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Development and Characterization of a Surface-Mounted Device Qi-Compliant Wireless Power Coil

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Abstract

This paper describes the development of a Qi-compliant surface-mounted device (SMD) wireless power coil and the implementation and test of the developed coil in a wireless power transfer (WPT) system. To ensure the reliability of the developed coil, different standardized high temperature, moisture and vibration test procedures have been performed. One of the main challenges is to ensure the robustness of the developed coil through the high-temperature reflow soldering process. The main objective was to develop a system for WPT, which enables the usage of the developed SMD coil on the transmitter and receiver side. Finally, the performance of the developed system using the SMD coil is compared to the Würth Elektronik (WE) 200 W design using a comparable through-hole technology (THT) coil with a similar design. The SMD coil design has been filed as a patent.

1 Introduction

1.1 State of the Art Qi-Compliant Wireless Power Coils

The Wireless Power Consortium (WPC) is an industry group of about 300 members that was established to create and promote standards for wireless charging technology. Founded in 2008, the WPC is best known for developing the Qi standard in the year 2010, which is widely used for wireless charging of smartphones, tablets, and other electronic devices. In 2023 and 2024, the Qi 2 standard and the cordless kitchen standard Ki have been published by the WPC. [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, which is designed in accordance with the Qi-A11 design, is shown in fig. 1.

Fig. 1 Qi-A11 wireless power charging coil (article number 760308100111) from WE [4]

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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 THT.

1.2 State of the Art Surface-Mounted Wireless Power Coils

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.
Although there are stamped coils, which have the same inductance and the same outer and inner diameter like the Qi-A11 coil in fig.1, they are not Qi-compliant. In addition, they 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.
These surface-mounted state of the art coil technologies 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.

2 Methods

2.1 Development Steps of the Qi-A11 SMD Coil

The following steps have been performed to develop a Qi-A11 compliant wireless power SMD coil:

1. 3D-design of a ferrite plate similar to the ferrite plate shown in fig.1 with grooves and design of u-clamps, which can be assembled on the grooves (see fig. 2).

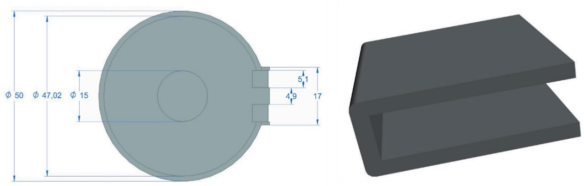

Fig. 2 CAD model of the ferrite plate (left) and the u-clamp (right, not to scale) [4]

2. Manufacturing of the ferrite plate (material: Mn-Zn) and the u-clamps (material: copper) and assembly of the u-clamps into the grooves.
3. Winding of a coil, which is identical to the coil shown in fig. 1, but with shortened leads. The resulting coil is shown in fig. 3.

Fig. 3 Winded coil in accordance to the Qi-A11 design [4]

4. Shortening and tinning of the leads of the winded coil shown in fig. 3 and glueing of the coil onto the manufactured ferrite plate (see fig. 4).

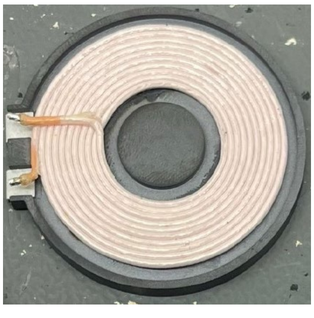

Fig. 4 Glued Qi-A11 coil on top of the ferrite plate [4]

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5. Soldering of the tinned ends of the coil onto the surface of the u-clamp and coverage of the surface of the coil with a heat resistant epoxy (for the first prototype, the epoxy Sirnice CC1011 has been used). Fig. 5 shows the resulting product, manufactured by the WE production site. The final product has the part number 750371636.

Fig. 5 WE Qi-A11 SMD coil 750371636 (left: front side, right: back side)

2.2 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 120 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. [5] [6]

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.

2.3 Qi-Compliance Verification

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

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).

