AN848

915 MHz Single-ended Antenna Matrix Measurement Reports

1. Introduction

This document summarizes the measured results of the antennas applied in the Silicon Labs 915 MHz antenna matrix (WES0110-01-AMS915-01).

- The antenna is realized on a 1.55 mm thick FR4.
- Target antenna impedance is 50 Ω.

A picture of the WES0110-01-AMS915-01 915 MHz Antenna Matrix is shown in Figure 1. For the 915 MHz band, nine different PCB antenna solutions are proposed:

- Medium Sized Printed ILA (or optionally IFA) around the PCB circumference (WES0111-01-APL915M-01)
- Ceramic (Chip) Antenna (WES0112-01-ACM915D-01)
- Small Sized (Wire) Helical Antenna (WES0113-01-AWH915S-01)
- Medium Sized (Wire) Helical Antenna (WES0114-01-AWH915M-01)
- Panic Button IFA (Printed) along the circumference (WES0115-01-APF915P-01)
- Panic Button ILA (Printed) along the circumference (WES0116-01-APL915P-01)
- Printed Meander Monopole (WES0117-01-APN915D-01)
- Small Sized Printed ILA (or optional IFA) in dedicated small antenna area (WES0118-01-APL915S-01)
- Printed BIFA in a dedicated bigger antenna area (WES0119-01-APB915D-01)

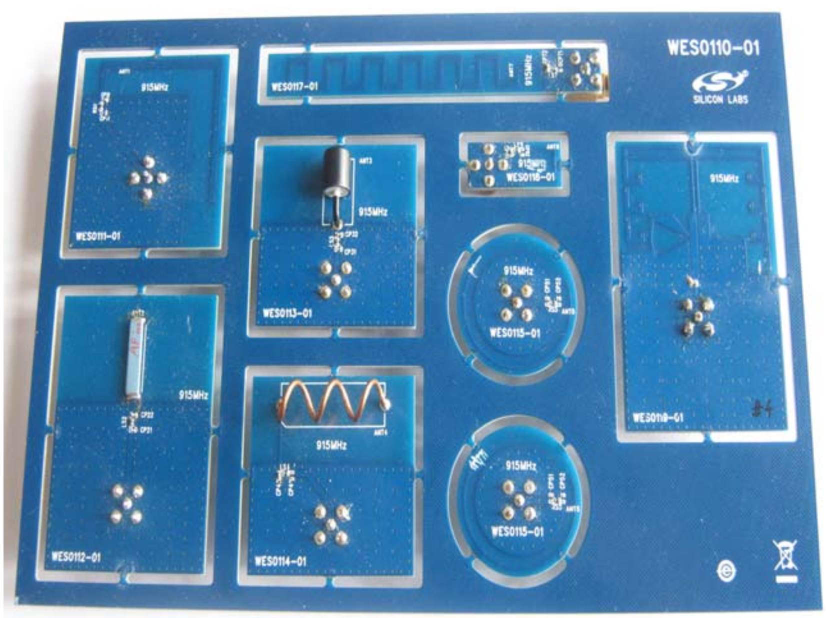


Figure 1. 915 M, 50 Ω, Single-ended Antenna Matrix (WES0110-01-AMS915-01)

1.1. Antenna Results Summary

The results of the 915 M single-ended matrix antennas are compared in Table 1. More details can be found in the separate antenna chapters.

Table 1. Compared Results of the 915 M Single-ended Matrix Antennas

915 M Single-ended Antenna Type	External Match	Maximum EIRP [dBm][1]	Maximum Antenna Gain [dBi]	Maximum Range Outdoor [m][2]	Estimated Avg. Indoor Range [m][3]
Medium Sized ILA (WES0111)	Yes	9	–1.2	2038	71
Ceramic Antenna (WES0112)	Yes	4.7	–5.3	1277	54
Small Sized Helical (WES0113)	Yes	5.9	–4.3	1432	55
Medium Sized Helical (WES0114)	Yes	10.4	0.2	1857	81
Panic Button IFA (WES0115)	No	7.7	–2.5	2078	73
Panic Button ILA (WES0116)	Yes	8.4	–1.8	2009	80
Printed Meandered Antenna (WES0117)	Yes	8.3	–1.9	2079	100
Small Sized ILA (WES0118)	Yes	6.6	–3.6	1454	60
BIFA (WES0119)	Yes	10.7	0.5	2104	74

Notes:

1. With the reduced power 4463PCE20C915 Pico Board and WMB-930 Wireless Motherboard working in a reduced V_{DD} (~2.6 V) from two AA batteries. Delivered power to the antenna is ~10.2 dBm.
2. This value is the highest outdoor range achieved with the pair of identical antennas with 13 dBm TX power and 50 kbps, 25 KHz deviation, and ~103 KHz RX bandwidth. 1% PER with 10-byte long packets. In some cases the antenna direction found for maximum range is different from the direction of maximum in the pattern measurements. The range test was performed with hand effect on the Motherboard, while the pattern measurements were done without any hand effect.
3. To the normal direction of usage (X-axes facing each other). Link parameters are identical to that of the outdoor range measurements.

