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A study of stretchable flat spiral inductors

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THE PROBLEM

In recent years the interest in stretchable, or soft, electronics has risen due to their versatility and possible applications in numerous fields. Solution processing techniques are often used to create these circuits. However, once the solvent has dried the remaining conductive track can tear and crack after some use. This limits the stretchability of the circuit and can inhibit proper power transfer. To solve these problems, another method for creating conformable electronics can be used. This method consists of creating microfluidic channels in a stretchable substrate, encapsulating the channels and filling them with a liquid metal. Using this method, stretchable inductors can be made. These can provide power to the circuit wirelessly trough inductive power transfer.

Turn spacing *t*

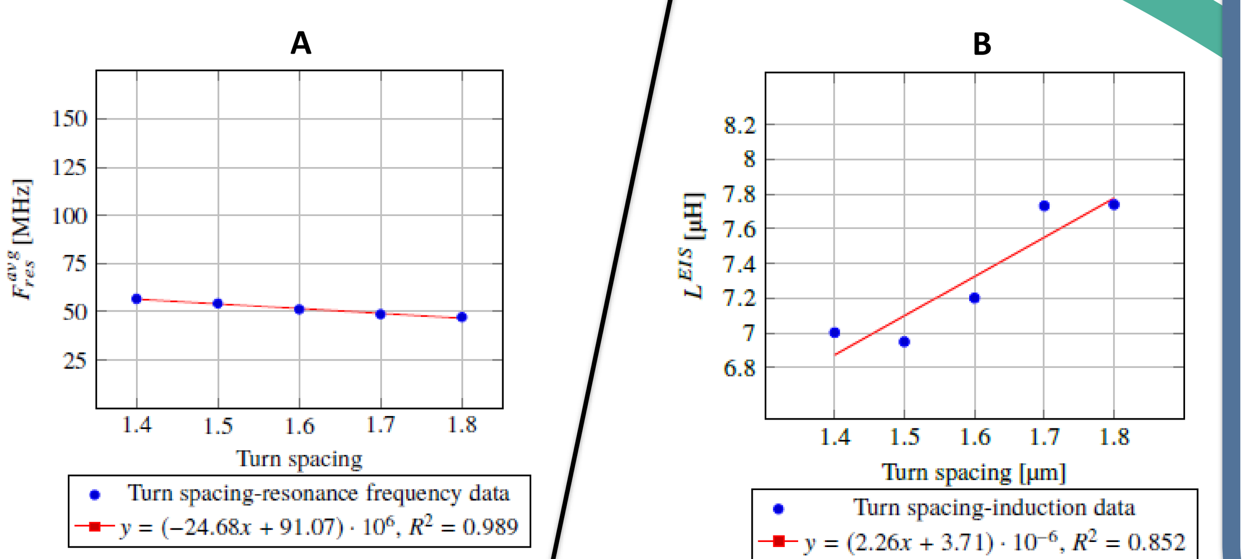

Figure 1: Influence of the turn spacing on the resonance frequency(A), and the inductance(B)

METHOD

In this research, these stretchable inductors are made using laser engraving which cuts in a stretchable material known as PDMS. The inductor has several different design parameters which influence the inductance. For this research, the amount of turns *N*, the width of the conductive track *w*, and the spacing between the centres of two consecutive turns *t* are altered and their influence on the inductance is measured. To get the inductance, an impedance measurement is done. This data is then used in EIS Analyser which fits the data to a model of a real inductor and estimates the inductance, capacitance, and resistance of the inductor. Figure 2 shows the model for a real inductor. Another measurement will be done using a vector network analyser to get an accurate result of the resonance frequency of the inductor.

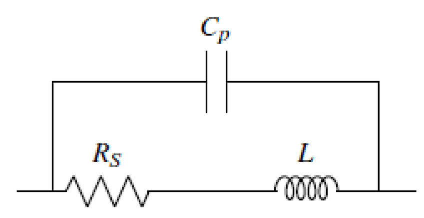

Figure 2: Equivalent circuit of a real inductor

R_S = Series resistance
L = Inductance
C_p = Parasitic capacitance

$$L = \frac{N^2 \cdot A^2}{30A - 11D_i},$$
$$A = \frac{D_i + N \cdot (t)}{2},$$

Where L = Inductance of the coil
N = Number of turns
A = Coil area
D_i = Inner diameter
$t = w + s$
w = Wire diameter
s = Spacing between turns

Equation 1: Inductance of air core flat spiral inductors [1]