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Parameter explanations	Qi-A11 coil parameters	SMD coil parameters
Litz wire type	105*0.08mm	105*0.08mm
Outer coil diameter	44 ± 1.5 mm	42.9 mm
Inner coil diameter	20.5 ± 0.5 mm	20.4 mm
Maximum coil thickness	2.1 ± 0.5 mm	2.3 mm
Number of turns per layer	10 (5 if bifilar)	10
Number of layers	1 (if unifilar) 2 (if bifilar)	1 (unifilar)

Table 1 Layout parameter comparison between Qi-A11 design and developed SMD article (average values of four measured parts)

2.4 Functionality Test Method of the Developed SMD Article 750371636

To test if the developed SMD article works similar to the Qi-A11 coil (see fig. 1), a complete wireless power system has been developed, based on the WE 200 W WPT design, which can be found on the WE webpage [7]. The working principle of the system is defined in [8]. The developed system, including the article 750371636 on the transmitter and receiver side, can be seen in fig. 6. The developed system is compared with the WE 200 W system using the Qi-A11 coil (see fig. 1) on both sides. The DC input voltage for both systems is 24 V. The DC output voltages (V_{OUT}), the DC output currents (I_{OUT}), the DC input currents (I_{IN}), the DC input powers (P_{IN}), the DC output powers (P_{OUT}) and the DC-to-DC efficiencies η are determined for both systems within a frequency ranges from 125 kHz – 205 kHz and compared afterwards.

3 Results

3.1 Electrical Parameters Test Results

The average values of the electrical parameters of four samples of the part 750371636 have been measured with an LCR meter at room temperature of 25 °C and at a frequency of 125 kHz. The measuring results are shown in table 2.

Parameter explanation	Value defined in the datasheet	Measured average value
Inductance L [µH]	6.3 ± 10 %	6.8
DC Resistance R_{DC} [Ω]	48 (max.)	44.5
Q factor	90 (max.)	88

Table 2 Measured electrical parameters of the developed SMD article 750371636 (average values of four measured parts)

3.2 Reliability Test Results

Table 3 shows the test results of the high temperature exposure storage tests (test procedure 1). A test procedure is considered to pass if the electrical parameters are within the datasheet parameter tolerances after the respective test is finished.

Parameter explanation	Before test (average)	After test (average)
Inductance L [µH]	6.8	6.7
DC Resistance R_{DC} [Ω]	44	44.5
Q factor	88	85

Table 3 Results of test procedure 1

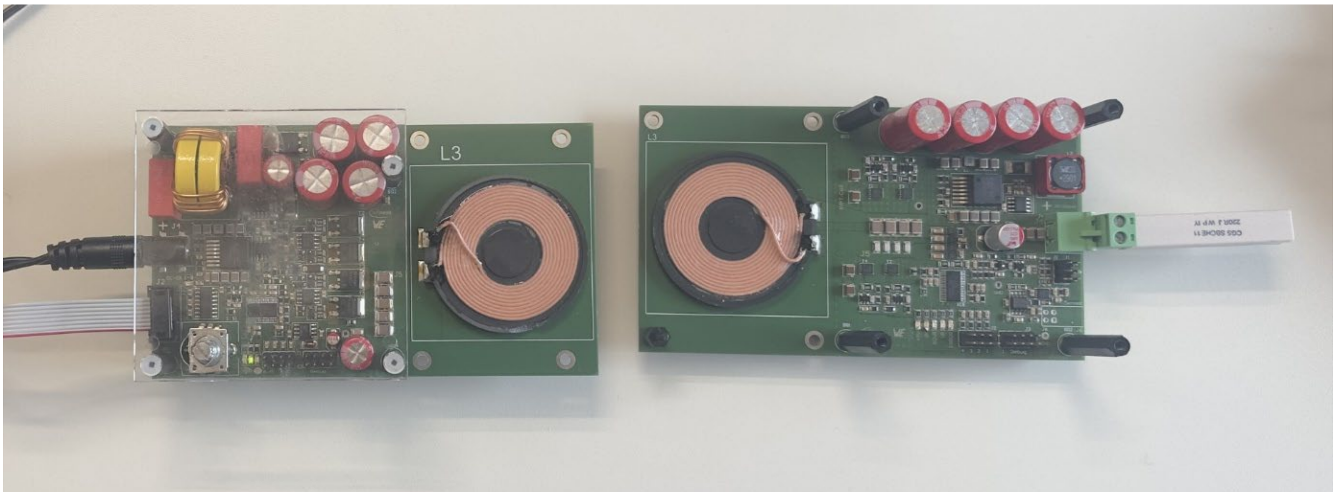

Fig. 6 Developed SMD WPT system

Table 4 shows the thermal shock test results (test procedure 2)

