AN5535

Application note

Coil selection tool guide for STWLC68GUI

Introduction

This document provides a possible approach to the design of a wireless power receiving coil for low-power applications. Many parameters are involved in such a design flow, therefore different approaches are possible according to which one is considered the most relevant one (efficiency, overall quality factor of the coupled resonant circuits, etc.).

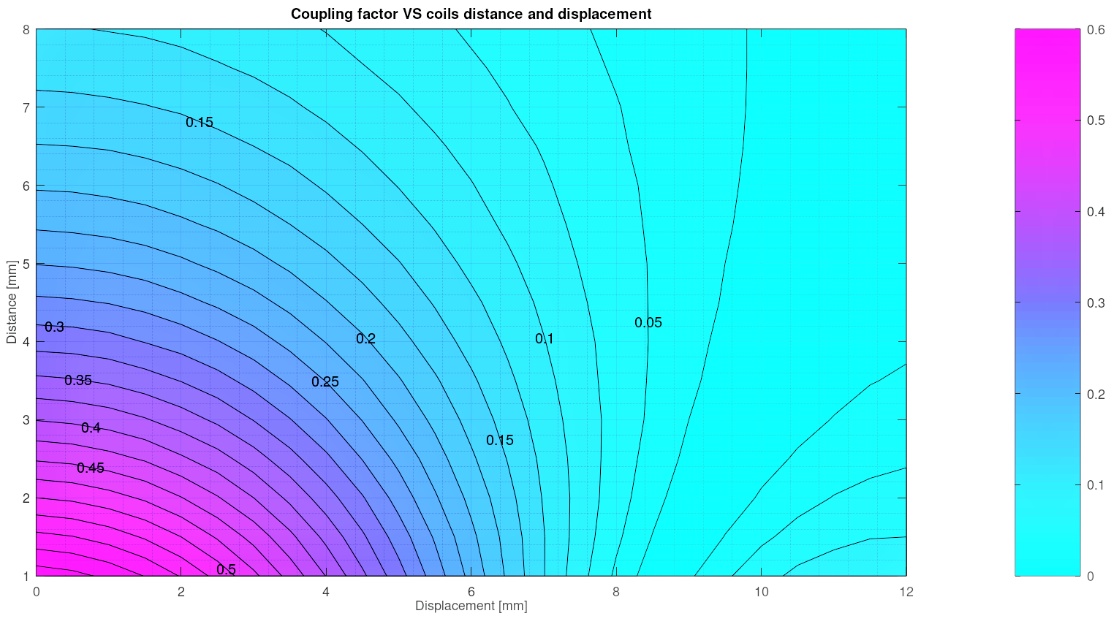
The overall efficiency of a wireless power transfer system is generally a reasonable starting point. Mechanical constraints and/or non-ideal alignment of the coils, as well as data-transfer requirements (e.g. ASK modulation index at transmitter side), are remarkably impacting on the whole design.

Apart wearable applications requiring customized coils with unusual shapes, usually both transmitting and receiving coils could be selected from a pool of commercial products based on well-proven designs and showing semi-standardized form-factors and electrical characteristics. From this perspective, the design of the transmitting coil is not covered by this document.

1 Coupling factor considerations

The coupling factor between transmitter and receiver coils is one of the most critical parameters in the design of a wireless power transfer system and it may significantly vary due to many reasons. Applications designed to provide a sort of guided and relatively accurate mechanical alignment of transmitter and receiver coils lead to a more controlled and predictable operation of the system. On the other side, approximate and variable relative positioning of the coils requires some margins to ensure power transfer reliability. Figure 1 shows how the coupling factor between two commercial coils, specifically designed for transmitter and receiver for wearable applications, varies as a function of distance and relative radial displacement.

Figure 1. Coupling factor versus coils distance and radial displacement



In Figure 1 it also noticeable that perfect axial alignment and proximity (1 mm distance in the origin of the plot) of the coils results in a maximum coupling factor near 0.6. The coupling factor quickly drops with distance and displacement: in real applications the minimum distance is dictated by the external enclosure of both transmitter and receiver active surfaces and the best-case coupling factor could be relatively low. A too low coupling factor directly impacts on the overall power transfer efficiency, as a consequence of higher power losses in the transmitter. Figure 1 refers to the first two coils reported in Table 1, used in the STEVAL-ISB045V1T evaluation board (L1) and in the receiver of the STEVAL-ISB68WA evaluation kit (L2).

