Operational Description
(Wireless Temperature SAW Sensor)

SAW-based temperature sensing involves electrically inducing an acoustic wave into a piezoelectric material and then reconverting the energy of the wave (influenced by the temperature to which the sensing element is exposed) back into an electrical signal for temperature measurement. One significant advantage of SAW devices is their passive operation, which makes them very amenable to operation in harsh environments via wireless interrogation. Passive, wireless, SAW-based sensing systems have been described in many publications and some systems are now being offered. Some of the available systems utilize SAW resonators and some are SAW delay line based. The interrogation techniques sometimes can include coding schemes Possibly the simplest and lowest cost techniques use uncoded resonators at multiple frequencies. This limits the number of unique identifiers available, but this can prove sufficient for certain applications, a few of which are discussed in this paper. With any wireless system design, the ambient RF noise environment must be understood and addressed. Each application area presents challenges requiring engineering support for mounting structures and methods, packaging, antenna design, etc., along with local regulations (e.g. FCC, CE, or UL) regarding emissions and safety requirements in hazardous environments. In the systems described herein, enclosures surrounding the SAW sensors may be well-shielded, allowing resonator frequencies that are outside of regulated frequency bands. The SenGenuity system operates from approximately 428 MHz to 439 MHz.

In these types of applications, SAW-based passive wireless temperature sensing technology offers distinct advantages over these traditional measurement methods, including

- Passive operation, since SAW-based temperature sensors require no batteries or external power-supply. The resulting advantages over actively powered sensing solutions include:
    - Low environmental foot print as passive SAW temperature sensors avoid the adverse environmental impact of batteries.
    - Logistical advantage: The burden of regularly needing to monitor remaining battery life and replace them is eliminated.
- Electrically non-invasive solution: by not requiring wires to power/read sensors, a SAW-based temperature measurement solution can provide an electrically non-invasive solution for high power equipment such as switchgear and other Smart Grid applications.
- Wireless interrogation: SAW-based temperature sensors can be read wirelessly. This makes them well suited for rotating applications and for those applications where sensors are placed in difficult to reach or isolated locations.

The SenGenuity wireless SAW resonator (SAWR) based temperature sensing solution consists of a reader (RF Transceiver) RF or capacitively linked to one or more SAWR sensing elements as depicted in Figure 1. The system operates in a range from 428 MHz to 439 MHz.

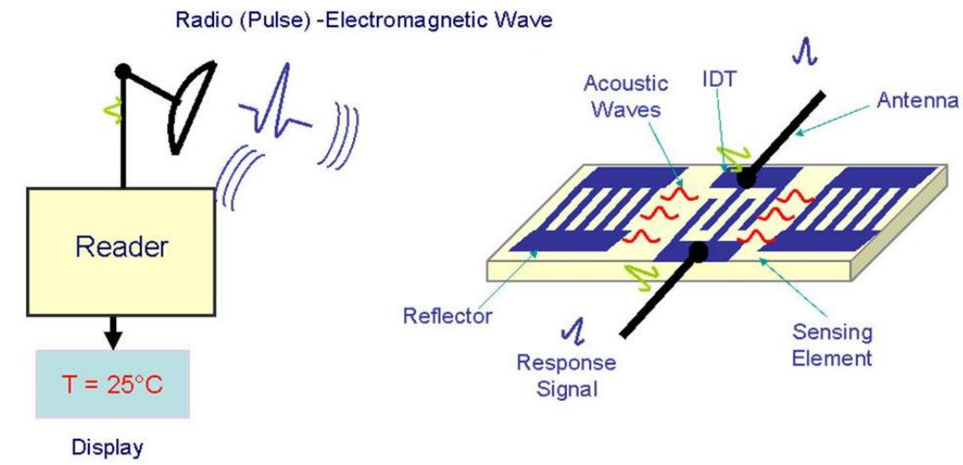

Figure 1: Wireless SAW Temperature Sensing System

Wireless sensors based on changes in resonant frequency require an appropriate reader. TempTrackr reader is base on "time domain" approach which is typically employs double heterodyne down-conversion with in-phase and quadrature sample streams at base-band. Direct down-conversion and single heterodyne conversion are possible although the susceptibility to possible out-of-band spurious signals is worse. Discrete Fourier Transform (DFT) analysis of the in-phase and quadrature samples to obtain power spectral density (PSD) and curve fit interpolation of the PSD values are employed. While these extra steps incur additional electronics complexity and computational burden, they overcome the limitations of the purely "frequency domain" method. The spacing of the interrogation frequencies is primarily limited by the bandwidth of the resonator response of the sensor and the bandwidth of the pulse's power spectral density. Saturation of the receiver is desired in the time domain samples since frequency information is not lost through saturation. The effects of saturation in frequency domain and time domain readers is analogous to the same effect in amplitude modulated (AM) versus frequency modulated (FM) radio receivers.

In the time domain, saturation tends to make the ring-down of the resonator appear longer and more uniform, resulting in better apparent accuracy, as seen in Figure 3. The degree of saturation should still be somewhat limited to prevent deterioration of the spurious signal rejection ratio.

