Self-shielded Multi-turn Surface Coils for Decoupling RF Coil Arrays in Low Field MRI

N. Reid Bolding, Sai Abitha Srinivas, Snow Lin, Aria Patel, Jessie E.P. Sun, and *Mark A. Griswold*

Department of Physics
Department of Biomedical Engineering
Case Western Reserve University
Correspondence: reid@case.edu

CASE WESTERN RESERVE UNIVERSITY
University Hospitals

Highlights

- **A method for coil decoupling is proposed.**
- **This method uses counter-wound concentric multi-loop coils to create multiple geometric decoupling methods.**
- **When these counter-wound loops with different radii are joined in series and placed coaxially, much of the Electromagnetic Interference (EMI) received by the imaging coil is canceled by the EMI received by the shielding (counter-wound) coil.**
- **The coil field magnitude in the imaging volume is minimally impacted.**
- **The shield coil introduces new geometric decoupling modes for maintaining channel independence in an array.**
- **This coil design is particularly useful at frequencies below 10 MHz.**
- **Adding turns that increase coil inductance leads to higher B1+ efficiency and allows for better shield ratios.**

Motivation: Low field MRI using RF based gradients can reduce both its cost and bulk. Multi-channel RF arrays can enable this . Effective methods to decouple these coils and mitigate EMI are necessary for building efficient RF encoding based systems.

Goal: To improve multi-channel RF array performance for low field MRI and automatically reject EMI.

Approach: Develop an array of multi-turn surface coils with concentric shields. These are verified with an EMI rejection test and geometric decoupling tests.

Results: These coils automatically reject environmental noise and add two additional geometric coupling modes when used in an array, allowing for more array configurations.

Methods

Theory: For a given multiturn surface coil with n_c turns and radius r_s, a counter loop with $n_s < n_c$ turns to remove EMI will have a radius

$$r_c = r_s\sqrt{\frac{n_c}{n_s}}.$$

This gives a counter loop with approximately the same total sensitivity to a homogenous field, which when reversed cancels EMI. If r_c and r_s are close, coil field strength is reduced in the imaging volume due to the proximity of the shield. This is remedied by increasing n_c with $r_c < r_s$.

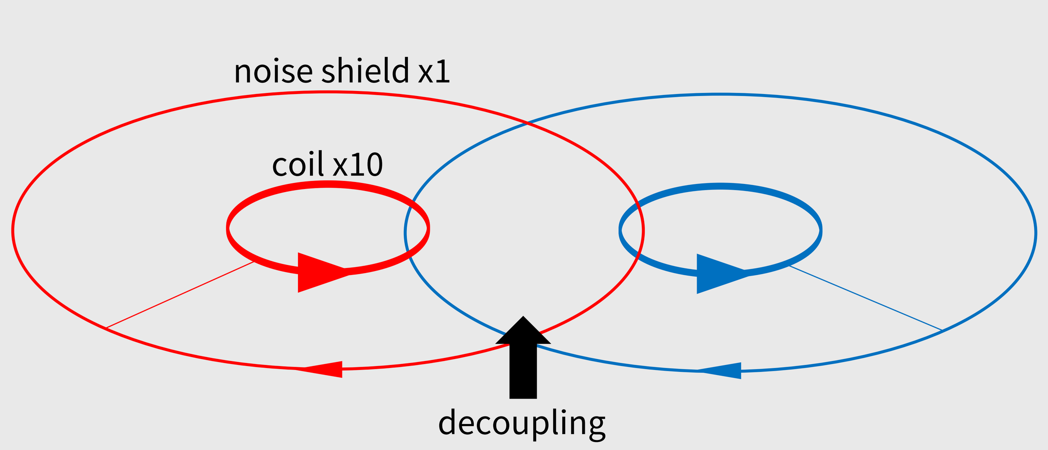
EMI mitigation : A coil with $r_s = 5$ cm with $n_s = 10$ turns is used as the imaging loop. Two configurations are tested for the counter loops:

1. $n_c = 1$ and $r_c = 15.81$ cm for a 10:1 self shielded coil.
2. $n_c = 2$ and $r_c = 10.17$cm for a 10:2 self shielded coil.