Table 1. Transmitter and receiver coils examples

Coil PN (WE)	Ref	Inductance & DRC max	Dimensions
TX: 760308101104	L1	6.8 μH, 125 mΩ	20 mm diameter
RX: 760308101219	L2	11.8 μH, 750 mΩ	15 mm diameter
TX: 760308104113	L3	12 μH, 72 mΩ	60 x 46 mm
RX: 760308102207	L4	8 μH, 80 mΩ	40 x 40 mm

In Figure 2 and Figure 3 the coupling factor of a different TX-RX coils pair (L3 used in STEVAL-ISB044V1 and L4 used in STEVAL-ISB68RX) is shown. Because of the rectangular shape of the transmitter coil, the coupling factor slightly differs for X-axis and Y-axis displacements.

Figure 2. Coupling factor versus coils distance and X-axis displacement

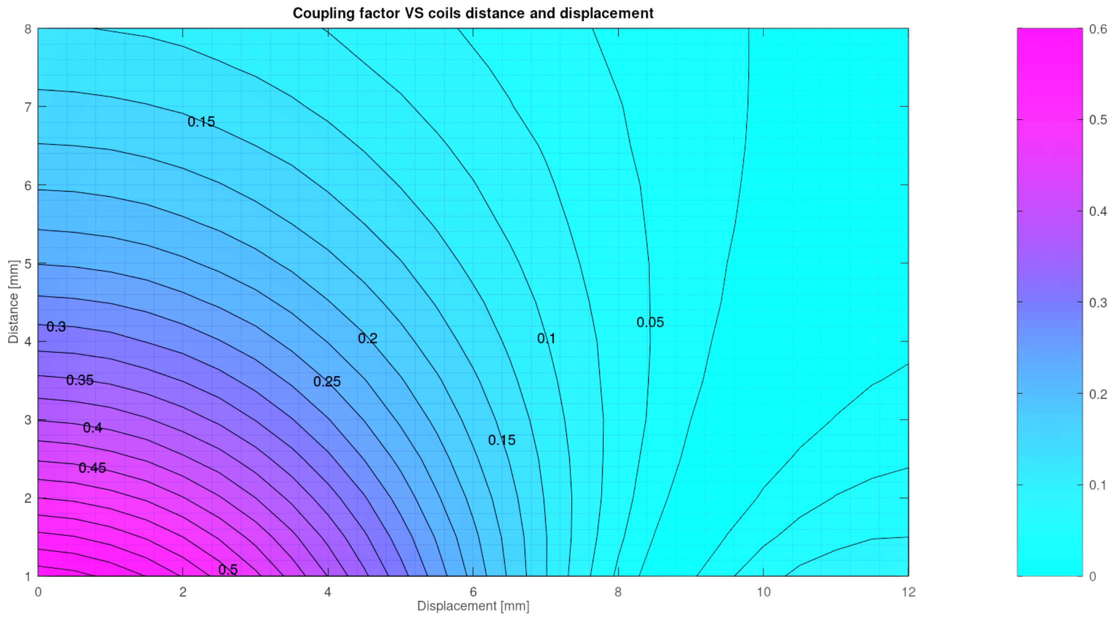
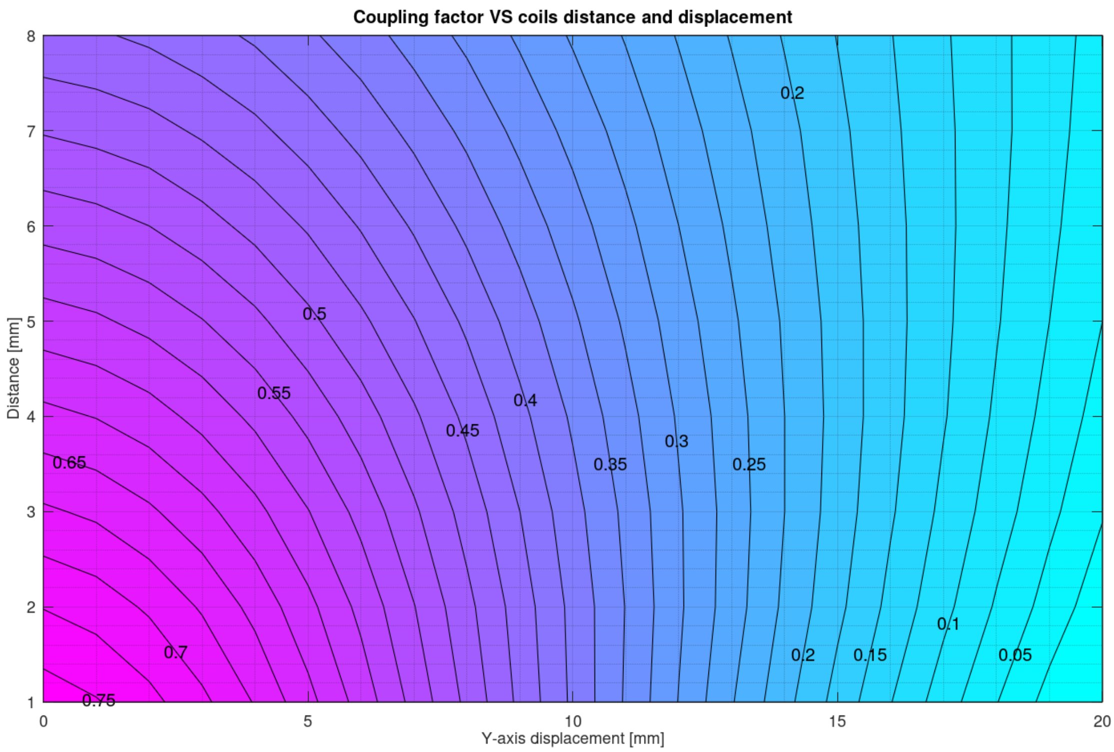


