NUMERICAL INVESTIGATION OF A SELF-DETUNING SIGNAL ENHANCEMENT METASURFACE FOR 3T MRI

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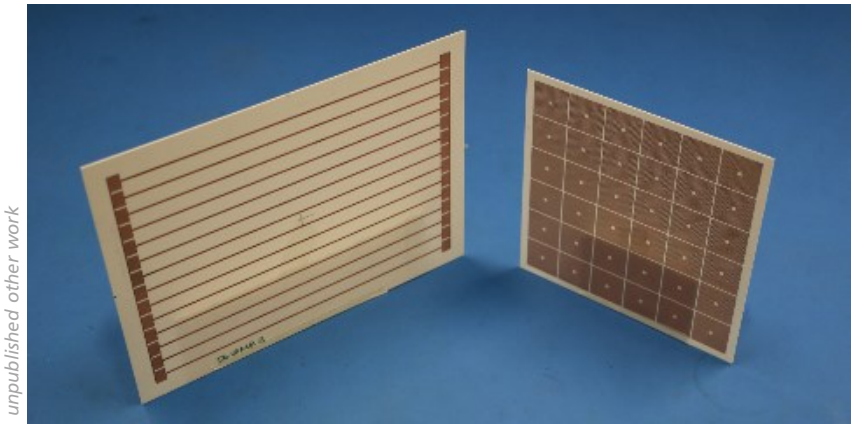
OUTLINE

- Metamaterials in Magnetic Resonance Imaging
- Self-detunable metasurface enhancement plate (EP)
- Design and device performance in numerical simulations
- Preliminary on-bench measurements
- Conclusions

Metamaterials in MRI

- Metamaterials
  - Artificial or composite materials specifically designed to achieve certain macroscopic propagation properties, typically periodic, microscopic structures (<< λ)
  - Achievable effects: effective material properties, dispersion properties, stop bands, surfe waves, leaky waves, anistropy

- Application in MRI
  - Focus on B_1 field manipulation
  - Sheath current suppression
  - Perfect magnetic lens (μ = -1)
  - Signal amplification effect



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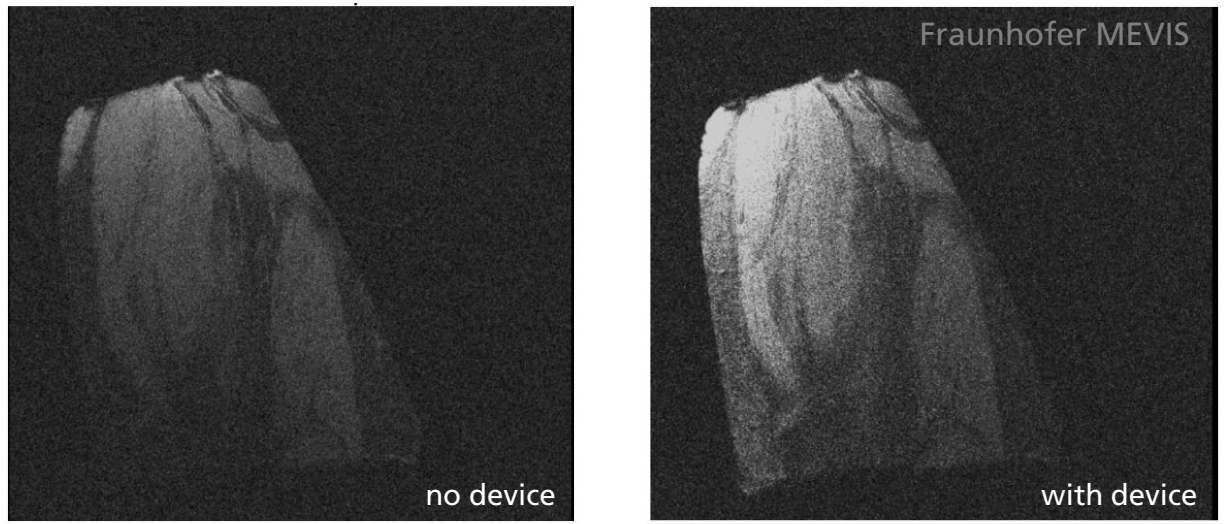
Preliminary ex-vivo results



