AN14391

MCX W71 Loadpull Report

Rev. 1.0 — 10 September 2024 Application note

Document information

Information	Content
Keywords	AN14391, MCX, MCX W71, Bluetooth Low Energy, radio, loadpull
Abstract	The purpose of the measurements is to monitor the supply current, the transmit power, and the harmonics level while the complex load seen by the DUT is tuned in amplitude and phase.

1 Introduction

This document describes measurement methodology and associated results on the load-pull characteristics.

1.1 Test purpose

The purpose of the measurements is to monitor the supply current, the transmit power, and the harmonics level. The complex load seen by the DUT is tuned in amplitude and phase.

The automated impedance tuner MT982BL from MAURY MICROWAVE is used to vary the DUT load.

Section 2.2 covers the tuner standalone and Section 3 covers the load pull results on the **MCX W71** device.

Test limitations: The calibration of the MAURY MICROWAVE with the DUT load must be done at each channel frequency (fundamental and each harmonic). For the described measurements, we control the load at the fundamental frequency. But the return loss of the impedance tuner at the harmonic frequencies is not known.

1.2 Power and supply current summary results

VSWR = 1:1

- TX power and current supply are almost constant whatever the phase is.
- Delta TX power is 0.23 dB and delta power consumption is 90 µA.
- Power @SMA pin is +10.66 dBm for an EVK power consumption of 25.33 mA.

VSWR = 2:1

- The power varies from +8.89 dBm to +10.51 dBm depending on the phase.
- Delta TX power is 1.62 dB and delta power consumption is 2.6 mA.
- Power @SMA pin is +10.04 dBm for an EVK power consumption of 25.95 mA.

VSWR = 3:1

- The power varies from +7.65 dBm to +9.81 dBm depending on the phase.
- Delta TX power is 2.16 dB and delta power consumption is 3.82 mA.
- Power @SMA pin is +9.17 dBm for an EVK power consumption of 26.22 mA.

Overall results

- Power @SMA pin: from +7.65 dBm (minimum) to +10.66 dBm (maximum); +10.66 dBm @VSWR=1
- EVK Power consumption: from 23.24 mA (minimum) to 27.06 mA (maximum); 25.33 mA @VSWR=1

1.3 Conclusion

TX power level: Up to 2.1 dB variation with a poor quality antenna.

Supply current: Significant extra consumption (~3.8 mA) with a poor quality antenna.

Harmonics:

- H2 is more sensitive to poor quality antenna (out of European Telecommunication Standards Institute (ETSI) limits in some cases).
- H3 is sensitive but within an acceptable range.

2 Hardware setup — Characterizing the tuner

Figure 1 shows the bench diagram that is used to calibrate the full bench and perform the measurements.

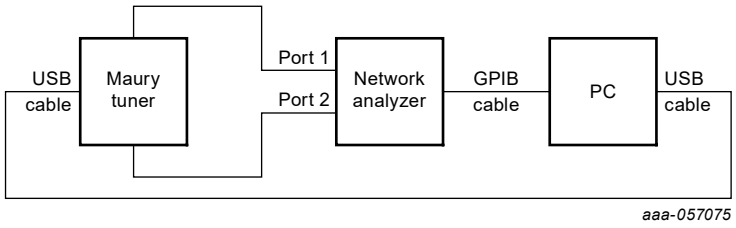

Figure 1. Hardware lab bench setup

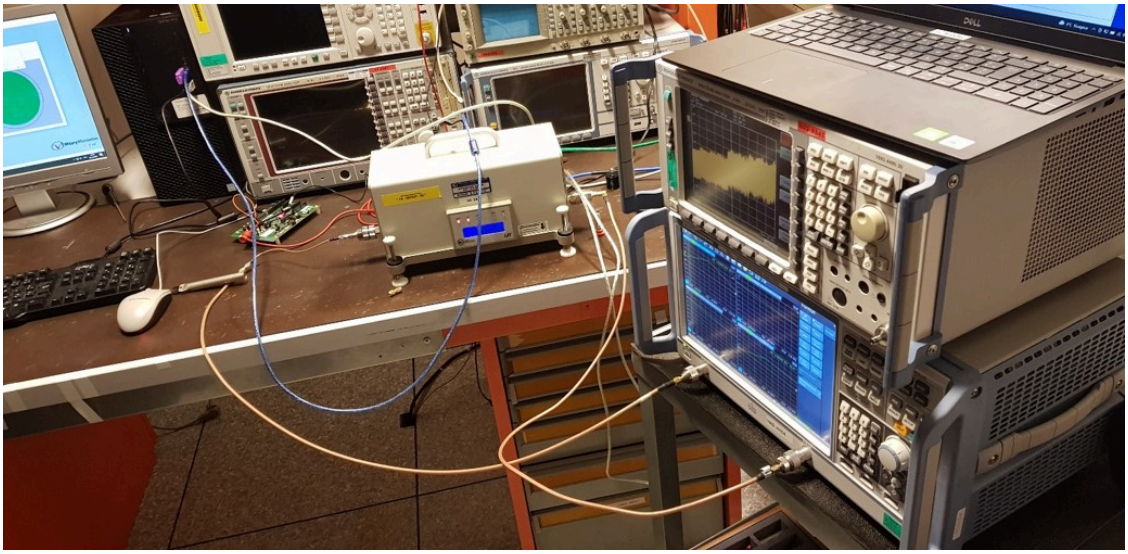

Figure 2. Hardware connection

2.1 Software lab bench setup

Launch Tuner Characterization Software (TCS64).

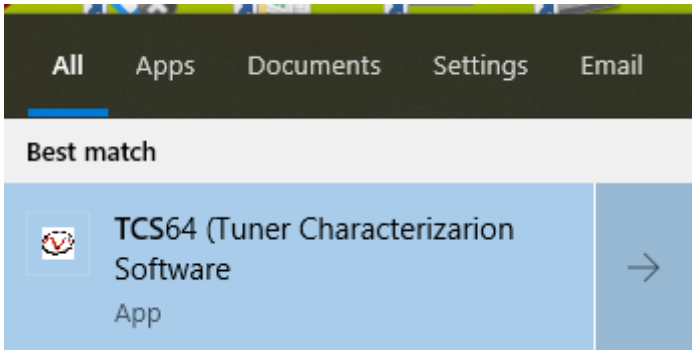

Figure 3. TCS software

The tuner and the spectrum are declared in the right way and are ready to use.

