>

**Table 1. Component Grades**

**TS 16949**

Factories supplying products or components with compliance to AEC-Qxxx standards are also required to be certified ISO/TS 16949, commonly denoted as TS 16949. This technical specification addresses the development of a Quality Management System [QMS] for the supply and delivery chain of the automotive industry. Originally based on ISO9001, the current specification released in 2016 as IATF16949: 2016 by the International Automotive Task Force superseded the ISO Tech Committee and replaced ISO/TS 16949:2009. TS 16949 was implemented as a supplement to and in conjunction with ISO 9001:2015.
PPAP Levels

Within the confines of automotive grade products and components is the Production Part Approval Process [PPAP]. Established by the Automotive Industry Action Group [AIAG], PPAP creates a set of reference manuals, procedures, reporting formats, and technical nomenclature that verifies a manufacturer’s ability to produce and consistently provide an automotive grade device that fully complies with customer requirements. The PPAP documentation package must comply with one of the five submission levels known as Part Submission Warrant [PSW]; reference Table 2. Level 3 submission is typical for standard automotive grade crystals and oscillators.

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Part Submission Warrant (PSW) only.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 2</td>
<td>PSW with product samples and limited supporting data.</td>
</tr>
<tr>
<td><strong>Level 3</strong></td>
<td>PSW with product samples and complete supporting data.</td>
</tr>
<tr>
<td>Level 4</td>
<td>PSW and other requirements as defined by the customer</td>
</tr>
<tr>
<td>Level 5</td>
<td>PSW with product samples and complete supporting data available for review at the manufacturing location.</td>
</tr>
</tbody>
</table>

Table 2. PPAP Submission Levels

There are 18 elements addressed within the PPAP submission document package. A specific PSW level will define which elements must be present in the PPAP data package. The following list highlights some of the key elements; however, the latest PPAP revision should always be consulted to ensure compliance with current requirements.

| Element 1 | Design Documentation |
| Element 2 | Engineering Change Documentation |
| Element 3 | Customer Engineering Approval |
| Element 4 | Design Failure Mode and Effects Analysis |
| Element 5 | Process Flow Diagram |
| Element 6 | Process Failure Mode and Effects Analysis |
| Element 7 | Control Plan |
| Element 8 | Measurement System Analysis Studies |
| Element 9 | Dimensional Results |
| Element 10 | Records of Material / Performance Tests |
| Element 11 | Initial Process Studies |
| Element 12 | Qualified Laboratory Documentation |
| Element 13 | Appearance Approval Report |
| Element 14 | Sample Production Parts |
| Element 15 | Master Sample |
| Element 16 | Checking Aids |
| Element 17 | Customer Specific Requirements |
| Element 18 | Part Submission Warrant |

Table 3. Elements of PPAP

REFER TO P. 14 – 16 FOR CTS PRODUCT DETAILS
HIGH TEMPERATURE FREQUENCY CONTROL SOLUTIONS

MILITARY AND AEROSPACE COMPONENTS

Electronic component suppliers to military and aerospace programs are very familiar with designing products that function over the standard -55°C to +125°C temperature range. Add to the operating environment high shock or vibration conditions, and the challenge to create robust devices that survive considerably magnifies. Highly developed MIL standards clearly define the requirements for approved use in military systems, covering commercial-off-the-shelf [COTS] and high-reliability components.

Frequency references and timing solutions are used in various mil/aero systems. CTS product portfolio provides automotive-grade crystal resonators and oscillators that are gaining popular use as COTS devices. Customized designs are also available to address high reliability and rugged packaging needs; low power, low G-sensitivity and enhanced phase noise performance requirements. CTS provides qualification testing, options for production electrical test screening [Group testing], and alternate solder attach pad finishes to address gold embrittlement issues.

COTS

Commercial-Off-The-Shelf [COTS] devices are not new to the aerospace, defense, and space industries. The movement to use these components has escalated in recent years to avoid using expensive custom made, highly specialized military parts.

COTS offers a more standardized set of components, since these designs meet industry standard package foot prints, automated process equipment, and excellent performance parameters. Product availability is essential to providing shorter lead-times and lower costs. Engineers using COTS components must assess the risk for using commercial parts and mitigate that risk in their given design and overall system.

As previously noted many mil/aero companies are evaluating and using automotive grade [AEC-Qxxx] devices in applications utilizing COTS components. The extra standards that govern AEC-Qxxx provide a higher grade product at lower costs with improvements in reliability testing, traceability, stability of supply; compared to “true” commercial devices or costly specialized military-grade components.

The CTS portfolio of quartz crystals and oscillators recommended for COTS applications benefits from improved manufacturing technologies. Full cleanroom facilities on highly automated production lines reduces product variability and promotes more industry standardization.
Hi-Reliability
As previously discussed, COTS frequency devices are finding use in many military and aerospace electronics applications. However, some applications will see a poor performance when COTS type components are used. In these designs, an engineer should consider using a device that offers a higher level of reliability that have attributes allowing for more customization in areas of electrical design, part construction, manufacturing processes and additional product testing, typically beyond the scope of a commercially produced device.

Applications that require a high precision frequency reference can have the electrical design manipulated to minimize phase noise, and phase jitter affects, which are essential in today’s modern circuit applications. In oscillator designs, phase noise/jitter is mostly dependent on the quartz resonator design, quality of process crystal modeling, and assembly within the oscillator. Understanding the application environment, taking into account operating temperature range, shock and vibration concerns, and direct exposure to the elements; the frequency engineer can enhance the oscillator design by accounting for interfering modes or coupled modes on the quartz blank that can cause activity dips [perturbations] at specific temperature points over the range greatly affecting noise performance.

Oscillator start-up performance at cold temperatures will also be evaluated, to make sure it is reliable, especially for start-up at -55°C. The design engineer will further assess whether using an alternate crystal package and/or mounting structure is needed to reduce the effects of shock, vibration, and G-Sensitivity on the oscillator’s overall noise performance.

A well-controlled process and a sound design is key to producing a quality precision frequency reference. Utilizing a cleanroom environment with strict contamination controls to manufacture the quartz resonator and oscillator is crucial to eliminating activity dips and improved oscillator aging performance. Electrical testing of finished oscillators to MIL-PRF-38534 and MIL-PRF-55310 for Class B/H and Class S/K standards is common and critical to ensure performance meets customer requirements. Finally, a sound Quality Management System [QMS] is essential to mitigate potential manufacturing process issues, provide complete traceability for components and materials used, and provide surveillance audits to ensure production personnel and quality inspectors are fully trained to controlled procedures.
**Thermal Resistance**
When a designer evaluates their system’s overall reliability, it sometimes requires the knowledge of the thermal resistance of electrical components. The printed circuit board must be able to handle heat generated by the power consumption of integrated circuits. Understanding component power dissipation and high heat areas are necessary to prevent overheating the PC board and premature component failure. This can be especially important to component function as system PC boards are downsized, required to operate with extended operating temperature maximums, and in reduced air flow or “fan less” conditions.

An electrical component’s thermal resistance is defined as the temperature difference occurring between the semiconductor element within the device package and the package surface or ambient atmosphere when the device consumes 1 watt [W] of power.

Thermal resistance measures the device package’s heat dissipation capability from the active surface of the IC die [or junction] to a specific reference point, i.e. board, package, ambient, etc. The two thermal relationships most often documented for components with ICs are the junction-to-air thermal resistance [Θja] and the junction-to-case thermal resistance [Θjc].

CTS customers who commonly request thermal resistance information use our quartz resonator-based oscillators in mil/aero applications. CTS provides Θjc, Θja, and Tjmax recommendations upon request. Typical maximum junction temperature is +125°C. Refer to Table 3 for example model details. Consult CTS for characterization of other devices.

**Thermal Relationships and Associated Formulas**
The package detail shown in Figure 1 illustrates the common thermal relationships. The following associated formulas are defined as:

**Common Thermal Resistance Parameters**
[Typical Oscillator Package]
**Junction-To-Case**
The symbol $\Theta_{jc}$ defines the thermal resistance from the semiconductor junction to the oscillator’s case. A low $\Theta_{jc}$ value describes increased heat conduction, and a high value describes decreased heat conduction.

