Foreign object detection (FOD) tuning guide for wireless power transmitters

Applicable to WLC ICs

About this document

Scope and purpose

The wireless charger (WLC) power transmitter solution reference board is a highly integrated wireless solution with Type-C Power Delivery (PD).

This application note is a guide to configure the foreign object detection (FOD) parameters required for custom designs based on the WLC power transmitter reference design.

Intended audience

Experts who customize designs based on REF_WLC_TX15W_C1 or REF_WLC_TX50W_N1-based wireless power transmitters.

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1 Introduction

This application note serves as a guide to tune the FOD parameters for optimal power transmitter performance. The Wireless Charging Configuration Utility enables the user to configure FOD parameters. See [8] and [9] for more details on the product reference design, referred to as "reference design" in this document. Contact the Infineon sales team for any additional support.

1.1 Document structure

- **Section 2** [Getting started] describes the FOD mechanism recommended by the Qi Standard and the WLC power transmitter approach for the FOD mechanism. Advanced users may skip this section.
- **Section 3** [FOD parameter tuning] describes the data collection, configuration parameter calculation, and updating of the WLC power transmitter using the Wireless Charging Configuration Utility. This section provides the following details:
  - **Q factor scaling factor and threshold tuning:** This section defines the process for configuring the scaling factor and thresholds for a Q factor-based FOD approach.
  - **Resonance frequency scaling factor and threshold tuning:** This section defines the process for configuring the scaling factor and thresholds for an RF-based FOD approach.
  - **System power loss curve coefficient tuning:** This section defines the tuning process to estimate and configure the power loss parameters. These parameters shall be programmed to the WLC power transmitter for aiding FOD using power loss measurements.
- **Section 4** [FOD functionality verification] provides the post-tuning process to validate the configurations and confirm the performance of the new settings the user makes.
- **Section 5** [Checklist for tuning operation] is a checklist of items to be ensured during the tuning operation.
- The appendices contain normative information for users.

2 Getting started

The WLC power transmitter provides Qi-compliant FOD features. See the FOD chapter in the Qi Standard for further details (see [1] and [4]). The following sections discuss the WLC power transmitter implementation of the FOD functionality.

2.1 FOD mechanism

The Qi Standard defines two mechanisms for FOD:

1. FOD before power transfer or pre-power transfer method
2. FOD during power transfer or in-power transfer method

2.1.1 FOD before power transfer

The pre-power transfer FOD method has the following mechanisms to detect a FO before power transfer between Rx and Tx starts:

1. Q factor FOD (FOD/qf)
2. Resonance frequency FOD (FOD/rf)

The receiver sends FOD/rf and/or FOD/qf packets during the negotiation phase. The Tx responds to these packets with an ACK packet if no FO is found and with a NAK packet if a FO is found. According to Qi, the Rx reports the Q factor and resonance frequency values measured to a standard MP-A1 coil. The transmitter measures the Q factor and resonance frequency values differently from the receiver-reported values, as it may have a different coil. A scaling factor is used to convert the receiver-reported Q factor and resonance frequency values to those equivalent to the transmitter coil.

The scaling factor is a function of the shielding material and friendly materials present in the Rx. This is derived from the relationship between the Q factor and resonance frequency devised by the MP-A1 coil and the experimentally measured Q factor and resonance frequency values. The scaling factors for the Q factor and resonance frequency measurements can be unique. The FOD/qf packets are sent by all extended power profile (EPP) receivers compliant with Qi 1.2 or above. The FOD/rf packets are sent by all EPP receivers compliant with Qi 1.3 or above.

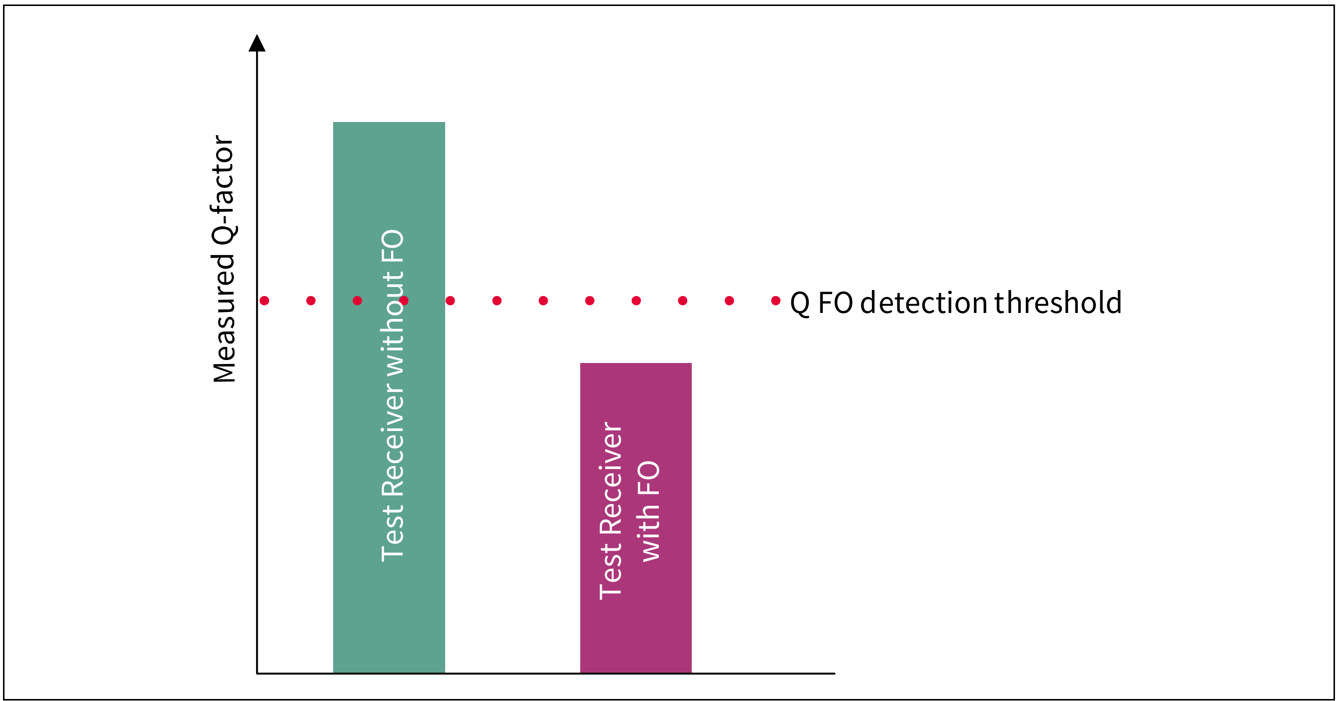


Figure 1 **FOD mechanism based on Q factor**

Q factor: This involves the measurement of the Q factor when an EPP TPR is placed on the interface surface of the transmitter. All the EPP TPRs report the reference Q factor measured with an MP-A1 transmitter coil. The transmitter controller needs to apply a scaling factor to derive the reference Q factor value with its transmitter coil (i.e., the coil considered for transmitter design). Compare the measured Q factor by the WLC power transmitter with the Q FO detection threshold, which is calculated from the scaled reference Q factor. Comparison of the measured Q factor with the Q FOD threshold determines the FO presence on the interface surface before the power transfer starts. The FO is detected if the difference between the measured and receiver-reported reference Q factor (FOD/qf packet) is less than the threshold. The measured Q factor includes a scaling factor [7].

If Q_{rep} is the receiver-reported Q factor and Q_{scl} is the scaled Q factor, then,

$$Q_{scl} = S_{factor} * Q_{rep} \qquad \text{Equation 1}$$

Where S_{factor} is the scaling factor for the custom transmitter. FO detection occurs when:

$$Q_{meas} < Q_{threshold} \qquad \text{Equation 2}$$

Where $Q_{threshold}$ is the threshold Q factor and Q_{meas} is the measured Q factor. The measurement of $Q_{threshold}$ and its relation with Q_{scl} is explained in [11].

Resonance frequency: This involves measurement of the resonance frequency (RF) when an EPP TPR is placed on the interface surface of the Tx. The reported RF is scaled to the Tx coil type by using a scaling factor. The measured RF is compared with the scaled RF and if the shift (difference) in RF is greater than the threshold, FO presence is confirmed.

The resonance frequency (in Hz) is derived from the supporting data as follows:

$$F_{res} = (2 * FOD/rf\ supporting\ data) + 72 \qquad \text{Equation 3}$$

$$F_{scaled} = ScalingFactor * F_{res} \qquad \text{Equation 4}$$

$$F_{threshold} = F_{scaled} * Threshold\_percent \qquad \text{Equation 5}$$

Where F_{res} is the reported RF, F_{scaled} is the scaled RF, and $F_{threshold}$ is the threshold RF. Threshold_percent and ScalingFactor are configurable from the Wireless Charging Configuration Utility.

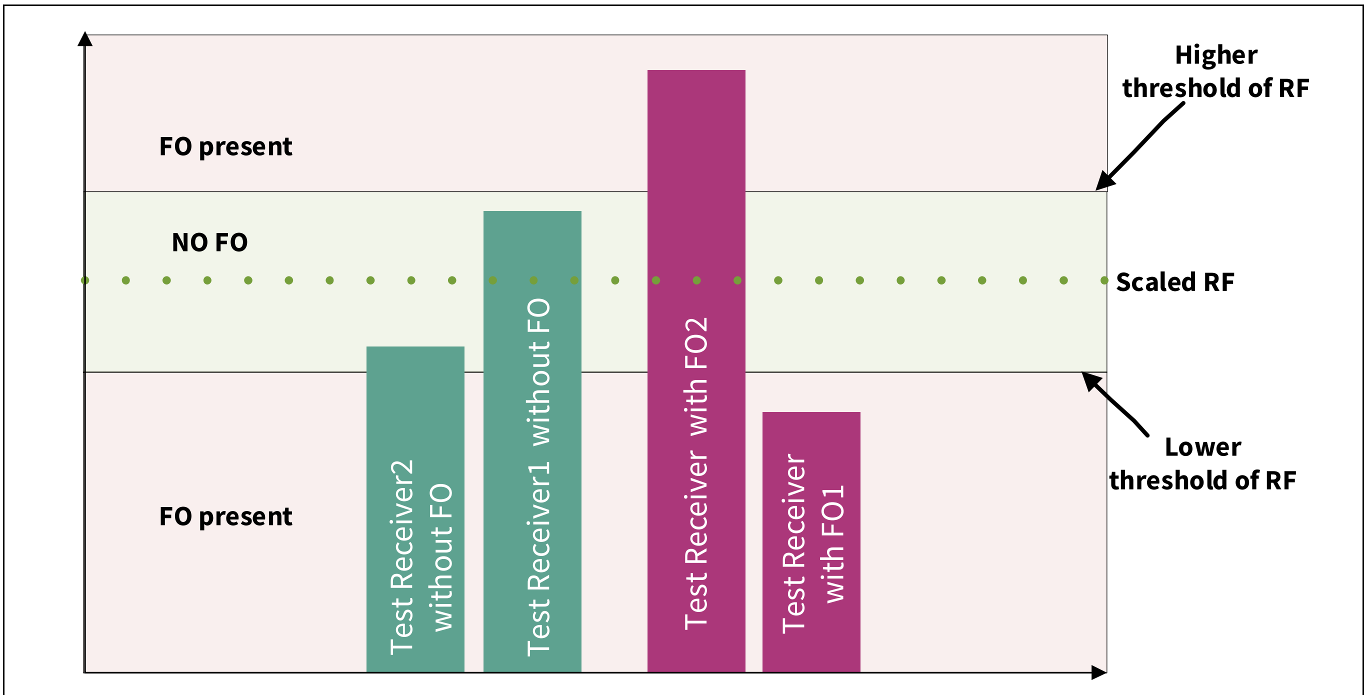


Figure 2 Resonance frequency-based FOD

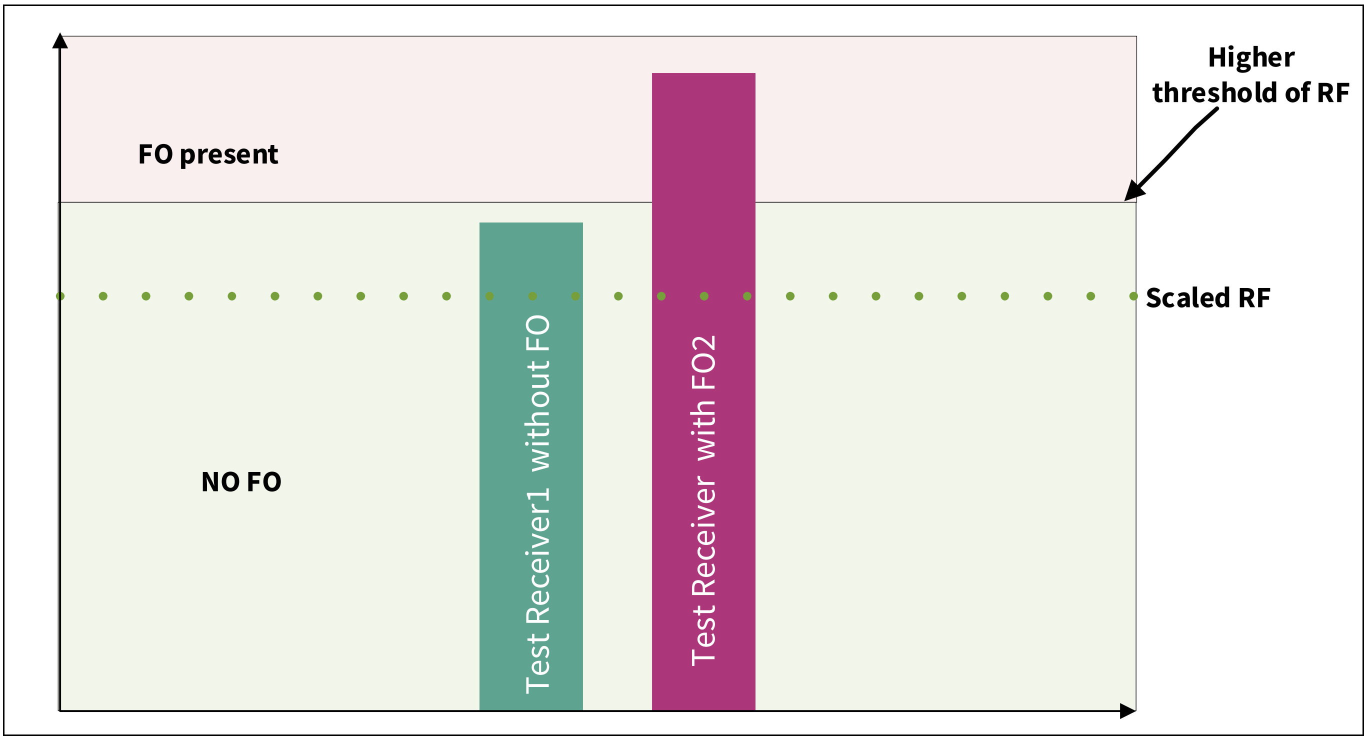


Figure 3 **Resonance frequency-based FOD for REF_WLC_TX50W_N1**

The FO is detected if the difference between the measured and scaled reference resonance frequency is greater than the threshold. "ScalingFactor" and "Threshold_percent" are configurable from the Wireless Charging Configuration Utility.

In case of a FOD, the Tx responds to the FOD/rf or FOD/qf packets with a NAK packet leading to immediate power disconnect. The communication is re-established only after the object is removed. See the user manual for LED user interface for FO detection.

2.1.2 FOD during power transfer

The power loss FOD mechanism involves measuring the transmitter power periodically during power transfer and comparing the measured power with the loss curve estimates given by the receiver. To improve the reliability and accuracy of FOD, additional methods are introduced by the WLC power transmitter.

