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The Feasibility of Wireless Power Transfer Integration in Contemporary Furniture

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***Abstract*—A range of furniture pieces which allow inductive charging of low power devices have entered the market. Usually, the wireless charger module is cut through the furniture surface. As a consequence, the surface is not entirely smooth, which is aesthetically a disadvantage. It would be preferable if the wireless charger would be invisible, implying integration underneath the surface of the furniture. In this paper, we study the feasibility of inductive wireless power transfer with the most common used table top materials and coatings. We install the transmitter coil beneath the furniture surface so the wireless charger module remains invisible. We also measure the efficiency and power transfer of a typical bedside table with inductive powering, already available on the market, as a case study in order to obtain a reference for future furniture applications. Our main conclusion is that the presence of the most common furniture panels and coatings does not adversely influence inductive power transfer.**

***Keywords*—wireless power transfer; inductive charging; furniture; coupling factor**

I. Introduction

In 2015, the furniture shop IKEA^{TM} started selling a range of furniture that permits wireless charging [1]. It allows a user to put a device, e.g., a suitable smartphone or tablet, on top of a piece of furniture in order to charge it wirelessly. Obviously, this improves the user experience since no cable has to be connected to the device. The charging is done by inductive coupling: an alternating current in a transmitter coil generates a magnetic field, which induces a current in a receiver coil within the device.

Fig. 1 shows an example: the bedside table “Selje”. The supply cable with the plug is seamlessly hidden within the leg of the piece of furniture. A wireless charger module is implemented in the surface of the bedside table. A cross indicates where the user has to position his device to charge it (Fig. 1). Notice that the charger module is visible through the surface; in other words, a circle is cut in the surface through which the charger is put. As a consequence, the surface is not entirely smooth, which is aesthetically a disadvantage.

Also other companies recently brought furniture on the market that allows wireless charging, e.g.,

- *Evoni Design*^{TM} with a range of tables and (bed) side tables [2].

Fig. 1. The bedside table “Selje” from IKEA^{TM}. The cross indicates the wireless charger module.

- *Zens*^{TM} with a table charger implemented with 7 coils to allow more position flexibility [3].
- *FoneSalesman*^{TM} with a bamboo charging side table which can be powered with a USB source [4].
- *QInside*^{TM} with a table where the charger is supplied by a battery in the table leg [5].
- *The Worden Company*^{TM} with a range of benches and (tablet) tables [6].

In all those examples, the wireless charger module is cut through the furniture surface, just as in the example of the bedside table of IKEA^{TM}.

It would be preferable if the wireless charger would be invisible, integrated underneath the surface of the furniture. However, the bedside table of IKEA^{TM} is entirely built out of metal, which makes it at priori unsuitable to install a transmitter coil hidden beneath the surface, since the metal shields the wireless power transfer; the charger itself is implemented in plastic.

In this paper, we study the feasibility of inductive wireless power transfer with the most common used table top materials.

We install the transmitter coil beneath the furniture surface so the wireless charger module remains invisible. Obviously, if the table top would be only wood, it would not hinder the energy transfer between transmitter and receiver because no metal is present. But some common used varnishes or coatings might be conductive and thus reduce the energy transfer. More specifically, the contributions of this paper are:

- We measure the efficiency and power transfer of the IKEA™ bedside table as case study in order to obtain a reference for future furniture applications (section II).
- We study the feasibility of the most common table tops for wireless power transfer by measuring the coupling factor for the different materials (section III).

II. Case study

The wireless power transfer in the IKEA™ furniture (but also in the other examples above) follows the Qi interface standard [7]. The Wireless Power Consortium developed this standard for inductive power transfer over distances of up to 4 cm.

The Qi standard defines two basic types of wireless power transfer [7]:

- Type A designs use a single transmitter coil, thus requiring axial alignment with the receiver coil. In addition, this design type allows either guided positioning (e.g., with magnet alignment) or free positioning.
- The designs of type B use an array of several transmitter coils, thus enabling free positioning and allowing the possibility to charge multiple receivers at once.