Figure 3. Coupling factor versus distance and Y-axis displacement

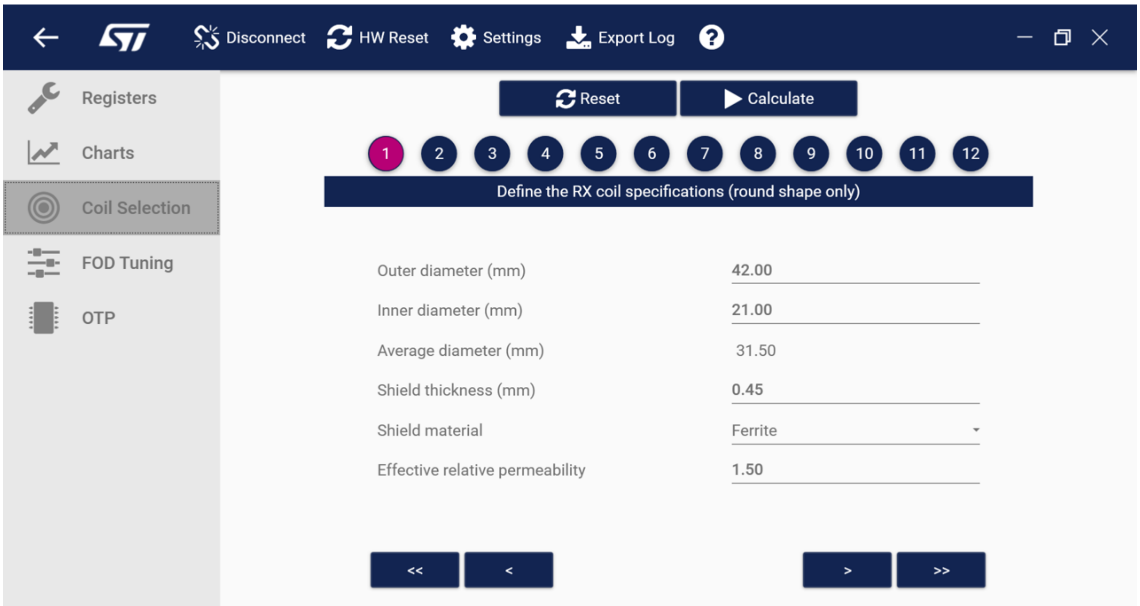


The bigger size of both coils significantly helps in getting a higher coupling factor over a much wider mis-alignment area.

