Design of a Surface-Mounted Qi-Compliant Wireless Power Coil

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***Abstract*—The Wurth Electronics (WE) Midcom wireless power team has developed a wireless power Qi-compliant coil, which can be surface-mounted on a printed circuit board (PCB) by using reflow soldering. One of the main challenges is to ensure robustness of the coil through the high temperature soldering process. To prove the article reliability, different temperature, humidity and vibration tests have been performed. The design has been filed as a patent.**

***Keywords*—SMD coil; wireless power transfer (WPT); Qi-compliant wireless coil**

I. Introduction

A. *Qi-Compliant Wireless Power Coils with Flying Leads*

The wireless power consortium (WPC) is a multinational consortium established in 2008 with more than 300 members. Its primary mission is to develop and promote standards for wireless charging technologies. It has published the Qi standard in 2010, the Qi 2 standard in 2023 and the new cordless kitchen Ki standard in 2024. [1]

Qi-compliant wireless power coils are essential components in wireless charging systems, enabling interoperable power transfer between transmitters and receivers. These coils operate based on the principle of electromagnetic induction, where an alternating magnetic field in the transmitter coil induces a voltage in the receiver coil. The WPC defines in the Qi-standard about 40 different coil designs for the transmitter side. The Qi-compliant coils are typically planar and round and made of litz or solid copper wire on a ferrite plate suitable for powers up to 15 W. They can also be constructed using PCB or flex-circuit technology for thinner applications. [2]

WE customers often use the Qi-A11 design for their WPT applications. For this design, a copper litz wire with 1.15 mm diameter and 105 strands with 0.08 mm diameter is defined. The coil should be wound with 10 turns in a single layer and the inner diameter of the coil is defined as 20.5 ± 0.5 mm and the outer diameter of the coil is defined as 44 ± 1.5 mm. The shielding must comprise either Mn-Zn or Ni-Zn ferrite, with a thickness of at least 0.5 mm. It should be noted that the shielding must extend to at least 2 mm beyond the outer diameter of wired coil, and should be placed below the coil at a distance of at most 1.0 mm. [3]

A WE product, using this design is for example the standard article 760308100111. Figure 1 shows the design of the article.

Fig. 1. WE wireless power standard coil (article number 760308100111). [4]

As can be seen in fig. 1, the termination of the wires comprises of flying leads with tinned endings. This endings are inserted through holes in a PCB and soldered to pads on the opposite side at the assembly process. This mounting method is called through-hole technology (THT).

B. *State of the Art Surface-Mounted Wireless Power Coil Designs*

There are some surface-mounted wireless power coils technologies on the market, like for example stamped coils.

These coils are very flat (from 0.1 mm up to 0.25 mm) and can be mounted on the surface of the PCB. One example of such a stamped coil can be seen in fig. 2.

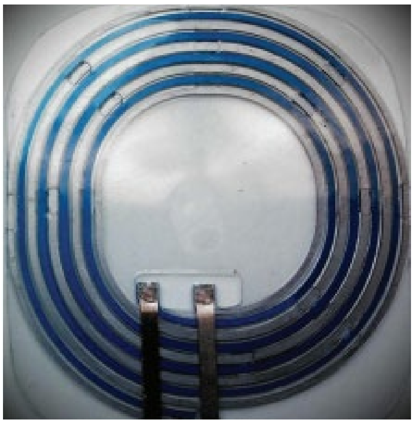

Fig. 2. Stamped inductive charging wireless power coil. [5]

Although the stamped coil in fig. 2 has the same inductance and the same outer and inner diameter like the Qi-A11 coil in fig.1, it is not Qi-compliant. In addition, it cannot be used at a power level of 15 W, because of the thin copper traces.

Another surface-mounted coil technology are flexible printed coils (FPC), which are also part of the WE customized product portfolio. The copper traces are directly printed on a ferrite or plastic layer. The power capability is limited to a few watts. The coils can use a connector or can use SMD pads to get mounted on the PCB. They are also not Qi-compliant, but can be designed due to the Qi-A11 design in regard of number of turns, inductance and inner and outer diameter. Fig. 3 shows a FPC coil available at WE, based on the Qi-A11 design with an inductance of 6.3 µH.

Fig. 3. Flexible printed coil (without ferrite) based on the Qi-A11 design. [6]

C. *Qi-Compliant Surface-Mounted Wireless Power Coil Design Demand*

The surface-mounted state of the art coil technologies presented in the previous section are not Qi-compliant, therefore they cannot be used by customers, who need this compliance for their products. In addition, there is a demand by customers of Qi-compliant surface-mounted coils, because an easier and cheaper assembly process is possible with SMD compared to THT coils, which are soldered often manually after the SMD components of the wireless power system have been mounted on the PCB.

This is why the WE wireless power team has developed an SMD wireless power coil, which is fully Qi-compliant. The development process, the reliability tests, Qi-compliance verification and the test of functionality of the coil in a whole WPT setup is described in detail in the following. The resulting coil design has been filed as a patent. The development process of the SMD Qi-A11 coil has been done in the frame of a bachelor thesis.

