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Piezoelectric radiofrequency transducers as passive buried sensors

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Ground Penetrating Radar (GPR) is a classical tool for characterizing sub-surface electromagnetic impedance interfaces, either due to permittivity or conductivity changes [1]. The electromagnetic pulses generated to probe such passive interfaces are also usable to power cooperative targets, i.e. sensors buried by the user to monitor the evolution of quantities such as pressure, stress or temperature [2].

While wireless, battery-less sensors provide useful informations for buried sensor applications (no battery leak with aging, power loss, communication wire damage), classical silicon-based radio-frequency identification systems (RFID) are hardly usable with standard GPR systems due to the low power of each radiofrequency pulse, insufficient to reach the threshold voltage of the rectifier diode used to power an electronic circuit, and incompatibility of the communication strategy with the receiver stage of a GPR. An alternative strategy for manufacturing battery-less, wireless sensors is based on the use of a piezoelectric substrate to convert the incoming electromagnetic pulse in a mechanical wave (inverse piezoelectric effect), and converting back the mechanical wave in an electromagnetic signal (direct piezoelectric effect). The mechanical wave acts as the probe signal to monitor properties of the piezoelectric transducer, with a velocity dependence on a given property associated with the sensor design [3].

The frequency range and working principle of GPR happens to be very close to the well-known dedicated interrogation unit designed to interrogate such piezoelectric sensors [4]. In one classical configuration – the so called delay line – the incoming electromagnetic pulse is converted to a mechanical pulse propagating on the piezoelectric substrate until it reaches a Bragg mirror: the reflected wave is delayed by a duration function of the physical property under investigation. Typical delays are in the microsecond range, consistent with the typical GPR sampling duration. Furthermore, the piezoelectric electromagnetic to mechanical conversion being a linear process, no threshold power is needed to power the sensor: the interrogation range is only limited by the receiver noise level, below which the returned pulse is no longer detected.

We demonstrate the use of piezoelectric delay lines as cooperative targets for 100 and 200 MHz commercial GPR systems, with the measurement of the temperature of a sensor buried 2 to 5 meters deep in ice. The signal to noise ratio of the recorded signal hints at an interrogation range of 40 m. No modification of the GPR hardware is needed: the sensor information extraction is performed solely on the digital signal processing step. The temperature resolution is in the kelvin range, depending on the signal to noise ratio. Beyond the use of these sensors for temperature measurements, pressure and stress dependent transducers have already been demonstrated in the literature, and are applicable to the demonstrated interrogation strategy.

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