

Proceedings Article

# An Experimental Study: Multi-channel Ring Receive Coil for Magnetic Particle Imaging

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## Abstract

In compact-bore MPI systems, the commonly used Opposed-pair Coil suffers from azimuthal dead zones and an insufficient filling factor. We propose a Multi-channel Ring Coil that tiles the bore circumferentially with small, interleaved elements, expanding the sensitive coverage area without increasing volume, thereby improving uniformity and sensitivity. In experiments using a magnetic dipole coil for frequency sweeps, the proposed array—under equal-volume constraints—yields a 58.9% increase in signal amplitude and a 43.9% improvement in uniformity over the Opposed-pair baseline. Moreover, each channel in the ring provides multi-angle directional information, offering richer azimuthal inputs for graph-neural-network-based array reception analysis in the future.

## I. Introduction

Opposed-pair coils are a common receive geometry because they cancel common-mode interference and are simple to build [1]. However, in compact bores they leave a substantial contact gap, leaving spatial utilization and receive strength with room for improvement. Motivated by successes of multi-channel receive arrays in MRI—where element diversity improves SNR and enables accelerated acquisitions—we explore a multi-channel geometry tailored to our setting.

In this study, we present a Multi-channel Ring Coil composed of small receive elements uniformly arrayed around the bore to cover the full aperture, with optional axial stacking of rings. Allowing partial overlap between adjacent elements at their contact regions improves utilization of the circumferential space and increases the filling factor, without increasing the footprint.

## II. Method

The receive array consists of  $2N$  identical elements uniformly distributed along the ring circumference. Two symmetric coil elements are connected in series as one group with the same winding direction. The maximum number of groups  $N$  satisfies

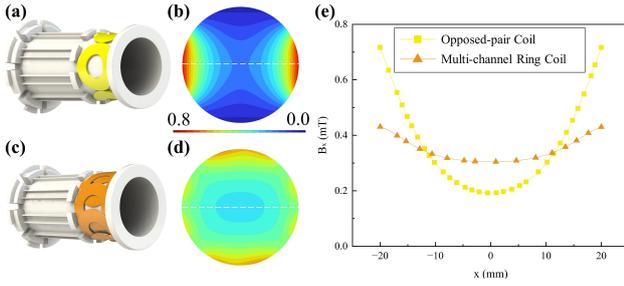
$$N \leq \frac{2\pi(R_s + d_s)}{D_c} \quad (1)$$

Here,  $R_s$  and  $D_c$  denote the aperture radius of the coil frame and the **outer radius of the coil**, respectively, and  $d_s$  is the thickness of the coil frame.

Detection of the magnetic-particle signal is realized by Faraday detection. The induced voltage in the receive coil is:

$$u(t) = -\frac{d}{dt} \int_V \mathbf{M}(\mathbf{r}, t) \cdot \mathbf{p}(\mathbf{r}) d^3\mathbf{r}. \quad (2)$$

Here,  $\mathbf{M}$  is the magnetization of the SPIONs, and  $\mathbf{p}(\mathbf{r})$  is the coil sensitivity. By reciprocity, the vector sensitiv-



**Figure 1:** Comparison of receive-coil structures and sensitivity distributions: (a), (c) Opposed-pair Coil and Multi-channel Ring Coil; (b), (d) sensitivity distribution of the Opposed-pair Coil and Multi-channel Ring Coil. (e) Sensitivity distribution of the receive coil along the  $x$ -axis.

**Table 1:** Receive coil parameters

Parameter	Symbol	Value
Turns per channel	$n_{OP}, n_{MCR}$	20, 10
Channels per array	$N_{OP}, N_{MCR}$	2, 5
Coil inner diameter	$D_c^{in}$	20 mm
Coil outer diameter	$D_c^{out}$	30 mm
Coil frame aperture radius	$R_s$	24.5 mm
Coil frame thickness	$d_s$	2 mm

ity equals the magnetic field per ampere at the SPION location [2],

$$\mathbf{p}(\mathbf{r}) = \frac{\vec{H}}{I}, \quad (3)$$

where  $\vec{H}$  is the magnetic field (A/m) produced by a test current  $I$  through the coil.

Each group in the ring array is connected to an independent acquisition channel, forming the receive sequence  $\{u_i\}$ . During processing, signals from all channels are summed to obtain a composite signal. The particle signal in an arbitrary azimuth  $\theta$  is

$$u_\theta = \sum_{i=1}^N \sigma_i u_i \cdot \omega_i, \quad \sigma_i = \begin{cases} +1, & |\varphi_i - \theta| < \pi, \\ -1, & |\varphi_i - \theta| \geq \pi, \end{cases} \quad (4)$$

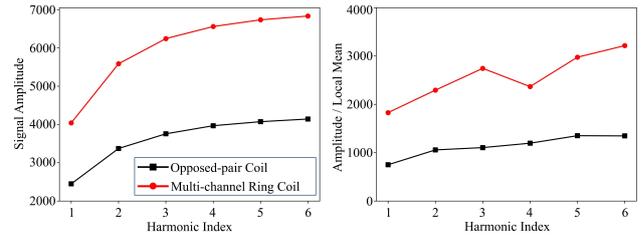
where  $\varphi_i$  is the geometric angle of the  $i$ -th coil.

We used COMSOL to simulate the sensitivities of the two coil types. Taking  $x$ -direction excitation/reception as an example, the simulation parameters are set as shown in Table 1. The sensitivity uniformity of the coil is computed as [3]:

$$\delta = \frac{p_{\min}}{p_{\max}} \times 100\%. \quad (5)$$

### III. Results

Fig. 2 illustrates the comparison of sensitivity distributions. In simulation experiments, the sensitivity of the proposed multi-channel ring array increases from 0.192



**Figure 2:** (a) Physical prototypes of the two receive coils and the test platform; (b) Signal comparison of the two receive coils.

to 0.305 relative to the traditional opposed-pair coil, representing an improvement of 58.9%. Furthermore, the sensitivity uniformity improves from 26.8% to 70.7%.

To experimentally validate the design, we fabricated the proposed coils. To compare the coil sensitivity, we built a small loop with a diameter of 10 mm and drove it with a constant current at target harmonics  $f_k = k \times f_{drive}$  ( $k = 1, 2, \dots, 6$ ), treating it as a standard magnetic dipole source. For each frequency, we recorded the per-channel transfer function  $Tr_i(f_k) = V_i(f_k)/I_i(f_k)$ . The normalized transfer function amplitude (received signal amplitude divided by input current) is presented in the left plot of Fig. 2, showing a signal increase of approximately 65%. The right plot of Fig. 2 displays the harmonic amplitude divided by the surrounding signal floor (analogous to SNR), which demonstrates a maximum improvement of 143.70%. These results indicate that the proposed multi-channel ring coil achieves significantly higher amplitude gain and sensitivity compared to the traditional orthogonal opposed-pair coil.

## IV. Conclusion and discussion

The circumferential multi-channel array improves sensitivity and angular coverage uniformity without increasing volume. In addition, the multi-channel measurements supply richer information for the subsequent image-reconstruction stage. Future work will validate the approach on the full system.

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## Author's statement

Authors state no conflict of interest.

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