The formula shown below is used to calculate junction to case thermal resistance, specified in degrees Celsius per watt [°C/W].

$$\Theta_{jc} = \frac{T_j - T_c}{P_d}$$

- $T_j$ = Junction temperature of the semiconductor device in degrees Celsius [°C]
- $T_c$ = External case or package temperature of the oscillator in degrees Celsius [°C]
- $P_d$ = Power dissipation of the oscillator in watts [W]

**Junction-To-Ambient**
Represented by the symbol $\Theta_{ja}$, it defines the thermal resistance from the semiconductor junction to the ambient air. It measures the capacity of a device to dissipate heat from the die surface to the ambient air.

The formula shown below is used to calculate junction to ambient thermal resistance, specified in degrees Celsius per watt [°C/W].

$$\Theta_{ja} = \Theta_{jc} + \Theta_{ca} = \frac{T_j - T_a}{P_d}$$

- $T_j$ = Junction temperature of the semiconductor device in degrees Celsius [°C]
- $T_a$ = Ambient temperature outside the oscillator in degrees Celsius [°C]
- $P_d$ = Power dissipation of the oscillator [in watts [W]]

**Case-To-Ambient**
Represented by the symbol $\Theta_{ca}$, it defines the thermal resistance between package surface and ambient air.

Final formulas are used to calculate junction temperature and power dissipation of an oscillator.

$$T_j = \Theta_{ja} \times P_d + T_a \text{ or } T_j = \Theta_{jc} \times P_d + T_c$$

$$P_d = \frac{T_j - T_a}{\Theta_{ja}} \text{ or } P_d = \frac{T_j - T_c}{\Theta_{jc}}$$

Using the thermal resistance parameters to estimate the junction temperature [$T_j$] of the semiconductor, it is essential not to exceed the published maximum junction temperature [$T_{jmax}$], to ensure long-term reliability for the electric component.

<table>
<thead>
<tr>
<th>Model CB3LV</th>
<th>[7.0mmx5.0mm Ceramic Package]</th>
<th>Model CA70</th>
<th>[7.0mmx5.0mm Ceramic Package]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Junction to Ambient [$\Theta_{ja}$]</td>
<td>181.4°C/W</td>
<td>Junction to Ambient [$\Theta_{ja}$]</td>
<td>185.2°C/W</td>
</tr>
<tr>
<td>Junction to Case [$\Theta_{jc}$]</td>
<td>40.4°C/W</td>
<td>Junction to Case [$\Theta_{jc}$]</td>
<td>74.1°C/W</td>
</tr>
<tr>
<td>Maximum Junction Temperature [$T_{jmax}$]</td>
<td>150°C</td>
<td>Maximum Junction Temperature [$T_{jmax}$]</td>
<td>150°C</td>
</tr>
<tr>
<td>Recommended Maximum Junction [$T_{jmax}$]</td>
<td>125°C</td>
<td>Recommended Maximum Junction [$T_{jmax}$]</td>
<td>125°C</td>
</tr>
</tbody>
</table>

Table 3. Model Details
**REFER TO P. 14 – 22 FOR CTS PRODUCT DETAILS**
As previously mentioned, the operating temperature range -40°C to +105°C is becoming the standard for industrial-grade components. The exponential expansion of connectivity, communicating with “all things”, via the Industrial Internet of Things [IIoT], is the driving factor for a wider temperature range. Connections to remote equipment and machinery, many times operating in harsh confines, has challenged component manufacturers to develop devices that will survive in these environments to extend beyond the traditional parameters of the past.

Through multiple communication protocols, connectivity is being made, pushing new performance-levels for the frequency reference [crystal resonator or oscillator] needed in these architectures. Extended temperature ranges, extreme temperature operation, shock and vibration requirements; CTS has a frequency solution to support many industrial applications.

IIoT
The Fourth Industrial Revolution, dubbed Industry 4.0, describes the continuation of automating conventional manufacturing and industrial practices, incorporating fast-developing Smart technologies. Industry 4.0 is driving the need to exchange and analyze vast sums of collected data that improve process control, increase throughput, and enable self-monitoring that can diagnose issues without operator intervention.

Industrial IoT [IIoT] applications are using more wireless technologies to connect large scale machine-to-machine communication [M2M], creating demands for reliable frequency timing components that can function in the operating environments of the Smart Factory. These environments offer challenges, including higher temperature ranges, shock and vibration elements, and low power constraints to support battery operation yet require processing large amounts of information with minimal time synchronization error, data loss, and very short and stable latency issues.

CTS has developed a portfolio of crystal resonators and clock oscillators for next generation IIoT MCUs, SoCs or FPGAs supporting 5G communication requirements for faster data speeds, low noise performance, and low power consumption. To meet the above standards CTS’s IoT Enhanced crystals [4xxW Series] are designed and processed with the lowest series resistance values, while coupled with small load capacitance options, securing a safe gain margin GM for reliable oscillator start-up. Industrial grade clock oscillators [CHT Series] offer smaller stability options, improved noise performance, and maximum operating temperature to +125°C.

REFER TO P. 23 – 26 FOR CTS PRODUCT DETAILS
Extreme Environments
Many electrical systems are required to function and survive in extreme operating environments beyond the standard MIL-STD operating temperature range of -55°C to +125°C. Over the years, industrial applications have developed sensors, gauges, and data acquisition systems that can operate at +200°C and above in areas of deep well drilling, geothermal logging, and process monitoring, to name a few. In addition to high temperatures, many of these electronic devices need to survive under high shock and vibration conditions.

Even though the market for high-temperature electronics is small, predominately dominated by the petroleum industry, there are opportunities for new applications to expand in the transportation, automotive, military, and aerospace markets. The benefits for high-temperature components come from eliminating the need for heat sinks, supplemental cooling, creating lighter weight and smaller size systems.

In many of the high-temperature applications discussed, there will be requirements for a robust frequency reference. Building from rugged design techniques developed for military programs, CTS has oscillators and timing solutions that provide outstanding performance operating in severe conditions.

REFER TO P. 27 - 28 FOR CTS PRODUCT DETAILS

CONCLUSION
Harsh operating environments, which include expanded temperature ranges, bring demands and challenges for frequency reference and timing solution designs that impact performance and survivability. The increased use of AEC-Q200 compliant automotive components in multiple industries, military and aerospace standards for COTS, and high-reliability devices operating in extreme industrial environments; continue to push manufacturers to upgrade the reliability, standardization, and stability of the supply chain.

ABOUT CTS
CTS is a leading designer and manufacturer of products that Sense, Connect, and Move. The company manufactures sensors, actuators, and electronic components in North America, Europe, and Asia. CTS provides solutions to OEMs in the aerospace, communications, defense, industrial, information technology, medical, and transportation markets. Our extensive frequency control solutions include:

- Crystal resonators and clock oscillators that are qualified to AEC-Q200, produced on TS 16949 certified production lines, with PPAP compliance.
- Timing solutions supporting next generation chipsets for 5G and IoT.
- COTS frequency devices for military and aerospace applications.
- Options for customization to support high-reliability oscillators and timing solutions.
- Designs that can function in extreme environment that include high shock and vibration elements.

CTS has many products that are available through distribution partners, are competitively priced, have a variety of performance and package options, and that can be customized. Contact CTS to discuss the right timing solution for your application needs.

