Supporting Information
Magnetically Actuated Tunable Soft Electronics

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Supporting Information

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**Figure S1.** Fabrication process of axial inductors. From left: 1- Fabricating a $3 \times 3 \times 40$ mm$^3$ cuboid made of PDMS with 5 mm wall thickness; 2- Inserting a 3D printed core in the channel to prevent deformation during wire winding; 3- Winding copper wire around the channel; 4- Using a 3D printed mold and PDMS casting to add 2 mm thickness to the walls in order to reinforce the walls before removing the core; and 5- Removing the 3D printed core and mold when the added PDMS is cured and can hold the shape of the channel. Using this process, the inductor is close enough to the channel while the walls are thick enough to prevent the channel from unwanted deformations during the experiments.

**Figure S2.** Variable planar inductor connected to the VNA.
**Figure S3.** The effect of mobile component quantity (a-d) and position (e-i) on inductance and Q-factor of a planar inductor unit (unit #1) plotted vs frequency. Changing the iron amount a) without and b) with the magnet being present. c) Changing the iron amount with both the ferrofluid and magnet being present. d) Changing the ferrofluid volume in presence of the magnet. Changing the iron position e) without and f) with the magnet being present. g) Changing the position of a mixture of iron and ferrofluid with magnet being present. h) Changing the position of the ferrofluid with magnet being present. i) Changing the position of magnet.
Figure S4. The effect of mobile component quantity (a-d) and position (e-i) on inductance and Q-factor of a planar inductor unit (unit #2) plotted vs frequency. Changing the iron amount a) without and b) with the magnet being present. c) Changing the iron amount with both the ferrofluid and magnet being present. d) Changing the ferrofluid volume in presence of the magnet. Changing the iron position e) without and f) with the magnet being present. g) Changing the position of a mixture of iron and ferrofluid with magnet being present. h) Changing the position of the ferrofluid with magnet being present. i) Changing the position of magnet.
Figure S5. The effect of mobile component quantity (a-d) and position (e-i) on inductance and Q-factor of a planar inductor unit (unit #3) plotted vs frequency. Changing the iron amount a) without and b) with the magnet being present. c) Changing the iron amount with both the ferrofluid and magnet being present. d) Changing the ferrofluid volume in presence of the magnet. Changing the iron position e) without and f) with the magnet being present. g) Changing the position of a mixture of iron and ferrofluid with magnet being present. h) Changing the position of the ferrofluid with magnet being present. i) Changing the position of magnet.
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Figure S24. Experiments with the most significant change in tuning range for a) planar inductor, b) axial inductor, c) capacitor, and d) resistor.
Table S1: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of a planar inductor’s characteristics between three measurements at each position. These measurements are taken in three trials, each set starting with position 1 and ending with position 3. The mobile component is a mixture of iron particles (0.105 g) and ferrofluid (500 µl), moved with a magnet.

| Position | Characteristics | Mean  | SEM   | SEM/Mean | DoF |
|----------|-----------------|-------|-------|----------|-----|
| 1        | Inductance (µH) | 2.57  | 2.50E-03 | 9.74E-04 | 2   |
|          | Q_factor        | 23.7  | 0.012 | 5.15E-04 | 2   |
|          | SRF (MHz)       | 40.7  | 0.047 | 1.17E-03 | 2   |
| 2        | Inductance (µH) | 2.96  | 6.38E-03 | 2.15E-03 | 2   |
|          | Q_factor        | 33.6  | 0.255 | 7.61E-03 | 2   |
|          | SRF (MHz)       | 38.5  | 0.031 | 8.16E-04 | 2   |
| 3        | Inductance (µH) | 3.14  | 3.43E-03 | 1.09E-03 | 2   |
|          | Q_factor        | 45.6  | 0.134 | 2.94E-03 | 2   |
|          | SRF (MHz)       | 38.5  | 0.047 | 1.23E-03 | 2   |
Table S2: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of an axial inductor’s characteristics between three measurements at each position. These measurements are taken in three trials, each set starting with position 1 and ending with position 3. The mobile component is a mixture of iron particles (0.095 g) and ferrofluid (40 µl), moved with a magnet.

