A Review of SAW Sensor Technology

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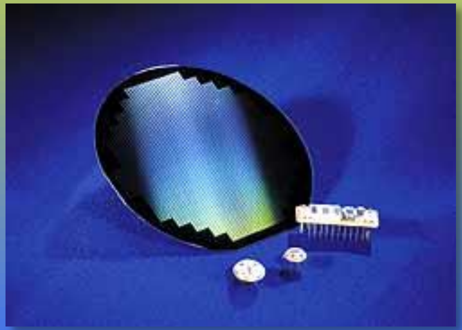
CAAT

Why SAW Passive Sensors?

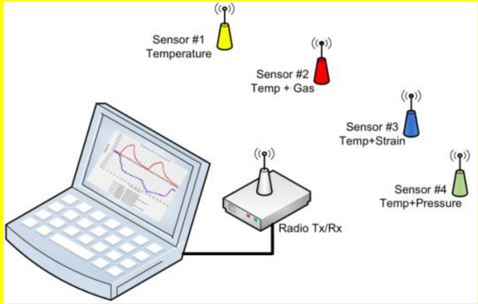
- A game-changing approach
- Wireless, “infinite-life”, and multi-coded
- Single communication platform for diverse sensor embodiments
- Broad frequency range of operation and range (.25-2.5 GHz)
- Many different embodiments
- Multiple sensor operations on a single chip
  - Physical
  - Gas
  - Liquid
  - other

Highlights

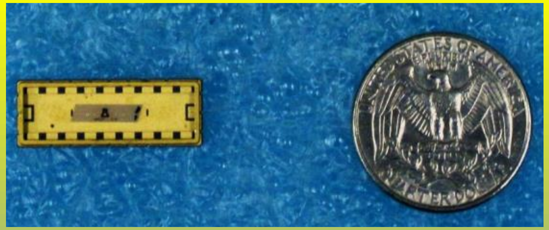
- Solid state
- Piezoelectric
- Freq: 0.2 – 2.4 GHz
- Temp: 0.1 – >1000K
- Rad Hard
- SS-RFID
- Current Sensors: temp, gas, strain, liquid, magnetic



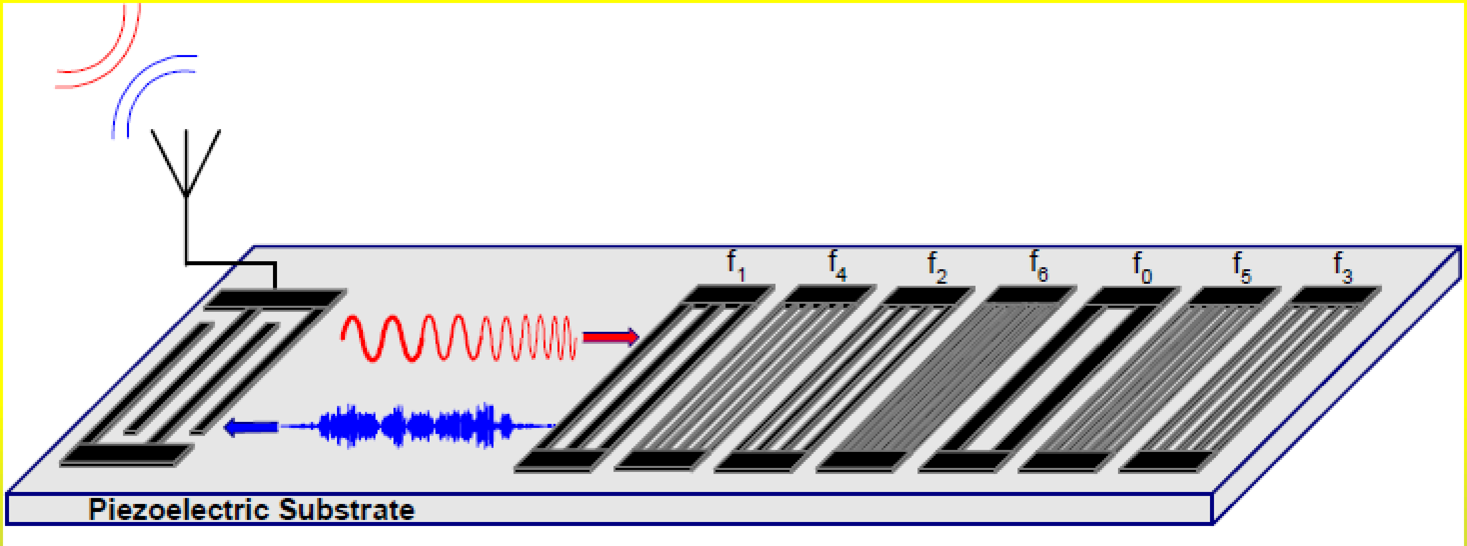
Wireless SAW Sensor Applications



- Temperature –Braking, Motors, High Voltage Arrestors
- Relative Humidity
- Gas H2, Co2, Isopropyl Alcohol
- Stress
- ID-Tag for Toll System (Norway)
- ID system for Munich Subway (Siemens)
- Accelerometers
- Pressure - tire pressure (Siemens)
- Fluids (biomedical applications)
- Magnetic (wireless hall sensor - Reed switch)



Single IDT SAW Sensor



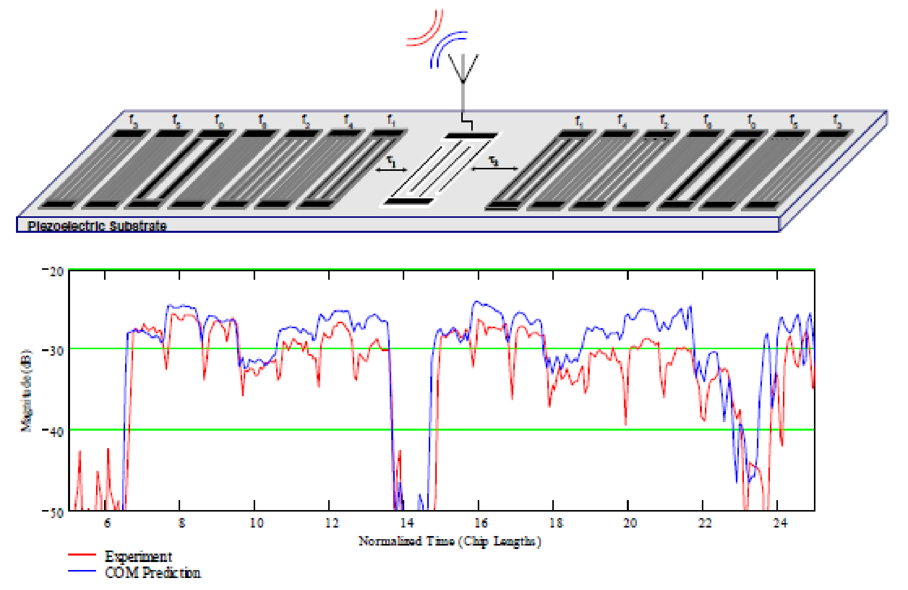
Drawing of a single IDT and a seven chip OFC SAW device grating frequencies match chip center frequencies (RED – Interrogation signal, BLUE- sensor signal)

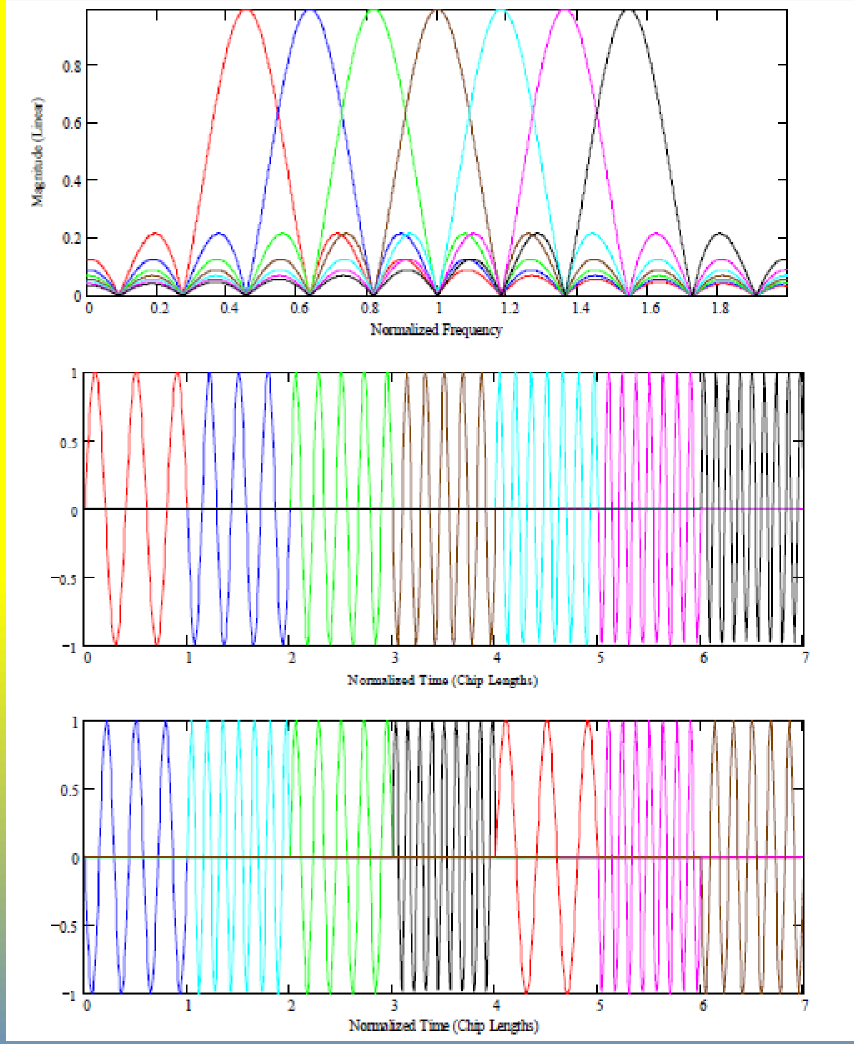
Common SAW Device Materials

Material	Vel(m/s)	$\Delta v/v$ (%)	TCD (ppm/˚C)
Lithium Niobate $LiNbO_3$,Y-Z	3488	2.4	94
$LiNbO_3$, 128˚Y-X	3979	2.7	75
SiO_2Quartz ST-X (42.75˚Y-X)	3159	0.06	0(32)
Lithium Tantalate $LiTaO_3$, X-112˚Y	3300	0.35	18
Lithium Tetraborate $Li_2B_4O_7$, 45˚X-Z	3350	0.45	0(270)
$LiNbO_3$,64˚Y-X	4742	5.5	80
$LiNbO_3$,41˚Y-X	4792	8.5	80
$LiNbO_3$,36˚Y-X	4212	2.4	32
Quartz, 36˚Y-X +90˚	5100	–	0(6)

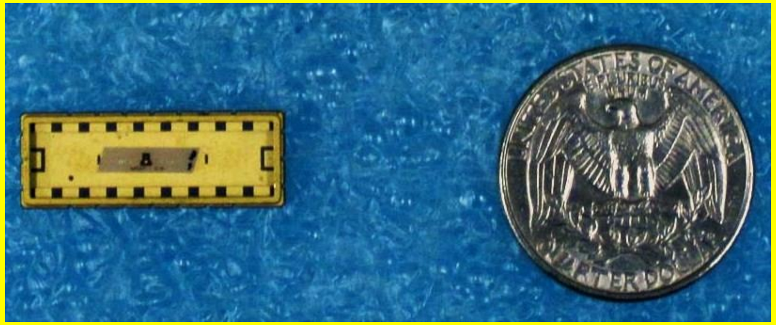
Coupling Constant $K^2 = 2 \cdot \Delta v/v$