Both configurations are tuned to 2 MHz and matched. Both configurations were tested for EMI mitigation by transmitting 2 MHz from a 50 cm radius coil at 150 cm from the test setup.

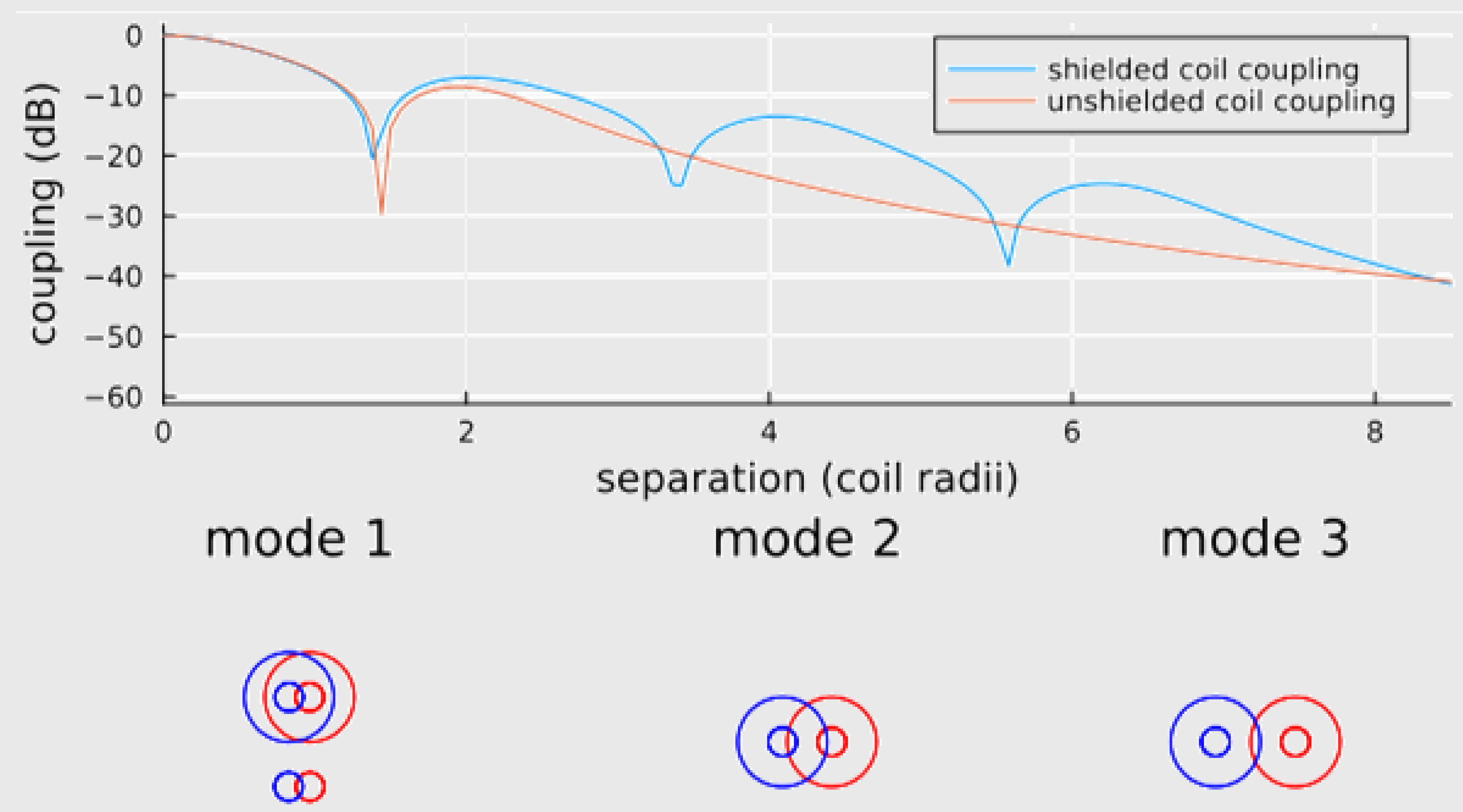
Coil decoupling: Simulations were performed to test for decoupling using two 10:1 self shielded coils by varying the distance between their centers. Three geometric decoupling modes are predicted. This includes the decoupling mode of unshielded surface coils. The new modes are shields overlapping each other, and shields overlapping each other and the coils. This is further validated experimentally by creating 3D printed formers and winding both coils. These are tuned to 2 MHz for testing. An S21 measurement into a pair of decoupled pickup-loops coupled through one shielded coil showed when the other coil was fully decoupled by independence of the first coil's tune.

