RESONANCE BASED MEASUREMENT TECHNIQUE FOR THE DETECTION OF FERROMAGNETICALLY TAGGED BIO-MOLECULES

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I. INTRODUCTION

The diagnosis and treatment of many communicable diseases is highly reliant upon the detection of pathogens, and the need to develop more efficient bio-detection techniques is an emerging area. The most effective bio-molecule detection techniques, such as the popular fluorescent technique [1] currently available, require expensive equipment and infrastructure. Therefore, there is a strong need for a more economical and portable way of detection.

While fluorescent tagging of particles is one way to isolate bio molecules, another possibility is tagging with ferromagnetic particles [2]. In this paper, we use the resonant frequency of an oscillator to detect the presence of iron nano particles suspended in acetone. When the iron particles pass through the core of an inductor, the particles cause a change in the resonant frequency that can be electronically detected.

Previously, we attempted to detect the change in resonance with a dual coil configuration in which one coil was pulsed with a square wave while the other coil was part of an LC circuit that resonated [3]. However, due to limitations in the minimum detectable number of particles of this method, we have switched our focus to a single coil oscillator design.

II. EXPERIMENTAL SETUP

Oscillator Design

The setup for this experiment consisted of an oscillator circuit using an inductor wound around a capillary tube. The frequency of the oscillator was then observed on an oscilloscope while fluids of differing iron nano particle concentration were passed through the tube.

The oscillator circuit we used was a Colpits LC oscillator, as it required a single inductor as opposed to a Hartley oscillator which requires two [4]. Figure 1 shows the schematic for the oscillator, along with an inverter and pull-up resistor at the output.

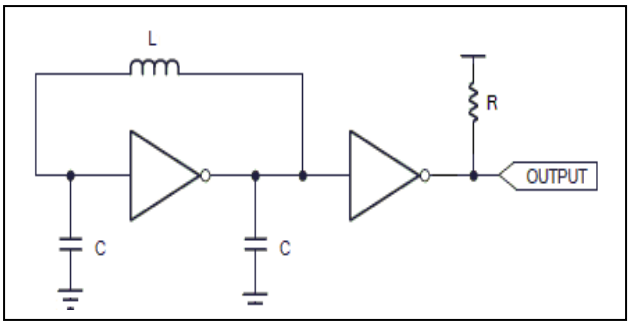

Figure 1: Colpits oscillator with pull-up resistor

The centre frequency for the oscillator is given by Equation 1 [4].

$$f = \frac{1}{2\pi\sqrt{LC_{tot}}}, \quad (1)$$

where C_{tot} is the total capacitance of the oscillator circuit and L the effective inductance of the coil.

When taking into account the capacitance across the inverter and the capacitive component of the inductor, C_{tot} becomes $C/2 + C_{Inv} + C_L$, and we get the following formula for the frequency:

$$f = \frac{1}{2\pi\sqrt{L\left(C/_2 + C_{Inv} + C_L\right)}}, \quad (2)$$

where C_{Inv} is the inverter capacitance and C_L is the inductor capacitance, which we assume is zero when the coil is empty.

The inductance of a circular loop of wire can be found by Equation 3 [5].

$$L_{Circle} \approx N^2 R \mu_0 \mu_r \left[\ln\left(\frac{8R}{a}\right) - 2 \right], \quad (3)$$

Where *N* is the number of turns, *R* is the radius of the coil, μ_0 is the permeability of free space, μ_r is the relative permeability, and *a* is the radius of the wire. The inductor that we used was created by winding 20 turns of AWG 40 wire around a 1.2 mm diameter glass capillary. According to Equation 3, the inductance of this coil is 0.632 µH.

We used 10 pF capacitors and using Equation 1 got a frequency of 91.8 MHz. The inverter we used was a 74HCU04, which has a 7 pF capacitance [6]. After taking this into account, and using Equation 2, we calculated a frequency of 57.792 MHz.

Samples

Our test samples were made from 35-50 nm iron particles suspended in acetone. The samples were prepared by weight percentage. The concentrations we used for this experiment, by estimated weight percentage, were 0% (pure acetone), 0.0001%, 0.001%, 0.15%, and 0.3%.

