Modular multi-channel parallel-imaging microfluidics platform with exchangeable capillary diameters

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Introduction

We present a parallel low-cost MR receiver array for microfluidic analysis. The platform is based on a standard printed circuit board (PCB) process and a laser cut PMMA. Each PCB holds four glass capillaries. Each capillary has a solenoidal pick-up coil wrapped around it. The coil forms part of a resonant tuning and matching circuit, which is connected to a channel of the MRI spectrometer via co-axial cable. The PMMA layer holds the capillaries in position and simplifies the microfluidic connection to the capillaries. By using a rapid prototyping laser cutter the setup is easily adjusted to different capillary diameters. The resonant circuits are tuned to 400 MHz for use in a Bruker 9.4 T Scanner in which first measurements were made.

Modular capillary holder

The array holder is a three layer substrate stack. Its lowest layer is an MR-compatible mechanically robust PCB, that also provides all electrical connections. On top is a 2 mm PMMA frame which is attached to the PCB using a sticky semitransparent 150 µm thick 3M foil. The PMMA aligns the capillaries w.r.t. the PCB (and hence to the B_0-field of the MR-scanner) and eases the fluidic connection to the capillaries. One area of the PCB is used to connect the coils electrically. The second area contains the other electrical parts of the resonance circuit and the cable connector to the scanner. The PCB has space for four capillary setups.The PCBs are stacked vertically to form an array that is theoretically limited by the number of available measurement channels. The platform is used in receive mode in the 9.4 T scanner, and hence needs to fit into the 72 mm bore of the transmit coil, thereby currently limiting the stack to three layers or 12 channels as shown in Figure 1. The PMMA is micromachined with a rapid prototyping infrared laser. This approach allows an adaption of the system to different types of capillaries and coils. The PMMA layer has an opening at each end of the capillary forming a vial. The capillary is fixed in the holder using thermally setting glue. The glue also seals the vials. A liquid that is inserted into a vial is held there by surface tension forces, and additionally is sucked into the capillary. An initial version of this device using highly precise MEMS techniques, consisting of SU8 on a gold track carrying wafer was reported [1]. The new approach is not only considerably cheaper but also allows rapid reconfiguration due to the laser process. Through heating the thermosetting glue, the capillaries are easily replaced and allows reuse of the PCBs.

Tuning and matching circuit

Rotating transverse magnetisation from nuclear spins of the fluid creates an induction voltage in an electric conductor in the vicinity. For this purpose a solenoidal coil that is part of a resonant circuit is intimately wound around the capillary to pick up the MR signal of the fluid´s spins. The resonant circuit that filters the signal consists of the coil and additionally of three capacitors, which are used to tune to a resonance frequency of 400 MHz and to match the circuit to the 50 Ω of the scanner cable. Being solenoids, the coils do not significantly couple to each other.

Solenoidal wire coils

The setup is designed to take different types of receiver coils. Coils of type 1 are made of a manually wound copper wire. For this approach the inductances of the coils varies from coil to coil. Having tuning and matching capabilities for each coil this can be compensated for. Figure 2 shows the frequency response of the wire coils. The Q-factor is around ~42, the coils should therefore have good receiving properties.

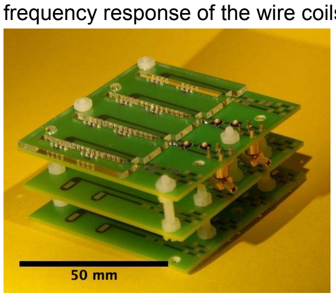

Fig 1: Photo of a stack of 3 PCBs with 12 parallel receive channels.

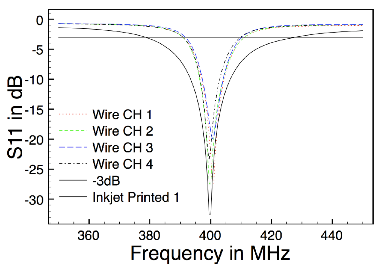

Fig. 2 Frequency response of four wire coils and one inkjet printed coil.

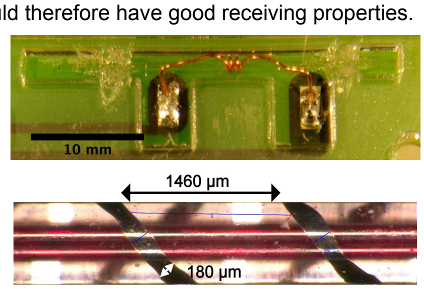

Fig. 3: Pictures of a wire coil in the holder and an inkjet printed silver coil.

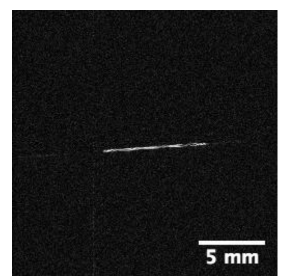

Fig. 4: FLASH image with a fluid filled inkjetted capillary.

Printing solenoidal coils directly on the cylindrical glass capillary

A more precise and yet very flexible way of manufacturing the solenoid is by inkjet printing. The feasibility of inkjet printing as a production technique for surface MR receiver coils was already shown [2]. A custom-made inkjetting platform allows the printing of silver suspensions on rotating substrates [3]. This enables us to directly inkjet-print multilayer silver tracks on the glass capillaries (Figure 3). The technique provides good reproducibility while maintaining large variability with regard to the shape of the coils, unlike other techniques that only allow for equidistant windings [4]. The frequency response of an inkjet printed coil is also shown in Fig. 2. Figure 4 shows first results of MR experiments using a Bruker 9.4 T scanner to image a fluid-filled capillary in which the inkjet printed coil was used for reception of the MR signal.

Conclusions and outlook

A cheap and versatile parallel imaging system for small volume detection was developed. The device allows the use of different disposable capillary diameters and repeated reuse of the PCB substrate. The system shows good frequency responses and also provided first reasonable MR images. The next step is to make multiple measurements with the setup for various capillary diameters and coil shapes to optimise the signal. The setup could allow a faster and more reliably production of micro-receiver coils than hand-wound ones.

References

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