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WIRELESS TEMPERATURE SENSING BY ACOUSTIC WAVE SENSORS

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Introduction

There is a predominant market need for sensors that are competitively priced due to mature and established manufacturing methodologies, inherently rugged because of the implementation of advanced packaging techniques and very sensitive and intrinsically reliable. Additionally, the sensors need to be of a very small size, not influenced by magnetic fields, while at the same time contribute to emerging market needs of being able to support data and monitoring functions wirelessly, complementing additional functionalities such as low power requirements and being passively and wirelessly interrogated (no sensor power source required).

Acoustic wave technology also lends itself very well to such sensing applications, having the ability to fulfill the above market requirements. Acoustic wave devices have played an important role in consumer and communication systems over the last 50 years due to their high performance, small size and high reproducibility. The telecommunications industry is the largest volume application, accounting for filters and oscillators in mobile cell phones and base stations. These are typically surface acoustic wave (SAW) devices and function as band-pass filters in both the radio frequency and intermediate frequency sections of the transceiver electronics.. Current applications include automotive applications (tire pressure and oil condition monitoring sensors) and industrial and commercial applications (temperature in ovens, pressure in tanks).

The acoustic wave sensors operate at high frequencies, wherein the electronic circuitry is well known and allows for the transfer of the output signal over short distances by using capacitive or inductive connectors. Because the sensors are passively energized, they do not require batteries, and the interrogation electronics can be such that allows for easy integration into any host control or data acquisition system.

Since advanced packaging and manufacturing techniques are well-established for acoustic wave devices, they are an attractive candidate for wireless sensor applications where a small footprint coupled with cost-effectiveness, and robust/reliable design with very low power requirements are critical for wide-scale implementation. One area in particular where wireless acoustic wave sensors are having an impact is in the industrial temperature sensor industry.

Acoustic Wave Sensor Technology

Acoustic wave sensors function by generating an acoustic wave on a piezoelectric material when a bias is applied. As the acoustic wave propagates through or on the surface of the material, any changes to the characteristics of the propagation path affect the velocity, and/or amplitude of the wave. Changes in velocity can be monitored by measuring the frequency or phase characteristics of the sensor and can then be correlated to the corresponding physical quantity being measured.

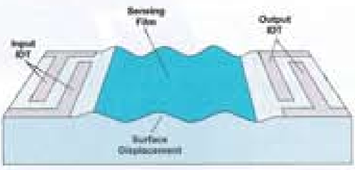

Figure 1: Rayleigh surface acoustic wave operating principles

Starting with the Rayleigh surface acoustic wave (SAW) delay line *(see Figure 1)*, the propagating wave is confined to the top surface of the substrate. Because of this, the SAW is a very sensitive probe for measuring mechanical properties such as stress or strain coupled into the SAW substrate whether it be through the packaging or on a diaphragm on which the SAW transducer is fabricated. Rayleigh SAW devices can also be tailored with special cuts of piezoelectric substrate to create a very linear SAW frequency versus temperature dependence. The result is a very high resolution temperature sensor.

Acoustic Wave Technology For Wireless Applications

The aforementioned characteristics are complemented by the ability of SAW sensors to operate with no wire connection or battery, as they are connected only by a radio frequency link to a transceiver or reader unit. This is due to the very low input signal levels and high electrical efficiency.

A representation of wireless sensor/identification system is shown in *Figure 2*. A high-frequency electromagnetic wave is emitted from a RF transceiver and is received by the antenna

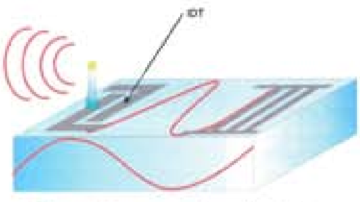

Figure 2: Representation of a wireless temperature sensor

of the SAW sensor. The IDTs (interdigital transducers; the comb-like pattern of metal on the device that converts the electric field energy to mechanical wave energy and then back to an electric field) are connected to the antenna to convert the received signal into an acoustic wave, which propagates along the sensor and results in the operation as mentioned above. Depending on the construction of the device (using metal patterns such as reflectors et. al), the IDTs can retransmit to the receiver. The received signal is amplified and then converted to a baseband frequency in the RF module and then analyzed by a signal processor. Because the operating frequencies high, SAW sensors are well protected from electromagnetic interference that often occurs in the vicinity of industrial equipment, such as motors and high-voltage lines.

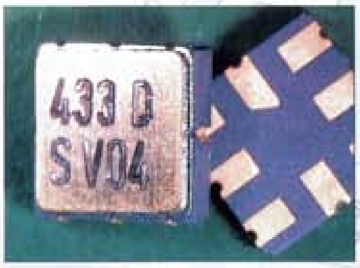

Figure 3: A commercially available wireless temperature sensor

A commercial SAW temperature sensor offered, for example, is a 433.78MHz one-port SAW resonator structure specifically designed to have a linear frequency versus temperature characteristic *(see Figure 3)*. With a temperature coefficient frequency of 16.2 ppm/°C (~7028 Hz/°C), it is operable from 0 to 120°C. The sensor has an unloaded Q of 8000, it is low loss (2.5dB max) and it is designed for a 50-ohm system. When combined with an antennae and interrogation unit, this SAW sensor chip makes a great solution for numerous wireless temperature sensing applications.

The wireless sensors works within the ISM 433.92 MHz for the defined operating temperature range. The sensors are designed to provide instantaneous wireless temperature measurements for embedded real-time, in-line environments requiring high resolution and accuracy. A characteristic of the SAW temperature sensors is their exceptional stability characteristics, passing DIN IEC 68 T2-27 specifications for shock rating and screening according to DIN IEC 68 T2-6 standards for vibration rating. Temperature stability characteristics are assured by DIN IEC 68 Part 2 - 14 Test N standards.

Such wireless temperature sensors have been installed in commercial markets such as cooking ovens. And currently they continue to be evaluated for industrial applications, such as the determination of contact temperature in high voltage breaker boxes in the electrical power industry and monitoring of temperature in rotating equipment.

Figure 4: Interrogator with wireless temperature sensor and antenna

Customers in the marketplace are offered a starter kit that allows for the evaluation and validation of wireless temperature technologies and products *(see Figure 4)*. The starter kits are offered with an interrogation unit and standard off-the-shelf antenna which can be easily attached to a computer for data capture and visualization. The number of sensors that can be interrogated and the design of the antenna are application specific considerations that are addressed by modifying the interrogation electronics, sensor characteristics and antenna design.

Finally, a wireless temperature monitoring sensor in a reflow solder oven provides another application sector. An acoustic sensor, soldered on to a PCB with an appropriately designed antenna, continuously reads the temperature of the oven, as it travels through the oven, verifying the thermal profile present. The readings are taken very accurately since the frequency of the sensor changes as a linear function of the temperature due to the miniscule expansion (on the order of parts per million) of the sensing element. The data is sent wirelessly to a reader that reads and displays the temperature in real-time.

In conclusion, wireless acoustic wave temperature sensors have unique features that allow customers to address specification needs and requirements that otherwise may not have been possible due to design constraints and sensor suppliers are well poised to provide solutions for these multiple applications.

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