Example of Seven Chip Orthogonal Frequencies

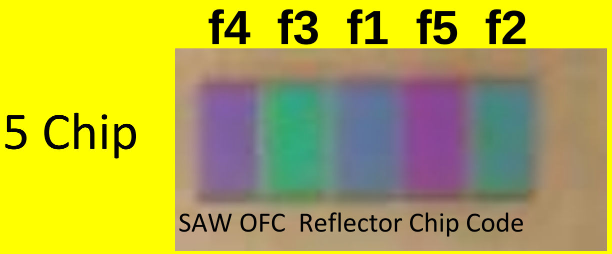


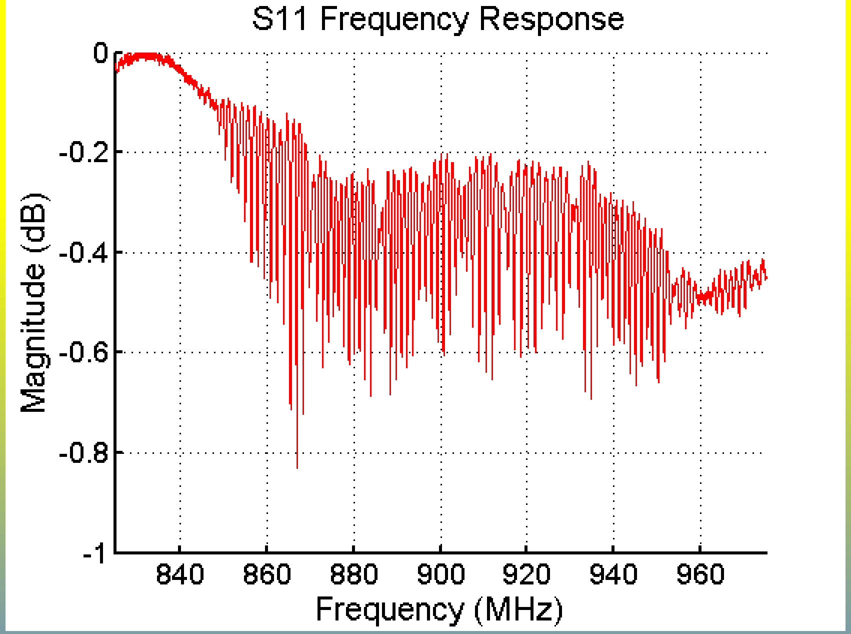


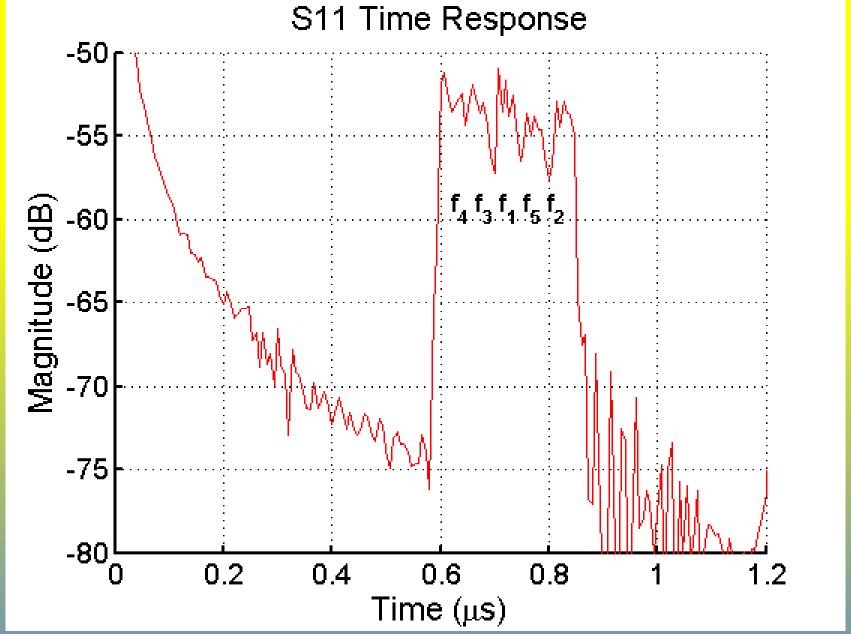
Example 915 MHz SAW OFC Sensor



Light Micrograph





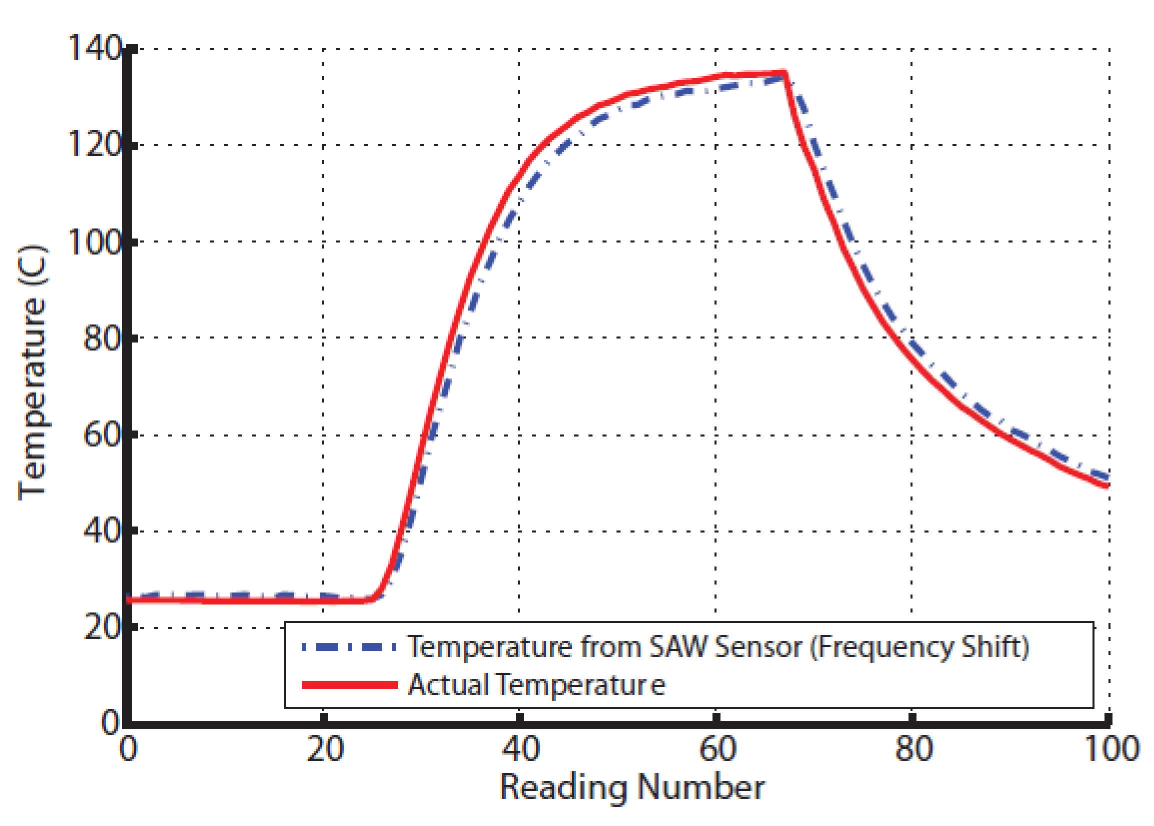


Integrated Wireless SAW Temperature Sensors and Wideband Antenna

With single IDT and reflector (smaller size, broader bandwidth)

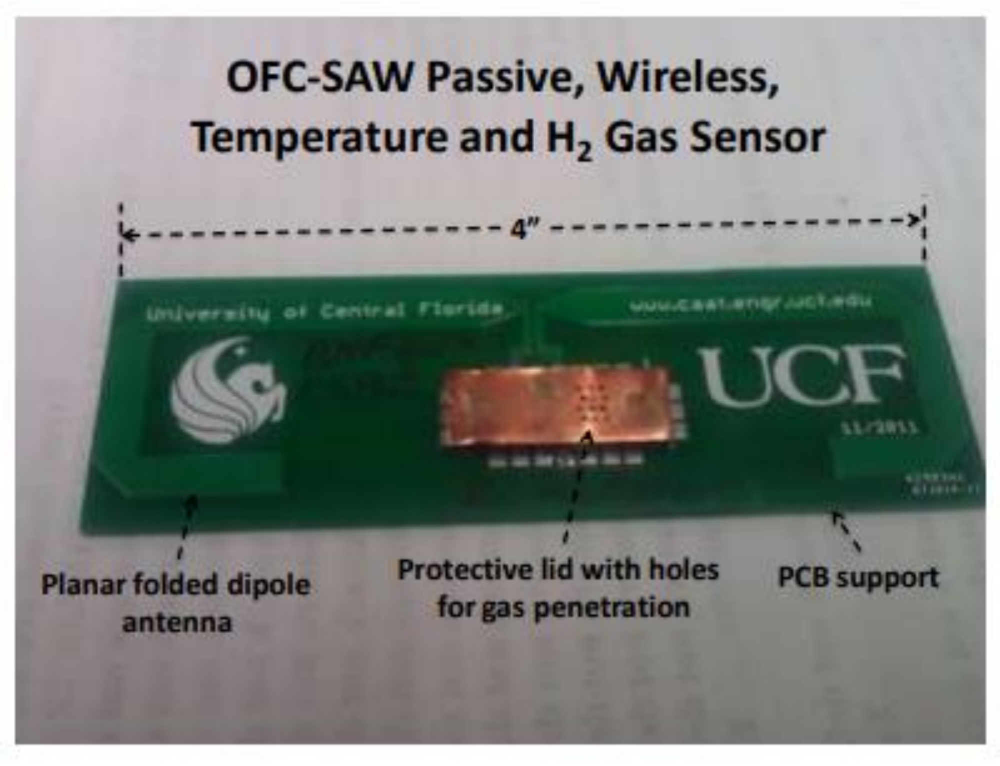
Center Frequency 915 MHz

Experimental Temperature Results



Wireless SAW temperature Sensor at 250 MHz using OFC compared to a thermocouple.