2 Designing the receiver coil with the GUI

The STEVAL-ISB68WA evaluation kit provides a control GUI that embeds a section dedicated to the design of a receiving coil (Figure 4). The design procedure is intended as a guideline and has therefore some limitations (for example only round coils are supported), but it could be used as a starting point for prototyping a receiving coil. The initial assumption is that a transmitter is already identified or, at least, its characteristics are suitable for the mechanical specifications of the receiver coil. For example, wearable applications must probably rely on customized transmitters due to the mechanical constrains dictated by the design of the device. The first page of the coil design section allows the user to insert basic mechanical characteristics of the receiver coil, namely its outer and inner diameter. Since most of the coils are equipped with some shielding material, typically ferrite compounds, the inductance of the coil is affected. The estimation of the equivalent relative permeability is difficult, since it depends on many factors. As a first approximation, since the magnetic reluctance of the air gap is much higher than the ferrite path's one, a value not far from unity (relative permeability of the air) is chosen.

Figure 4. Initial RX coil specifications



The “Calculate” push-button is used to process the modified values, but an automatic recalculation is performed whenever the current page is left. In case improper values or unexpected results are encountered, a pop-up window with a message may appear.

The second page of the design section is dedicated to the transmitter's details. A set of pre-loaded standardized transmitting coils is available. Outer and inner diameters, nominal inductance and DC-resistance of the coil are shown. A customized coil could be eventually specified if not already included in the list. The output impedance of the power stage of the transmitter (typically the Rds_on of the power transistors) can also be entered to refine the estimation of the power losses and the quality factor (Figure 5. Transmitter details).

Figure 5. Transmitter details

In this section the expected distance between the transmitter and receiver coils is entered. This parameter, as already highlighted, may significantly impact on the coupling factor and it will be further addressed in the design process.

Proceeding with the third page, the ratio between the average diameters of both transmitter and receiver coils is calculated (Figure 6).

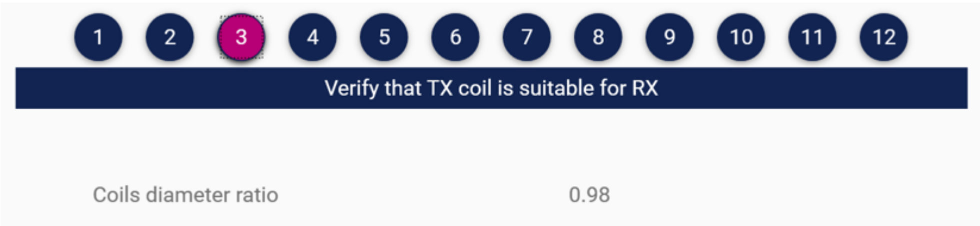
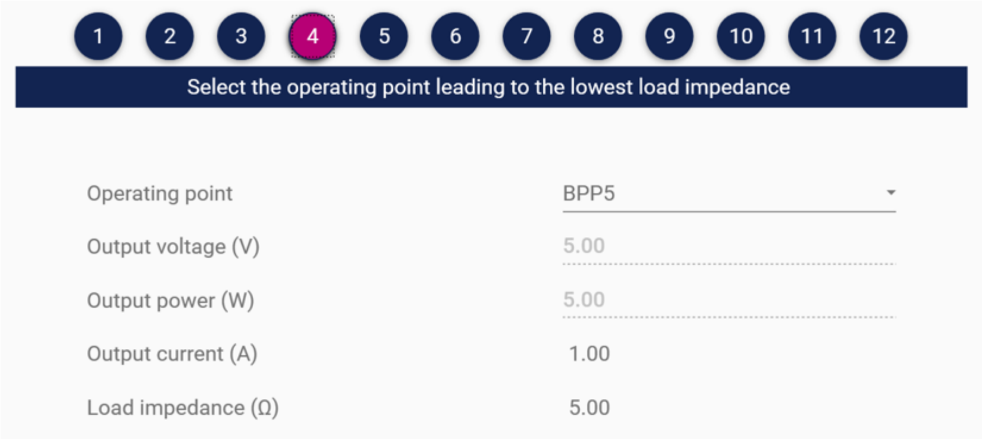


Figure 6. Average coils diameter ratio

This ratio is a preliminary indication of a potential critical coupling between the transmitter and the receiver: a ratio much lower than unity means that the selected transmitter coil is probably oversized for the desired receiver coil. For this reason, a good starting point is getting a diameters ratio in the 0.8 – 1.0 range and a pop-up message could appear to highlight that this condition is not verified. Lower values (e.g. down to 0.5 or less) could also be considered to widen the area of tolerable reciprocal coils mis-alignment, at the cost of lower coupling factor (with all related consequences).