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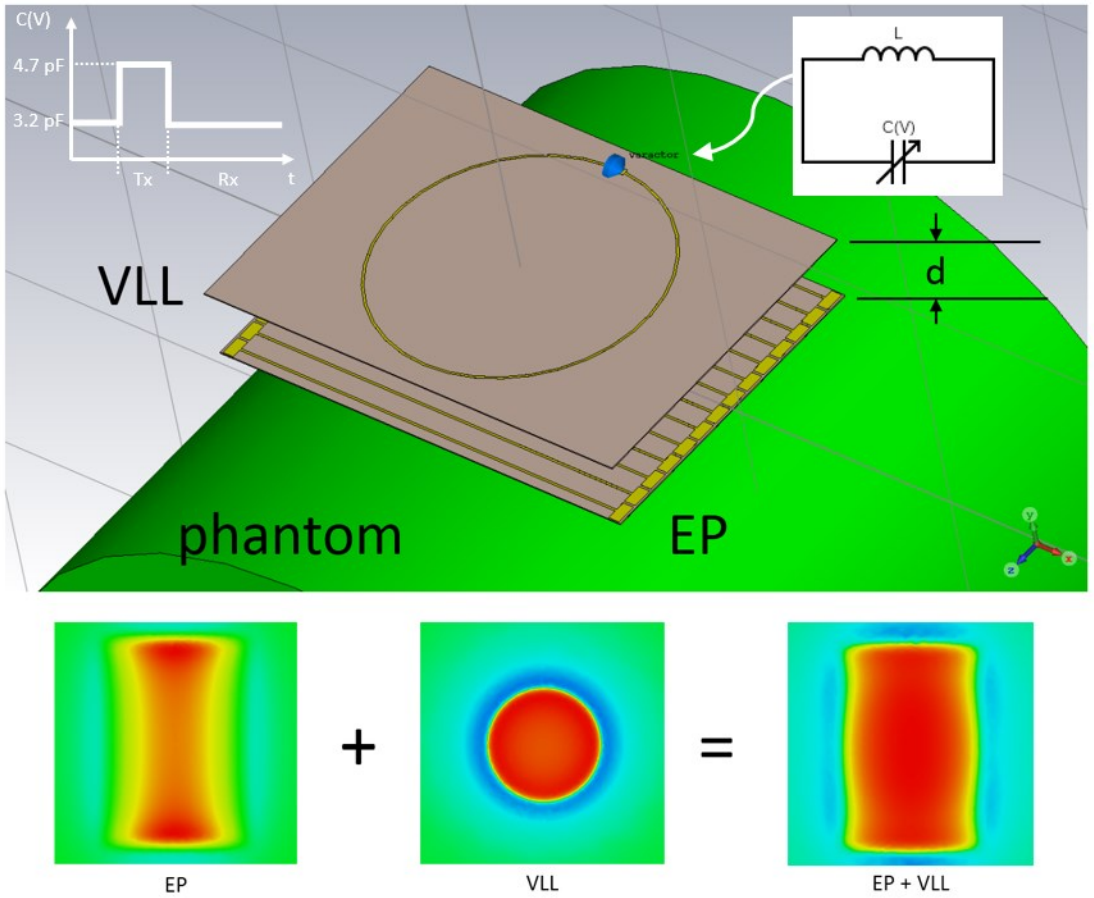
Motivation and operational principle

- Provides local SNR increase by enhancing the B_1 field during both Tx and Rx phases
- However, if not detuned during Tx:
  - modifies the target flip angle in the region of interest (ROI)
  - patient safety issues

- The system is composed of:
  - A 2D metasurface consisting of closely-coupled capacitely-loaded resonant wires (EP)
  - A varactor-loaded conductive loop (VLL)
- The hybrid eigenmodes that result from the coupling are exploited for signal enhancement