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### TABLE 11 - TABLE OF METHODS REFERENCED: QUARTZ CRYSTALS

<table>
<thead>
<tr>
<th>Stress</th>
<th>NO.</th>
<th>Reference</th>
<th>Additional Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre- and Post-Stress Electrical Test</td>
<td>1</td>
<td>User spec.</td>
<td>Test is performed except as specified in the applicable stress reference and the additional requirements in Table 11.</td>
</tr>
<tr>
<td>High Temperature Exposure (Storage)</td>
<td>3</td>
<td>MIL-STD-202 Method 108</td>
<td>1000 hrs at rated operating temperature (e.g. 85°C part can be stored for 1000 hrs at 85°C. Same applies for 125°C). Unpowered. Measurement at 24±4 hours after test conclusion.</td>
</tr>
<tr>
<td>Temperature Cycling</td>
<td>4</td>
<td>JESD22 Method JA-104</td>
<td>1000 cycles (-40°C to 125°C) Note: If 85°C part the 1000 cycles will be at that temperature rating. Measurement at 24±4 hours after test conclusion. 30min maximum dwell time at each temperature extreme. 1 min. maximum transition time.</td>
</tr>
<tr>
<td>Biased Humidity</td>
<td>7</td>
<td>MIL-STD-202 Method 103</td>
<td>1000 hours 85°C/85%/RH. Rated Vcc applied with 1 MΩ and inverter in parallel, 2X crystal Cc capacitors between each crystal leg and GND. Measurement at 24±4 hours after test conclusion.</td>
</tr>
<tr>
<td>Operational Life</td>
<td>8</td>
<td>MIL-STD-202 Method 108</td>
<td>Note: 1000 hrs @ 125°C. If 85°C part will be tested at that temperature. Rated Vcc applied with 1 MΩ and inverter in parallel, 2X crystal Cc capacitors between each crystal leg and GND. Measurement at 24±4 hours after test conclusion.</td>
</tr>
<tr>
<td>Physical Dimension</td>
<td>10</td>
<td>JESD22 Method JB-100</td>
<td>Verify physical dimensions to the applicable device detail specification. Note: User(s) and Suppliers spec. Electrical Test not required.</td>
</tr>
<tr>
<td>Terminal Strength (Leaded)</td>
<td>11</td>
<td>MIL-STD-202 Method 211</td>
<td>Test leaded device lead integrity only. Conditions: A (227 g), C (227 g).</td>
</tr>
<tr>
<td>Resistance to Solvents</td>
<td>12</td>
<td>MIL-STD-202 Method 215</td>
<td>Note: Also aqueous wash chemical - OKEM clean or equivalent. Do not use banned solvents.</td>
</tr>
<tr>
<td>Mechanical Shock</td>
<td>13</td>
<td>MIL-STD-202 Method 213</td>
<td>Figure 1 of Method 213. Condition C</td>
</tr>
</tbody>
</table>

### TABLE 11 - TABLE OF METHODS REFERENCED: QUARTZ CRYSTALS - Continued

<table>
<thead>
<tr>
<th>Stress</th>
<th>NO.</th>
<th>Reference</th>
<th>Additional Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration</td>
<td>14</td>
<td>MIL-STD-202 Method 204</td>
<td>5g’s for 20 minutes 12 cycles each of 3 orientations. Note: Use 8”x8” PCB .062” thick with 7 secure points on one 8” side and 2 secure points on corners of opposite sides. Parts mounted within 2” from any secure point. Test from 10-2000 Hz.</td>
</tr>
<tr>
<td>Resistance to Soldering Heat</td>
<td>15</td>
<td>MIL-STD-202 Method 210</td>
<td>Condition B No pre-heat of samples. Note: Single Wave solder - Procedure 1 with solder within 1.5 mm of device body for Lead. Procedure 1 except 90° and immerse only to level to cover terminalse for SMD.</td>
</tr>
<tr>
<td>Solderability</td>
<td>18</td>
<td>J-STD-002</td>
<td>For both Lead &amp; SMD. Electrical Test not required. Magnification 50 X. Conditions: Leaded: Method A @ 235°C, category 3. SMD: a) Method B, 4 hrs @ 155°C dry heat @ 235°C b) Method B @ 215°C category 3. c) Method D category 3 @ 230°C.</td>
</tr>
<tr>
<td>Electrical Characterization</td>
<td>19</td>
<td>User Spec.</td>
<td>Parametrically test per lot and sample size requirements, summary to show Min, Max, Mean and Standard deviation at room as well as Min and Max operating temperatures.</td>
</tr>
<tr>
<td>Flammability</td>
<td>20</td>
<td>UL-94</td>
<td>V-0 or V-1 Acceptable</td>
</tr>
<tr>
<td>Board Flex</td>
<td>21</td>
<td>AEC Q200-005</td>
<td>60 sec minimum holding time.</td>
</tr>
<tr>
<td>Terminal Strength (SMD)</td>
<td>22</td>
<td>AEC Q200-006</td>
<td>Interval measurements for 1000 hour tests required at 250 and 500 hrs.</td>
</tr>
</tbody>
</table>

**Note:** Pre-stress electrical tests also serve as electrical characterization.
Operating environments that automotive-grade components are subjected to vary whether under the hood, within the drivetrain, or in-cabin applications. Beyond the automobile, automotive-grade components are widely accepted for use in medical, industrial, and mil/aero COTS type applications. Optimized for non-safety applications with wide temperature ranges, to +150°C, CTS has an array of standard crystal and oscillator products compliant to AEC-Q200 standards and manufactured on certified TS 16949 production lines.

### AEC-Q200 Crystal and COTS Crystal Product Tables

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SA164</td>
<td>1.6x1.2 4-Pad</td>
<td>24-60</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>150 - 100 Fund</td>
</tr>
<tr>
<td>SA204</td>
<td>2.0x1.6 4-Pad</td>
<td>16-96</td>
<td>±20</td>
<td>±20</td>
<td>-40 to +105</td>
<td>200 - 60 Fund</td>
</tr>
<tr>
<td>SA254</td>
<td>2.5x2.0 4-Pad</td>
<td>12-80</td>
<td>±30</td>
<td>±20</td>
<td>-40 to +125</td>
<td>180 - 60 Fund</td>
</tr>
<tr>
<td>SA324</td>
<td>3.2x2.5 4-Pad</td>
<td>8-160</td>
<td>±50</td>
<td>±20</td>
<td>-40 to +150</td>
<td>500 - 50 Fund 100 3rd OT</td>
</tr>
<tr>
<td>SA532</td>
<td>5.0x3.2 2-Pad</td>
<td>7.6-160</td>
<td>±50</td>
<td>±20</td>
<td>90k</td>
<td></td>
</tr>
<tr>
<td>SA534</td>
<td>5.0x3.2 4-Pad</td>
<td></td>
<td></td>
<td></td>
<td>100 - 40 Fund 80 3rd OT</td>
<td></td>
</tr>
<tr>
<td>TFA16</td>
<td>1.6x1.0 2-Pad</td>
<td>32.768</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>90k</td>
</tr>
<tr>
<td>TFA20</td>
<td>2.0x1.2 2-Pad</td>
<td></td>
<td></td>
<td></td>
<td>40 to +85 -40°C to 125°C</td>
<td></td>
</tr>
<tr>
<td>TFA32</td>
<td>3.2x1.5 2-Pad</td>
<td></td>
<td></td>
<td></td>
<td>70k</td>
<td></td>
</tr>
<tr>
<td>HTA</td>
<td>12.3x4.83 HC-49/US-SM</td>
<td>3.2 - 64</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>150 - 30 Fund 80 - 60 3rd OT</td>
</tr>
</tbody>
</table>

**AT Cut Fundamental & 3rd Overtone**
Crystal Product Features

<table>
<thead>
<tr>
<th>CTS Key Crystal Parameters</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS16949 Certified, AEC-Q200 Qualified, PPAP Compliant</td>
<td>Compliance to automotive industry requirements</td>
</tr>
<tr>
<td>Multiple package sizes w/ industry standard pinout for drop-in replacement</td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Ranges, to -55°C/+125°C</td>
<td>Supporting high temperature applications</td>
</tr>
<tr>
<td>Common Crystal Frequencies Available</td>
<td>Standard Disty stock for off-the-shelf availability</td>
</tr>
<tr>
<td>Low ESR Values</td>
<td>Provides more design margin to ensure robust system performance</td>
</tr>
<tr>
<td>High Q, Small Size, AT-Cut Quartz Resonators [except TFA products]</td>
<td></td>
</tr>
<tr>
<td>Calibration Tolerance Options, ±25ppm, ±30ppm, ±50ppm, ±100ppm, ±150ppm</td>
<td></td>
</tr>
<tr>
<td>Temperature Stability Options, ±25ppm, ±30ppm, ±50ppm, ±100ppm, ±150ppm</td>
<td>Application design flexibility</td>
</tr>
<tr>
<td>Standard Load Capacitance Values Available</td>
<td></td>
</tr>
<tr>
<td>Customized Performance Parameters [contact factory for availability]</td>
<td></td>
</tr>
</tbody>
</table>