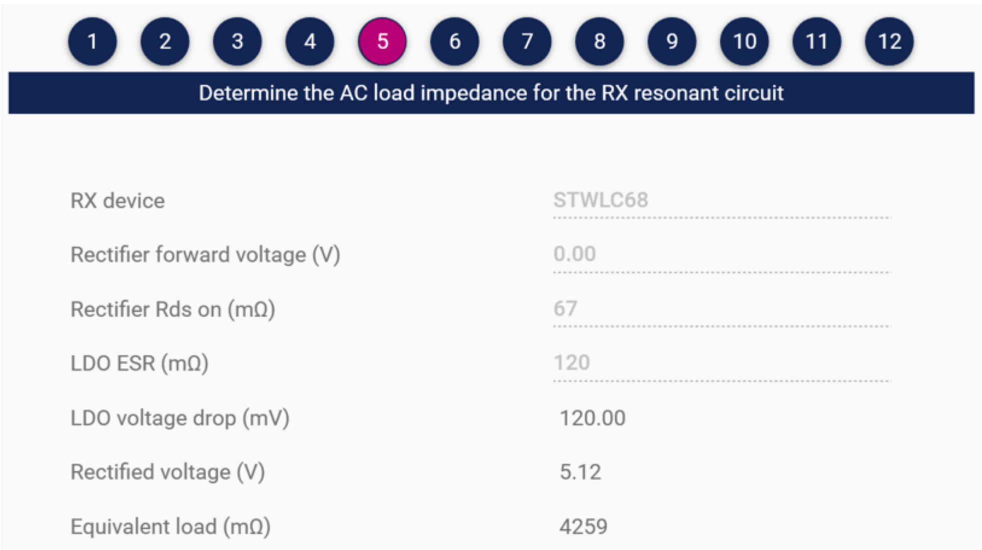
Moving to page 4, the operating point is selected. The design of the coil must consider the maximum output power to be delivered. An application targeting BPP, for example, requires a 1 A current capability at an output voltage of 5 V (Figure 7).

Figure 7. **Operating point selection**



The following step consists in translating the DC load resulting from the selected operating point into the equivalent AC impedance seen by the L-C series resonant circuit the receiver coil is part of. This calculation includes the voltage drops across the rectifier and the main linear regulator. Both contributions are strictly related to internal parameters of the device and they are a function of the operating point. Since the corresponding operating frequency is not predictable at this stage, a 100 kHz reference is used. The voltage at VRECT pin (output of the rectifier) is thus estimated and the equivalent impedance at the AC1 -AC2 pins calculated (Figure 8).

Figure 8. **Resonant circuit load impedance calculation**



In page 6 a further step is done to determine a target value for the inductance of the receiver coil. The concept is avoiding peak-splitting, a condition that could occur when two resonant circuits having a close resonance frequency are tightly coupled. Since the power transfer is based on a frequency control (operated by the transmitter), peak splitting may affect the overall transfer function and it is therefore undesirable. The critical coupling factor value is the boundary value (for a fixed system) that avoids peak-splitting. In practice a coupling factor 1.5 times the critical one is still acceptable (also considering that relative displacement of the coils leads to a reduction of the coupling factor), and the resulting calculated inductance provides a reference upper limit.

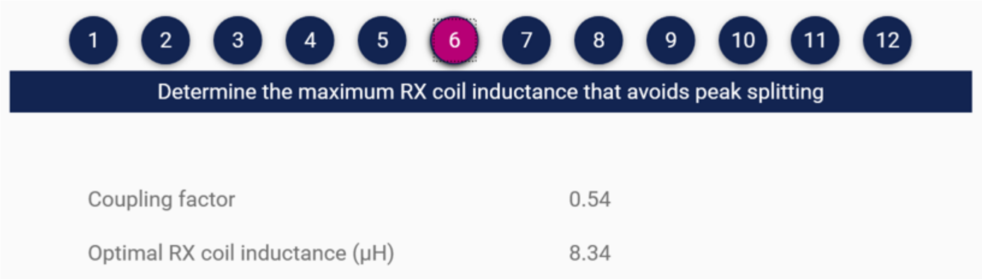


Figure 9. Coupling factor and coil inductance estimation

Once the inductance of the receiver coil is selected, an approximate calculation of the number of turns follows. The fill factor of the winding is set to 0.8 by default, but it can be changed as per user need. The winding should fit the available area between outer and inner diameters previously defined. The maximum wire diameter is then calculated (Figure 10).