1.2. Detailed Antenna Measurement Results

1.2.1. Medium Sized Printed ILA (WES0111-01-APL915M-01)

A parallel 1.5 pF capacitor is required at the antenna input to match it to 50 Ω. Also, in the antenna PCB, a series 0 Ω resistor connects the antenna input to the feeding 50 Ω coplanar line. The footprint for the third additional parallel matching elements is unpopulated. The matching network schematic is shown in Figure 2.

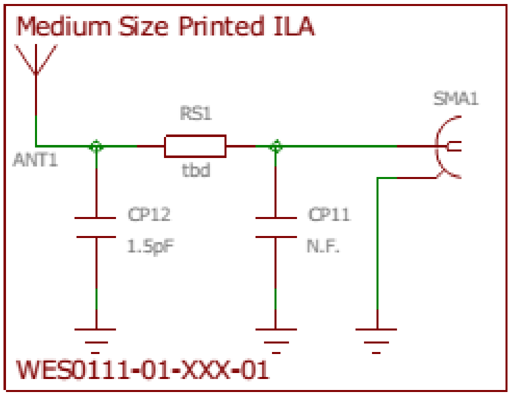


Figure 2. Small ILA Board (WES0111-01-APL915M-01) Antenna Matching Network Schematic

The Medium Sized ILA antenna is shown in Figure 3:

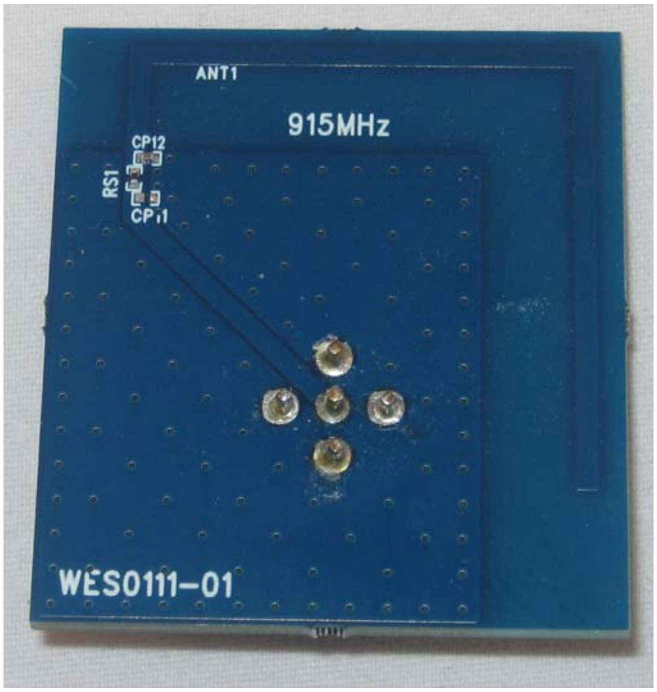


Figure 3. Medium Sized Printed ILA Antenna (WES0111-01-APL915M-01)

1.2.2. Impedance (WES0111-01-APL915M-01)

The impedance measurement setup is shown in Figure 4. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test, the user’s hand holds the motherboard. A typical hand position is shown in Figure 5.

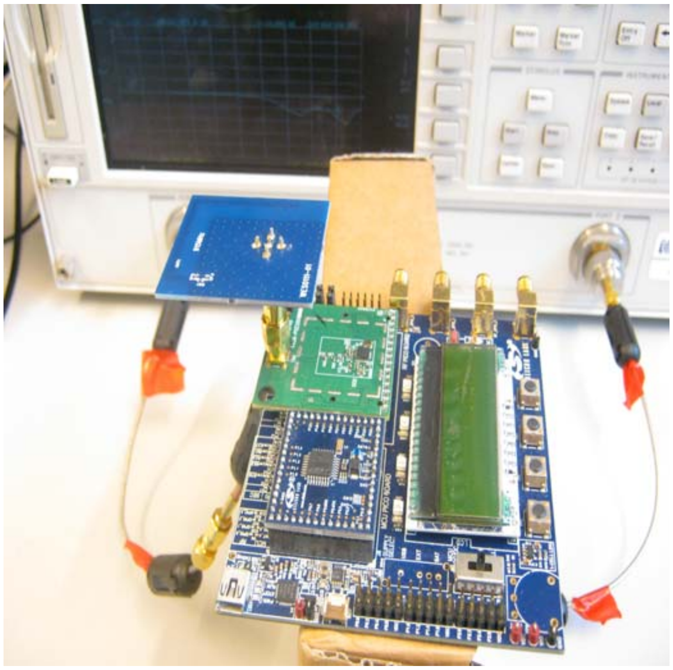


Figure 4. DUT in the Impedance Measurement Setup (WES0111 Medium ILA Board)