The bedside table from IKEA™ is designed according to type A, more specifically, type A10: a single transmitter coil without magnet alignment. A transformer converts 230 AC net voltage to 19 V DC input voltage. With a half-bridge inverter, this DC voltage is converted to an AC waveform that drives a resonant circuit, which consists of the transmitter coil (24 ± 10 % μH) and a series capacitor (100 ± 5 % nF) [7].

Fig. 2 show the transmitter coil and temperature sensor within the charger module. The coil consists of 1.15 mm diameter litz wire with two layers on top of each other. Each layer has 10 turns, with an inner and outer diameter of 20.5 and 43 mm respectively. A ferrite layer is present under the transmitter coil, on the one hand to improve the direction of the magnetic field to the receiver, on the other hand to protect the underlying electronic circuit from the magnetic field [8]. The working frequency of the inductive link ranges from 110 to 205 kHz. A temperature and current sensor are present for fire safety. At 60 °C, the charger turns itself off. A led indicator is present immediately next to the cross on the surface to indicate ongoing charging, finished charging and malfunctions. Underneath the surface, accessible via the drawer of the bedside table, a USB connection is provided as extra (wired) charging point with a transmitter power of 10 W.

We measure the efficiency and power transfer of this bedside table as case study in order to obtain a reference for future furniture layouts. For our measurements, we connect the

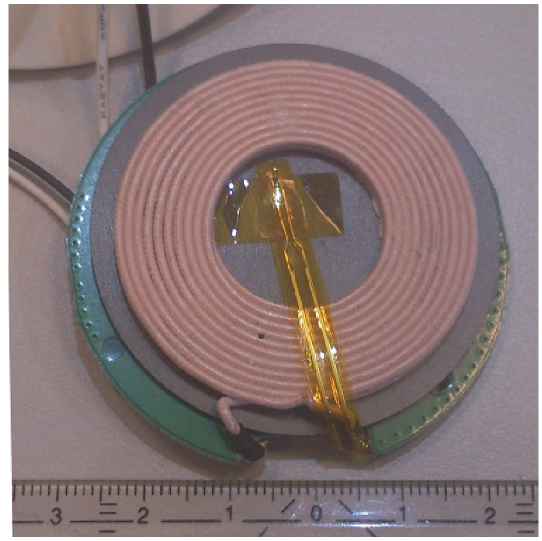

Fig. 2. The transmitter coil and temperature sensor within the wireless charger module of the bedside table "Selje".

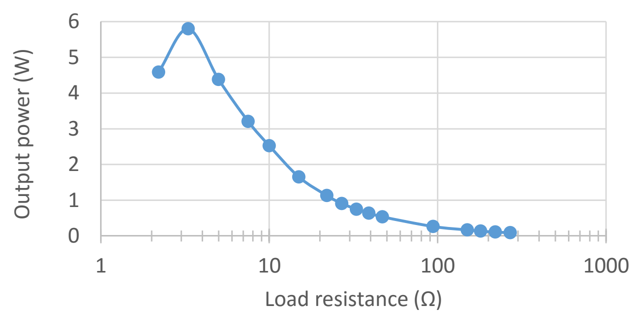

Fig. 3. The output power in function of the load resistance for the wireless charger module within the bedside table "Selje".

transmitter module directly to an EX2020R Power Supply which delivers 19 V input voltage. The input current is measured by this power supply. As receiver device, we use the Texas Instruments Receiver bq25046EVM which follows the Qi standard. We measure the voltage over and current through different loads connected to the receiver with a 4 3/4 Digit Programmable Multimeter HM8012. The vertical distance between transmitter and receiver is 1 mm. We measure a lateral misalignment tolerance between transmitter and receiver of 1.0 cm. For our measurements, we aligned both coils perfectly above each other. We define the efficiency η as the output power over the load resistance to the input power of the source. Fig. 3 shows the output power for different load resistances. We notice that our measurement configuration is optimized for a load of several ohms, resulting in a power transfer up to about 6 W. The output power is maximal for a load of 3.3 Ω. Fig. 4 and 5 show the efficiency of the wireless power transfer for different loads and output current. Efficiencies up to maximal 70 % are reached in the relevant range of operation. The power transfer is in that case 3 to