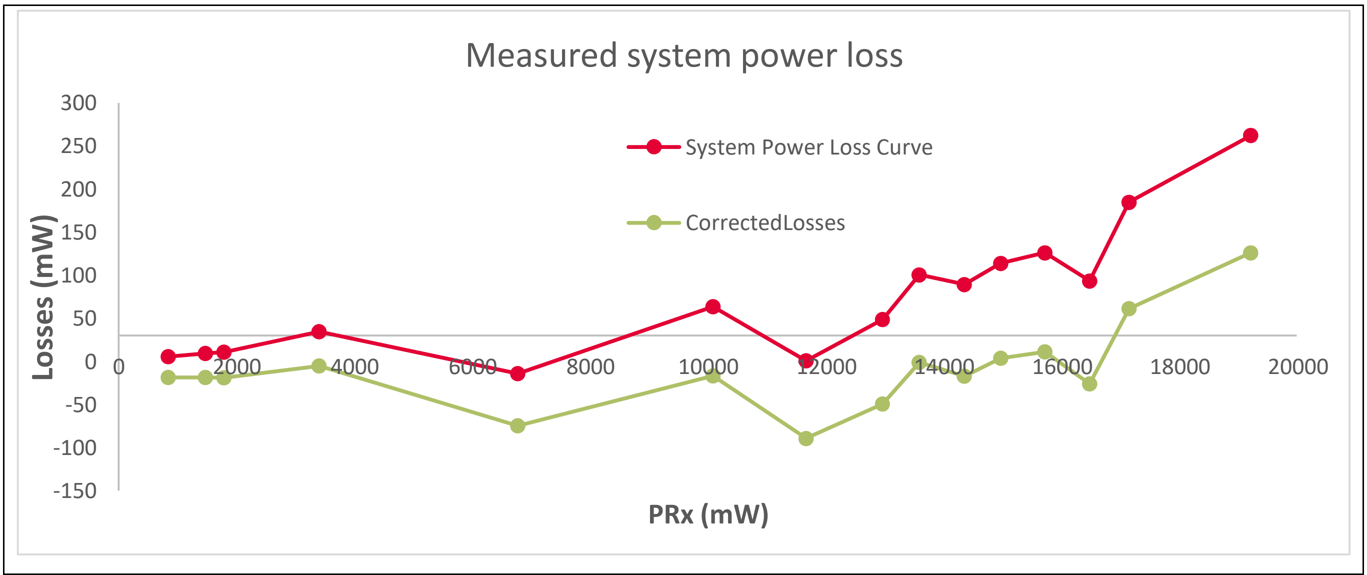


Figure 4 **Typical power loss measurement with power delivery range**

System power loss: The FO is detected if the measured system power loss exceeds the system power loss threshold value. See [2] for more details on the FOD techniques recommended by the Qi Standard.

Accurate FOD requires reference to the power loss calibrated parameter data for a given hardware design and interface surface height (Z-axis). This reference calibration data is required to compensate for the power loss balance deviations induced by the system. The WLC power transmitter system power loss varies with transmitter power delivery range, receiver device coupling factor, temperature, etc. Section 3.5 shows a typical power loss measurement over the power delivery range and the respective loss correction curve. This is a typical behavior of loss correction along with the system power losses.

Initiates power loss calculations on receipt of an RPP. The calibrated transmitter power is derived from the RP value as follows:

$$P_{Tx\_calib} = \mathbf{a} * P_{Rx}^2 + \mathbf{b} * P_{Rx} + \mathbf{c} \qquad \text{Equation 6}$$

Where **a**, **b,** and **c** are the system power loss curve coefficients. These coefficients are unique for each power transfer mode as follows:

- EPP 15 watt (EPP15W): Representative test power receiver (TPR) is TPR#MP3. The load power typically ranges from 300 mW to 15 W.
- EPP 5 watt (EPP5W): Representative TPR is TPR#7. The load power typically ranges from 300 mW to 5 W.
- Baseline power profile (BPP): Representative TPR is TPR#5. The load power typically ranges from 300 mW to 5 W.

Infineon High Power Proprietary Protocol: Representative test power receiver (TPR) is Infineon High Power. The load power typically ranges from 300 mW to 50 W. A **system power loss curve** is used to account for the losses from the transmitter. The power loss equation relates the transmitter power and the reported power as follows:

$$P_{loss} = P_{Tx} - P_{Tx\_calib} \quad \text{Equation 7}$$

Where P_{Tx_calib} is derived from Equation 6. The criteria for FO presence are:

$$P_{loss} >= P_{Threshold} \quad \text{Case 1}$$

$$P_{loss} >= P_{Threshold\_max} \quad \text{Case 2}$$

Where $P_{Threshold}$ and $P_{Threshold\_max}$ are configuration parameters:

$$P_{Threshold\_max} > P_{Threshold}$$

Case 1 represents the region ① and Case 2 represents the region ② in Figure 5.

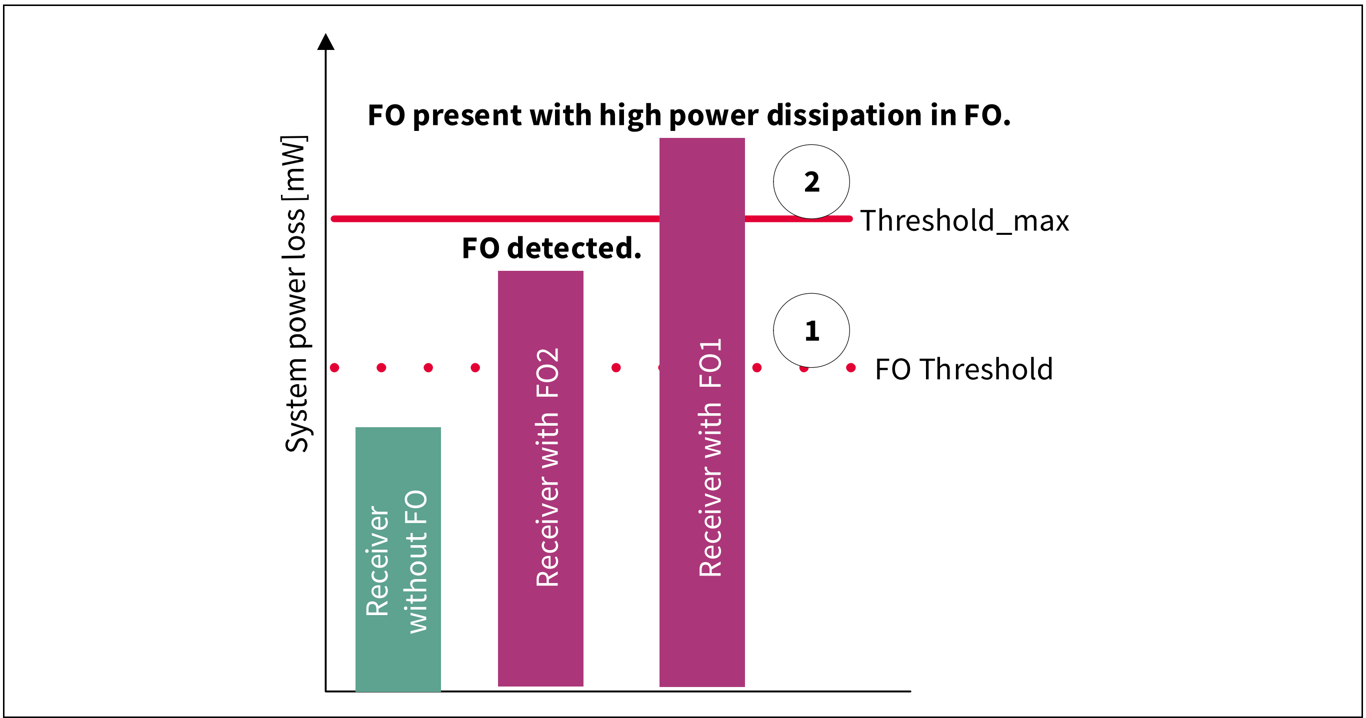


Figure 5 **FOD mechanism based on system power loss**

The thresholds for FOD can be configured. See section 3.6 for tuning thresholds for power loss-based FOD.

2.1.3 FOD using pre- and in-power transfer methods

Figure 6 illustrates the free-air Q factor FOD mechanism. The object detection mechanism identifies the placement of an object and initiates the Qi communication stack, which involves pre- and in-power transfer FOD mechanisms. Measure the pre-power transfer data by the Tx during the analog pings. Upon object detection, the free-air FOD method finds FOs. If the device is a valid receiver, it proceeds to the identification and configuration phases. The FOD/qf packet exchanges for an EPP device optimize the FOD for EPP devices. The WLC's patented Q factor-based FOD mechanism identifies the FOs already present or while entering the interface field before power transfer starts.

A power loss-based FOD mechanism identifies FOs, which may enter the interface surface after power transfer. The WLC power transmitter uses a combination of both Q factor and power loss-based mechanisms for optimal and efficient FOD in BPP and EPP devices. Refer to the user manual for UI indication for FOD.

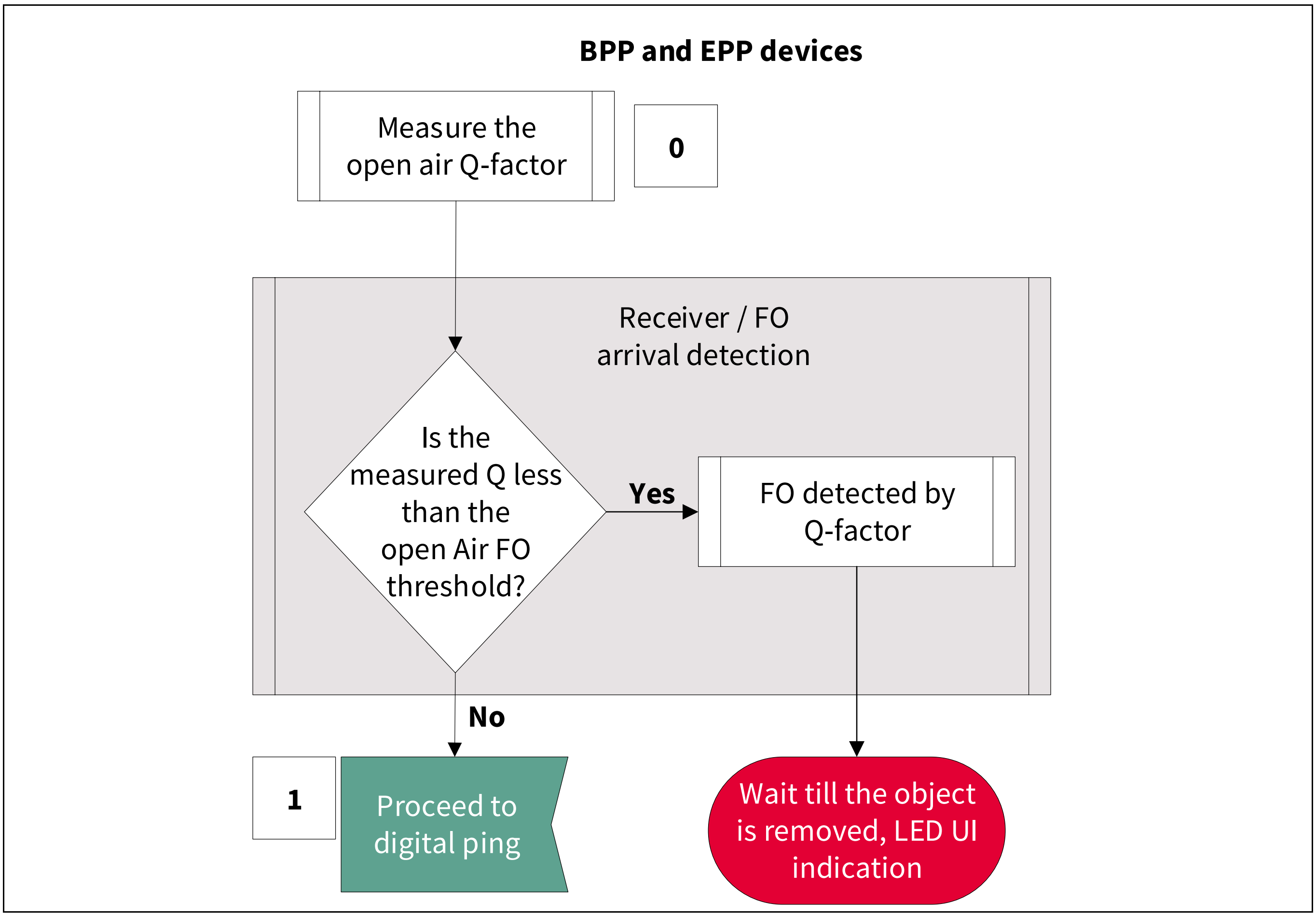


Figure 6 **Procedure for free-air Q factor FOD in BPP, EPP, and High Power devices**

Figure 7 illustrates the FOD using Q factor mechanism.

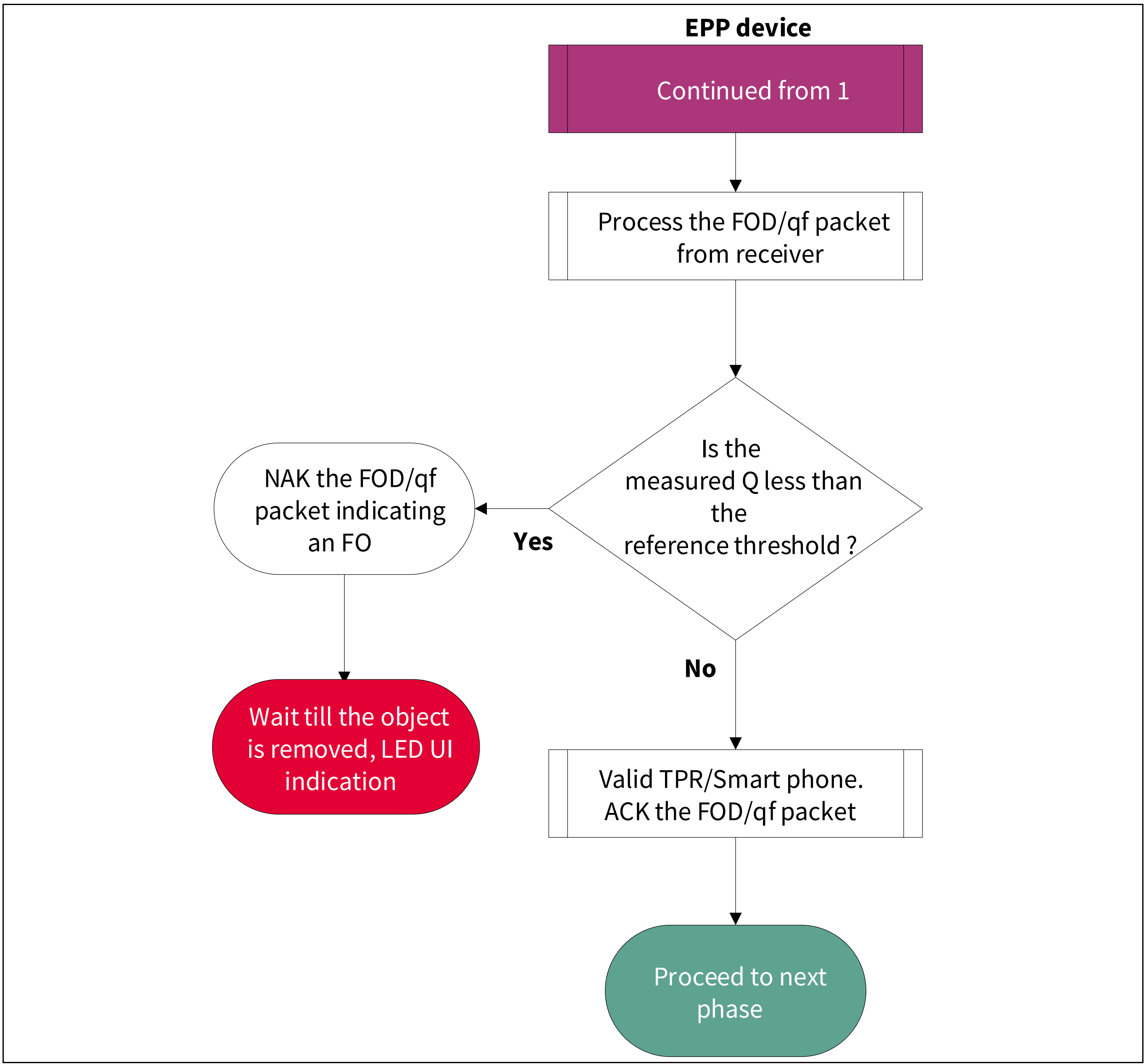


Figure 7 Procedure for Q factor FOD in High Power and EPP devices

Figure 8 illustrates FOD using the resonance frequency mechanism.