AEC-Q200 and COTS Clock Oscillator Product Tables

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HCMOS</td>
<td>CA20  2.0x1.6 4-Pad</td>
<td>1.25 - 100</td>
<td>±25, ±30, ±50, ±100, ±150</td>
<td>±25, ±30, ±50, ±100, ±150</td>
<td>-40 to +85</td>
<td>&lt;1</td>
</tr>
<tr>
<td></td>
<td>CA25  2.5x2.0 4-Pad</td>
<td></td>
<td>1.8</td>
<td>2.5</td>
<td>-40 to +105</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CA32  3.2x2.5 4-Pad</td>
<td>1.25 - 156.25</td>
<td>3.3</td>
<td>±50, ±100, ±150</td>
<td>-40 to +125</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CA50  5.0x3.2 4-Pad</td>
<td></td>
<td></td>
<td>±100, ±150</td>
<td>-40 to +150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CA70  7.0x5.0 4-Pad</td>
<td></td>
<td></td>
<td></td>
<td>-55 to +105</td>
<td></td>
</tr>
</tbody>
</table>
### Clock Oscillator Product Features

<table>
<thead>
<tr>
<th>CTS Clock Parameters</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS16949 Certified, AEC-Q200 Qualified, PPAP Compliant</td>
<td>Multiple package sizes w/ industry standard pinout for drop-in replacement</td>
</tr>
<tr>
<td>Operating Temperature Ranges, -40°C/+105°C &amp; -40°C/+125°C</td>
<td>Compliance to automotive industry requirements</td>
</tr>
<tr>
<td>Common Clock Frequencies Available</td>
<td>Supporting standard automotive applications</td>
</tr>
<tr>
<td>HCMOS Output</td>
<td>Standard Disty stock for off-the-shelf availability</td>
</tr>
<tr>
<td>RMS Jitter [12kHz - 20MHz], 500fs Typical</td>
<td>Waveform parameters providing high speed switching</td>
</tr>
<tr>
<td>Custom Frequencies Available</td>
<td>Provides more design margin to ensure robust system performance</td>
</tr>
<tr>
<td>Frequency Stability Options, ±25ppm, ±30ppm, ±50ppm, ±100ppm, ±150ppm</td>
<td>Application design flexibility</td>
</tr>
</tbody>
</table>

### Industry Applications

<table>
<thead>
<tr>
<th>Automotive</th>
<th>Industrial</th>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive Electronics</td>
<td>Industrial IoT [IIoT]</td>
<td>Ultrasound Equipment</td>
</tr>
<tr>
<td>Mobile Multimedia</td>
<td>M2M Communication</td>
<td>Physical Therapy Devices</td>
</tr>
<tr>
<td>Infotainment Systems</td>
<td>Industrial Controls</td>
<td>Respiration Monitors</td>
</tr>
<tr>
<td>Automotive Ethernet</td>
<td>Wireless Communication</td>
<td>Diagnostic Imaging</td>
</tr>
<tr>
<td>Audio/Video Systems</td>
<td>Test and Measurement</td>
<td>Lab Measurement Equipment</td>
</tr>
</tbody>
</table>

### Military Applications

<table>
<thead>
<tr>
<th>Commercial Military/ Aerospace *</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless Communication</td>
<td>Portable Manpack Radio</td>
</tr>
<tr>
<td>Edge Computing</td>
<td>Microwave Communication</td>
</tr>
<tr>
<td>In-Flight Entertainment</td>
<td>Mil Radio</td>
</tr>
<tr>
<td>Cabin Management Systems</td>
<td>GPS Holdover</td>
</tr>
<tr>
<td>COTS Crystals &amp; Clock Oscillators</td>
<td>Drone</td>
</tr>
<tr>
<td>Surveillance Radio</td>
<td>Airborne Datalink</td>
</tr>
<tr>
<td>Data Links and Mobile Communication Systems</td>
<td>Secure Networking</td>
</tr>
</tbody>
</table>

*No Group testing or other military screenings are performed on AEC-Q200 products.
MILITARY OSCILLATORS AND HI-RELIABILITY PRODUCTS

Frequency references and timing solutions are used in a variety of military and aerospace systems. Standard and customized designs are available from CTS that address high reliability and rugged packaging needs; low power, low G-sensitivity, and enhanced phase noise performance requirements. CTS provides qualification testing, options for production electrical test screening [Group testing], and alternate solder attach pad finishes to address gold embbrittlement issues.

Military Oscillator Product Tables

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>144 HCMOS</td>
<td>21.8x15x7.5</td>
<td>8 - 120</td>
<td>3.3, 5.0</td>
<td>0.15</td>
<td>500G, 1 msec/30G to 2000 Hz</td>
</tr>
<tr>
<td>148 HCMOS</td>
<td>15.9x15.1x10</td>
<td>8 - 100</td>
<td>3.3, 5.0</td>
<td>0.15</td>
<td>500G, 1 msec/30G to 2000 Hz</td>
</tr>
<tr>
<td>VFOV404 HCMOS Sinewave</td>
<td>21.85x15.1x10</td>
<td>5 - 250</td>
<td>3.3, 5.0</td>
<td>0.15</td>
<td>30g, 11 msec/10G to 2000 Hz</td>
</tr>
<tr>
<td>VFOV405 HCMOS Sinewave</td>
<td>15.9x15.1x10</td>
<td>5 - 100</td>
<td>3.3, 5.0</td>
<td>0.15</td>
<td>30g, 11 msec/10G to 2000 Hz</td>
</tr>
<tr>
<td>VFOV406 HCMOS Sinewave</td>
<td>21.85x15.1x11.9</td>
<td>5 - 250</td>
<td>3.3, 5.0</td>
<td>0.15</td>
<td>30g, 11 msec/10G to 2000 Hz</td>
</tr>
<tr>
<td>VFOV504 HCMOS Sinewave</td>
<td>21.85x15.1x10</td>
<td>30 - 120</td>
<td>3.3, 5.0</td>
<td>0.15</td>
<td>30g, 11 msec/10G to 2000 Hz</td>
</tr>
</tbody>
</table>

Military TCXO Product Tables

<table>
<thead>
<tr>
<th>Low Noise HFTCXOs</th>
<th>Package Size [mm]</th>
<th>Frequency Range</th>
<th>Stability -40°C/+85°C [ppm]</th>
<th>Pull Range [±ppm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFTX100 LVPECL</td>
<td>25x22x6</td>
<td>to 1 GHz</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>VFTX120 VFTX130 CMOS Sinewave</td>
<td>25x22x6</td>
<td>to 200 MHz</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>VFTX210 Sinewave</td>
<td>20x20x6</td>
<td>to 1 GHz</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>VFTX1412C LVCMOS</td>
<td>14x12x5</td>
<td>to 165 MHz</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>VFTX1412P LVPECL</td>
<td>14x12x5</td>
<td>to 165 MHz</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>577 HCMOS</td>
<td>7x5x1.35</td>
<td>to 122.88 MHZ</td>
<td>2.4</td>
<td>-</td>
</tr>
</tbody>
</table>
# Clock Oscillator and TCXO Product Features

