Supplementary material – A frequency modulated wireless interrogation system exploiting narrowband acoustic resonator for remote physical quantity measurement

C. Droit, G. Martin, and S. Ballandras
FEMTO-ST, Time & frequency department
32, avenue de l'Observatoire, 25044 Besançon FRANCE

J.-M Friedt
SENSeOR
32, avenue de l'Observatoire,
25044 Besançon FRANCE[*]

(Dated: March 22, 2010)

PACS numbers: 43.60.Qv

Keywords: Surface acoustic wave, sensor, wireless, interrogation unit, frequency modulation, phase locked loop

---

[*] Electronic address: `jmfriedt@femto-st.fr`

Tabletop experiment description

A preliminary tabletop prototyping experiment was performed following the setup displayed in Fig. 1. A low-frequency function generator synthesizes a 1 to 10 kHz sine wave. This signal is fed to the FM input of a RF function generator, whose carrier frequency is software-defined through a GPIB link to a personal computer: this carrier frequency is in the 433.05-434.79 MHz European Industrial, Scientific and Medical (ISM) band range. The FM modulated, RF signal feeds a RF switch which alternately feeds energy to a dual-resonator, or connects to a wideband RF power detector. The switch position is controlled by a pulse generator with a repetition rate of 30 kHz, or the characteristic loading time of a resonator exhibiting a minimum quality factor of 8000 around 434 MHz, simulating the pulse repetition rate of a RADAR. The low frequency output of the power detector is bandpass filtered for removing the pulse switching and only keeping the average returned power: the closer the carrier frequency is to one resonance of the temperature sensor, the stronger the signal. This output is frequency modulated: the ω_m components vanishes at resonance and only the $2\omega_m$ remains at resonance. Finally, the filtered received power signal and modulating signal are both displayed on a digital storage oscilloscope: both channels are recorded through a GPIB link by the same personal computer mentioned above. The phase information is computed, and the carrier frequency adjusted in order to keep the phase information close to a fixed setpoint (Fig. 2).

Parameter analysis and bias source

We have constrained the interrogation rate, associated to the modulation frequency ω_m, with the response time of the resonator. A less obvious parameter is the modulation excursion B. This parameter determines the span of the resonator response swept during an interrogation step and the spectral occupation of the emitted signal: an intuitive selection of this parameter is a frequency excursion smaller than the width at half height of the resonance, yet large enough for the two magnitude measurements at maximum FM deviation to be well separated and reduce the influence of noise on the power detector. An experimental analysis of the influence of B has been performed, yielding an estimate of the bias on the computed resonance frequency due to various values of B. Indeed, since the feedback control aims at identifying the position of the frequency modulated signal so that both contributions on the positive and negative slopes of the resonance compensate, the detected resonance frequency is computed as the carrier, *i.e.* the frequency in the middle of the maximum and minimum excursion. However, this assumption is only valid for an even function: the actual Butter worth-van Dyke (BvD) response of the resonator significantly departs from this assumption considering the measurement accuracy we are targeting (Fig. 3). However, once the excursion B is selected, we control the carrier frequency in order to always equilibrate the positive and negative slope halves of the frequency modulated signal, so that this offset is kept constant and no longer affects the accuracy of the relative physical quantity measurement.

Temperature coefficient of frequency

We use differential measurements in order to minimize the dependency of the measured frequency *difference* with respect to local oscillator drift and correlated noise source (e.g. stress, antenna impedance). Each temperature coefficient of frequency is individually identified during a calibration step, and the resulting *differential* coefficients (second order polynomial fit) are computed. As an example of a typical calibration result, Fig. 4 exhibits the evolution of each resonance with temperature, and the resulting differential frequency dependency with temperature, which is the quantity actually used to convert the frequency measurement to temperature.

