# Improving SNR of 1.5T MRI using Flexible Magnetic Metasurfaces based on Rectangular Windings

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*Abstract*— **Magnetic resonance imaging (MRI) has become an essential non-invasive imaging technique for diagnosing pathological diseases and therapeutic follow-up. The signal-to-noise ratio (SNR) of these conventional MRIs can be enhanced by wrapping different human body parts undergoing MRI scans with metasurfaces. Flexible metasurfaces can uniformly boost the image resolution of different scan slices of MRI irrespective of body part curvatures, which cannot be achieved by using rigid metasurfaces inside MRI scanners. Here, a magnetic metasurface based on rectangular-windings is demonstrated to boost SNR by ~12 times inside phantoms mimicking human body for 1.5 T MRI. The proposed metasurface can be integrated as "flexible add-ons" inside commercial body-specific MRI coils for improved imaging.**

***Keywords—flexible metasurfaces, signal-to-noise ratio, magnetic resonance imaging***

## I. INTRODUCTION

Over the years, magnetic resonance imaging (MRI) has become an increasingly popular and reliable diagnostic tool in modern healthcare [1]. This non-invasive imaging technique does not expose a patient to ionizing radiations. MRI uses high magnetic field and its gradients with radiofrequency (RF) signals for imaging the organs inside a human body [1,2]. A typical 1.5 T MRI procedure takes around 30–40 minutes with several different scans, each 5–10 minutes long and of slightly different contrast [2,3]. However, the imaging quality is limited by the available signal-to-noise ratio (SNR), and achieving a higher resolution to resolve finer details demands an impractically long image acquisition time [3, 4].

Metasurfaces can localize strong electromagnetic near-field in the vicinity of its unit cells, which can be engaged to shape the RF field distribution in the volume of interest under study during an MRI scan [2]. Thus, the use of metasurfaces was proposed for improving 1.5 T MRI's performance by either increasing the SNR, which leads to better image quality or reduced scan time for usual image quality [2].

However, these reported magnetic metasurfaces for 1.5T MRIs are rigid in shape and thus could not be wrapped around different shapes of the subject's body parts undergoing scan [4,5]. In this manuscript, we develop a flexible magnetic metasurface based on a 2D array of rectangular windings capable of boosting SNR by a magnitude of 12 and promising to be compatible for use in the clinical 1.5T MRI machines. The proposed flexible magnetic metasurface of merely 0.18 mm thickness can act as an "add-on" to the existing MRI scanners. Moreover, it can be wrapped around various body parts such as knees, thighs, *etc.*, for a uniform and substantial boost of SNR, which will result in improved imaging.

## II. DESIGN, RESULTS, AND DISCUSSION

Fig. 1. demonstrates the top and bottom views of the metasurface (an array of 8 × 8 of unit cells), which constitutes polyimide substrate (thickness of 0.11 mm) sandwiched between a 2D array of rectangular windings and square patches of copper (thickness of 0.035 mm). The rectangular windings have a strip thickness $b = 0.5$ mm with a gap of $g = 0.5$ mm between these strips. The inner radius of the windings is $r = 6$ mm with a square patch of length $d = 5$ mm attached to the center of the windings. The bottom side of the unit cell constitutes a square patch of length $D_u = 29$ mm. The size of the unit cell is $L_u \times L_u = 30$ mm × 30 mm. For numerical study, a cylindrical phantom is created of radius 100 mm which mimics the properties of a human body

