[Epson Toyocom Corp]

Crystal Gyro-Sensors Lead to New Dimension in Sensing

The crystal gyro-sensors from Epson Toyocom Corp of Japan use the firm's original "double-T"structure to achieve high precision,extremely low power consumption,and the excellent stability of crystal, providing a new dimension in sensing that the customer can utilize without having to worry about. These outstanding characteristics are leading to the creation of a host of brand-new applications that may well change our daily lives .Teruhisa Miyazawa,manager,Strategic Product Planning Dept,Development & Design Management Div at the firm,spoke about their principles of operation,near-future applications and everything in between at the Sensor Symposium 2008 organized by Nikkei Electronics.

Teruhisa Miyazawa,
Epson Toyocom Corp

"When you think about what actually constitutes good sensing, from the concept of using a ruler to measure something, there are five criteria all beginning with the letter 'S'," said Teruhisa Miyazawa, manager, Strategic Product Planning Dept, Development & Design Management Div, Epson Toyocom Corp in his talk. He began by describing the fundamental role of the sensor.

"5S" Criteria for Good Sensors

"In order to measure something accurately, you first have to be sure that the zero point of the ruler is accurately aligned with the end of the object to be measured (**Fig 1**). If the ruler is not as long as the object, it is possible to make a mark at the point the ruler reaches, align the zero point there, and measure again; but this approach can potentially introduce a variety of errors. For example, the initial zero point alignment could be off, the ruler might be placed at an angle, the mark made when the ruler was moved could be off, the scale might be read incorrectly, or the scale might have been incorrect to begin with! When the same situation is applied to sensing devices, it is essential to always ensure a constant zero point regardless of specific conditions. For example, there must be no zero point offset, the scale must be unaffected by changes in the external environment such as temperature or humidity, there must be no hysteresis, and there must be no interference with other axes (noise)."

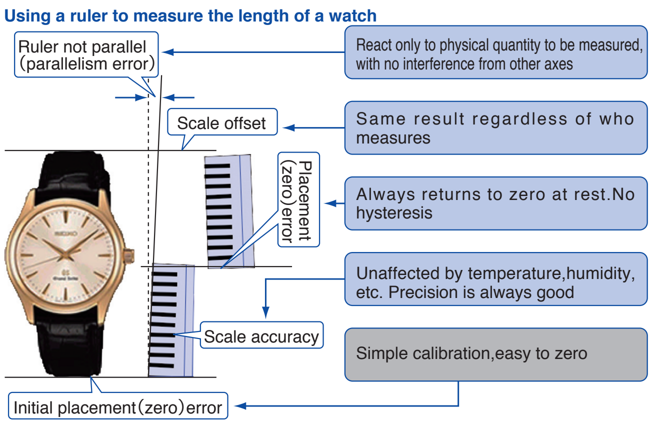


Fig 1 Performance Demanded of Sensing Devices

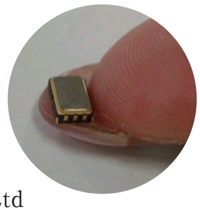
Miyazawa provided another example: that of a car braking abruptly. When the driver presses the brake pedal, the braking effect builds linearly. In other words, the system responds immediately to changes in physical quantities, the response is large, and the sensing results are proportional to the amount of change. He said that these characteristics are crucial in sensing devices.

Miyazawa explained that these essential sensor characteristics can be grouped into five criteria beginning with the letter "S", namely Speed (responsiveness to a change in physical quantity), Sensitivity (the degree of response to a change), Selectivity (the ability to respond to only specified changes), Straight response (accuracy in the response to a change in physical quantity), and Stability (remaining unaffected by the external environment). "We believe that the performance of the sensing device depends on these five characteristics, which we call the 5S."