We chose acetone as the suspension fluid because it has a lower dielectric constant than water (20.7 vs 80.0 [7]), and the resonant frequency of our circuit is affected by a change in capacitance as well as inductance. A pure acetone sample was used to identify the baseline frequency shift for the iron samples. This shift was observed to be 58 kHz, and working backwards with Equation 2, we estimate that the acetone results in a 0.024 pF capacitor in parallel with the inductor.

Procedure

The circuit was powered and the frequency shift for the introduced sampled was observed. The capillary tube was oriented vertical (with reference to gravity). Samples were inserted by a syringe pump.

The frequency output of the circuit was recorded over time. We started recording the frequency 15 seconds before the sample was inserted, and continued recording until the sample completely passed through the coil. The capillary was thoroughly cleaned between each sample.

In order to keep the suspension as uniform as possible, the sample container was mixed with an ultrasonic probe, and then loaded into the syringe pump. The syringe was continuously shaken right up until insertion. Despite our best efforts, we still observed a considerable amount of particles settling prior to insertion.

III. SIMULATION

The circuit from Figure 1 was simulated using Hspice. The resulting frequency was 54.236 MHz. The theoretical and simulated results for the initial frequency are comparable. The following table summarizes the results of simulation and theoretical predictions for frequency when the inductance and capacitance of the coil are changed. The first row shows the initial state, followed by the estimated change in capacitance due to the acetone. The final row includes the estimated changes to capacitance and inductance due to the 0.0001% sample.

Table 1: Frequency results for changes to coil inductance and capacitance

C_L (pF)	**L(µH)**	**Frequency (MHz) and Drop (kHz)**			
		Theoretical		***Simulated***	
0	0.632	57.792	-	54.236	-
0.024	0.632	57.735	57	53.912	324
0.024	0.6325	57.712	80	54.012	224

The simulation results for the frequency drop are quite different from the theoretical predictions, even showing a smaller drop for the case with the 0.0001% sample is present. This discrepancy suggests that our simulation model may need to be refined, and will be looked at in our future work.

IV. RESULTS

The results of the frequency change for each sample are plotted and they are shown in Figures 2 through 6. The solid line represents the raw data collected and the dashed line represents the average value. The drop indicates when the sample passed through the coil. For the acetone, we did not have to worry about residual iron particles stuck in the capillary, so we were able to push a second sample through during the same run, which explains the second drop seen in Figure 2.