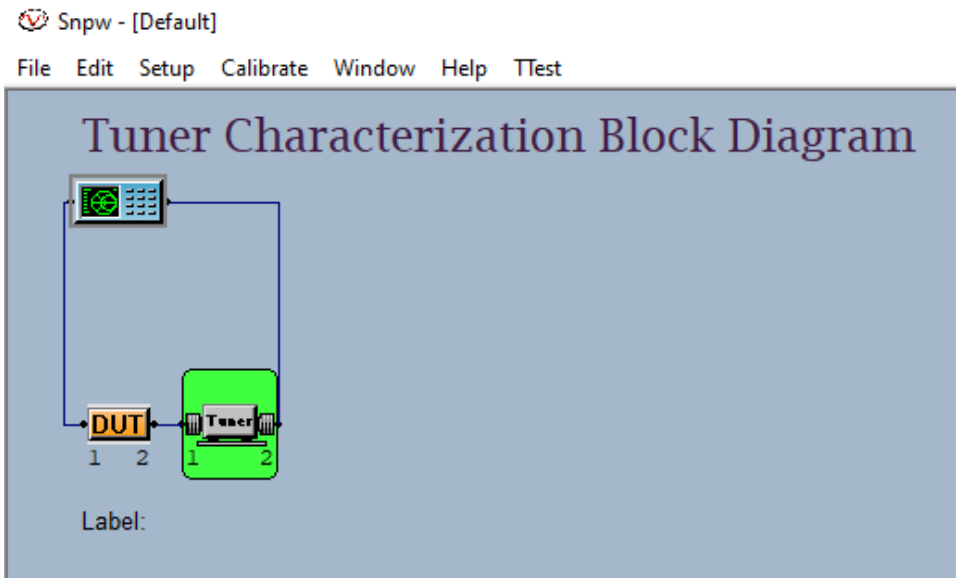

Figure 4. Tuner characterization block diagram

2.2 Characterizing the tuner

When the tuner characterization is done (calibrated), verification can be done.

Verification step: Move the tuner to one position. Right-click the mouse button and then select "Move Tuner".

On the spectrum, check the S11 parameter (for example):

- Real Amplitude = 0.621 dB
- Phase = 19.51°
- Ga = -2.58 dB

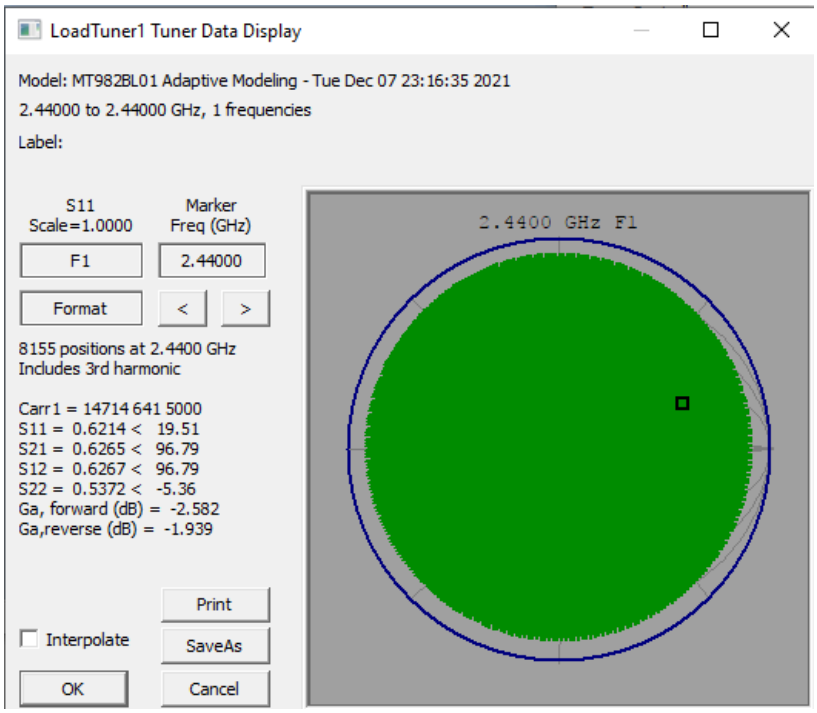

Figure 5. Characterizing the tuner

2.3 DUT measurements

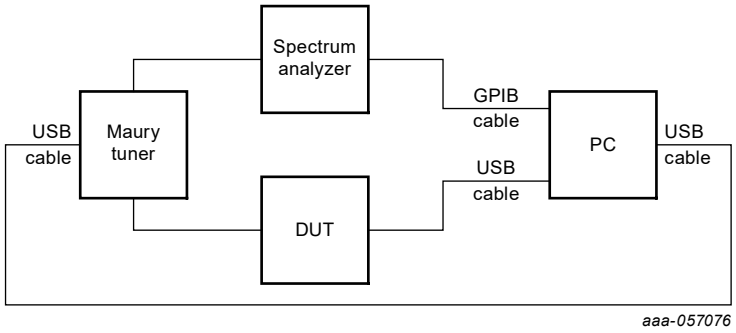

Figure 6. DUT measurement

To start the magnitude and phase measurements, perform the following steps:

1. Click the green tuner box. **Load Port Tuner Control** dialog box opens.
   Verify that **Interpolate Impedance** is not selected (on the **Setup** tab) and **Tuner 1** is selected.

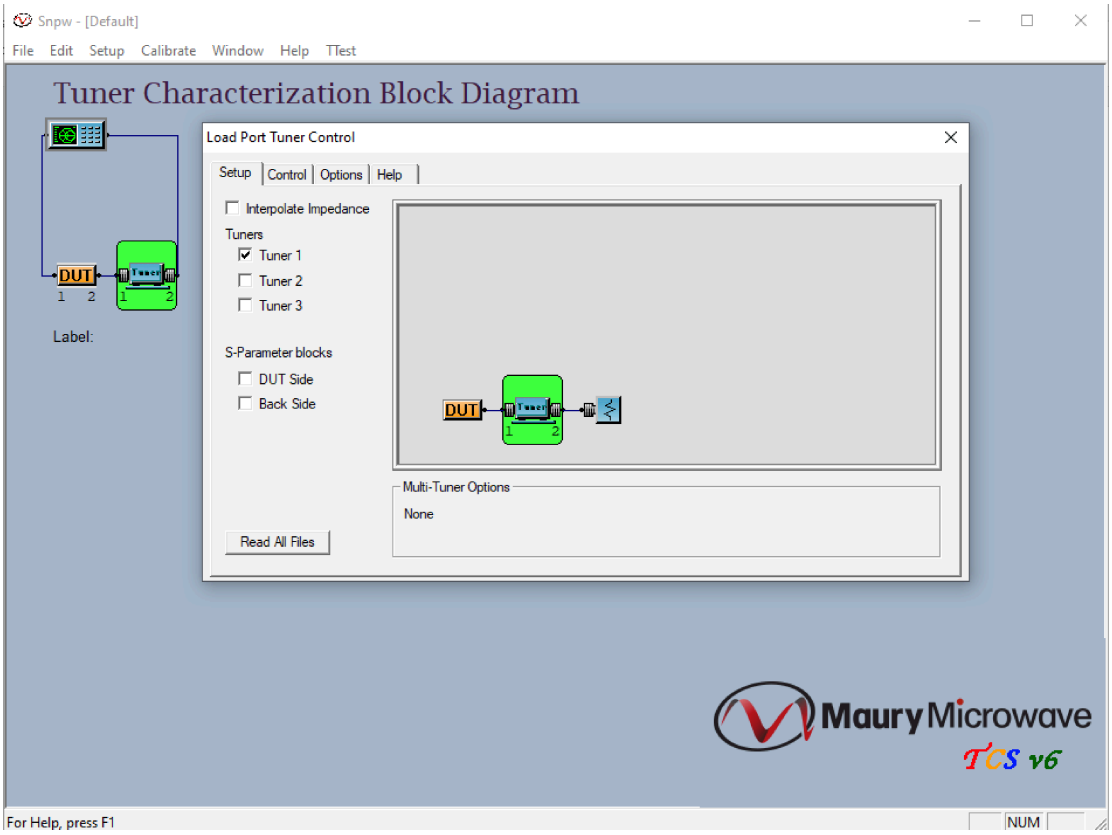

Figure 7. Select Tuner 1

2. Select the **Control** tab.
   Choose the **Target Mag** (VSWR) and **Phase** (°) values.
   Three markers (1: fund; 2: H2; 3: H3) are represented in the smith graph.

