Acoustic Wave Sensors Impact Auto Industry

Acoustic wave devices are an attractive candidate for wireless sensor applications where a small footprint, robust design and low power requirements are critical for wide-scale implementation.

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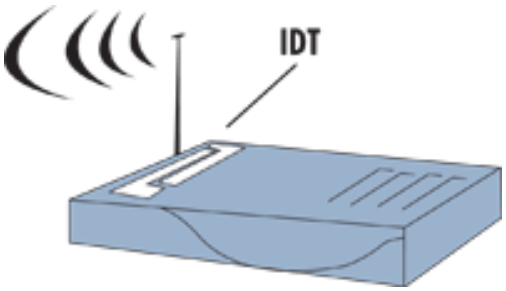
Acoustic wave devices have played an important role in consumer and communication systems over the last 50 years due to their high performance, small size and high



reproducibility. The telecommunications industry is the largest volume application, accounting for filters 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.

Acoustic wave technology also lends itself very well to sensing applications. This emerging market holds the potential of equaling, and even exceeding the demand of the telecommunications market, across multiple application sectors. Applications include automotive applications (tire pressure and oil condition monitoring sensors) and industrial and commercial applications (temperature, chemical/gas sensors). Acoustic wave sensors are competitively priced due to mature manufacturing methodologies, inherently rugged because of the implementation of advanced packaging techniques and very sensitive and intrinsically reliable given the inherent design principles. Finally, they are complemented by additional functionalities such as low power requirements and being passively and wirelessly interrogated (no sensor power source required).

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 automobile industry, specifically, wireless tire pressure monitoring (TPM).

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

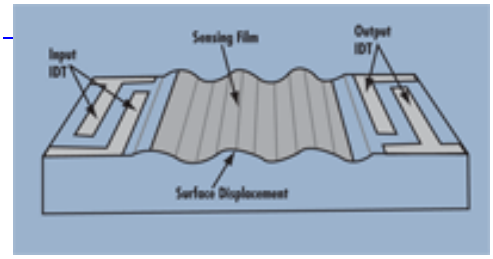


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Figure 1. Rayleigh surface acoustic wave sensing principles.

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.

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. For a particle (whether it is the molecules of a liquid or molecules of a gas) on the surface of the substrate, the propagation of the Rayleigh wave will cause the particle to experience a vertically aligned elliptical motion. Because of this, the SAW is a very sensitive probe for measuring mechanical properties such as their sensitivity to mass loading and visco-elastic changes like stiffening (increase in the oscillation frequency) and softening (decrease in the oscillation frequency). The Rayleigh SAW is also sensitive to 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. This characteristic makes Rayleigh SAW devices ideal platforms for torque and pressure sensing applications. 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.

A commercial SAW temperature sensor offered is a 433.78 MHz one-port SAW resonator structure specifically designed to have a linear frequency versus temperature characteristic. With a temperature coefficient of frequency of 16.2 ppm/&#176C (~7028 Hz/&#176C), it is operable from 0 to 120&#176C. 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.

Since there is a vertically polarized displacement, the Rayleigh SAW can only be used for gas sensing or physical sensing applications. Application of the Rayleigh SAW as a gas sensor is achieved by placing a gas specific sensing film on the surface of the device. When the sensing film gets exposed to the target gas (and the concentration of gas adsorbs onto the surface of the sensing film), mechanical and electrical perturbations in the sensing film

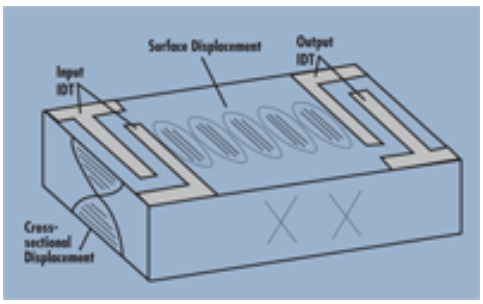

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Figure 2. Shear horizontal acoustic plate mode operating principle.

will cause a corresponding change in the resonant frequency of a SAW resonator or a change in the delay of a SAW delay line. When the device is combined with an oscillator circuit, the result for both is a change in the oscillation frequency.

However, putting the SAW in an aqueous environment will result in the SAW being completely damped out due to energy loss into the liquid. This desired functionality can be attained by other acoustic wave designs.

There are many types of acoustic wave sensors, each with a specific construction and operating mechanism. For example, the shear horizontal acoustic plate mode (SH-APM) device combines the best properties of both the BAW (bulk acoustic wave) and SAW (surface acoustic wave) devices (see Figure 2). It employs separate input and output transducers in order to allow differential signal measurements, like the SAW structures, but also allows the sensor crystal to be employed as a physical barrier between the electronics and the sensing medium.