II. Methods

A. *Qi-Compliant A11 Wireless Power Coil SMD Design with U-Clamps*

Based on the ferrite design of the Qi-A11 coil 760308100111 (see fig. 1), the ferrite design shown in fig. 4 has been created with computer aided design (CAD).

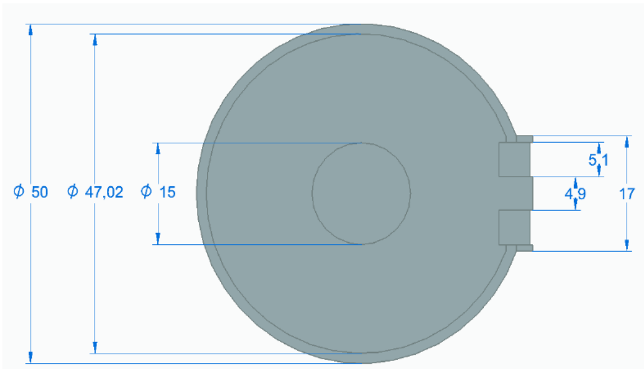

Fig. 4. CAD created ferrite design for an SMD Qi-coil, units in mm. [4]

At the ferrite grooves at the right side of fig. 4, u-shaped copper clamps (see fig. 5) are mounted.

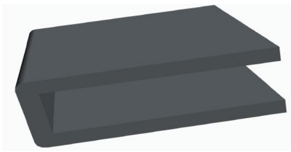

Fig. 5. 3D-view of the CAD model of the u-clamp.

The coil windings of the developed coil are identical with the Qi-A11 coil shown in fig. 1, in regard of number of turns, inner and outer diameter and wire type. The coil is glued on top of the ferrite, the leads are shortened and the tinned ends are soldered on top of the u-clamps. The back side of the u-clamps is meant to be soldered on the PCB. To make the coil resistant to a high temperature of about 250 °C, which is used at the reflow soldering at the assembly process, the top of the SMD coil is covered with a heat resistant resin.

The picture of the first prototype coil manufactured at the WE production site is shown in fig. 6. The coil has the part number 750371636.

Fig. 6. SMD coil 750371636 front side (left) and back side (right).

B. *Electrical Parameter, Soldering, Thermal and Moisture Reliability Test Methods*

The electrical parameters of the SMD coil like inductance (L), the coil quality factor (Q) and the DC resistance (R_{DC}) are determined by using an LCR meter. The reliability of the SMD coil is tested in regard of thermal behavior (high temperature exposure storage and shock tests) and in regard of moisture resistance. In addition, the SMD coil is tested in a reflow soldering process at 250 °C.

The high temperature exposure storage test procedure (in the following referred as test procedure 1) has been performed according to the standard MIL-STD-202-108 and the high temperature shock test procedure (in the following referred as test procedure 2) according to the standard MIL-STD-202-107. In this test, four samples of the SMD coils have been stored in an oven for 96 hours at 125 °C.

The moisture resistance test procedure (in the following referred as test procedure 3) is performed due to the standard MIL-STD-202-106. In this test, four samples of the SMD coils have been stored at a climate chamber for 196 hours at 65 °C and 95 % humidity.

The SMD coils are also tested with regard to their resistance to a soldering reflow process, which is used by customers to mount the SMD coil on the PCB. Reflow soldering is a widely used process in electronics manufacturing for attaching surface mount components to PCBs. This method involves using a solder paste, which is a mixture of powdered solder and flux, to temporarily secure components to their contact pads on the PCB.

The solder paste reflows in a molten state, creating permanent solder joints. Heating is accomplished by passing the assembly through the reflow oven (in this case, a Mistral 260 solder oven is used) in the following four step process:

1. Preheat: The PCB assembly is gradually heated to prevent thermal shock and component damage
2. Thermal Soak: The entire assembly reaches a uniform temperature, activating the flux and removing oxides from the surfaces
3. Reflow: The temperature peaks, causing the solder paste to melt and form strong metallurgical bonds between component leads and PCB pads
4. Cooling: The temperature is rapidly lowered to solidify the solder joints

The reflow oven's temperature profile is crucial for successful soldering. For lead-free solder (Sn/Ag), the reflow temperature is typically at about 250 °C. The profile must be carefully controlled to ensure proper solder joint formation without damaging components or causing defects. [7] [8]

Before and after the test procedures, the above mentioned electrical parameters are measured and compared with each other. To pass the test, the electrical parameters should be within a predefined tolerance range, which is defined in the datasheet of the device under test (DUT). In addition, an optical inspection of the DUT has been performed in regard of defects of the windings, cracks in the ferrite or optical irregularities.

C. *Qi-Compliance Verification*

Table 1 shows the comparison of the Qi-A11 electrical and layout parameters with the developed SMD coil (only wire part of the SMD product without ferrite).