<table>
<thead>
<tr>
<th>CTS OCXO Oscillator Features</th>
<th>CTS TCXO Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinewave, Clipped Sinewave, HCMOS Outputs</td>
<td>Sinewave, Clipped Sinewave, HCMOS, LVPECL Outputs</td>
</tr>
<tr>
<td>Low G-sensitivity &lt;0.3ppb/g</td>
<td>Stratum 3 stability &lt;0.28ppm</td>
</tr>
<tr>
<td>High Stability &lt;±1ppb</td>
<td>Phase Noise -170dBc/Hz at 100kHz</td>
</tr>
<tr>
<td>Low Phase Noise -174dBC/Hz</td>
<td>Output frequency Up to 1 GHz</td>
</tr>
<tr>
<td>Low Power &lt;150mW</td>
<td>Ultra Low Jitter and Phase Noise &lt;170dBc/Hz @100kHz</td>
</tr>
<tr>
<td>Fast warm-up</td>
<td>Utilizes CTS Proprietary ASIC Technology [VFJA1412x]</td>
</tr>
</tbody>
</table>

## Synthesizer Modules

<table>
<thead>
<tr>
<th>Synthesizer Modules Models</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VFJA1490P 9mmx14mm</td>
<td></td>
</tr>
<tr>
<td>VFJA1491P 9mmx14mm</td>
<td></td>
</tr>
<tr>
<td>VFJA1491C 9mmx14mm</td>
<td></td>
</tr>
<tr>
<td>VFJA9591C 9.5mmx9.1mm</td>
<td></td>
</tr>
</tbody>
</table>

## Synthesizer Features

<table>
<thead>
<tr>
<th>Synthesizer Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jitter Attenuators/Frequency Translators VCXO o/p Stage</td>
</tr>
<tr>
<td>PECL, CMOS, SINE Outputs</td>
</tr>
<tr>
<td>Any Frequency In to Any Frequency Out [&lt;1000MHz]</td>
</tr>
<tr>
<td>Low Jitter @ &lt;0.25ps Typical</td>
</tr>
<tr>
<td>Optional Ruggedized Structure for Mobile Applications</td>
</tr>
</tbody>
</table>

## Integrated ASIC Synthesizer Solution

![Diagram of an integrated ASIC synthesizer solution](image-url)

- **Fin**
- **EE-Prom**
- **R-Divider**
- **PFD**
- **N-Divider**
- **EE-Prom**
- **Low Noise VCXO**
- **Filter**
- **LNA**
- **LVPECL**
  - **Fout**
  - **Disable**
- **HCMOS**
  - **Fout 1**
  - **Fout 2**
<table>
<thead>
<tr>
<th>Industry Applications</th>
<th>Commercial Military/ Aerospace</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless Communication</td>
<td>Portable Manpack Radio</td>
</tr>
<tr>
<td></td>
<td>Mobile and Airborne Communication</td>
</tr>
<tr>
<td>Edge Computing</td>
<td>Microwave Communication</td>
</tr>
<tr>
<td></td>
<td>Mobile Test Equipment</td>
</tr>
<tr>
<td>In-Flight Entertainment</td>
<td>Mil Radio</td>
</tr>
<tr>
<td></td>
<td>Radar Detection</td>
</tr>
<tr>
<td>Cabin Management Systems</td>
<td>GPS Holdover</td>
</tr>
<tr>
<td></td>
<td>Satellite Based Broadband</td>
</tr>
<tr>
<td>COTS Crystals &amp; Clock Oscillators</td>
<td>Drone</td>
</tr>
<tr>
<td></td>
<td>Air Traffic Control</td>
</tr>
<tr>
<td>Surveillance Radio</td>
<td>Airborne Datalink</td>
</tr>
<tr>
<td></td>
<td>Military Radar</td>
</tr>
<tr>
<td>Data Links and Mobile Communication Systems</td>
<td>Secure Networking</td>
</tr>
<tr>
<td></td>
<td>PLL Reference for Datalinks</td>
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</tbody>
</table>

### High Reliability Product Tables

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>HCMOS Clocks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>680</td>
<td>7.0x5.0 4-Pad</td>
<td>1 - 100</td>
<td>1.8, 2.5 2.8, 3.3</td>
<td>-55 to +200</td>
<td>&lt;1</td>
</tr>
<tr>
<td>VFH2121</td>
<td>7.0x5.0 4-Pad</td>
<td>0.5 - 125</td>
<td>3.3, 5.0</td>
<td>-55 to +85 -55 to +125</td>
<td>&lt;6</td>
</tr>
<tr>
<td>VFH2321</td>
<td>7.0x5.0 4-Pad</td>
<td>0.85 - 165</td>
<td>1.8</td>
<td>-55 to +85 -55 to +125</td>
<td>&lt;1</td>
</tr>
<tr>
<td>T5321/T5421</td>
<td>7.0x5.0 4-Pad</td>
<td>1 - 100</td>
<td>3.3</td>
<td>-55 to +85 -55 to +125</td>
<td>&lt;1</td>
</tr>
<tr>
<td>T5621/T5721</td>
<td>7.0x5.0 4-Pad</td>
<td>0.16 - 100</td>
<td>5.0</td>
<td>-55 to +85 -55 to +125</td>
<td>&lt;1</td>
</tr>
<tr>
<td>HCMOS/TTL VCXOs</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>VFH5070</td>
<td>7.0x5.0 6-Pad</td>
<td>1.0 - 80</td>
<td>3.3, 5.0</td>
<td>-55 to +85 -55 to +125</td>
<td>0.2 Typ</td>
</tr>
<tr>
<td>VFHV750</td>
<td>7.0x5.0 6-Pad</td>
<td>1.0 - 80</td>
<td>3.3, 5.0</td>
<td>0 to +175 -40 to +175 -55 to +85 -55 to +125</td>
<td>0.2 Typ</td>
</tr>
<tr>
<td>M6306</td>
<td>20.32x12.62 Thru-Hole M-1 Pkg.</td>
<td>1.0 - 35</td>
<td>5.0</td>
<td>-55 to +125</td>
<td>&lt;15</td>
</tr>
</tbody>
</table>
### Product Information

<table>
<thead>
<tr>
<th>CTS Oscillator Features</th>
<th>Product Benefits</th>
<th>Environmental and Mechanical Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCMOS Outputs</td>
<td>Mechanically robust and weigh less than 0.2 grams</td>
<td>Shock –1000Gs, 0.35ms, ½ sine wave, 3 shocks in each plane</td>
</tr>
<tr>
<td>Stabilities – ±20ppm - ±75ppm</td>
<td>SMD packages are hermetic sealed ensuring integrity of the device</td>
<td>Vibration – 10-2000 Hz of 0.06” d.a. or 20Gs, whichever is less</td>
</tr>
<tr>
<td>Temperature Range – -55°C to +125°C or +200°C</td>
<td>Each oscillator is burned in at +125°C for 168 hours, temperature cycled and centrifuged then fully tested in accordance to Military Reliability Standards</td>
<td>Humidity – Resistant to 85% R.H. at +85°C</td>
</tr>
<tr>
<td>Phase Noise – Low as -170dBc/Hz</td>
<td>5 year minimum lifetime support [10 - 15 years on critical military and aerospace programs]</td>
<td>Leak – Per MIL-STD-883, Method 1014, Condition A and Condition C</td>
</tr>
<tr>
<td>Phase Jitter to 22fs</td>
<td>Specialized hybrid staff working inside an ISO Standard 14644-1:2015 Grade 7 Clean Room</td>
<td>Case – Hermetically sealed ceramic LCC</td>
</tr>
<tr>
<td>Vibration – MIL-STD 883, Method 2007, Test Condition A</td>
<td>R&amp;D on-site to support any design integration inquiries</td>
<td>Solder dipped termination finish [optional]</td>
</tr>
<tr>
<td>Humidity – Resistant to +85°C @ Relative Humidity 85%</td>
<td>Marking – Laser engraved RoHS 6/6</td>
<td>Resistant to Solvents – Per MIL-STD-202, Method 215</td>
</tr>
</tbody>
</table>