The wave is a waveguide mode with energy throughout the bulk of the crystal and is dependent on the thickness of the substrate. Like all the previous surface generated acoustic wave devices, the SH-APM device uses input and output 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) to launch and receive the acoustic wave. Similar to the BAW thickness shear mode device, the maximum displacements occur on the top and bottom surfaces of the plate. Similar to the STW and Love Mode devices, the surface displacement is shear and in the plane of the plate so it can be used for liquid-based applications. The waveguide modes have energy distributed between the two surfaces as a standing wave as in the BAW sensor but traveling along the surface as in a SAW. The continuous exchange of energy between the two surfaces allows the signal between the IDTs to be influenced by changes on the opposite surface.

Since the wave interacts with both surfaces of the plate, either surface can be used as the sensing surface. For liquid sensing applications (complete immersion in liquid) and for corrosive or explosive gases, this is a great advantage over the Rayleigh, STW (surface transverse wave) and Love Mode device because you can isolate the sensing medium from the electrodes by making the bottom surface of the SH-APM device the sensing surface. Similarly, it can become a chemical-biological sensor when a coating is applied that absorbs only specific chemical or

biological agent.

Among the piezoelectric substrate materials that can be used for acoustic wave sensors the most common is quartz, with different cuts and orientations. Each has specific advantages and disadvantages, which include cost, temperature dependence, attenuation and propagation velocity allowing for customized solutions for specific applications. And since, the sensors are made from a photolithographic process that results in the IDTs permanently deposited on the device, it is possible to further fine-tune the performance of the sensor by changing the length, width, position and thickness of the IDT.

Implementing appropriate signal conditioning together with optimized IDT design, the SH-APM sensor can be a viscosity sensor for embedded real time, in-line oil condition monitoring applications (see Figure 3) in a screw-on bolt packaging. Measurements are made by placing a hermetically packaged piezoelectric crystal chip with an abrasion resistant proprietary hard-coat surface in contact with liquid. The liquid's viscosity determines the thickness of the fluid hydro-dynamically coupled to the surface of the sensor. As the acoustic wave penetrates the fluid, viscosity is calculated by measuring the power loss. Because the acoustic wave sensor is a solid-state device, it requires no calibration, contains no moving parts, and can be completely immersed into harsh operating conditions.

Acoustic Wave Technology in Wireless

The aforementioned characteristics are complemented by another outstanding property of SAW devices; namely, their ability 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 SAW devices operating at very low input signal levels and high electrical efficiency.

A representation of wireless sensor/identification system is shown in Figure 4. A high-frequency electromagnetic wave is emitted from a RF transceiver and is received by the antenna of the SAW sensor. The IDTs 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 are in the GHz range, SAW sensors are well protected from electromagnetic interference that often occurs in the vicinity of industrial equipment, such as motors and high-voltage lines.

Such is the construction of a wireless tire pressure monitoring (TPM) sensor, such as pioneered by companies like Transense. An acoustic TPM sensor continuously reads the tire pressure and temperature by detecting miniscule strain changes on a diaphragm structure that flexes due to the tire pressure. The temperature measurement is important because it allows for the temperature compensation of the pressure reading. The data is sent wirelessly to a gate reader or a handheld unit that reads the tires while the equipment is in motion. Additionally, it is possible to manufacture the sensor with its own integrated radio frequency identification tag utilizing the construction of a delay line (which enables the SAW response to be separated from environmental echoes) and a series of reflectors arranged in a pattern similar to a barcode. This feature in a TPM sensor signals the receiving unit when a specific tire is losing pressure. The United States government has passed legislation that requires all new passenger vehicles (most 2008 models and all 2009+ models and light trucks under 10,000 pounds of gross vehicle weight) to be equipped with tire pressure monitoring systems. The ability of vehicles, especially critical transport vehicles, to carry the specified load is a direct function of maintaining correct tire pressure. The correct pressure results in the avoidance of catastrophic failure and allows for increased fuel economy.

It's been estimated that about one out of every four vehicles on the road is running on under-inflated tires resulting in lower vehicular fuel economy and handling abilities, while also reducing their tires' durability and tread life. One of the goals of the National Highway Traffic Safety Administration (NHTSA) is to install a direct tire pressure monitoring system that would warns drivers when the air pressure in any of their tires drops a pre-determined threshold value below the recommended cold tire inflation pressure. Doing so, allows the drivers of the vehicles to make a real-time decision concerning their tires without compromising vehicular safety or fuel economy. About the Author

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