H2 Wireless SAW Gas Sensor



Integrated Wireless SAW Sensor
and Wideband Antenna

Gas flow test fixture applying H2 gas

H2 Wireless SAW Gas Sensor

Experimental Results

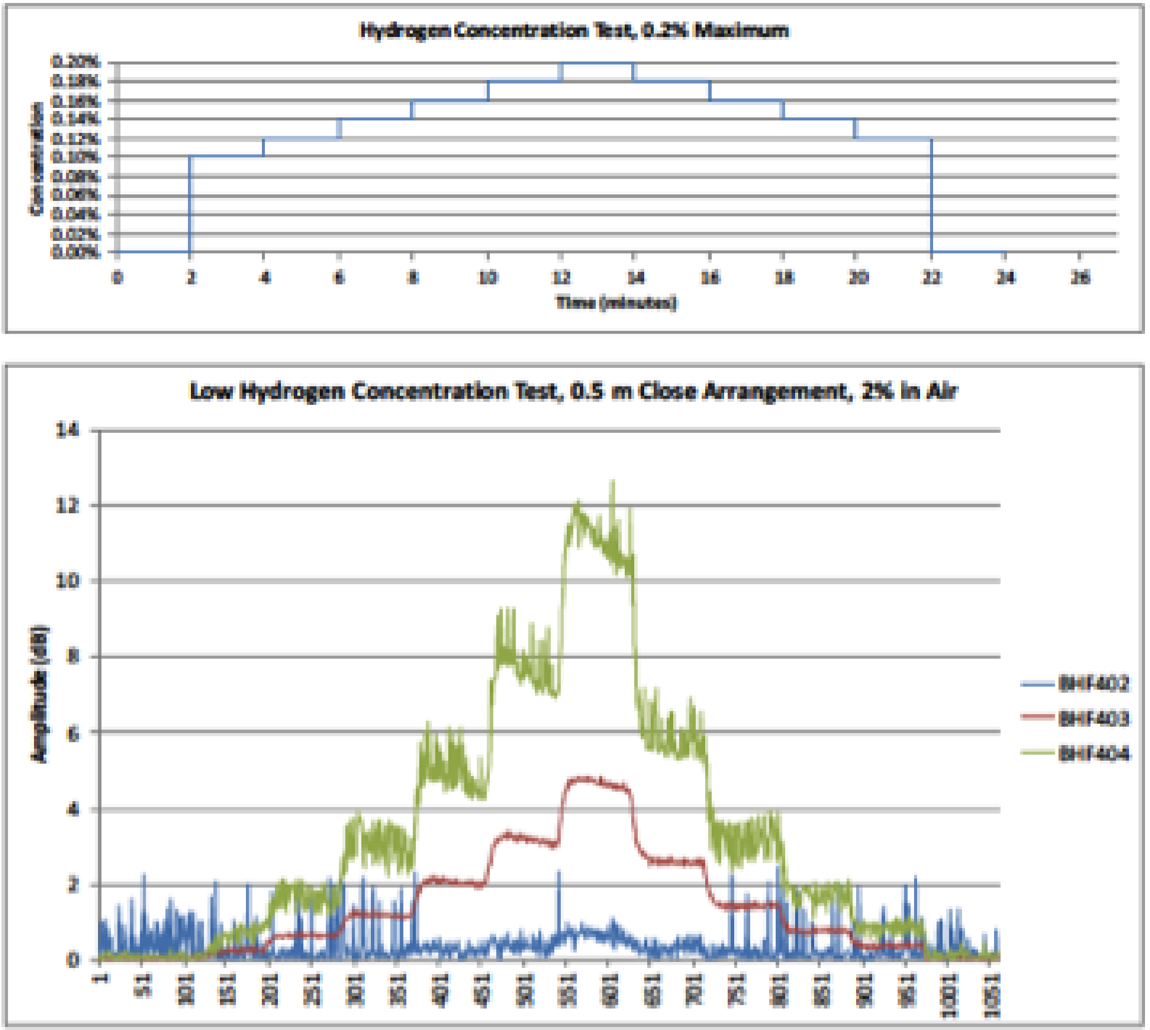
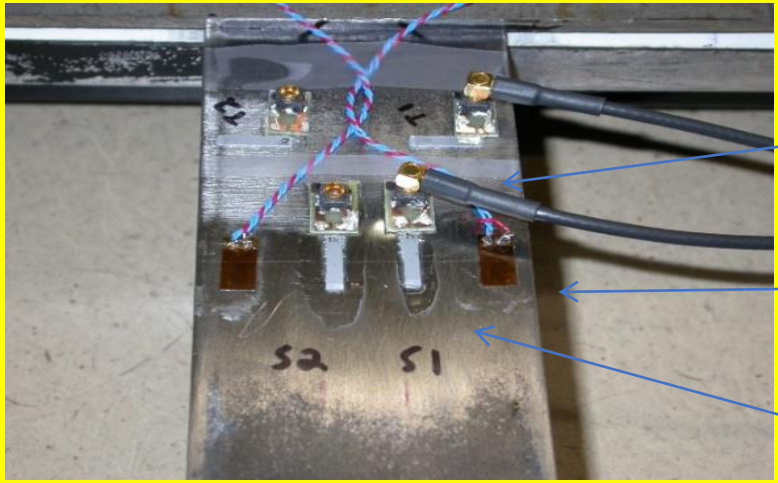


Figure 45. Low hydrogen concentration test, input profile and results

- < 50 ppm
- RT reversible
- Response <1s

Wireless SAW H2 sensor step response to a step concentration of applied H2 gas

SAW Strain Gauge Experimental Setup



SAW Temperature

Omega

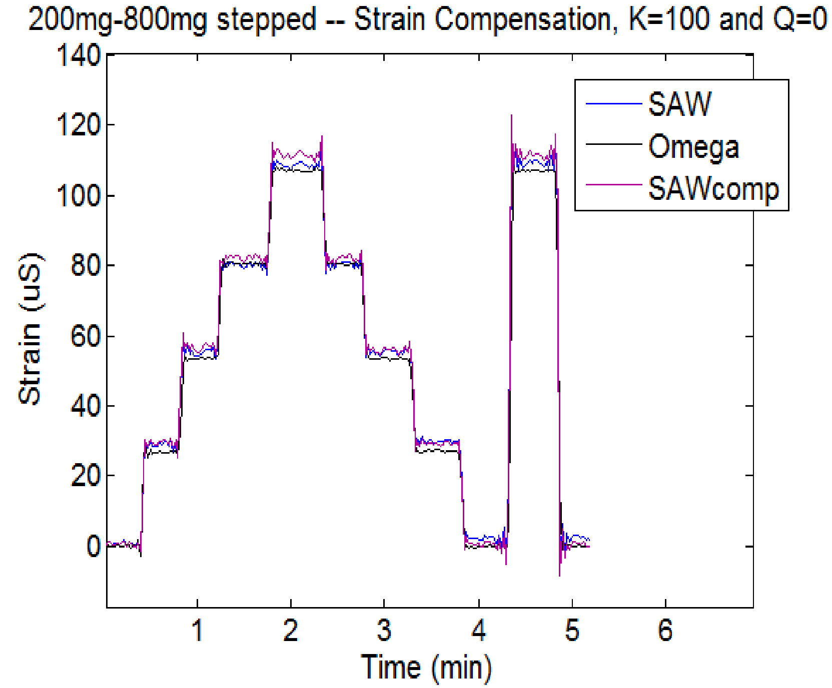
SAW Strain

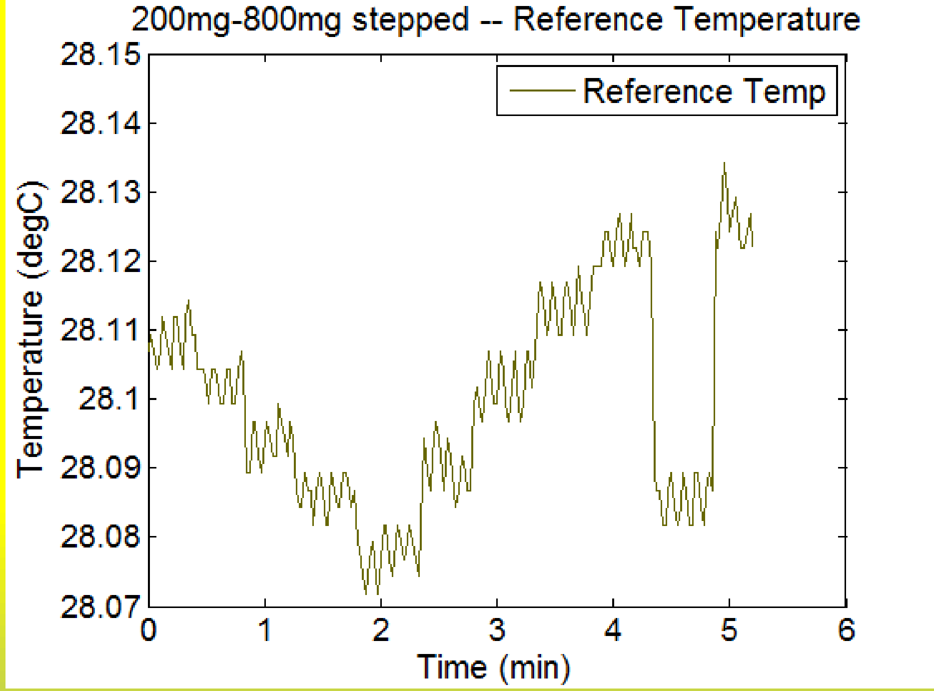
Weight

- Strain and Temperature sensors mounted a cold iron cantilever bar.
- Temperature sensor mounter perpendicular to the strain sensor to minimize strain. coupling into the temperature sensor.
- Two sets of sensors for redundancy.
- Omega strain sensors also mounted on cold iron bar for reference measurements.

StrainComp = StrainMeasured - (referenceTemp – referenceTemp_initial_value)*K + Q

