Theoretical & experimental analysis of high Q SAW resonator transient response in a wireless sensor interrogation application

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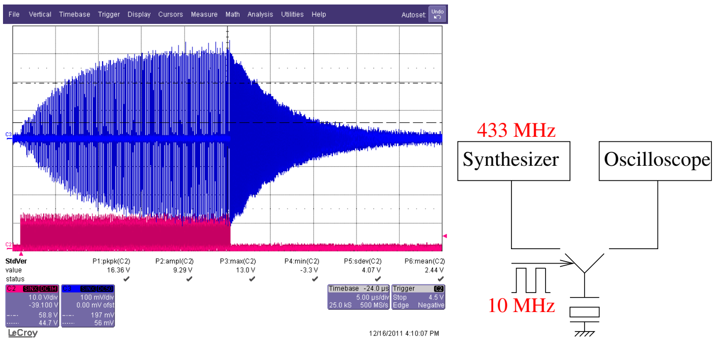
Context: surface acoustic wave (**SAW**) devices used as **passive sensors** interrogated through a **wireless link** using a **monostatic, frequency-sweep pulsed RADAR**

Objective: link budget and **frequency identification resolution** including electronic component noise and acoustic device characteristics in order to identify limiting factor in interrogation range

Oscillator noise limitation

- Phase noise S_φ of local oscillator (LO) = frequency fluctuation of the reference signal: $S_\varphi(f_c) = \frac{\Delta\varphi_{RMS}}{BW}$ (BW: measurement bandwidth, f_c offset from carrier)
- The longer the interrogation, the higher the chance of phase fluctuations (=high phase noise close to carrier)
- resonator time constant $\tau = Q/(\pi f_0) \simeq 7$ µs for resonator at $f_0 = 433$ MHz and quality factor $Q = 10000$: wait for 5τ to reach 99% of load/unload (independent sequence of measurements)
- frequency sweep strategy: $N = 128$ points/frequency band (fixed frequency comb [a]) or 2-point strategy (feedback on measured frequency [b])
  $\Rightarrow S_\varphi$ at $f_c = 1/(2 \times N \times \tau) \in [0.1 - 7]$ kHz



Experimental load/unload of resonator: the carrier is chopped during load so that the stored energy is visible

Phase to frequency noise: $\boxed{S_{\Delta f} = f_c^2 S_\varphi = \frac{\Delta f_{RMS}^2}{BW}}$ *i.e.* for a measurement bandwidth BW of $2 \times f_c$,

$$\Delta f_{RMS} = \sqrt{2 \times f_c^3 \times S_\varphi}$$

Phase noise	f_0	Q	Δf_{RMS}	resolution
-170 dBc/Hz	434 MHz	10000	0.01 Hz	4.10^{-6} K
-130 dBc/Hz	434 MHz	10000	1 Hz	4.10^{-4} K
-90 dBc/Hz	434 MHz	10000	140 Hz	50 mK
-170 dBc/Hz	2.450 GHz	1500	2 Hz	10^{-4} K
-130 dBc/Hz	2.450 GHz	1500	230 Hz	10 mK
-90 dBc/Hz	2.450 GHz	1500	23000 Hz	1 K

assuming 6 ppm/K (200 K range within 434 MHz ISM band).
Receiver amplifier noise floor: kT/P (P received power, temperature T) dominates at large range, -114 dBc/Hz if $P = -60$ dBm

[a] J.-M Friedt, C. Droit, G. Martin, and S. Ballandras *A wireless interrogation system exploiting narrowband acoustic resonator for remote physical quantity measurement*, Rev. Sci. Instrum. **81**, 014701 (2010)

[b] J.-M Friedt, C. Droit, S. Ballandras, S. Alzuaga, G. Martin, P. Sandoz *Remote vibration measurement: a wireless passive surface acoustic wave resonator fast probing strategy*, Rev. Sci. Instrum. **83**, p.055001 (2012)

SAW transducer limitation

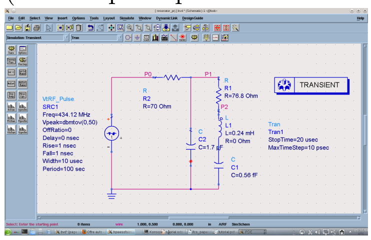
Two approaches:

- finite element modelling followed by mixed matrix assembly of elementary structures (transducer, cavity) $\rightarrow S_{11}$ response file
- equivalent electrical model (Butterwortdh-van Dyke) with fitted motional parameters

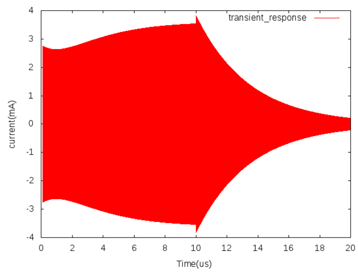
Modelling sequence:

1. include either model in ADS in addition to RADAR electronics component models, antenna impedance set to 70 Ω load (to be improved later)
2. time-domain analysis for transient response of acoustic device probed by pulse with variable frequency carrier
3. record amplitude at time $t \ll Q/(\pi f_0)$ for resonator operating at frequency $f_0 \simeq 433$ MHz and quality factor $Q \simeq 10000$

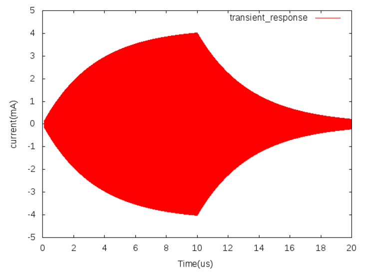
Challenge: high quality factor $\Rightarrow$ simulation time step $\ll 1/f_0$ (here 10 ps steps for a total 10 µs simulation)



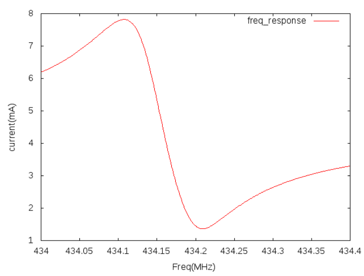
ADS model of the resonator with gated source: source at 434.12 MHz. BVD equivalent circuit: L_m=0.24 mH, C_m = 0.56 fF, R_m = 76.8 Ω, C_0 = 1.7 pF

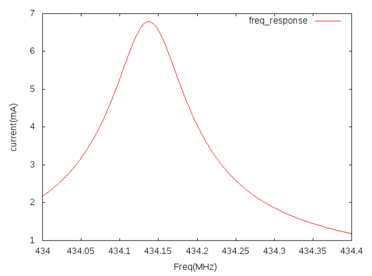


Current through BvD (load & unload)



Current through motional branch





Frequency dependent current through BvD (←) and motional branch (→)

Current in motional branch = mechanically stored energy (current continuity condition is met)

Conclusion: towards full wireless SAW reader modelling tool, including phase noise of LO and contribution of noise of electronics & transducer. LO is limiting at low range, receiver noise at range > 1 m.

Perspectives: add propagation path/medium losses (buried sensors) and antenna impedance/radiation pattern.