Better Zeroing Characteristics

There is a good reason why Miyazawa chose to begin his talk in this fashion: gyro-sensors, depending on their characteristics, have been shown to significantly improve image stabilization performance in digital single-lens reflex (SLR) cameras. In digital SLRs, the gyro-sensor is used to detect angular velocity, which is converted to express the amount of camera shake, which is then fed back to the lens via an actuator. About a decade ago, when the image stabilization function was brand new, the 5S performance of the gyro-sensor was far below the current level, and the only effect was to drop the shutter speed by about one. The XV-3500CB ultra-miniature vibration gyro-sensor released by Epson Toyocom in 2005, however, offered high and well-balanced 5S performance. It was designed to return to the zero point faithfully throughout continuing vibrations, allowing the shutter speed to be dropped by four.

Crystal device manufacturer Epson Toyocom, which developed



the XV-3500CB, began operations in October 2005. The company was formed through a merger of the Quartz Device Operations Div of Seiko Epson Corp of Japan and Toyo Communication Equipment Co Ltd of Japan. Both firms had experience in handling crystal electronic devices, and their fusion provided a synergistic effect that fueled the development of a host of innovative products leveraging the unique qualities of quartz monocrystal. The XV-3500CB is extremely small, in a package measuring only 5.0mm x 3.5mm (**Fig 2**). As mentioned above, the chip has been utilized for optical image stabilization in a large number of recent digital SLRs, and is gradually establishing a presence in car navigation systems and other products. A wide variety of applications are possible thanks to its precision, stability and other characteristics, and as the package continues to shrink, totally new applications are being pioneered.

While the name "gyro-sensor" — especially the "gyro" part — is well known, a surprisingly large number of people don't understand what's inside them. Many people confuse them with acceleration sensors, it seems.

"Probably angular velocity sensors are relatively rare because of the difficulty involved in sensing angular velocity," Miyazawa explained. " I don't think humans can sense angular velocity." Angular velocity sensors like the gyro-sensor measure physical quantities that we cannot sense; it is fairly difficult for most people to understand properly what they cannot feel themselves.

Angular Velocity: the Coriolis Force

The gyro-sensor converts the change in angle over a period of one second into an electrical signal for output. It is used in a wide range of applications from aerospace to industry, and to consumer products. For example, artificial satellites use gyro-sensors to detect their angular velocity and calculate the virtual center of their own motion, thereby determining their reference points. This process demands extremely high precision and therefore makes use of the Sagnac effect which reguires much more expensive mechanism, but most consumer applications use vibration gyros

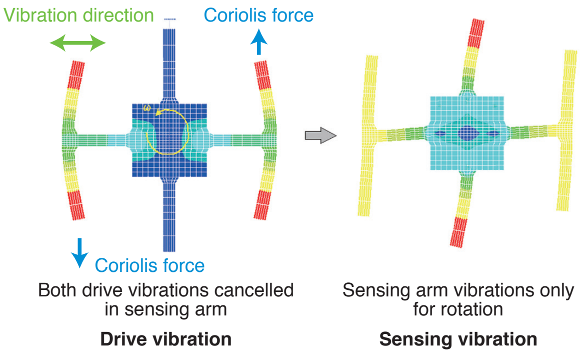
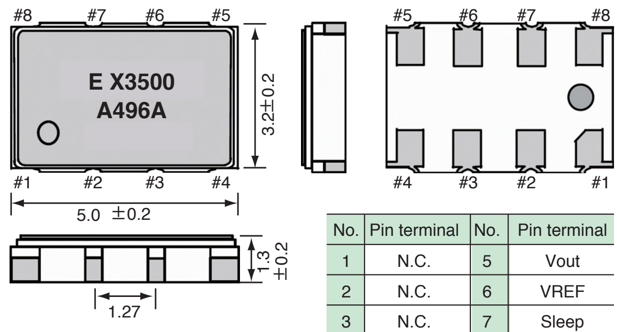


Fig3 Double-T Structure
The quartz crystal and double-T structure provide high sensitivity,humidity-independent stability,etc.



