AN1495: Optimizing RF Performance for the SiWx917 Wireless-MCU Family

Optimizing RF performance is one the most crucial aspects for any wireless product to achieve stable wireless connection. This application note offers a step-by-step guide for improving RF performance when using the Silicon Labs-recommended matching network designs.

The optimization process relies on Vector Network Analyzer (VNA) and Spectrum Analyzer/Wireless Connectivity Tester measurements.

For a detailed analysis of the matching network designs for SiWx917, refer to AN1423: SiWx917 RF Matching and Layout Design Guide.

KEY POINTS

- Performing RF measurements with SiWx917
- Evaluating RF performance through various RF metrics
- Matching network concept overview
- Hardware debugging techniques to improve RF performance (with VNA impedance measurements)
- Practical example for RX tuning
- TX and RX load/source pull measurements

1. Performing RF Measurements with SiWx917

The SiWx917 family is a Wireless MCU SoC that supports various WLAN and BLE protocols. The complete guide on performing TX and RX sensitivity measurements for any modulation PHY and frequency channel is described in the application note, AN1491: SiWx917 RF Transmit & Receive Measurements.

The three main RF measurements are TX, RX sensitivity, and EVM. An example is given in the table below for each test:

- Flash a CLI Demo Application file on the device
- In Serial Debug Assistant, send the following commands:

Table 1.1. CLI Commands for TX and RX Testing

TX/EVM	RX
wifi_init -i transmit_test wifi_set_antenna -i client -a *0* wifi_transmit_test_start 127 0 100 1 1 wifi_transmit_test_stop	wifi_init -i transmit_test wifi_set_antenna -i client -a 0 wifi_start_statistic_report - i client -c 1 -n 30

The examples above correspond to the following settings:

```
wifi_transmit_test_start <power=127> <data_rate=1> <length=100> <mode=1> <channel=1>
```

```
wifi_start_statistic_report -i client -c <channel=1> -n <stats_count=30>
```

Read more about interpreting the results and setting up the measuring instrument in the referenced application note.

The commands above will be used during the VNA measurement-optimization process, but mainly for the purpose of putting the radio into the respective operational mode so that it presents its “active mode” output/input impedance (PA/LNA). These commands will be used for the impedance tuning method where the VNA is connected to the antenna port and the radio is put into its respective operational mode.

2. Evaluating RF Performance through Various Metrics

The matching efforts strive to simultaneously achieve the following criteria:

- Provide the desired nominal TX output power level at the nominal supply voltage (measured at the connector to the antenna load).
- Achieve desired PA output linearity (e.g., good EVM performance) when using the SiWx917's highly linear OFDM PA.
- Provide optimal RX Sensitivity.
- Minimize current consumption (i.e., maximize power efficiency).
- Comply with regulatory specifications for spurious emissions (e.g., especially TX harmonics) with the help of an additional Band Pass Filter (BPF).

The matching network designs involve load pull techniques which allow changing the PA/LNA termination impedance in a controlled manner while measuring TX and RX performance.

3. Overview of the Matching Network Concept

A detailed guide on the two matching network concepts can be seen in AN1423: SiWx917 RF Matching and Layout Design Guide.

To analyze the matching network, we need to understand that optimal RF performance (e.g, nominal TX power, EVM, and RX sensitivity) is solely dependent – at least from the viewpoint of the PCB designer – on the impedance relations between the SoC and the antenna.

The recommended matching network is the result of an extensive impedance tuning effort to yield such RF performance that is the compromise between all RF performance metrics. For the matching network to be re-used, the user also must strictly follow the layout recommendations in the referenced application note.

However, RF performance degradation might arise due to the following reasons:

1. Correct component values, but different manufacturer (different SMD parasitics).
2. Layout recommendations not perfectly followed. RF performance is extremely sensitive to different PCBs (even if the naked eye sees no such discrepancies). Some factors with large impedance tuning effect at @2.4 GHz are:
    a. Different PCB stack-ups
    b. Interconnection trace properties
    c. Band Pass Filter (BPF) and RF Switch characteristic differences on customer PCB layout

As a collective effect of the above, the Z_{IN} input impedance of the TX and RX matching networks (measured from the SoC point of view) should provide the following:

Table 3.1. Optimum Termination Impedance of the RF_TX, RF_RX, and RF_BLETX Pins @2.45 GHz

Operation mode \ Pin	RF_TX	RF_RX	RF_BLETX
TX	65 - 10j Ω	—	50 Ω
RX	—	35 + 44j Ω	

The values in the table are not be confused with the antenna impedance. They are the impedances that the PA/LNA matching networks (or simply matching networks) transform the antenna impedance into for the PA and LNA to “see”. These optimum impedances are an inherent property of the PA/LNA designs, which are not detailed here.

Consequently, the Silicon Labs matching network values are only applicable if the antenna impedance is a standard 50 Ω. Most SMD chip antennas are not 50 Ω on smaller PCBs, and require an additional matching network between the matching network match and the antenna. In this application note, aside from the load/source pull measurements, the antenna termination is always 50 Ω as it is the VNA/Spectrum Analyzer port.

As the matching network is determined by load-pull measurements, its purpose is not necessarily to yield as much power as possible, which complex conjugate matches do. In fact, the investigations show that due to the strict EVM limits, the match is not a perfect complex conjugate of the PA output impedance, but nonetheless is close to it. However, the RX matching network is designed based on the perfect complex conjugate criteria.

It is essential to understand that due to the symmetric nature of passive circuits, a complex conjugate matching realization on the input of the matching network also yields the same property on the output – that is, a Z_{OUT} measurement with the SoC intact and put into the respective operation mode (e.g., RX) will show the complex conjugate of the antenna termination (50* Ω = 50 Ω). The matching network impedance measurements can therefore be done on the input and also on the output, which will be presented in the next chapter when discussing the debugging process.

The two recommended Silicon Labs matching network designs are:

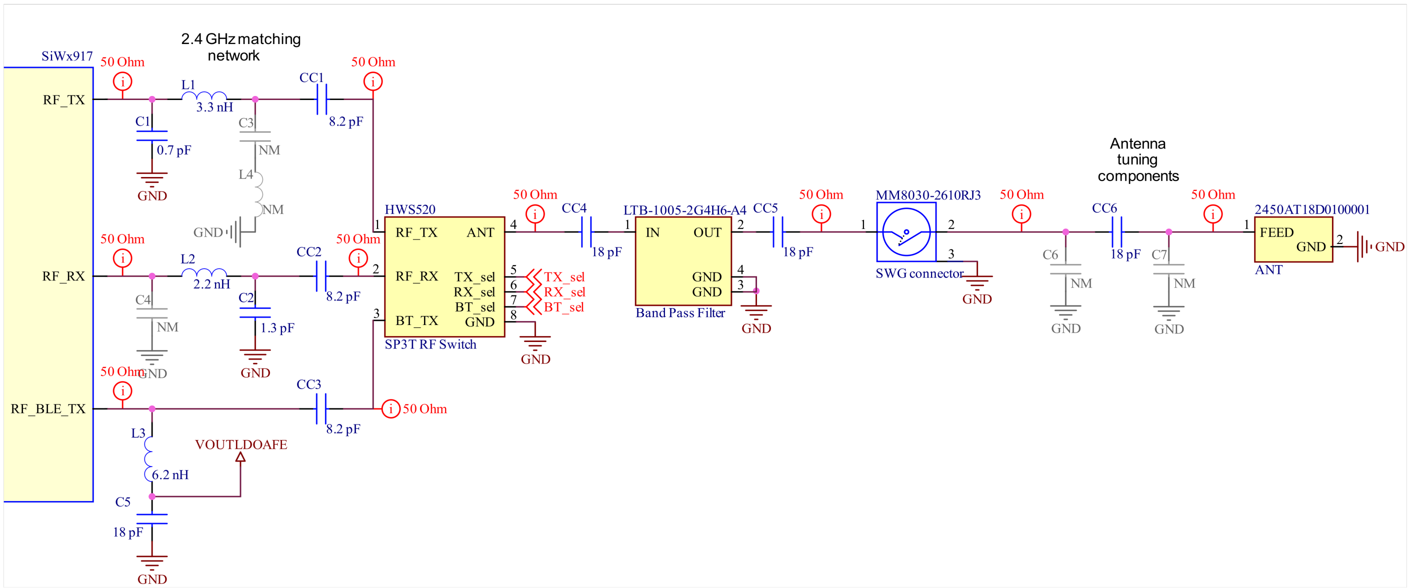

Figure 3.1. RF Schematic of the BRD4338A Radio Board (with External RF Switch)

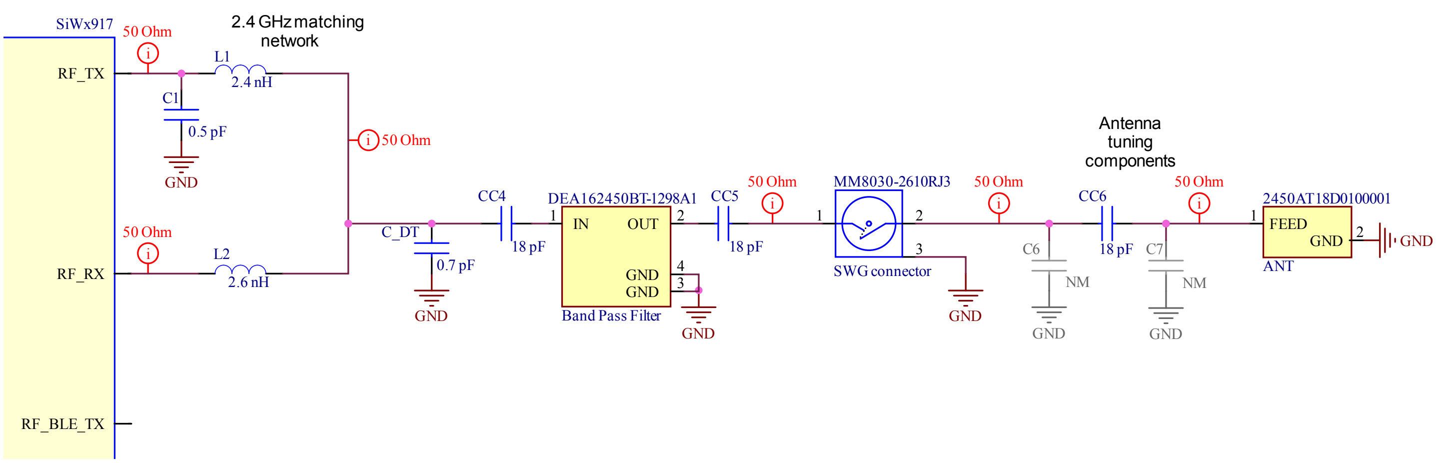

Figure 3.2. RF Schematic of the BRD4342A Radio Board (Internal Switch or “Direct Tie”)

4. Hardware Debugging Techniques to Improve RF Performance

The figure below shows the layout of the RF front-end. The structure of the matching network and the ports for the VNA measurements are marked.

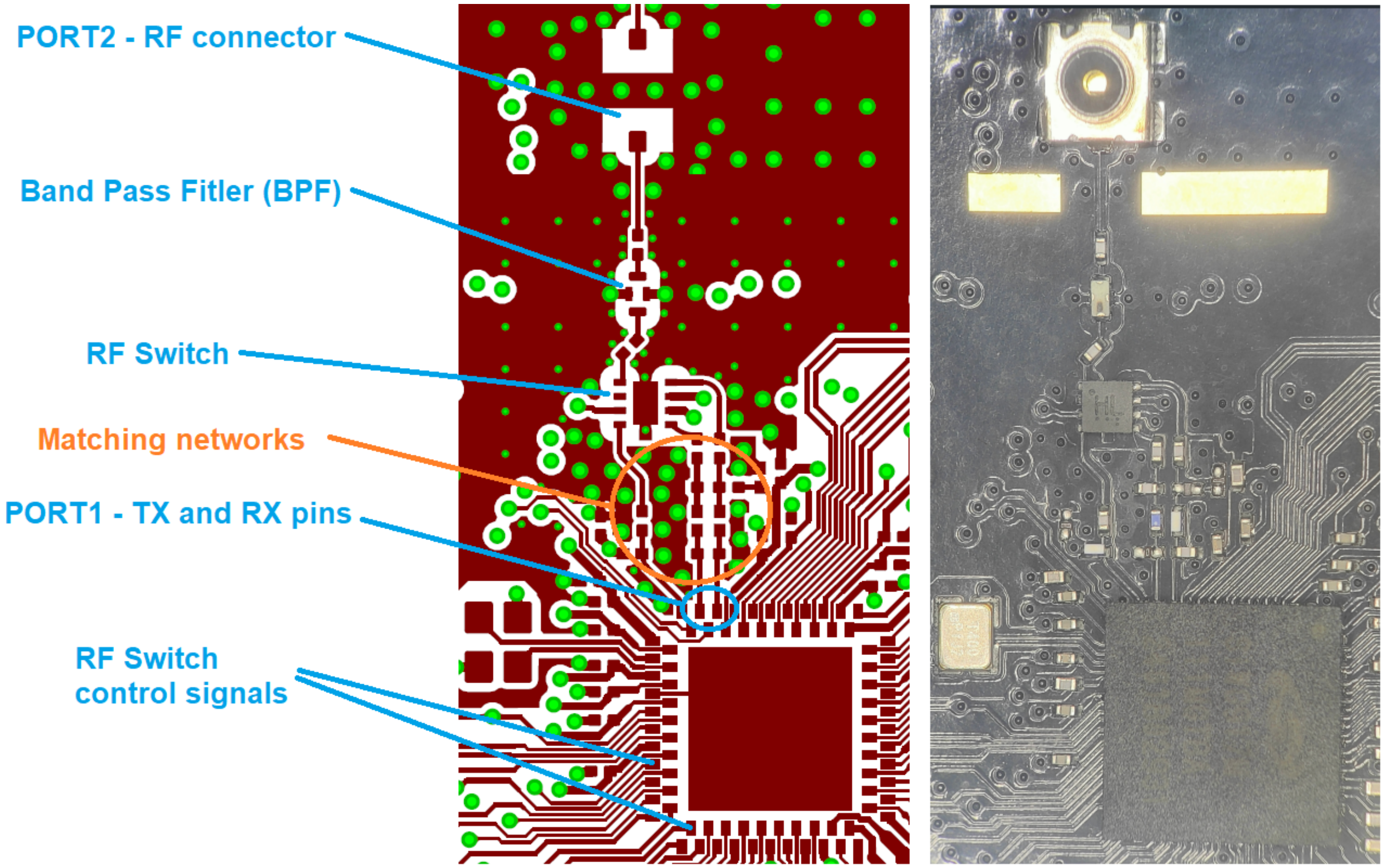

Figure 4.1. RF Front-end Layout of the BRD4338A Radio Board (External Switch)

See AN1423:SiWx917 RF Matching and Layout Design Guide for a detailed analysis of the impedance transformation effects of the RF Switch and the BPF. Their precise effect is not detailed in this application note, hence the PORT2 output termination is after the RF front-end, which includes the effect of those components in the measurements.