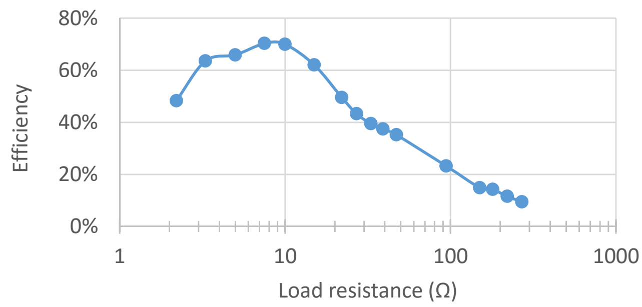

Fig. 4. The efficiency in function of the load resistance for the wireless charger module within the bedside table "Selje".

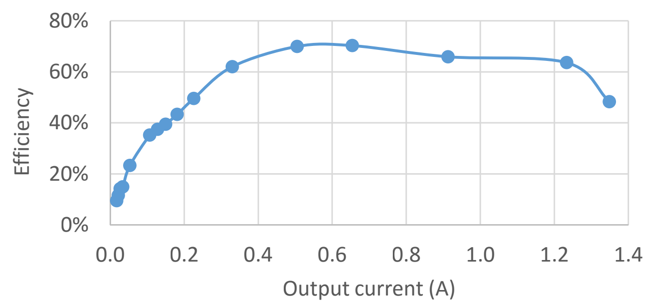

Fig. 5. The efficiency in function of the output current for the wireless charger module within the bedside table "Selje".

5 W, depending on the load of the receiver. Maximal efficiency is reached between 7.5 and 10.0 Ω. Notice the discrepancy between the optimal range for maximizing the efficiency and maximizing the power transfer, as can be expected according to the maximum power transfer theorem [9].

III. The coupling factor for different table tops

We got information of a local furniture factory on the most common table tops for furniture. Each table top consists of different material combinations (as well different coatings as different base materials). The table top materials are off the shelf and are within the industry referenced with the following names:

- Plywood with formica
- Formica
- High gloss panel
- Melamine
- Rubberwood
- White lacquered furniture surface
- White medium-density fiberboard
- Fireproof medium-density fiberboard with formica

A cross section of these table tops can be found in Fig. 6. The thickness of the panels varies from 17.6 to 20.1 mm.

We determine the coupling factor between two coils, perfectly aligned to each other, with the different materials as spacer between the transmitter and receiver coil. We also perform the measurements with air as spacer as reference,

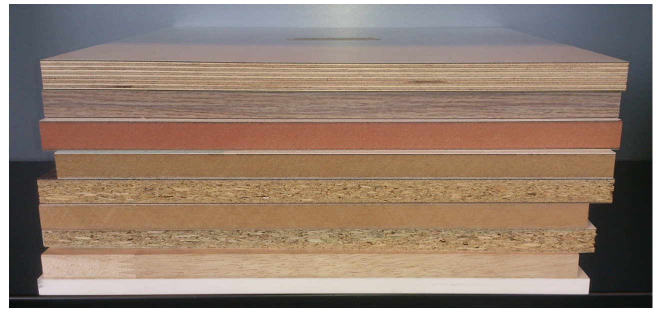

Fig. 6. Cross section of the different table tops considered in this study.

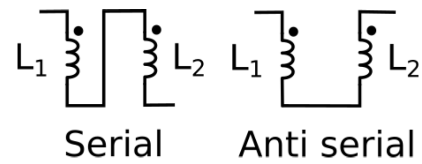

Fig. 7. Set-up of two coils in serial and in anti serial configuration.

with the vertical distance varying. As expected, the coupling factor k is dependent on the distance between transmitter and receiver. The goal is to determine if certain coatings are present that negatively influence the inductive power transfer.