### Screening Information

<table>
<thead>
<tr>
<th>Screening Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Level B Class 2 Oscillators [MIL-PRF-55310]</td>
</tr>
<tr>
<td>Internal Visual Inspection</td>
</tr>
<tr>
<td>Stabilization Bake – MIL-STD-883 Method 1008, Condition B</td>
</tr>
<tr>
<td>Temperature Cycling - MIL-STD-883 Method 1010, Condition B</td>
</tr>
<tr>
<td>Fine Leak – MIL-STD-883 Method 1014, Condition A</td>
</tr>
<tr>
<td>Gross Leak – MIL-STD-883 Method 1014, Condition C</td>
</tr>
<tr>
<td>Burn-In – MIL-STD-883 Method 105, Condition B [+125°C for 160 hours with bias]</td>
</tr>
<tr>
<td>Electrical Test @ +25°C</td>
</tr>
<tr>
<td>Current – Frequency at max VDD</td>
</tr>
<tr>
<td>Rise Time – Frequency at min VDD</td>
</tr>
<tr>
<td>Fall Time – “Zero” logic level</td>
</tr>
<tr>
<td>Duty Cycle – “One” logic level</td>
</tr>
<tr>
<td>Tristate Option</td>
</tr>
<tr>
<td>Frequency at +25°C and frequency verification at temperature extremes</td>
</tr>
<tr>
<td>Serialized test data on each unit available upon request</td>
</tr>
<tr>
<td>First Article Inspection [FAI] Upon Request</td>
</tr>
</tbody>
</table>
CTS Reliability Test Procedures and Conditions for Quartz Crystal Oscillators

**Group A Test**

**Electrical Characteristics at +25°C**

*Frequency at normal supply voltage and endpoints*
- Input current
- Symmetry (Duty Cycle)
- Zero/One levels
- Rise/Fall times
- Frequency (verify frequency at the temperature extremes)

*Physical Dimensions*
- Length/Width
- Height
- Package finish (Corrosion, discoloration, etc.)
- Marking placement/legibility

**Group B Test**

1000 hrs at or above +125°C, normal voltage, proper load (sample size by MIL-PRF-55310 Table 6, max. aging within 15 years requirement without catastrophic failures)

**Group C Test. All units have passed Group A testing**

**A. Subgroup 1: 8 pcs.**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Condition</th>
<th>Description</th>
<th>End Point Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIL-STD-883</td>
<td>Method 2002 B</td>
<td>Mechanical Shock 1500 g’s, 0.5ms 5 drops, 6 axis</td>
<td>Frequency Output Waveform</td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Method 2007 B</td>
<td>Vibration, var. freq. 20 g’s 0.06” disp., 20-20, 000-20 Hz</td>
<td></td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Method 2003</td>
<td>Solderability</td>
<td>Visual 95% Coverage</td>
</tr>
</tbody>
</table>

**B. Subgroup 2: 4 pcs (one-half of Subgroup 1)**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Condition</th>
<th>Description</th>
<th>End Point Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIL-STD-883</td>
<td>Method 1011 B</td>
<td>Thermal Shock Liq. To liq. 15 cycles</td>
<td>Frequency Output Waveform</td>
</tr>
<tr>
<td>MIL-STD-202</td>
<td>Method 105 B</td>
<td>Altitude, 3.44 inch Hg. 12hrs</td>
<td>Frequency Output Waveform</td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Method 1004</td>
<td>Moisture resist. with supply voltage applied ±25°C to ±65°C 90 to 100% RH, 10 cycles</td>
<td>Frequency Output Waveform</td>
</tr>
<tr>
<td>MIL-STD-202</td>
<td>Method 210 A</td>
<td>Frequency Output Waveform</td>
<td></td>
</tr>
</tbody>
</table>
## C. Subgroup 3: 4 pcs. (one-half of Subgroup 1)

<table>
<thead>
<tr>
<th>Standard</th>
<th>Condition</th>
<th>Description</th>
<th>End Point Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIL-STD-883</td>
<td>Storage Temp. No. Oper</td>
<td>24 hrs. @ -55°C 24 hrs. @ -125°C</td>
<td>Frequency Output Waveform</td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Method 1009 COND. A</td>
<td>Salt Atmosphere 24 hrs. @ +35°C 0.5-3.0% Solution</td>
<td>Frequency Output Waveform Visual</td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Method 1014 COND. A</td>
<td>Fine Leak</td>
<td>Qs &lt;5 X10^8</td>
</tr>
<tr>
<td>MIL-STD-883</td>
<td>Method 1014 COND. C</td>
<td>Gross Leak</td>
<td>Visual in +125°C Detector Fluid</td>
</tr>
</tbody>
</table>

## Product Applications

<table>
<thead>
<tr>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secured Network</td>
</tr>
<tr>
<td>Secured Satcomm Terminal</td>
</tr>
<tr>
<td>Missile Launcher</td>
</tr>
<tr>
<td>Naval Vessel Circuits Base Stations</td>
</tr>
<tr>
<td>Air Force Plane Circuits</td>
</tr>
<tr>
<td>Military Land Vehicle Circuits</td>
</tr>
<tr>
<td>Airborne or Stationary Radar Systems</td>
</tr>
</tbody>
</table>
INDUSTRIAL GRADE COMPONENTS

The operating temperature range -40°C to +105°C is becoming the standard for industrial-grade components. The exponential expansion of connectivity, communicating with “all things,” via the Industrial Internet of Things (IIoT), is the driving factor for a wider temperature range. Connections to remote equipment and machinery, many times operating in harsh confines, has challenged component manufacturers to develop devices that will survive in these environments to extend beyond the traditional parameters of the past. Extended temperature ranges, extreme temperature operation, shock and vibration requirements; CTS has a frequency solution to support many industrial applications.

IoT Enhanced Crystals

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<thead>
<tr>
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<tbody>
<tr>
<td>412W</td>
<td>1.2 x 1.0</td>
<td>32 – 80</td>
<td>±7ppm - ±30ppm</td>
<td>±10ppm - ±100ppm</td>
<td>-40°C to +85°C</td>
<td>100 – 60</td>
<td>1.0 Typ. &lt;3.0 Max.</td>
</tr>
<tr>
<td>416W</td>
<td>1.6 x 1.2</td>
<td>24 – 52</td>
<td>±10ppm - ±30ppm</td>
<td>±10ppm - ±100ppm</td>
<td>-40°C to +85°C</td>
<td>150 – 80</td>
<td>1.0 Typ. &lt;3.0 Max.</td>
</tr>
<tr>
<td>402W</td>
<td>2.0 x 1.6</td>
<td>16 – 52</td>
<td>±10ppm - ±30ppm</td>
<td>±10ppm - ±100ppm</td>
<td>-40°C to +85°C</td>
<td>150 – 50</td>
<td>1.0 Typ. &lt;3.0 Max.</td>
</tr>
<tr>
<td>425W</td>
<td>2.5 x 2.0</td>
<td>16 – 52</td>
<td>±10ppm - ±30ppm</td>
<td>±10ppm - ±100ppm</td>
<td>-40°C to +85°C</td>
<td>100 – 40</td>
<td>1.0 Typ. &lt;3.0 Max.</td>
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<tr>
<td>403W</td>
<td>3.2 x 2.5</td>
<td>10 – 54</td>
<td>±10ppm - ±30ppm</td>
<td>±10ppm - ±100ppm</td>
<td>-40°C to +85°C</td>
<td>150 – 35</td>
<td>1.0 Typ. &lt;3.0 Max.</td>
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</table>

Low ESR Tuning Fork Product Table

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>TFE16</td>
<td>1.6 x 1.0</td>
<td>32.768kHz Tuning Fork</td>
<td>±20ppm</td>
<td>-0.034ppm/°C² Temp Coefficient</td>
<td>-40°C to +85°C</td>
<td>60k</td>
<td>1.5 Typ.</td>
</tr>
<tr>
<td>TFE20</td>
<td>2.0 x 1.2</td>
<td>32.768kHz Tuning Fork</td>
<td>±20ppm</td>
<td>-0.034ppm/°C² Temp Coefficient</td>
<td>-40°C to +85°C</td>
<td>50k</td>
<td>1.8 Typ.</td>
</tr>
<tr>
<td>TFE32</td>
<td>3.2 x 1.5</td>
<td>32.768kHz Tuning Fork</td>
<td>±20ppm</td>
<td>-0.034ppm/°C² Temp Coefficient</td>
<td>-40°C to +85°C</td>
<td>50k</td>
<td>1.0 Typ.</td>
</tr>
</tbody>
</table>
**RTC TCXO**