Design of the EP: eigenmode

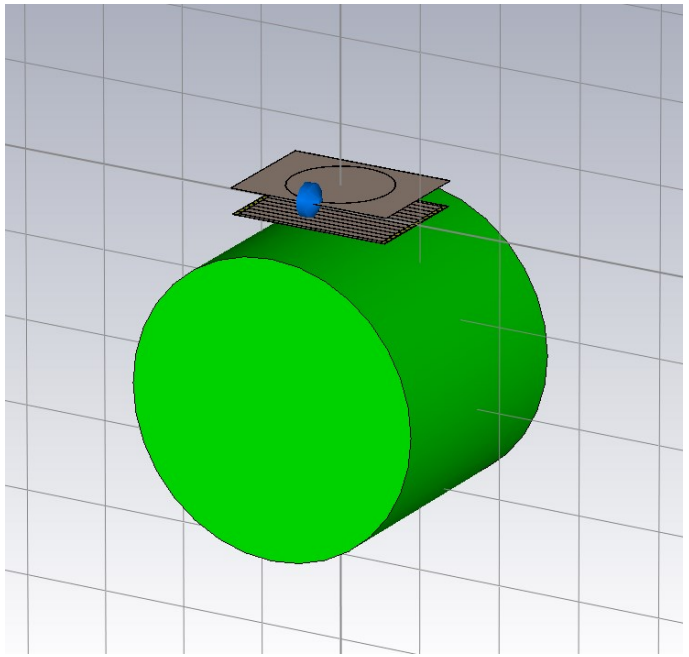
- Eigenmode simulations were adopted to tune the hybrid mode of the self-detunable EP to 123.5 MHz, operational frequency of an available 3T scanner

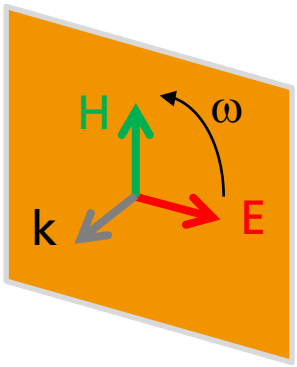
- Enhancement Plate: composed of 14 copper stripes 180 mm long and 1 mm wide, 10 mm distant from each other, the capacitive patches are 9 mm wide and 5 mm long, the EP alone resonates at about 141 MHz
- Varactor-loaded loop: 60 mm radius, 1 mm wide, loaded by a varactor modelled in simulation as a two-state switchable capacitance of values 3.2 pF and 4.7 pF during Rx and Tx respectively, the VLL alone resonates at 131.4 and 110 MHz
- The coupled system resonates at 123.45 and 147.3 MHz
- By varying the distance between the two PCBs, some fine tuning can be performed. The best result was obtained for a distance d = 30 mm.

- Both structures are meant to be laser milled on RO4003 substrate

Device performance: full wave simulations

- The device in presence of a phantom is excited by a circularly polarized plane wave
- A homogeneous phantom of 350 mm radius and 200 mm axial extent is included to account for loading in a realistic MR experiment
- The device is postioned 10 mm above the phantom
- Open boundary conditions were adopted