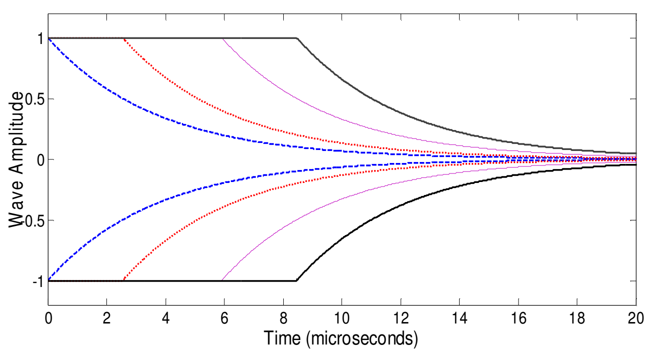

Figure 3. The decay envelope is shown for a resonator with a Q of 10,000. The blue lines indicate the received signal with no saturation. Red, purple and black indicate 2x, 5x, and 10x amplitude saturation resulting in 2.5, 6, and 8.5 µs of apparent increase in the decay time of the digitized waveform.

The Q of the SAW resonator is a critical parameter, both as the unloaded Q and as the loaded Q determined by the radiation resistance and loss resistances of the antenna. Figure 4 illustrates that the resonator, with an unloaded Q of nearly 12,000, requires a loaded Q of at least 6,000 for high received signal strengths. A low-Q resonator of similar design is also shown with an unloaded Q of approximately 7,500. The diminished pulse width is seen to reduce the received power by 3 dB. These values of Q are readily achievable with SAW resonators.

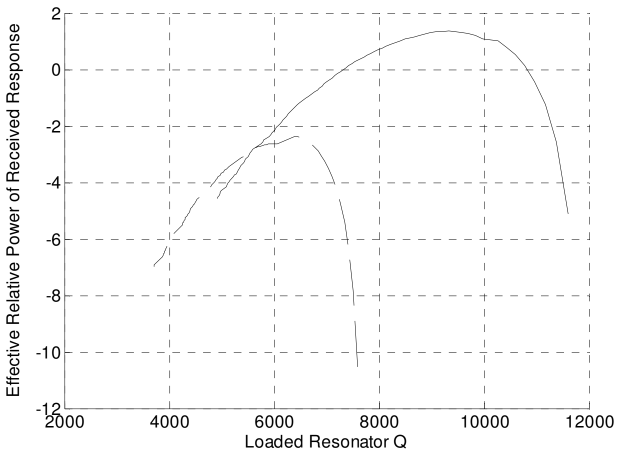

Figure 4. A SAW response with high Q (TFSS432, solid) is analyzed assuming a 1μs switching time between interrogation pulse and receiving and a 22 μs receive gate time. The roll-off at very high loaded Q's result because the wave is not sufficiently reradiated by the antenna. The roll-off at low

Figure 5. Interrogation unit (reader) and three typical SAW temperature sensor modules. The sensor elements are 3.8mm x 3.8mm ceramic-packaged resonators embedded in the PCB package. The coil antenna shown has been designed for operation in the vicinity of 433 MHz with a desirable radiation pattern.

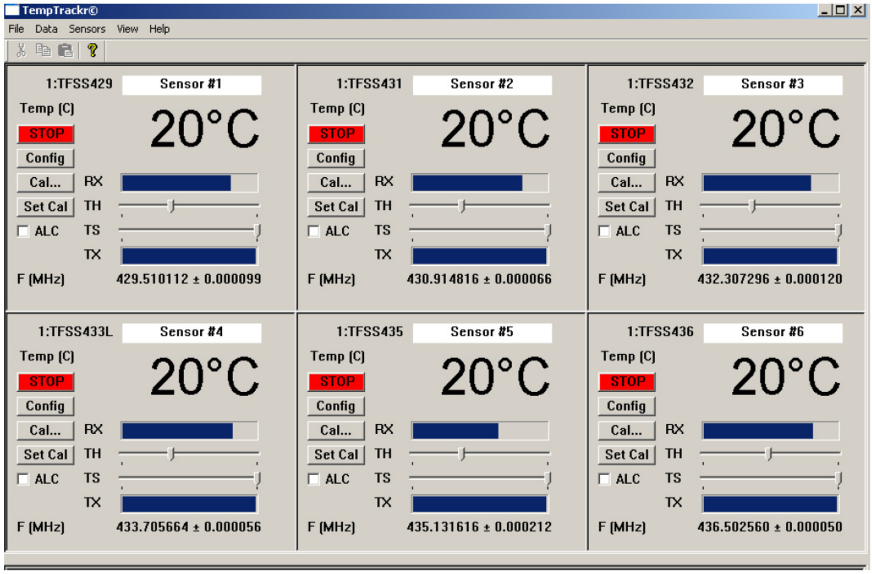

Figure6. In standalone applications, the temperatures can be displayed as shown on this PC screen image. Typical installations embed the reader electronics into the overall system monitoring electronics.