4.1 Methods for Verifying Matching Network Impedance in the Event of Sub-Optimal RF Performance

1. **Z_{IN} input impedance measurement at SoC side with the SoC removed.** As explained before, a good matching network should show Z_{IN} close to the design goal values of Table 3.1 Optimum Termination Impedance of the RF_TX, RF_RX, and RF_BLETX Pins @2.45 GHz on page 4 with an antenna port termination of 50 Ω. The PORT2 termination can be another port of the VNA, which extends the S parameter measurement from a simple S_{11} to an S_{11} and S_{21}/S_{12} measurement. If only S_{11} is needed, a 50 Ω resistor is also adequate. S_{21} is important for verifying the attenuation in the RF path, which is critical when the user is experimenting with different RF Switches and BPFs. S_{21} is also essential for verifying harmonic frequency attenuation but differences in harmonic levels might be observed in radiated (compared to conducted) TX measurements as the antenna impedance of the harmonic frequencies can be different than the wideband 50 Ω nature of the Spectrum Analyzer.

Remember that matching networks with the same number of components but with Z_{IN} closer to 50 Ω will always show better S_{21} at the 2.4 GHz fundamental band as there is less reflection (therefore more transfer) at the VNA 50 Ω port during the VNA measurement. Consequently, a match with Z_{IN} = 35 + 44j Ω (which is the ideal RX match) will show a worse S_{21} reading than a match with Z_{IN} = 50 Ω (which is equivalent to connecting an unmatched 50 Ω antenna to the RX pin). However, RX performance will be evidently better in the first scenario. For a representative reading, the user must determine how much of the measured total loss is attributed to the mismatch at the VNA port (using well-known formulas) and subtract that from the S_{21} measurement to get the conductor/dielectric losses of the RF front-end.

The HW setup for the measurement is the following:

- Remove the IC and solder an RF probe ("pigtail") on PORT1 (e.g., on the RX pin pad). Firmly solder the pigtail shield to the exposed GND pad of the SoC. For an S2p measurement, use the antenna RF connector or a second pigtail for the PORT2 termination. Both options have their advantages and disadvantages:
  - The former option allows the user to evaluate the complete RF front-end, including the RF connector, and perfectly emulates the spectrum analyzer measurement setup. The downside is that RF connectors can alter the 50 Ω impedance of the Spectrum Analyzer termination with their non-ideal impedance characteristics, resulting in a different termination than with a tuned 50 Ω antenna in the real application.
  - The latter option allows the user to have a reliable 50 Ω termination through a good quality coaxial pigtail, emulating a tuned 50 Ω antenna in the real application. The downside is the increased soldering efforts.
- Control the RF Switch from an external power supply. Instead of soldering the PSU cables directly to the RF Switch control pads (which could detune the matching network), it is recommended to solder them to the two control pads on the SoC side or to a physically more stable point on the PCB, such as the pad of a large filtering capacitor, while also making an on-board connection between the pad of the capacitor and the control pads on the SoC side (see the figure below). Supply 3.3 V to the RX control signal wire, for example, to enable the RX path of the RF switch. Make sure to also connect the GND of the external power supply to the GND of the PCB. Set a maximum current of ~20 mA on the PSU in case the 3.3 V cable is accidentally in contact with a GND pad, to avoid potential damage to the RF Switch.

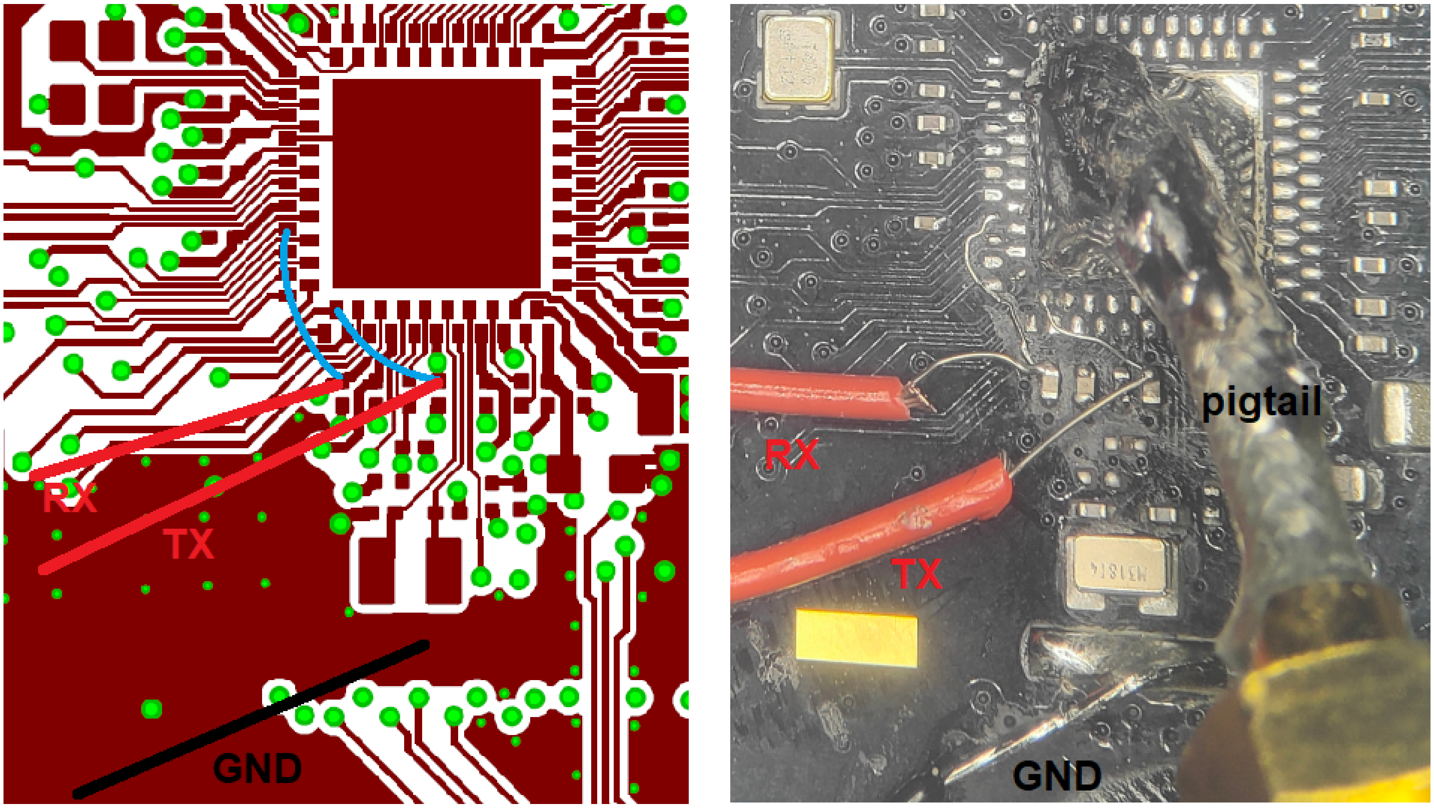

Figure 4.2. Pigtail Soldering and Recommended RF Switch Control Signal Controlling

- In a direct tie matching network (~internal RF Switch), the unused RF path will be "hanging" off the direct tie connection point with an open termination at the SoC side. To avoid this and its potential detuning effects, the user should either cut this path at the direct tie connection point, or leave it but terminate it with an impedance that emulates the off-mode impedance of the PA/LNA (See AN1423 Figure 4.5).

