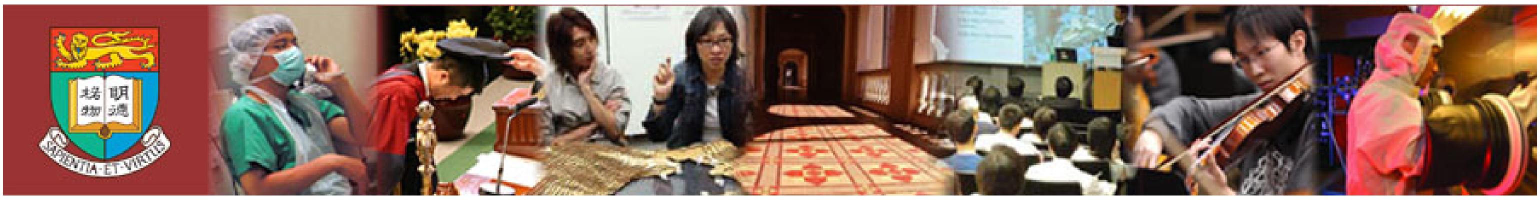


Title	**On the relationship of quality factor and hollow winding structure of coreless printed spiral winding (CPSW) inductor**
Author(s)	**Su, Y; Liu, X; Lee, CK; Hui, SY**
Citation	**IEEE Transactions on Power Electronics, 2012, v. 27 n. 6, p. 3050-3056**
Issued Date	**2012**
URL	**http://hdl.handle.net/10722/155744**
Rights	**IEEE Transactions on Power Electronics. Copyright © IEEE**

On the Relationship of Quality Factor and Hollow Winding Structure of Coreless Printed Spiral Winding (CPSW) Inductor

Yipeng Su, *Student Member, IEEE*, Xun Liu, *Member, IEEE*, Chi Kwan Lee, *Member, IEEE*,
and S. Y. (Ron) Hui, *Fellow, IEEE*

***Abstract*—The principle of using hollow spiral winding is not novel, but the study on this topic is far from complete. In this paper, how hollow the central region of the coreless printed spiral winding (CPSW) inductor should be for a given footprint area in order to achieve the maximal quality factor $Q_{\max}$ and to maintain high inductance value is explored. A hollow factor based on the ratio of the inner hollow radius and the outer winding radius $\tau = R_{\rm in}/R_{\rm out}$, is proposed as for optimization and quantifying how hollow a spiral winding is. The relationship between τ and $Q_{\max}$, which depends on the operating frequency and the dimensional parameters of CPSW inductor, is established. For a specific operating frequency, it is discovered that if the conductor width is comparable with the skin depth, or the conductors are placed relatively far away from each others, the hollow design of the CPSW inductor has little improvement on Q but reduces the inductance. If the conductor width is much larger than the skin depth and the conductors are closely placed, the hollow spiral design is recommended. The optimal range of τ with which the $Q_{\max}$ can be achieved is found to be around 0.45–0.55.**

***Index Terms*—Planar magnetics, quality factor.**

I. Introduction

The increasing demand for slim portable electronic appliances, such as notebook and palmtop computers, highlights the significance of the low-profile low-power power converters. Lots of efforts have been put into planar integrated power passive modules design [1], [2], which aims at reducing the volume and vertical dimension of the power electronic circuits. Increasing the switching frequency leads to a reduction in the required energy storage and permits the use of smaller passive components. The magnetic core of the inductor can be eliminated if the operating frequency is sufficiently high. Coreless inductors pave the way to fully integrated power converters [3]. Understanding of the coreless printed circuit boards (PCB) transformer theory [4], [5], optimal operation [6], and applications [7] helps to eliminate previous misunderstandings that coreless PCB transformer might have unacceptable low magnetic coupling, low voltage gain, and high electromagnetic interference (EMI) radiation problems. Specifically, a resonant technique has been incorporated into the use of the coreless PCB transformers so as to achieve a high voltage gain (to overcome the apparent low magnetic coupling) and take advantage of the leakage inductance (to turn the apparent disadvantage into an advantage) [8]–[10]. The EMI radiation problems also can be solved through including various EM shielding structures into the coreless PCB transformers [11]. So the coreless printed spiral winding (CPSW) becomes a desirable alternative for power inductors and transformers integration. Furthermore, due to its low profile and excellent “contactless” properties, coreless PCB transformers have been extensively used in wireless power transmission applications, in which the load can be movable with respect to the energy transmitter [12]–[14].

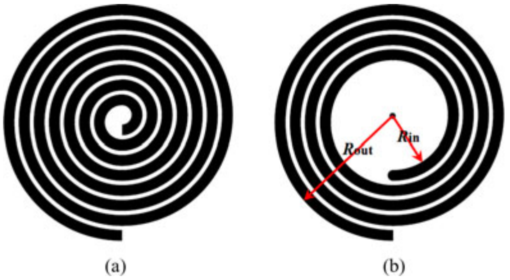


Fig. 1. Spiral winding types. (a) Full spiral. (b) Hollow spiral.