Parameter explanation	Before test (average)	After test (average)
Inductance L [µH]	6.8	6.4
DC Resistance R_{DC} [Ω]	44	41.5
Q factor	90	88

Table 4 Results of test procedure 2

Table 5 shows the moisture resistance test results (test procedure 3)

Parameter explanation	Before test (average)	After test (average)
Inductance L [µH]	6.8	6.4
DC Resistance R_{DC} [Ω]	48	48
Q factor	86	92

Table 5 Results of test procedure 3

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.

3.3 Functionality Test Results

During the functional tests, the 200 W kit and the equivalent SMD version were tested using an similar setup. For this purpose, the same distance and the same load were set for both kits and then the frequency was varied. Various parameters such as output voltage, input power, output power and more were then determined and compared. Table 6 shows the different electrical parameters of the 200 W kit.

Frequency [kHz]	I_{IN} [mA]	V_{OUT} [V]	I_{OUT} [mA]	P_{IN} [W]	P_{OUT} [W]	η
205	782	19.5	773	18.8	15.1	0.80
201	801	19.6	776	19.2	15.2	0.79
195	795	19.7	782	19.1	15.4	0.81
191	897	21.1	838	21.5	17.7	0.82
185	904	20.6	819	21.7	16.9	0.78
181	835	20.2	801	20.0	16.2	0.81
175	880	20.6	818	21.1	16.9	0.80
171	874	20.7	820	21.0	16.9	0.81
165	924	21.7	860	22.2	18.6	0.84
161	963	21.8	867	23.1	18.9	0.82
155	989	22.1	876	23.7	19.3	0.82
151	1036	22.6	896	24.9	20.2	0.81
145	1106	23.4	931	26.5	21.8	0.82
141	1195	24.2	961	28.7	23.3	0.81
135	1296	25.5	1012	31.1	25.8	0.83
131	1396	26.4	1048	33.5	27.6	0.83
125	1581	28.2	1119	38.0	31.5	0.83

Table 6 Different parameters of the tested 200 W kit

Table 7 shows the same parameters but of the SMD version of the 200 W kit.

Frequency [kHz]	I_{IN} [mA]	V_{OUT} [V]	I_{OUT} [mA]	P_{IN} [W]	P_{OUT} [W]	η
205	1050	20.7	827	25.2	17.1	0.68
201	1137	21.7	865	27.3	18.7	0.69
195	1075	21.0	840	25.8	17.6	0.68
191	1146	20.8	833	27.5	17.3	0.63
185	1100	21.8	871	26.4	19.0	0.72
181	1139	21.4	856	27.3	18.3	0.67
175	1148	21.8	871	27.6	19.0	0.69
171	1090	21.2	849	26.2	18.0	0.69
165	1153	21.9	874	27.7	19.1	0.69
161	1148	21.6	862	27.5	18.6	0.67
155	1139	21.8	871	27.3	19.0	0.70
151	1180	22.2	889	28.3	19.8	0.70
145	1176	22.1	885	28.2	19.6	0.70
141	1221	22.6	904	29.3	20.5	0.70
135	1280	23.4	934	30.7	21.8	0.71
131	1314	22.7	946	31.5	21.5	0.68
125	1373	24.3	971	33.0	23.6	0.72

Table 7 Different parameters of the tested SMD kit

The comparison of the tables 6 and 7 show very similar results. The average DC-to-DC efficiency of the SMD kit is about 0.7 and of the 200 W kit the average value is about 0.8. However, as the SMD version has a longer track length and the SMD coil also has poor heat dissipation, this leads to a slightly poorer overall performance of the PCB. This can be avoided by professional PCB design.

4 Discussion

All layout parameters in table 1 and all electrical parameters in table 2 of the developed SMD coil are fulfilling the Qi requirements. Because of this, the whole SMD article 750371636 is compliant in accordance to the Qi-A11 design.

In addition, the SMD coil has passed all performed reliability tests (see tables 3-5), which shows a good product quality.

Finally, the SMD coil has shown a similar behavior like the Qi-A11 design (see fig. 1), on which it is based on, which is shown in section 3.3.

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