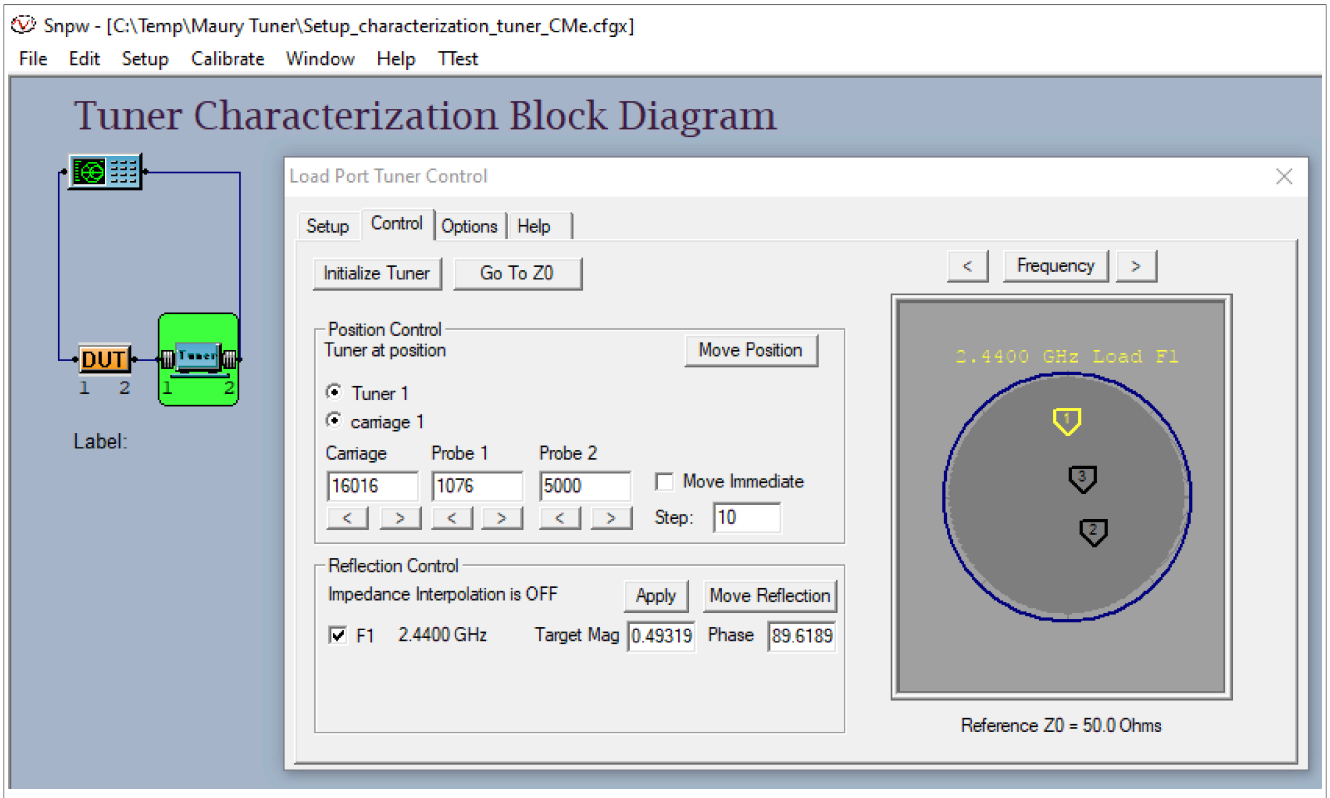

Figure 8. Select Control tab

3. Click **Apply** and then **Move Reflection**. Go to the graph.
4. Right-click the mouse and select **Show S-parameters**.
   The shown example is for magnitude 0.5 (VSWR:3) and phase 90°
   Target magnitudes:
   0 corresponds to VSWR:1
   0.333 corresponds to VSWR:2

