Design and optimization of microfabricated planar coils for tactile displays

Juan Jose Zarate [a], Giordano Tosolini [b], Simona Petroni [b], Herbert Shea [a], Massimo De Vittorio [b]

[a] LMTS, Ecole Polytechnique Fédérale de Lausanne (EPFL), Neuchâtel 2002, Switzerland
[b] Center for Biomolecular Nanotechnologies @UNILE, Istituto Italiano di Tecnologia, Via Barsanti, Arnesano, 73010 Lecce, Italy

e-mail: giordano.tosolini@iit.it, juan.zarate@epfl.ch

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The sense of touch has a fundamental role for visually impaired people. The benefit of a personalized and portable tactile display that translates images into bas-reliefs would be immeasurable. Magnetostatic micro-actuators based on the interaction between a magnet and a coil-induced magnetic field can be used as a building block for a tactile display, i.e. as a tactile equivalent to the pixel (*taxel*). 3D wirewound inductors approach has been proposed to this respect but the scale up to large taxels arrays is quite challenging [1]. In view of this, here we present a novel analytical approach, complemented with finite element simulation (FEM) and experimental studies to optimize the interaction force between a planar microcoil and a bulk magnet to obtain a taxel with a diameter of 4 mm, i.e. comparable with tactile two-point discrimination threshold [2] and inter-dot distances of Braille cells. The coils have been microfabricated and experimental values of the magnetostatic force and power have been measured to validate the theoretical model.

We developed an analytical model to study the interaction force between a magnet and a planar coil, on the basis of previous theoretical studies in the field [3][4]. Furthermore, the electrical power applied to the system was computed in order to take into account also the consumption and dissipation constraints. Then, both the magnetic force and the electrical power were combined to analyze the influence of different design parameters, including distance between magnet and coil, magnetization, radius and height of the magnet and the dimensions of the coils: trace width (w) and separation between traces (s), thickness (t), number of turns (N), maximum and minimum radius of the coils (a_{max}, a_{min}).

In order to experimentally validate the analytical model, we fabricated different designs of planar microcoils. The generic structure of the coil consists of a multi-turn, one or two level metal layer spiral. Parameters w and s varies from 10 µm to 50 µm while the ratio a_{min}/a_{max} varies between 300/1700 µm and 800/1200 µm (i.e. N varies from 8 to 35). The microfabrication process starts with the sputtering of a 2 µm thick aluminum layer on a SiO_2-Si substrate followed by dry etching patterning. A 2 µm thick silicon oxide layer is sputtered to insulate the first metal layer. Afterwards, the via holes are opened into the SiO_2 by wet etching, a second layer of aluminum is deposited via sputtering and defined by dry etching. In figure 1 and 2, we report an optical image of a die with different coils designs and a SEM micrograph of a coil detail at the end of the fabrication process. We obtained a yield higher than 80%, being the coils with w=10 µm and s=5 µm the most critical ones. In order to study the system in an array of 3x3, we also fabricated planar microcoils with wider w/s on a printed circuit board (PCB).

The planar coils were experimentally tested to obtain values of magnetic force and power dissipation as function of the design parameters. The same systems were studied also via FEM simulation using Comsol software, then both experimental and simulation results were compared with the analytical model, obtaining very good agreement. Since the magnetic force increases linearly with the current I but the dissipated power scales with I^2, the value of magnetic force can be scaled up or down multiplying by the square root of the desired power. As an example, in figure 4 the results of the magnetic force are presented in a $F/\sqrt{P}$ vs coil-to-magnet spacing graph. For all the systems under study, force values in the range from 5 and 20 mN/√W were obtained, depending on magnet dimensions and the fabrication technology. While these values agrees with requirements for a first prototype of taxel, such force values can be improved by increasing the number of layers, increasing their thickness or adding a magnetic backplane.

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[1] J. Streque, A. Talbi, P. Pernod, V. Preobrazhensky, J. Micromech. Microeng. 22 (2012) 095020.
[2] J. Tong, O. Mao and D. Goldreich. Front. Hum. Neurosci. 7 (2013) 579.
[3] A Kruusing, Sensor. Actuat. A-Phys. 101 (2002) 168-174.
[4] A. Feustel, O. Krusemark, J. Müller, Sensor. Actuat. A-Phys. 70 (1998): 276-282.

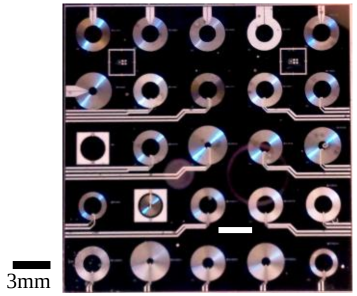

Figure 1. Die at the end of the fabrication process: there are 25 different designs of planar micro-coils

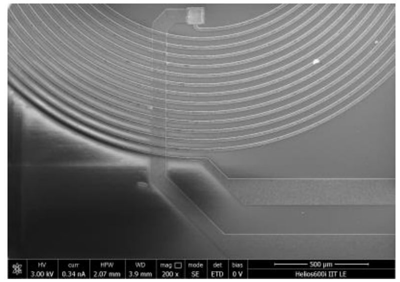

Figure 2. SEM micrograph of a one metal layer spiral micro-coil. The lower metal layer lead and the upper metal layer spiral inductor can be easily identified in the image.

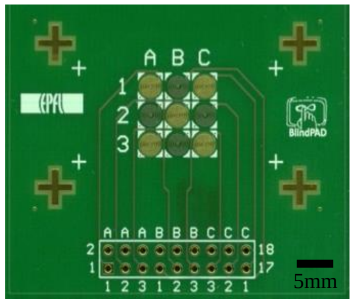

Figure 3. Image of one of the PCB's coil array used for testing different parameters designs. This example corresponds to a double conductive layer PCB, with a 35 µm Cu thickness each layer, w/s= 150/150 µm and N=4.

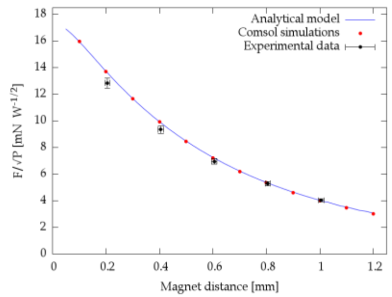

Figure 4. Magnetic force F, normalized by the squared root of the applied power P, as a function of the distance d between the magnet and the coil top surface. The results of the analytical model, the FEM Comsol simulations and the experimental measurements on the PCB are reported in the graph. The FEM simulations perfectly agree with the analytical model, while the experimental results are just 5% lower than the model predicted values.