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Improving the efficiency of magnetic coupling energy transfer by etching fractal patterns in the shielding metals

Key words: Fractal pattern, Metal-layer-shield, Eddy current, Magnetic coupling energy transfer

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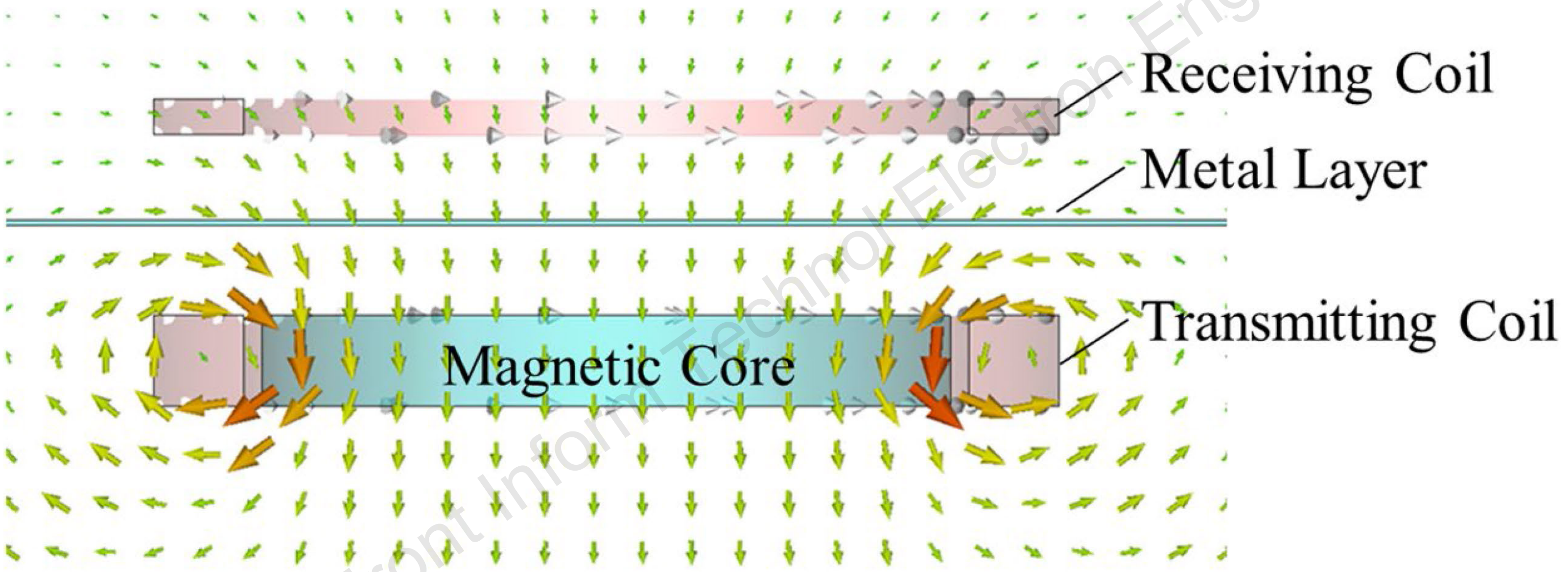
Introduction

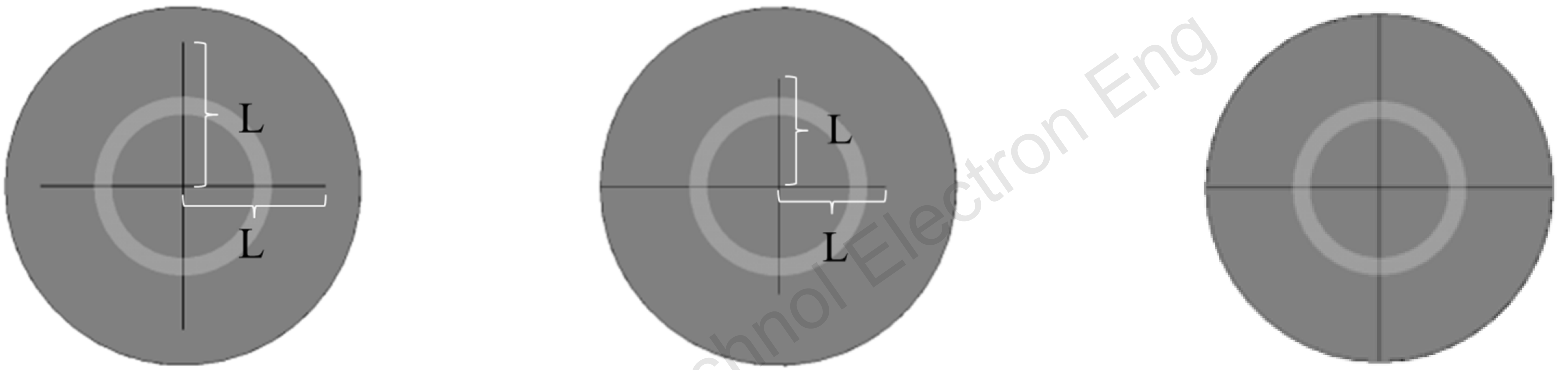
- Metal objects are often located in the coupling region of magnetic coupling energy transfer (MCET) systems. Eddy currents in the metals reduce the energy transfer efficiency and increase device heating.