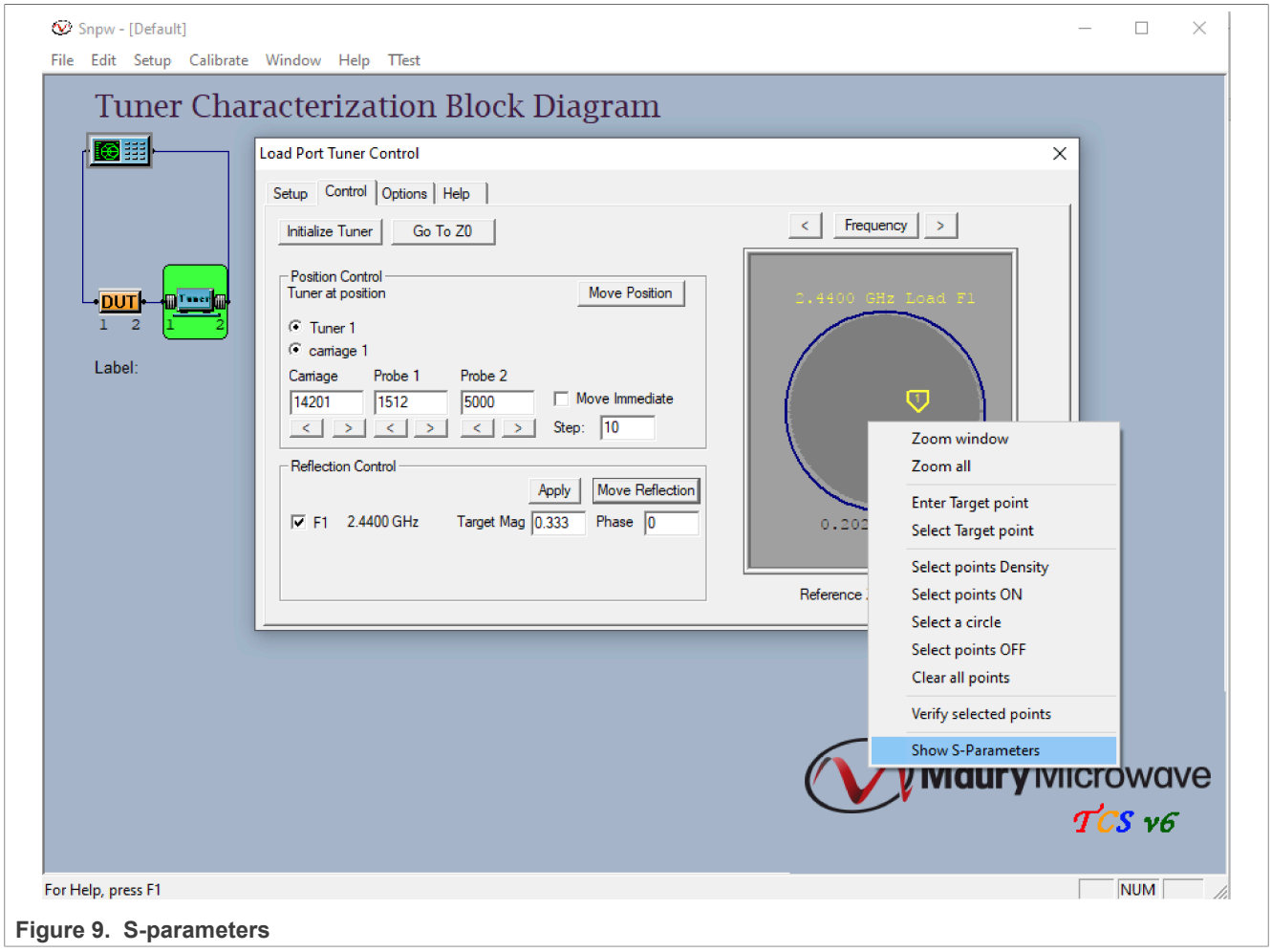

Figure 9. S-parameters

5. When the **Show S-parameters** is selected, the **Current Load Tuning Block** dialog box opens.
   Available information:
   Fundamental H2 and H3 frequencies and S11, S12, S21, S22 values.

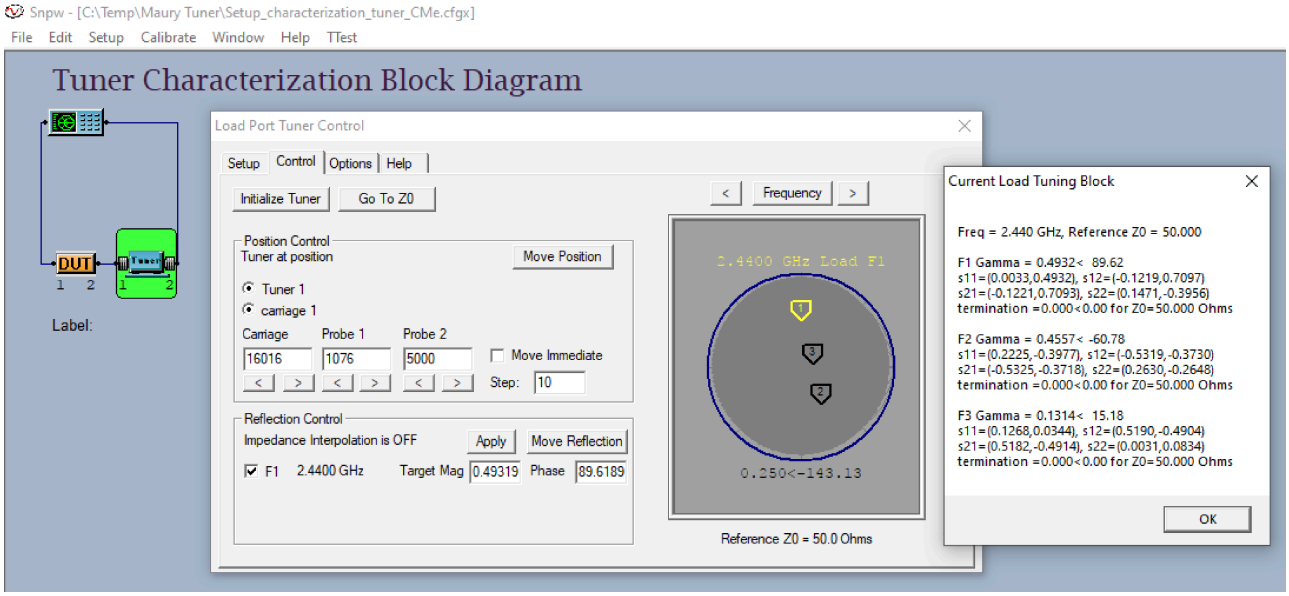

Figure 10. Open Current Load Tuning block

3 Test

This section provides the conditions to perform the tests.

3.1 Test conditions

The measurements have been done under the following conditions:

- Channel 19 (2440 MHz), continuous CW, power level +10 dBm, buck mode
- USB power supply (5.0 V)
- Temperature = Room temperature
- Three values of VSWR have been tested:
  - 1.004:1 (return loss = 54 dB): Good return loss
  - 2:1 (return loss = 9.5 dB): Corresponds to a ceramic antenna without matching
  - 3:1 (return loss = 5.8 dB): Poor return loss

For each value of VSWR, the phase is varied from 0° to 315° by 45 ° steps.

- Spectrum analyzer settings for harmonic measurements:
  - Reference amplitude: +12 dBm
  - Resolution bandwidth (RBW): 10 KHz
  - VBW: 30 KHz
  - Span: 1 MHz
  - RF attenuation = 0 dB
- TX fundamental:
  - Center frequency: 2.44 GHz
  - RBW: 100 kHz
  - VBW: 300 kHz
  - Span: 10 MHz
  - Ref level: 20 dBm; Trace average mode

$$Reflection\ \ coefficient = \Gamma = \frac{Z_L - Z_S}{Z_L + Z_S} \quad (1)$$

3.2 Test results

This section shows the test results for the fundamental and harmonic conditions.

3.2.1 Fundamental frequency

This section shows the test results for the fundamental frequency.

Table 1. Fundamental frequency = 2.44 GHz

Fundamental frequency (2.44 GHz)									
VSWR = 1.0	**RL = 54 dB**								
|ZL|	50.015 ohms	50.011 ohms	49.988 ohms	49.984 ohms	50.019 ohms	50.011 ohms	49.991 ohms	49.984 ohms	
Phase	0°	45°	90°	135°	180°	225°	270°	315°	
impedance (Ohms)	0.0111+0.0095i	0.0049+0.0098i	-0.0011+0.0117i	-0.0063+0.0151i	-0.0187+0.0003i	-0.0092-0.0058i	0.0015-0.0093i	0.0128-0.0098i	**delta**
TX power (dBm) @SMA	10.66 dBm	10.43 dBm	10.45 dBm	10.55 dBm	10.44 dBm	10.49 dBm	10.48 dBm	10.49 dBm	**0.23 dB**
Vdd Current (mA)	25.33 mA	25.33 mA	25.33 mA	25.33 mA	25.24 mA	25.25 mA	25.25 mA	25.26 mA	**0.09 mA**
VSWR = 2.0	**RL = 9.5 dB**								
|ZL|	99.665 ohms	100.337 ohms	100.340 ohms	100.344 ohms	100.341 ohms	100.346 ohms	99.656 ohms	99.666 ohms	
Phase	0°	45°	90°	135°	180°	225°	270°	315°	
impedance (Ohms)	0.3352-0.0019i	0.2332+0.2432i	-0.0078+0.3397i	-0.2417+0.2448i	-0.3414-0.0002i	-0.2469-0.2423i	0.004-0.3442i	0.2368-0.2362i	**delta**
TX power (dBm) @SMA	10.04 dBm	10.34 dBm	10.51 dBm	10.10 dBm	9.40 dBm	8.89 dBm	9.12 dBm	9.59 dBm	**1.62 dB**
Vdd Current (mA)	25.95 mA	26.60 mA	26.40 mA	25.50 mA	24.40 mA	24.00 mA	24.01 mA	24.88 mA	**2.60 mA**
VSWR = 3.0	**RL = 6.02**								
|ZL|	149.504 ohms	150.490 ohms	150.493 ohms	149.498 ohms	149.495 ohms	150.513 ohms	150.511 ohms	149.483 ohms	
Phase	0°	45°	90°	135°	180°	225°	270°	315°	
Impedance (Ohms)	0.4961-0.0001i	0.3504+0.3427i	0.0033+0.4932i	-0.3489+0.3605i	-0.5054+0.0044i	-0.3617-0.3636i	-0.0062-0.5105i	0.3633-0.3685i	**delta**
TX power (dBm) @SMA	9.17 dBm	9.44 dBm	9.81 dBm	9.17 dBm	8.22 dBm	7.65 dBm	7.91 dBm	8.63 dBm	**2.16 dB**