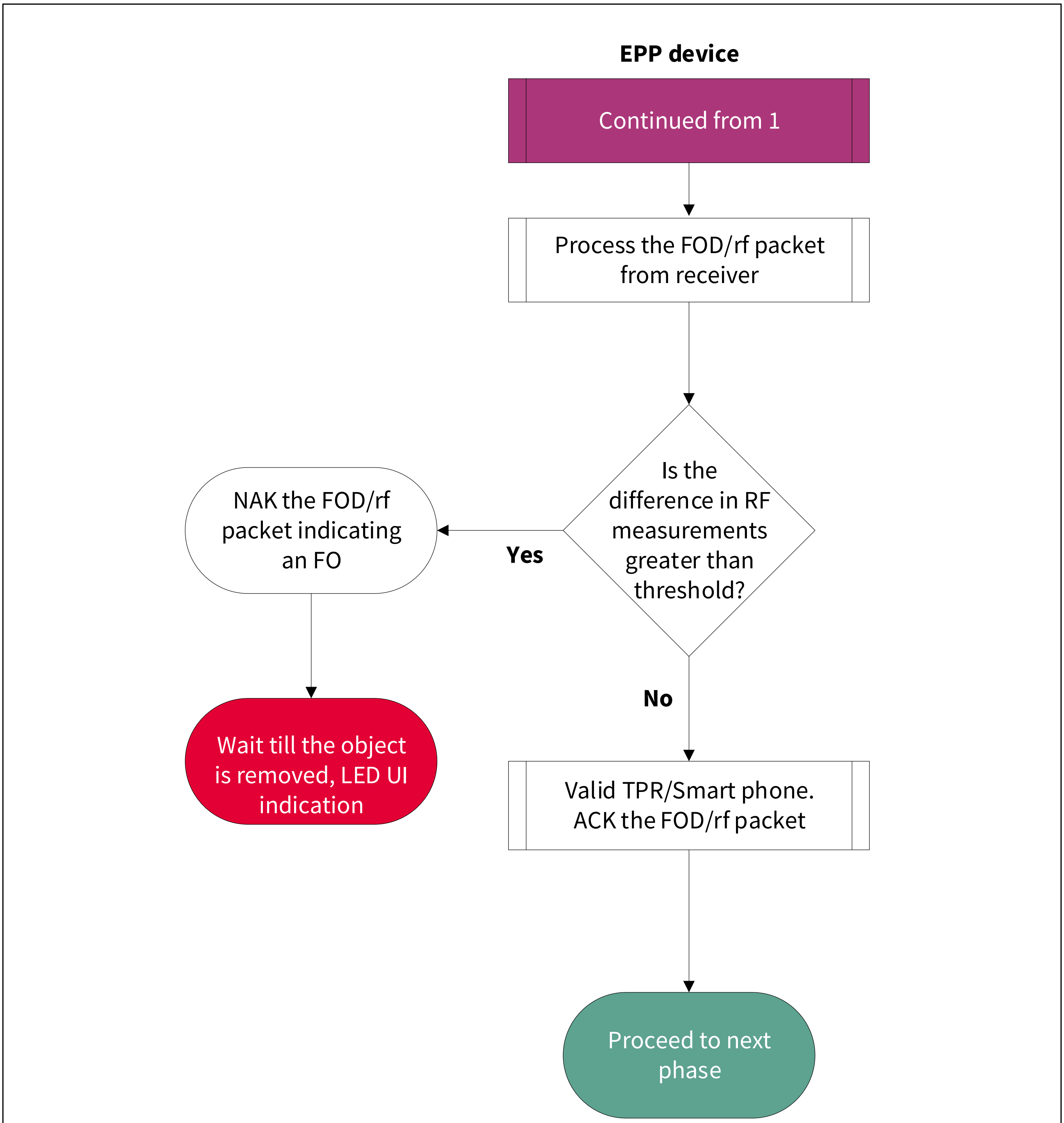


Figure 8 Procedure for resonance frequency FOD on High Power and EPP devices

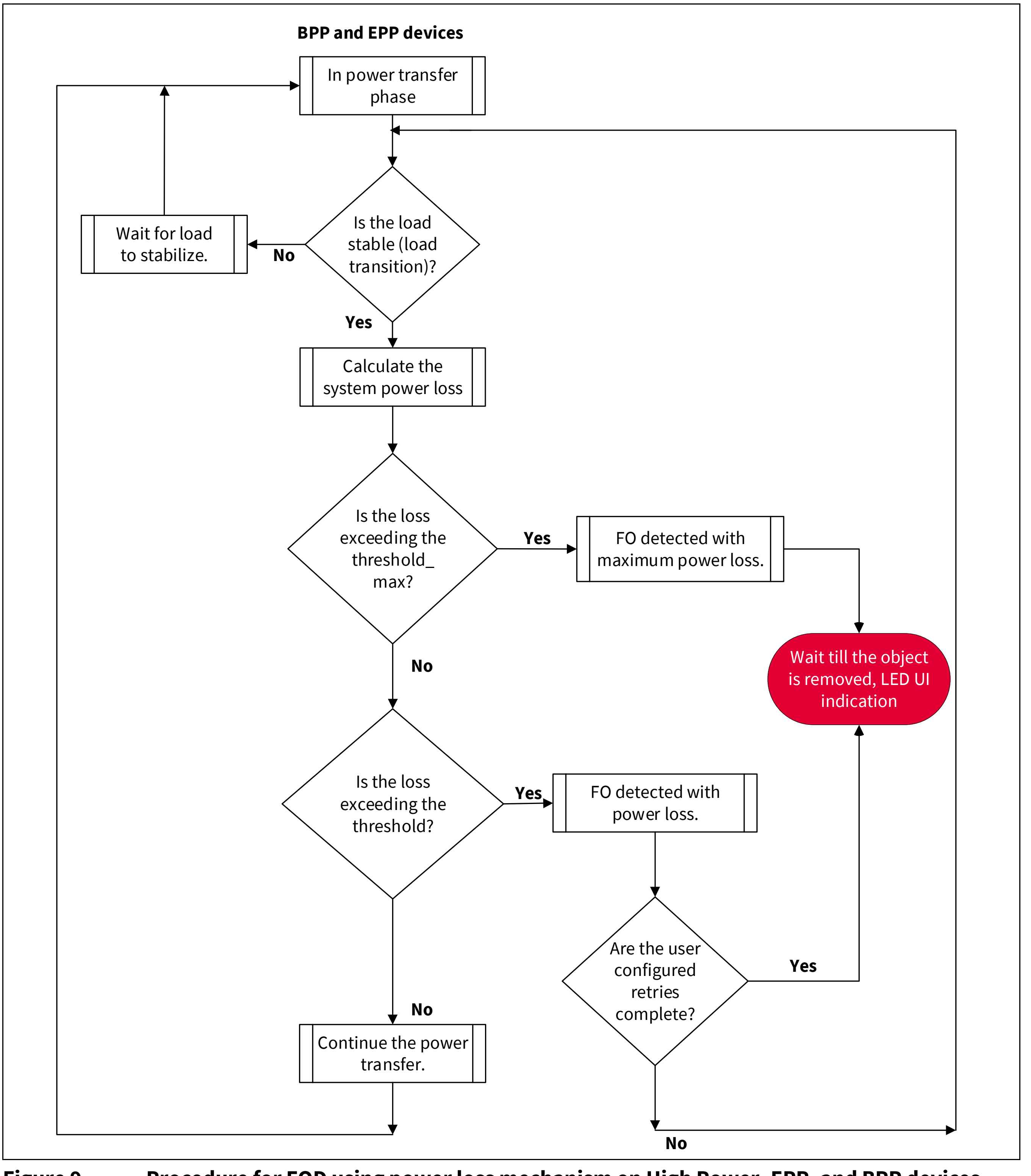


Figure 9 **Procedure for FOD using power loss mechanism on High Power, EPP, and BPP devices**

As shown in Figure 9, the system power loss measurements start only after a stable load condition. This is ensured by checking the control error packet (CEP) value.

3 FOD parameter tuning

FOD parameter tuning is required when the reference design of the WLC power transmitter is changed. The following changes from the WLC power transmitter reference design will result in a need to retune the FOD:

1. Transmitter coil used in the design
2. Change in any shielding or packaging of the transmitter coil
3. Spacing between coil and interface surface (Z-height)

These lead to changes in the Q factor and/or resonance frequency and/or system power loss measurements. Tuning FOD by updating the configuration parameters optimizes the FOD functionality for custom designs.

FOD parameter tuning includes the process of data collection, calculating the appropriate parameters, and updating these parameters in the Wireless Charging Configuration Utility.

Data collection and calculation of parameter values use the *FOD_TuningGuide_Calculator.xlsx* as a supporting document. This tuning calculator provides the following worksheets that require user input:

- **SystemPowerLoss_data**: Input data for power loss FOD parameter calculations are collected here. The coefficients calculated here are used for configuring the WLC power transmitter.
- **QF Scaling Factor Calc**: Q factor tuning data is collected in the "User Inputs" section on this page. The calculations section gives the parameter values for Q factor tuning based on user inputs.
- **RF Scaling_Threshold Calc**: The RF-based data is collected in the "User Inputs" section. The scaling factor and threshold frequency are auto-generated based on the user data.

Wireless Charging Configuration Utility saves the configurations to the WLC power transmitter. These calculations are taken from *FOD_TuningGuide_Calculator.xlsx*.

The tuning process requires a WPC-approved compliance tester tool setup. The following sections discuss the tools required and the steps to prepare the setup. Use *FOD_TuningGuide_Calculator.xlsx* to enter the data from the setup to auto-generate the tuning parameters.

3.1 Tuning objectives

The following are the desired objectives for optimal FOD system performance:

- Scaling factor and threshold tuning for FOD using Q factor
- Scaling factor and threshold tuning for FOD using resonance frequency
- System power loss curve coefficient tuning

As discussed in section 2.1.2, the system power loss curve coefficients relate the reported receiver power to the calibrated transmitter power and therefore, improve the reliability of the FOD mechanism. The reported Q factor and the resonance frequency are measured using an MP-A1 transmitter coil. However, the transmitter may have any other coil in its design and so the reference values of the Q factor have to be scaled (or converted) to the corresponding coil type. The scaling factor is a conversion constant factor to calculate Q factor values for the transmitter designed without an MP-A1 coil. See [2] for more details on the Qi Standard FOD mechanisms.

3.2 Required tools

The following tools are required for the tuning process:

1. Custom design power transmitter board.

Figure 10 WPC-approved reference compliance tester

2. WPC-approved compliance tester. The user may approach the WPC's authorized test labs (ATLs) [5] in case of the unavailability of the compliance tester tools. The user must see the WPC member login page for details of the list of WPC-approved compliance testers. The following accessories are available along with the software tool.

- Test power receivers (TPRs): For the tuning process the following TPRs are needed:
  - TPR#MP1A
  - TPR#MP1B
  - TPR#MP1C
  - TPR#MP4
  - TPR#MP3
  - TPR#1A
  - TPR#7
  - TPR#5
- FO frame.
- Glass weight: For making the TPR stable.

3. USB-UART device for capturing UART logs from the WLC power transmitter board.

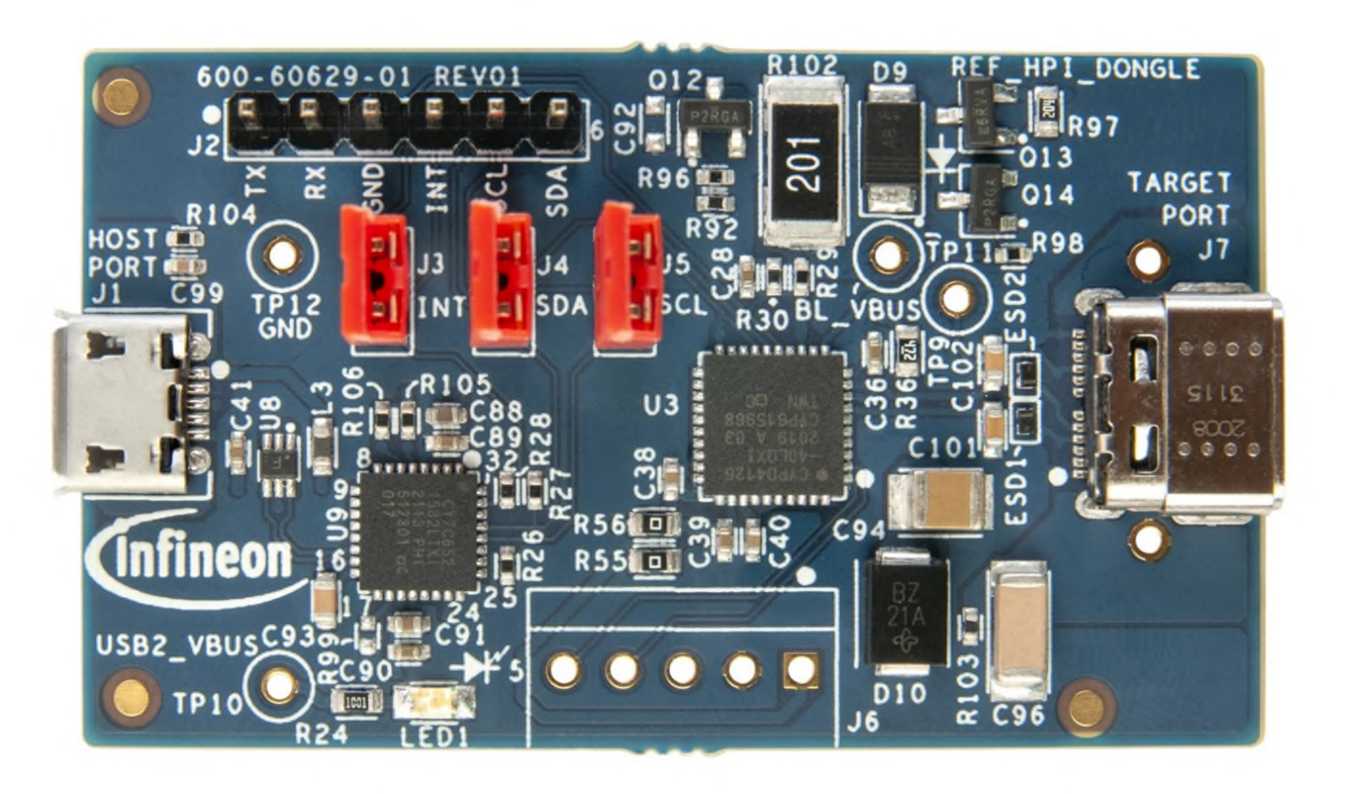


Figure 11 Infineon USB-to-UART device

4. Tera Term or Putty or any serial communication-based PC tool for capturing UART logs from the WLC power transmitter board (ensure that the PC tool used for data logging is capable of processing UART data at 1,000,000 baud with minimal losses).

3.3 Hardware setup

1. Enable the UART debugs from the Wireless Charging Configuration Utility. See Appendix C for details.
2. Connect the UART Tx line from the power transmitter board to the UART Rx line of the USB-UART device.
3. Connect the ground of the transmitter board to the USB–UART device.

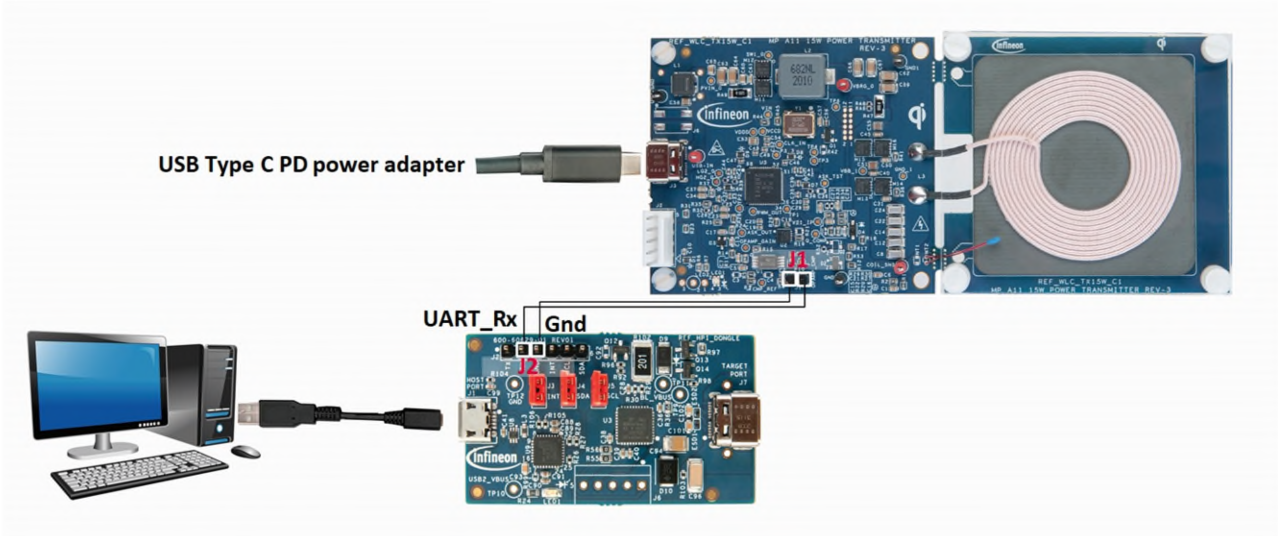
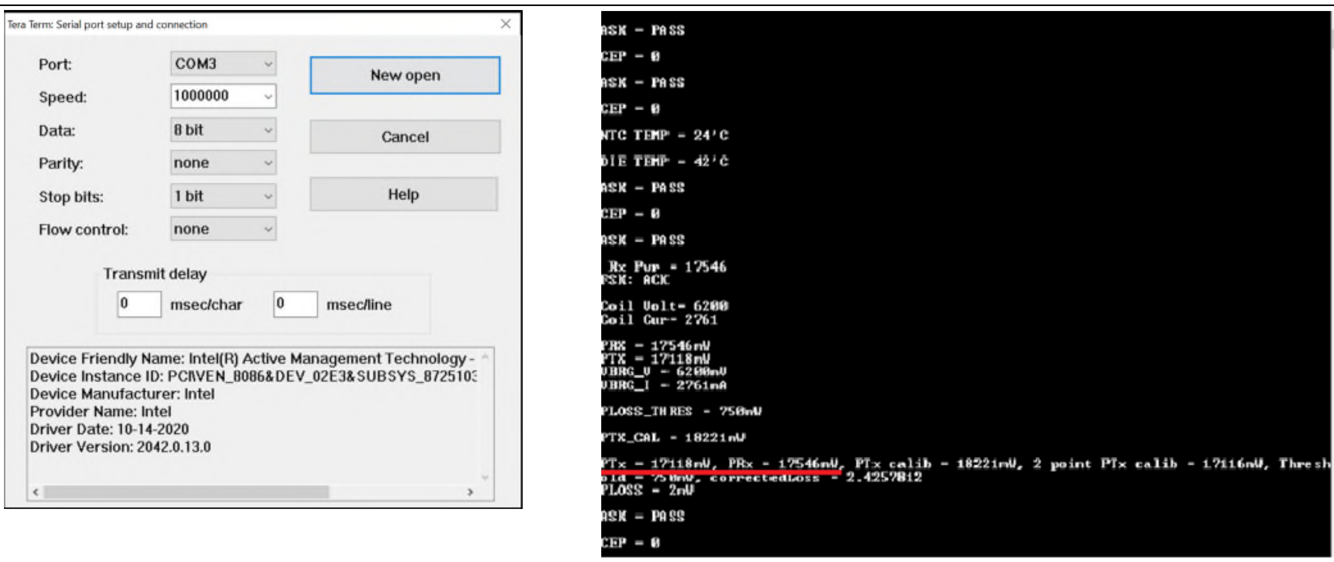


Figure 12 UART connections with PC

4. Open the serial communication terminal (such as Minicom/Tera Term/Putty) and set the baud rate to 1000000.
5. Leave the rest of the UART settings as default.
6. Power on the transmitter board to see UART logs (human-readable ASCII characters) on the serial communication tool (UART interface).