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>TT32</td>
<td>3.2 x 2.5</td>
<td>32.768kHz HCMOS</td>
<td>+1.8V - +3.3V</td>
<td>±5.0ppm</td>
<td>-40°C to +85°C</td>
<td>2.0</td>
<td>15</td>
</tr>
</tbody>
</table>

**AEC-Q200 Crystal and COTS Crystal Product Tables**

<table>
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</thead>
<tbody>
<tr>
<td>SA164</td>
<td>1.6x1.2 4-Pad</td>
<td>24-60</td>
<td>±10</td>
<td>±15</td>
<td></td>
<td>150 - 100 Fund</td>
</tr>
<tr>
<td>SA204</td>
<td>2.0x1.6 4-Pad</td>
<td>16-96</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>200 - 60 Fund</td>
</tr>
<tr>
<td>SA254</td>
<td>2.5x2.0 4-Pad</td>
<td>12-80</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>180 - 60 Fund</td>
</tr>
<tr>
<td>SA324   AT Cut Fundamental &amp; 3rd Overtone</td>
<td>3.2x2.5 4-Pad</td>
<td>8-160w</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>500 - 50 Fund 100 3rd OT</td>
</tr>
<tr>
<td>SA532</td>
<td>5.0x3.2 2-Pad</td>
<td>7.6-160</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>100 - 40 Fund 80 3rd OT</td>
</tr>
<tr>
<td>SA534</td>
<td>5.0x3.2 4-Pad</td>
<td></td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td></td>
</tr>
<tr>
<td>TFA16   Tuning Fork Crystal Design</td>
<td>1.6x1.0 2-Pad</td>
<td>32.768</td>
<td>±10</td>
<td>±20</td>
<td>-40 to +105</td>
<td>90k</td>
</tr>
<tr>
<td>TFA20</td>
<td>2.0x1.2 2-Pad</td>
<td></td>
<td>-0.034ppm/°C² Temperature Coefficient</td>
<td>-40 to +105</td>
<td>90k</td>
<td></td>
</tr>
<tr>
<td>TFA32</td>
<td>3.2x1.5 2-Pad</td>
<td></td>
<td>±15</td>
<td>±20</td>
<td>-40 to +125</td>
<td>70k</td>
</tr>
<tr>
<td>HTA    AT Cut Fundamental &amp; 3rd Overtone</td>
<td>12.3x4.83 HC-49/US-SM</td>
<td>3.2 - 64</td>
<td>±10</td>
<td>±15</td>
<td>-40 to +85</td>
<td>150 - 30 Fund 80 - 60 3rd OT</td>
</tr>
</tbody>
</table>
### Industrial Grade Clock Oscillator Product Table

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>CHT25</td>
<td>2.5x2.0 4-Pad</td>
<td>1.25 - 156.25</td>
<td>1.8 2.5 3.3</td>
<td>±100, ±150</td>
<td>-55 to +105</td>
<td>-55 to +125</td>
<td>&lt;1</td>
</tr>
<tr>
<td>CHT32</td>
<td>3.2x2.5 4-Pad</td>
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<td></td>
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</tr>
<tr>
<td>CHT50</td>
<td>5.0x3.2 4-Pad</td>
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</tr>
<tr>
<td>CHT70</td>
<td>7.0x5.0 4-Pad</td>
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</tr>
<tr>
<td>CHT25</td>
<td>2.5x2.0 4-Pad</td>
<td>1.25 - 156.25</td>
<td>1.8 2.5 3.3</td>
<td>±100, ±150</td>
<td>-55 to +105</td>
<td>-55 to +125</td>
<td>&lt;1</td>
</tr>
<tr>
<td>CHT32</td>
<td>3.2x2.5 4-Pad</td>
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<tr>
<td>CHT50</td>
<td>5.0x3.2 4-Pad</td>
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</tr>
<tr>
<td>CHT70</td>
<td>7.0x5.0 4-Pad</td>
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</tr>
</tbody>
</table>

### IoT Enhanced Crystals Product Features

<table>
<thead>
<tr>
<th>CTS Product Parameters</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Plating Capacitance, &lt;3.0pF [C0]</td>
<td>Multiple package sizes w/ industry standard pinout</td>
</tr>
<tr>
<td>Low ESR Ranges</td>
<td>Power savings for low energy applications</td>
</tr>
<tr>
<td>Small Load Capacitance Options</td>
<td>Reduction in oscillator gain margin</td>
</tr>
<tr>
<td>Fundamental Crystal Designs</td>
<td>Improves oscillator start-up over wide temperature ranges</td>
</tr>
<tr>
<td>Common Wireless Frequencies Available</td>
<td>Enhances system signal to noise ratios</td>
</tr>
<tr>
<td>Operating Temperature Ranges, -40°C/+105°C &amp; -40°C/+125°C</td>
<td>Supporting extended temperature industrial applications</td>
</tr>
<tr>
<td>Frequency Tolerance Options, ±7ppm to ±30ppm</td>
<td>Application design flexibility</td>
</tr>
<tr>
<td>Frequency Stability Options, ±10ppm to ±150ppm</td>
<td></td>
</tr>
<tr>
<td>Custom Frequencies Available</td>
<td></td>
</tr>
</tbody>
</table>

### Low ESR Tuning Fork Product Features

<table>
<thead>
<tr>
<th>CTS Product Parameters</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Plating Capacitance [C0], 1.0pF Typical</td>
<td>Industry standard package sizes</td>
</tr>
<tr>
<td>Low ESR Values [R1] &lt;50k Ohms</td>
<td>Power savings for low energy applications</td>
</tr>
<tr>
<td>Small Load Capacitance Options [C1]</td>
<td>Reduction in oscillator gain margin</td>
</tr>
<tr>
<td>Temperature Range to -40°C to +85°C</td>
<td>Improves oscillator start-up over wide temperature ranges</td>
</tr>
</tbody>
</table>

### RTC TCXO Product Features

<table>
<thead>
<tr>
<th>CTS Product Parameters</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Current Consumption, &lt;2µA</td>
<td>Small package size</td>
</tr>
<tr>
<td>Tight Frequency Stability, ±5.0ppm</td>
<td>Power savings for low energy applications</td>
</tr>
<tr>
<td>Temperature Range to -40°C to +85°C</td>
<td></td>
</tr>
</tbody>
</table>
Industrial Grade Clock Oscillator Product Features

<table>
<thead>
<tr>
<th>CTS Product Parameters</th>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature Ranges, -55°C/+105°C &amp; -55°C/+125°C</td>
<td>Multiple package sizes w/ industry standard pinout for drop-in replacement</td>
</tr>
<tr>
<td>Common Clock Frequencies Available</td>
<td>Supporting high temperature applications</td>
</tr>
<tr>
<td>HCMOS Output</td>
<td>Standard Disty stock for off-the-shelf availability</td>
</tr>
<tr>
<td>RMS Jitter [12kHz - 20MHz], 500fs Typical</td>
<td>Waveform parameters providing high speed switching</td>
</tr>
<tr>
<td>Custom Frequencies Available</td>
<td>Provides more design margin to ensure robust system performance</td>
</tr>
<tr>
<td>Voltage Options, +1.8V, +2.5V &amp; +3.3V</td>
<td>Application design flexibility</td>
</tr>
<tr>
<td>Frequency Stability Options, ±25ppm, ±30ppm, ±50ppm, ±100ppm, ±150ppm</td>
<td></td>
</tr>
</tbody>
</table>