| Position | Characteristics | Mean     | SEM      | SEM/Mean  | DoF |
|----------|-----------------|----------|----------|-----------|-----|
| Position 1 | Inductance (μH) | 0.393    | 2.01E-03 | 5.12E-03  | 2   |
|          | Q_factor        | 21.8     | 1.392    | 6.39E-02  | 2   |
|          | SRF (MHz)       | 112      | 12.016   | 1.08E-01  | 2   |
| Position 2 | Inductance (μH) | 0.441    | 3.13E-03 | 7.11E-03  | 2   |
|          | Q_factor        | 18.9     | 0.282    | 1.50E-02  | 2   |
|          | SRF (MHz)       | 106      | 11.770   | 1.12E-01  | 2   |
| Position 3 | Inductance (μH) | 0.454    | 2.07E-03 | 4.56E-03  | 2   |
|          | Q_factor        | 23.6     | 1.146    | 4.86E-02  | 2   |
|          | SRF (MHz)       | 106      | 10.820   | 1.02E-01  | 2   |
Table S3: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of a capacitor’s characteristics between three measurements at each position. These measurements are taken in three trials, each set starting with position 1 and ending with position 3. The mobile component is iron particles (0.185 g) moved with a magnet.

| Position | Characteristics | Mean   | SEM      | SEM/Mean | DoF |
|----------|-----------------|--------|----------|----------|-----|
| Position 1 | Capacitance (pF) | 3.25   | 1.67E-03 | 5.14E-04 | 2   |
|          | Q_factor        | 489    | 128.285  | 2.62E-01 | 2   |
|          | SRF (MHz)       | 720    | 2.299    | 3.19E-03 | 2   |
| Position 2 | Capacitance (pF) | 2.91   | 2.85E-02 | 9.79E-03 | 2   |
|          | Q_factor        | 986    | 179.114  | 1.82E-01 | 2   |
|          | SRF (MHz)       | 851    | 12.940   | 1.52E-02 | 2   |
| Position 3 | Capacitance (pF) | 2.78   | 2.20E-03 | 7.92E-04 | 2   |
|          | Q_factor        | 1020   | 561.117  | 5.52E-01 | 2   |
|          | SRF (MHz)       | 892    | 3.359    | 3.77E-03 | 2   |

Table S4: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of a resistor’s characteristics between three measurements at each position. These measurements are taken in three trials, each set starting with position 1 and ending with position 3. The mobile component is a mixture of iron particles (0.443 g) and ferrofluid (500µl), moved with a magnet.

| Position | Characteristics | Mean   | SEM      | SEM/Mean | DoF |
|----------|-----------------|--------|----------|----------|-----|
| Position 1 | Resistance (kΩ) | 0.373  | 1.22E-02 | 3.26E-02 | 2   |
| Position 2 | Resistance (kΩ) | 0.774  | 2.67E-02 | 3.45E-02 | 2   |
| Position 3 | Resistance (kΩ) | 1.15   | 6.35E-02 | 5.53E-02 | 2   |
Table S5: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of the percentage change in characteristics of planar inductors between three different samples. The mobile component is a mixture of iron particles (0.182±0.066 g) and ferrofluid (500 µl), moved with a magnet. Inductance is measured in µH and SRF in MHz.

|          | Mean   | SEM    | SEM/Mean | DoF |
|----------|--------|--------|----------|-----|
| Inductance | 20.89  | 1.27   | 0.06     | 2   |
| Q-factor  | 39.97  | 6.59   | 0.16     | 2   |
| SRF       | 5.79   | 0.48   | 0.08     | 2   |

Table S6: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of the percentage change in characteristics of axial inductors between three different samples. The mobile component is a mixture of iron particles (0.093±0.012 g) and ferrofluid (40 µl), moved with a magnet. Inductance is measured in µH and SRF in MHz.

|          | Mean   | SEM    | SEM/Mean | DoF |
|----------|--------|--------|----------|-----|
| Inductance | 23.67  | 9.83   | 0.42     | 2   |
| Q-factor  | 174.78 | 25.66  | 0.15     | 2   |
| SRF       | 9.40   | 3.70   | 0.39     | 2   |

Table S7: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of the percentage change in characteristics of capacitors between three different samples. The mobile component is iron particles (0.186±0.003 g) moved with a magnet. Capacitance is measured in pF and SRF in MHz.

|          | Mean   | SEM    | SEM/Mean | DoF |
|----------|--------|--------|----------|-----|
| Capacitance | 13.28  | 2.49   | .19      | 2   |
| Q-factor  | 259.19 | 141.38 | .55      | 2   |
| SRF       | 17.43  | 3.84   | .22      | 2   |
Table S8: Mean, standard error of the mean (SEM), and the ratio of SEM/Mean of the percentage change in characteristics of resistors between three different samples. The mobile component is a mixture of iron particles (0.447±0.013 g) and ferrofluid (500µl), moved with a magnet. Resistance is measured in kΩ.

| Sample   | Mean  | SEM   | SEM/Mean | DoF |
|----------|-------|-------|----------|-----|
| Resistance | 187.23 | 2.48  | 0.01     | 2   |