2. **Z_{OUT} output impedance measurement at the antenna port with the SoC intact and in the respective operation mode**

In an optimal matching network, Z_{out} is close to the complex conjugate of the antenna termination (50* Ω = 50 Ω) in RX mode and TX mode. The TX match should always be fine-tuned with a combination of TX power and EVM spectrum analyzer measurements, so the 50 Ω matching criteria is not a strong requirement. Additionally, as the input power limit of most VNAs is typically less than 27 dBm, you might have to decrease the TX power level from 20 dBm to prevent damage to the VNA (the peak power of the OFDM signal can exceed 20 dBm). The PA output impedance changes according to the output power setting, therefore, tuning the matching network at e.g., 15 dBm, might not be optimal for the standard 20 dBm application.

The HW setup is simply connecting the VNA to the RF connector of the PCB while putting the SoC in the respective operational mode (e.g., RX) with the commands in 4.1 Methods for Verifying Matching Network Impedance in the Event of Sub-Optimal RF Performance.

5. Example – WLAN RX Tuning Process on a Customer PCB (External RF Switch)

After identifying WLAN RX performance degradation, the RX tuning process can be started with a VNA in the lab. The improved matching network yields RX sensitivity improvement across all channels and modulations.

Silicon Labs has experienced that WLAN TX performance is more stable and usually does not require tuning on customer designs. The steps performed are according to the two methods detailed in section 4.1 Methods for Verifying Matching Network Impedance in the Event of Sub-Optimal RF Performance.

BLE performance is also usually optimal as the path is not matched, so it is practically terminated with the 50 Ω antenna at the RF port (through the Z_0 = 50 Ω traces, RF Switch, and the BPF).

Note: Silicon Labs recommends using the same pigtail for both the customer PCB and the radio board impedance measurements. Different pigtails can result in different measurements, hence trying to converge the RX Z_{IN} on the customer PCB to that of the radio board measurement when different pigtails are used can give deceiving and sub-optimal results.

1. **Method 1: Z_{IN} input impedance measurement at SoC side with the SoC removed**

The method is to compare the Z_{IN} of the RX path to that of a reference radio board (which is the design goal). The figure below shows that, as expected, a discrepancy can be seen which corresponds to the RX degradation on the customer PCB.

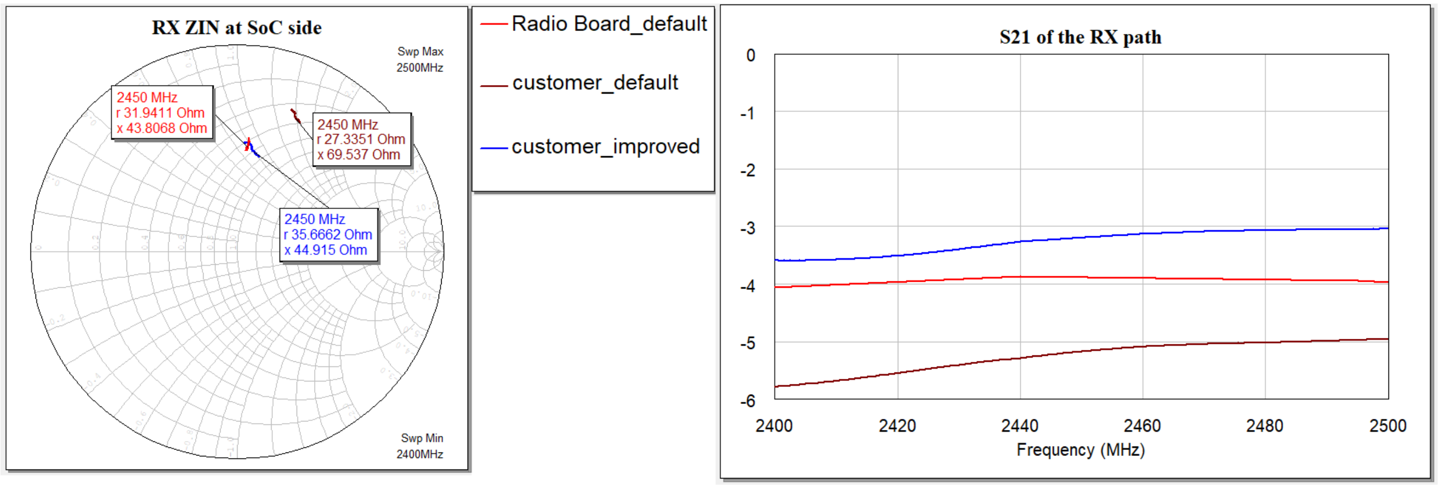

Figure 5.1. Z_{IN} of the RX Path Tuned to Reference Value (on Customer PCB)

The root cause of the issue is different layout and RF Switch/BPF parasitic properties than on the radio board. See the application note, AN1423:SiWx917 RF Matching and Layout Design Guide, for more details. Simple software programs do not take into account these aspects (only in expensive 3D EM simulators and only to an extent). Hence, the user must have a good understanding of the Smith-chart transformations of discrete L and C components and be able to execute the logical steps to increase/decrease the values of the components to get the point closer to the reference value in a VNA measurement where these parasitic effects are also present.

The figure below shows the impedance transformation effects and the resulting RX Z_{IN} input impedance (TP3) using recommended RX matching values in an ideal scenario (Smith v4.1 simulation). The VNA measurement would agree with this result only if no PCB and interconnection trace parasitics were present, and the RF Switch and BPF were also ideal.

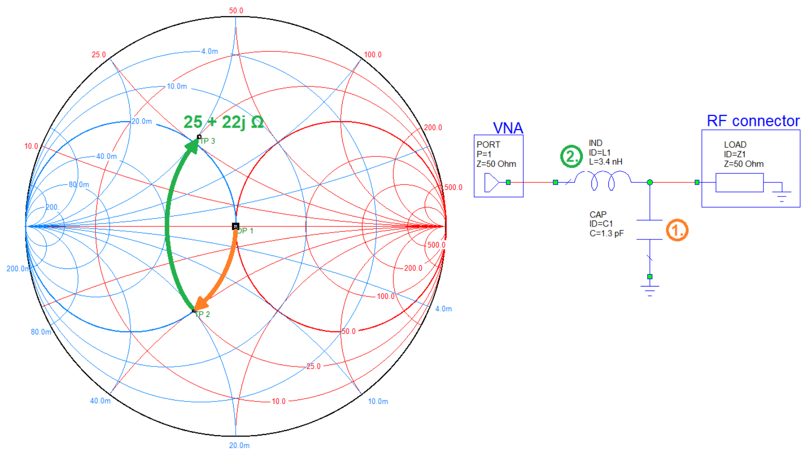

Figure 5.2. Z_{IN} of the RX Path with Default Values in Simulation

The recommended components result in RX Z_{IN} = 25 + 22j Ω in the ideal simulation, which shifts to 33 + 44j Ω on the radio board and to 27 + 69j Ω on the customer board in the VNA measurements due to the parasitics. Standard Smith-chart operations suggest that a decrease in both C and L would move the customer board impedance closer to the radio board impedance, which proved to be the optimal matching network modification (3.4 nH → 2.6 nH and 1.3 pF → 0.4 pF).