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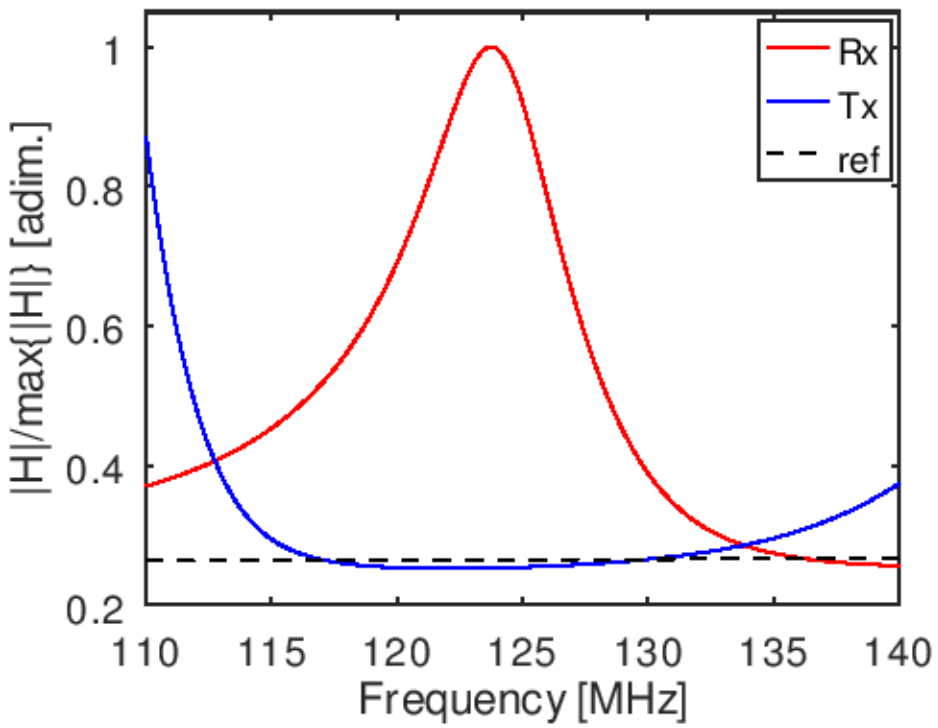
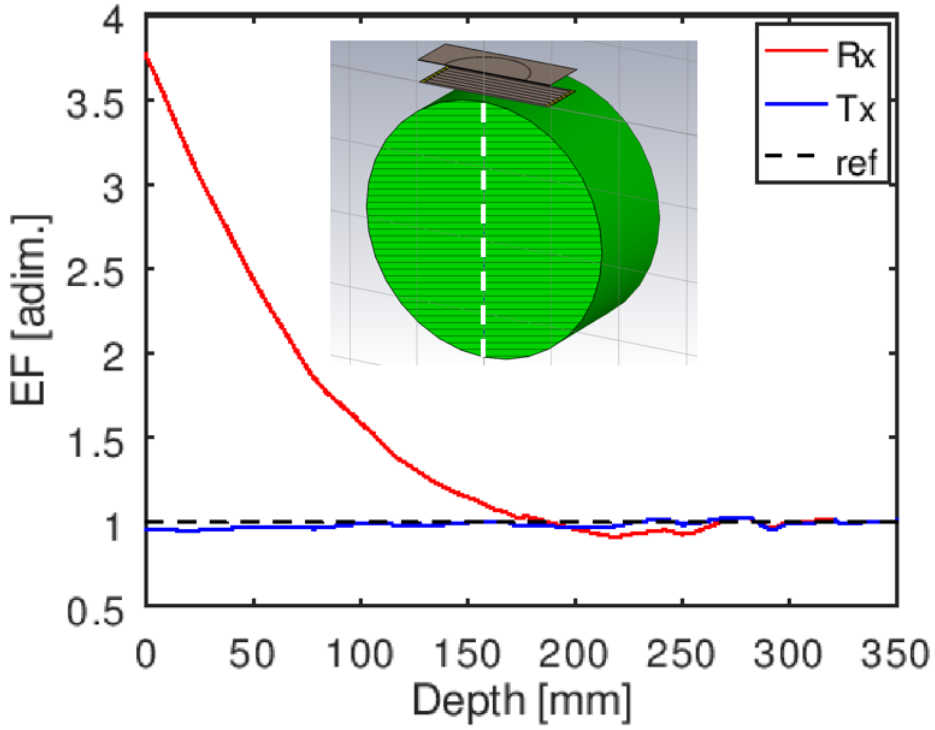
Device performance: results