We use the Precision LCR-meter Agilent 4285 A to measure the coupling factor k between two coils with a diameter of 43 mm. Because the series resistance of the coils is small, we have to take into account the ohmic losses of the test leads. Therefore, we perform a four point measurement which will, after calibration of the LCR-meter, compensate for those ohmic losses. The measurements are performed at a frequency of 125 kHz, in accordance with the Qi standard for the charging of low power devices. In order to determine the coupling factor k, we first measure the inductance L_s of both coils in serial configuration. Next, we measure the inductance L_a of both coils in anti serial configuration (Fig. 7). The mutual inductance M between both coils is then given by [10]:

$$M = \frac{|L_s - L_a|}{4} \tag{1}$$

Finally, we measure the self inductance of both coils: $L_1 = 25.3$ μH and $L_2 = 6.00$ μH. In that way, the coupling factor

TABLE I
Measurement results with air as spacer in function of different vertical distances d.

d (mm)	L_a (μH)	L_s (μH)	M (μH)	k
16.5	26.5	37.2	2.68	21.7 %
17.2	26.7	36.9	2.55	20.7 %
17.9	27.1	36.4	2.32	18.8 %
18.8	27.4	35.9	2.14	17.3 %
19.1	27.3	36.0	2.18	17.7 %
19.9	27.5	35.6	2.02	16.4 %
20.3	27.7	35.5	1.95	15.8 %

TABLE II

MEASUREMENT RESULTS WITH THE DIFFERENT FURNITURE PANELS AS SPACER.

Panel	thickness (mm)	L_a (μH)	L_s (μH)	M (μH)	k
Formica	17.6	26.7	36.8	2.53	20.5%
High gloss panel	17.8	26.8	36.6	2.45	19.9%
White lacquered furniture surface	18.2	27.0	36.4	2.37	19.1%
Melamine	18.2	27.0	36.5	2.38	19.3%
Rubberwood	18.2	26.9	36.5	2.39	19.4%
White medium-density fiberboard	18.3	27.0	36.4	2.35	19.1%
Plywood with formica	19.7	27.5	35.7	2.06	16.7%
Fireproof medium density fiberboard with formica	20.1	27.6	35.5	1.98	16.1%

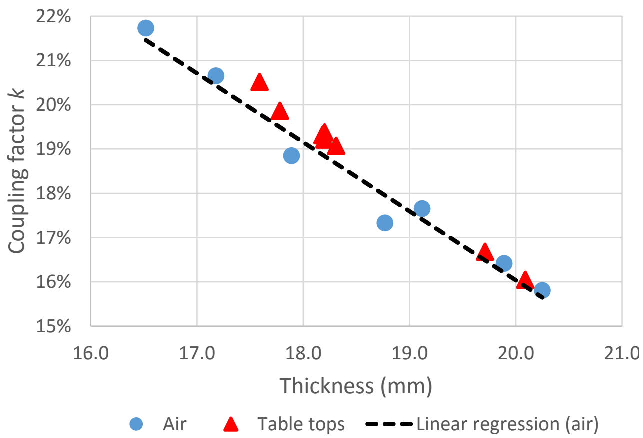

Fig. 8. The coupling factor k with air and the table tops as spacer. The dotted line indicates the linear regression of the measurements with air as spacer.

k can be calculated:

$$k = \frac{M}{\sqrt{L_1.L_2}} \tag{2}$$

Table I and II give an overview of the measurement results.

Fig. 8 summarizes the results. The graph shows, as can be expected, that the higher the vertical distance between the aligned coils, the lower the coupling factor k. In order to take this into account, we have plotted the linear regression of the measurements with air as spacer as a dotted line. Because none of the measurements with the furniture panels as spacer show a lower coupling factor than this linear regression, we can conclude that the presence of these furniture panels with the most commonly used, off the shelf, coatings, do not adversely influence the inductive power transfer.

IV. CONCLUSIONS

We measured the efficiency and power transfer of a typical bedside table with inductive powering, already available on the market, as a case study in order to obtain a reference for future furniture applications. Depending on the load, power transfer up to 6 W is possible, with efficiencies up to 70 % in the relevant range of operation. We also studied the feasibility of the most common table tops for wireless power transfer by measuring the coupling factor for different materials. Our main conclusion is that the presence of the contemporary furniture panels and coatings we investigated does not adversely influence inductive power transfer.

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