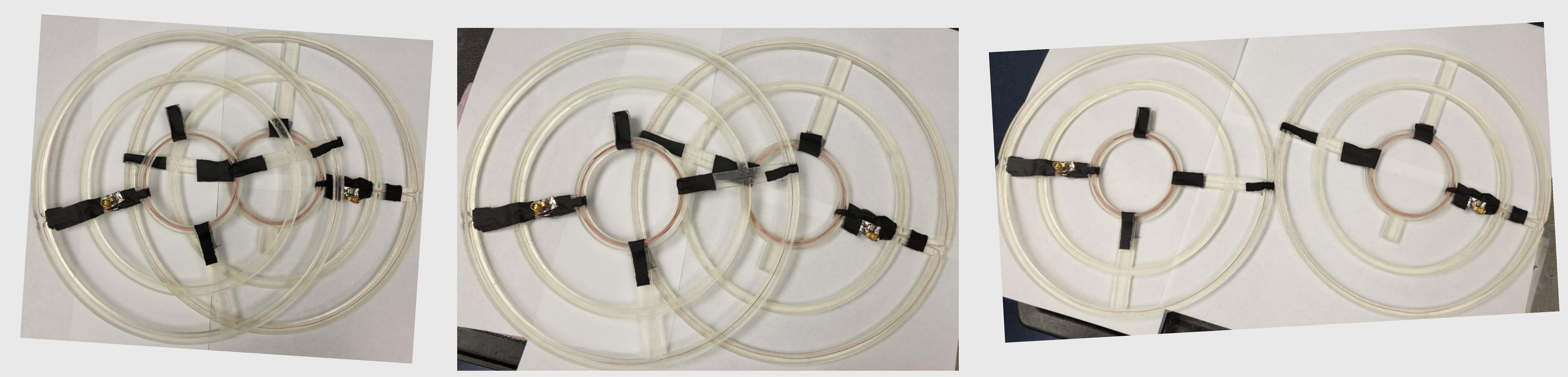
For a multi-turn coil, a concentric counter-wound shield of fewer turns can be constructed to reject EMI. When such shielded coils are used in an array, they decouple in two overlap positions in addition to the geometric decoupling position of unshielded coils.



Coupling Between Two Coils with 10:1 shields

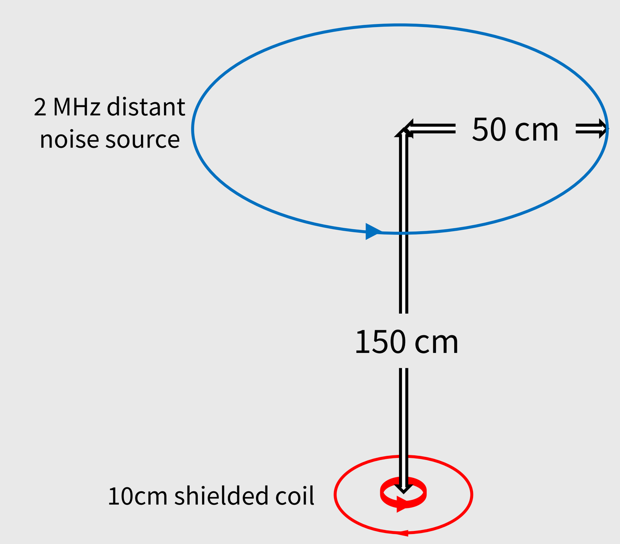
Simulation of the Biot-Savart law suggests two geometric decoupling modes for shielded coils in addition the decoupling mode of an unshielded surface coil as shown in the simulation results at the top of the figure. Indeed, the bottom of the figure shows three modes in which we found shielded coils to decouple corresponding to the simulation results. Position differences are likely due to the thickness of the actual coils which is not accounted for in simulation.