H-field at phantom's surface



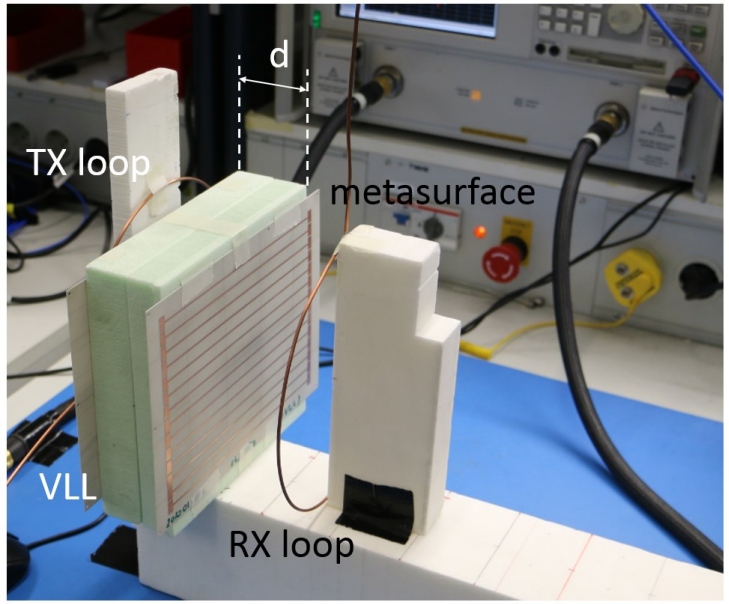
H-field enhancement along monitoring line at 123.5 MHz

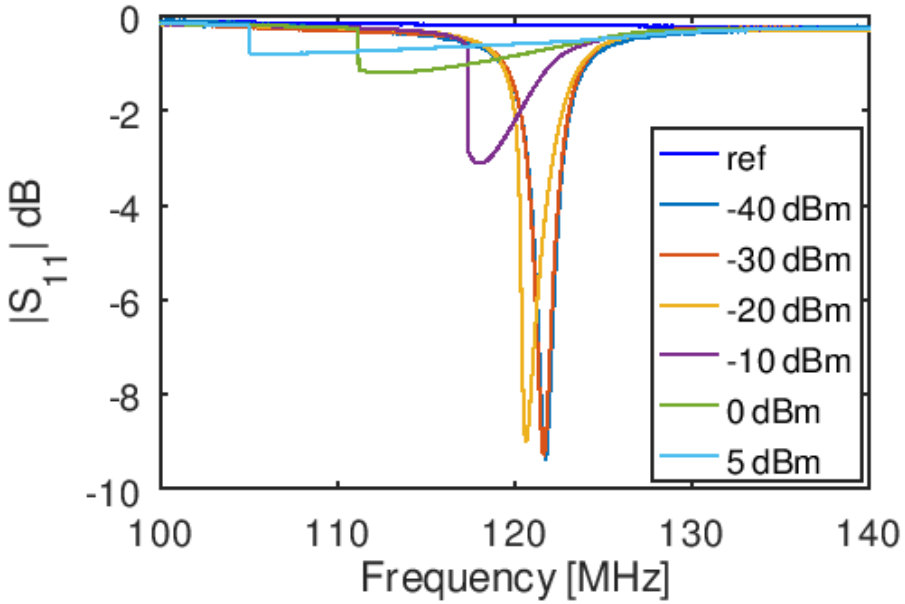


- Maximum enhancement factor at 123.74 MHz (slightly higher than the eigenmode predicted one, 3.77 at 123.5 MHz)
- Enhancement up to a depth of 175 mm during Rx phase, very small attenuation during Tx

Preliminary on-bench measurements

- A prototype was manufactured (after the submission deadline) and tested on bench with a typical setup to observe the detuning of the plate at increasing incident power (Port 1 of PNA)
- The detuning can be observed by looking at the S_{11} plots at varying incident power.





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Conclusions

- A self-detuning signal enhancement device composed of a metasurface and a varactor-loaded conducting loop has been presented
- Self-detuning during Tx phase allows for correct flip angle excitation and provides for patient safety
- During the Rx phase, the system supports a hybrid mode resonating at 123.5 MHz leading to a field enhancement by a factor larger than three, while the penetration depth is shown to coincide with the lateral dimension of the enhancement plate.
- A first prototype of the numerically investigated device has been manufactured and preliminary lab measurements show the correct detuning at increasing incident power
- A custom-made MR measurement protocol allows to separate effects on the Tx and Rx signals (to be performed)