For power conversion and power transmission, the efficiency of the magnetic component is an important factor. Several studies have sought to reduce the power consumption in CPSW and improve its quality factor Q. Design approach for winding’s layout with geometric radii was addressed in [15] in order to achieve low dc resistance. Eddy current loss due to the high frequency effects can be suppressed by the subdivided conductors [16], planar litz structure [17], and layout optimization [18]. Especially when CPSW inductors are used as the transmitter or receiver of the wireless power transmission system, the eddy current loss suppression becomes much more significant, because all the current components in the windings are high-frequency ac. These techniques in [16]–[18], however, do not offer simple design and manufacture process. In [19], a proposal has

Manuscript received March 22, 2011; revised July 12, 2011; accepted October 20, 2011. Date of current version March 16, 2012. This work was supported by the Hong Kong Research Grant Council under Project HKU114410. Recommended for publication by Associate Editor R.-L. Lin.

Y. Su is with the Virginia Polytechnic Institute and State University, Blacksburg, VA 24060, USA (e-mail: yipengsu@vt.edu).
X. Liu is with the ConvenientPower (HK) Ltd., Shatin, New Territories, Hong Kong (e-mail: xun.liu@convenientpower.com).
C. K. Lee is with The University of Hong Kong, Pokfulam, Hong Kong (e-mail: cklee@eee.hku.hk).
S. Y. R. Hui is with The University of Hong Kong, Pokfulam, Hong Kong, and also with Imperial College London, London SW7 2AZ, U.K. (e-mail: ronhui@eee.hku.hk).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.
Digital Object Identifier 10.1109/TPEL.2011.2174654

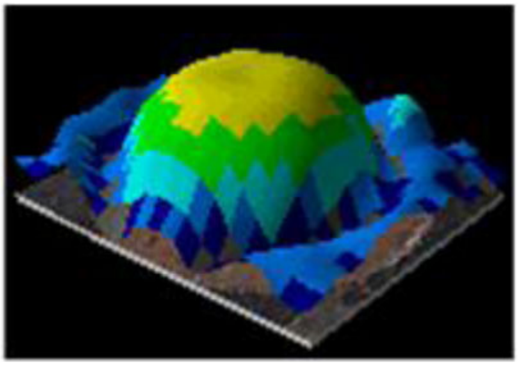


Fig. 2. Magnetic field intensity *H* of spiral winding scanned by EMC scanner [21].

been made to simply remove some inner turns, resulting in a centrally hollow spiral winding as shown in Fig. 1(b). However, the design approach of the hollow spiral winding is incomplete. The optimal ratio of the radius of the inner hollow region and the radius of the outer winding for maximizing the quality factor, *Q*, has not been analyzed, namely how hollow the spiral winding should be is unrevealed. This project fills this gap by using finite element analysis (FEA) to evaluate the quality factors of a series of CPSW inductors, with the objective of determining the relationship of the optimal quality factor and the hollowness of CPSW.

II. HOLLOW SPIRAL WINDING DESIGN PRINCIPLE

The equivalent ac resistance of the CPSW can be increased substantially by skin effect and proximity effect at high frequency. The detailed mechanisms of skin effect and proximity have been analyzed in [20]. With a critical assumption, 1-D analytical model for isolated single foil conductor in [20] demonstrates that the eddy current power loss for each metal conductor is highly related to the frequency and external magnetic field penetrating the conductor perpendicularly. The trend is that the higher the frequency and the magnitude of the external magnetic field are, the more significant the eddy current loss becomes. For some CPSWs, which are filled with turns going to the center of the coil [i.e., full winding in Fig. 1(a)], the magnetic field distribution is nonlinear in a "convex" manner that its highest magnitude occurs in the central region of the spiral winding as shown as in Fig. 2. Because the total magnetic field intensity *H* of central area is the superposition of magnetic field intensity of each turn, the inner turns have relatively high contribution to the total power loss of the winding due to their high-ac resistance, but low contribution to the inductance due to the small area they enclose. In other words, their presence causes a dramatic deterioration of the overall quality factor. In order to suppress the current crowding effect in metal traces, a simple but effective way is to remove the metal traces out of the central region where *H* is large. It means that some inner turns should be eliminated from the winding structure. This well-known design philosophy results in a hollow spiral winding.

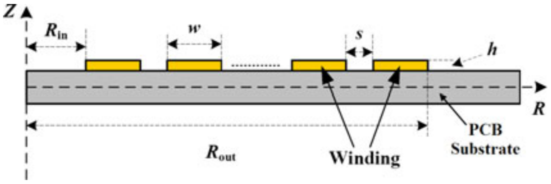


Fig. 3. Cross-sectional view of the single layer CPSW inductor in half *R–Z* plane.