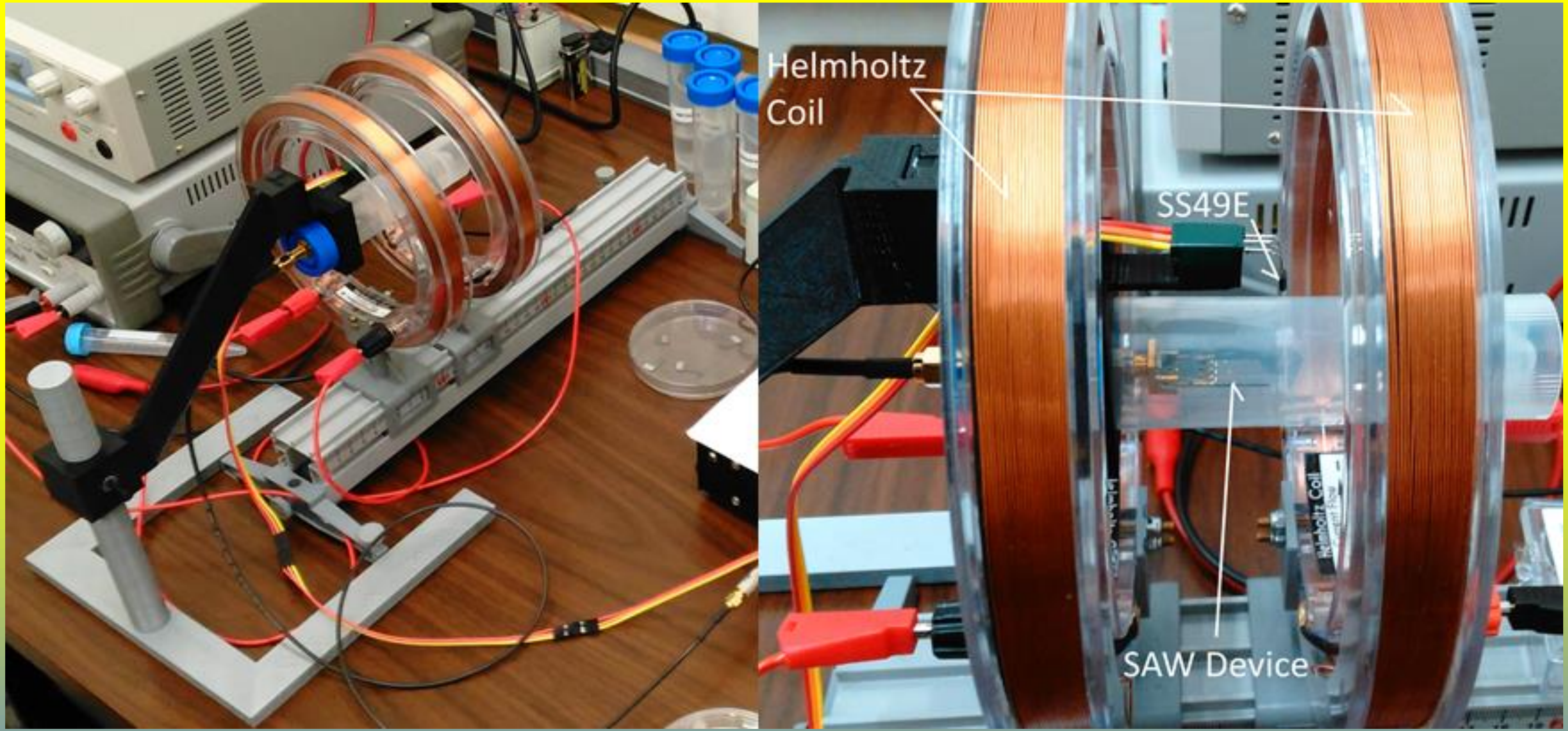
SAW Stepped Strain Experimental Data





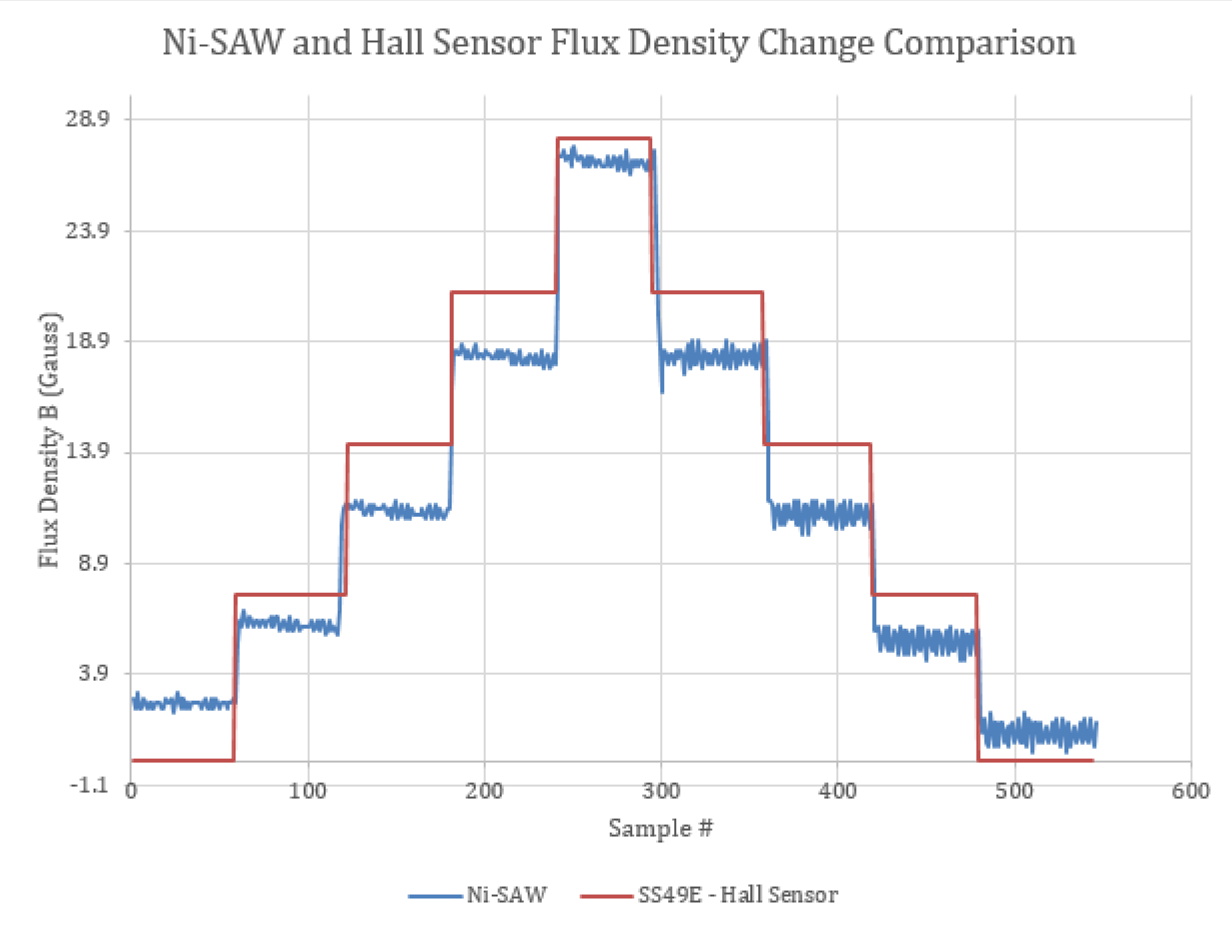
Temperature data showing cross coupling of
strain into the SAW temperature sensor

SAW Magnetic Experimental Setup



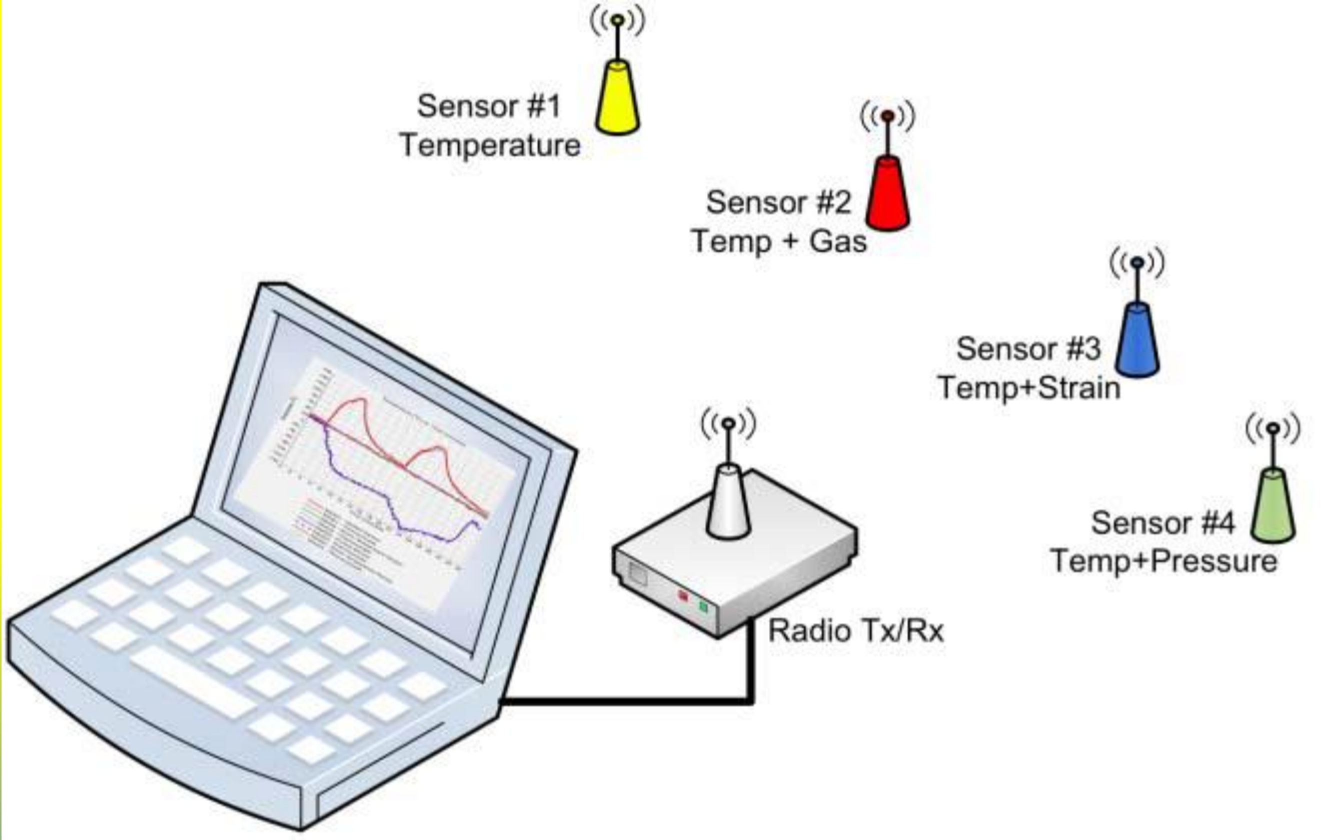
Helmholtz coil used to apply a magnetic B field
to the Wireless Saw sensor
(B field measured with a standard Hall sensor)

SAW Stepped Magnetic (B) Field Experimental Data



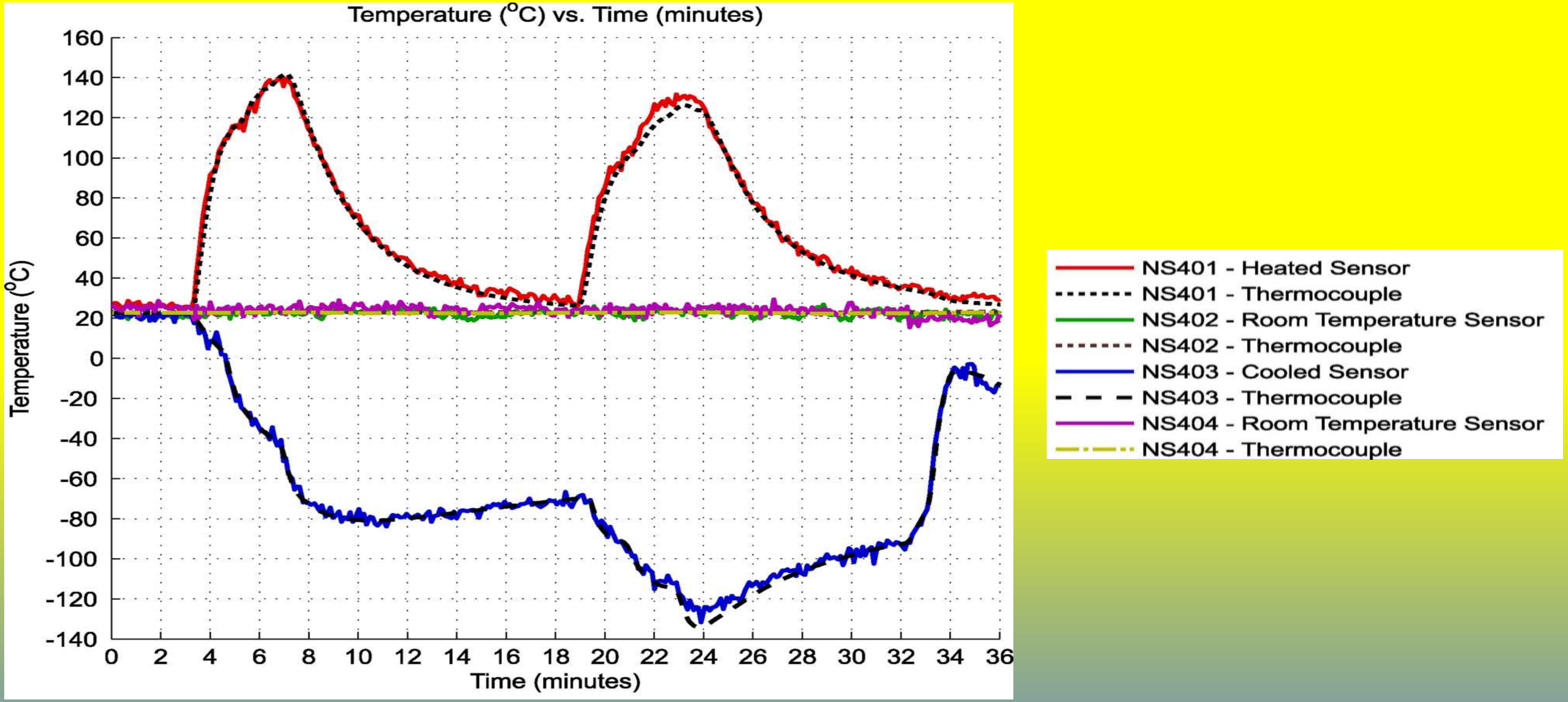
Wireless SAW magnetic sensor step response to a step concentration of applied magnetic (B) field.