2. **Method 2: Z_{out} output impedance measurement at the antenna port with the SoC intact and in the respective operation mode (e.g., RX)**

Measuring close to 50 Ω in this setup validates the optimality of the matching network and that RX Z_{IN} is indeed the complex conjugate of the LNA impedance (RX Z_{IN} = 35 + 44j Ω → Z_{LNA} = 35 - 44j Ω). This can be verified on any radio board as has been done by Silicon Labs in the past.

The figure below shows that, as expected, a discrepancy can be seen which corresponds to the RX degradation. The proposed improvements in the previous chapter satisfy the Z_{OUT} = 50 Ω match condition and strengthen the validity of the improved matching network. The figure also includes a matching network that was also found to be close to optimal.

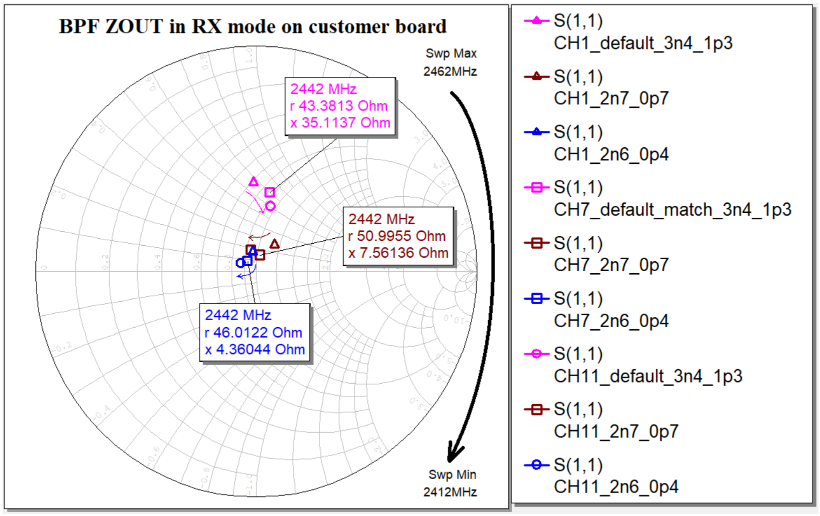

Figure 5.3. Z_{out} of the RX Path Tuned to 50 Ω (on Customer PCB)

If the user wishes to use this method only (due to the demanding soldering efforts of Method 1), it is essential to understand the effect of the RF Switch and BPF with Z_0 = 50 Ω characteristic impedance. See the schematic for the measurement and the explanation below.

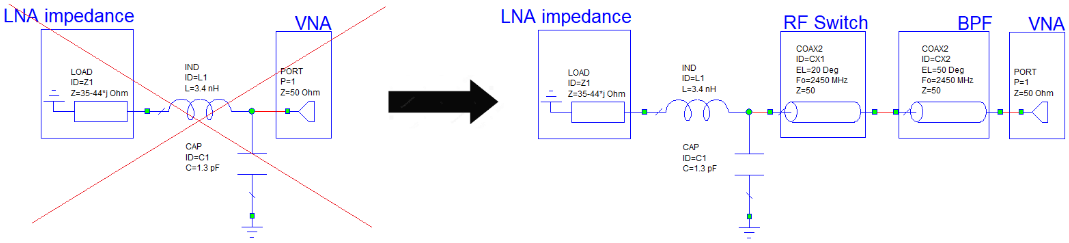

Figure 5.4. Schematic for the Z_{out} Output Impedance Measurement at the Antenna Port

The RF Switch and BPF rotate the impedance point, which is the theoretical measurement of the left side schematic of the figure above, around the center of the Smith-chart according to their arg(S_{11}) phase characteristics, just like a Z_0 = 50 Ω transmission line would do. This effect can only be incorporated in simulations if the reader has done VNA characterizations for these two components, and transmission lines models are available in the software utility. On top of that, it has been observed in AN1423:SiWx917 RF Matching and Layout Design Guide that their Z_0 can vary from 50 Ω, depending on the PCB stack-up and layout properties, hence the rotation might not be around the exact center of the Smith-chart. If Z_0 = 50 Ω is confirmed for the RF Switch and BPF, the user can calibrate the VNA reference plane back to the immediate output of the matching network with its port extension ("calibrate for short" functionality is recommended using a 0 Ω short termination). That way, the VNA measurement performed at the RF port actually starts immediately after the matching network described in the left part of the figure above, and the standard Smith-chart rules using discrete L and C components apply.

The parasitic-free simulation including the rotation effect of the RF Switch and BPF can be seen below (VNA is on the RF connector, and the termination is the SoC with its LNA impedance).

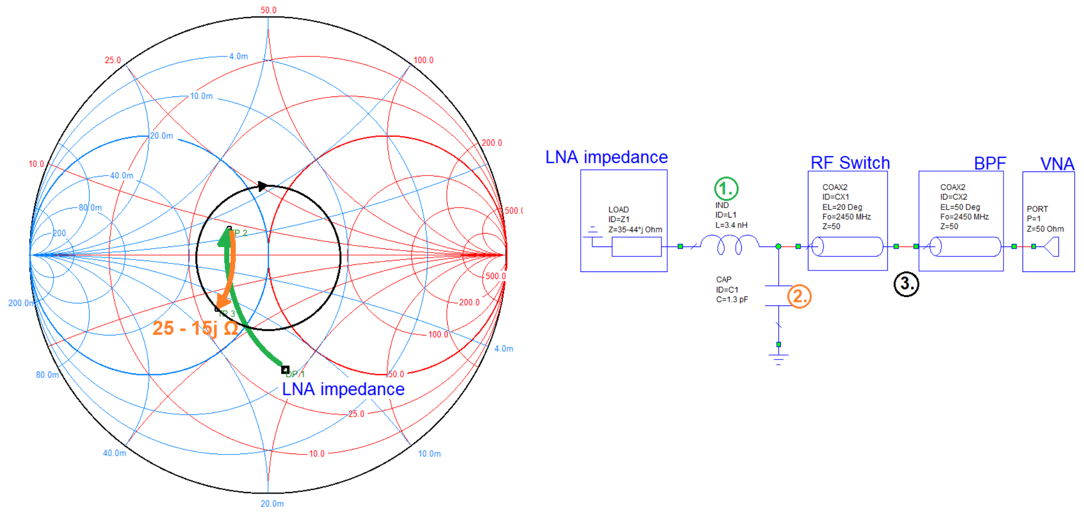

Figure 5.5. Rotation Effect of the RF Switch and BPF (Ideal Z_0 = 50 Ω) for the Z_{out} Output Impedance Measurement at the Antenna Port

A similar remark as with the RX Z_{IN} method can be stated:

The recommended components result in RX Z_{OUT} = 28 - 15j Ω in the ideal simulation rotated around the VSWR circle that the RX Z_{OUT} is on. This impedance shifts to 50 Ω on the radio board, and to 43 + 35j Ω on the customer board in the VNA measurements due to the parasitics (see Figure 5.3 Z_{out} of the RX Path Tuned to 50 Ω (on Customer PCB) on page 11). Standard Smith-chart operations suggest that a decrease in both C and L moves the customer board impedance closer to the radio board impedance (50 Ω), which proved to be the optimal matching network modification (3.4 nH → 2.6 nH and 1.3 pF → 0.4 pF).