VSWR = 3.0	RL = 6.02								
Vdd Current (mA)	26.22 mA	27.06 mA	26.88 mA	25.55 mA	23.88 mA	23.24 mA	23.48 mA	24.56 mA	**3.82 mA**

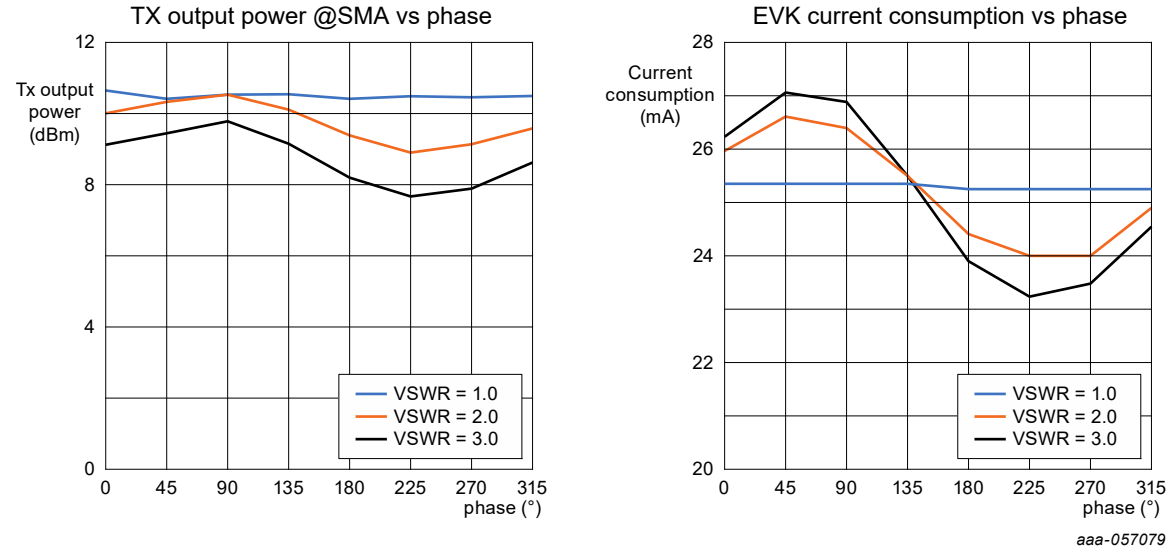

Figure 11. Fundamental frequency

3.2.2 H2 frequency

This section shows the test results for the harmonic 2 (H2) frequency.

Table 2. H2 frequency

H2: Harmonic 2 frequency (4.88 GHz)								
VSWR = 1.0	RL = 54 dB							
|ZL|	49.882 ohms	49.893 ohms	49.903 ohms	50.091 ohms	50.074 ohms	49.914 ohms	49.894 ohms	49.874 ohms
Phase	0°	45°	90°	135°	180°	225°	270°	315°
Impedance (Ohms)	0.118-0.0103i	0.1066-0.0106i	0.0968-0.0049i	0.091+0.0049i	0.0736+0.0001i	0.084-0.018i	0.1022-0.0282i	0.1228-0.0278i
TX power (dBm) @SMA	-31.98 dBm	-31.97 dBm	-33.18 dBm	-32.59 dBm	-32.85 dBm	-31.52 dBm	-32.96 dBm	-32.89 dBm

VSWR = 2.0	RL = 9.5 dB								
|ZL|	50.340 ohms	100.188 ohms	99.676 ohms	50.404 ohms	50.318 ohms	100.248 ohms	99.638 ohms	50.413 ohms	
Phase	0°	45°	90°	135°	180°	225°	270°	315°	
Impedance (Ohms)	0.1144+0.3199i	-0.1882-0.0087i	0.1782-0.2703i	0.39+0.1051i	-0.0203+0.3173i	-0.2149-0.1241i	0.1923-0.3071i	0.4119+0.0278i	**delta**
TX power (dBm) @SMA	-32.51 dBm	-34.47 dBm	-35.53 dBm	-39.08 dBm	-35.96 dBm	-31.21 dBm	-26.96 dBm	-29.64d Bm	**12.12dB**

VSWR = 3.0	RL = 6.02								
|ZL|	50.448 ohms	150.341 ohms	149.544 ohms	50.529 ohms	50.450 ohms	150.412 ohms	149.502 ohms	50.532 ohms	
Phase	0°	45°	90°	135°	180°	225°	270°	315°	
Impedance (Ohms)	0.0542+0.4451i	-0.3374-0.0502i	0.2225-0.3977i	0.4996+0.173i	-0.1156+0.4344i	-0.3179-0.2614i	0.3247-0.3775i	0.5136+0.1382i	**delta**
TX power (dBm) @SMA	-36.02 dBm	-35.85 dBm	-37.46 dBm	-39.57 dBm	-36.50 dBm	-31.91 dBm	-25.26 dBm	-28.94 dBm	**14.31dB**

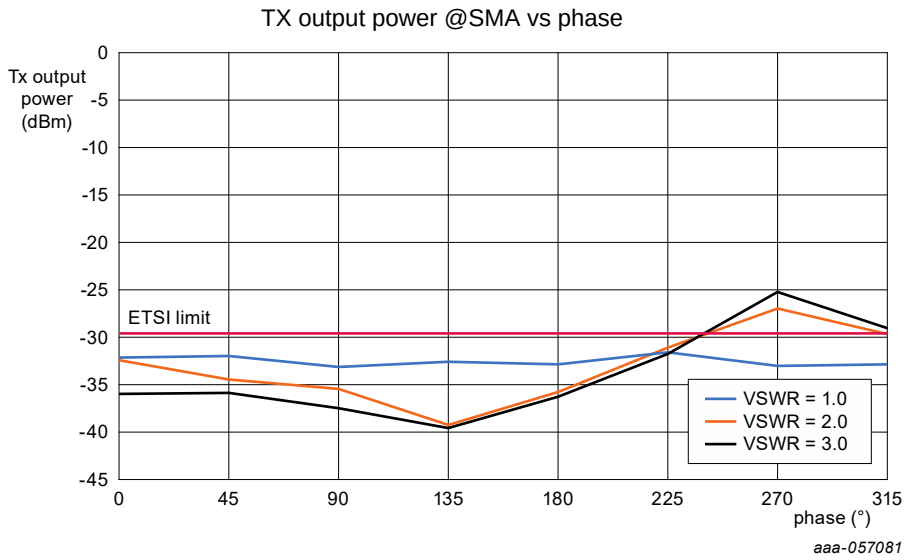

Figure 12. H2 frequency

3.2.3 H3 frequency

This section shows the test results for the harmonic 3 (H3) frequency.