Wireless SAW Multi-Sensor System



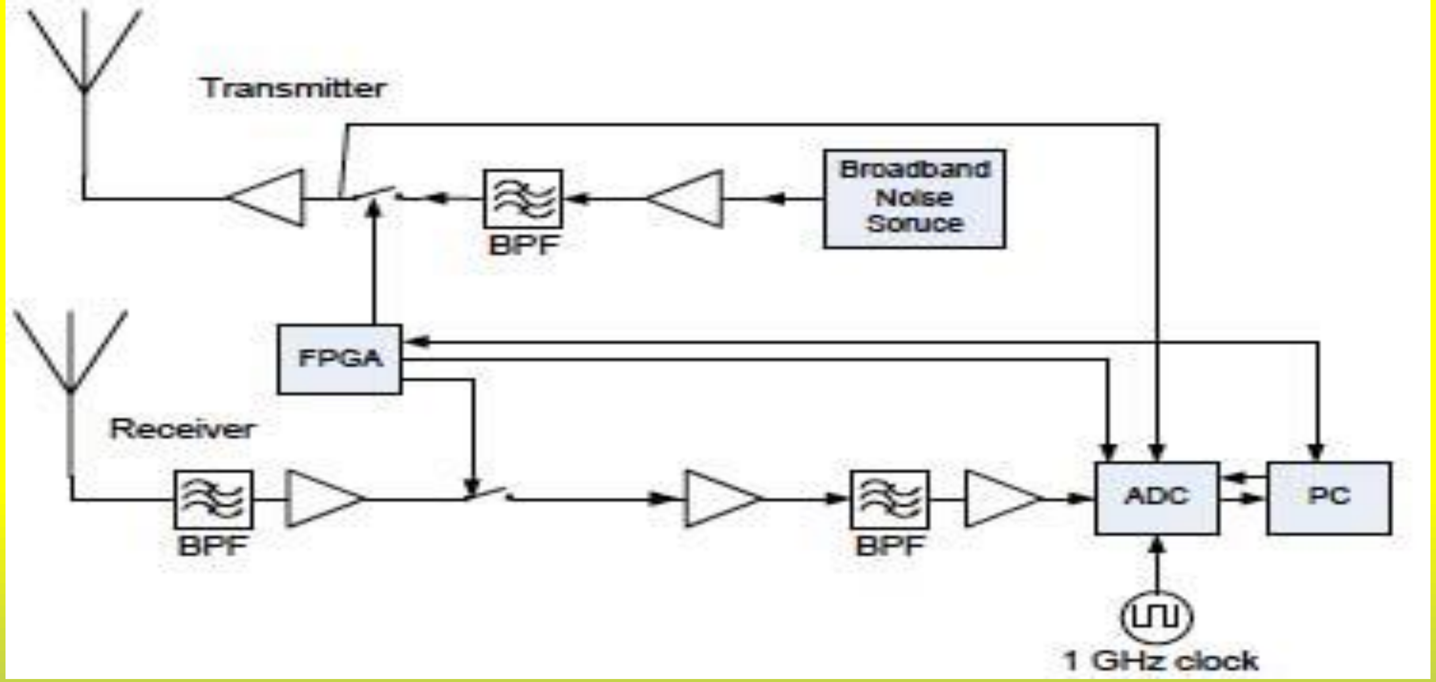
Shown are several different types of sensors, an interrogator and a computer system for post processing of the received sensor data.

Multi SAW Sensor Experimental Temperature Results



Wireless SAW temperature Sensor at 915 MHz using OFC compared to a thermocouple.

A simple transceiver block diagram



- The FPGA controls the timing of the transmit signal, the actuation of the receiver, the sampling of the transmitter signal (for reference) and the start of the A/D to acquire sensor data
- The Bandpass filters limit the bandwidth to 15MHz to meet the required maximum bandwidth (26 MHz) for the 915 MHz ISM band

SNR Analysis of The Wireless SAW Sensor System

$$SNR = \frac{[P_o \cdot G_{Sensor} \cdot G_{Tx-ant} \cdot G_{Rx-ant} \cdot N_{sum} \cdot B \cdot \tau]}{[PL \cdot kT \cdot B \cdot NF*]}$$

Typically the minimum detectable signal is set to input noise power

$NF^* = NF + \gamma$ $\quad\quad$ $P_{MDS} = NF^* \cdot kT/\tau$

$$\gamma = [N_{ext} + (N_{ADC}/G_{Rx})/[kT \cdot B]$$

Where, N_{ext} is any external noise sources

$$SNR = \frac{[P_o \cdot G_{Sensor} \cdot G_{Tx-ant} \cdot G_{Rx-ant} \cdot N_{sum}]}{[P_{MDS} \cdot PL]}$$

$$SNR = \frac{[V^2_r \cdot G_{Sensor} \cdot G_{Tx-ant} \cdot G_{Rx-ant} \cdot N_{sum}]}{[V^2_{MDS} \cdot PL]}$$

where V_r is the transmit voltage level and V_{MDS} is the voltage level detectable at the ADC

G_{Sensor} = Sensor Gain (incl. $G_{SAW} * G^2_{Sensor-Ant}$)
G_{Rx-Ant} = Gain of Receive Antenna
G_{Tx-Ant} = Gain of Transmit Antenna
G_{Rx} = Receiver Gain from Antenna Input to ADC
τ = Output signal time length
B = Bandwidth of signal at ADC
P_0 = Power to transmit antenna
ADC = Ideal Analog-to-Digital Converter Gain
MDS = Minimum Detectable Signal @ ADC
S = Signal Power Measured at ADC
N = Noise Power Measured at ADC
kT = Thermal Noise Energy
PG = Signal Processing Gain of the System (τB)
PL = Path Loss
NF = Receiver Noise Figure
Next = External Noise Source at Antenna Output
N_{ADC} = ADC Equivalent Noise
N_{sum} = Number of Synchronous Integrations at the ADC

Wireless Transceiver Development By UCF

Previous Versions

Several models were made at UCF to interrogate sensors:

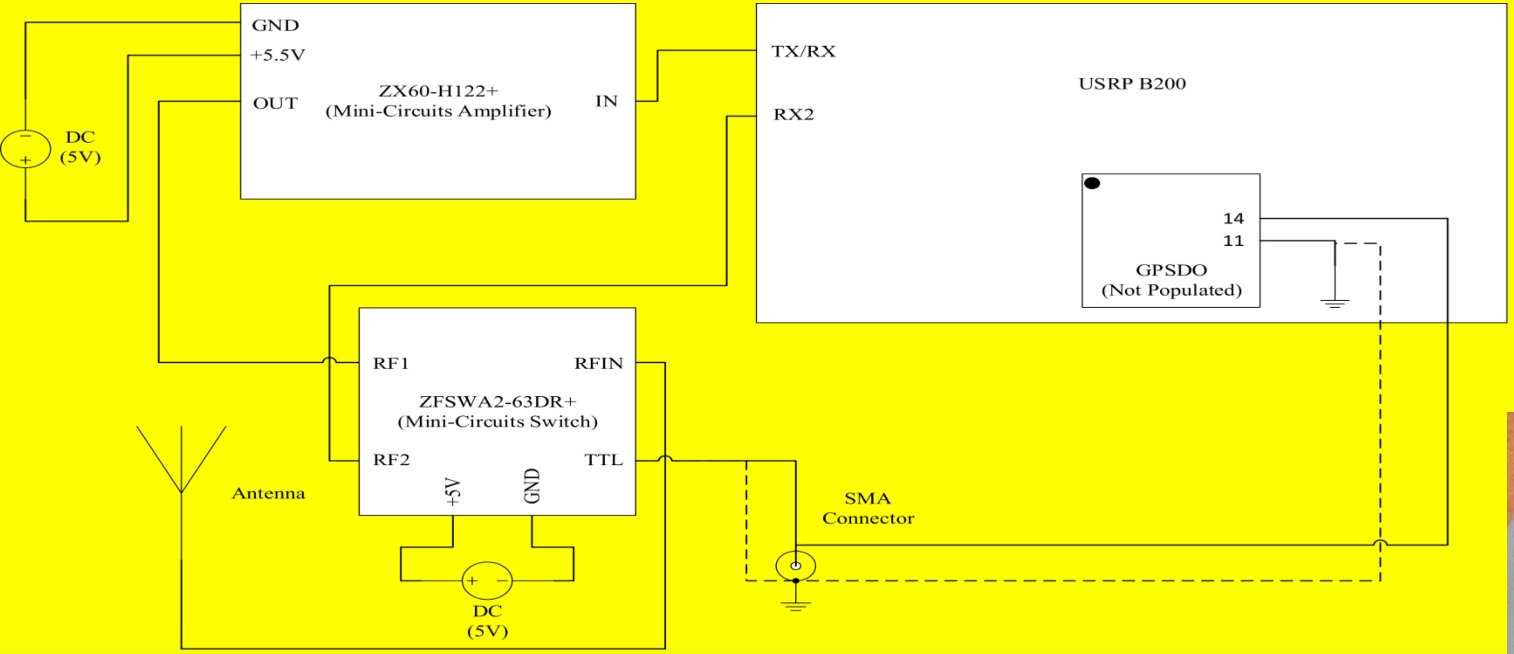
- The first version (bigger one on the left).

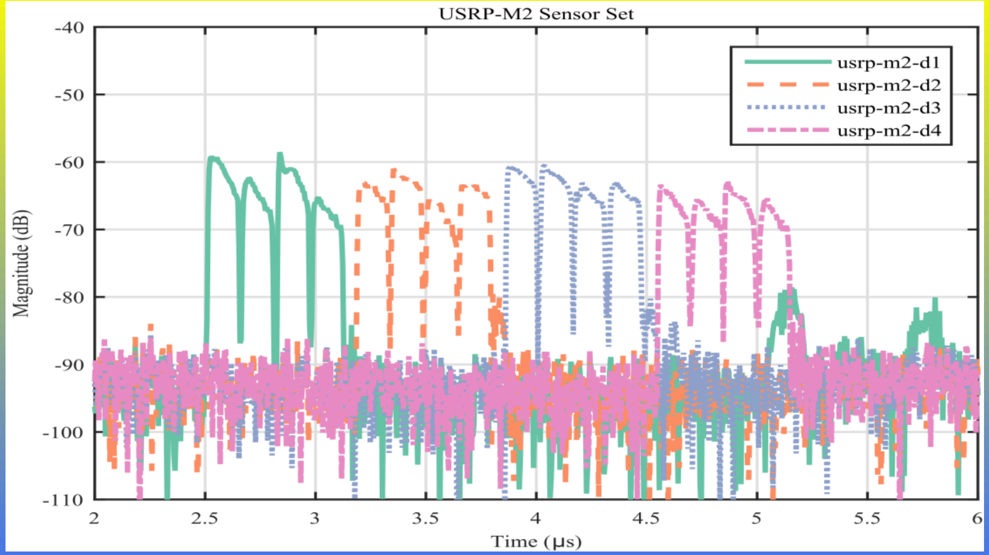
- Version II (black box to the right) uses an USRP B200 SDR system from Ettus Research Inc. with additional amplifiers and RF switches to increase the transmitter power and to improve the receiver noise figure.
  This version requires a separate host computer to run.