- To solve the problem, the use of fractal slots in these metals is proposed to suppress the eddy currents and improve the transfer efficiency.

Simulation model



Features of patterns that effectively suppress the eddy currents



(a) (b) (c)

Fig. 2 Three etching schemes for the metal sheet

The slots which can effectively suppress the eddy currents should reach the metal edge, be etched in the high intensity magnetic field region, and should pass completely through the metal.

Different slot fractal patterns

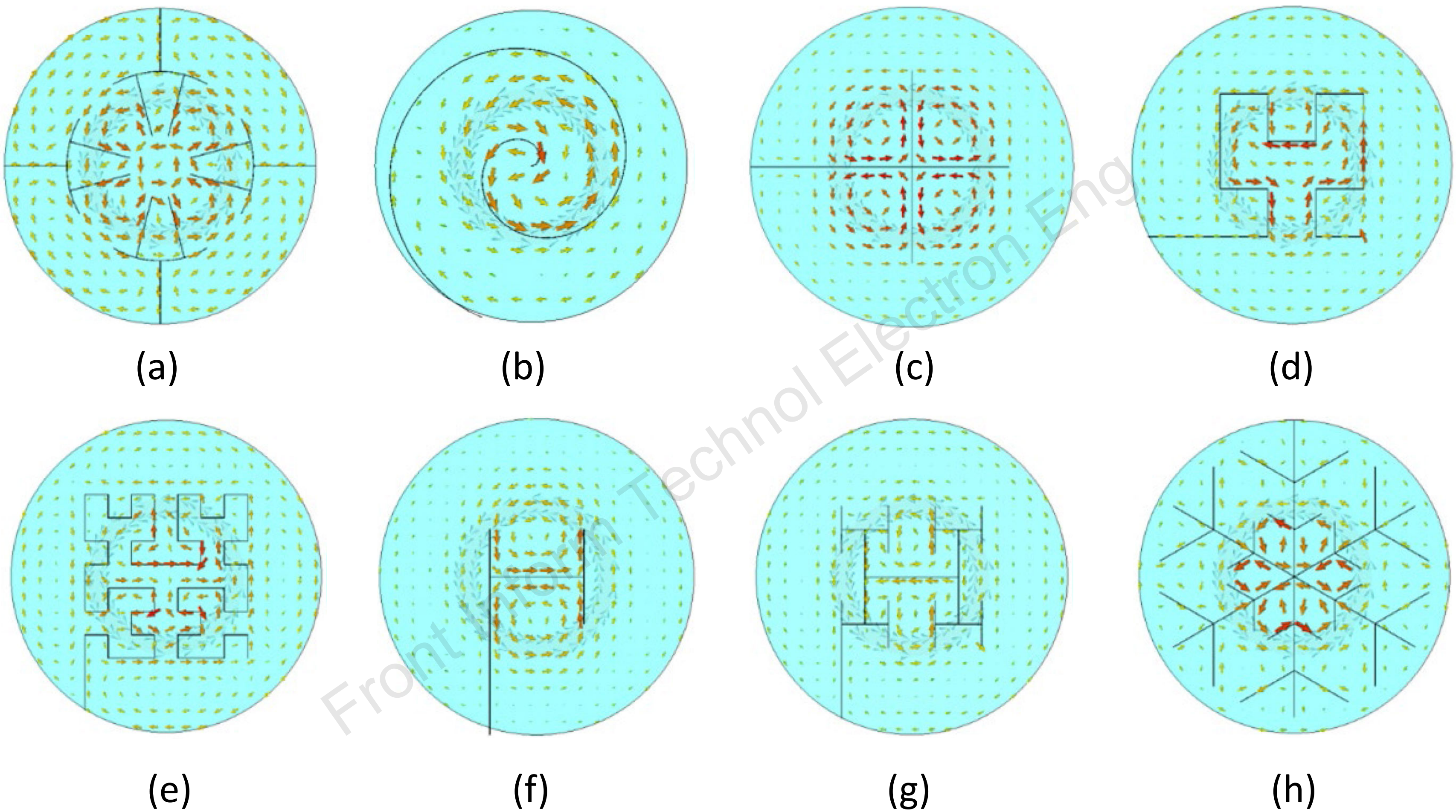


Fig. 4 (a) Tree fractal; (b) Helical fractal; (c) Cross fractal; (d) Hilbert fractal with order two; (e) Hilbert fractal with order three; (f) H-shaped fractal with order one; (g) H-shaped fractal with order two; (h) Snow fractal. The arrows in the metal sheet represent the flow direction of the eddy currents