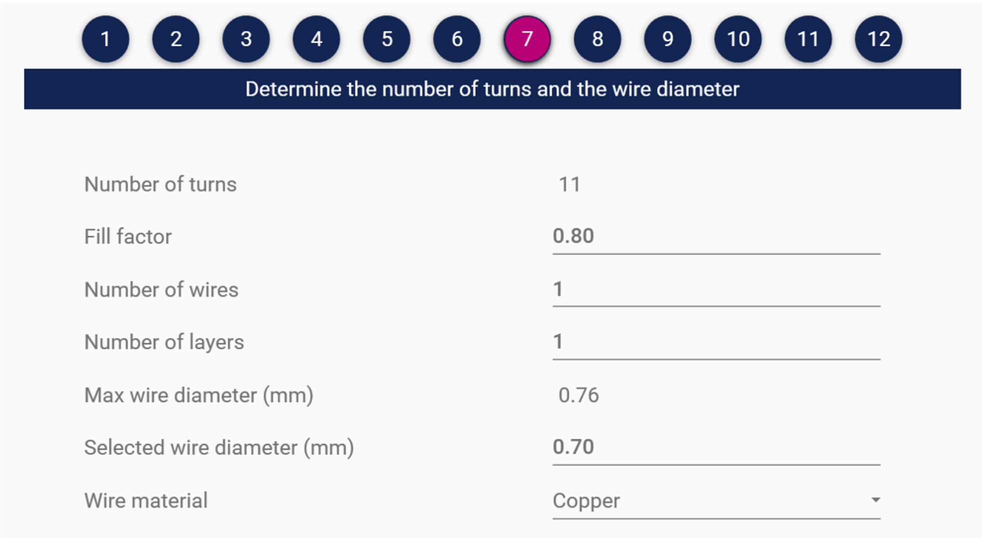


Figure 10. Coil winding specifications

The selection of the wire diameter and its resistivity allow a rough estimation of the DC-resistance and the associated power loss (at the reference operating point), as well as the quality factor of the coil (Figure 11).

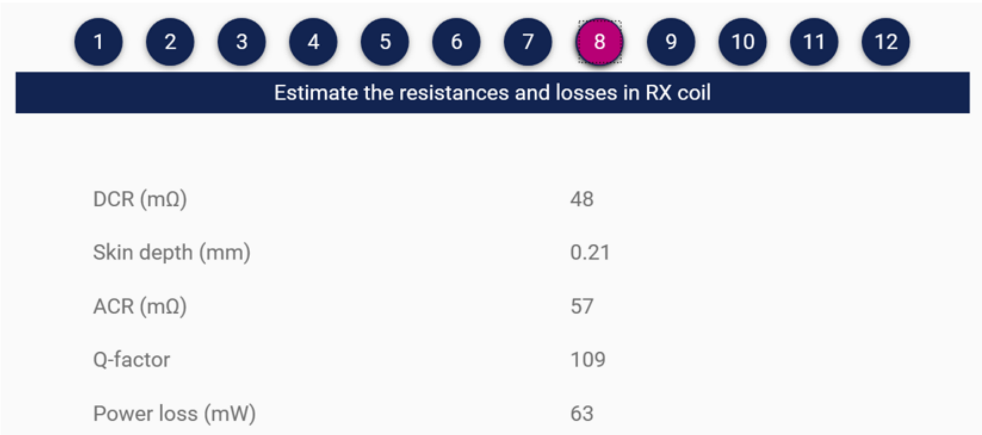
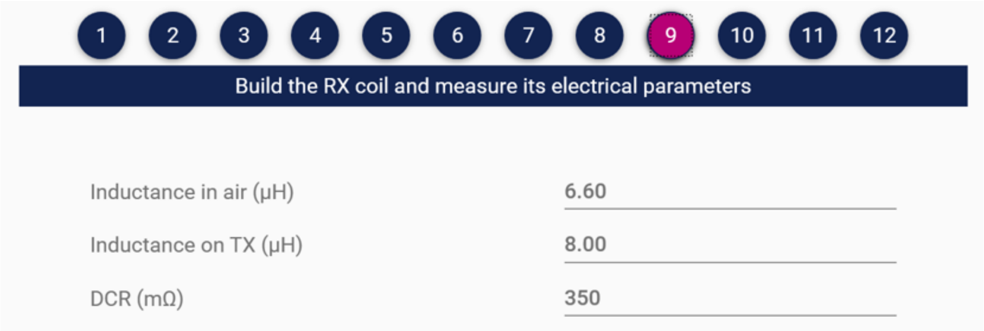


