This PDF file includes:

Supplementary Texts S1 and S2

Fig. S1-S4

Supplementary Text

Text S1. The case of magnetic flux splitting into two regions

The QD coil essentially divides the magnetic flux region of a square coil into four sections. To provide a comprehensive explanation of the magnetic flux folding method, we will now supplement this discussion by addressing the scenario where the magnetic flux is split into two regions. Taking a square coil as an example, the magnetic flux region is split into two D coils (Fig. S1). The wire diameter, fillet radius, and core material of the simulation model here are consistent with those in Fig. 1-4, with all having 10 turns. Based on the coil winding direction, it can be determined that Fig. S1a and Fig. S1b are equivalent. To ensure fair comparison, simulations were performed on Fig. S1b. Under conventional conditions, the equivalent mutual inductance is $|M_{ps1} + M_{ps2}|$. After magnetic flux folding, the equivalent mutual inductance becomes $|M_{ps1}| + |M_{ps2}|$. By comparing the mutual inductance curves, when displacement occurs along the y-axis, the two are equivalent. When displacement occurs along the x-axis, the folded magnetic flux effect is significant, reducing fluctuations in mutual inductance with displacement while simultaneously avoiding coupling zeros.

Similar to the main text, magnetic flux mode analysis can be performed. Considering symmetry, only the case of positive displacement is analyzed. In Fig. S1d, there are two flux states:

[State I]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} > 0$, (i = 1, 2).

[State II]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} < 0$, (i = 1, 2).

In Fig. S1e, the flux states consist of four:

[State I]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} > 0$, (i = 1, 2).

[State II]: M_{ps}, M_{ps2}, Ψ_{ps}, $\Psi_{ps2} > 0$, M_{ps1}, $\Psi_{ps1} < 0$.

[State III]: M_{ps2}, $\Psi_{ps2} > 0$, M_{ps}, M_{ps1}, Ψ_{ps}, $\Psi_{ps1} < 0$, (i = 1, 4, j = 2, 3).

[State IV]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} < 0$. (i = 1, 2).

Where $M_{ps} = M_{ps1} + M_{ps2}$, $\Psi_{ps} = \Psi_{ps1} + \Psi_{ps2}$.

For two receiving coils, the decoupling circuit is divided into two types (Fig. S2). When the two receiving coils are wound in the same direction, the mutual inductance M_{12} is negative, and an inductor is used as decoupling component. Conversely, a capacitor is employed. The compensation parameter design method is shown in Eq. (S1).

$$\begin{cases} 0 = j\omega L_{si}' + (j\omega C_{si})^{-1}\ ,\ (i = 1,\ 2) \\ 0 = j\omega L_{f1} + (j\omega C_{f1})^{-1} \\ \mathrm{j}\omega L_{f1} = j\omega L_{p} + (j\omega C_{p1})^{-1} \\ G_{v} = \dfrac{U_{o}}{U_{in}} = 2\dfrac{M_{ps}}{L_{f1}} = 2\dfrac{|M_{ps1}| + |M_{ps2}|}{L_{f1}} \end{cases} \tag{S1}$$

The equivalent self-inductance after decoupling is shown in Eq. (S2). When $M_{12} > 0$, The compensating component is a capacitor, as shown in Eq. (S3). When $M_{s1s2} < 0$, The compensating component is an inductor, as shown in Eq. (S4).

$$\begin{cases} L_{s1}' = L_{s1} - M_{12} \\ L_{s2}' = L_{s2} - M_{12} \end{cases} \tag{S2}$$

$$C_{m} = \frac{1}{\omega^{2} M_{12}} \tag{S3}$$

$$L_{m} = -M_{12} \tag{S4}$$

Text S2. The case of magnetic flux splitting into three regions

Similarly, Fig. S3a and Fig. S3b are equivalent. To ensure fair comparison, simulations were performed on Fig. S3b. Under conventional conditions, the equivalent mutual inductance is $|M_{ps1} + M_{ps2} + M_{ps3}|$. After magnetic flux folding, the equivalent mutual inductance becomes $|M_{ps1}| + |M_{ps2}| + |M_{ps3}|$. By comparing the mutual inductance curves, when displacement occurs along the y-axis, the two are equivalent. Based on symmetry, we examine the displacement along the x-axis and the line $y = -\sqrt{3}x$. When displacement occurs along the x-axis or the line $y = -\sqrt{3}x$, the folded magnetic flux effect is significant, reducing fluctuations in mutual inductance with displacement while simultaneously avoiding coupling zeros. Considering symmetry, we will also only analyze the case of positive displacement.