TABLE I
DIMENSIONAL PARAMETERS OF THE TESTED CPSW INDUCTORS IN STUDY 1

	R_{out}/(*mm*)	*h*/(*μm*)	*w*/(*mm*)	*s*/(*mm*)	No. of turns
1#	15	105	1.0	0.5	10
2#	15	105	0.8	0.4	12
3#	15	105	0.6	0.3	16
4#	15	105	0.4	0.2	24

III. CPSW WITH OPTIMAL HOLLOWNESS

A 1-D analytical model for an isolated single foil conductor can be used to study the dependence of eddy current loss on frequency *f* and external magnetic field intensity *H*, and it can accurately predict high-frequency loss when the winding structure is relatively simple. Nevertheless, for a CPSW inductor with multiple twins, the interaction among turns becomes prominent and the magnetic flux distribution is much more complex than that of an isolated single foil conductor, especially at high frequency. Therefore, its high-frequency loss cannot be evaluated accurately by the 1-D model. Finite-element analysis (FEA) has been proven over many years as a useful tool to precisely predict the high-frequency metal ac resistance. In this study, the Ansoft Maxwell 2-D eddy current simulator is employed to evaluate the inductance value, ac loss as well as the quality factor of the CPSW inductor. A series of single-layer CPSW inductors with different dimensional parameters are built as practical prototypes for investigation. Their half cross-sectional view and dimensions are shown in Fig. 3. A new hollow factor, defined as the ratio between inner radius and outer radius ($\tau = R_{\mathrm{in}}/R_{\mathrm{out}}$), is introduced here to represent the hollow scale of a winding. The higher value of τ is, the more hollow the central area of a winding becomes. In the following case studies, the footprint, namely the outer radius, of the CPSWs is always kept as constant. With this predetermined footprint, the primary objective of this paper is essentially to find the optimal configuration in terms of maximizing the quality factor while still maintaining high inductance value.

A. Study 1: Spirals With Different Conductor Width w

In this first study, four single-layer CPSW inductor models are developed with the FEA software. Their dimensional parameters are listed in Table I. The outer radius of the windings R_{out} and the thickness of the trace, *h*, are kept as constant for all of them, while the trace width w is decreased from 1.0 to 0.4 mm with the step of 0.2 mm. We also keep the ratio of trace width w to trace separation *s* at a constant value (i.e., 2). The number of turns of the windings is initially designed to be the maximum

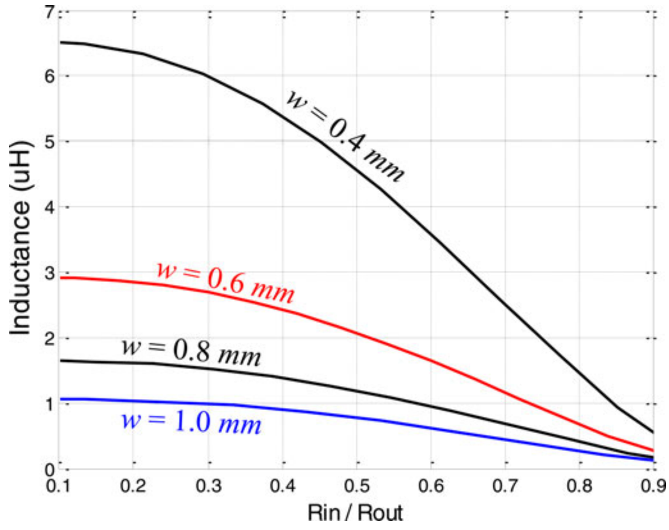


Fig. 4. Inductance value as a function of τ with different conductor widths. (a) $f = 100$ kHz (skin depth 0.237 mm). (b) $f = 500$ kHz (skin depth 0.106 mm). (c) $f = 1$ MHz (skin depth 0.075 mm). (d) $f = 5$ MHz (skin depth 0.034 mm).

value according to the other parameters. So these four windings can be regarded as full CPSW inductor.