Industry Applications Table

| Internet of Things [IoT] / Industrial IoT [IIoT] / Smart Applications / Medical |
|---------------------------------------------------------------|---------------------------------------------------------------------------|
| Wireless Communication                                       | Bluetooth, Bluetooth Low Energy                                           | Industrial Monitoring & Control                                           |
| Low Power MCUs, SoCs, RF ICs                                 | LoRa, LPWAN, 6LowPan, WLAN                                                 | Home/Building Automation                                                  |
| M2M Communication                                            | Near Field Communication                                                  | In-Flight Entertainment                                                    |
| WiFi, ZigBee, ZigBeeRF4CE                                    | Low Drive Chipsets                                                        | Test and Measurement                                                       |
| Z-Wave, Sigfox, SimpleLink                                   | ISM Band Applications                                                      | Physical Therapy Devices                                                  |

Industry Application Table

<table>
<thead>
<tr>
<th>Industrial Clock Oscillator</th>
<th>Medical Clock Oscillator</th>
<th>Commercial Military/Aerospace Clock Oscillator *</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial IoT [IIoT]</td>
<td>Ultrasound Equipment</td>
<td>Wireless Communication</td>
</tr>
<tr>
<td>M2M Communication</td>
<td>Physical Therapy Devices</td>
<td>Edge Computing</td>
</tr>
<tr>
<td>Industrial Controls</td>
<td>Respiration Monitors</td>
<td>In-Flight Entertainment</td>
</tr>
<tr>
<td>Wireless Communication</td>
<td>Diagnostic Imaging</td>
<td>Cabin Management Systems</td>
</tr>
<tr>
<td>Test and Measurement</td>
<td>Lab Measurement Equipment</td>
<td>COTS Clock Oscillators</td>
</tr>
</tbody>
</table>

* No Group testing or other military screenings are performed on CHT Series products
Many electrical systems are required to function and survive in extreme operating environments that go beyond the standard MIL-STD operating temperature range of -55°C to +125°C. Deep well drilling, geothermal logging, and process monitoring are some of applications that require components to operate at +200°C, in environments that may have high shock and vibration conditions. Building from ruggedized design techniques developed for military programs, CTS has oscillators and timing solutions that provide outstanding performance operating in severe conditions.

### Extreme Environment Clock Oscillators Product Table

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>HCMOS 680</td>
<td>7.0x5.0 4-Pad</td>
<td>1 - 100</td>
<td>1.8, 2.5, 2.8, 3.3</td>
<td>-55 to +200</td>
<td>&lt;1</td>
</tr>
<tr>
<td>T1250/T3250</td>
<td>7.0x5.0 4-Pad</td>
<td>1 - 100</td>
<td>3.3, 5.0</td>
<td>-55 to +85, -55 to +125</td>
<td>&lt;1</td>
</tr>
<tr>
<td>T561/T5721</td>
<td>7.0x5.0 4-Pad</td>
<td>0.16 - 100</td>
<td>1.8</td>
<td>-55 to +85, -55 to +125</td>
<td>&lt;1</td>
</tr>
<tr>
<td>T7250/T9250</td>
<td>7.0x5.0 4-Pad</td>
<td>1 - 100</td>
<td>5.0</td>
<td>-55 to +85, -55 to +125, -55 to +200</td>
<td>&lt;1</td>
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</tbody>
</table>

### Extreme Environment VCXO’s Product Table

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<tbody>
<tr>
<td>HCMOS/VFH5070</td>
<td>7.0x5.0 6-Pad</td>
<td>1.0 - 80</td>
<td>3.3, 5.0</td>
<td>-55 to +85, -55 to +125</td>
<td>0.2 Typ</td>
</tr>
<tr>
<td>VFH750</td>
<td>7.0x5.0 6-Pad</td>
<td>1.0 - 80</td>
<td>3.3, 5.0</td>
<td>0 to +175, -40 to +175, -55 to +85, -55 to +125</td>
<td>0.2 Typ</td>
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</tbody>
</table>

### Shock and Vibration Clock Oscillator Product Table

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</thead>
<tbody>
<tr>
<td>HCMOS 680</td>
<td>7.0x5.0 4-Pad</td>
<td>1 - 100</td>
<td>1.8, 2.5, 2.8, 3.3</td>
<td>-55 to +200</td>
<td>&lt;1</td>
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</tbody>
</table>

### Shock and Vibration VCXO Product Table

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</thead>
<tbody>
<tr>
<td>HCMOS M6306</td>
<td>20.32x12.62 Thru-Hole M-1 Pkg.</td>
<td>1 - 35</td>
<td>5.0</td>
<td>-55 to +125</td>
<td>&lt;15</td>
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</tbody>
</table>
### Shock and Vibration OCXO’s Product Table

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</tr>
</thead>
<tbody>
<tr>
<td>HCMOS</td>
<td>148</td>
<td>15x15 Thru-Hole 5-pin</td>
<td>1 - 80</td>
<td>3.3, 5.0</td>
<td>-40 to +85</td>
</tr>
</tbody>
</table>

### Product Information

<table>
<thead>
<tr>
<th>Product Features</th>
<th>Manufacturing Process</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clock Oscillator Devices – Developed w/ Special Components &amp; Epoxies for High Temperature Ranges</td>
<td>Stabilization Bake – MIL-STD 883, Method 1008, Condition B</td>
<td>Down-Hole Drilling</td>
</tr>
<tr>
<td>Crystals – Designed Specifically to Withstand High Operating Temperature Ranges</td>
<td>Temperature Cycling – MIL-STD 883, Method 1010, Condition B</td>
<td>Oven Controllers</td>
</tr>
<tr>
<td>Temperature Range – -55°C to +200°C Available</td>
<td>Burn-In – MIL-STD 883, Method 1015, Condition B +125°C for 168 hours w/ bias</td>
<td>Industrial Process Control</td>
</tr>
<tr>
<td>Stabilities – ±25ppm [±0.01ppm OCXO] to ±75ppm</td>
<td>Fine Leak – MIL-STD 883, Method 1014, Condition A1</td>
<td>Military Communications and Military Vehicles</td>
</tr>
<tr>
<td>Output Types – CMOS, HCMOS, LVPECL, LVDS</td>
<td>Gross Leak – MIL-STD 883, Method 1014, Condition C</td>
<td>Vibrating Test Equipment</td>
</tr>
</tbody>
</table>

### Electrical Test Information

<table>
<thead>
<tr>
<th>Electrical Test – +25°C &amp; Temperature Extremes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
</tr>
<tr>
<td>Frequency @ +4.5V</td>
</tr>
<tr>
<td>Current</td>
</tr>
<tr>
<td>Duty Cycle [no load] and [full load]</td>
</tr>
<tr>
<td>“One” Logic Level</td>
</tr>
<tr>
<td>Frequency @ +5.5V</td>
</tr>
<tr>
<td>Fall Time [full load]</td>
</tr>
<tr>
<td>Rise Time [full load]</td>
</tr>
<tr>
<td>“Zero” Logic Level</td>
</tr>
</tbody>
</table>

### WEBSITE REFERENCE LINKS

International Automotive Task Force [IATF]: [https://www.iatfglobaloversight.org/](https://www.iatfglobaloversight.org/)
Automotive Industry Action Group [AIAG]: [https://www.aiag.org/](https://www.aiag.org/)
Product Links

CTS Frequency Control Products Homepage
https://www.ctscorp.com/products/frequency-control-products/

IoT Market Page
https://www.ctscorp.com/markets/iot-and-connectivity/

Crystals
https://www.ctscorp.com/connect_product_line/crystals/

Clock Oscillators
https://www.ctscorp.com/connect_product_line/clock-oscillators/

Timing Modules
https://www.ctscorp.com/connect_product_line/timing-modules/

TCXO Oscillators
https://www.ctscorp.com/connect_product_line/tcxo/

OCXO Oscillators
https://www.ctscorp.com/connect_product_line/ocxo/

VCXO
https://www.ctscorp.com/connect_product_line/vcxo/

Releases and Content Links

Automotive Grade AEC-Q200 Crystals
https://www.ctscorp.com/portfolio-expansion-automotive-grade-crystal-resonators/

Industrial Grade AEC-Q200 Clock Oscillators

CTS IoT Enhanced Crystals Designs

Whitepaper: Crystal Solutions for Low Power Applications


Webinar: IoT Demand for Timing at Low Power
https://www.youtube.com/watch?v=rm-JcAYOyN0
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