In Fig. S3d, there are four flux states:

[State I]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} > 0$, (i = 1, 2, 3).

[State II]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} > 0$, M_{ps2}, $\Psi_{ps2} < 0$, (i = 1, 3).

[State III]: M_{psi}, $\Psi_{psi} > 0$, M_{ps}, M_{ps2}, Ψ_{ps}, $\Psi_{ps2} < 0$, (i = 1, 3).

[State IV]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} < 0$. (i = 1, 2, 3).

In Fig. S3e, the flux states consist of three:

[State I]: M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} > 0$, (i = 1, 2, 3).

[State II]: M_{ps}, M_{ps3}, Ψ_{ps}, $\Psi_{ps3} > 0$, M_{psi}, $\Psi_{psi} < 0$, (i = 1, 2).

[State II]: M_{ps3}, $\Psi_{ps3} > 0$, M_{ps}, M_{psi}, Ψ_{ps}, $\Psi_{psi} < 0$, (i = 1, 2).

Where $M_{ps} = M_{ps1} + M_{ps2} + M_{ps3}$, $\Psi_{ps} = \Psi_{ps1} + \Psi_{ps2} + \Psi_{ps3}$.

For three receiving coils, the decoupling circuit is also divided into two types (Fig. S4). When the three receiving coils are wound in the same direction, the mutual inductances satisfy $M_{12} = M_{13} = M_{23} = M$. If two ($L_{s1}$ and L_{s2}) are in the same direction and one (L_{s3}) is in the opposite direction, the mutual inductances satisfy $-M_{12} = M_{13} = M_{23} = M$. The compensation parameter design method is shown in Eq. (S5).

$$\begin{cases} 0 = j\omega L_{si}' + (j\omega C_{si})^{-1} \ , \ (i = 1,\ 2,\ 3) \\ 0 = j\omega L_{f1} + (j\omega C_{f1})^{-1} \\ j\omega L_{f1} = j\omega L_{p} + (j\omega C_{p1})^{-1} \\ G_{v} = \dfrac{U_{o}}{U_{in}} = 2\dfrac{M_{ps}}{L_{f1}} = 2\dfrac{|M_{ps1}| + |M_{ps2}| + |M_{ps3}|}{L_{f1}} \end{cases} \tag{S5}$$

The equivalent self-inductance after decoupling is shown in Eq. (S6). When $M_{12} > 0$, The compensating component is a capacitor, as shown in Eq. (S7). When $M_{s1s2} < 0$, The compensating component is an inductor, as shown in Eq. (S8).

$$\begin{cases} L_{s1}' = L_{s1} - M \\ L_{s2}' = L_{s2} - M \\ L_{s3}' = L_{s3} - M \end{cases} \tag{S6}$$