Table S9: The correlation between the resulting inductance of planar inductors (µH) and the position of the mobile component. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is a mixture of iron particles (0.182±0.066 g) and ferrofluid (500µl), moved with a magnet.

| Sample | Regression Equation | R²   |
|--------|---------------------|------|
| 1      | y = -0.36x + 4.49   | 0.978|
| 2      | y = -0.37x + 4.41   | 0.9705|
| 3      | y = -0.30x + 4.22   | 0.9958|
| 1,2,3  | y = -0.35x + 4.37   | 0.9259|
Table S10: The correlation between the resulting inductance of axial inductors (µH) and the position of the mobile component. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is a mixture of iron particles (0.096±0.001 g) and ferrofluid (40 µl), moved with a magnet.

| Sample | Regression Equation | R²     |
|--------|---------------------|--------|
| 1      | y = 0.25x + 0.43    | 0.9549 |
| 2      | y = 0.83x + 0.31    | 0.9608 |
| 3      | y = 0.83x + 0.31    | 0.9608 |
| 1,2,3  | y = 0.64x + 0.35    | 0.8094 |

Table S11: The correlation between the resulting capacitance of capacitors (pF) and the position of the mobile component. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is iron particles (0.090±0.002 g) moved with a magnet.

| Sample | Regression Equation | R²     |
|--------|---------------------|--------|
| 1      | y = -0.20x + 3.25   | 0.8597 |
| 2      | y = -0.21x + 3.19   | 0.9934 |
| 3      | y = -0.12x + 3.26   | 0.9159 |
| 1,2,3  | y = -0.18x + 3.23   | 0.6108 |
Table S12: The correlation between the resulting impedance of resistors (kΩ) and the position of the mobile component. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is a mixture of iron particles (0.447±0.013 g) and ferrofluid (500µl), moved with a magnet.

| Sample | Regression Equation | R²  |
|--------|---------------------|-----|
| 1      | y = 0.33x + 0.03    | 0.9999 |
| 2      | y = 0.33x + 0.03    | 1    |
| 3      | y = 0.33x + 0.01    | 1    |
| 1,2,3  | y = 0.33x + 0.02    | 0.9996 |

Table S13: The correlation between the resulting inductance of planar inductors (µH) and concentration of iron particles. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is a mixture of iron particles and ferrofluid, moved with a magnet. The amount of different elements in the mobile component is according to Table 5.

| Sample | Regression Equation | R²  |
|--------|---------------------|-----|
| 1      | y = 0.24x + 3.24    | 0.9931 |
| 2      | y = -0.40x + 3.36   | 0.5349 |
| 3      | y = -0.96x + 2.64   | 0.3287 |
| 1,2,3  | y = -3.01x + 3.41   | 0.1553 |
Table S14: The correlation between the resulting inductance of axial inductors (µH) and concentration of iron particles. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is a mixture of iron particles and ferrofluid, moved with a magnet. The amount of different elements in the mobile component is according to Table 5.

| Sample | Regression Equation | R²   |
|--------|---------------------|------|
| 1      | y = 1.95x + 4.36    | 0.9956 |
| 2      | y = 1.40x + 3.72    | 0.9748 |
| 3      | y = 2.12x + 4.18    | 0.9987 |
| 1,2,3  | y = 2.04x + 4.07    | 0.0321 |

Table S15: The correlation between the resulting capacitance of capacitors (pF) and concentration of iron particles. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is a mixture of iron particles and ferrofluid, moved with a magnet. The amount of different elements in the mobile component is according to Table 5.

| Sample | Regression Equation | R²   |
|--------|---------------------|------|
| 1      | y = 2.37x + 2.82    | 0.9843 |
| 2      | y = 1.54x + 2.55    | 0.999 |
| 3      | y = 2.05x + 3.17    | 0.9666 |
| 1,2,3  | y = 1.97x + 2.85    | 0.0331 |
Table S16: The correlation between the resulting impedance of resistors (kΩ) and concentration of iron particles. These correlations are calculated separately for each sample as well as between all three samples. The mobile component used is a mixture of iron particles and ferrofluid, moved with a magnet. The amount of different elements in the mobile component is according to Table 5.

| Sample | Regression Equation | R²   |
|--------|---------------------|------|
| 1      | y = -0.27x + 0.46   | 0.9974|
| 2      | y = -0.30x + 0.49   | 0.9004|
| 3      | y = -0.89x + 0.38   | 0.9723|
| 1,2,3  | y = -0.21x + 0.44   | 0.5351|
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