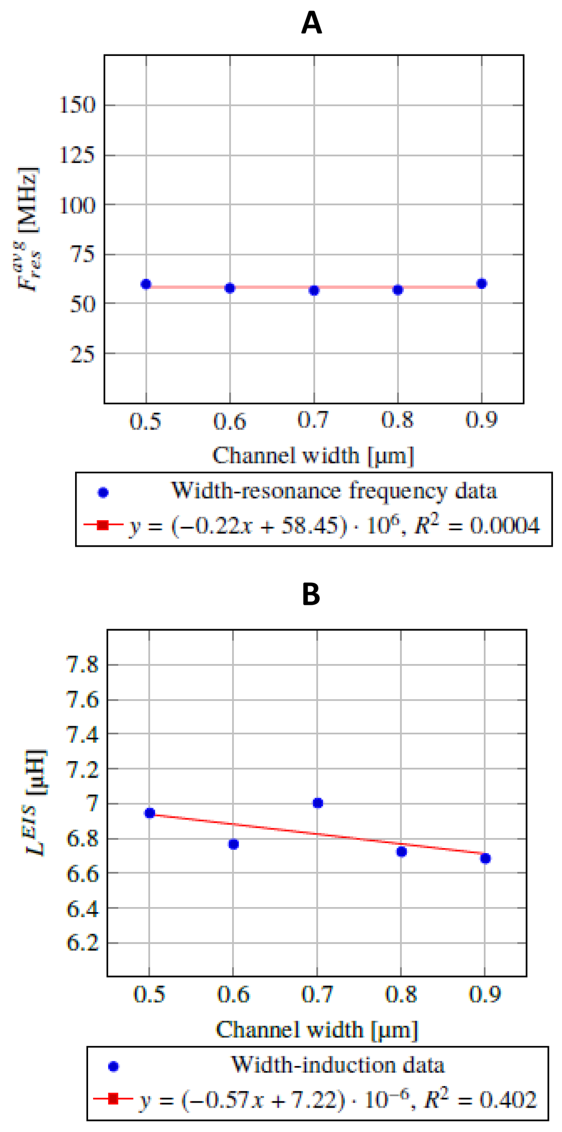

Figure 4: Influence of the width on the resonance frequency(A), and the inductance(B)

Channel width *w*

CONCLUSION

In this research, several stretchable flat spiral inductors have been made and characterised. The inductors were created for use in stretchable electronic applications where they could be used for powering a stretchable circuit. To make the inductors stretchable, a material known as Shore 15 Polydimethylsiloxane was used. After curing, a laser engraver was used to photothermally ablate the inductor in this layer of silicone. A second layer of silicone was then used to seal the inductor after it was cleaned from the laser residue. To finish the inductor, all the air in the channels was extracted in a vacuum chamber and was refilled with a liquid metal known as Galinstan. Several parameters of the inductor design were altered to study their effects on the inductance and resonance frequency. The altered parameters consisted of the number of turns *N*, the width of the channel *w*, and the spacing between the centres of two consecutive turns *t*. The inductance for air core flat spiral inductors can be calculated using equation 1. The results of these calculations show that the inductance is not greatly affected by the use of PDMS and Galinstan. Other similarities include that *N* has the most influence on the inductance, that *t* also has some influence, and that *w* has no influence.

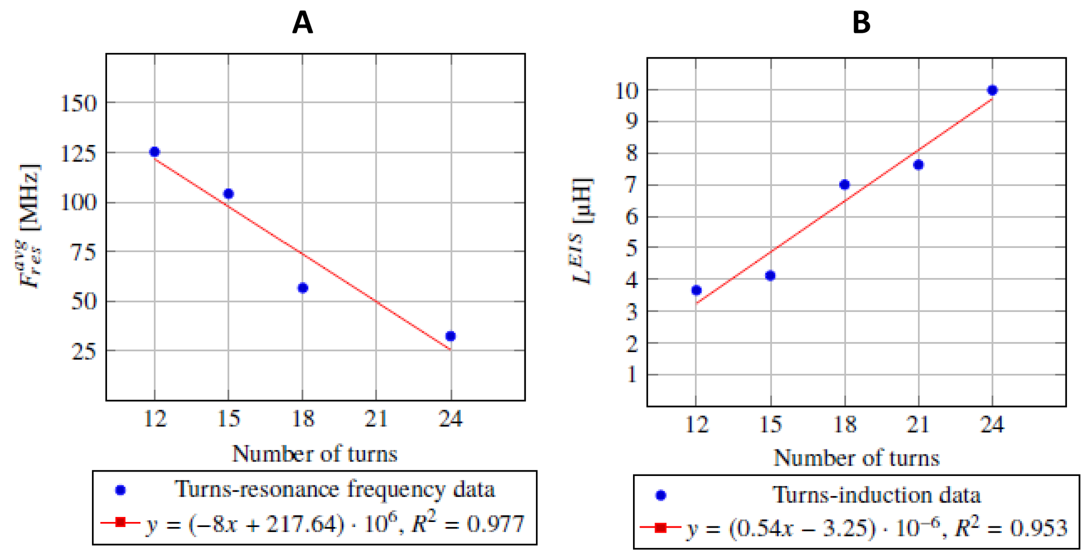

Figure 3: Influence of the amount of turns on the resonance frequency(A), and the inductance(B)

Amount of turns *N*

RESONANCE FREQUENCY RESULTS

Because a capacitance was added to the circuit when measuring the impedance, the real resonance frequency of the inductors was altered. For accurately measuring this frequency, a Hewlett Packard 8753E network analyser was used. The results from these measurements were similar to the once from the impedance analyser. In figure 1(A), it can be seen that the resonance frequency decreases with 2.468 MHz when the turn spacing is increased with 0.1 mm. Figure 3(A) shows that the amount of turns and resonance frequency are linearly related with an 8 MHz decrease for each additional turn. The assumption that the channel width does not influence the inductance is further supported by the results shown in figure 4(A) where this relation is visualized.

INDUCTANCE RESULTS

The impedance was measured using a 4194A impedance/gain-phase analyser from Hewlett-Packard. A capacitance of 30 nF was added in parallel to reduce the resonance frequency to a point where it was measurable. Figure 1(B) illustrates the influence of the turn spacing on the inductance. The results show a linear increase of 0.226 μH in inductance for each 0.1 mm increase in turn spacing. Figure 3(B) shows the relation between the amount of turns and the inductance. This relation is also linear with an increase of 0.54 μH for each turn that is added. Figure 4(B) depicts the effect of the width on the inductance. The coefficient of determination (R^2) is relatively close to 0 which indicates that the width does not affect the inductance.

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[1] Tesla institute, "Flat spiral coil inductor calculator"[Online]. Available: url: http://www.tesla-institute.com/!app/sim/fscic.php.