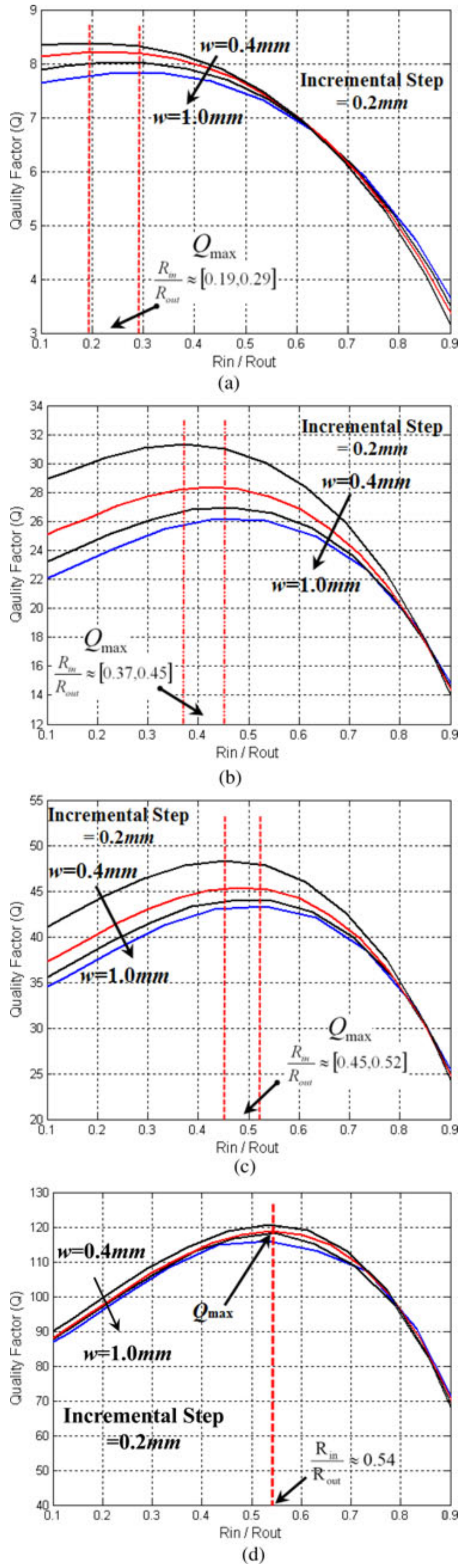
First, FEA is carried out in order to obtain the inductance and quality factor values of each full winding. Then we remove the innermost turns out of the coils one by one and perform the analysis for each configuration. The footprint of all CPSWs simulated is kept as πR_{out}^2. The variation of the inductance and quality factor can be plotted when the innermost turn is removed one by one, namely the winding is gradually transformed from "full" to "hollow." A range of operating frequencies (i.e., 100 kHz, 500 kHz, 1 MHz, and 5 MHz) is considered. Because the impact of frequency on the inductance value for each coreless winding configuration is negligible, only one graph as Fig. 4 is used to compare the inductance with different conductor widths. It can be seen that with the same $R_{\text{in}}/R_{\text{out}}$, the inductance value with smaller conductor width w is always higher than that with larger w, because a larger number of turns can be accommodated within the same footprint area. The ac loss of the winding as well as its quality factor is changed significantly when the frequency is increased. So the Q values of the CPSWs as a function of τ can be plotted in Fig. 5(a)–(d), for 100 kHz, 500 kHz, 1 MHz, and 5 MHz, respectively. It can be found that at low frequency (100 kHz), there is little improvement on the quality factor when inner turns are removed. However, with the frequency increasing into several megahertz, the hollow layout can enhance the winding quality factor prominently.

Actually, the skin depth in the copper conductor for the frequency of 100 kHz, 500 kHz, 1 MHz, and 5 MHz can be calculated by (1) as 0.237, 0.106, 0.075, and 0.034 mm, respectively

$$\delta = \sqrt{\frac{\rho}{\pi \cdot \mu \cdot f}} \tag{1}$$

where ρ and μ are the resistivity and the permeability of the copper material, respectively, and f is the operating frequency.

After the comparison of the simulation results for different frequency, it can be demonstrated that, if the conductor width



(a)

(b)

(c)

(d)

Fig. 5. Quality factor value as a function of τ with different conductor widths. (a) $f = 100$ kHz (skin depth 0.237 mm). (b) $f = 500$ kHz (skin depth 0.106 mm). (c) $f = 1$ MHz (skin depth 0.075 mm). (d) $f = 5$ MHz (skin depth 0.034 mm).

TABLE II
DIMENSIONAL PARAMETERS OF THE TESTED CPSW INDUCTORS IN STUDY 2

	$R_{\text{out}}/(mm)$	$h/(\mu m)$	$w/(mm)$	$s/(mm)$	No. of turns
5#	15	105	0.6	0.3	16
6#	15	105	0.6	0.6	12
7#	15	105	0.6	0.9	10

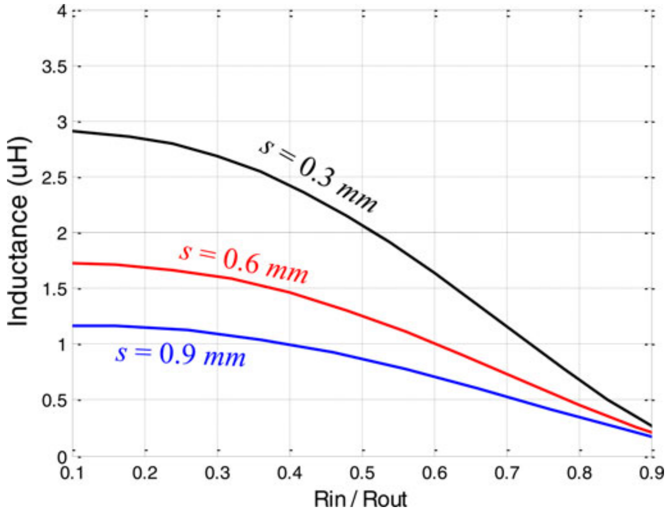


Fig. 6. Inductance as a function of τ with different conductor separations. (a) $f = 100$ kHz (skin depth 0.237 mm). (b) $f = 500$ kHz (skin depth 0.106 mm). (c) $f = 1$ MHz (skin depth 0.075 mm). (d) $f = 5$ MHz (skin depth 0.034 mm).

is comparable to the skin depth at a given frequency (i.e., w is 2–5 times of δ), the hollow winding layout does not increase the Q value, but will decrease the winding inductance, as shown in Fig. 5(a). Therefore, the full winding layout is preferred at this relatively low frequency. On the contrary, if the traces width is at least ten times larger than skin depth, the hollow winding layout is better due to the significant improvement on the quality factor, as illustrated in Fig. 5(d). The maximum Q is always achieved when τ is equal to 0.54, because all the curves almost follow the same path under this condition.