H3: Harmonic 3 frequency (7.32 GHz)								
VSWR = 1.0	**RL = 54 dB**							
|ZL|	50.146 ohms	50.146 ohms	50.145 ohms	50.144 ohms	50.143 ohms	50.145 ohms	50.146 ohms	50.146 ohms
Phase	0°	45°	90°	135°	180°	225°	270°	315°
Impedance (Ohms)	0.1382+0.0471i	0.1385+0.046i	0.1377+0.045i	0.1367+0.0448i	0.1359+0.0443i	0.1375+0.0445i	0.1384+0.0455i	0.1384+0.0472i
TX power (dBm) @SMA	-33.18 dBm	-33.78 dBm	-34.62 dBm	-33.22 dBm	-37.30 dBm	-32.76 dBm	-36.62 dBm	-34.14 dBm

VSWR = 2.0	**RL = 9.5dB**								
|ZL|	50.139 ohms	50.143 ohms	50.135 ohms	50.145 ohms	50.132 ohms	50.140 ohms	50.148 ohms	50.129 ohms	
Phase	0°	45°	90°	135°	180°	225°	270°	315°	
Impedance (Ohms)	0.1304+0.0475i	0.1332+0.0508i	0.1255+0.0485i	0.1368+0.0477i	0.1214+0.0524i	0.1341+0.0387i	0.1353+0.0597i	0.1194+0.0495i	**delta**
TX power (dBm) @SMA	-35.12 dBm	-35.80 dBm	-35.55 dBm	-33.81 dBm	-35.14 dBm	-32.76 dBm	-32.16 dBm	-34.11 dBm	**3.64 dB**

VSWR = 3.0	**RL = 6.02**								
|ZL|	50.159 ohms	50.130 ohms	50.131 ohms	50.155 ohms	50.108 ohms	50.159 ohms	50.147 ohms	50.103 ohms	
Phase	0°	45°	90°	135°	180°	225°	270°	315°	
Impedance (Ohms)	0.1531+0.0433i	0.1138+0.0629i	0.1268+0.0344i	0.1389+0.0678i	0.0987+0.0437i	0.1544+0.037i	0.1206+0.0848i	0.099+0.029i	**delta**
TX power (dBm) @SMA	-37.04 dBm	-40.23 dBm	-33.87 dBm	-38.86 dBm	-33.46 dBm	-30.07 dBm	-31.83 dBm	-34.24 dBm	**10.16 dB**

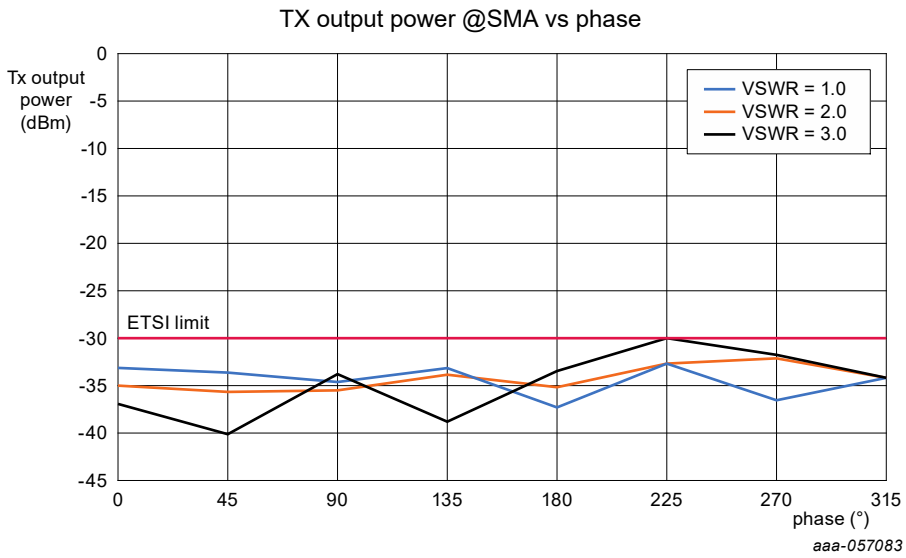

Figure 13. H3 frequency

3.2.4 Results

Power @SMA pin: +10.66 dBm (VSWR:1, phase 0°) for a power consumption of 25.33 mA.

Table 3. TX output power and associated power consumption vs frequencies for VSWR:1

VSWR : 1, Phase : 0°										
Real/Im measured values										
Frequency (GHz)	S11		S12		S21		S22		S1p_Spectrum	
	Real	Imag	Real	Imag	Real	Imag	Real	Imag	Real	Imag
2.44	0.0111	0.0095	-0.204	0.8258	-0.2043	0.8253	0.0131	0.8258	0.0178	0.02
4.88	0.118	-0.0103	-0.6468	-0.431	-0.6479	-0.4292	-0.0259	-0.0006	0.0363	-0.0843
7.32	0.1382	0.0471	0.5817	-0.4281	0.5811	-0.4291	0.005	0.1106	-0.0292	-0.0912
	S11 complex		S12 complex		S21 complex		S22 complex		S1p Spectrum complex	
2.44	0.0111-0.0095i		-0.204+0.8258i		-0.2043+0.8253i		0.0131+0.8258i		0.0178+0.02i	
4.88	0.118+0.0103i		-0.6468-0.431i		-0.6479-0.4292i		-0.0259+0.0006i		0.0363-0.0843i	
7.32	0.1382+0.0471i		0.5817-0.4281i		0.5811-0.4291i		-0.005+0.1106i		-0.0292-0.0912i	

DUT power calculation					
Frequency (GHz)	Pout_Spectrum (dBm)	Current (mA)	Ga	Loss (dB)	Pout (dBm)
2.44	9.11	25.33	0.7	1.55	10.66
4.88	-34.06		0.62	2.08	-31.98
7.32	-35.94		0.53	2.76	-33.18

Power @SMA pin: +10.04 dBm (VSWR:2, phase 0°) for a power consumption of 25.95 mA.