Results for the slot fractal patterns in Fig. 4

Table 1 Results for different slot fractal patterns in Fig. 4

Scheme	P_E (%)	P_T (%)	η (%)	P_T/P_{TR} (%)	Slots length (mm)	Suppression efficiency (%/mm)
Fig. 4a	10.1	98.7	92.8	88.0	245.66	0.366
Fig. 4b	23.9	96.6	84.1	74.7	280.88	0.271
Fig. 4c	13.3	98.2	90.7	84.3	140.00	0.619
Fig. 4d	11.5	98.4	91.8	86.7	247.50	0.357
Fig. 4e	4.0	99.6	97.1	95.2	489.25	0.196
Fig. 4f	16.6	97.5	88.5	81.9	125.00	0.667
Fig. 4g	6.5	99.1	95.3	92.8	292.50	0.320
Fig. 4h	3.5	99.6	97.4	96.4	635.00	0.152
No slot	100.0	81.8	51.1	38.6	Null	Null
No metal	Null	100.0	100.0	100.0	Null	Null

Suppressing eddy current effects in multilayer metal sheets

Table 2 Eddy current suppression in three metal layers

Scheme	P_E (%)	P_T (%)	η (%)	P_T/P_{TR} (%)
No copper	100.0	100.0	100.0	100.0
No slot	88.1	34.2	44.3	50.0
Etching one layer	99.9	46.0	53.7	56.3
Etching two layers	103.7	94.0	94.0	93.8

Experiments

Features of patterns which effectively suppress the eddy current effects

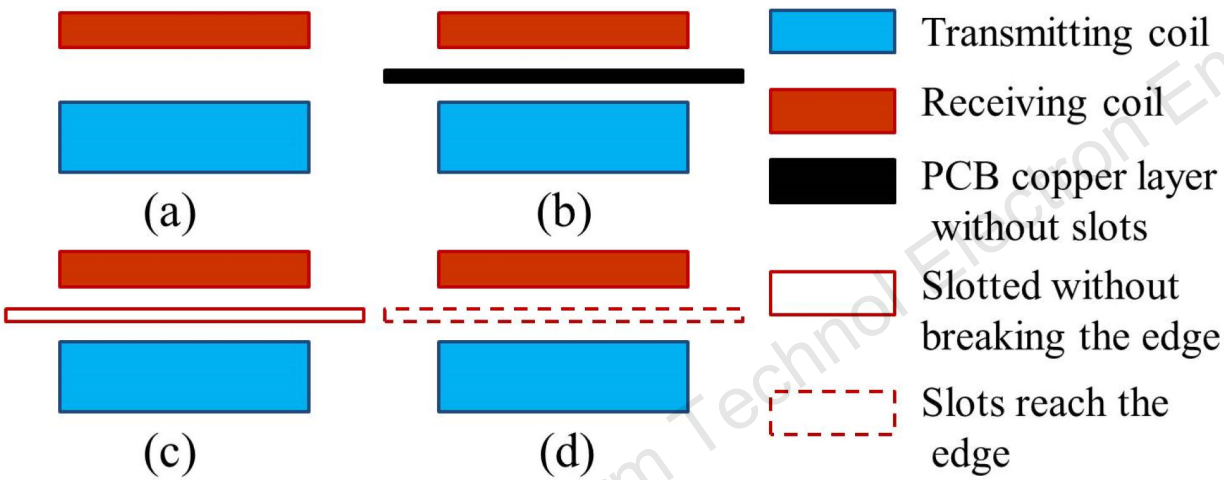


Fig. 9 Four experimental designs for evaluation of slots' key pattern features

(a) No metal is presented between the transmitting coil and the receiving coil; (b) A PCB copper layer without slots is present between the coils; (c) A PCB copper layer slotted without breaking the edge is present between the coils; (d) A PCB copper layer with slots reaching the edge is present between the coils

Experiments (Cont'd)

Table 3 Results for the four conditions in Fig. 9

Scheme	P_E (%)	P_T (%)	η (%)	P_T/P_{TR} (%)
Fig. 9a	0	100.0	100.0	100.0
Fig. 9b	100.0	64.7	20.6	8.7
Fig. 9c	79.0	75.2	27.9	12.4
Fig. 9d	6.7	95.8	86.2	72.0