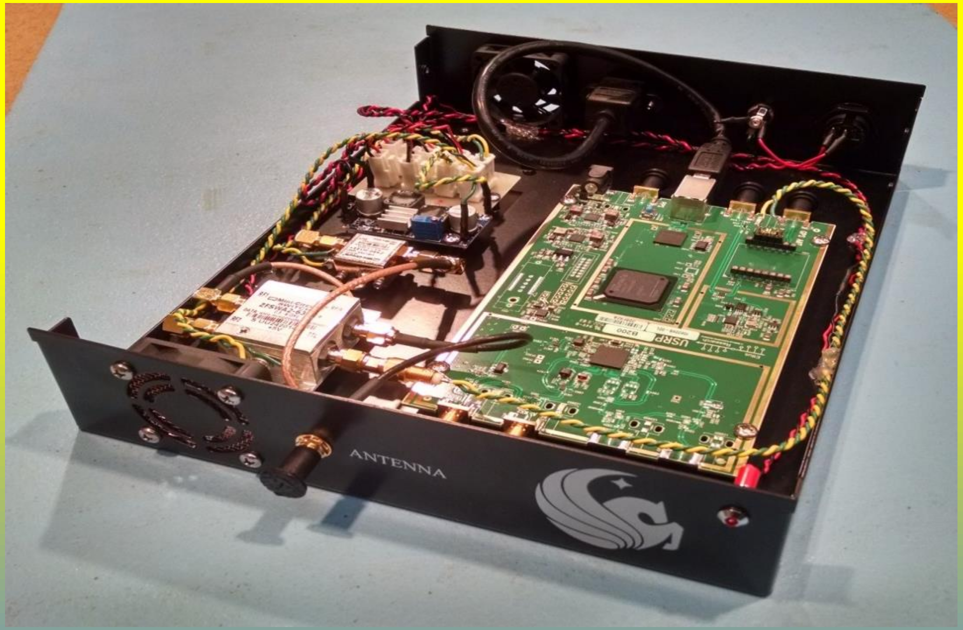
- Version III (Blue box) is a standalone interrogation system that have same capabilities as the 2016-B200-1.B, but implements a Minnowboard MAX embedded computer, eliminating the need of a separate computer. This version only requires a keyboard, mouse and a display to show the correlation system.

- Version IV (yellow box) features the same functionality as the previous version but uses an USRP B200-mini SDR system from Ettus Research Inc.

Software Design Radio (SDR) Transceiver 915 MHz

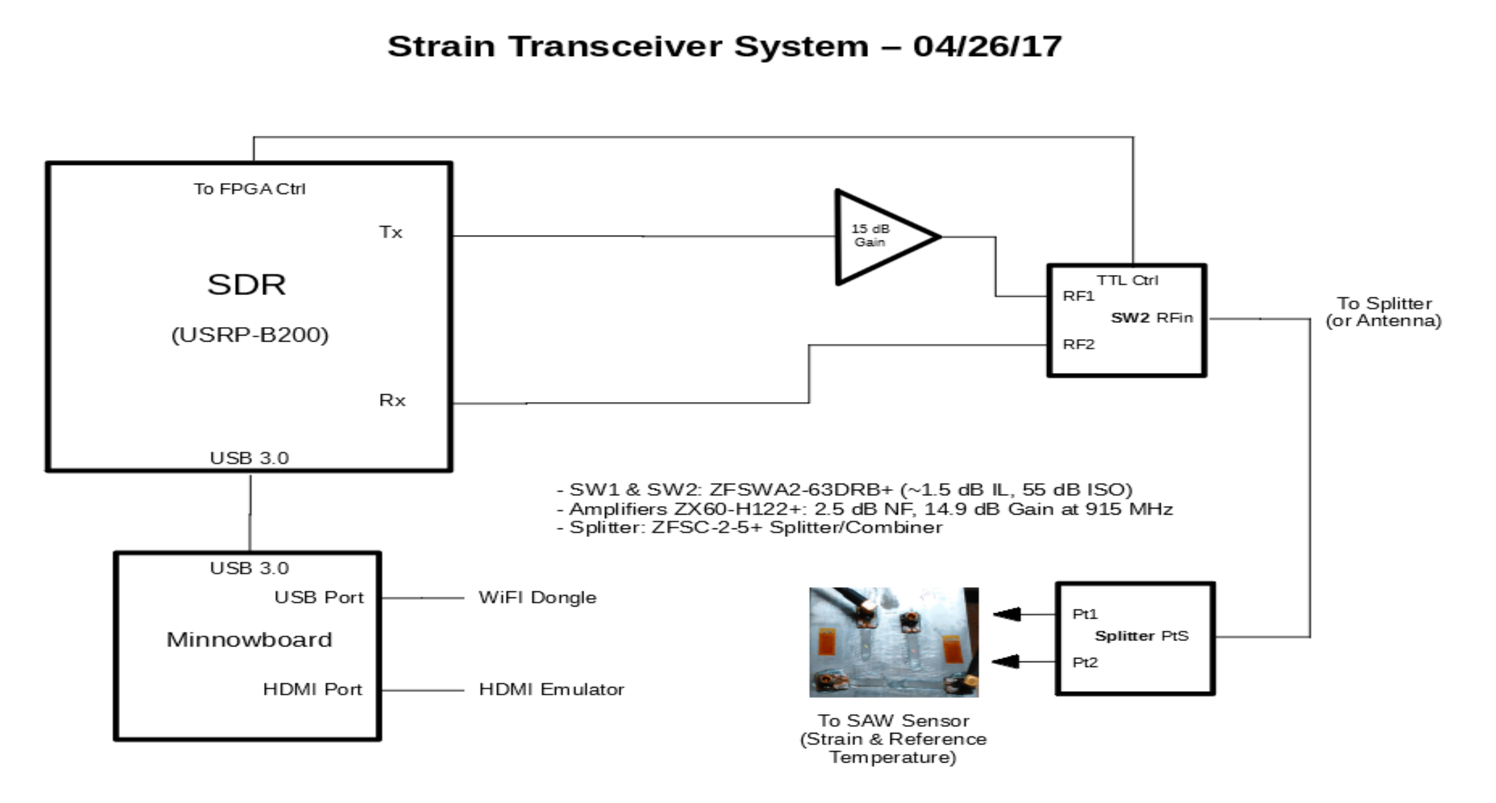






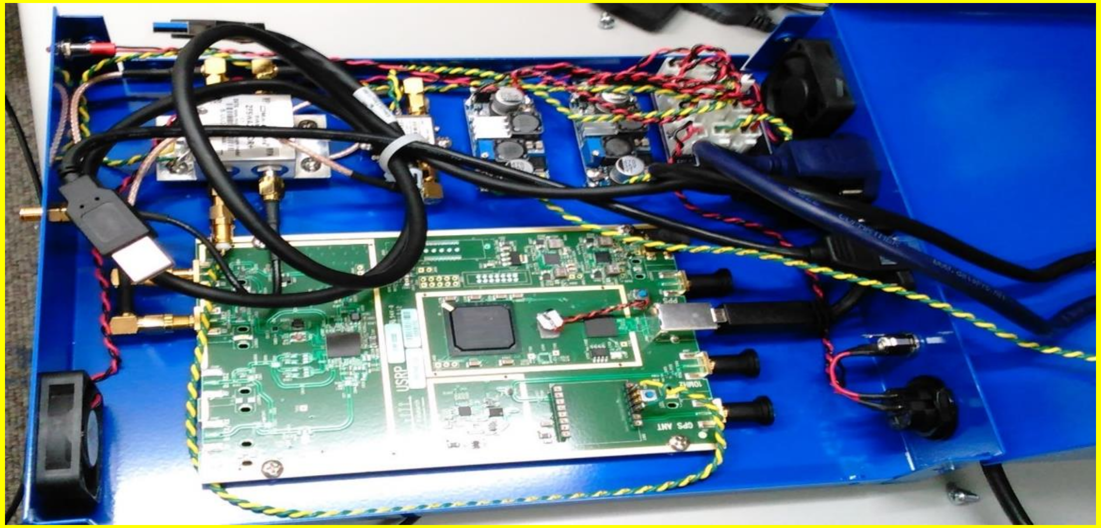
SAW TRANSCEIVER SYSTEM WITH EMBEDDED COMPUTER

Ettus Research B200 SDR
Minnowboard



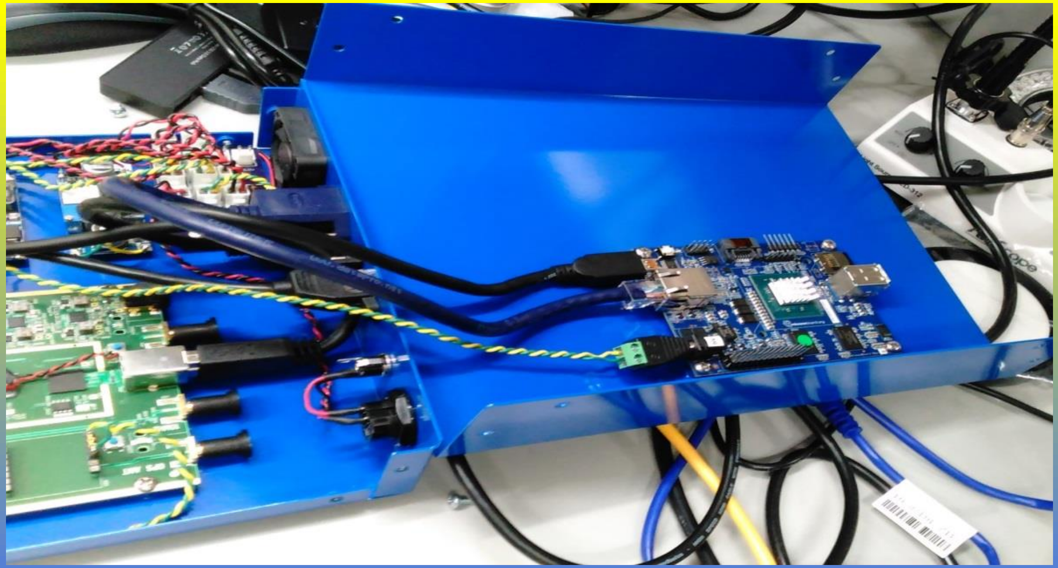
The FPGA on the SDR board controls the timing of the transmit signal, the actuation of the receiver, the sampling of the transmitter signal (for reference) and the start of the A/D to acquire sensor data.