Table 4. TX output power and associated power consumption vs frequencies for VSWR:2

VSWR : 2 , Phase : 0°										
Real/Im measured values										
Frequency (GHz)	S11		S12		S21		S22		S1p_Spectrum	
	Real	Imag	Real	Imag	Real	Imag	Real	Imag	Real	Imag
2.44	0.3352	-0.0019	-0.1572	0.7756	-0.1575	0.7752	0.2663	0.1177	0.0178	0.02
4.88	0.1144	0.3199	-0.5971	-0.39	-0.5978	-0.3885	-0.2777	0.0107	0.0363	-0.0843
7.32	0.1304	0.0475	0.5387	-0.469	0.5381	-0.4697	-0.0021	0.0963	-0.0292	-0.0912
	S11 complex		S12 complex		S21 complex		S22 complex		S1p Spectrum complex	

Table 4. TX output power and associated power consumption vs frequencies for VSWR:2*...continued*

VSWR : 2 , Phase : 0°					
Real/Im measured values					
Frequency (GHz)	S11	S12	S21	S22	S1p_Spectrum
2.44	0.3352-0.0019i	-0.1572+0.7756i	-0.1575+0.7752i	0.2663+0.1177i	0.0178+0.02i
4.88	0.1144+0.3199i	-0.5971-0.39i	-0.5978-0.3885i	-0.2777+0.0107i	0.0363-0.0843i
7.32	0.1304+0.0475i	0.5387-0.469i	0.5381-0.4697i	-0.0021+0.0963i	-0.0292-0.0912i

DUT power calculation					
Frequency (GHz)	Pout_Spectrum (dBm)	Current (mA)	Ga	Loss (dB)	Pout (dBm)
2.44	8.55	25.95	0.71	1.49	10.04
4.88	-34.95		0.57	2.44	-32.51
7.32	-37.96		0.52	2.84	-35.12

Power @SMA pin: +10.04 dBm (VSWR:3, phase 0°) for a power consumption of 25.95 mA.

Table 5. TX output power and associated power consumption vs frequencies for VSWR:3

VSWR : 3 , Phase : 0°										
Real/Im measured values										
Frequency (GHz)	S11		S12		S21		S22		S1p_Spectrum	
	Real	Imag	Real	Imag	Real	Imag	Real	Imag	Real	Imag
2.44	0.4961	-0.0001	-0.1097	0.7075	-0.1099	0.7073	0.4062	0.1328	0.0178	0.02
4.88	0.0542	0.4451	-0.5572	-0.3545	-0.5577	-0.3536	-0.3463	0.0946	0.0363	-0.0843
7.32	0.1531	0.0433	0.523	-0.4902	0.5226	-0.4906	0.0118	0.1148	-0.0292	-0.0912
	S11 complex		S12 complex		S21 complex		S22 complex		S1p Spectrum complex	
2.44	0.4961-0.0001i		-0.1097+0.7075i		-0.1099+0.7073i		0.4062+0.1328i		0.0178+0.02i	
4.88	0.0542+0.4451i		-0.5572-0.3545i		-0.5577-0.3536i		-0.3463+0.0946i		0.0363-0.0843i	
7.32	0.1531+0.0433i		0.523-0.4902i		0.5226-0.4906i		-0.0118+0.1148i		-0.0292-0.0912i	

DUT power calculation					
Frequency (GHz)	Pout_Spectrum (dBm)	Current (mA)	Ga	Loss (dB)	Pout (dBm)
2.44	7.5	26.22	0.68	1.67	9.17
4.88	-38.7		0.54	2.68	-36.02
7.32	-39.8		0.53	2.76	-37.04

3.2.5 Output power (Pout) results

The following TX output power results are provided by using the IVCAD software (license software from the AMCAD company). Previous results from Section 3.2.4 are performed by the Tuner Control Software (TCS). TCS is a freeware software from the MAURY TUNER company).

Table 6. Output power calculated using IVCAD software

VSWR	Pout
Minimum	7.94 dBm
VSWR = 1	**10.47 dBm**
Maximum	10.62 dBm

Table 7. Output power calculated using TCS software

VSWR	Pout
Minimum	7.65 dBm

Table 7. Output power calculated using TCS software...*continued*

VSWR	Pout
VSWR = 1	**10.66 dBm**
Maximum	10.66 dBm

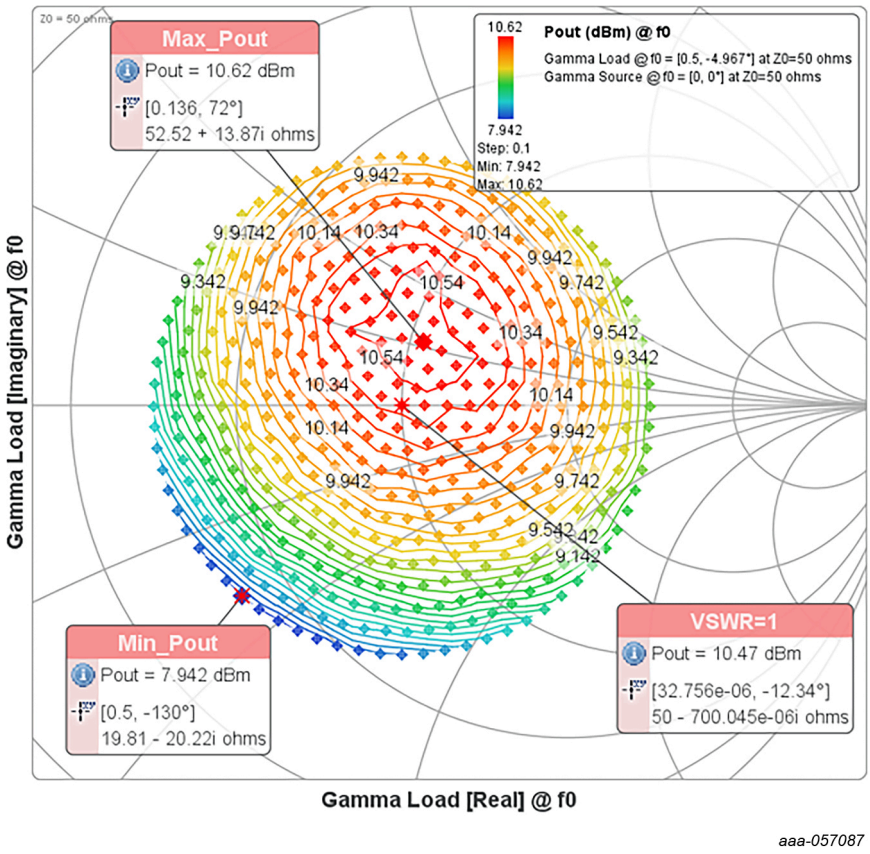

Figure 14. Results given by IVCAD: Pout

3.2.6 Iout results (EVK)

The following power consumption of the KW45 linked to the load (Iout) results are provided by using the IVCAD software and Tuner Control Software.