Furthermore, based on the results in Figs. 4 and 5, both of the inductance and the quality factor of the winding with narrow traces are always better than that with wide traces. In summary, with a given footprint, a CPSW with narrow trace width is always preferred. Since the narrow trace width cannot only realize larger number of turns to maximize the inductance value, but also suppress the high-frequency skin effect and proximity effect. However, the trace width cannot be as small as in infinite. It is normally determined by manufacturing capability, application current level, and thermal limitation. After the minimal trace width is determined by these requirements, the hollowness should be optimized by considering skin depth at the operating frequency.

In practice, the inductance plots (see Fig. 4) and the quality factor plots (see Fig. 5) should be used together in order to choose an optimal coil arrangement. Fig. 4 shows the inductance variations of coil examples with different conductor widths as a function of the $R_{\text{in}}/R_{\text{out}}$ ratio. In the frequency range under investigation (up to 5 MHz), the effect of the variation of the frequency on the inductance value of a CPSW is small. These inductance profiles are roughly independent of the frequency because the coils are coreless (like air-coil inductors, but are in planar structures). Examining the inductance profiles (see Fig. 4) with the Q factors under different frequencies [see Fig. 5(a) to (d)] allows the designer to locate the best Q-factor for a given conductor width. One can then choose the best conductor width that allows the highest inductance value at the highest Q-factor point (at the chosen frequency).

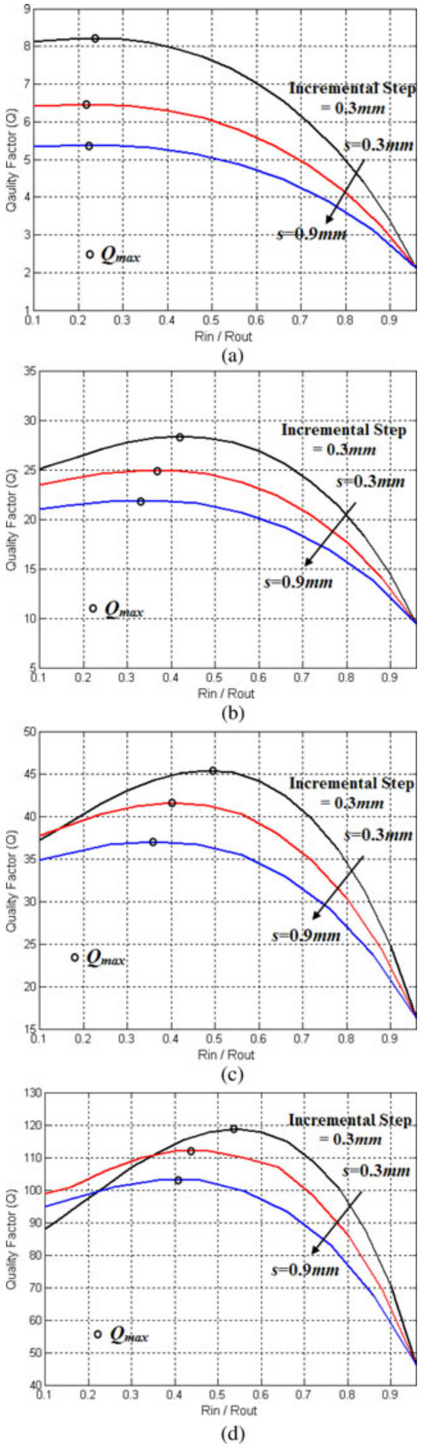
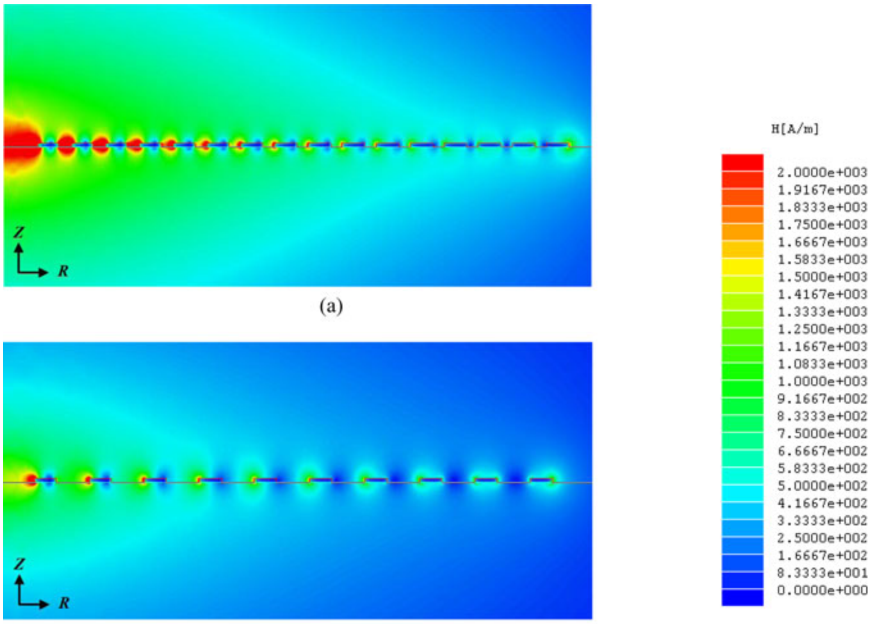


Fig. 7. Quality factor value as a function of τ with different conductor separations. (a) H distribution for 5# winding. (b) H distribution for 7# winding.