SAW Transceiver System With Embedded Computer



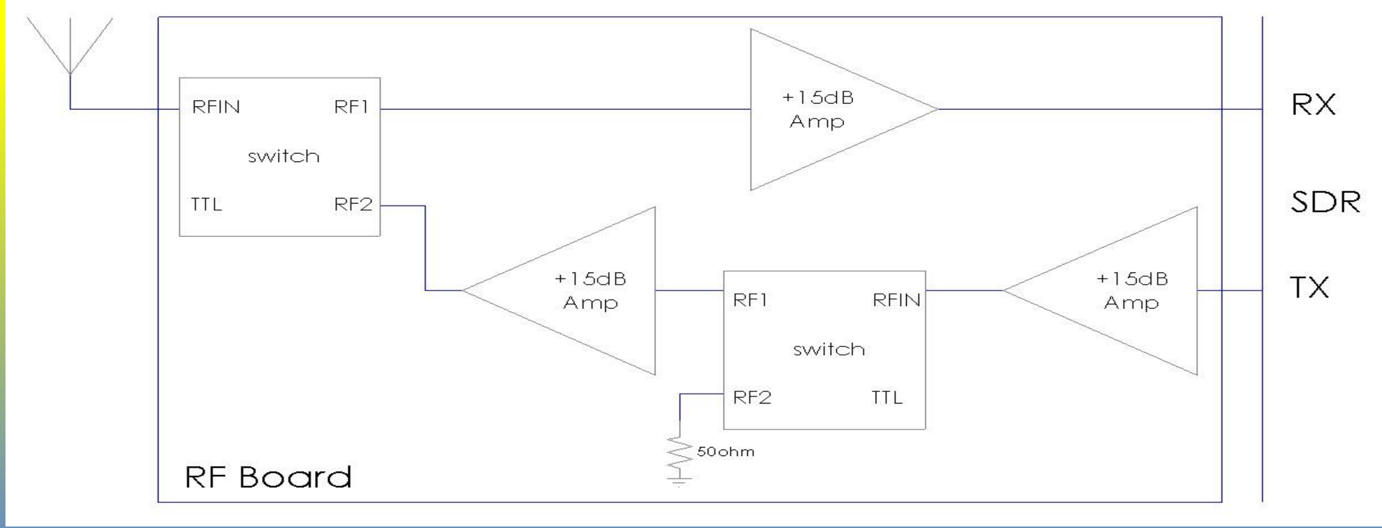
Ettus B200 SDR:
- SDR 70 MHz –6 GHz
- Full duplex operation
- 56 MHz of bandwidth
- Computer interface USB 3.0
- GNURadio and OpenBTS
- Spartan 6 XC6SLX75 FPGA
- Uses Analog Devices AD9364

Minnowboard Computer:
- CPU: Dual Core Intel® Atom™ E3826
  (2 x 1.46 GHz, 1MB cache)
- DRAM: 2GB DDR3L 1067MT/s
  Storage: 1x SATA2, 1x MicroSD
- I/O Connectors: 1x USB 2.0 host
- 1x USB 3.0 host,
- 8x buffered GPIO, I2C, SPI
- 1Gb Ethernet



Wireless Transceiver Development By UCF

The first handheld transceiver RF section:



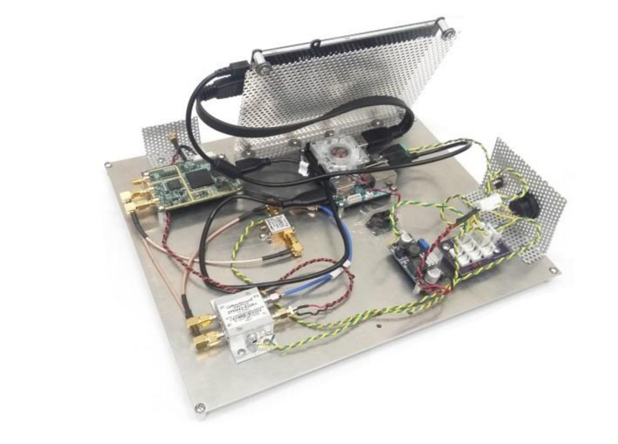
Uses a 12V power bank and a buck regulator for 5 volts

Wireless Transceiver Development By UCF

Previous Versions

The first handheld transceiver, built by UCF, has the same configuration of version III (Blue box) but uses:

- An ODROID XU4 embedded computer instead of the Minnowboard .
- A 7-inch capacitive touchscreen
- Internal rechargeable battery for power.
- This unit has a total volume of 1842cm^3

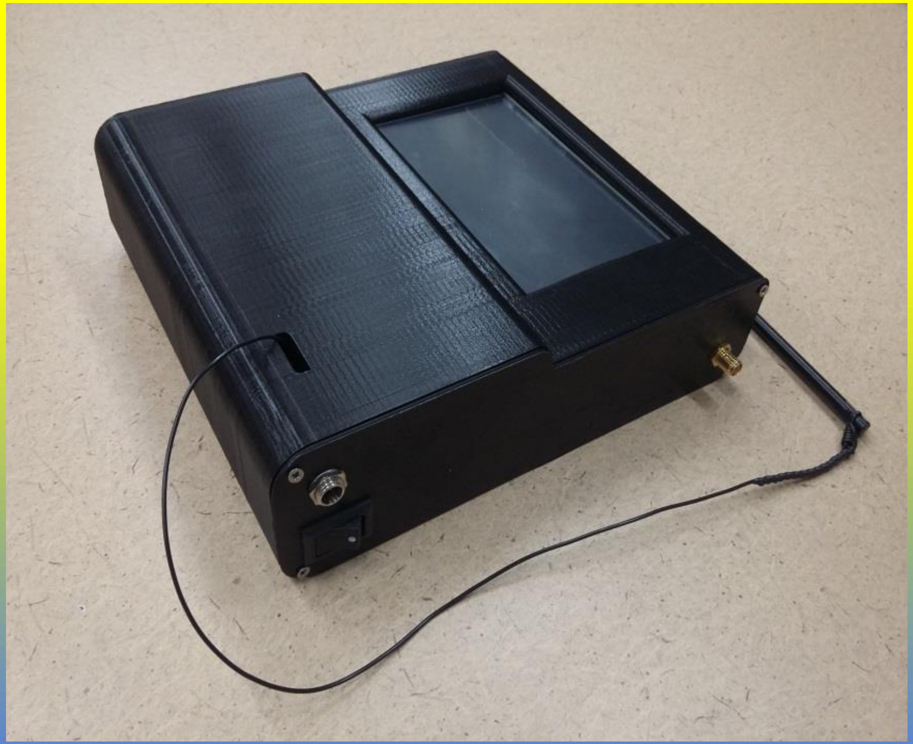


Proof-of-concept interrogator system implementing a USRP B200-mini, an embedded computer and a TFT LCD touchscreen.

Wireless Transceiver Development By UCF
Previous Versions

The RF components were arranged to minimize space utilization.

The two dominate components that occupy the majority of the volume is the battery and the LCD panel.



Wireless Transceiver Development By UCF

Previous Versions

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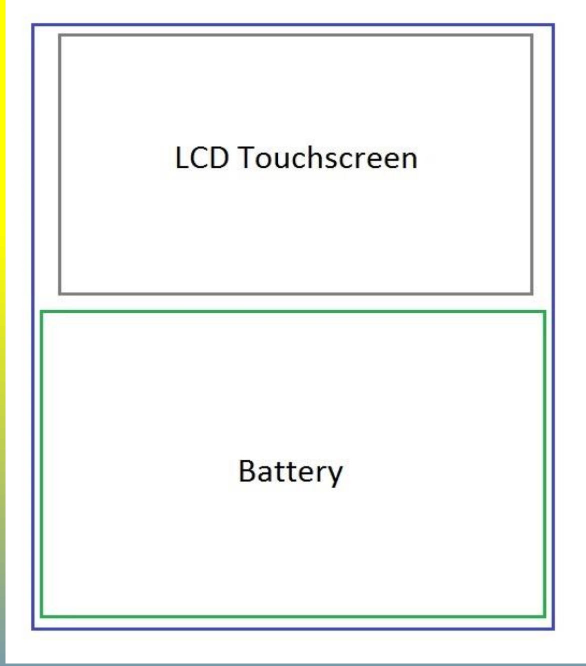
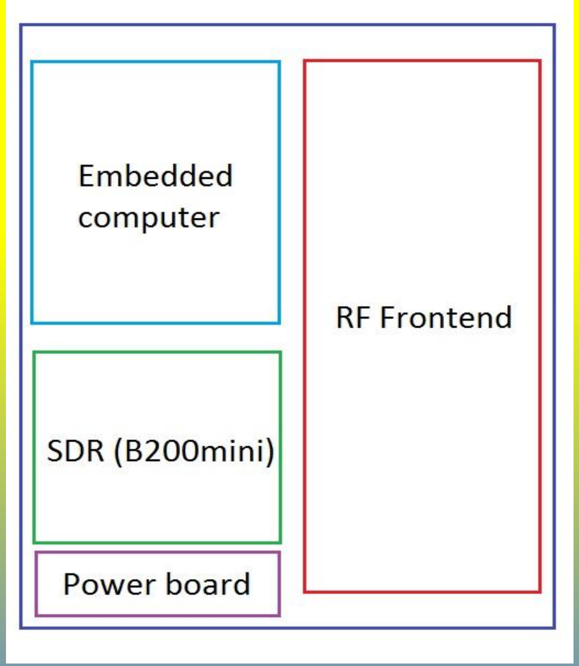




Top

Bottom

Wireless Transceiver Development By UCF

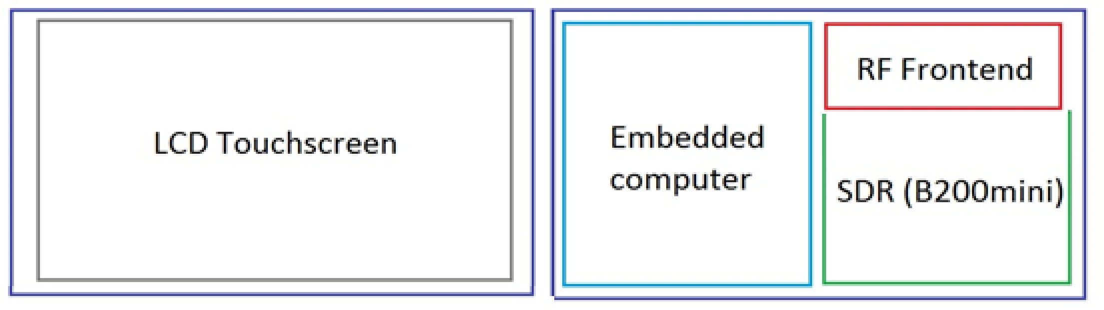
Current Version

The RF frontend was miniaturized and placed on a custom PCB further reducing the size of the overall unit.

The rechargeable battery was made external for ease of transport and replacement.