Table 8. Power consumption calculated using IVCAD software

VSWR	Iout
minimum	23.33 mA
VSWR = 1	25.38 mA
maximum	27.13 mA

Table 9. Power consumption calculated using TCS software

VSWR	Iout
minimum	23.24 mA

Table 9. Power consumption calculated using TCS software*...continued*

VSWR	Iout
VSWR = 1	25.33 mA
maximum	27.06 mA

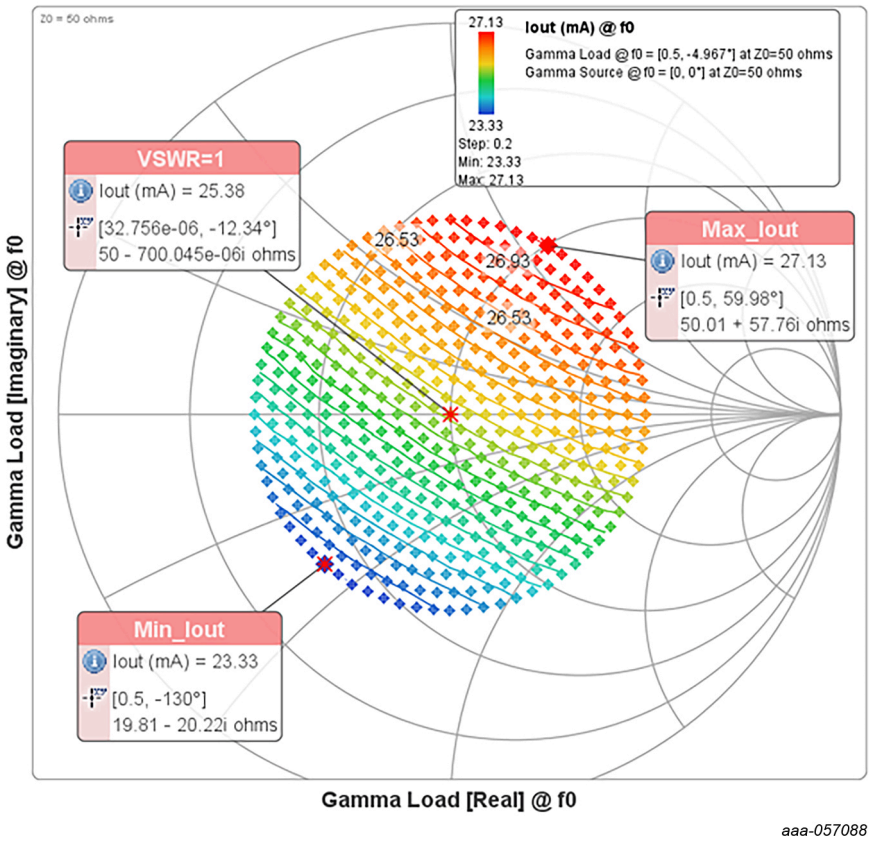

Figure 15. Results given by IVCAD: Iout (EVK)

3.2.7 MCX W71: Delta Pout vs VSWR

Figure 16 show the difference between the ideal output power and the output power linked to the load variation (magnitude and phase). Figure 17 show the TX output power versus the VSWR.

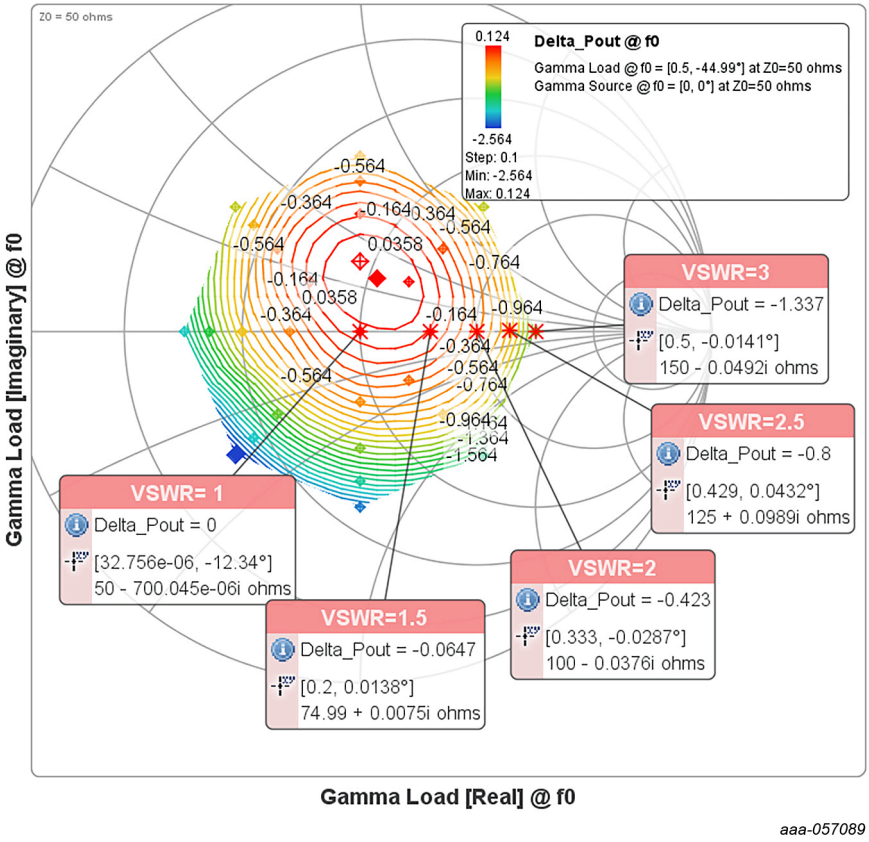

Figure 16. Delta Pout vs VSWR

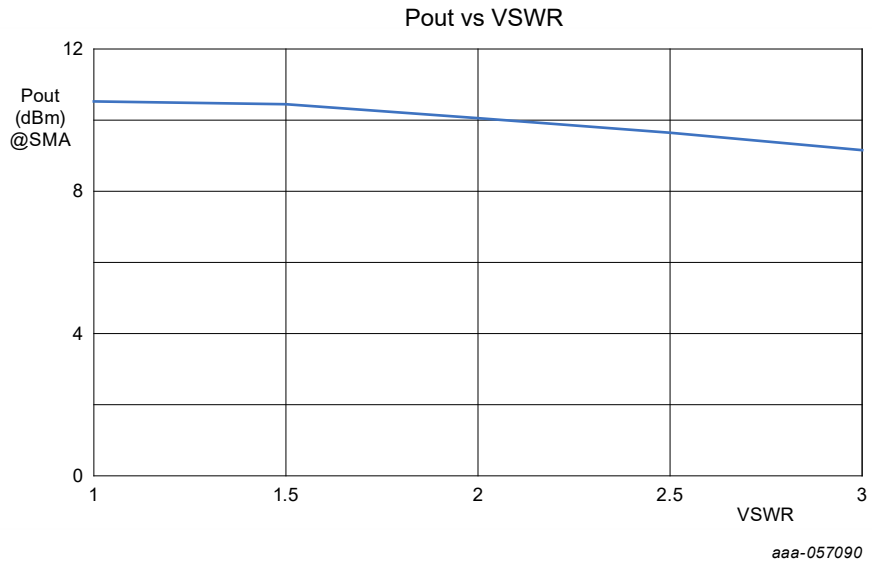

Figure 17. Delta Pout vs VSWR

4 Revision history

Table 10 summarizes the revisions to this document.

Table 10. Revision history

Document ID	Release date	Description
AN14391 v.1.0	10 September 2024	Initial public release

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