

Coded wireless temperature sensors with design specified sensitivity

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Abstract— ASR&D has developed a patented surface acoustic wave (SAW) temperature sensor with individual sensor identification codes and design-controlled temperature sensitivity. Temperature sensitivities demonstrated during this work range from $-165\text{ppm}/^\circ\text{C}$ to $+680\text{ppm}/^\circ\text{C}$, all on YZ lithium niobate, a piezoelectric substrate with an inherent temperature sensitivity of magnitude $94\text{ppm}/^\circ\text{C}$. A set of 32 individually identifiable coded SAW temperature sensor devices were developed. Wireless measurements confirmed the ability to selectively detect any single sensor out of the combined response of multiple sensors. The wireless electronic reader system currently being developed at ASR&D is a single-channel reader that can be manually adjusted to select any one sensor out of a group of up to 32 sensors simultaneously operating in the field of view (FOV) of the reader. This system avoids code collision problems typical of prior coded SAW wireless sensor systems, and can be extended to read 32 or more sensors operating in the FOV of one reader, at ranges of up to 100 feet, with sampling times of 1-10 msec.

Index Terms—coded sensor, code collision avoidance, design specified sensitivity, temperature sensor, wireless temperature sensor.

I. INTRODUCTION

Surface acoustic wave (SAW) temperature sensors typically exploit the temperature coefficient of frequency (TCF) or the temperature coefficient of delay (TCD) inherent to the piezoelectric substrate on which the sensor is built to produce a device with performance characteristics that vary predictably with temperature. Individual wireless temperature sensors systems have historically used measurements of the frequency of a resonator, or the frequency of a delay line oscillator to determine temperature. Current commercially available wireless multisensory temperature sensor systems using SAW sensors include those that use frequency diversity to identify the multiple temperature sensors. Use of frequency diversity divides the available frequency bandwidth into sub-bands, each of which is dedicated to a single temperature sensor. Due

to bandwidth limitations and the need to error band each sensor, frequency diverse systems necessarily place a modest limit on the possible number of simultaneous sensors.

The temperature sensors developed by ASR&D and the wireless reader they operate with function differently. The device geometry is modified in these sensors to provide a reflected frequency response (or power spectral density – PSD) with characteristic features that vary predictably with temperature, the frequency of which can be measured. Unlike prior SAW temperature sensors, the temperature sensitivity of the device is not solely dependent on the inherent TCF of the substrate. Rather, the device design can be varied to generate sensors with a wide range of temperature sensitivities on a given substrate. Each sensor also includes a code for individual device identification, and a set of 32 individually identifiable sensors has been developed. The wireless reader being developed at ASR&D is capable of synchronizing with and identifying each sensor from the combined response of multiple sensors within the FOV of the measurement system, and taking a reading from that sensor. Work is planned to extend this system to allow automated measurement of all 32+ sensors simultaneously operating in the reader FOV. Results of temperature sensor measurements for sensors with different temperature sensitivity and wireless detection of coded sensors from the combined response of a group of sensors will be shown.

II. TEMPERATURE SENSOR MEASUREMENTS

The substrate used for the temperature sensors presented here was YZ lithium niobate (YZ-LiNbO_3), a piezoelectric substrate with an inherent temperature sensitivity of magnitude $94\text{ppm}/^\circ\text{C}$ [1]. This corresponds to the fractional change in frequency for a change in device temperature of 1°C , for a device with a SAW propagating along the Z-axis of the crystal. This TCF value is itself temperature dependent, and applies only in some limited range of temperatures around room temperature. Operation of a temperature sensor with a SAW propagating along the Z-axis of YZ-LiNbO_3 will exhibit TCF values that change with temperature at extreme temperatures (high and low). Due to the anisotropy of the crystal, waves propagating in different directions on the wafer will have different velocities, room temperature TCF values, and TCF temperature dependencies.

While wave propagation in any given direction has TCF

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properties governed by the crystal substrate, by modifying the sensor device design it is possible to produce temperature sensors that have user-defined temperature sensitivities that are either + or -, with a wide range of possible magnitudes, for operation within a defined temperature range of interest. Fig. 1 shows the measured response of one such sensor, which utilizes wave propagation in the Z-axis direction for one portion of the device, yet has a TCF of +680ppm/°C, more than seven times the TCF characteristic of the substrate. Additional sensors with TCF ranging from -165.2 ppm/°C to +384 ppm/°C have been demonstrated.