Silicon Labs has experienced that RX performance tends to be the worst at the center channels (CH5 to CH7) due to unavoidable RX spurs (“spur channels”). It has also been observed that the upper channels (CH11 to CH14) also suffer more with sub-optimal RX matching networks. It is recommended to increase the effort to match the upper region of the 2.4 GHz band to 50 Ω.

6. RX Sensitivity Measurements

A comparison of the RX performance between the default and the improved matching networks on the customer board are shown below from CH1 to CH11.

					channel 1		channel 2		channel 3		channel 4		channel 5		channel 6		channel 7		channel 8		channel 9		channel 10		channel 11	
WiFi standard	datasheet reference	mode	datarate [Mbps]	EVM limit [dB]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]
802.11b	DSSS-1Mbps	B0	1	-9																						
	DSSS-2Mbps	B1	2	-9																						
	CCK-5.5Mbps	B2	5.5	-9																						
	CCK-11Mbps	B3	11	-9																						
802.11g	OFDM-6Mbps	G0	6	-5		-92.5		-92.5		-91.5		-92.5		-91.5		-91.5		-90.5		-91.5		-91.5		-90.5		-90.5
	OFDM-9Mbps	G1	9	-8		-91		-90.5		-90.5		-90.5		-90		-89.5		-89		-90.5		-90.5		-89		-88.5
	OFDM-12Mbps	G2	12	-10		-90.5		-90		-90		-89.5		-89.5		-89		-88		-90		-90		-88.5		-89.5
	OFDM-18Mbps	G3	18	-13		-88		-87.5		-87		-87.5		-87		-86.5		-86		-90		-87.5		-86.5		-86.5
	OFDM-24Mbps	G4	24	-16		-85		-84.5		-84.5		-85		-84.5		-84		-84		-84		-85		-83.5		-83.5
	OFDM-36Mbps	G5	36	-19		-81.5		-81		-81		-81		-80.5		-80		-79		-81		-81		-80		-79.5
	OFDM-48Mbps	G6	48	-22		-77.5		-77		-77		-77		-76.5		-76		-75.5		-76.5		-77		-76		-76
	OFDM-54Mbps	G7	54	-25		-75.5		-75		-75		-75		-74.5		-74		-73.5		-75		-75.5		-74		-74
802.11n	MCS0 Mixed Mode	MCS0	7.2	-5		-91		-90.5		-90.5		-90		-90.5		-90		-88.5		-90.5		-90.5		-89.5		-93
	MCS1 Mixed Mode	MCS1	14.4	-10		-88.5		-87.5		-87		-88		-87.5		-87		-86.5		-87		-87.5		-86.5		-86.5
	MCS2 Mixed Mode	MCS2	21.7	-13		-86		-85		-85		-85.5		-84.5		-83.5		-83.5		-84.5		-85		-84.5		-83.5
	MCS3 Mixed Mode	MCS3	28.9	-16		-83		-83		-82		-82.5		-82		-81		-81.5		-82		-82.5		-81.5		-81.5
	MCS4 Mixed Mode	MCS4	43.3	-19		-78.5		-78.5		-78		-78.5		-78		-77.5		-77.5		-78.5		-79		-77.5		-77.5
	MCS5 Mixed Mode	MCS5	57.8	-22		-75		-74		-74		-74		-74.5		-74		-74		-74		-74.5		-73.5		-73
	MCS6 Mixed Mode	MCS6	65	-25		-72.5		-72.5		-72		-72.5		-72		-76.5		-71.5		-76.5		-72.5		-71.5		-71
	MCS7 Mixed Mode	MCS7	72.2	-27		-70.5		-70.5		-70		-70.5		-70		-69.5		-69.5		-69.5		-70		-70		-69.5
802.11ax	MCS0 SU	AX_MCS0	8.6	-5		-91		-91		-90.5		-91		-90.5		-89.5		-89.5		-90.5		-91		-89		-89.5
	MCS1 SU	AX_MCS1	17.2	-10		-88		-87		-87		-87.5		-87.5		-86		-86.5		-86.5		-88		-86.5		-85
	MCS2 SU	AX_MCS2	25.8	-13		-84.5		-84		-82.5		-85		-82		-81		-82.5		-84.5		-85.5		-83.5		-81
	MCS3 SU	AX_MCS3	34.4	-16		-82		-81.5		-81		-82		-82		-81.5		-80		-81.5		-82		-81.5		-81
	MCS4 SU	AX_MCS4	51.6	-19		-77.5		-77		-77.5		-78		-76.5		-76		-76.5		-77.5		-78		-77		-75
	MCS5 SU	AX_MCS5	68.8	-22		-74		-74		-73.5		-74		-73		-73		-72		-74		-74.5		-73		-72.5
	MCS6 SU	AX_MCS6	77.4	-25		-72		-71.5		-72		-72		-71.5		-70		-70.5		-71.5		-72		-71		-69.5
	MCS7 SU	AX_MCS7	86	-27		-70		-69		-69.5		-70		-68		-68		-68		-68.5		-70.5		-68.5		-68.5

Figure 6.1. RX Sensitivity Measurements with the Default RX Matching Network (Customer PCB)