$$C_{m} = \frac{1}{\omega^{2} M_{12}} \tag{S7}$$

$$L_{m} = -M_{12} \tag{S8}$$

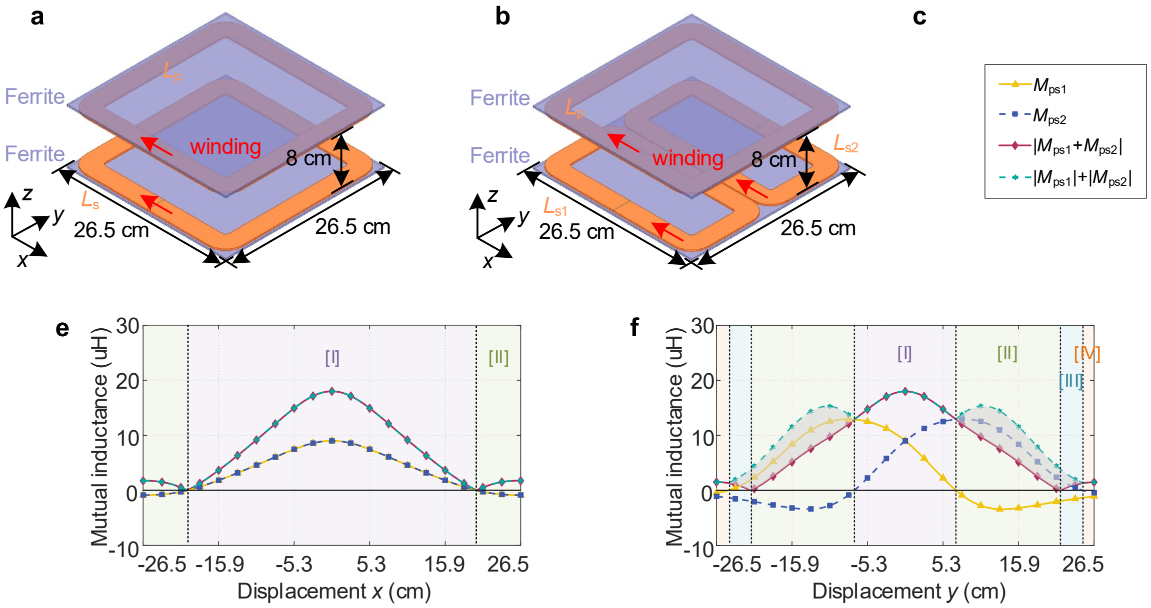

Fig. S1. Schematic and mutual inductance curves of transmitter and two receiver coils with displacement. a, b Overall diagram of transmitter square coil and (**a**) receiver square coils, (**b**) receiver two D coils. **c** Mutual inductance curves legend. **d**, **e** Mutual inductance curves with source square coil of displacement along the (**d**) *x*-axis and (**e**) *y*-axis.

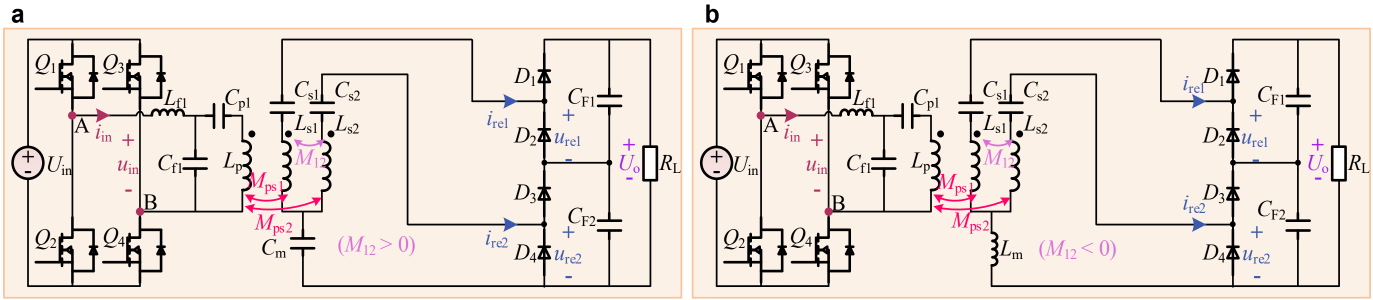

Fig. S2. Schematic diagrams of two coils decoupling. a One decoupling capacitor. **b** One decoupling Inductor.