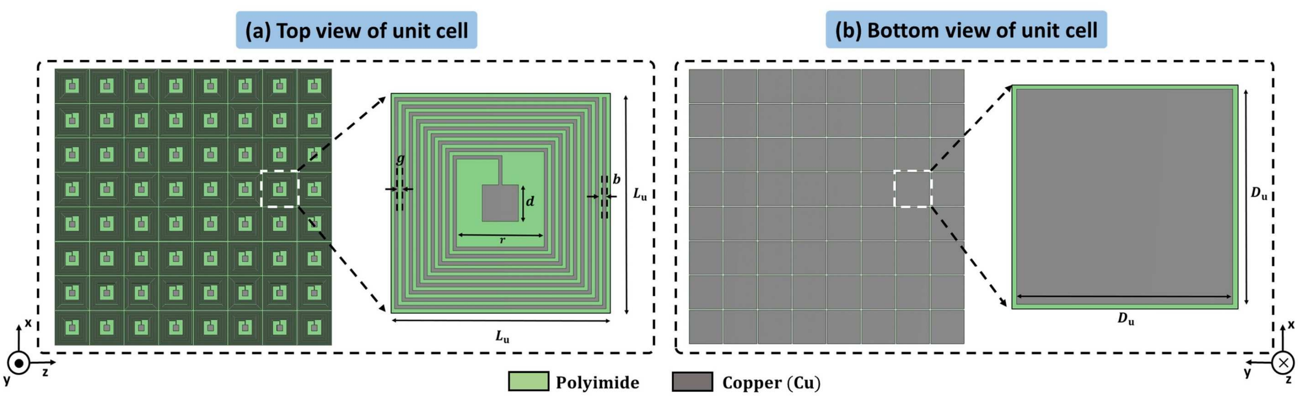


Fig. 1. (a) Top and (b) bottom view of the designed metasurface. The metasurface constituting polyimide substrate sandwiched between the top layer comprising an 8 × 8 array of rectangular windings and the bottom side comprising 8 × 8 array square patches of copper. A zoomed-in view of the unit cells are also demonstrated for both the top and bottom views of the metasurface.

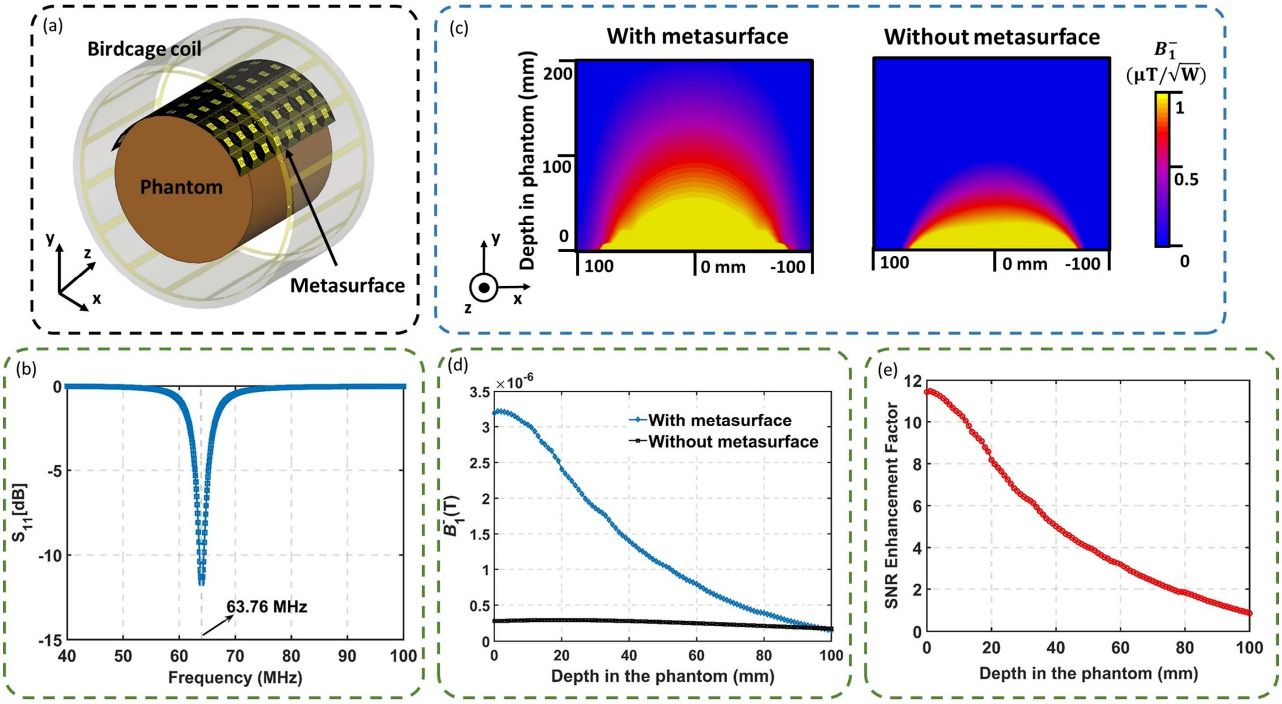


Fig. 2. (a) Simulation view of a phantom wrapped by our proposed metasurface inside a birdcage coil. (b) Frequency response of the reflection coefficient. (c) Comparison of received magnetic field distribution $|B_1^-/\sqrt{P_{\rm abs}}|$ inside the phantom with and without the magnetic metasurface. (d) $B_1^-$(T) along the depth of the phantom. (e) SNR enhancement factor as a function of depth in phantom.