No.	Pin terminal	No.	Pin terminal
1	N.C.	5	Vout
2	N.C.	6	VREF
3	N.C.	7	Sleep
4	GND	8	VDD

Announced August 2004

Fig 2 Epson Toyocom's XV-3500CB Ultra-Miniature Crystal Gyro-Sensor

based on the Coriolis effect. Epson Toyocom has commercialized this latter type.

The Coriolis effect is the force acting on objects moving within a rotating coordinate system. It appears as if force is being applied perpendicular to the direction of travel, but, as Miyazawa explained, "Think about the wind in a typhoon. It forms a vortex rotating counter-clockwise in the northern hemisphere, due to the Coriolis force caused by the rotation of the earth."

The key applications driving the vibration gyro market based on the Coriolis force are image stabilization in digital SLRs and autonomous operation for car navigation systems when the global positioning satellite (GPS) signal is lost. Recently gyro-sensors and acceleration sensors have been combined to detect player motions and reflect them in games. They are also entering use in robotics, such as in housekeeping robots.

Gyros with Crystal Oscillators

Epson Toyocom manufactures vibration gyro-sensors utilizing crystal oscillators. The XV-3500CB is currently the prime model, and comes in a surface mount device (SMD) package measuring only 5.0mm x 3.2mm, small enough to sit on the tip of your finger. It has a single detection axis.

Characteristic specifications with an operating voltage of 3V include a detection range of ±100deg/s, and output of 1deg/s as a 0.67mV electrical signal. Its environmental capabilities are excellent due to the hermetically sealed package, and it offers outstanding characteristics including the high stability of a crystal oscillator and low current consumption in sleep mode. Since the product began shipping in 2005 it has earned high marks in sectors demanding high precision, hysteresis performance, minimal zero offset and other characteristics, and today it is used in a diverse range of applications.

A fundamental signal is input to the long, thin crystal arms, and when rotation is applied, the Coriolis force generates a voltage. The load thus created is efficiently detected, making it possible to sense rotation. Normally a tuning fork sensor element is used, but Epson Toyocom applied the same principle of operation to

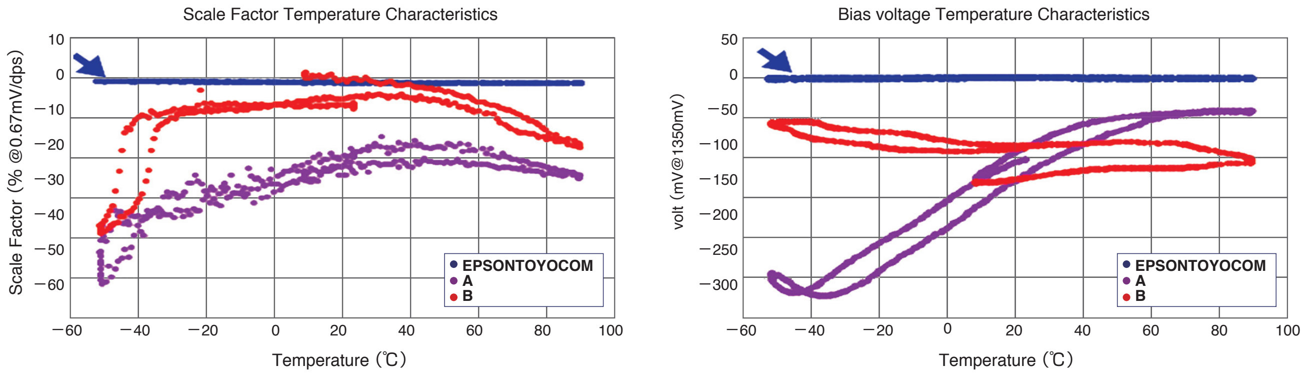


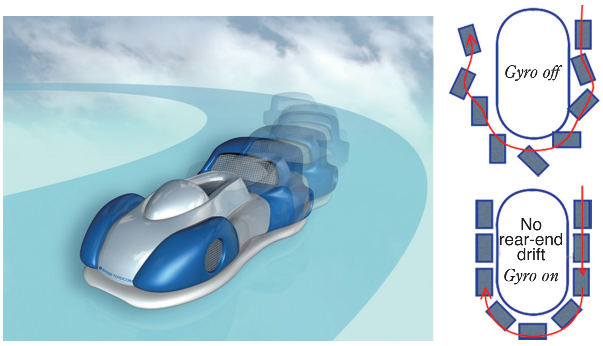
Fig 4 Excellent Stability of Double-T Structure Gyro
Blue shows Epson Toyocom XV-3500CB. Other colors are for competing products with equivalent noise levels.