Experiments (Cont'd)

Suppressing the eddy current effects in multiple metal layers

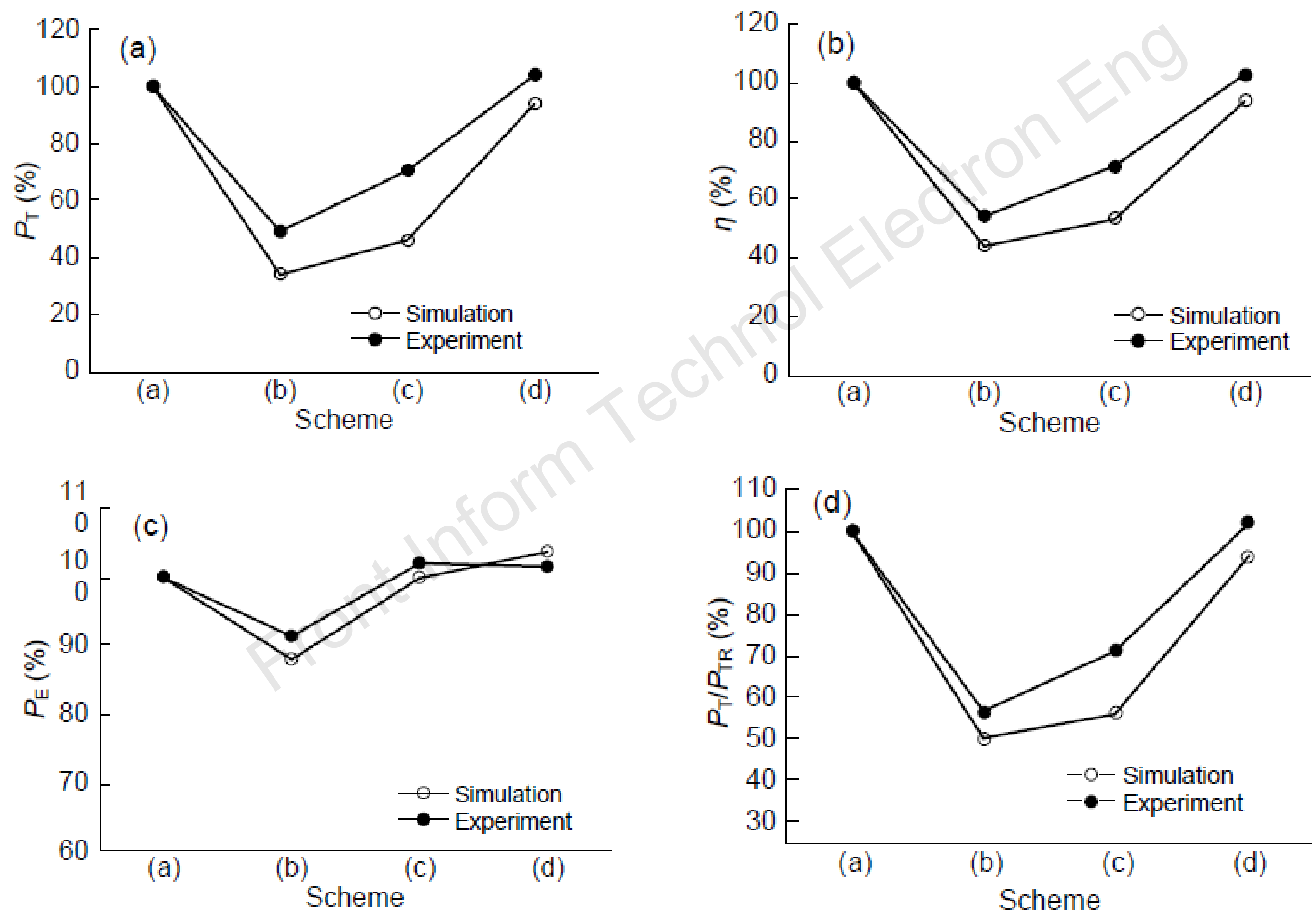


Fig. 11 Comparisons of simulation and experimental results in Fig. 10

(a) Comparison of *P*T; (b) Comparison of *η*; (c) Comparison of *P*E; (d) Comparison of *P*T/*P*TR

Conclusions

- Fractal patterns can be etched in metal surfaces to suppress eddy currents and improve the efficiency of magnetic coupling energy transfer.
- Maintaining the simple connectivity of the metal plane and etching completely through the metal are the essential requirements for suppressing the eddy currents.