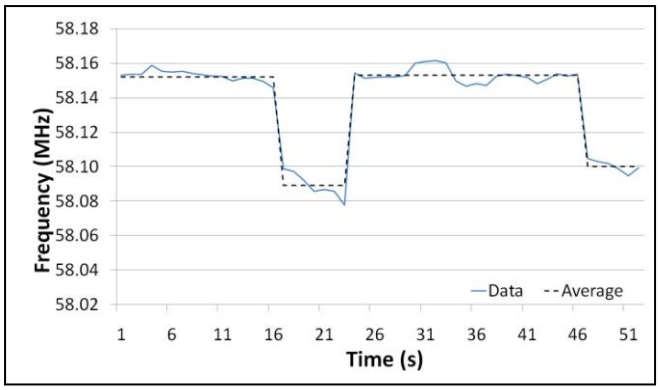

Figure 2: Frequency vs Time for pure acetone

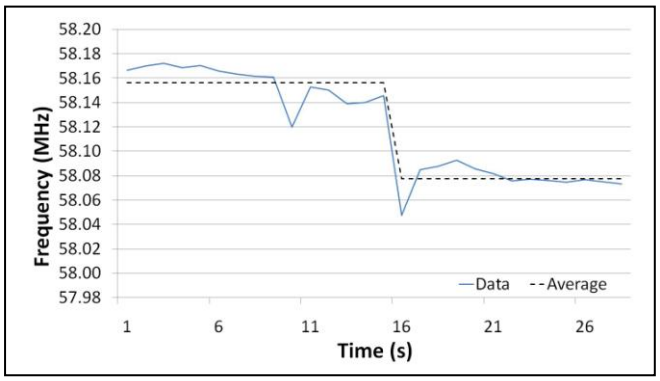

Figure 3: Frequency vs Time for 0.0001%

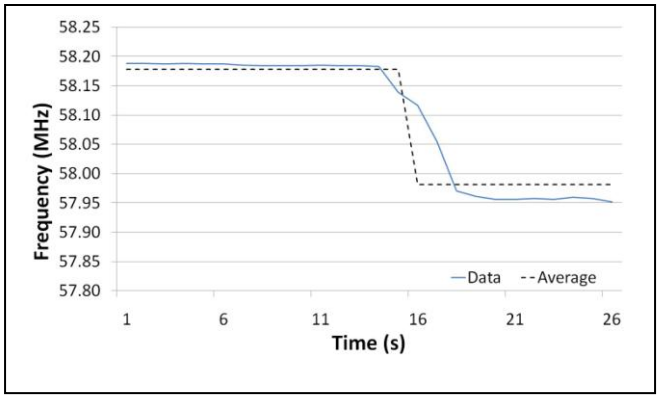

Figure 4: Frequency vs Time for 0.001%

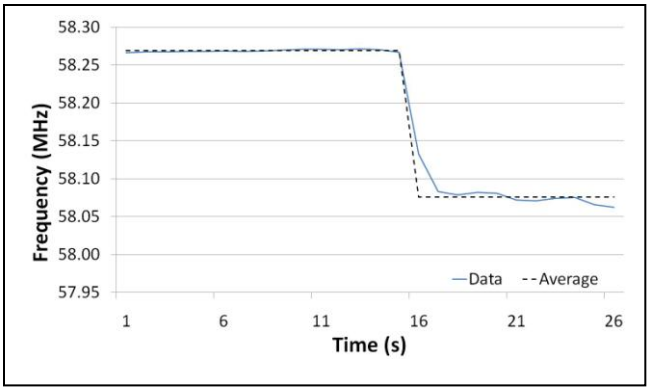

Figure 5: Frequency vs Time for 0.15%

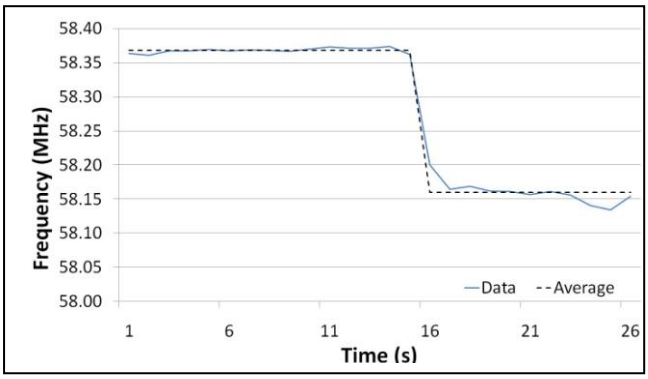

Figure 6: Frequency vs Time for 0.3%

The following figure shows a summary of the frequency change for each sample. It appears that once the concentration reaches 0.001%, the iron concentration through the coil has saturated and no further frequency change can be observed.

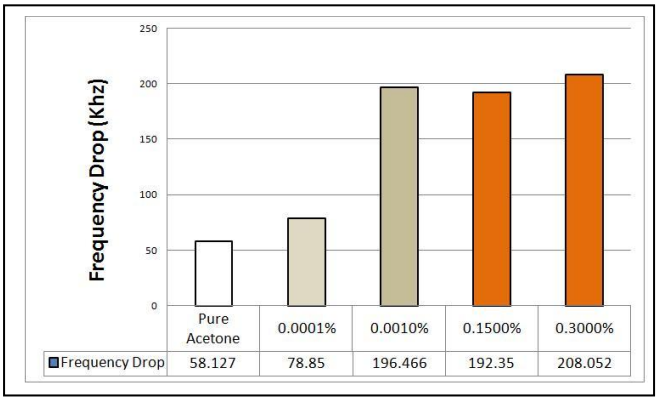

Figure 7: Frequency drop for each sample

V. CONCLUSION

Our experimental circuit for the detection of iron nano particles functioned very closely to what we expected based on our theoretical predictions and simulations. We observed an oscillation frequency of about 58 MHz, compared to the 57.792 MHZ predicted by theory and 54.236 MHz predicted by simulation.

When introducing samples into the coil, we were able to observe a frequency shift with an estimated iron nano particle concentration of 0.0001%. Increasing the concentration beyond 0.001% exceeded the limitations of our test equipment. Future work will focus on concentrations below 0.001%.

In order to avoid the problem of the iron particles settling, we will find a suitable dispersant that will keep the particles in suspension.

By refining this resonance based measurement technique, we can construct a device that can detect ferromagneticlaly tagged bio-molecules with a required number of particles similar to the fluorescent technique.

VI. REFERENCES

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