Figures

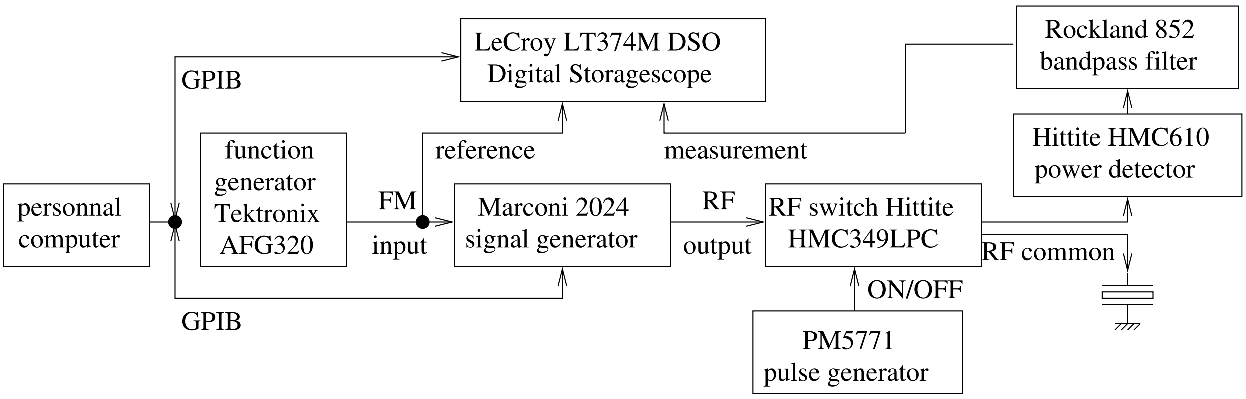
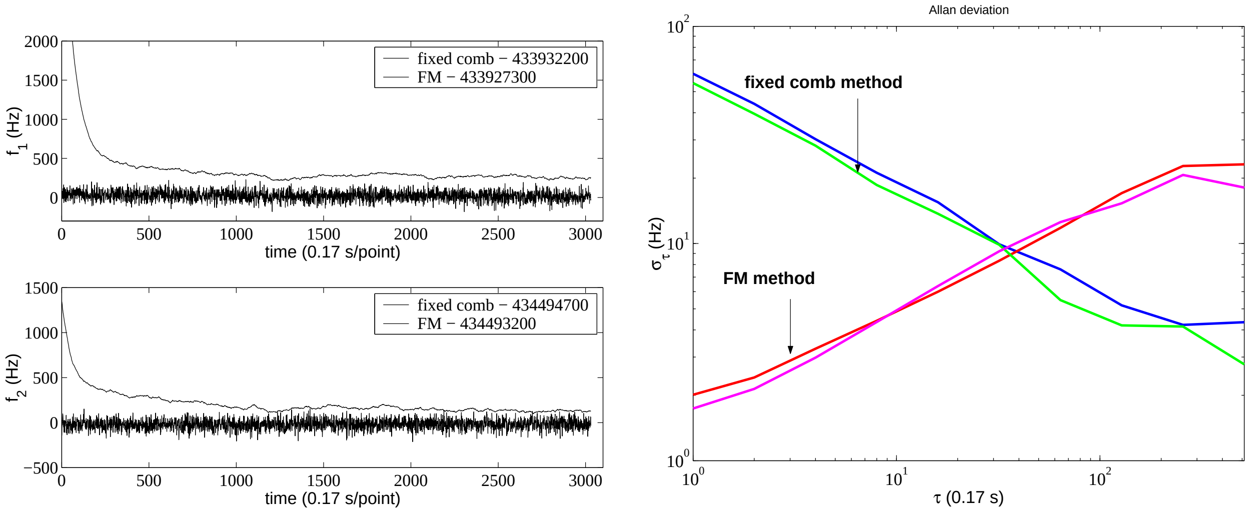


FIG. 1: Schematic description of the tabletop prototyping experiment for demonstrating the FM-modulation strategy for interrogating wireless passive resonators.



(a) (b)

FIG. 2: (a) Comparison of the openloop, fixed comb interrogation strategy, and closed loop control FM measurement of the frequency in order to minimize the component of the amplitude modulated signal at ω_m. These results were obtained using the setup described in Fig. 1. (b) Allan deviation of both strategies. The fixed comb exhibits a $\simeq$60 Hz standard deviation at short term while the FM strategy exhibits sub-10 Hz performance. The closed loop noise level degrades for longer interrogation time: we attribute this slow divergence of the Allan deviation to the simple proportional feedback strategy we used.