(a)

(b)

Fig. 8. H distribution from simulation for compact and loose winding structure. (a) H distribution for $5\#$ winding. (b) H distribution for $7\#$ winding.

B. Study 2: Spirals With Different Conductor Separation s

In the second study, the other three single-layer CPSW inductors, whose dimensional parameters are listed in Table II, are analyzed. Similar to study 1, the outer radii of the windings $R_{\rm out}$ and the thickness of the trace, h, are kept constant. A major difference from study 1 is the trace width w which is kept as 0.6 mm for all of inductor samples. The trace separation s is increased from 0.3 to 0.9 mm with step of 0.3 mm (i.e., from $0.5w$ to w and then to $1.5w$). Following the same process in study 1, these three CPSW inductors are also initially designed to be the full windings, then the variation of quality factor can be obtained as the inner turns are removed one by one. The inductance values of the CPSWs with different trace separations are displayed and compared in Fig. 6. It is seen that the inductance value with smaller s is always higher than that with larger s, also due to the larger number of turns as the first study case. The quality factor of these windings as a function of τ at 100 kHz, 500 kHz, 1 MHz, and 5 MHz operating frequency is plotted in Fig. 7(a)–(d), respectively. The maximum Q value has been marked by a circular dot in each curve.

The series of curves show that at relatively low operating frequency, such as 100 kHz in Fig. 7(a), the trace separation s has little effect on the τ value with which $Q_{\max}$ can be achieved. The optimal τ values are roughly equal to 0.22 for all the analyzed winding structures. The hollow winding structure is undesirable under this circumstance, because removing some inner turns does not improve the quality factor of the winding, but rather decreases its inductance. However, as the operating frequency increasing up to megahertz, the design principle is highly dependent on the trace separation s. Taking frequency of 5 MHz in Fig. 7(d) as an example, if the winding has a compact structure, namely every turn of the winding is placed relatively close to each other compared with the trace width ($w = 0.6$ mm and $s = 0.3$ mm), a hollow structure CPSW is preferred due to the significant improvement of quality factor. In contrast, if the trace separation of the winding is equal to or larger than the trace width ($w = 0.6$ mm, $s = 0.6$ mm and $w = 0.6$ mm, $s = 0.9$ mm), namely the winding has a "loose" (or noncompact) structure, a hollow CPSW design cannot improve the quality factor value. Thus, such noncompact structure should not be used. This can be explained by the reexamination of the magnetic flux intensity H distribution of the CPSW. Fig. 8 shows the simulated H distribution for 5# and 7# windings when the peak excitation currents are both 1 A. It can be seen that the H value distribution of loose winding is slightly more even than that of compact winding, and also the central H value of loose winding is smaller than that of compact winding due to the less number of turns. Therefore, the hollow structure can be utilized for compact winding, but not appropriate for loose winding at very high frequency.

Moreover, for a given trace width, the maximum quality factor value and the inductance that can be achieved in a compact winding are always larger than that in loose winding. Therefore, the conclusion here is similar to that obtained in study 1: within the manufacturing capability, the application current level, and the thermal limitations, one should design a CPSW as compact as possible, in order to maximize the inductance and the quality factor. Whether the hollow structure should be employed or not is again determined by the relationship between conductor width and skin depth of the conductor material at that given frequency.

As a summary of studies 1 and 2, we address the practical design philosophy of a CPSW inductor with the objective of optimizing the quality factor of the CPSW inductor while maintaining a high inductance value for a given footprint area. It must also be noted that if an inductance value is the design objective, the same design approach can lead to smaller footprint area.

For a particular set of application specifications (i.e., if the footprint, operating frequency, power and current level, and thermal limitation of the CPSW inductor are all given), the winding layout should be designed with the following steps:

1) first, the conductor width and the conductor separation both should be as small as possible within the constraints of the application specifications;
2) second, if the conductor width value obtained from step one is much larger than the skin depth of the conductor at given frequency, the hollow winding structure with $\tau \approx 0.54$ is recommended. On the contrary, if the conductor width value is comparable with the skin depth, the full winding structure is preferred.

IV. CONCLUSION

Coreless planar spiral winding is a basic component used in many wireless charging systems for portable electronics products. With the objective to optimize the hollow design approach for a power CPSW inductor, a new hollow factor based on the innermost and outmost radii of the winding is introduced as a measure of hollowness of the winding in this paper. The choice of using either a hollow or a full winding structural design in order to maximize the quality factor while maintaining high inductance for a given footprint area is discussed. Two typical FEA studies on different series of windings indicate that the trace width and trace separation should be as small as possible within the thermal limitations and manufacturing capability. Optimal hollowness of the winding depends on the ratio of the conductor width to the skin depth at a given frequency. This design principle results in great quality factor improvement and power loss reduction of the planar magnetic component and simultaneously maintaining high inductance for a footprint area. The outcome of this paper can also be used to study and design the planar coreless windings for low-profile planar integrated converter and future wireless power systems with high efficiency.