[2]. The phantom is wrapped by the designed metasurface and uniformly excited by a birdcage coil (16 −rung high pass designed in CST Microwave Studio Suite®). Spiral resonators can act as resonant magnetic unit cells as they generate magnetic dipoles due to circulating currents on the metallic spirals when excited by an RF source [3]. The proposed metasurface resonates at the operating frequency of 1.5T MRI ($f_0$ = 63.8 MHz, see Fig. 2b) and significantly boosts the received magnetic field with higher field penetration inside the phantom compared to the scanning setup without the metasurface, as shown in Fig. 2(c & d). The SNR of the birdcage coil is proportional to the ratio of the received RF magnetic field $B_1^-$ and the square root of the accepted power $P_{\rm abs}$ of the coil [5].

$$\mathrm{SNR} \propto \frac{B_1^-}{\sqrt{P_{\rm abs}}} \quad (1)$$

Both $B_1^-$ and $P_{\rm abs}$ are measured in simulations for one unit of current fed to the coil. The SNR enhancement factor inside the phantom is calculated as [6, 7]:

$$\text{SNR Enhancement Factor} = \frac{\mathrm{SNR}_{\rm with\_metasurface}}{\mathrm{SNR}_{\rm without\_metasurface}} \quad (2)$$

Numerical simulations demonstrate the SNR is enhanced by a factor of ∼12 on the surface of the phantom, and the enhancement factor remains above unity inside the phantom till the depth of 100 mm, as shown in Fig. 2(e). Thus, the proposed magnetic metasurface, when used as a "flexible add-on," should be able to boost the quality of MRI scans of human body parts with different curvatures.

## III. Conclusion

A flexible rectangular windings-based magnetic metasurface is exhibited to boost the SNR by ∼12 times on the surface of a human-properties mimicking phantom to be fit inside a commercial birdcage coil for 1.5 T MRI. The metasurface can conform according to the shapes of different human body parts. This will be useful to uniformly boost the scanned image quality from commercial 1.5T MR scanners.

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## References

[1] P.S. Jacobs *et al.*, "In vivo $B_1^+$ enhancement of calf MRI at 7T via optimized flexible metasurfaces," Magnetic resonance in medicine, 2024.

[2] J. Gupta, P. Das, R. Bhattacharjee, and D. Sikdar, "Resonating sub-wavelength metallic wires based pads for boosting signal-to-noise ratio of birdcage head coils at 1.5T MRI," Results in Physics, 53, p.106972, 2023.

[3] J. Gupta, P. Das, R. Bhattacharjee, and D. Sikdar, "Enhancing signal-to-noise ratio of clinical 1.5T MRI using metasurface-inspired flexible wraps," Applied Physics A, 129(10), p.725, 2023.

[4] J. Gupta, P. Das, T. Bhowmik, R. Bhattacharjee, and D. Sikdar, "RF Metasurface Based 'Add-Ons' for Boosting Signal-To-Noise Ratio of 1.5T MRI Scans," In 2023 National Conference on Communications (NCC), pp. 1-4, IEEE, 2023.

[5] E. A. Brui, A. V. Shchelokova, M. Zubkov, I. V. Melchakova, S. B. Glybovski, and A. P. Slobozhanyuk, "Adjustable Subwavelength Metasurface-Inspired Resonator for Magnetic Resonance Imaging," physica status solidi (a), 215(5), p.1700788, 2018.

[6] J. Gupta, P. Das, R. Bhattacharjee, and D. Sikdar, "Flexible Metasurface-Based Wraps for Improving Magnetic Field Enhancement in 1.5T MRI," In CLEO: Applications and Technology, pp. JTu2A-2, Optica Publishing Group, 2023.

[7] J. Gupta, P. Das, R. Bhattacharjee, and D. Sikdar, "A Metasurface-Inspired Flexible Structure for Boosting the Signal-To-Noise Ratio (SNR) in 1.5T MRI Scans," Indian Patent, Patent Office Journal No. 51/2023.