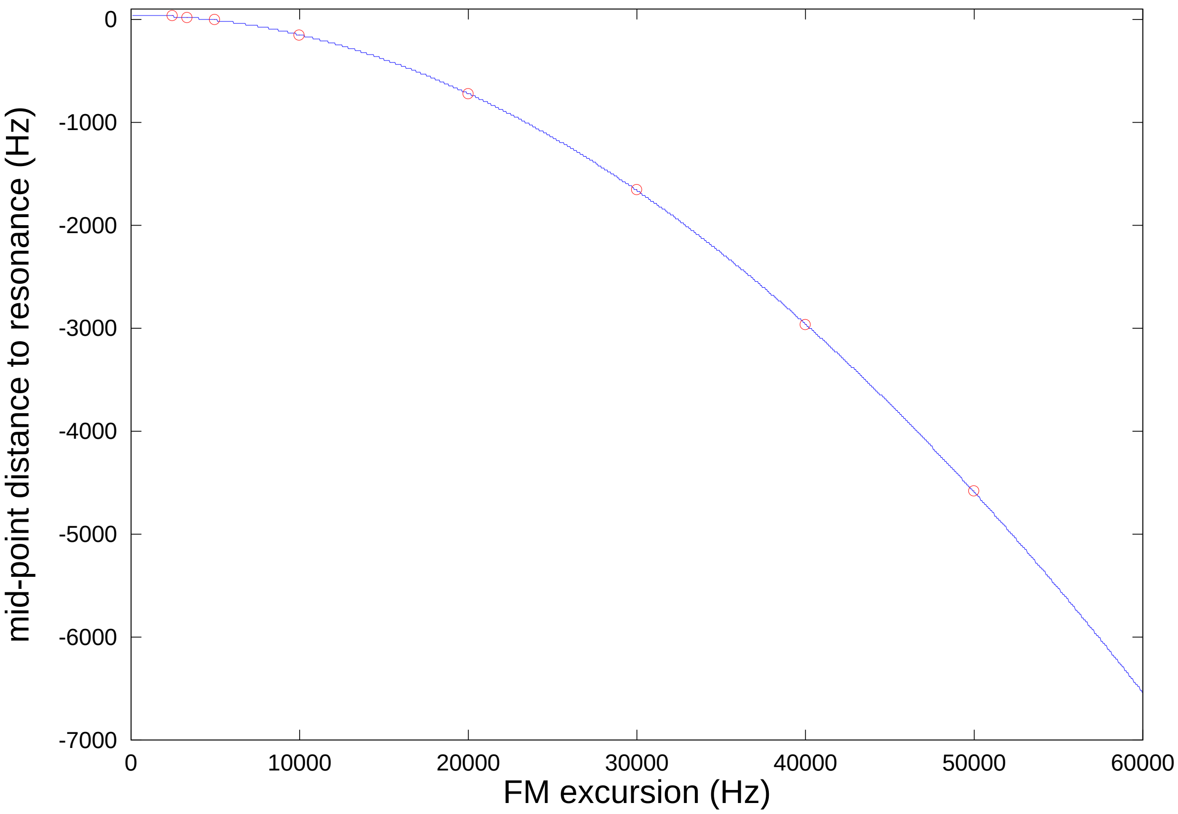


FIG. 3: Bias of the estimated resonance frequency obtained as the middle value of the two frequencies for which the magnitude of the BvD model are equal, as a function of the spacing between these two frequencies (FM excursion). This simulation was performed with a BvD model using L_1=72.8 μH, C_1=1.85 fF, R_1=21 and C_0=3.3 pF, for a resonance frequency around 433.67 MHz and a quality factor of 9500.

FIG. 4: Top and middle: evolution of each resonance frequency with temperature. Bottom: resonance frequency difference evolution with temperature. A second order polynomial fit of the latter data provides the coefficients for converting the measured frequency different to a temperature.