III. SENSOR IDENTIFICATION

Successful operation of a multisensor system with passive sensors requires the ability to discriminate between sensors based solely on the characteristics of the signal reflected by each of the sensors back to the reader. There is no "handshake" mechanism to allow the reader to query and identify sensors before taking a measurement, and there is also no way to actively delay or time the delivery of specific sensor signals to provide system synchronization. The arbitrary placement of sensors in the FOV of the reader introduces a small difference in propagation delay between individual sensors and the reader, which must be accounted for to properly read the sensors.

ASR&D has developed coded temperature sensors that incorporate both time diversity and frequency coding to produce 32 uniquely identifiable sensors. These sensors were designed to function with the self-synchronizing wireless sensor interrogation system currently under development at ASR&D. This system utilizes the correlative nature of the codes in each sensor to identify the sensor among a group of functionally orthogonal codes, and time diversity allows a small group of "good" codes to be re-used in different time intervals. Since the system uses mixing with a reference signal and integration that is performed at a single point in time, rather than traditional correlation, this system is inherently relatively immune to the code-collision problems that have plagued orthogonal frequency coded (OFC) and standard SAW coded RFID tag devices.

Wireless testing of the coded devices was performed using an Agilent E5070B network analyzer as a signal source and receiver. The wireless measurements were made using one coded correlation device in line with the receive port of the ENA. Multiple coded sensors were placed in the field of view of the transmit antenna, and the received response was measured. Then, the sensor with a code matching the correlator device being used was removed, and the response was measured again and compared with the original response. Figure 2 shows the response of a group of coded sensors containing all four codes (A, B, C, and D) measured wirelessly (red line). In this test, a code B correlator was used, and we see a single correlation peak. To confirm that this peak is due to a sensor with code B, the sensor with that code was removed from the field of view of the antennas, and the

response of the group of sensors without sensor B was re-measured. Notice that, in spite of the fact that sensors with codes A, C, and D are still operating within the measurement system FOV, the combined sensor field signal has a very low level of cross correlation with correlator B.

IV. CONCLUSION

These results show that we can clearly identify the response due to a single sensor with an individual code by using the appropriate correlator in the receiver signal path. Cross-correlation with other codes is not significant enough to cause problems with identification. Each of four sensor codes can be discerned at any one of eight discrete delays, using a single correlator that matches the code to be detected. Thus, a set of 32 individually identifiable sensors has been demonstrated, using both time and code diversity. Wireless measurements have confirmed the ability to detect any of the 32 sensors out of a group of sensors simultaneously operating within the field of view of the measurement system. This approach can be extended straightforwardly to 100 or more sensors.

REFERENCES

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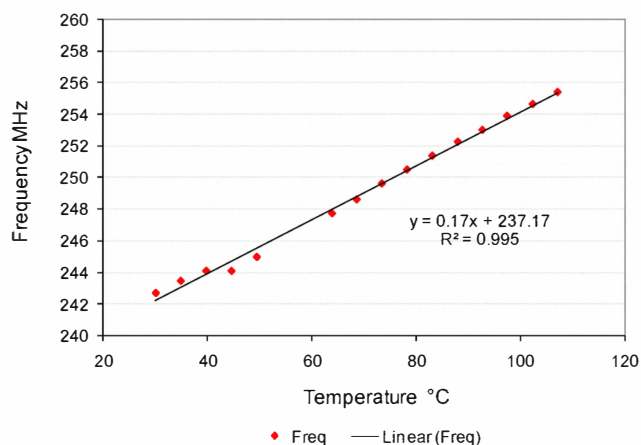


Fig. 1. Measured YZ-LiNbO₃ sensor response with TCF +680ppm/°C.

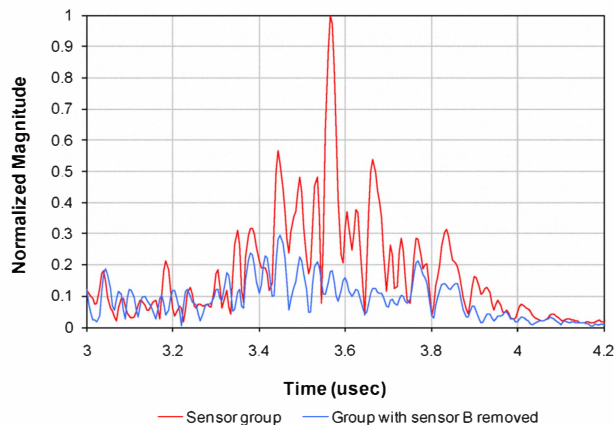


Figure 7. Wireless code recognition of sensors with four codes (A, B, C, and D) received with a correlator of code B. Note low signal level when the sensor with code B is removed from the measurement FOV.