Default Tera Term screen | UART log on Tera Term

Figure 13 Tera Term debug screen and log UI for reference

3.4 Q factor scaling factor tuning process

Use the "*QF Scaling Factor Calc*" page in *FOD_TuningGuide_Calculator.xlsx* as the supporting document for this section. Update the "User Inputs" section with the measured and reported Q-Factor values. The measured and reported Q-Factor values can be taken from the UART logs of the WLC power transmitter. The "Calculations" section in the "*QF Scaling Factor Calc*" page, generates the scaled Q–factor values. Q Factor method is based on TPRs with the least friendly metals, for instance, standard Qi compliance TPRs like TPR#MP3, TPR#7, and TPR with highly friendly metals such as TPR#MP4.

3.4.1 Q factor scaling and threshold tuning process

The Q factor scaling derives the reference Q factor for the WLC power transmitter from the receiver-reported reference Q factor. The WLC power transmitter uses two scaling factors.

- **Q-high scale factor:** Used for scaling the reference Q factor by the TPRs without friendly metals. The EPP TPRs, without friendly metal, report a reference Q factor of greater than 100.
- **Q-low scale factor:** Used for scaling the reference Q factor by the TPRs with friendly metals. The EPP TPRs, with friendly metal, report a reference Q factor of less than 100.

Follow these steps to tune the Q scaling factor:

1. Capture the receiver-reported reference Q factor for all the EPP TPRs on the "QF Scaling Factor Calc" page of the supporting document under the "Q factor Scaling with TPRs without Friendly Metals" table for the following TPRs:
   a) TPR#MP3
   b) TPR#MP4
   c) TPR#7

   See Figure 14 for the UART logs for the receiver-reported reference Q factor.
2. Capture the measured Q value by the WLC power transmitter with all the EPP TPRs listed below. Ensure no foreign object is present on the interface surface during these measurements. See Figure 14 for UART logs for the WLC-measured Q factor.

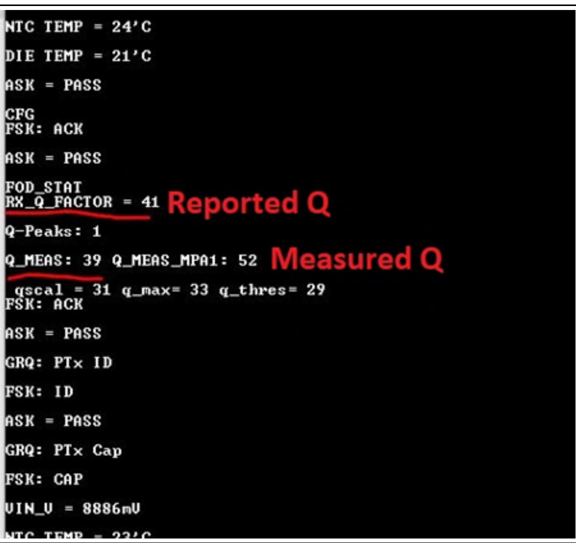


Figure 14 UART logs for receiver-reported and WLC power transmitter measured Q factor

3. Record the high scaling factor from "QF Scaling Factor Calc" and update the Wireless Charging Configuration Utility parameters in the respective field as shown in Figure 16. See section 3.4 for more details.
4. Repeat Steps 1 through 3 with Q factor scaling with TPRs without friendly metals.
5. Enter the measured and reported Q factor values in the respective cells on the "QF Scaling Factor Calc" page. The scaling factor is calculated on this page.

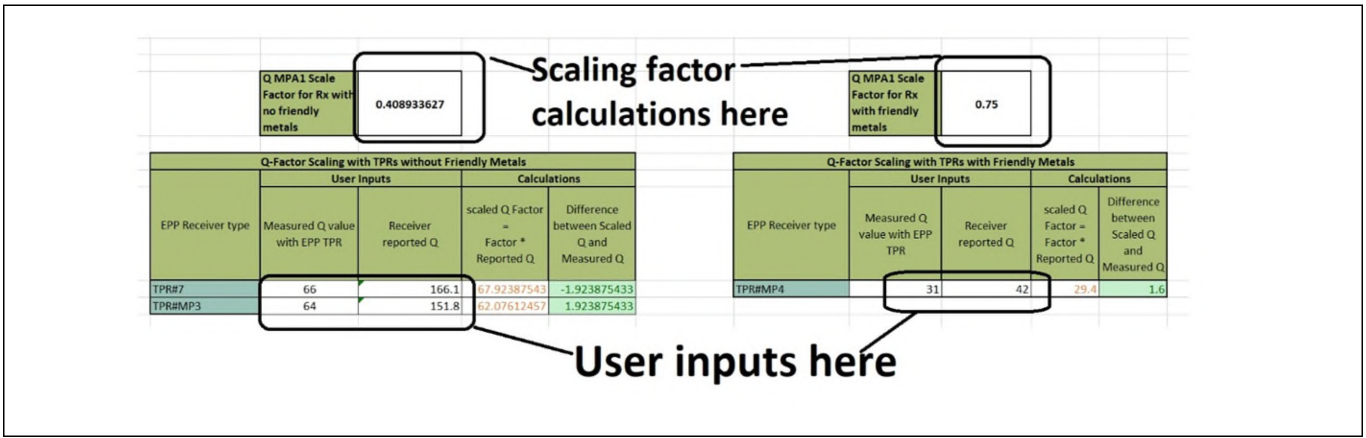


Figure 15 User input section in "QF Scaling Factor Calc" page

The following section explains the usage of the parameters generated in the supporting document.

3.4.2 Q factor-based FOD tuning

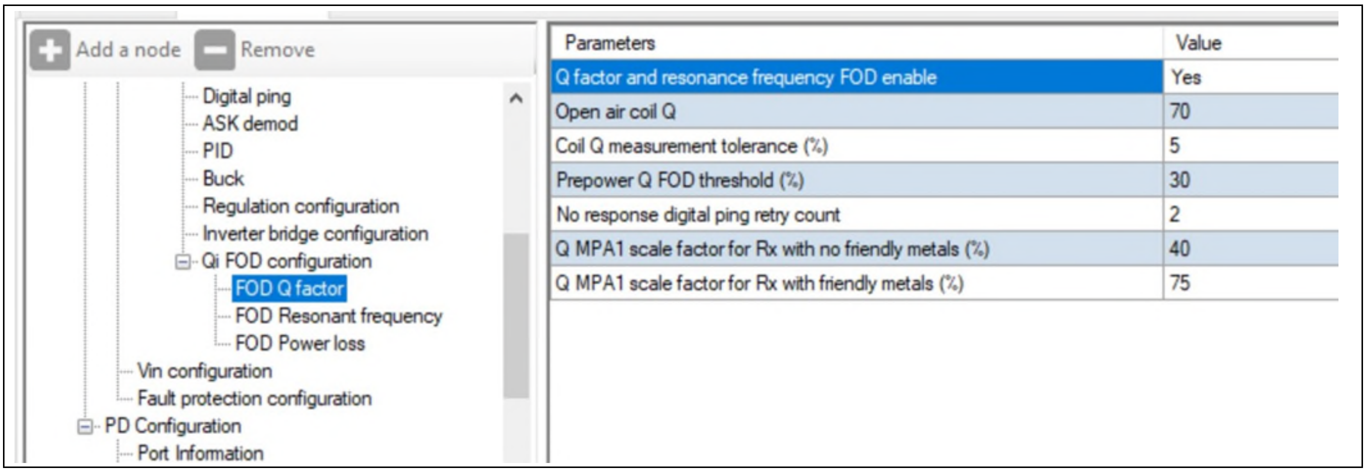


Figure 16 View of Q factor settings configuration tool

Table 1 Q factor configuration setting parameters

S. no.	Parameter	Description
1	Q factor and resonance frequency FOD enable	Enables Q factor measurement for FOD. Enabled by default.
2	Open air coil Q	Open air Q factor value. Measured by LCR meter without anything on the Tx. Default value is 72.
3	Coil Q measurement tolerance (%)	Coil Q measurement tolerance percentage of coil open air Q value. Default value is 5.
4	Prepower Q FOD threshold (%)	Q factor threshold for FO detection when there is no communication. Default value is 25.
5	No response digital ping retry count	Object detected with no communication/response to digital ping retries for initiating communication. Retry count expiry enters into the idle state. Default value is 3.
6	Q MPA1 scale factor for Rx with no friendly metals (%)	Scaling factor for TPRs with higher Q measurements. Default value is 40%.
7	Q MPA1 scale factor for Rx with friendly metals (%)	Scaling factor for TPRs with lower Q measurements. Default value is 66%.

3.5 Resonance frequency scaling factor and threshold tuning process

The resonance frequency method is an improvement of the pre-power transfer of the FOD mechanism using the Q factor. The experiments show that the resonance frequency-based FO is more efficient on Rx with friendly metals, such as smartphones, tablets, and so on. A reference TPR for such devices is TPR#MP4. Therefore, the scaling factor and threshold tuning process are based on the TPR#MP4.

See section 3.2 for the required tools and section 3.3 for setting up the hardware. Further steps for RF tuning are applicable for TPR#MP4.

3.5.1 Resonance frequency scaling and threshold tuning process

The process involves capturing the measured resonance frequency values from the UART logs (as shown in Figure 17) or using the digital signal oscilloscope or LCR meter [7]. This section details using system measurements available from the UART logs as shown in the following figure.

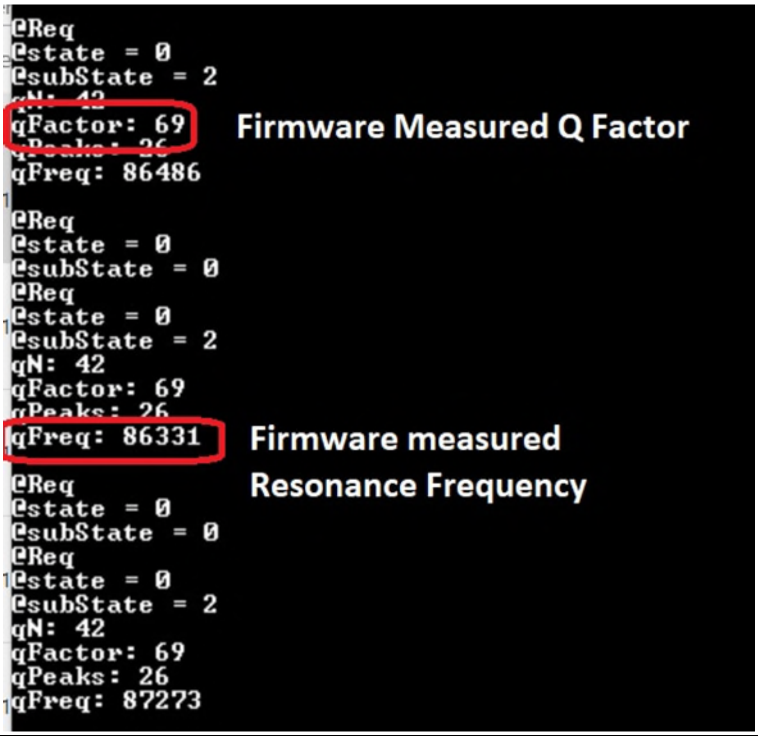


Figure 17 UART logs for receiver reported and WLC power transmitter measured resonance frequency

Follow these steps to tune the resonance frequency scaling factor and threshold values:

1. Place the TPR#MP4 on the interface surface along with the FOD frame to ensure maximum signal strength. Note that no FO is placed in the FO frame:

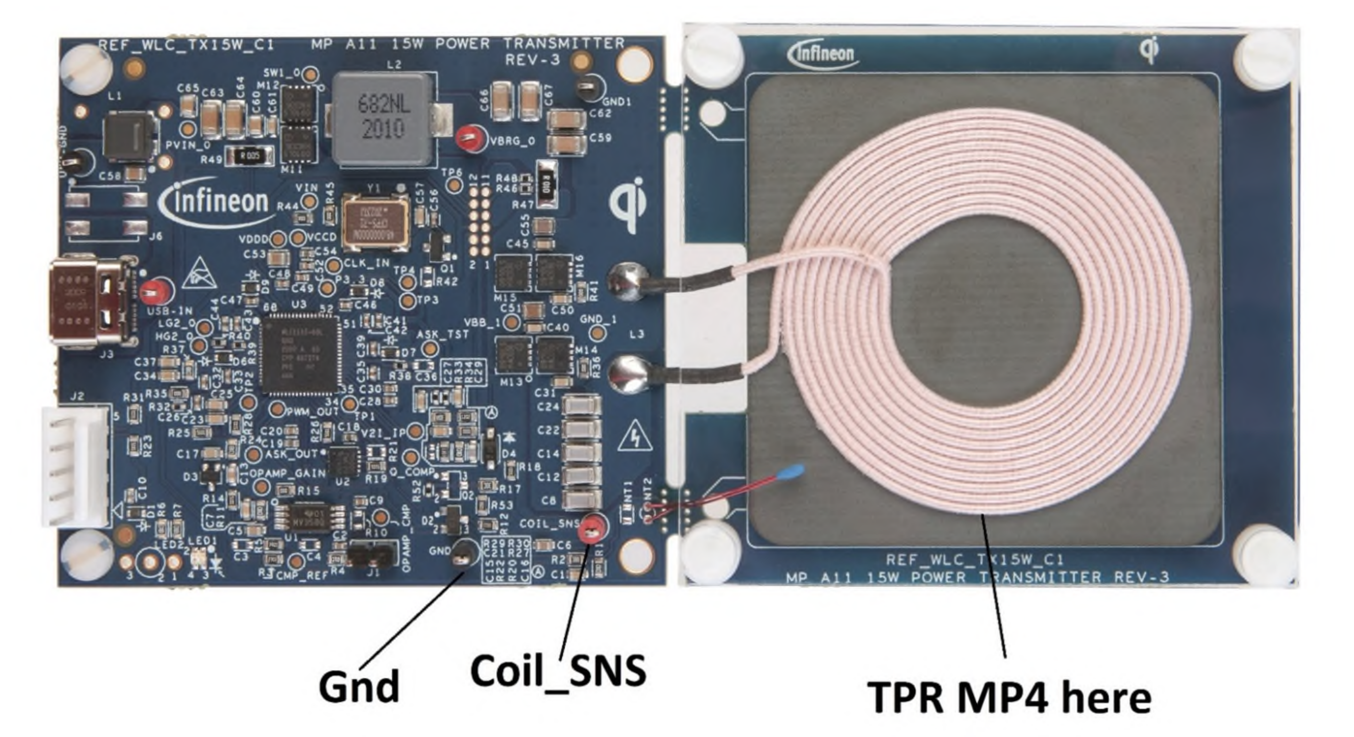


Figure 18 Lab setup for recording measured and reported resonance frequency values

2. Capture the receiver-reported reference resonance frequency for all the EPP TPRs in the "RF Scaling_Threshold Calc" page in *FOD_TuningGuide_Calculator.xlsx*. Enter the data in the row named "FOD/rf".
3. Update the "FOD/rf" section with the Rx-reported resonant values.
4. Update the row marked "Without FO" with the firmware-measured resonant values.
5. Insert FO1 into the FO frame such that FO is aligned with the center of the coils of Tx and Rx.
6. Enter the measured resonance frequency from the UART logs in the row marked as "FO_1_At_0mm".
7. Move FO1 to 15 mm marked on the FO frame. Enter the measured resonance frequency in the row marked under "FO_1_At_15mm".
8. Repeat Steps 4, 5, and 6 for FO2, FO3, and FO4. Record the data in the respective FO rows (see Figure 19).

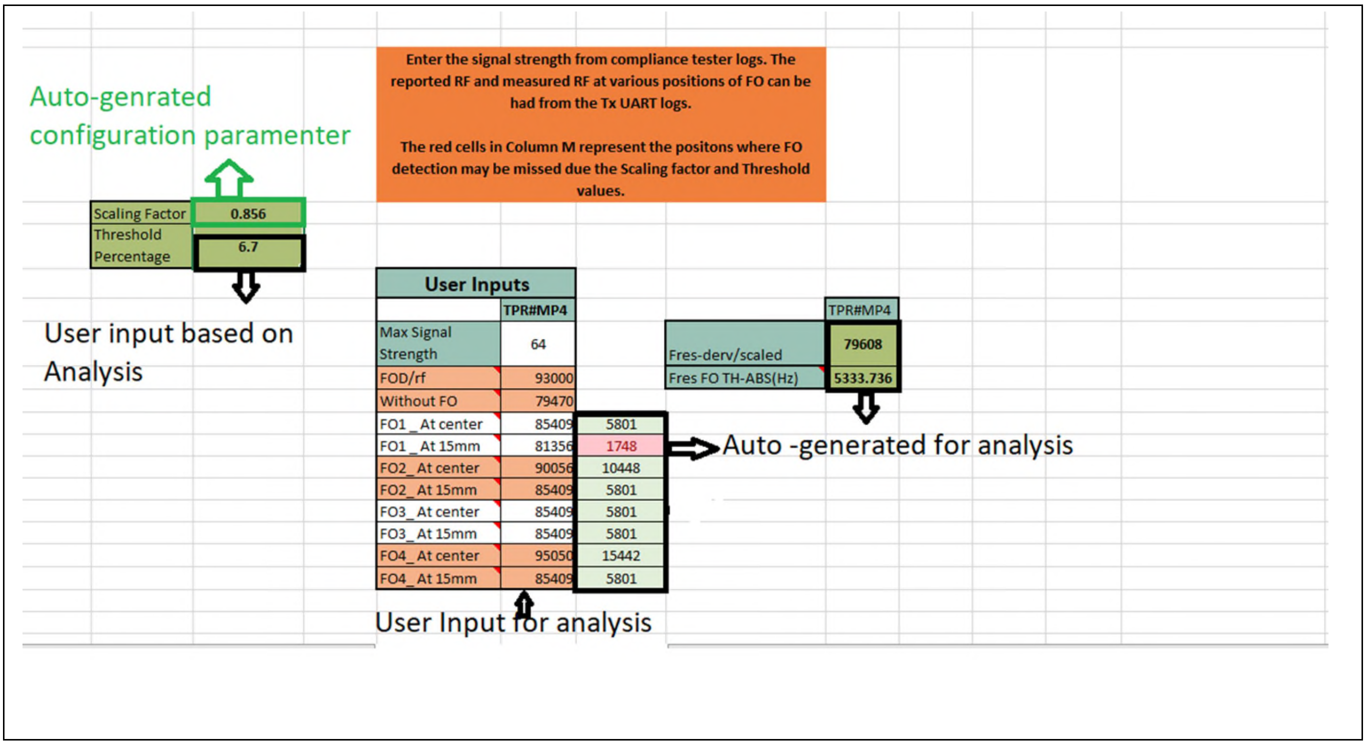


Figure 19 Reference view for resonance frequency measurements data

9. Use the analysis in Figure 19 for reference while tuning the scaling factor and threshold tuning parameters. Tune the FOD threshold for resonance frequency to get the maximum coverage of FOD (the green color in Figure 19 indicates the FO detection).
10. Update the Wireless Charging Configuration Utility parameters in the respective field as shown in Figure 20.

3.5.2 Resonance frequency-based FOD tuning

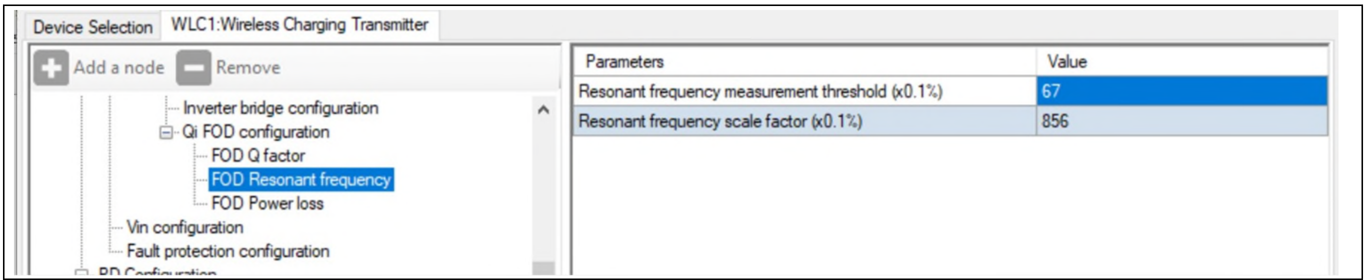


Figure 20 View of Q factor settings configuration tool

Table 2 Resonance frequency Q factor configuration setting parameters

S. no.	Parameter	Description
1	Resonance frequency measurement threshold (x0.1%)	Resonance frequency measurement threshold in percentage. x0.1% scale. Default value is 40.
2	Resonance frequency scale factor (x0.1%)	Resonance frequency measurement threshold in percentage. x0.1% scale. Default value is 1000.

3.6 System power loss curve coefficient tuning for REF_WLC_TX15W_C1

A Qi-compliant power transmitter has three modes of operation:

- EPP15: Illustrated with TPR#MP3
- EPP5W: Illustrated with TPR#7
- BPP: Illustrated with TPR#5

This section covers tuning FOD functionality parameters for all three modes of operation.

System power loss curve coefficient tuning requires a tuning setup based on the user. See the WPC member login page for details of the list of WPC-approved compliance testers. See section 3.2 for the required tools and section 3.3 for details on setting up the hardware. See the WPC member login page for details of the list of WPC-approved compliance tester-based experimental setups required for this tuning process.

3.6.1 Data collection and system loss curve coefficient calculation

1. Enter the Advanced mode on the compliance tester tool user interface.
2. Connect TPR#MP3 to the compliance tester. See the WPC member login page for details of the list of compliance tester tools and place it on the interface surface of the transmitter.
3. Select **Current load** in the **Power load** tab. (Default is Resistive load).
4. Ensure the best alignment between the transmitter and receiver coils. See Appendix A**.**

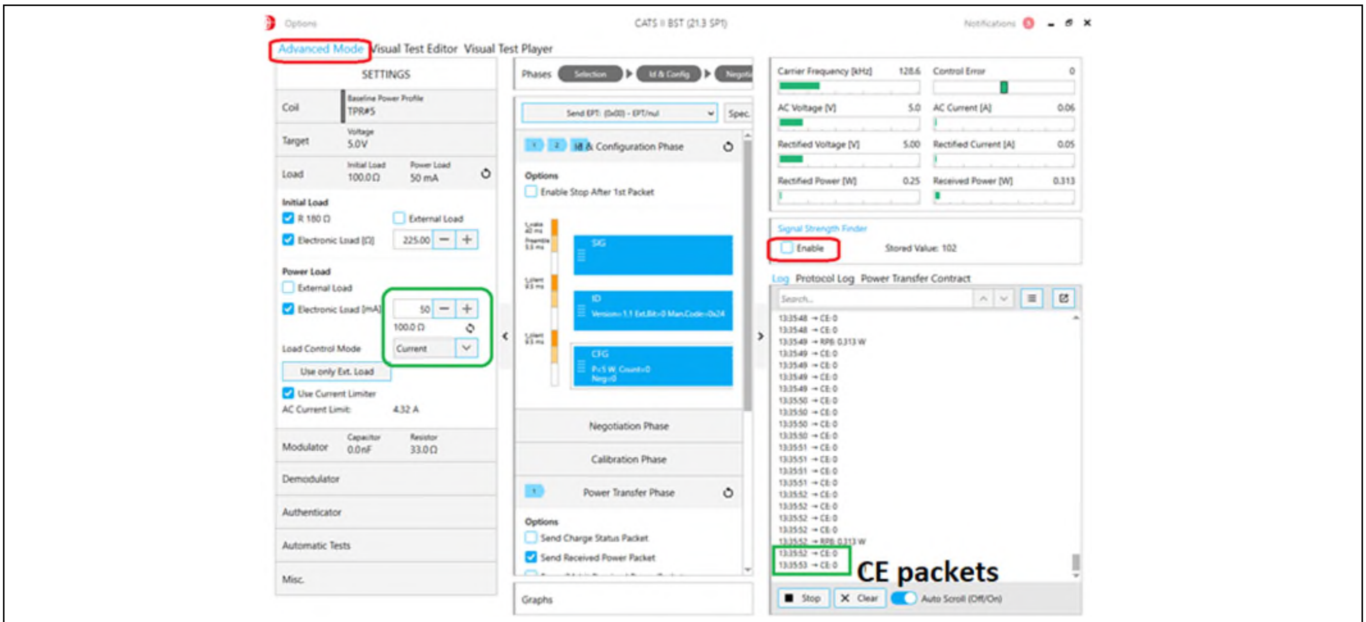


Figure 21 **UI for signal strength, CE packets, Advanced mode, Electronic load selection on reference compliance tester**

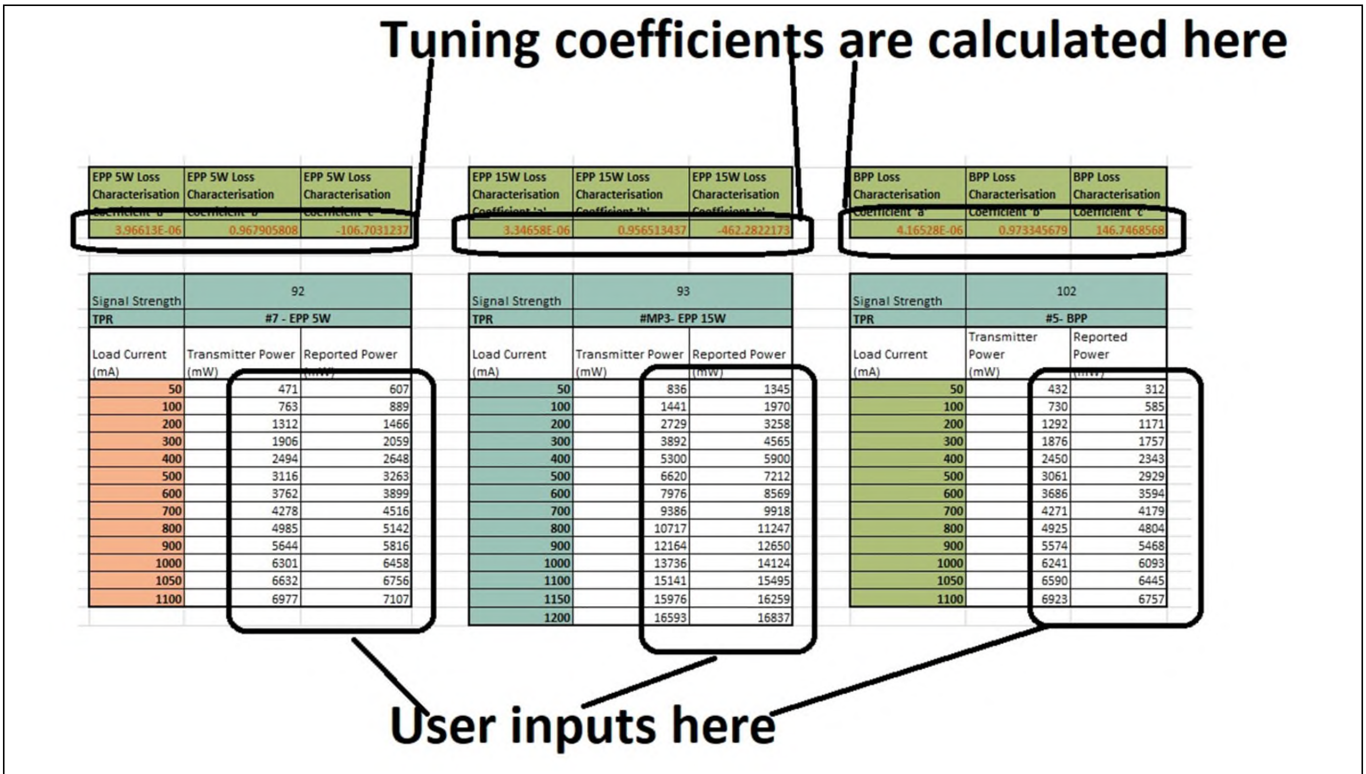
5. Set the load to the minimum load value. See the "SystemPowerLoss_data" page in *FOD_TuningGuide_Calculator.xlsx* for load values.
6. Wait for two consecutive CE packets with a 0 value (see Figure 17). Record the PTx (transmitter power) and PRx (reported receiver power) values from the UART debug log to the supporting document.
7. Increase the load to the next step. See the "SystemPowerLoss_data" page in *FOD_TuningGuide_Calculator.xlsx* for the next load value.

8. Repeat Steps 6, 7, and 8 until PRx and PTx values are captured for the maximum load value. The system power loss curve data for TPR#MP3 is ready.

```
PLOSS_THRES = 750mW

PTX_CAL = 4783mW

PTx = 4324mW, PRx = 4481mW, PTx calib = 4783mW, 2 point PTx calib = 3873mW, Threshold = 750mW, correctedLoss = -459.
PLOSS = -459mW

ASK = PASS

CEP = 0
```

Figure 22 PTx and PRx values from UART logs

9. Repeat Steps 2 through 9 with TPR#7 and TPR#5 to get system power loss curve data for TPR#7 and TPR#5.
10. The "SystemPowerLoss_data" page in *FOD_TuningGuide_Calculator.xlsx* automatically calculates the system power loss curve coefficients for EPP15W, EPP5W, and BPP devices upon entry of data in the respective cells.



EPP 5W Loss Characterisation Coefficient 'a'	EPP 5W Loss Characterisation Coefficient 'b'	EPP 5W Loss Characterisation Coefficient 'c'
3.96613E-06	0.967905808	-106.7031237

Signal Strength	92	
TPR	#7 - EPP 5W	
Load Current (mA)	Transmitter Power (mW)	Reported Power (mW)
50	471	607
100	763	889
200	1312	1466
300	1906	2059
400	2494	2648
500	3116	3263
600	3762	3899
700	4278	4516
800	4985	5142
900	5644	5816
1000	6301	6458
1050	6632	6756
1100	6977	7107

EPP 15W Loss Characterisation Coefficient 'a'	EPP 15W Loss Characterisation Coefficient 'b'	EPP 15W Loss Characterisation Coefficient 'c'
3.34658E-06	0.956513437	-462.2822173

Signal Strength	93	
TPR	#MP3- EPP 15W	
Load Current (mA)	Transmitter Power (mW)	Reported Power (mW)
50	836	1345
100	1441	1970
200	2729	3258
300	3892	4565
400	5300	5900
500	6620	7212
600	7976	8569
700	9386	9918
800	10717	11247
900	12164	12650
1000	13736	14124
1100	15141	15495
1150	15976	16259
1200	16593	16837

BPP Loss Characterisation Coefficient 'a'	BPP Loss Characterisation Coefficient 'b'	BPP Loss Characterisation Coefficient 'c'
4.16528E-06	0.973345679	146.7468568

Signal Strength	102	
TPR	#5- BPP	
Load Current (mA)	Transmitter Power (mW)	Reported Power (mW)
50	432	312
100	730	585
200	1292	1171
300	1876	1757
400	2450	2343
500	3061	2929
600	3686	3594
700	4271	4179
800	4925	4804
900	5574	5468
1000	6241	6093
1050	6590	6445
1100	6923	6757

Figure 23 User input section in "SystemPowerLoss_data" page

11. This data is used in the following section for configuring the WLC power transmitter.

3.6.2 Power loss-based FOD tuning

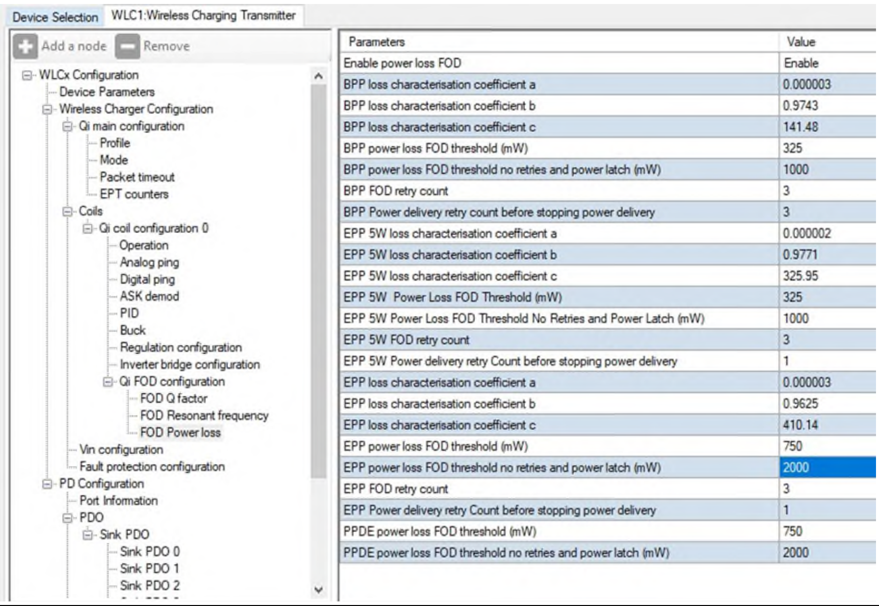


Figure 24 Power loss settings in the configuration tool

Table 3 describes the parameters used for tuning the FOD using the power loss method.

Table 3 Power loss configuration setting parameters

S. no.	Parameter	Description
1	Enable power loss FOD	Enable the FOD functionality in firmware using the power loss method. Enabled by default.
2	BPP Loss characterisation co-efficient 'a'	Coefficient "a" in Equation 6 for BPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 0.000003.
3	BPP Loss characterisation co-efficient 'b'	Coefficient b in Equation 6 for BPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 0.9743.
4	BPP Loss characterisation co-efficient 'c'	Coefficient c in Equation 6 for BPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 141.48.
5	BPP power loss FOD threshold (mW)	Power loss threshold (in mW) for BPP mode of operation. See Case 1. Default value is 325 mW.

S. no.	Parameter	Description
6	BPP power loss FOD threshold no retries and power latch (mW)	Maximum power loss threshold for BPP mode of operation. See Case 2. Default value is 1000 mW.
7	BPP FOD retry count	Count for power recycles after FOD for BPP device. Default value is 3 counts.
8	BPP Power delivery retry count before stopping power delivery	Count for power cycle after FOD for BPP device. Default value is 3 counts.
9	EPP 5W loss characterisation coefficient 'a'	Coefficient a in Equation 6 for 5W EPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 0.000002.
10	EPP 5W loss characterisation coefficient 'b'	Coefficient b in Equation 6 for 5W EPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 0.9771.
11	EPP 5W loss characterisation coefficient 'c'	Coefficient c in Equation 6 for 5W EPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 325.95.
12	EPP 5W power loss FOD threshold (mW)	Power loss threshold for 5 W EPP mode of operation. See Case 1. Default value is 325 mW.
13	EPP 5W power loss FOD threshold no retries and power latch (mW)	Maximum power loss threshold for 5W EPP mode of operation. See Case 2. Default value is 1000 mW.
14	EPP 5W FOD retry count	Count for power recycles after FOD for EPP 5 W device. Default value is 3.
15	EPP5W Power delivery retry count before stopping power delivery	Count for power cycle after FOD for EPP 5W device. Default value is 3.
16	EPP loss characterisation coefficient 'a'	Coefficient a in Equation 6 for 15 W EPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 0.000003.
17	EPP loss characterisation coefficient 'b'	Coefficient b in Equation 6 for 15 W EPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page.

S. no.	Parameter	Description
		Default value is 0.9625.
18	EPP loss characterisation coefficient ‘c’	Coefficient c in Equation 6 for 15 W EPP mode of power transfer. This value is auto-generated under the cell with the same name on the *SystemPowerLoss_data* page. Default value is 410.14.
19	EPP power loss FOD threshold (mW)	Power loss threshold for 15 W EPP mode of operation. See Case 1. The default value is 750 mW.
20	EPP power loss FOD threshold no retries and power latch (mW)	Maximum power loss threshold for 15 W EPP mode of operation. See Case 2. Default value is 2000 mW.
21	EPP FOD retry count	Count for power recycles after FOD for EPP 15 W device. Default value is 1 count.
22	EPP Power delivery retry count before stopping power delivery	Count for power cycle after FOD for EPP 15 W device. Default value is 1.
23	PPDE power loss FOD threshold (mW)	Threshold for a likely FO presence for PPDE. Default value is 750 mW.
24	PPDE power loss FOD threshold no retries and power latch (mW)	Threshold for a certain FO presence for PPDE. Default value is 2000 mW.

3.7 System power loss curve coefficient tuning for REF_WLC_TX50W_N1

Power transmitter has four modes of operation:

- EPP15: Illustrated with TPR#MP3
- EPP5W: Illustrated with TPR#7
- BPP: Illustrated with TPR#5
- Infineon High Power Proprietary Protocol: Illustrated Infineon High Power Receiver

This section covers tuning FOD functionality parameters for all four modes of operation.

System power loss curve coefficient tuning requires a tuning setup based on the user. See the WPC member login page for details of the list of WPC-approved compliance testers. See section 3.2 for the required tools and section 3.3 for details on setting up the hardware. See the WPC member login page for details of the list of WPC-approved compliance tester-based experimental setups required for this tuning process.

3.7.1 Data collection and system loss curve coefficient calculation

1. Enter the Advanced mode on the compliance tester tool user interface.
2. Connect TPR#MP3 to the compliance tester for EPP15. See the WPC member login page for details of the list of compliance tester tools and place it on the interface surface of the transmitter.
3. Select **Current load** in the **Power load** tab (Default is Resistive load).

4. Ensure the best alignment between the transmitter and receiver coils. See Appendix A.

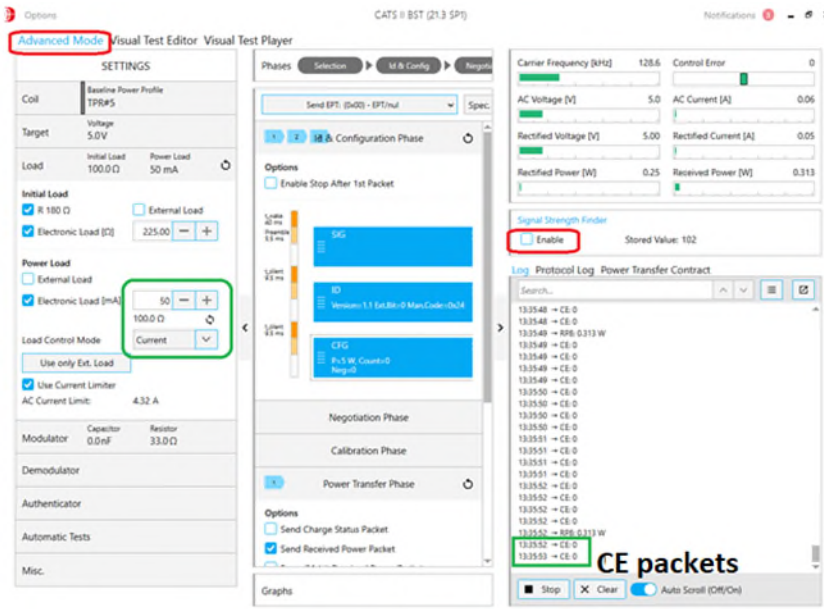


Figure 25 UI for signal strength, CE packets, Advanced mode, Electronic load selection on reference compliance tester

5. Open the Wireless Charging Configuration Utility and connect the device over the I2C interface as shown in Figure 26**.**
6. Select the device from the device selection tab.
7. Open the Read from device tab and disable the “Q factor and resonance frequency FOD enable” and “Enable power loss FOD” through static configuration as shown in Figure 27.
8. Invoke the Configure Device operation to update the flash of the device.
9. Open the **System Loss Calibration** tab using option available in the toolbar or tools menu.
10. Select the TPR type based on the operating mode from the **Test Power receiver type** dropdown menu as shown in Figure 28.
11. Select load value in percentage from the **Select load** dropdown menu. Load percentage is defined in power percentage. The current or resistance value can be derived from the receiver output voltage.
12. Click the **Start calibration** button to read power values from the device as shown in Figure 29**.** The utility polls the device until 2 CEP packets with values 0, 1, and -1 are read to ensure that the load is stabilized.
13. Increase the load to the next step and repeat Steps 9 and 10.
14. After the power values are read for all load values, the **Calculate coefficient** button gets enabled for the selected TPR type.
15. Click **Calculate coefficient** button to calculate and display loss curve coefficients. Figure 30 shows the coefficients calculated for the EPP15 test power receiver.
16. Copy the FOD co-efficients from the active TPR table and Close the **System Loss Calibration** tab.
17. Open the **Read from device** tab and Enable the “Q factor and resonance frequency FOD enable” and “Enable power loss FOD” through static configuration for FO detection.
18. Update the copied co-efficients at the appropriate textboxes of the static configuration as shown in Figure 31.
19. Invoke the Configure Device operation and the configuration will be updated to the flash of the device.

20. Repeat the process from Steps 2 to 17 with TPR#7 and TPR#5 to get calibrated with calculated coefficients for EPP5 and BPP respectively.
21. For the Infineon High Power Proprietary Protocol use any electronic load with (30 V – 5 A compatible) in Constant current mode and repeat the process 5 to 17 with Infineon High Power Receiver.

Note: *If the running mode of the device matches with the selected TPR, then the coefficients are updated to the device, otherwise, displays an error in a popup window. The Clear data option clears all the data present in the System loss calibration widow. Static configuration features are disabled when the System loss calibration window is open.*

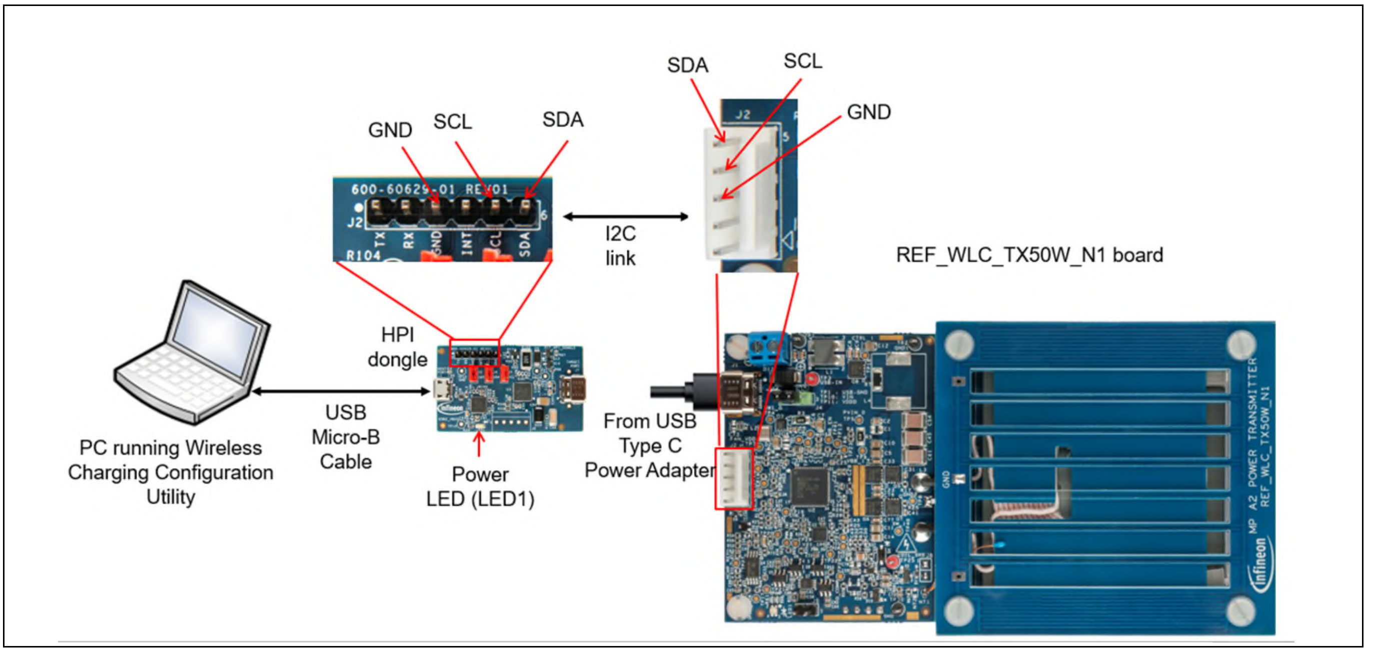


Figure 26 Wireless Transmitter to debugger I2C interface

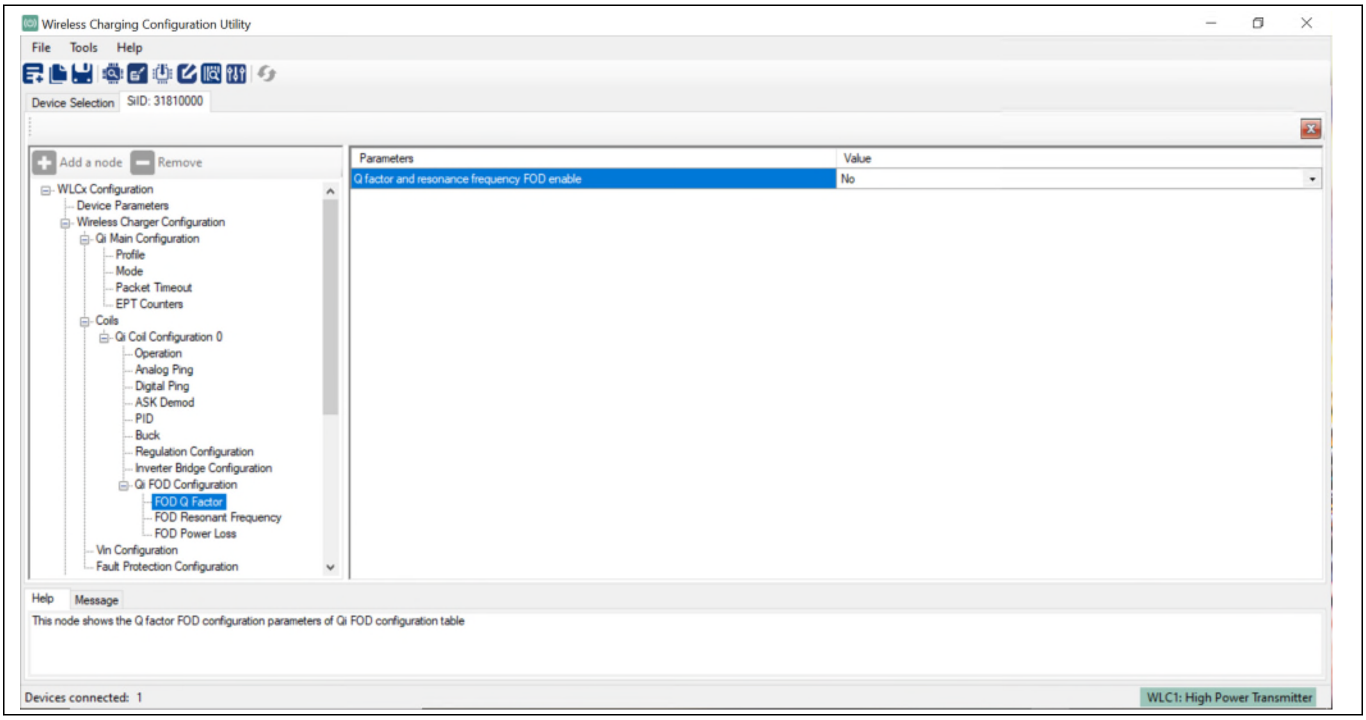


Figure 27 Static configuration interface to update the parameter

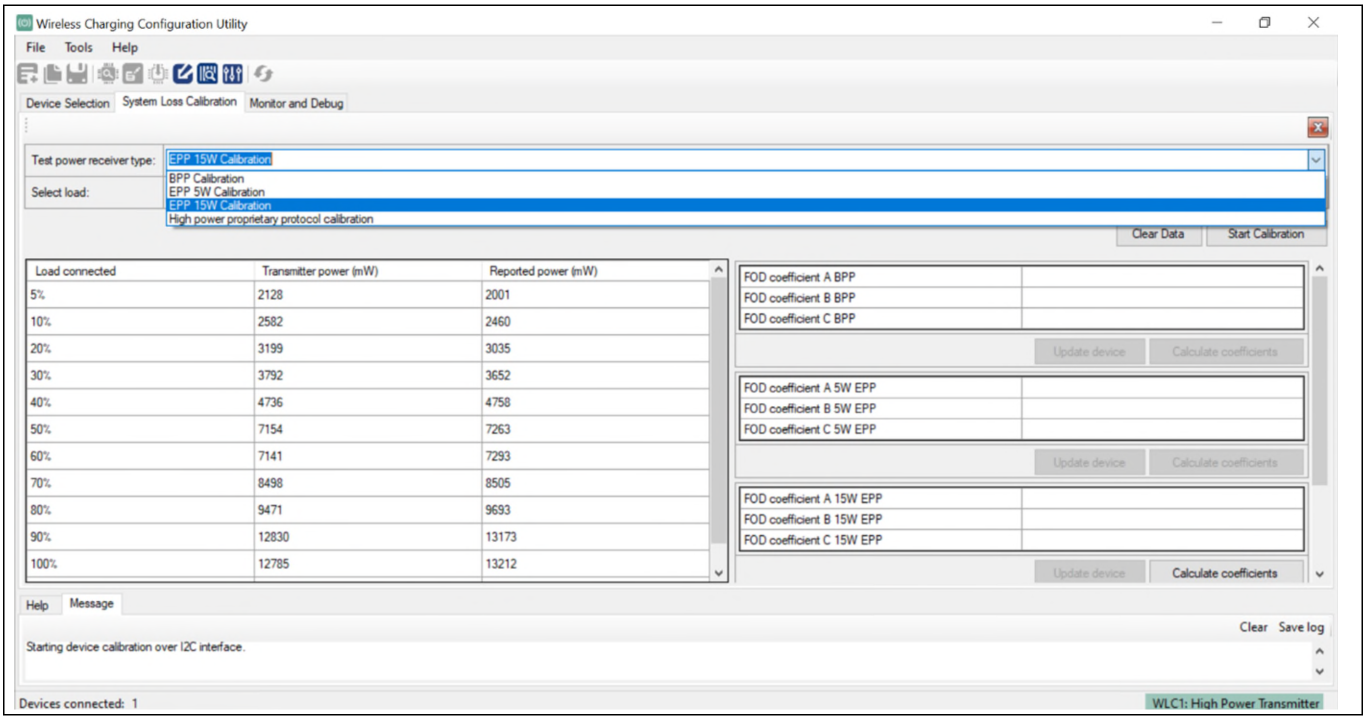


Figure 28 System loss calibration interface through Configuration Utility for TPR selection

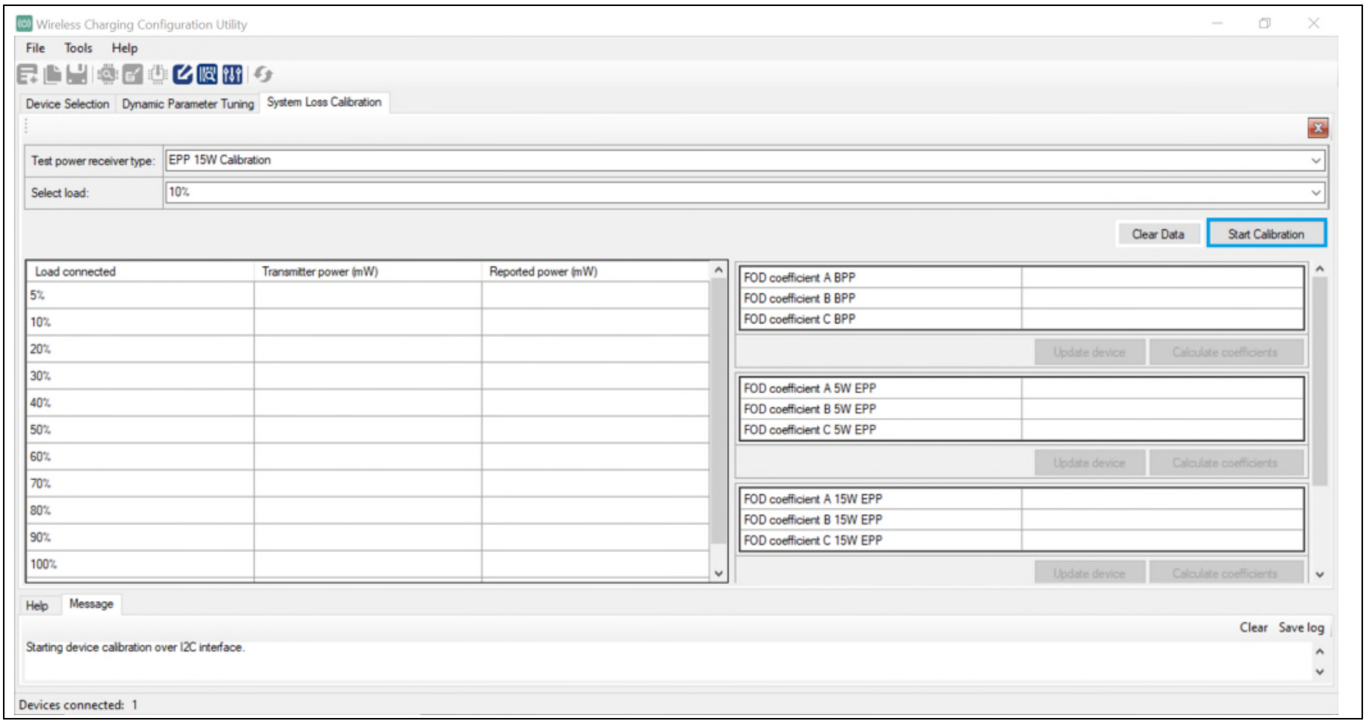


Figure 29 System loss calibration interface through Configuration Utility for calibration

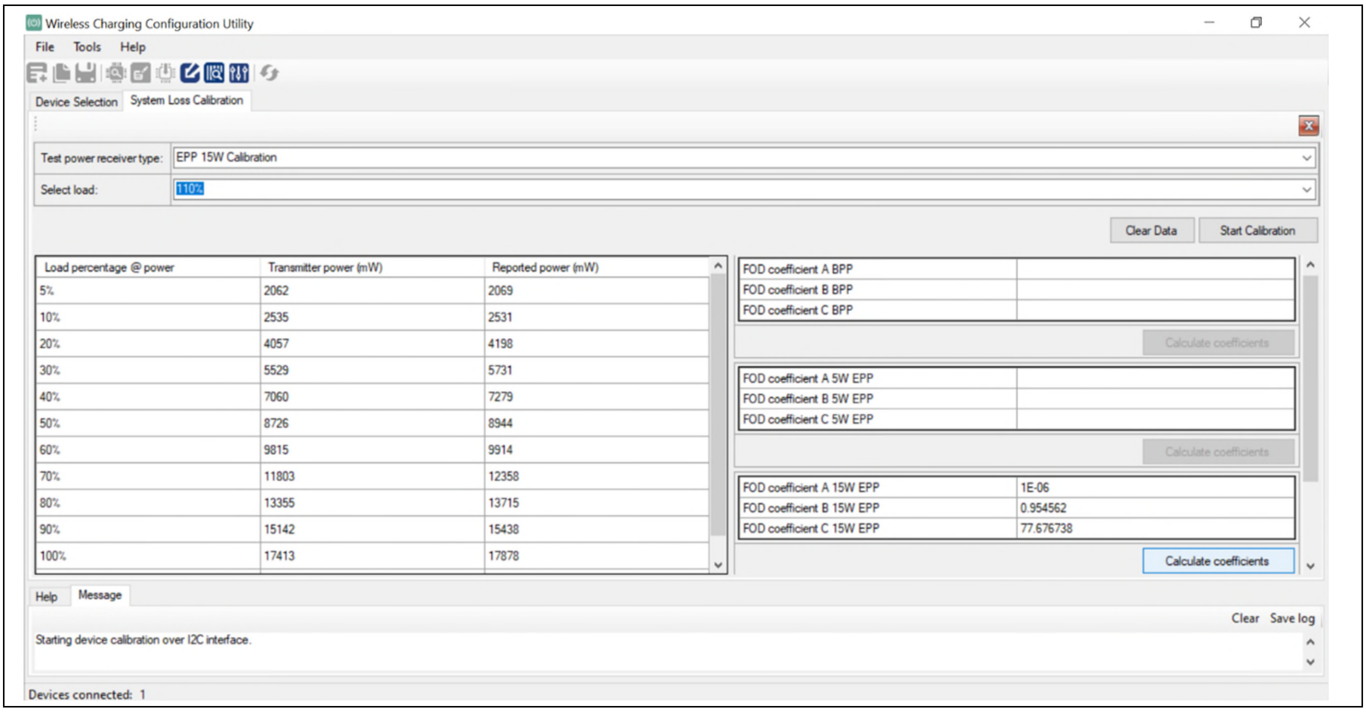


Figure 30 System loss calibration interface through Configuration Utility for coefficient calculation

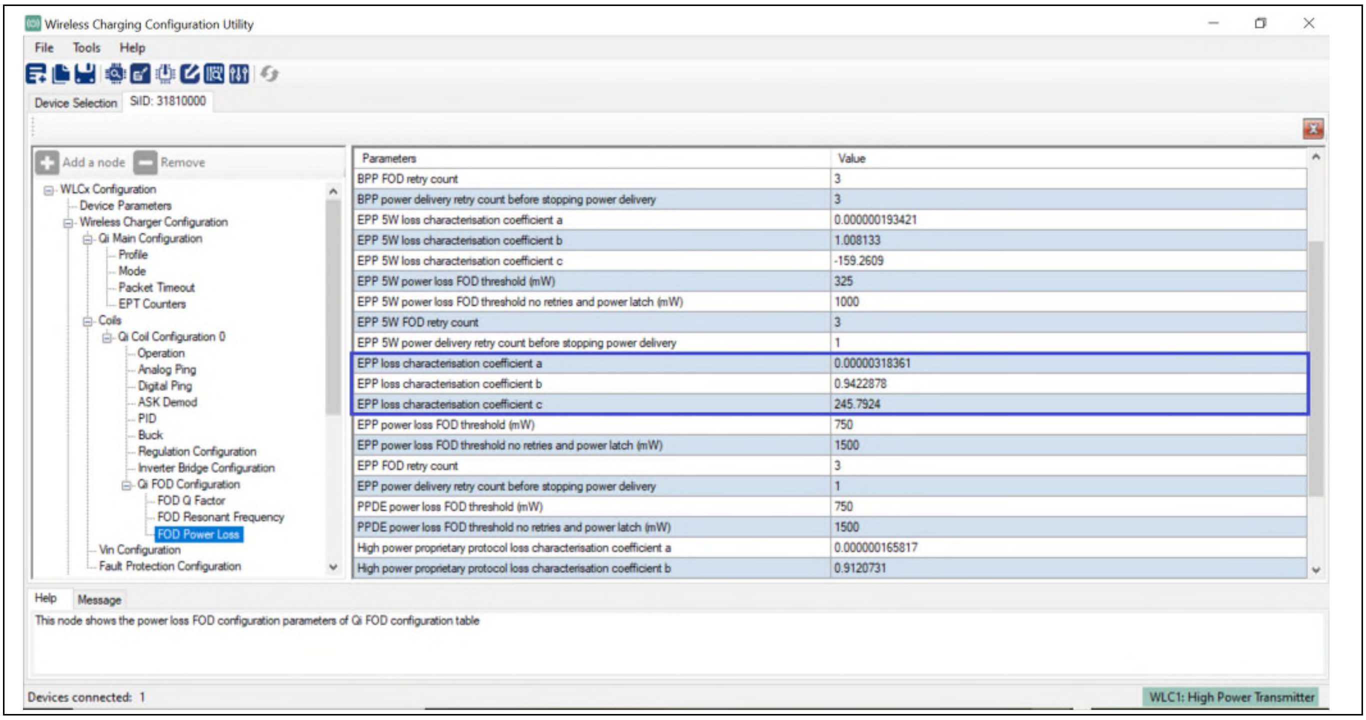


Figure 31 Parameter update in flash through static parameter tuning interface

3.7.2 Power loss-based FOD tuning

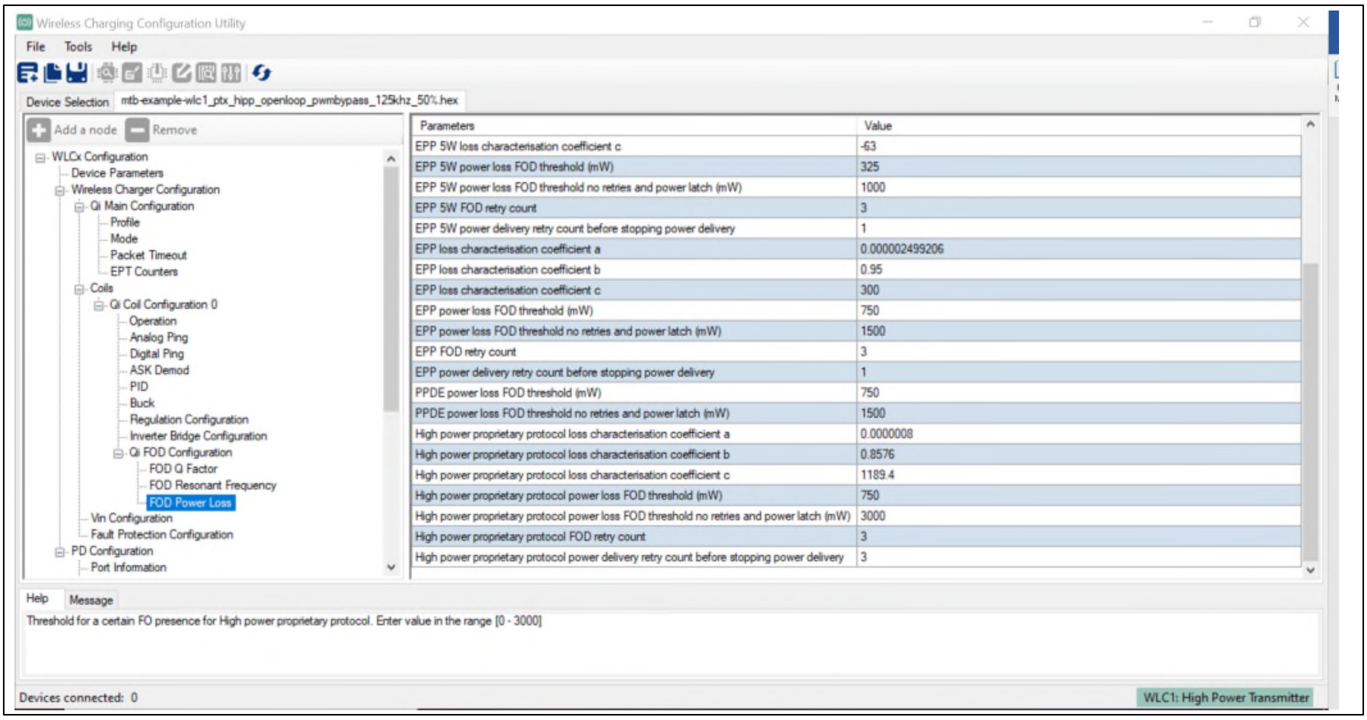


Figure 32 Power loss settings in the configuration tool

The following table describes the parameters used for tuning the FOD using the power loss method.

Table 4 Power loss configuration setting parameters

S. no.	Parameter	Description
1	Enable power loss FOD	Enable the FOD functionality in firmware using the power loss method. Enabled by default.
2	BPP Loss characterisation co-efficient ‘a’	Coefficient “a” in Equation 6 for BPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 0.00000250874.
3	BPP Loss characterisation co-efficient ‘b’	Coefficient b in Equation 6 for BPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 0.9762962.
4	BPP Loss characterisation co-efficient ‘c’	Coefficient c in Equation 6 for BPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab Default value is 126.0797.
5	BPP power loss FOD threshold(mW)	Power loss threshold (in mW) for BPP mode of operation. See Case 1. Default value is 325 mW.
6	BPP power loss FOD threshold no retries and power latch (mW)	Maximum power loss threshold for BPP mode of operation. See Case 2. Default value is 1000 mW.
7	BPP FOD retry count	Count for power recycles after FOD for BPP device. Default value is 3 counts.
8	BPP Power delivery retry count before stopping power delivery	Count for power cycles after FOD for BPP device. Default value is 3 counts.
9	EPP 5W loss characterisation coefficient ‘a’	Coefficient a for 5 W EPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 0.000000193421.
10	EPP 5W loss characterisation coefficient ‘b’	Coefficient b for 5 W EPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 1.008133.
11	EPP 5W loss characterisation coefficient ‘c’	Coefficient c for 5 W EPP mode of power transfer. This value is auto-generated under the

S. no.	Parameter	Description
		cell with the same name in the **System Loss Calibration** tab. Default value is -159.2609.
12	EPP 5W power loss FOD threshold (mW)	Power loss threshold for 5 W EPP mode of operation. See Case 1. Default value is 325 mW.
13	EPP 5W power loss FOD threshold no retries and power latch (mW)	Maximum power loss threshold for 5 W EPP mode of operation. See Case 2. Default value is 1000 mW.
14	EPP 5W FOD retry count	Count for power recycles after FOD for EPP 5 W device. Default value is 3.
15	EPP5W Power Delivery retry count before stopping Power Delivery	Count for power cycles after FOD for EPP 5 W device. Default value is 1.
16	EPP loss characterisation coefficient ‘a’	Coefficient a for 15 W EPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 0.00000318361.
17	EPP loss characterisation coefficient ‘b’	Coefficient b for 15 W EPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 0.9422878.
18	EPP loss characterisation coefficient ‘c’	Coefficient c for 15 W EPP mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 245.7924.
19	EPP power loss FOD threshold (mW)	Power loss threshold for 15 W EPP mode of operation. See Case 1. The default value is 750 mW.
20	EPP power loss FOD threshold no retries and power latch (mW)	Maximum power loss threshold for 15 W EPP mode of operation. See Case 2. Default value is 1500 mW.
21	EPP FOD retry count	Count for power recycles after FOD for EPP 15 W device. Default value is 3 count.
22	EPP Power delivery retry count before stopping power delivery	Count for power cycles after FOD for EPP 15 W device. Default value is 1.

S. no.	Parameter	Description
23	PPDE power loss FOD threshold (mW)	Threshold for a likely FO presence for PPDE Default value is 750 mW.
24	PPDE power loss FOD threshold no retries and power latch (mW)	Threshold for a certain FO presence for PPDE Default value is 1500 mW.
25	Infineon High Power Proprietary Protocol loss characterisation coefficient 'a'	Coefficient a for 50 W Infineon High Power Proprietary Protocol mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 0.000000165817.
26	Infineon High Power Proprietary Protocol loss characterisation coefficient 'b'	Coefficient b for 50 W Infineon High Power Proprietary Protocol mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 0.9120731.
27	Infineon High Power Proprietary Protocol loss characterisation coefficient 'c'	Coefficient c for 50 W Infineon High Power Proprietary Protocol mode of power transfer. This value is auto-generated under the cell with the same name in the **System Loss Calibration** tab. Default value is 1321.419.
28	Infineon High Power Proprietary Protocol power loss FOD threshold (mW)	Power loss threshold for 50 W Infineon High Power Proprietary Protocol mode of operation. See Case 1. The default value is 750 mW.
29	Infineon High Power Proprietary Protocol power loss FOD threshold no retries and power latch (mW)	Maximum power loss threshold for 50 W Infineon High Power Proprietary Protocol mode of operation. See Case 2. Default value is 2000 mW.
30	Infineon High Power Proprietary Protocol FOD retry count	Count for power recycles after FOD for 50 W Infineon High Power Proprietary Protocol device. Default value is 3 count.
31	Infineon High Power Proprietary Protocol Power Delivery retry count before stopping Power Delivery	Count for power cycles after FOD for 50 W Infineon High Power Proprietary Protocol device. Default value is 3.

4 FOD functionality verification

The following tests from the Qi compliance test suite can ensure an appropriate tuning of the FOD parameters for BPP devices:

1. Test#25 (a)
2. Test#25 (b)
3. Test#25 (c)
4. Test#25 (d)

The following tests from the Qi compliance test suite can ensure an appropriate tuning of the FOD parameters for EPP devices:

1. MP.TX.FOD.OPERATE.FOD.REACT.TC1
2. MP.TX.FOD.OPERATE.FOD.REACT.TC1a
3. MP.TX.FOD.OPERATE.FO.CRIT.TC1
4. MP.TX.FOD.OPERATE.FO.CRIT.TC1a
5. MP.TX.FOD.BEFOREPOWER.FO.CRITIC.TC1
6. MP.TX.FOD.BEFOREPOWER.FO.CRITIC.TC1a

Tests 1 and 2 validate the Threshold_max setting in EPP devices. The critical section tests (3 through 6) validate the Q factor and threshold settings. See [8] for details of the tools required for the Qi-recommended validation test setup, test procedure, and pass criteria.

Free-air FO can be tested by placing a US nickel or an Indian 2 ₹ coin on the interface at the center of the coil. This should be indicated by the FO UI (user manual for FO indication).

The following tests can ensure an appropriate tuning of the FOD parameters for Infineon High Power devices:

1. Check no false FO detection when Infineon High Power Receiver is placed up to a 4 mm radius from the center of the transmitter coil, in no load to full load.
2. For Qi recommended FO's (FO1, FO2, FO3, and FO4) detection follow this procedure:

a) Flash the FOD-tuned firmware in the PTx.

b) Place PTX and IFx RX in the center-aligned position.

c) For in-power FOD testing (Method 1):

- Turn on the power and check if the receiver output is voltage regulated to 20 V.
- Load the IFx Rx to 50 Watts (CR = 8 ohms).
- During the power transfer, place the FO(s) at a distance of 30 mm away from the center of the PTx/PRx alignment.
- Bring in the FO at a rate of 2 mm (step size) towards the center every 10 seconds.
- Ensure the FO temperature must not go beyond 60°C. Measure the temperature through NOK9 as shown in Figure 33.
- Observe the FO detection through LED indication or UART.
- Observation: FO detection range must be about 10 to 15 mm from the center of PTx/PRx alignment.

d) For pre-power FOD testing (Method 2):

- Place the FO(s) at a distance of 5 mm away from the center of the PTx/PRx alignment.
- Provide power to the PTx.

- Observe the FO detection through LED indication or UART.
- For UART analysis: EPT =7 provides a clear indication of pre-power FO detection.

Figure 33 **FOD verification for Infineon High Power Receiver**

5 Checklist for tuning operation

1. Use caution while moving the TPR toward the interface surface of the transmitter. Ensure that the movement is subtle and does not lead to any mechanical or electrical damage to the transmitter or receiver.
2. Ensure proper EMI discharge for the test equipment.
3. Ensure the power levels of the TPR are within the range of the expected current loads during load ramp tests.
4. Ensure the best possible signal strength alignment between TPR and transmitter. See Appendix A for finding the best signal strength.
5. Consider proper offset values while tuning the power loss FOD parameters. See Appendix B for more details.
6. Ensure that no FO is present on the interface surface or in the vicinity (field of influence) of the transmitter coil.
7. Enable the FOD functionality before verifying the design using section 4.
8. Monitor the FO temperature and take appropriate actions to avoid damage to Rx and Tx.
9. Ensure that the Debug prints are set to default after the tuning operation is complete.
10. Section 4 validates FOD functionality. To ensure complete Qi compliance, it is recommended to execute the compliance test in WPC-recommended ATLs.

6 Abbreviations and definitions

Table 5 Abbreviations

Abbreviation	Definition
USB PD	Universal Serial Bus Power Delivery
DUT/EUT	Device under test/Equipment under test
TX	Transmitter
RX	Receiver
BPP	Baseline power profile
EPP	Extended power profile
TPR	Test power receiver
ASK	Amplitude shift keying
FSK	Frequency shift keying
WPT	Wireless power transfer
CE	Control error
CEP	Control error packet
FO	Foreign object
OVP	Overvoltage protection
OCP	Overcurrent protection
UVP	Undervoltage protection
FOD	Foreign object detection
PCB	Printed circuit board
EMI	Electromagnetic interference
NTC	Negative temperature coefficient
UART	Universal asynchronous receiver-transmitter
LED	Light-emitting diode
RPP	Reported power packet
RP	Reported power
NAK	Not acknowledge packet (FSK response)
ACK	Acknowledge packet (FSK response)
RF	Resonance frequency
IFx	Infineon receiver

7 Appendix A: Finding signal strength

Note: This process is unique for every compliance tester.

1. Enable the Signal Strength Finder in the compliance tester tool. See Figure 34.
2. Ensure the TPR is placed at maximum signal strength (best alignment with transmitter coil).
3. Disable the Signal Strength Finder once the alignment procedure is complete.

8 Appendix B: Received power offset

Note: *This section is compliance tester-specific and may be subject to change. Contact sales support for more details.*

Received power offset is a modifiable parameter in the Power Transfer Phase setting in Advanced mode of the Qi compliance tester (see Figure 34).

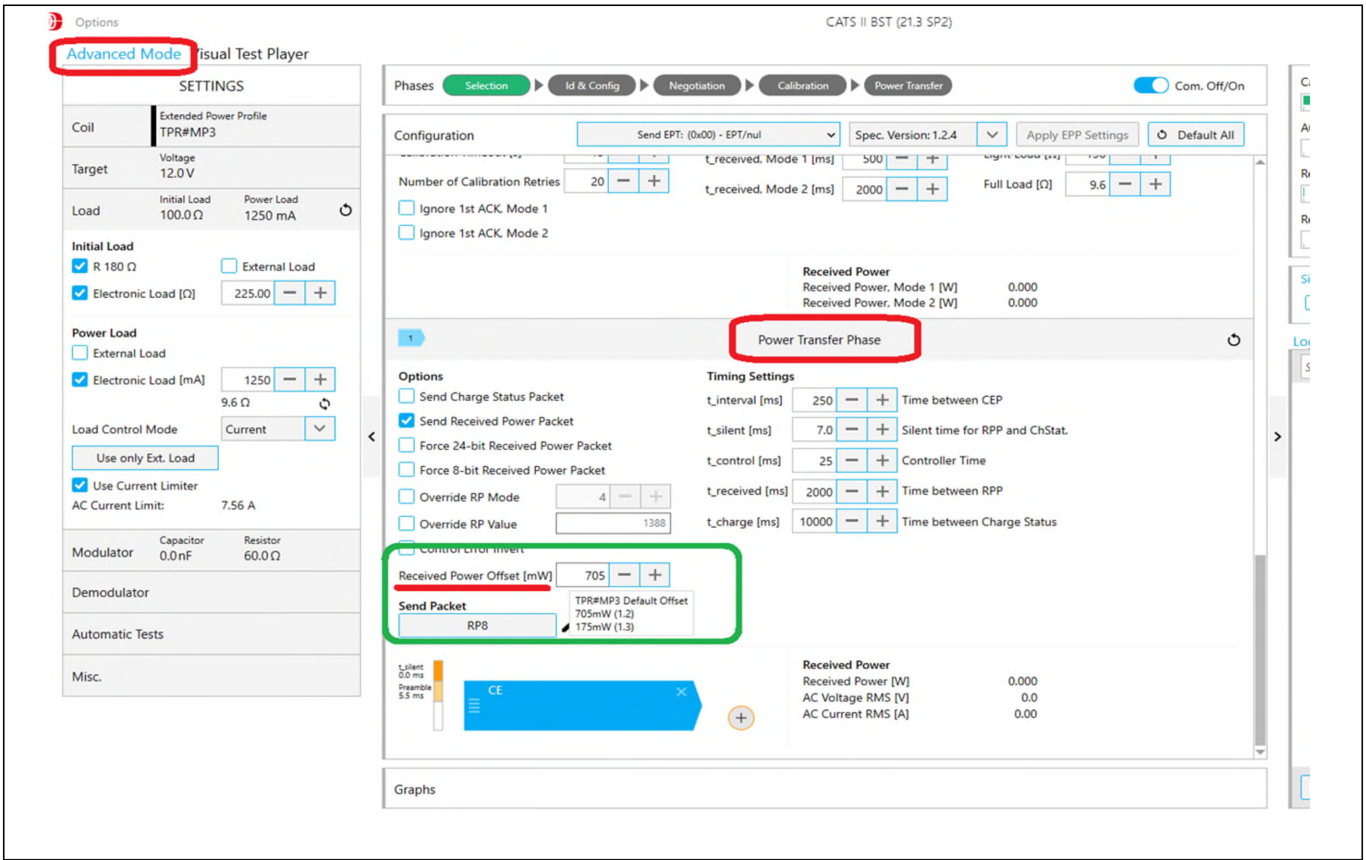


Figure 34 **Received Power Offset in Advanced mode**

The value of the Received Power Offset in the Advanced mode operation determines the accuracy of the system power loss coefficients used to calculate the system power loss. The default values of received power offset are different for Qi 1.2 and Qi 1.3 and may vary for Qi compliance tests as well as guaranteed power (GP) tests. The following table provides the default values for Received Power Offset (mW) for various Qi versions and GP tests:

Table 6 **Receiver power offset observed in compliance tool**

TPR	Qi 1.2	Qi 1.3	GP test
TPR#MP3	705	175	705
TPR#7	335	335	335
TPR#5	35	35	35

Please use the GP values as an offset for calibration operation.

9 Appendix C: Enabling UART logs using Wireless Charging Configuration Utility

Note: *The UART logs are not enabled in the system. The user must disable the UART logs when not needed. The standard system behavior is tested with UART logs disabled.*

Enable the UART logs by enabling the following parameters in the transmitter "Profile" page in the Wireless Charging Configuration Utility (see Figure 35).

1. UART enable
2. Critical enable
3. Message enable
4. Set Debug enable to Level 1

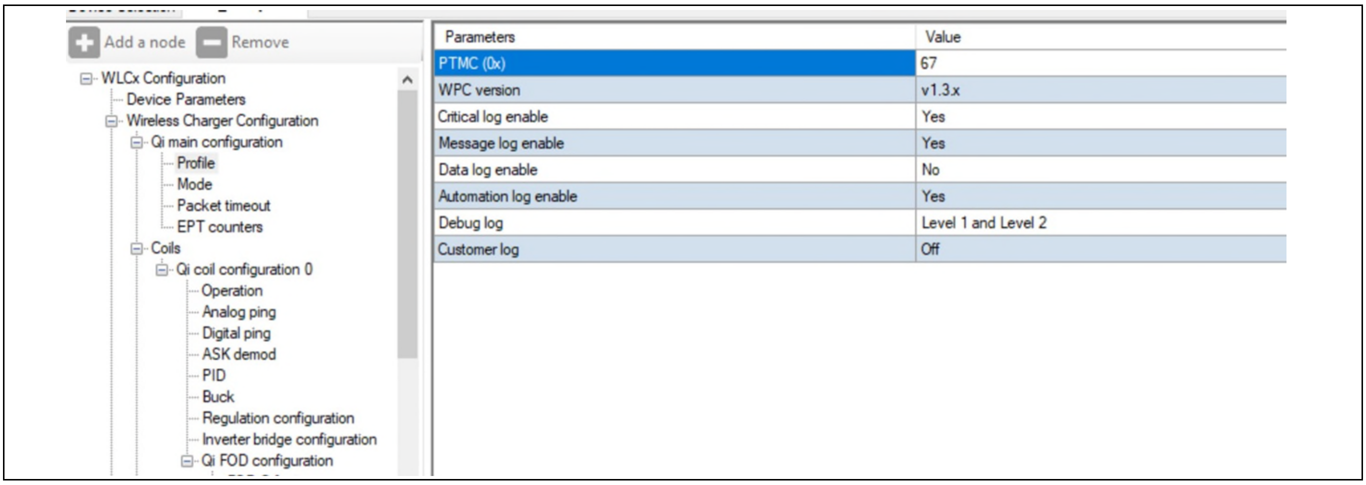


Figure 35 Profile page settings for enabling UART logs

Revert these changes to default on completion of the process. UART logs consume processor resources, and it is recommended to disable UART logs for optimal performance of the WLC power transmitter.

References

[1] Qi Standard Version 1.3.x

[2] Qi Standard (Version 1.3.1), Chapter "Foreign Object Detection"

[3] Qi Standard (Version 1.3.2), Chapter "Foreign Object Detection"

[4] Two-point calibration – Section 11.4.3.1 of Part 12, Qi Standard Version 1.2.4

[5] FOD based on calibrated power loss accounting – Section 11.4 of Part 12, Qi Standard Version 1.2.4

[6] (External link) WPC's list of ATLs

[7] Section 5.4.3.3, Part 3, "Compliance Testing", Qi Standard Version 1.2.4

[8] Section 11.3.3, Part 12, "Definition of the Reference Quality Factor", Qi Standard Version 1.2.4

[9] Section 5.4.3, Part 3, "Foreign Object Detection", Qi Standard Version 1.2.4

[10] 002-34843: Wireless Charging Configuration Utility user guide

[11] Reference board: REF_WLC_TX15W_C1 wireless power transmitter reference board

[12] Product datasheet: WLC1115, 15 W wireless power transmitter with integrated USB Type-C PD sink controller

[13] Q factor – Analysis and insights

[14] Annex A: Determining the reference FOD values, FOD Chapter of Qi-V1.3.2 Spec

[15] Reference board: REF_WLC_TX50W_N1 wireless power transmitter reference board

Revision history

Document revision	Date	Description of changes
**	2022-05-02	New application note
*A	2023-02-06	Added reference design REF_WLC_TX50W

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