Wireless Transceiver Development By UCF
Current Version

The RF frontend was miniaturized and placed on a custom PCB



Top

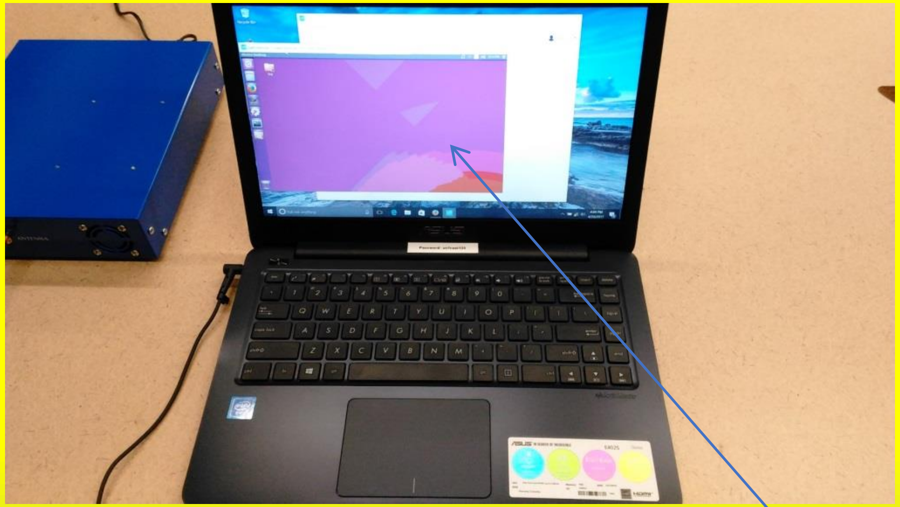
Bottom

Wireless Transceiver Development By UCF

≈60% Reduction in size from first Generation to latest.

Dual Networked SAW Strain System

Command and Control Computer



- Strain Tab
- Temperature Tab
- Debug Plots Tab
- Various User Interface Options

Control of each Transceiver individually via access to the Minnow Embedded computer.

Dual Networked SAW Strain System

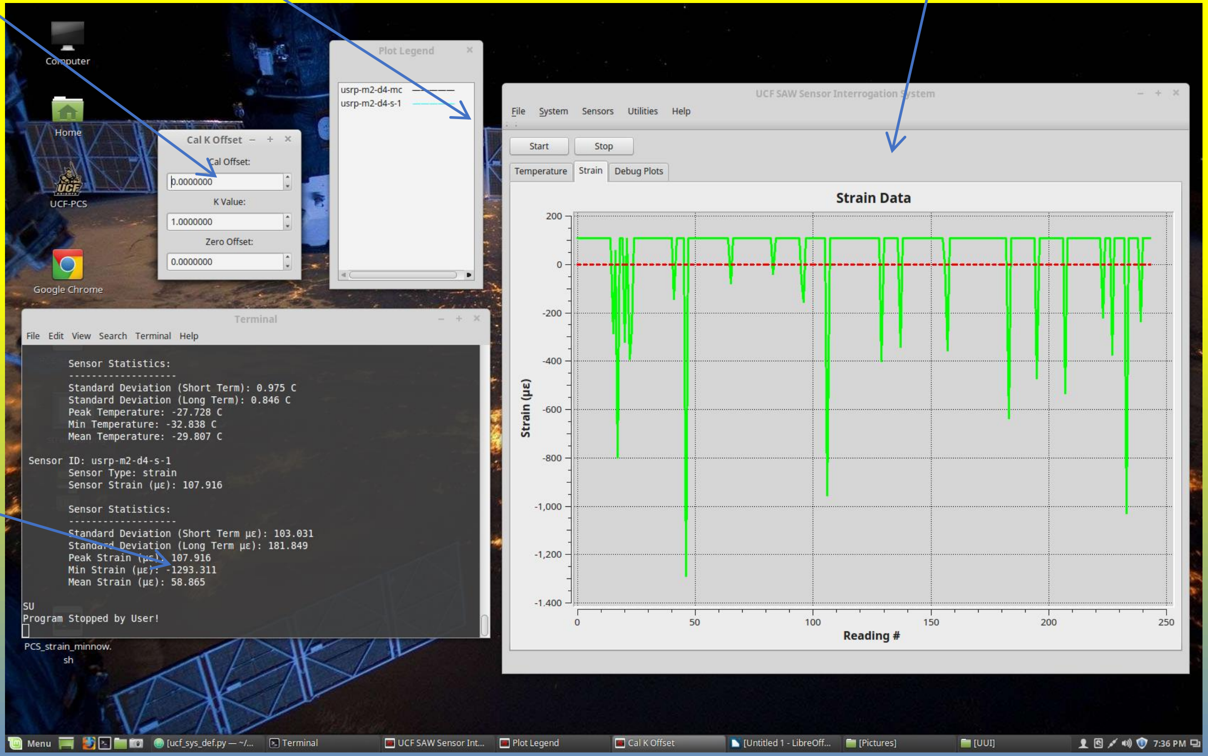
Command and Control Computer

User Input Textboxes

Active Sensors

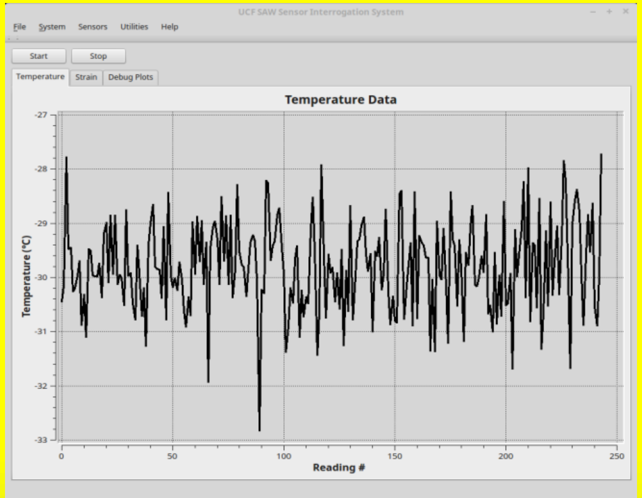
Strain Data Plot

Statistical Data

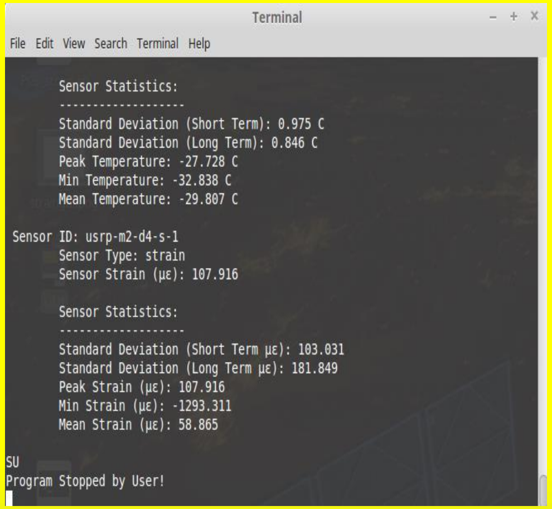


Dual Networked SAW Strain System Command and Control Computer

Temperature Plot Tab

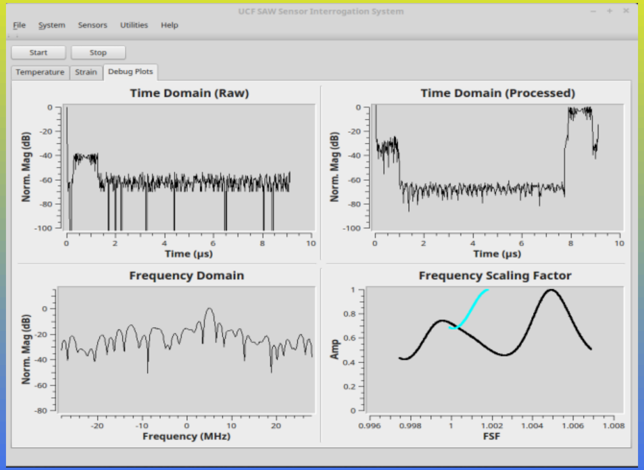


Terminal Output



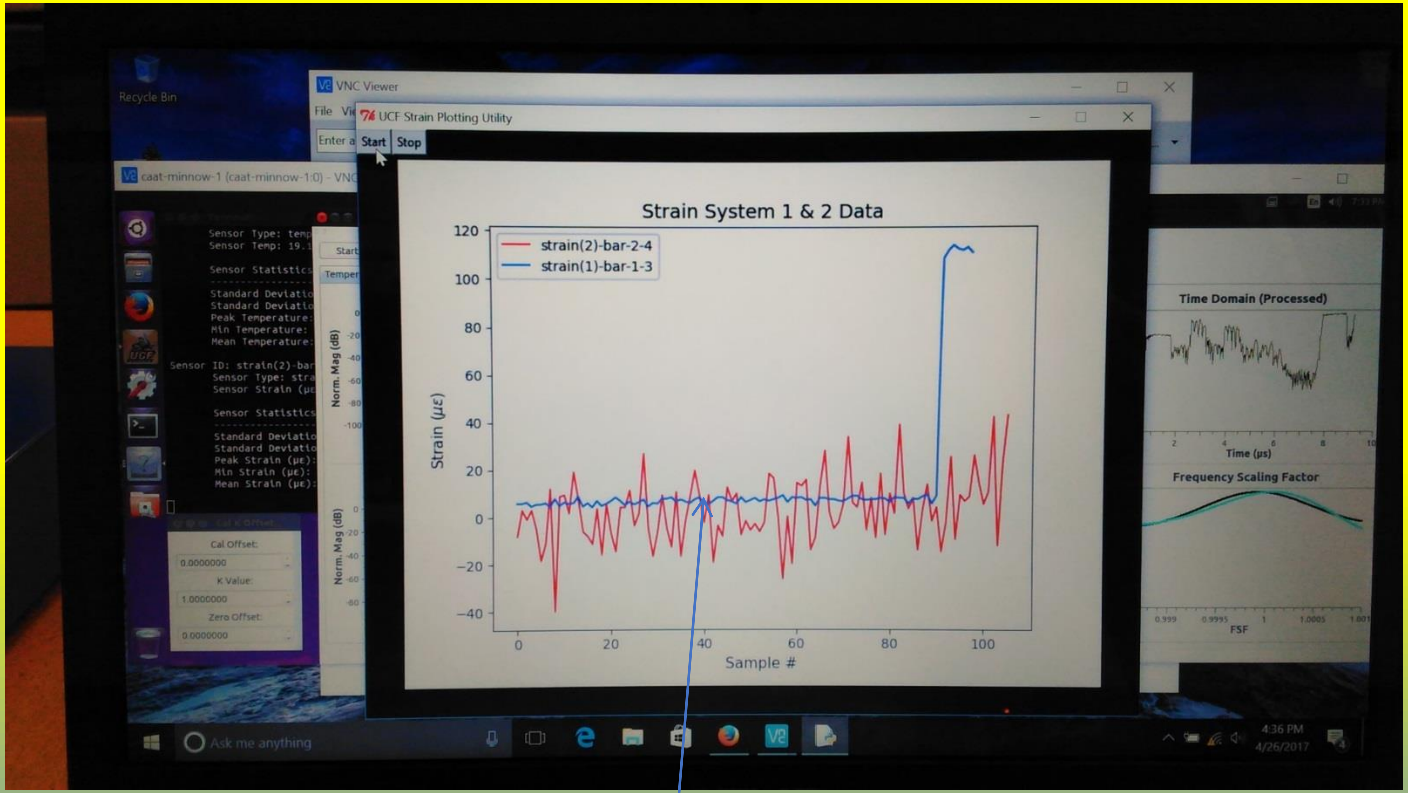
Strain Plot Tab

Debug Plot Tab



Dual Networked SAW Strain System

Command and Control Computer



Graphical interface showing strain data from both SAW strain systems that have been networked together.

UCF’s SAW Research Interests

- Wireless gas sensing
- Wireless strain sensor
- Wireless Extreme environment temperature sensor
- Magnetic sensing
- Miniature low-cost hand-held TxRx
- Compatible data exchange with SAW transceiver and Smartphone/portable devices.
- High data rate acquisition
- Sensor Fusion with SAW technology transceiver.