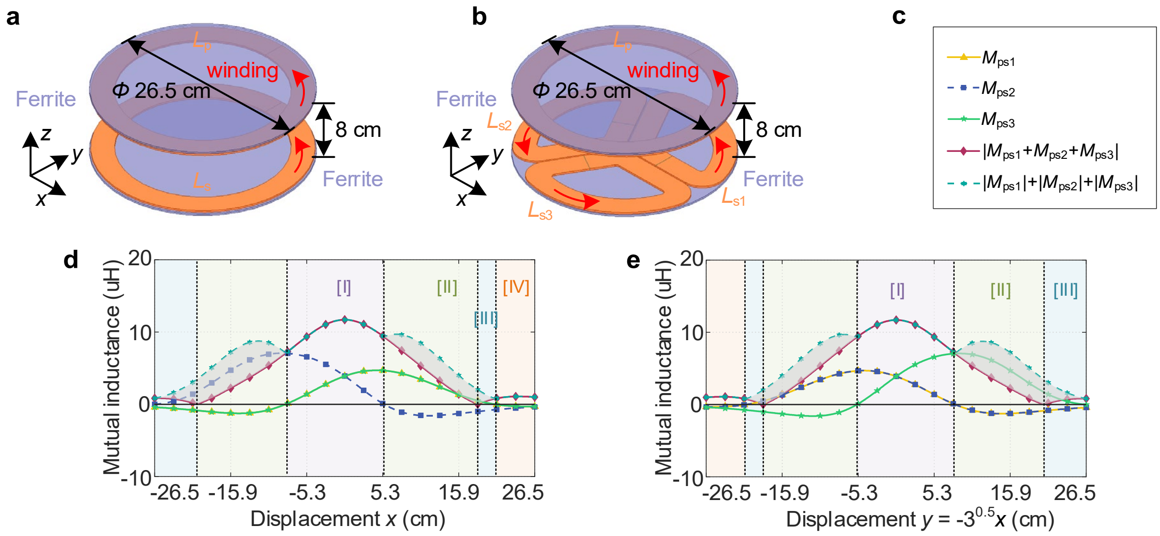

Fig. S3. Schematic and mutual inductance curves of transmitter and two receiver coils with displacement. a, b Overall diagram of transmitter circular coil and (**a**) receiver circular coils, (**b**) receiver three sector coils. **c** Mutual inductance curves legend. **d, e** Mutual inductance curves with source circular coil of displacement along the (**d**) x-axis and (**e**) the line $y = -\sqrt{3}x$.

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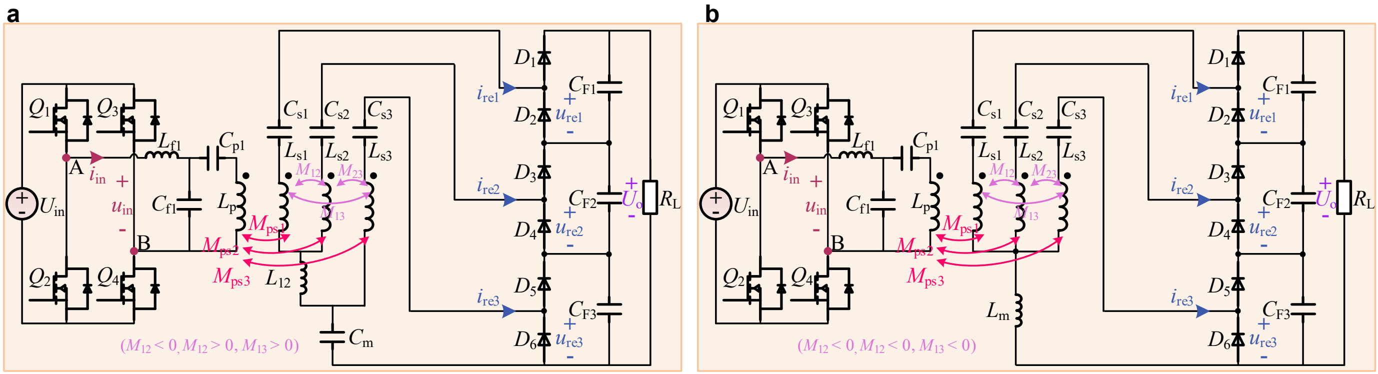

Fig. S4. Schematic diagrams of three coils decoupling. a One decoupling inductor and one capacitor. **b** One decoupling inductor.