its original double-T structure, obtaining effective sensing from a simple design while minimizing noise (**Fig 3**).

In operation, first the two T-shaped oscillators on either side are driven with a fundamental vibration of tens of kHz, with a symmetrical waveform (drive mode). The minute fundamental vibrations from the two T-shaped oscillators cancel each other out on the axis of symmetry. When rotation occurs, the Coriolis force acts in the direction perpendicular to the displacement of the fundamental vibration, producing a sensing vibration (sensing mode). The sensing vibration displacement is detected by a piezoelectric device. Orthogonal coordinate conversion is implemented through circuit processing, such as offsetting the phase and applying again, finally yielding a linear potential variation.

Miyazawa explained the merits of the double-T structure: "The sensing arm is an ideal structure, vibrating only during rotation. In addition, it is designed to flex from the base, so it can detect the sensing vibration without loss. The flexing vibration is in the same plane, making the design very resistant to external noise."

He added: "Because we use quartz monocrystal, temperature characteristics at the surface are much better than those of piezoelectric ceramic. Even at a different temperature, the drive and sensing modes exhibit the same changes, and output shows very little temperature dependence." A comparison of stability with other products of a similar noise level clearly demonstrates the flat temperature characteristics, and hysteresis-free zero-point temperature characteristics (**Fig 4**).



Planned demonstration for Epson Toyocom booth at CEATEC 2008

Fig 5 New Applications for Crystal Gyro-Sensors: Hovercraft Steering Control

5S to 7S: "Pure" Sensors

As described earlier, Epson Toyocom gyro-sensors are able to return accurate data almost regardless of the environment thanks to the 5S characteristics. Miyazawa said, "The XV-3500CB adds two more: Small, and Saving energy. So perhaps we should start talking about 7S now." The 7S design also means that the chip can provide mobility, and in the future it is possible that a miniaturized module might be mounted in a mobile phone to reduce the effects of hand vibration.

The term "pure" sensor is used to refer to a sensor capable of measuring only the target object with good response, unaffected by internal or external noise, and capable of measuring objects at rest as objects at rest. This type of sensor would also be easier to use. Epson Toyocom crystal devices come very close to being pure sensors; they offer high signal/noise ratios, high sensitivity and high stability, free of temperature dependence or hysteresis, for example. Their performance will lead to widespread utilization in a diverse range of applications.

In an attempt to make it as close to a pure sensor as possible, the gyro-sensor will be mounted in a hovercraft and operated round a track with normal rear-end drift. The gyro-sensor will be used in an attempt to achieve cornering with no drift (**Fig 5**). The demonstration is planned for CEATEC 2008 in October, but the technical issues are considerable because the frictional coefficient with the roadway is effectively zero.

"As a device manufacturer, we believe that we must provide sensors that are as close to being pure sensors as possible. The goal is providing sensors that are as easy for users to utilize as possible. Our sensors presently output electrical potential, and users have to pass this signal through filters, analog-digital converters or other components before it can be fed to a microcontroller. We hope to build all of this downstream