					channel 1		channel 2		channel 3		channel 4		channel 5		channel 6		channel 7		channel 8		channel 9		channel 10		channel 11	
WiFi standard	datasheet reference	mode	datarate [Mbps]	EVM limit [dB]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]	TXP [dBm]	RX sens. [dBm]
802.11b	DSSS-1Mbps	B0	1	-9		-96.5		-96.5		-97		-96.5		-96.5		-96.5		-96.5		-97		-97		-96.5		-96
	DSSS-2Mbps	B1	2	-9		-92		-92		-92		-92		-91.5		-91.5		-92		-91.5		-92		-91		-91
	CCK-5.5Mbps	B2	5.5	-9		-90.5		-90.5		-90.5		-90		-90.5		-90		-90		-90.5		-90.5		-90		-90
	CCK-11Mbps	B3	11	-9		-87		-87.5		-88		-87.5		-89		-89		-88		-87.5		-88		-87		-87
802.11g	OFDM-6Mbps	G0	6	-5		-92		-92.5		-92.5		-93		-92.5		-91.5		-92		-92.5		-93		-91.5		-91.5
	OFDM-9Mbps	G1	9	-8		-91.5		-91		-90.5		-91		-91.5		-90.5		-90.5		-91.5		-91.5		-91		-90.5
	OFDM-12Mbps	G2	12	-10		-91		-91		-90.5		-90.5		-90.5		-90		-90.5		-91		-91		-90		-90.5
	OFDM-18Mbps	G3	18	-13		-88		-88		-87.5		-88		-88		-88		-87.5		-88.5		-88		-88		-87.5
	OFDM-24Mbps	G4	24	-16		-86		-85.5		-85		-85.5		-87		-85		-85		-85.5		-85.5		-85		-85
	OFDM-36Mbps	G5	36	-19		-81.5		-81.5		-81.5		-81.5		-81.5		-81		-81		-82		-82		-81		-81
	OFDM-48Mbps	G6	48	-22		-77.5		-77.5		-77.5		-77.5		-77.5		-77		-77		-77.5		-77.5		-77.5		-77.5
	OFDM-54Mbps	G7	54	-25		-76.5		-76		-76		-76		-76		-75.5		-75.5		-76		-76		-75		-75.5
802.11n	MCS0 Mixed Mode	MCS0	7.2	-5		-90.5		-91		-90.5		-91		-91		-89.5		-91		-91.5		-91		-91		-91
	MCS1 Mixed Mode	MCS1	14.4	-10		-89		-88.5		-87.5		-91.5		-88		-88		-88		-88		-88		-87.5		-88
	MCS2 Mixed Mode	MCS2	21.7	-13		-86		-85.5		-88.5		-86		-86		-85.5		-88.5		-86		-86		-85.5		-85
	MCS3 Mixed Mode	MCS3	28.9	-16		-83		-83.5		-83		-83		-82.5		-82.5		-83		-83		-83.5		-82.5		-82.5
	MCS4 Mixed Mode	MCS4	43.3	-19		-79		-79.5		-78.5		-79.5		-79		-79		-78.5		-79		-79.5		-79		-79
	MCS5 Mixed Mode	MCS5	57.8	-22		-75		-75.5		-75		-75.5		-75.5		-75.5		-75.5		-75		-75.5		-75		-75
	MCS6 Mixed Mode	MCS6	65	-25		-73		-73.5		-73		-73.5		-73.5		-73		-73.5		-73.5		-73		-73		-73
	MCS7 Mixed Mode	MCS7	72.2	-27		-71.5		-71.5		-72		-71.5		-71.5		-71		-71		-74.5		-71.5		-71		-70.5
802.11ax	MCS0 SU	AX_MCS0	8.6	-5		-92		-91.5		-91.5		-92		-91.5		-91		-91		-92		-91.5		-90.5		-90
	MCS1 SU	AX_MCS1	17.2	-10		-89		-88.5		-88		-88		-88.5		-88		-88.5		-88.5		-88.5		-88		-88
	MCS2 SU	AX_MCS2	25.8	-13		-85.5		-84.5		-85		-86		-85		-85.5		-85		-85.5		-86		-85		-85.5
	MCS3 SU	AX_MCS3	34.4	-16		-83		-82.5		-82.5		-82.5		-83		-82.5		-82		-83		-83		-82.5		-82.5
	MCS4 SU	AX_MCS4	51.6	-19		-78.5		-78.5		-78		-78.5		-78.5		-79		-78.5		-79		-79		-79		-78
	MCS5 SU	AX_MCS5	68.8	-22		-75		-74.5		-74.5		-74.5		-74.5		-74.5		-74.5		-75		-75		-74.5		-74.5
	MCS6 SU	AX_MCS6	77.4	-25		-72.5		-72.5		-72.5		-73		-73		-72.5		-72.5		-73		-73		-73		-72
	MCS7 SU	AX_MCS7	86	-27		-70.5		-70.5		-70		-70.5		-70.5		-69.5		-70.5		-70.5		-71		-70.5		-70

Figure 6.2. RX Sensitivity Measurements with the Improved RX Matching Network (Customer PCB)

The cell colors are based on the following relationships compared to the reference values:

- Grey: within -2 dB
- Yellow: -2 to -4 dB worse
- Red: -4 dB or more worse

The tables show that 1.5 to 4 dB improvement was achieved with the improved matching network on the critical channels/modulations.

7. Load Pull Measurements

As shown, the RF performance of the SiWx917 is heavily dependent on the ideal TX and RX termination impedance. For a given matching network, this parameter is controllable by changing the antenna termination impedance from 50 Ω to values that cover a large portion of the complex impedance plane (Smith-chart). The RF performance can therefore be characterized by the:

1. Antenna impedance change
2. TX and RX termination impedance change caused by the antenna impedance change

It is important to emphasize the antenna impedance in the load pull measurements is defined as the impedance that the immediate output of the matching network “sees”, which is the RF port termination impedance rotated by the transmission line between the matching network and the RF port. This definition is necessary to eliminate the need for using a trace with the same length as on the Silicon Labs Radio board, for the presented load pull measurements to be applicable on the customer PCB.

The load pull measurements were performed with the following PHY settings:

- WLAN:
  - CH7 (2442 MHz)
  - OFDM 6 Mbps (G0 modulation)
  - Power level = 127
- BLE HP chain:
  - CH18 (2442 MHz)
  - Power level = 20