Figure 11. Coil electrical characteristics

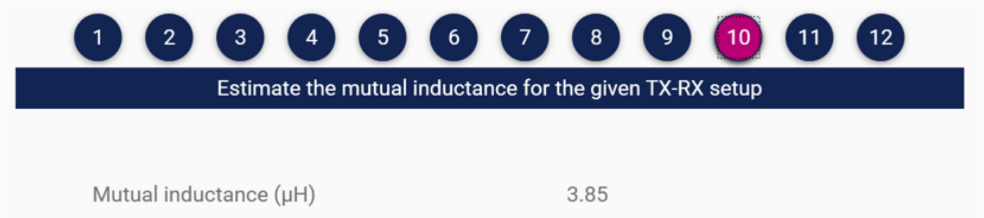
At this point of the coil design procedure a prototype is supposed to be built. Some iterations may be required to adjust the number of turns leading to the desired inductance value, eventually considering a thicker wire to reduce the DC-resistance. The electrical parameters of the final coil are then measured and used to proceed with the design of the series resonant circuit of the wireless receiver (Figure 12 and Figure 13). Optionally, if a coil prototype is not available, results from the previous sections could be used.

Figure 12. Actual coil characteristics



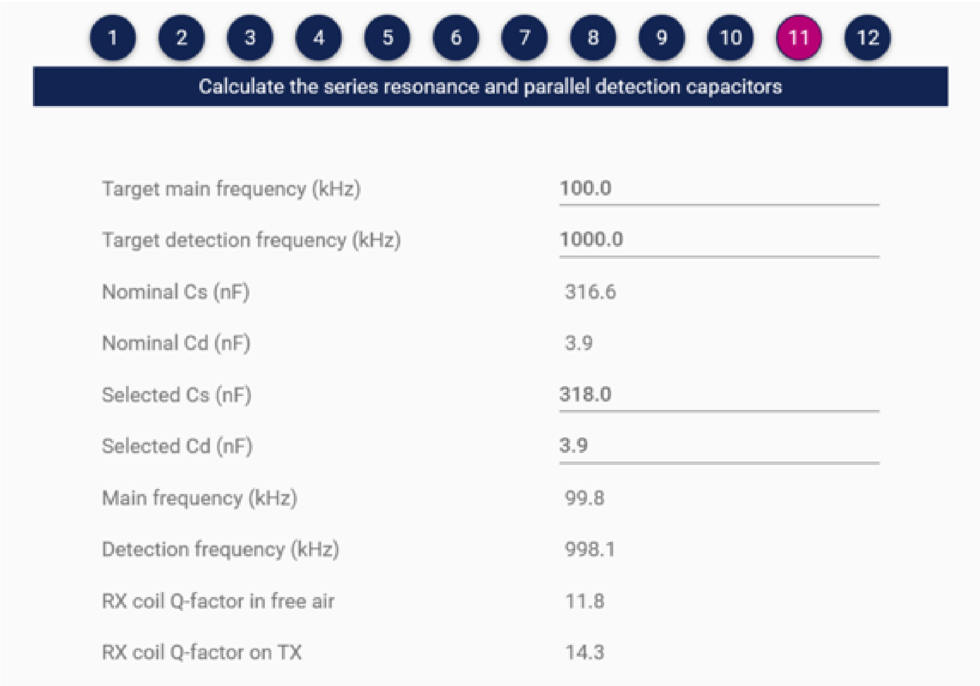
The proximity of the transmitter coil, usually equipped with a ferrite shield/core, significantly impacts on the inductance of the receiver coil. As per Qi specifications, this change (inductance on TX) must be taken into account when designing the series resonant circuit.

Figure 13. Mutual inductance estimation



In page 11 (Figure 14) the default values for both the resonance frequency and the detection frequency are set as per Qi specification, but they could be user-defined.