	Daily life	Industrial	Automotive
Gyro-sensor	・Image stabilization ・TV monitors ・Housekeeping robots ・Living support robots	・Equipment stabilization ・Robot control ・Precision fabrication stabilization	・Dead reckoning ・Inclinometers ・Yaw prevention ・Attitude control (yaw, roll, pitch)
Acceleration sensor	・Reclining beds ・Pedometers・Seismographs ・Wearable ・Controllers ・Hard disc protection ・Knife sharpeners	・Scales ・Surveying, measurement ・Seismographs	・Speedometers ・Airbags ・Inclinometers
Pressure sensor	・Weather forecasting ・Air conditioners ・Unit bathroom tubs and showers ・Scales ・Toilets ・Intelligent floorsxx ・High-voltage washing machines ・Dishwashers ・Air curtains	・Meteorological instrumentation ・Dam water depth gauges ・Elevator air pressure ・Air showers	・Air conditioner positive pressure ・management ・Altitude meters ・Tire pressure monitoring systems (TPMS)

Fig 6 Representative Applications for Crystal Sensors

processing into our product, such as offering digital output," said Miyazawa. He added that the firm is already well on its way towards achieving its goal of returning an identical value regardless of different usage conditions. The next step, he said, is smart sensing.

Smart Sensors Enable Futuristic Applications

These evolved, smart sensors open up a wide range of possible applications. For example, it would be possible to make a robot that gets carsick!

A number of firms are working on the development of a system combining 3-axis gyro-sensors with 3-axis acceleration sensors to completely replicate human functionality. If this can be achieved, it would be possible to make a robot that gets carsick, and use it in testing to develop vehicles that help protect people from getting carsick. "The ultimate implementation of smart sensing is to put it in robots," said Miyazawa. "I don't think this will make robots more like people... what it will do is turn robots into sensors."

One application that practically cries out for pure sensors is overall vehicle control: the capability of handling everything from horizontal slips (yaw) to acceleration, rolls and pitching. This sort of technology might change the driver's job from actually driving the vehicle to merely specifying the destination, and monitoring automatic driving performance.

If the sensor is being used in an application involving health or safety, for example, the sensing conditions become much more severe. Pure sensors must be further improved, and ensure accuracy through specifications such as temperature and hysteresis characteristics. "In this situation, sensor design may evolve from 5S to 7S or 9S," said Miyazawa. Currently users have to keep track of external factors themselves, and cancel out any effect they may have, the result being that it takes some skill to be able to utilize sensors effectively. In the future, engineers hope that smart sensors will be able to do this autonomously.

Crystal-Based Pressure, Acceleration Sensors

Epson Toyocom is developing a variety of crystal-based sensors, including pressure and acceleration sensors, in addition to gyro-sensors. Crystal pressure sensors operate by detecting the change in oscillation frequency caused by the application of tensile or compression stress to the crystal oscillator. High-resolution sensing is possible with this design, as frequency change is converted into a stress value (pressure value) over a wide range of 10% of oscillation frequency (within the device's dynamic range), and frequency stability is expected to be within 1ppm. The output is a digital frequency value, which simplifies downstream design.

In crystal acceleration sensors, on the other hand, acceleration applies pressure to the crystal piezoelectric oscillator, causing a change in its piezoelectric characteristics and oscillation frequency. This sensor is actually a type of frequency change sensor, and can also be used to measure gravitational acceleration. Under ± 1G acceleration it achieves 100ppm/G sensitivity and a resolution of about 1mG. If the outstanding characteristics of crystal can be utilized in not only gyro-sensors, but also in sensors for pressure, acceleration, etc, it will vastly expand the range of application (**Fig 6**).

"The essential element is applications: what people want to do. Once we know what they want we can create an interface for it, and figure out what type of sensor is needed to make it work," explained Miyazawa. Solving an application problem begins with determining what performance the sensor needs.

If the advantages offered by the properties of quartz are combined with the micro-electro mechanical systems (MEMS) fabrication process, it becomes possible to develop and supply sensing devices that are small, light, low-power and installable almost anywhere. Epson Toyocom has dubbed this manufacturing approach QMEMS and utilizes it to implement its line of sensing devices. For example, a gyro-sensor can be mounted in a wristwatch to measure bodily motion. The range of applications is limited only by the imagination: Epson Toyocom sensors have the potential to revolutionize our daily lives.

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