ACKNOWLEDGMENT

The authors would like to thank Convenientpower (HK) Ltd. for providing technical details.

REFERENCES

[1] I. W. Hofsajer, J. A. Ferreira, and D. van Wyk, "Design and analysis of planar integrated L-C-T components for converters," *IEEE Trans. Power Electron.*, vol. 15, no. 6, pp. 1221–1227, Nov. 2000.

[2] J. T. Strydom and D. van Wyk, "Electromagnetic design optimization of planar integrated power passive modules," in *Proc. IEEE Power Electron. Spec. Conf. (PESC)*, Jun. 2002, vol. 2, pp. 573–578.

[3] R. C. N. Pilawa-Podgurski, A. D. Sagneri, J. M. Rivas, D. I. Anderson, and D. J. Perreault, "Very high frequency resonant boost converters," in *Proc. IEEE Power Electron. Spec. Conf. (PESC)*, Jun. 2007, pp. 2718–2724.

[4] S. C. Tang, S. Y. R. Hui, and H. Chung, "Coreless planar printed-circuit-board (PCB) transformers - A fundamental concept for signal and energy transfer," *IEEE Trans. Power Electron.*, vol. 15, no. 5, pp. 931–941, Sep. 2000.

[5] S. C. Tang, S. Y. R. Hui, and H. Chung, "Characterization of coreless printed circuit board (PCB) transformers," *IEEE Trans. Power Electron.*, vol. 15, no. 6, pp. 1275–1282, Nov. 2000.

[6] E. Dallago, M. Passoni, and G. Venchi, "Design and optimization of a high insulation voltage DC/DC power supply with coreless PCB transformer," in *Proc. IEEE Int. Conf. Ind. Technol. (ICIT)*, Dec. 2004, vol. 2, pp. 596–601.

[7] P. Luniewski and U. Jansen, "Unsymmetrical gate voltage drive for high power 1200 V IGBT^4 modules based on coreless transformer technology driver," in *Proc. Power Electron. Motion Control Conf.*, Sep. 2008, pp. 88–96.

[8] H. Abe, H. Sakamoto, and K. Harada, "A noncontact charger using resonant converter with parallel capacitor of the secondary coil," *IEEE Trans. Ind. Appl.*, vol. 36, no. 2, pp. 444–451, Mar. 2000.

[9] C.-S. Wang, G. A. Covic, and O. H. Stielau, "Power transfer capability and bifurcation phenomena of loosely coupled inductive power transfer systems," *IEEE Trans. Ind. Electron.*, vol. 51, no. 1, pp. 148–157, Feb. 2004.

[10] S. Judek and K. Karwowski, "Supply of electric vehicles via magnetically coupled air coils," in *Proc. Power Electron. Motion Control Conf.*, Sep. 2008, pp. 1497–1504.

[11] Y. P. Su, X. Liu, and S. Y. R. Hui, "Extended theory on the inductance calculation of planar spiral windings including the effect of double-layer electromagnetic shield," *IEEE Trans. Power Electron.*, vol. 23, no. 4, pp. 2052–2061, Jul. 2008.

[12] N. Hemche and A. Jaafari, "Wireless transmission of power using a PCB transformer with mobile secondary," in *Proc. Mediterranean Electrotech. Conf.*, May 2008, pp. 629–634.

[13] Y. P. Su, X. Liu, and S. Y. R. Hui, "Mutual inductance calculation of movable planar coils on parallel surfaces," *IEEE Trans. Power Electron.*, vol. 24, no. 4, pp. 1115–1124, Apr. 2009.

[14] M. Takahashi, K. Watanabe, F. Sato, and H. Matsuki, "Signal transmission system for high frequency magnetic telemetry for an artificial heart," *IEEE Trans. Magn.*, vol. 37, no. 4, pp. 2921–2924, Jul. 2001.

[15] X. Huang and K. D. T. Ngo, "Design technique for a spiral planar winding with geometric radii," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 32, no. 2, pp. 825–830, Apr. 1996.

[16] M. Peter, H. Hein, F. Oehler, and P. Baureis, "Planar inductors with subdivided conductors for reducing eddy current effects," in *Proc. Topical Meet. Silicon Monolithic Integr. Circuits RF Syst.*, Apr. 2003, pp. 104–106.

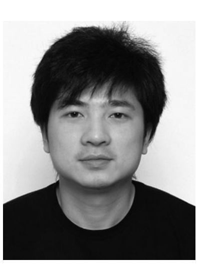
[17] Shen Wang, M. A. de Rooij, W. G. Odendaal, J. D. van Wyk, and D. Boroyevich, "Reduction of high-frequency conduction losses using a planar litz structure," *IEEE Trans. Power Electron.*, vol. 20, no. 2, pp. 261–267, Mar. 2005.