Figure 14. **Series resonant circuit design**



Note: adherence to Qi-specifications is not mandatory. If the receiver operates with a specific transmitter, tailoring the operating frequency range, the ping frequency and the resonance frequency could help in optimizing the maximum displacement and/or the overall TX-to-RX efficiency.

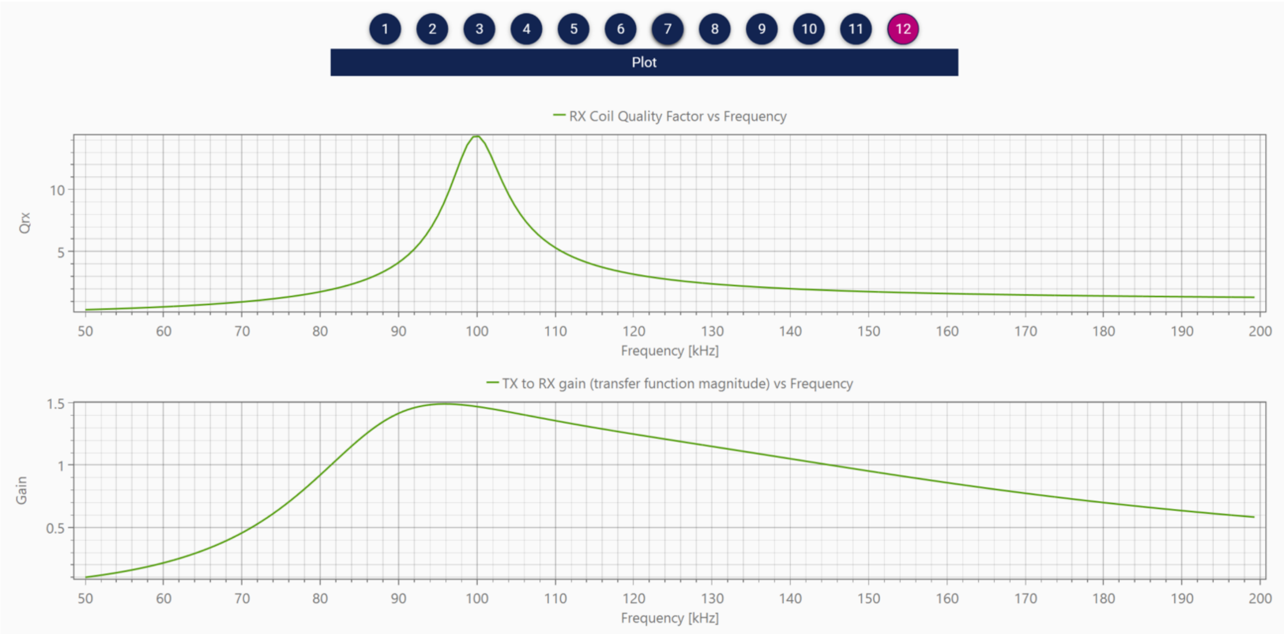
The series (Cs) and detection (Cd) capacitors leading to the target frequencies are then calculated. Slightly different values could be used (selected Cs & Cd), and the corresponding frequencies are recalculated for a final check. Regarding the capacitors, few simple suggestions are given:

- NP0 dielectric type is preferable whenever possible
- Capacitance variation due to DC bias/temperature-sensitive X5R/X7R (or similar) dielectric types should be limited to ensure adherence to Qi specifications.
- Multiple capacitors in parallel are preferable to reduce the Equivalent Series Resistance (ESR) and to increase the overall quality factor of the resonant circuit.
- Excessive RMS current easily stresses the capacitors, especially if tightly packed on a PCB showing poor cooling.

See also the STWLC68JRH data-sheet for additional considerations about external components.

The last page of the design tool (Figure 15) reports an approximate frequency plot of the quality factor of the receiver resonant circuit and the TX-to-RX gain (transfer function magnitude).

Figure 15. **Coil quality factor and transfer function calculation**



Once the design of the whole wireless power received is completed, it is good practice performing efficiency tests by sweeping over the full Qi frequency range for different operating conditions, monitoring the modulation index at the VRECT pin to ensure proper RX-TX communication.

Verifying the robustness of the designed receiver by testing different certified transmitters having (or not) similar coil-type and architecture (half-bridge/full-bridge driver, etc.) is also recommended.

Revision history

Table 2. Document revision history

Date	Version	Changes
24-Jul-2020	1	Initial release.