7.1 WLAN

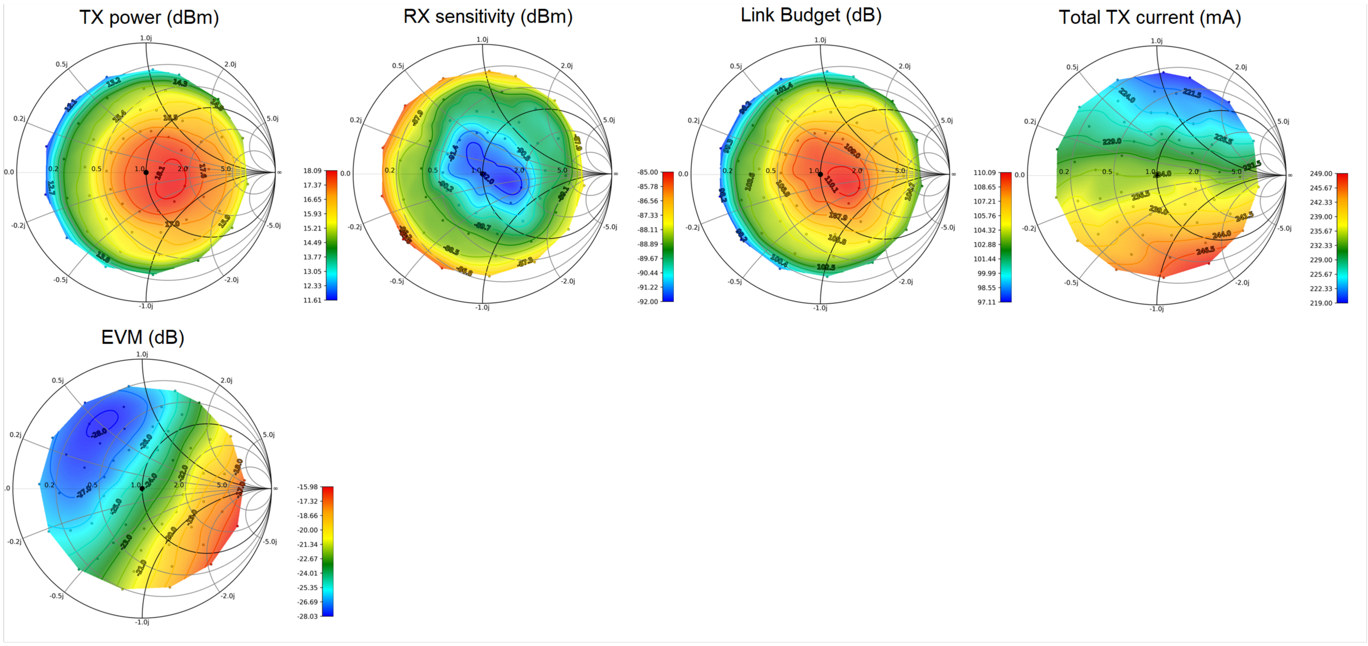

Figure 7.1. WLAN Antenna Load Pull Measurements at 2442 MHz 6 Mbps OFDM

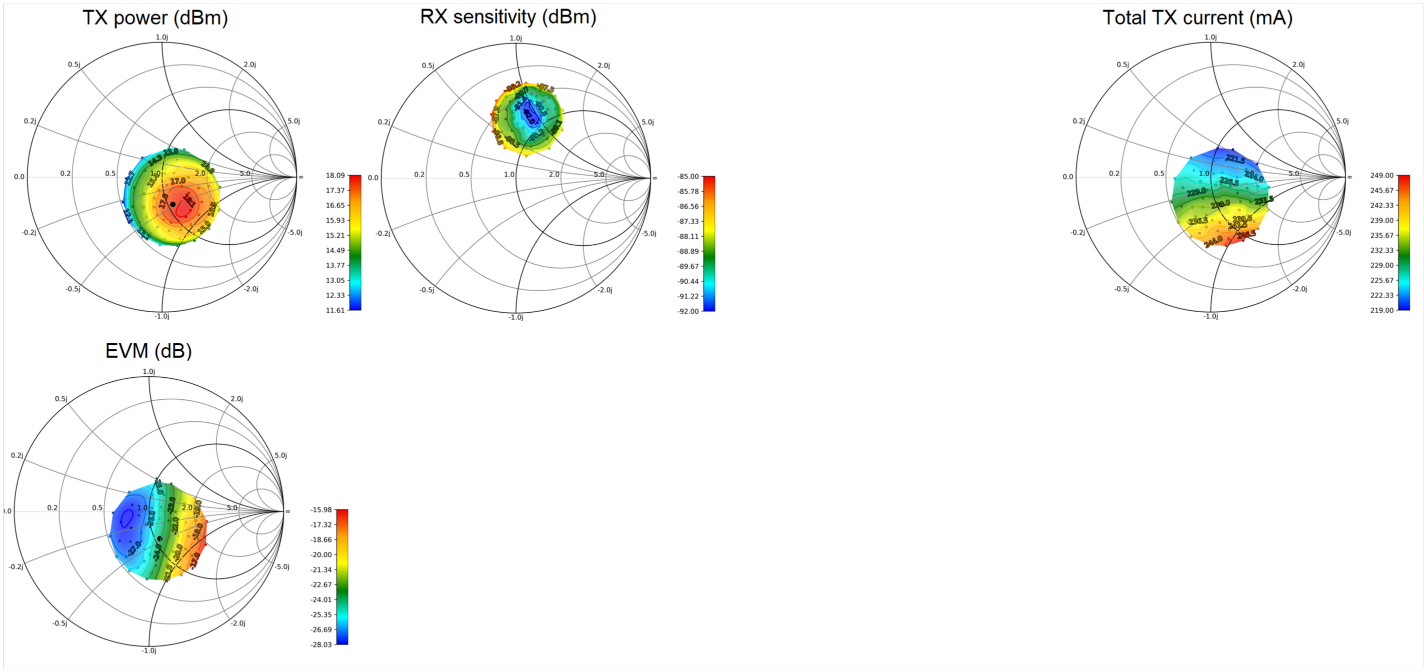

Figure 7.2. WLAN PA/LNA Load Pull Measurements at 2442 MHz 6 Mbps OFDM

Note: Link budget cannot be interpreted for the PA/LNA load pull measurements, as the TX and RX matching networks are separate. On the other hand, it is possible to plot the link budget metric for the antenna load pull measurements as the antenna port is the same for both paths.

7.2 BLE HP Chain

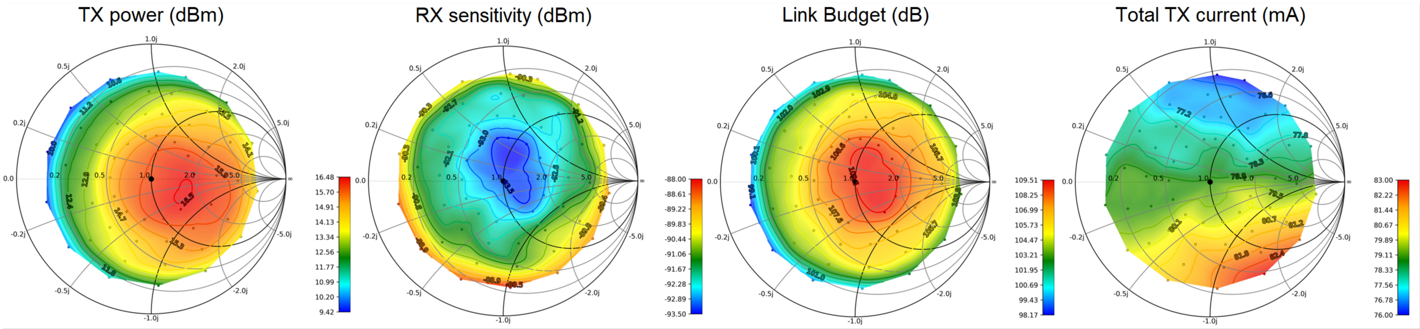

Figure 7.3. BLE HP Chain Antenna Load Pull Measurements @2442 MHz

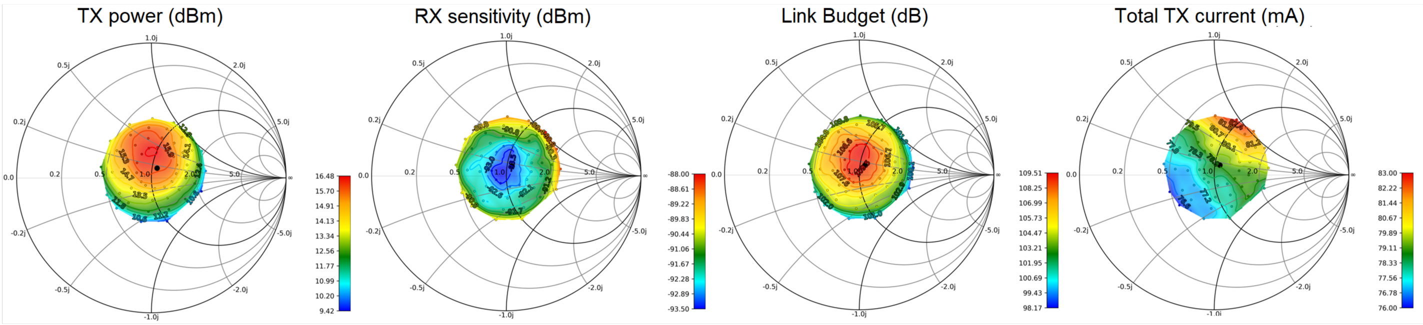

Figure 7.4. BLE HP Chain PA/LNA Load Pull Measurements @2442 MHz

Note: Figures 7.3 and 7.4 demonstrate perfectly the effect of a lossy RF front-end with Z_0 = 50 Ω characteristic impedance and significant electrical length: the antenna port termination impedance points are shrunk towards, and rotated around, the 50 Ω center of the Smith-chart.

8. Revision History

Revision 1.0

October, 2024

- Initial version.

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SILICON LABS

Silicon Laboratories Inc.
400 West Cesar Chavez
Austin, TX 78701
USA

www.silabs.com