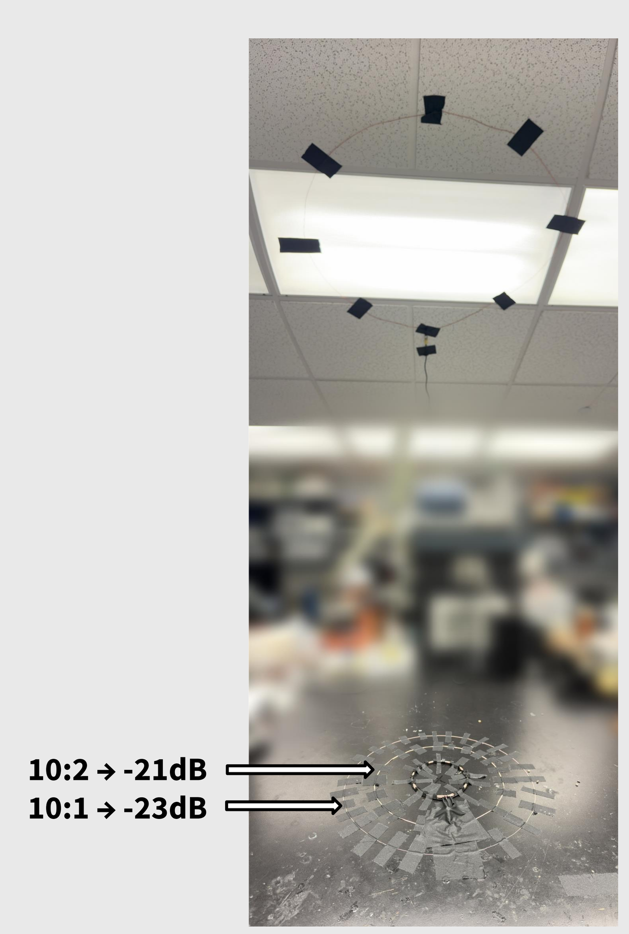




Environmental Noise Rejection

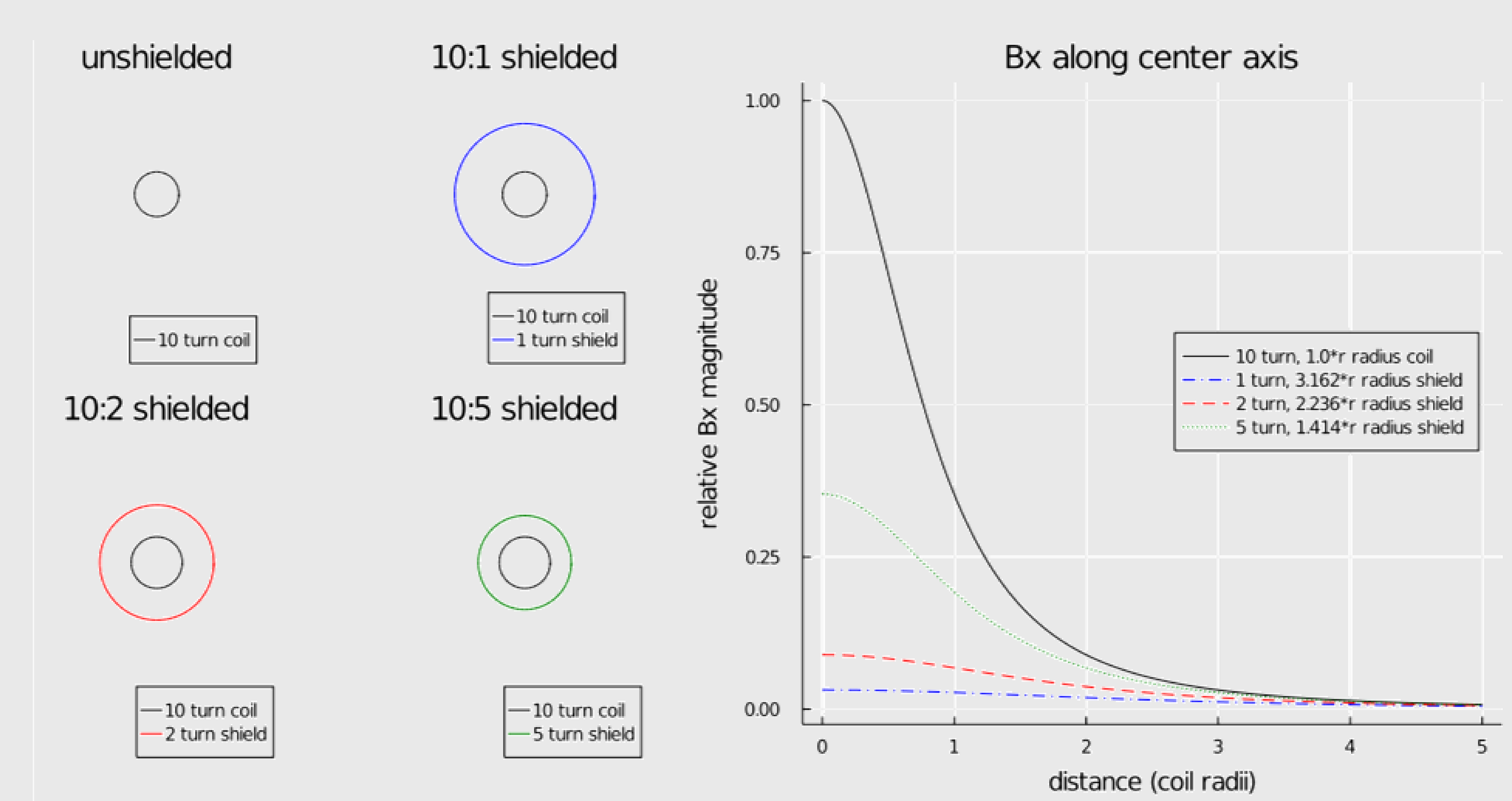
A 10:1 and a 10:2 shielded coil were tested for EMI rejection performance in this setup. Each coil was tuned and matched into a network analyzer, then the received magnitude of a 2 MHz signal from a distant source was compared with a tuned and matched unshielded coil.





Shield Diameter

Greater diameter shields have less field strength in the volume near the imaging coil and therefore cancel less of the desirable signal. Coils with a 2:1 coil to shield ratio, as has most frequently been previously investigated, are more compact, but lose more signal from the imaging volume.



Results

Noise rejection testing showed good performance with the 10:2 shielded coil and improved performance with the 10:1 shielded coil, 21dB and 23dB reductions in noise magnitude respectively relative to the unshielded 10 turn 10 cm coil.

For 10:1 coils we verified the decoupling modes, positions where the coil tunes were independent are pictured.

Discussion

In scenarios where EMI noise dominates, losing coil field strength may be worth it, otherwise it may adversely impact SNR. Having a primary coil with as many turns as possible is key to limiting the impact of the shield on imaging performance. The important feature of these shielded coils is performance in an array. While arrays are not often necessary at low field, for methods such as SENF they are essential. Adding these methods for decoupling will likely ease array construction.

For EMI mitigation, the best-case shield is a single turn. For a 10-turn coil, this radius is large, so we also compare performance to a more compact 10:2 shielded coil and show shielding is mildly reduced.

Conclusion

For low field imaging methods which rely on RF gradients for spatial information such as SENF, adding concentric shields to multiturn surface coil arrays is likely beneficial. This not only cancels some environmental noise automatically but adds additional geometric decoupling modes.

References

Lanz, T., M. Griswold. "Concentrically shielded surface coils-a new method for decoupling phased array elements." Proc Intl Soc Mag Reson Med. Vol 14. 2006.

Johns, Michael L, Fridjonsson, Einar O, Vogt, Sarah J & Haber, Agnes. “Mobile NMR and MRI: Developments and Applications”. 978-1-84973-915-3 (2016)

Acknowledgements

This research was funded by Siemens Healthineers.

View a digital copy: