Link Budget & Range Calculator

User Manual

1 Introduction

This User Manual describes how to use the Qorvo Link Budget & Range Calculator (“tool”) to calculate the link budget of Qorvo wireless connectivity solutions and estimate the maximum achievable connection range between two communication controllers. This tool supports not only Line-of-Sight (LOS) transmission, but also Non-Line-of-Sight (NLOS) propagation for more accurate modeling that matches practical cases.

In addition, the benefit of Qorvo’s Antenna Diversity can be easily visualized by the increase of reliable range in Matter over Thread / Zigbee (IEEE 802.15.4 – 2.4 GHz PHY) and Bluetooth® Low Energy (BLE) applications. And similarly, for Ultra-wideband (UWB) applications, the addition of a low noise amplifier (LNA), and different front-end configuration, is implemented for the interest in better range coverage.

Table of Contents

2 Getting Start

2.1 User Interface Overview

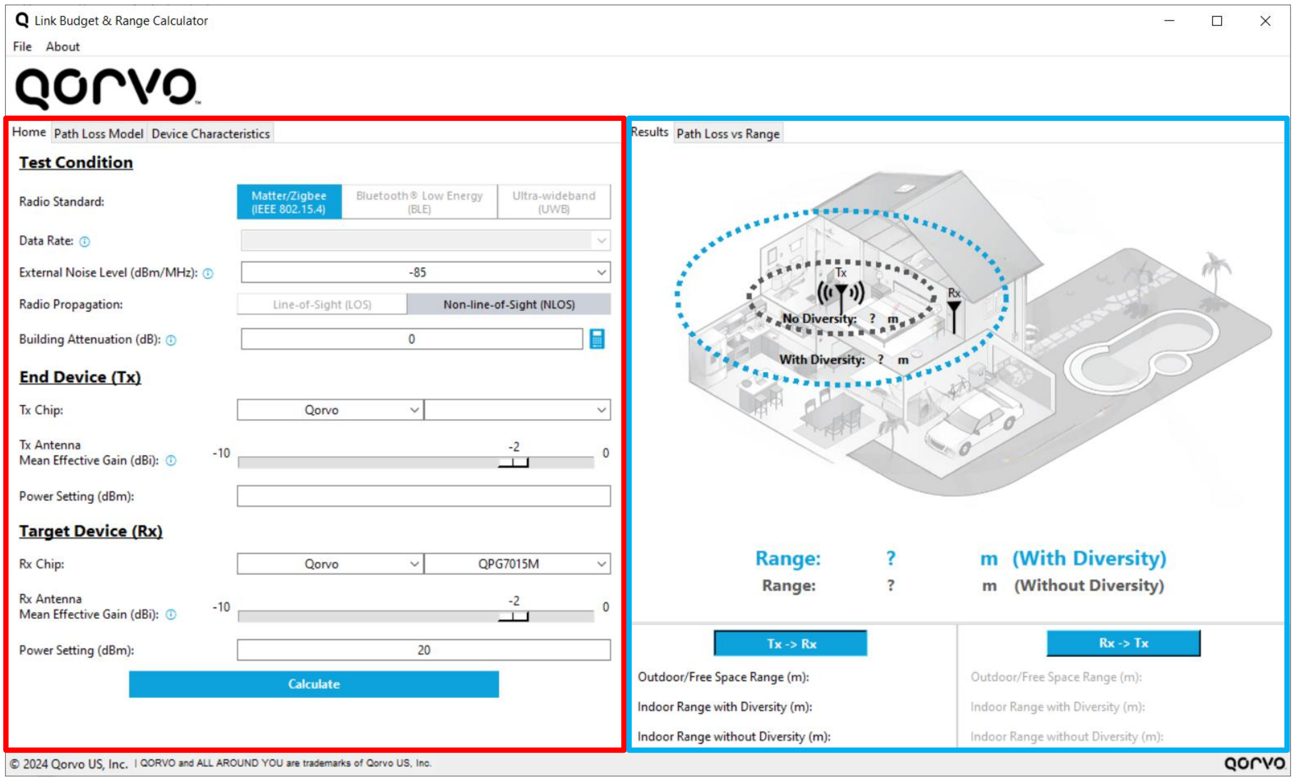

Figure 1: Start Screen of the Link Budget & Range Calculator

As shown in Figure 1, the start screen can be divided into User inputs (on the left) and Results (on the right).

The tabs [Home], [Path Loss Model] and [Device Characteristics] require user inputs used for link budget and range calculation. The most essential ones are all placed on [Home]. The default numbers given in the other two tags can be manipulated for more accurate wireless propagation models. The parameters contained in each tab will be described in section 2.2.

The tabs [Results] and [Path Loss vs Range] show the calculated results. [Results] show the calculated results of outdoor/free space range as well as indoor ranges with and without antenna diversity/LNA use cases. [Path Loss vs Range] shows the plot of link budgets and path loss against distance (i.e., behavior of respective path loss model). Again, more details will be discussed in Section 2.3.2.

More information about the tool can be found from [About] on the top left corner.

2.2 User Inputs

2.2.1 RF Setting

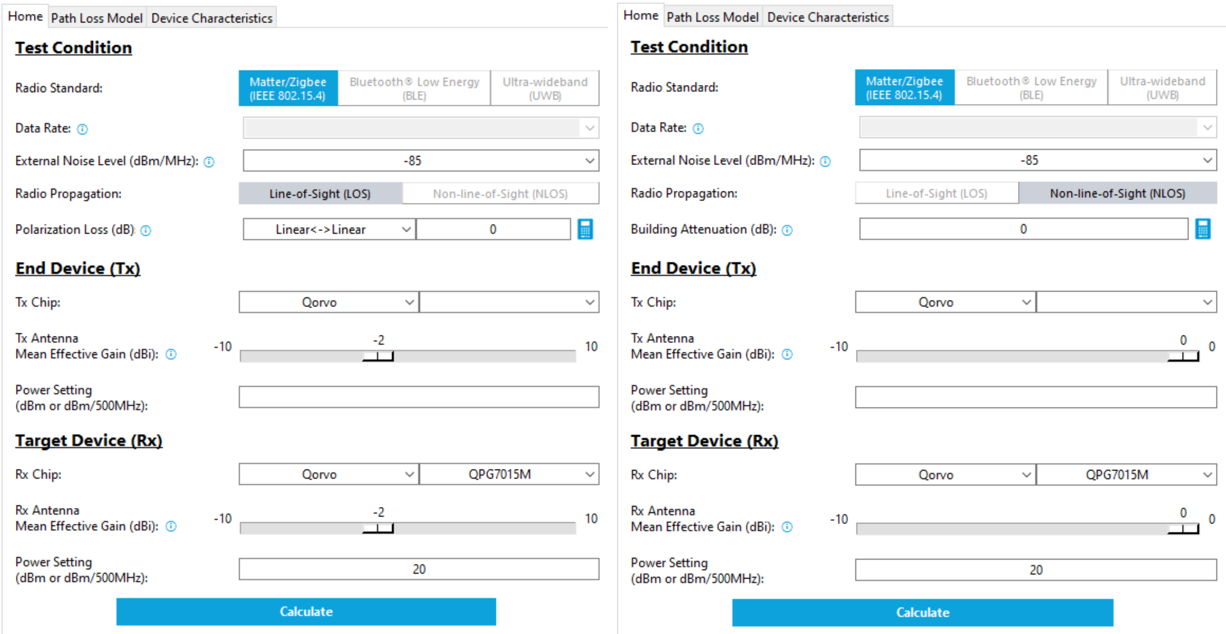

Figure 2: Home Page (left: LOS Propagation, right: NLOS Propagation)

Users have to first select the radio standard, i.e. Matter / Zigbee (the same IEEE 802.15.4 – 2.4 GHz PHY), Bluetooth® Low Energy (BLE) and Ultra-wideband (UWB) and thus, the available Qorvo part numbers can be selected through the drop-down menu from Tx Chip and Rx Chip. Please note that receiver sensitivity will be updated according to the selected data rate.

External noise level is to take environmental noise in 2.4 GHz ISM band into account, not application for UWB frequency channels. The next step is to select the propagation model. Line-of-Sight (LOS) represents a straight ray transmission between Tx and Rx without any object blocks in between, otherwise non-line-of-sight (NLOS) should be selected.

For the LOS model, the mismatched loss due to antenna polarization will be considered. If both antennas are linearly polarized (Linear<->Linear), the polarization loss, estimated by clicking the calculator icons, depends on the angle rotation (unit: degree) with respect to transmitting antenna. For the combination of circular and linear polarized antennas, polarization loss is fixed to 3 dB. The Two Ray Ground Reflection Model is used as the path loss model for LOS propagation.

In theory, the ground reflected ray should have no impact in the case of circularly polarized antennas at both sides. While for NLOS model, users can input respective building attenuation. Some examples of attenuation numbers for different building materials are shown in Table 1. Such values can also be found in the tool by hovering the cursor over the blue information mark, or simply, with the aid of the calculator icon. For NLOS propagation, the Dual Slope Model is used as the path loss model.

Table 1: RF Attenuation of Different Building Materials

Building Materials	Attenuation (dB)
Reinforced Concrete (15 cm)	12
Brick Stone Walls (10 cm)	8
Aerated Concrete (6 cm)	4
Layers of Wood (2.5 cm)	2

Qorvo is set as the default chipset vendor for both Tx and Rx chips. Users have to indicate the part number from the drop-down menu. The chip parameters, including maximum Tx power and Rx sensitivity, will be fetched from the respective datasheet automatically. For UWB applications, FCC has limited EIRP (Equivalent Isotropic Radiated Power) to -41.3 dBm/MHz. The tool can calculate EIRP in real time after the user updates power setting values / antenna gain. A warning message will pop up if the calculated EIRP exceeds the regulation limit, suggesting users to backoff Tx power to an acceptable level. For using non-Qorvo devices on either side, please refer to Section 3.

Antenna gain is another key parameter for link budget calculation, specifically in LOS propagation. But for NLOS propagation, the mean effective antenna gain (known as antenna efficiency) should be used, and its maximum value is 0 dB (100% efficiency). Tx power setting can be overruled to match the implementation loss in actual hardware.

In case of any doubts of the terms or value, users can hover their cursor over the blue information icon next to the text for more information.

2.2.2 Path Loss Models (recommended for Advanced Users)

As introduced previously, this section gives the guidelines of the key parameters with respect to Two Ray Ground Reflection Model and Dual Slope Model for LOS and NLOS propagation models accordingly. Parameters in [Path Loss Model] determine the range achieved in outdoor and indoor situations. In this tool, outdoor can be regarded as free space if the Free Space Path Loss Exponent / Path Loss Exponent before Breakpoint (g1) is 2.

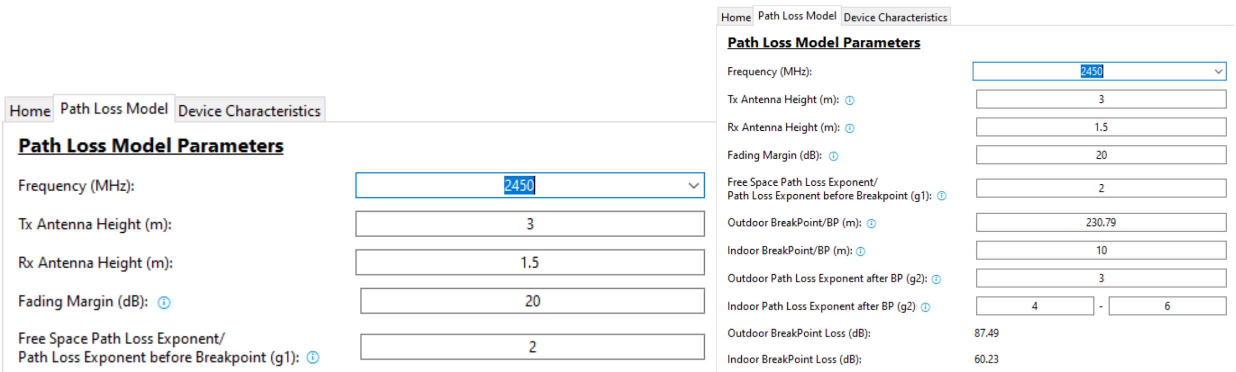

Figure 3: Path Loss Model Tab
(left: Two Ray Ground Reflection Model, right: Dual Slope Model)

Different parameters will be used differently for different scenarios. The different use cases of the parameters are summarized in Table 2.

Table 2: Use Case of Parameters in [Path Loss Model]

Parameter	Two Ray Ground Reflection Model	Dual Slope Model
Frequency	Both Indoor and Outdoor situations	
Tx Antenna Height	Indoor	Outdoor
Rx Antenna Height		
Fading Margin	Both Indoor and Outdoor situations	
Free Space Path Loss Exponent / Path Loss Exponent before Breakpoint (g1)	Outdoor	Both indoor and outdoor situations
Outdoor Breakpoint	N/A	Outdoor
Indoor Breakpoint		Indoor
Outdoor Path Loss Exponent after BP		Outdoor
Indoor Path Loss Exponent after BP		Indoor

Frequency is the channel frequency of devices in MHz.

Fading Margin is the difference between the Received Signal Strength and the radio Receiver Sensitivity. It is the safety margin allowed in the system to account for fading or losses due to a variety of factors. Users are recommended to leave a safety margin of 20 dB for Matter / Zigbee / IEEE 802.15.4 and 8 dB for Bluetooth LE.

2.2.2.1 Two Ray Ground Reflection Model

For the Two Ray Ground Reflection Model, it is important that users should not use same values for Tx and Rx Antenna Heights as it violates the assumptions of the Two Ray Ground Reflection Model. Free Space Path Loss Exponent is used to calculate the range achieved in free space / outdoor situations using the Friis Transmission Equation. The typical value for free space path loss exponent is 2.

2.2.2.2 Dual Slope Model

The Dual Slope Model does not require the antenna heights to be different as they are simply used to calculate the breakpoint distance in outdoor situations. Whilst breakpoint distance in indoor situations depends on a variety of factors, generally it is assumed to be 10 meters.

As the Dual Slope Model describes a path loss scenario where the path loss trends change from g1 to g2 once the signal has gone beyond the breakpoint distance, there are 2 different path loss exponents for both indoor and outdoor situations. The Path Loss Exponent before Breakpoint (g1) are shared among indoor and outdoor situations and are typically assumed to be 2 to indicate that it is a free space propagation.

The path loss exponents after breakpoint (g2) are different in indoor and outdoor situations. Optimistic and pessimistic estimates of g2 are required for indoor situations to determine the upper and lower boundary of range. The recommended values for g2 are shown in Table 3.

Table 3: Recommended Values for g2 in Different Scenarios

Environment		Path Loss Exponents (g2)
Outdoor Situations	Urban Area	2.7 – 3.5
	Suburban Area	3 – 5
Indoor Situations	Typical Optimistic Value	3
	Typical Pessimistic Value	4

For users that are interested in fine-tuning the path loss model parameters, recommended values and/or more information could be also obtained by hovering the cursor over the blue information icon, if applicable.

2.2.3 Device Characteristics

For IEEE 802.15.4 and Bluetooth LE radio standards (except for UWB), the datasheet numbers will be fetched to obtain sensitivity and SNR, if Qorvo communication controllers are used for both the Tx and Rx chip as shown in Figure 4. Users can update these values according to their use cases.

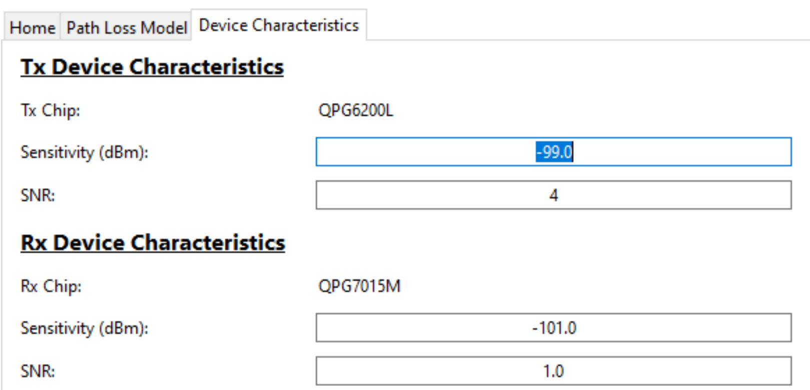

Figure 4: Device Characteristics Tab for non-UWB Applications

For UWB applications, users might consider adding an external LNA in addition to the BPF in the front-end configuration. An LNA can be used to further improve the noise figure and thus the sensitivity of the device [2]. This typically results in a 4 – 6 dB improvement in receiver sensitivity when an LNA with high gain and low noise figure is chosen.

Since UWB utilizes high frequency range and high bandwidths, losses can be significant for long RF traces if the front-end circuit is printed on classic FR4 substrate. This tool supports calculating the change in Noise Figure due to the implementation loss of RF traces. Users can update the parameters in this tab according to their front-end configuration for better range estimation.

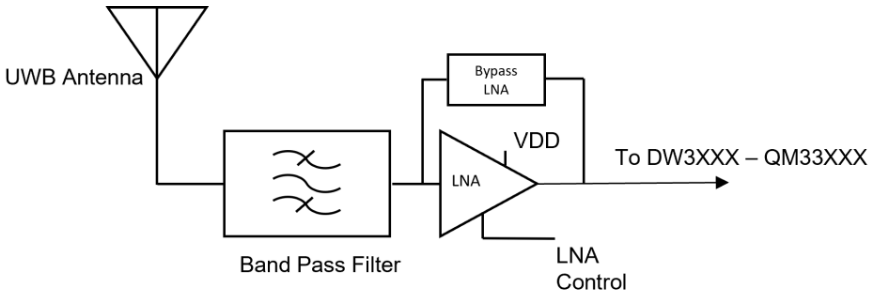

Figure 5: Basic Scheme for Incorporating an External LNA

As shown in Figure 6, the front-end configuration is generally an optional LNA sandwiched by passive components. Possible configurations are shown in Figure 7. Passive components include, but are not limited to, band-pass filters and RF traces.

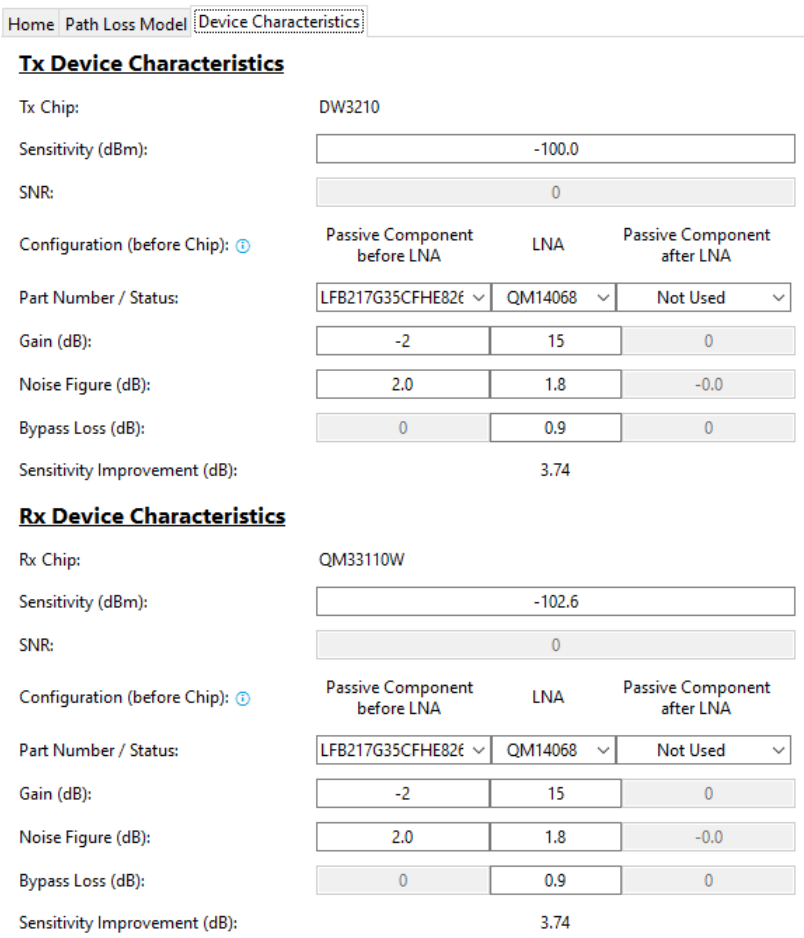

Figure 6: Device Characteristics Tab for UWB Application

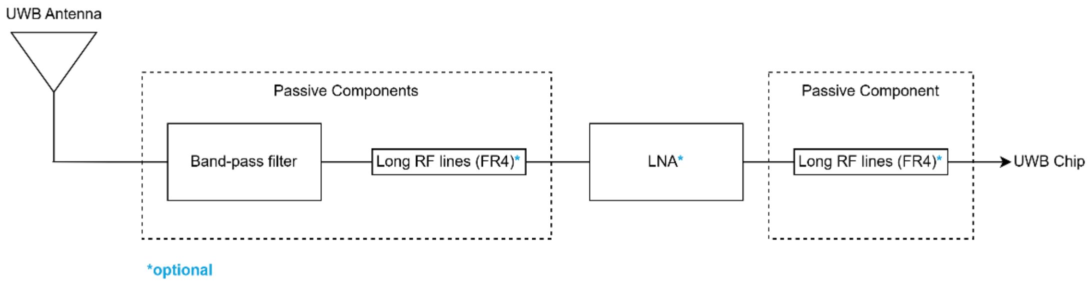

Figure 7: Possible Front-end Configuration

The default configuration in the tool is a BPF connected to a long RF trace (FR4), followed by the QM14068 as the LNA. Users can add additional components / remove any of the above components from the drop-down menu in Part Number / Status. Users can opt out from using any of the components mentioned above by filling in 0 for all entries but it is not recommended.

Please note that gain (positive number), noise figure and bypass loss (negative number) in [Device Characteristics] are in dB. These values can be fetched automatically if QM14068 is being used as the LNA. Otherwise, users will have to refer to the respective datasheet to look up needed values.

The insertion losses of passive components and bypass mode of the LNA will impact the TX power, and this will be considered in the calculation.

For passive components, the Part Number drop-down menu contains the part number of the recommended BPF. Users can select their choice of BPF, and its needed values will be fetched automatically. Otherwise, users will have to look up and calculate these manually. The choices of BPF supported by the tool are listed below.

Table 4: Recommended Band-pass Filters

Vendor	Part Number
Murata	LFB217G35CFHE826
TDK	DEA167240BT
Johanson Technology	7240BP15B2000E-AEC
Mini Circuits	LFCN-9170+ (LPF)* *A low-pass filter, included if only harmonic suppression is needed.

As mentioned above, RF traces can introduce considerable loss into the system. Users need to take note of this and calculate the resultant losses introduced and fill in the entries correspondingly. The loss values for straight RF traces on FR4 are shown in Table 5.

Table 5: Loss of RF Traces

Length	Loss (dB)
Short Straight Trace (~2cm)	1
Long Straight Trace (~4cm)	2

Users have to account for the loss introduced by the RF traces manually. This tool will not account for the loss introduced by RF traces. For example, if the configuration is a BPF from Murata (LFB217G35CFHE826), which has a gain of -2 dB, followed by a long straight RF trace, gain entry for passive component should be updated to -4 dB instead of -2 dB since there are long RF traces involved.

As Noise Figure should be the absolute value of the gain for passive components, users only have to input the gain for the passive components in this tool.

2.3 Calculated Results

After a user clicks the ‘Calculate’ button from [Home], the results section will be updated accordingly.

In the following sections, Qorvo’s QPG6200L and QPG7015M will be used as end device and target device respectively under IEEE 802.15.4 radio standard for demonstration purposes.

2.3.1 Range

Under [Results], it shows the connection range achieved by both devices. By default, the tool will select the determining device and range (i.e., shorter range) automatically, which is the transmission path from QPG6200L to QPG7015M (‘Tx -> Rx’) in this example. Users that are interested in knowing the performance of alternative path can toggle another button, which is to click ‘Rx to Tx’ button in this example.

In this tool, if Qorvo Antenna Diversity is supported by the devices, the range achieved with Qorvo Antenna Diversity will be displayed in blue to highlight the benefits of reliable link budget and thus range improvement. For more information about Qorvo Antenna Diversity, please refer to [1]. For UWB applications; ‘Diversity’ will be replaced by ‘LNA’ as the improvement in range is no longer contributed by Qorvo Antenna Diversity but the addition of external LNA. User may refer to 2.2.3 or [2] for more information on using an external LNA.

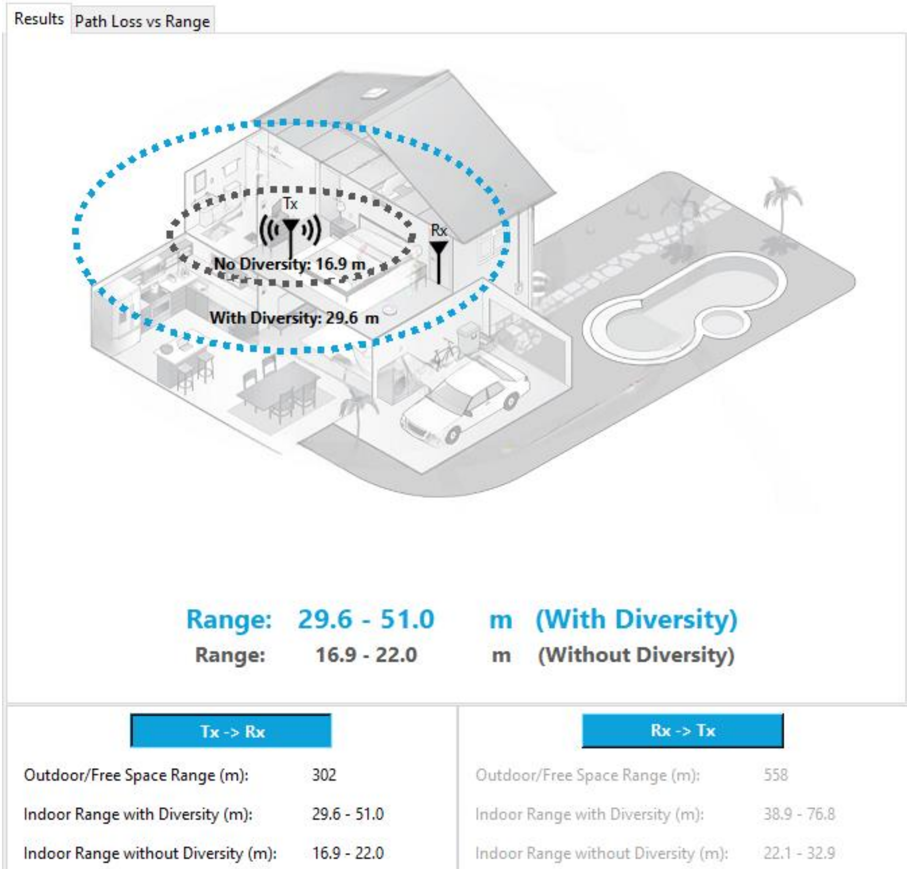

Figure 8: Results Tab

2.3.2 Path Loss vs Range

This tool not only provides estimated range. but also displays the path loss behaviors of transmission paths according to different path loss models.

Users will see a graph of path loss plotted against distance in this [Path Loss vs Range] tab. Link budgets with/without antenna diversity will also be shown in the graph. Users can again click the ‘Tx -> Rx’ or ‘Rx -> Tx’ button to view the respective link budgets of the 2 transmission paths. Users can also toggle the ‘Linear’ or 'Log' button to view the path loss against linear distance or log-distance respectively.

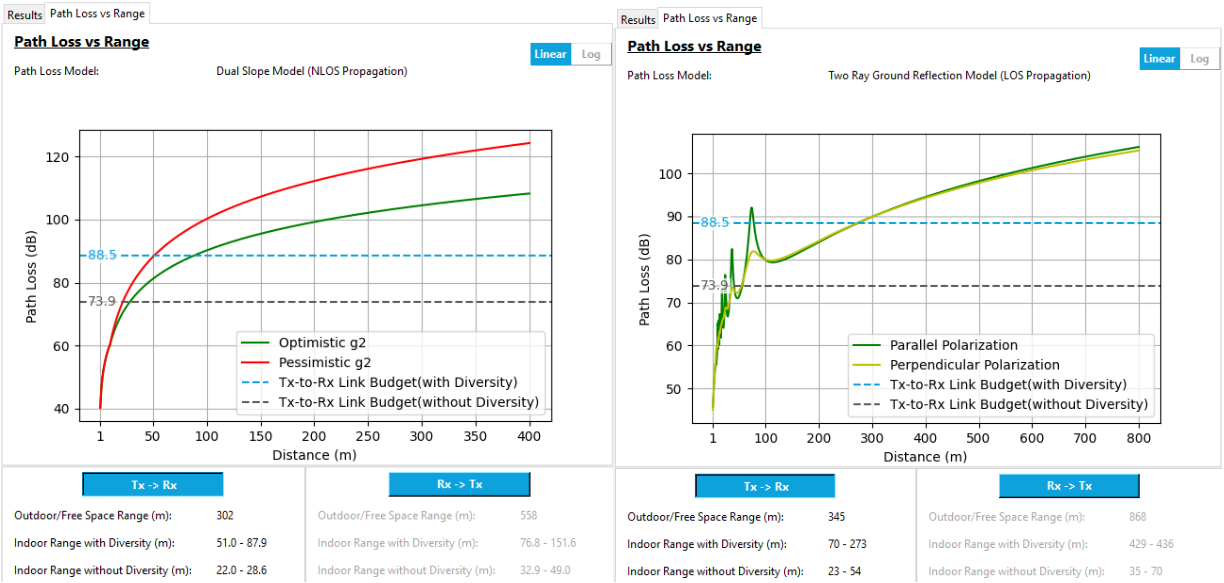

Figure 9: Path Loss vs Range in Linear Scale
(left: Dual Slope Model, right: Two Ray Ground Reflection Model)

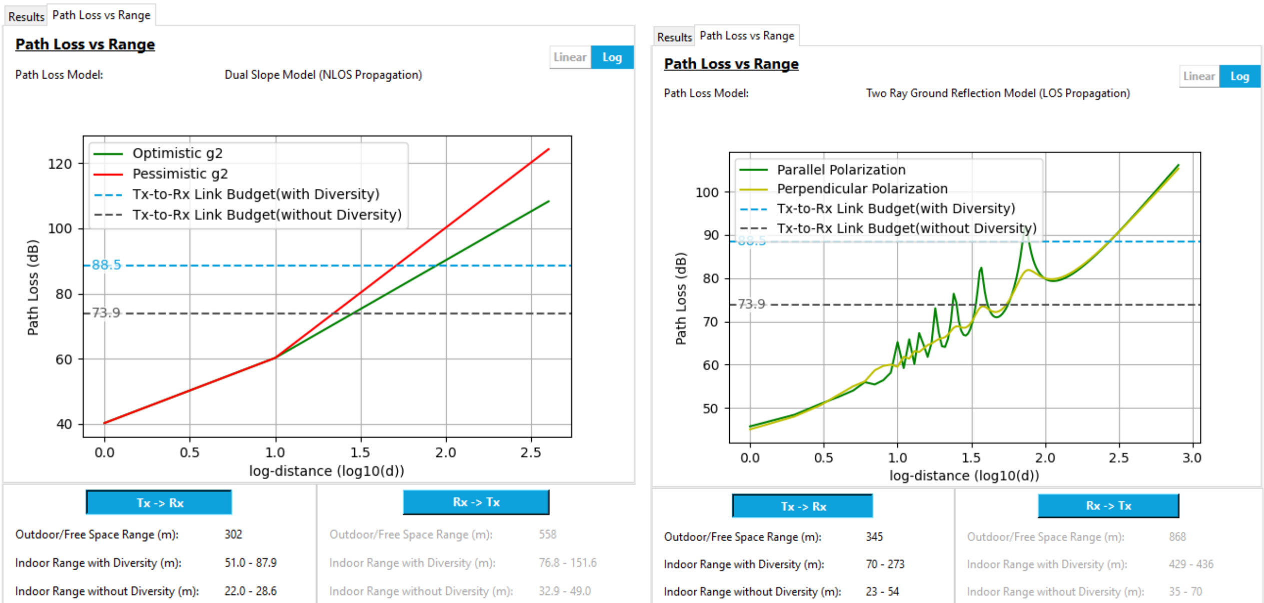

Figure 10: Path Loss vs Range in Log-distance Scale
(left: Dual Slope Model, right: Two Ray Ground Reflection Model)

3 Using non-Qorvo Devices

3.1 Adding New non-Qorvo Devices

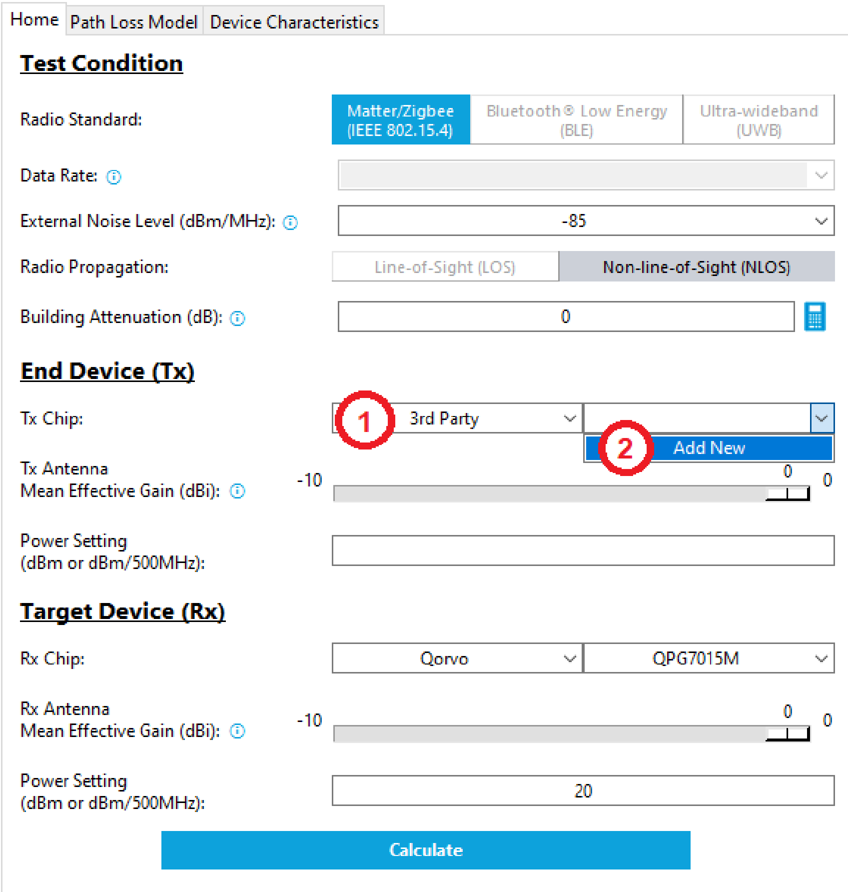

Figure 11: Adding New non-Qorvo Devices

If users would like to estimate the range for non-Qorvo devices as either Tx or Rx side, users will have to select ‘3rd Party’, then ‘Add New’ in the columns as shown in Figure 11.

An import window, as shown in Figure 12, will pop up and users can fill in information about the device accordingly.

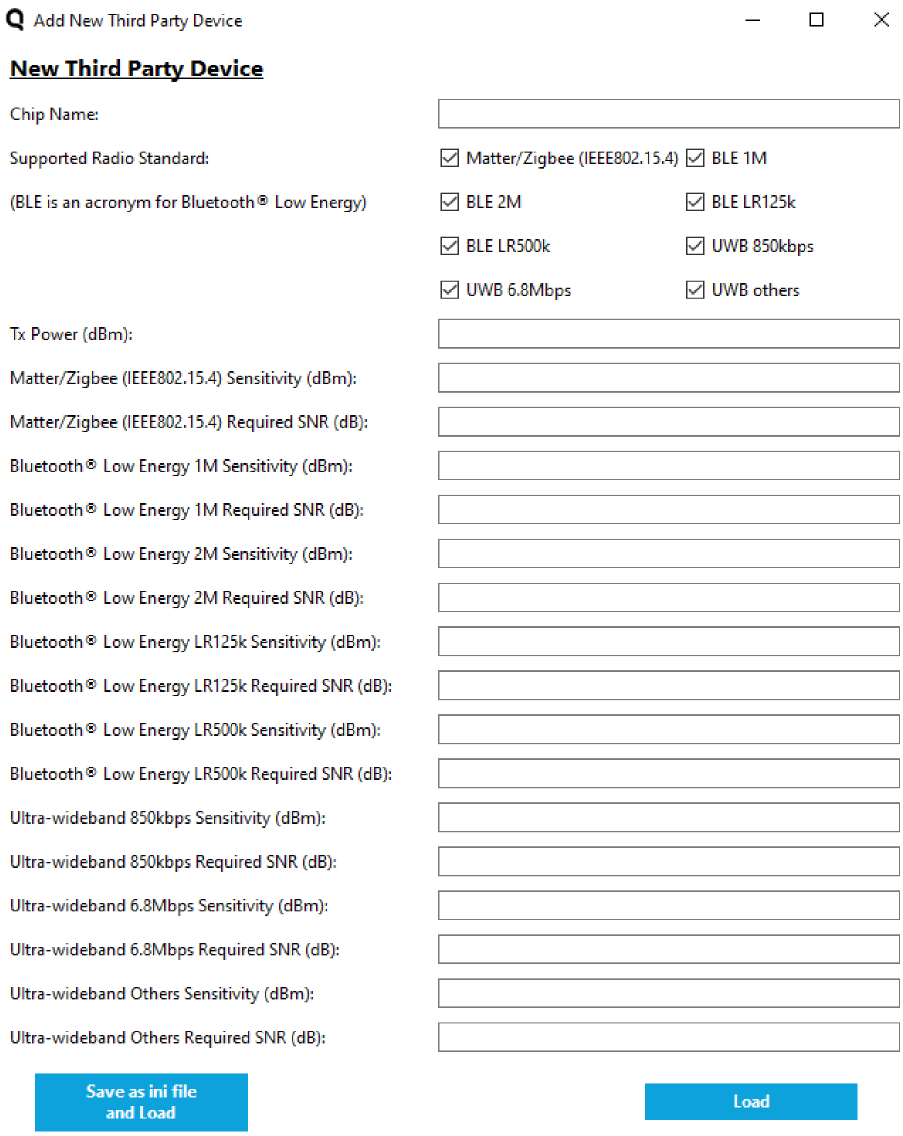

Figure 12: Add New Third Party Device Window

After all entries have been filled in, users can choose from two options on how to process the information. It is recommended to click the 'Save as ini file and Load' button if the device is expected to be used in the future again. This button will save the information filled in as an .ini file in a folder 'third_party_chip_info' under the same location of range calculation tool and users can recall this file if they would like to use this device again the next time they launch the tool.

In contrast; the 'Load' button will simply feed the data from the above window into the tool. No file will be created and thus the recall feature will not be available.

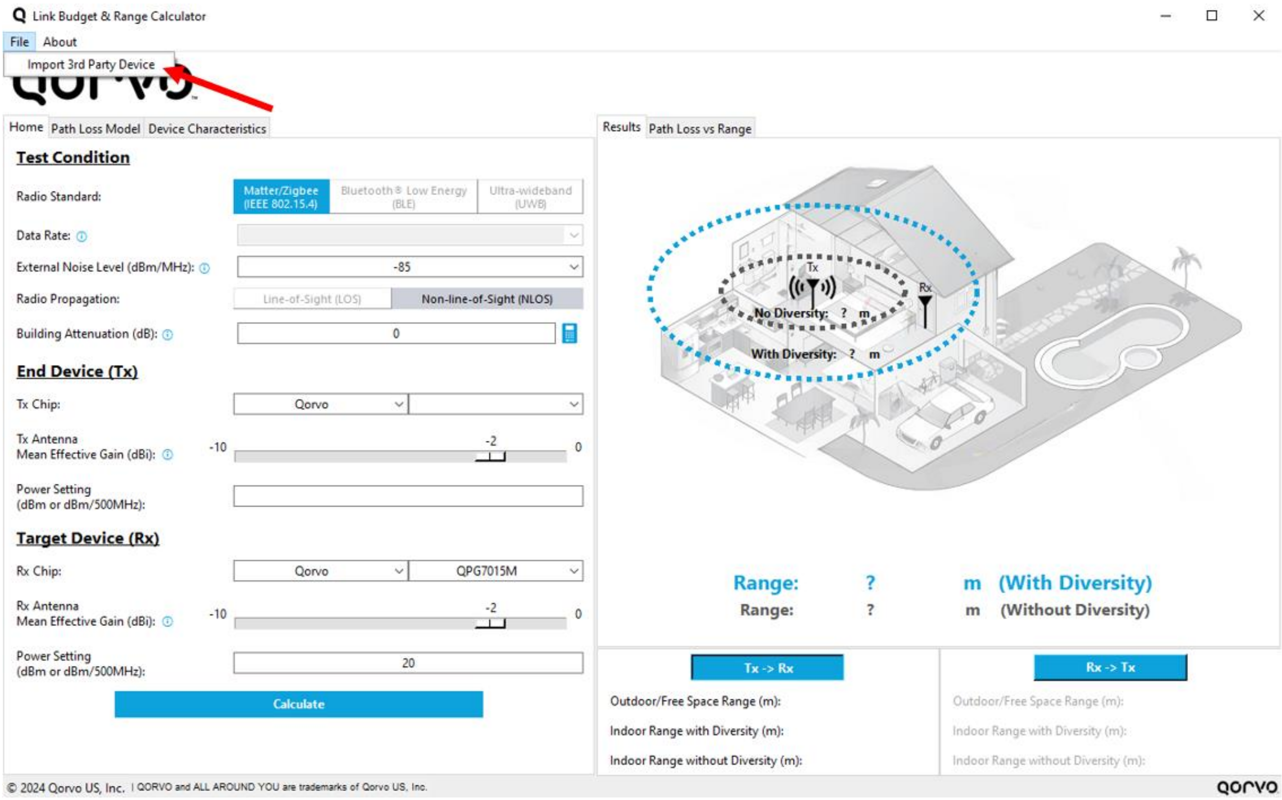

Figure 13: Importing 3rd Party Devices

To recall the third-party devices saved previously, users should use the [File] tab on the tool screen and click 'Import 3rd Party Device'. This will recall all the .ini files stored within the 'third_party_chip_info' folder. Users will then have to repeat the procedure as stated in Section 3.1 and choose the desired chip under the drop-down menu labelled as **2** in Figure 11 instead of choosing 'Add New'.

References

[1] Improved Range with ConcurrentConnect™ Antenna Diversity; Qorvo document GP_P008_AN_19983

[2] Increasing Range Using an External LNA; Qorvo document APS304 Rev 1.0

Abbreviations

BPF	Band-pass Filter	LNA	Low-noise Amplifier
RF	Radio Frequency	LOS	Line-of-Sight
UWB	Ultra-wideband	NLOS	Non-line-of-Sight
BLE	Bluetooth® Low Energy		

Important Notices

Document History

Version	Date	Section	Changes
1.0	10 Mar 2025		Initial release – Link Budget and Range Calculator v1.0 in Qorvo Website