Surface acoustic wave delay lines as passive buried sensors

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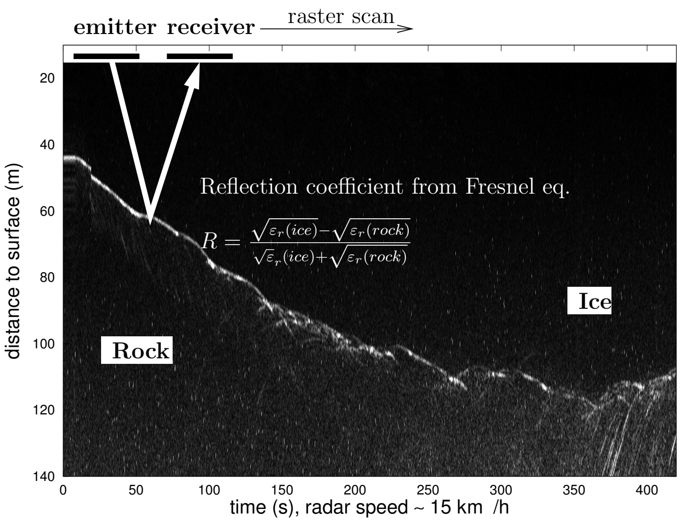
Wireless, passive (battery-less) sensors interrogated by Ground Penetrating RADAR

Objective: complementing widely available geophysical characterization instruments (GPR) with sensing capability :

Ground Penetrating RADAR (GPR):

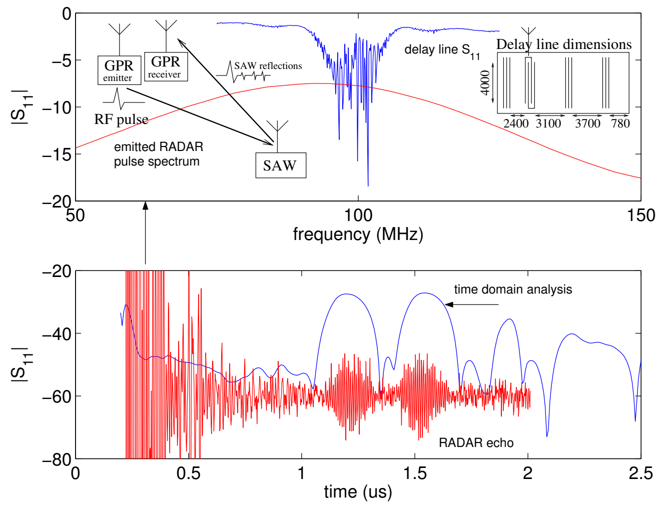
- bistatic antenna configuration, pulse emitter
- stroboscopic (equivalent time sampling) receiver
- ⇒ low power, low cost setup for baseband measurement (magnitude **and phase** informations)
- ⇒ typical center frequency $f_c \in [100-1000]$ MHz, sampling frequency $\simeq 10\times f_c$
- sampling duration $\simeq 3$ μs (225 m in ice)
- peak power 2 kW, interrogation raange $\geq$ 150 m in ice
- **BUT** sensitive to dielectric/conductivity changes



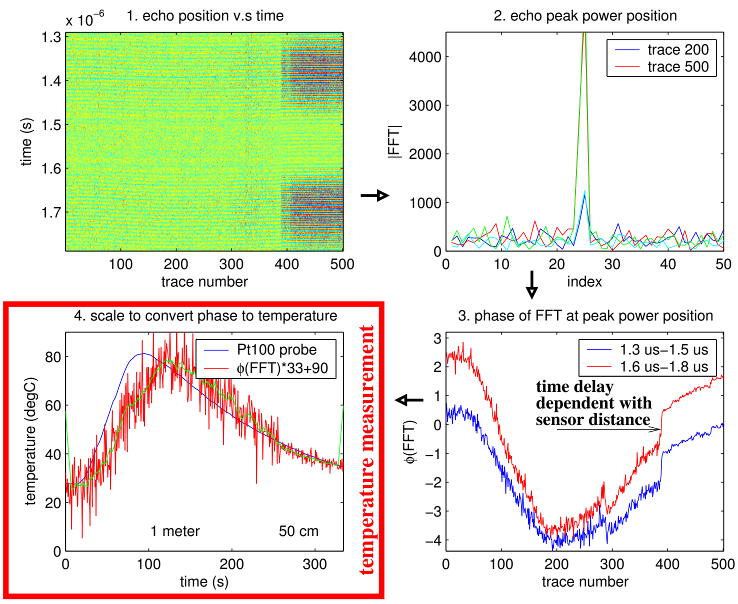
Ice-rock interface (East Loven Glacier, Spitsbergen, Norway, 79 ^{o}N)

Surface Acoustic Wave (SAW) delay line:

- electromechanical sensor based on piezoelectric substrates ($LiNbO_3$ (YXl)/128^o for its high coupling)
- sensing based on mechanical wave velocity measurement
- time delay between reflection ∼ physical quantity
- **intrinsic radiofrequency** sensor (no DC conversion)
- **linear** device (no rectifier threshold voltage)
- acoustic velocity $\simeq 10^{-5}\times$electromagnetic velocity
  ⇒ 3μs delay =9 mm path length = 4.5 mm long sensor
- **BUT** large antenna ($\lambda_{EM}/2 \simeq 1$ m at 100 MHz)



Comparison of the GPR and SAW delay line spectra (100 MHz)



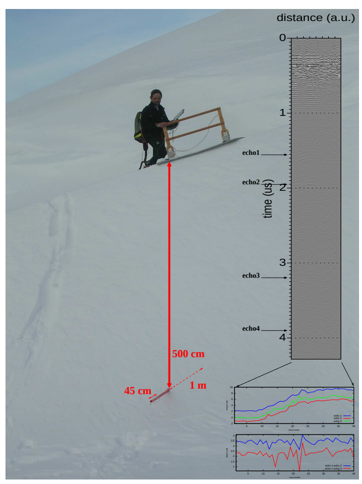
Sensor located at 1 m & 50 cm from receiving antenna

⇒ Practical **measurement strategy** demonstration:

1. probe delay line sensor with GPR,
2. identify delay response through Fourier transform (FFT),
3. measure absolute FFT phase,
4. phase difference insensitive to GPR-sensor distance,
5. representative of physical quantity (preliminary calibration), here temperature

Range d estimate :

1. point-like target ⇒ Free Space Propagation Loss as d^{-4}
2. $d_{SAW} = d_{interface} \times 10^{(IL_{interface}-IL_{SAW})/40}$, with typical SAW insertion loss (IL) at -35 dB, and ice-rock interface -19 dB ($\varepsilon_{rock}=5$, $\varepsilon_{ice}=3.1$, Fresnel eq.)



Conclusion and perspectives

- Interrogation range: **demonstrated at 5 m**, signal to noise ratio ⇒ **40 m** ?
- only requires post-processing, **no need to modify GPR hardware**
- mandatory **differential measurement** (poor local oscillator resolution + distance dependence)
- temperature with ∼ **K accuracy**
- applicable to **temperature** probe, **pressure** sensor, **strain** gage
- application to acoustic **resonators** ? (narrowband, low loss transducer)

Reference: Friedt *& al*, *Surface acoustic wave devices as passive buried sensors*, J. Appl. Phys **109** (3), 034905 (2011)