TABLE I. QI PARAMETER COIL COMPARISON

Parameter explanation	**Qi Parameters**		
	Qi-A 11 Coil Parameters	***SMD Coil parameters***	***Fulfilled?***
Litz wire type	105*0.08 mm	105*0.08 mm	yes
Outer coil diameter	44 ± 1.5 mm	42.9 mm	yes
Inner coil diameter	20.5 ± 0.5 mm	20.4 mm	yes
Maximum coil thickness	2.1 + 0.5 mm	2.3 mm	yes
Number of turns per layer	10 (5 if bifilar)	10	yes
Number of layers	1 (if unifilar), 2 (if bifilar)	1 (unifilar)	yes

The developed SMD product uses Mn-Zn as the ferrite material. The ferrite thickness is 2 mm and the shielding extends the coil to about 3 mm, so it also meets the Qi requirements for shielding (see Qi requirements at the introduction). Therefore the whole SMD article 750371636 is Qi-compliant.

III. RESULTS

A. *Electrical Parameter Test Results*

Table II shows the average values of electrical parameters of four samples of the SMD coils, measured with an LCR meter at room temperature of 25 °C and at a frequency of 125 kHz.

TABLE II. ELECTRICAL PARAMETERS OF THE SMD COIL

Parameter Explanation	Electrical Parameters		
	Needed value defined in the datasheet	*Measured average value*	*Measured value within tolerance?*
Inductance L [µH]	6.3 ± 10 %	6.8	yes
DC Resistance R_{DC} [mΩ]	48 (max.)	44.5	yes
Q factor	90 (max.)	78	yes

B. *Reliability Test Results*

Table III shows the test results of the high temperature exposure storage tests (test procedure 1). The tests are passed if the electrical parameters are within datasheet parameters after the test is finished.

TABLE III. HIGH TEMPERATURE STORAGE TEST RESULTS OF THE SMD COIL

Parameter Explanation	Electrical Parameters		
	Before test (average)	*After test (average)*	*Passed?*
Inductance L [µH]	6.8	6.7	yes
DC Resistance R_{DC} [mΩ]	44	44.5	yes
Q factor	88	85	yes

Table IV shows the thermal shock test results (test procedure 2).

TABLE IV. THERMAL SHOCK TEST RESULTS OF THE SMD COIL

Parameter Explanation	Electrical Parameters		
	Before test (average)	*After test (average)*	*Passed?*
Inductance L [µH]	6.8	6.4	yes
DC Resistance R_{DC} [mΩ]	44	41.5	yes
Q factor	90	88	yes

Four different samples have been tested visually and electrically after the samples have gone through the reflow process. The electrical and visual appearance did not change significantly after the reflow soldering process has been completed. Also the ferrite did not get brittle afterwards.

Table V shows the moisture resistance test results (test procedure 3).

TABLE V. MOISTURE RESISTANCE TEST RESULTS OF THE SMD COIL

Parameter Explanation	Electrical Parameters		
	Before test (average)	*After test (average)*	*Passed?*
Inductance L [µH]	6.8	6.4	yes
DC Resistance R_{DC} [mΩ]	48	48	yes
Q factor	86	92	yes

C. *Functionality Test*

For the functionality test, two SMD coils are soldered onto an unpopulated PCB, and two wires are then soldered to the PCB. After the reflow process, two Royer converters, described in [9], have been used for the power transmission. At the transmitter side, a DC power supply is connected to the Royer converter, and at the receiver side, the load is operated in the form of multiple light emitting diodes (LEDs). The Royer converter on the transmitter side is used as oscillator for generating a sinusoidal AC voltage, that is needed to transmit energy over the coil. At the receiver side, the Royer converter acts as a rectifier, which converts the AC back into a DC voltage that drives the LEDs. A representation of the arrangement can be seen in fig. 7. The functionality of the arrangement, and thus also of the SMD coils, can be checked by means of the illuminated LEDs. If the LEDs light up, it means that the transmission of energy from the transmitter side to the receiver side was successful and the SMD coils have fulfilled their function. [4]

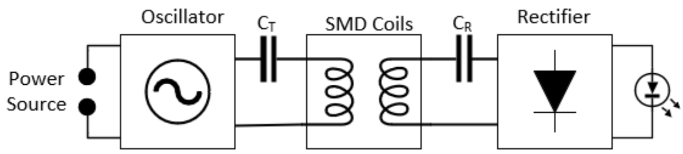

Fig. 7. Wireless power transmission principle using the developed SMD coils.

IV. DISCUSSION AND OUTLOOK

In this paper, the design and reliability tests of a SMD Qi-compliant wireless power coil have been described. The design of the SMD coil is related to the Qi-A11 transmitter design. It has been shown that the developed SMD coil is resistant to reflow soldering and that the SMD product is reliable against high temperatures of 125 °C and a humidity of 95 %. Finally, the SMD coils functionality has been tested with Royer converters on the transmitter and receiver side. In a next step, the SMD product will be tested in a complete WPT system based on the 200 W design of WE.

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