[18] J. M. Lopez-Villegas, J. Samitier, C. Cane, P. Losantos, and J. Bausells, "Improvement of the quality factor of RF integrated inductors by layout optimization," *IEEE Trans. Microw. Theory Tech.*, vol. 48, no. 1, pp. 76–83, Jan. 2001.

[19] J. Craninckx and M. S. J. Steyaert, "A 1.8-GHz low-phase-noise CMOS VCO using optimized hollow spiral inductors," *IEEE J. Solid-State Circuits*, vol. 32, no. 5, pp. 736–744, May 1997.

[20] S. Wang, "Modeling and design of planar integrated magnetic components,", Master thesis, Virginia Polytechnic Inst. and State Univ., Jul. 2003.

[21] X. Liu and S. Y. R. Hui, "Optimal design of a hybrid winding structure for planar contactless battery charging platform," *IEEE Trans. Power Electron.*, vol. 23, no. 1, pp. 455–463, Jan. 2008.



Yipeng Su (S'06) received the B.S. degree in electrical engineering from Tsinghua University, Beijing, China, in 2005, and the M.Phil. degree from the City University of Hong Kong, Kowloon, Hong Kong, in 2008. He is currently working toward the Ph.D. degree in the Center for Power Electronics Systems, Virginia Polytechnic Institute and State University, Blacksburg.

From September to December 2008, he was as a Research Associate at the Center for Power Electronics, City University of Hong Kong. His main research interests include low-profile magnetic design, circuit integration in power electronics, and low-voltage high-current dc–dc converter.

Xun Liu (M'07) was born in China in 1978. He received the B.S. and M.S. degrees in electrical engineering from Tsinghua University, Beijing, China, in 2001 and 2003, respectively, and the Ph.D. degree from the City University of Hong Kong, Kowloon, Hong Kong, in 2007.

He is currently the Chief Technology Officer at ConvenientPower (HK) Ltd., New Territories, Hong Kong, and responsible for the R&D of a new generation of universal wireless charging platform for a wide range of consumer electronic products. His main research interests include planar integration in power electronics, applied superconductivity, and EMC/EMI.

Chi Kwan Lee received the B.Eng. and Ph.D. degrees in electronic engineering from the City University of Hong Kong, Kowloon, Hong Kong, in 1999 and 2004, respectively.

He was a Postdoctoral Research Fellow in the Power and Energy Research Centre, National University of Ireland, Galway, Ireland, from 2004 to 2005. In 2006, he joined the Centre of Power Electronics, City University of Hong Kong, as a Research Fellow. From 2008 to 2011, he was a Lecturer of Electrical Engineering at the Hong Kong Polytechnic University. He is currently an Assistant Professor at the Department of Electrical and Electronic Engineering, The University of Hong Kong, Pokfulam, Hong Kong. His current research interests include applications of power electronics to power systems, advanced inverters for renewable energy and smart grid applications, reactive power control for load management in renewable energy systems, wireless power transfer, energy harvesting and planar electromagnetics for high frequency power converters.

S. Y. (Ron) Hui (F'03) received the B.Sc. (Eng.) (Hons.) degree from the University of Birmingham, Birmingham, U.K., in 1984 and the D.I.C. and Ph.D. degrees from Imperial College London, London, U.K., in 1987.

He has previously held academic position at the University of Nottingham, U.K. (1987–1990), the University of Technology, Sydney (1990–1991), the University of Sydney (1992–1996), and the City University of Hong Kong (CityU) (1996–2011). From July 2011, he holds the Chair Professorship at the University of Hong Kong. Since July 2010, he concurrently holds the Chair Professorship of Power Electronics at Imperial College London. He has published more than 200 technical papers, including more than 160 refereed journal publications and book chapters. More than 50 of his patents have been adopted by industry.

Dr. Hui is a Fellow of the IET. He has been an Associate Editor of the IEEE TRANSACTIONS ON POWER ELECTRONICS since 1997 and an Associate Editor of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS since 2007. He has been appointed twice as an IEEE Distinguished Lecturer by the IEEE Power Electronics Society in 2004 and 2006. He served as one of the 18 Administrative Committee members of the IEEE Power Electronics Society and was the Chairman of its Constitution and Bylaws Committee from 2002 to 2010. He received the Excellent Teaching Award at the CityU in 1998 and the Earth Champion Award in 2008. He won the IEEE Best Paper Award from the IEEE IAS Committee on Production and Applications of Light in 2002, and two IEEE POWER ELECTRONICS TRANSACTIONS Prize Paper Awards for his publications on wireless battery charging platform technology in 2009 and on LED system theory in 2010. His inventions on wireless charging platform technology underpin key dimensions of Q_i, the world's first wireless power standard, with freedom of positioning and localized charging features for wireless charging of consumer electronics. In November 2010, he received the IEEE Rudolf Chope R&D Award from the IEEE Industrial Electronics Society, the IET Achievement Medal (The Crompton Medal), and was elected to the Fellowship of the Australian Academy of Technological Sciences and Engineering.