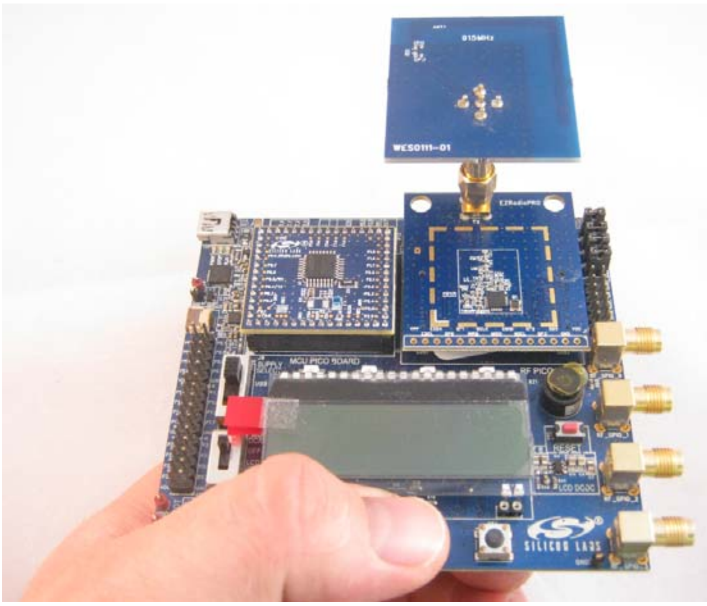


Figure 5. Typical Hand Effect on the Main Board During Impedance and Range Measurement (Medium ILA Antenna [WES0111] Board)

Measured impedance of the antenna is shown in Figure 6 (up to 3 GHz) with motherboard hand effect:

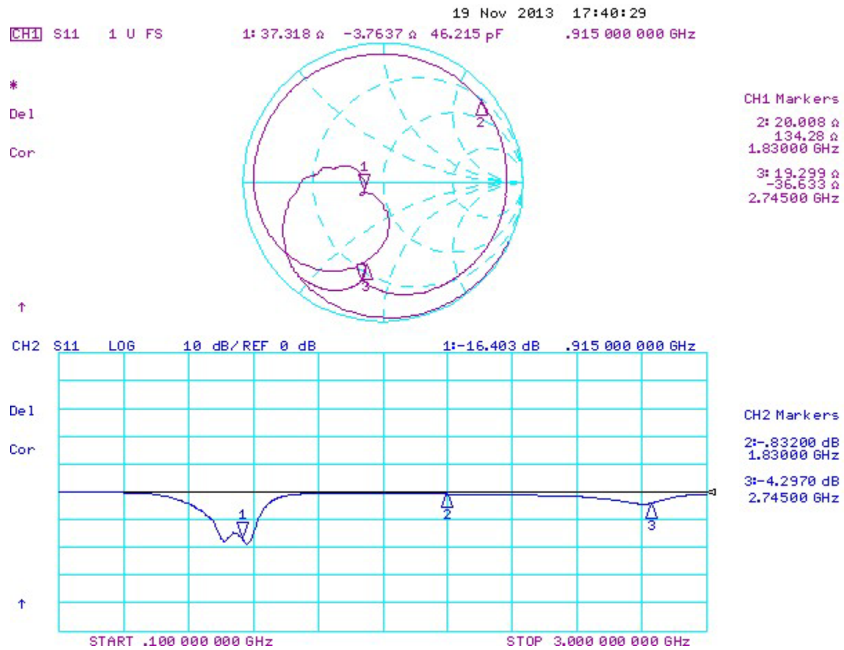


Figure 6. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

1.2.3. Antenna Gain (WES0111-01-APL915M-01)

The antenna gain is calculated from both the measured radiated power at the fundamental and from the delivered power to the antenna. In the radiation measurement, a P4463-PCE20C915 Pico Board drives the antenna in a reduced power state (0x1C and at 2.6 V V_{DD}) to deliver ~+10.2 dBm. The entire setup is fed by two AA batteries. The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced power state is shown in Figure 7. This method can be effectively applied because the S11 of the antenna is much better than –10 dB, so the reflection loss is negligible.

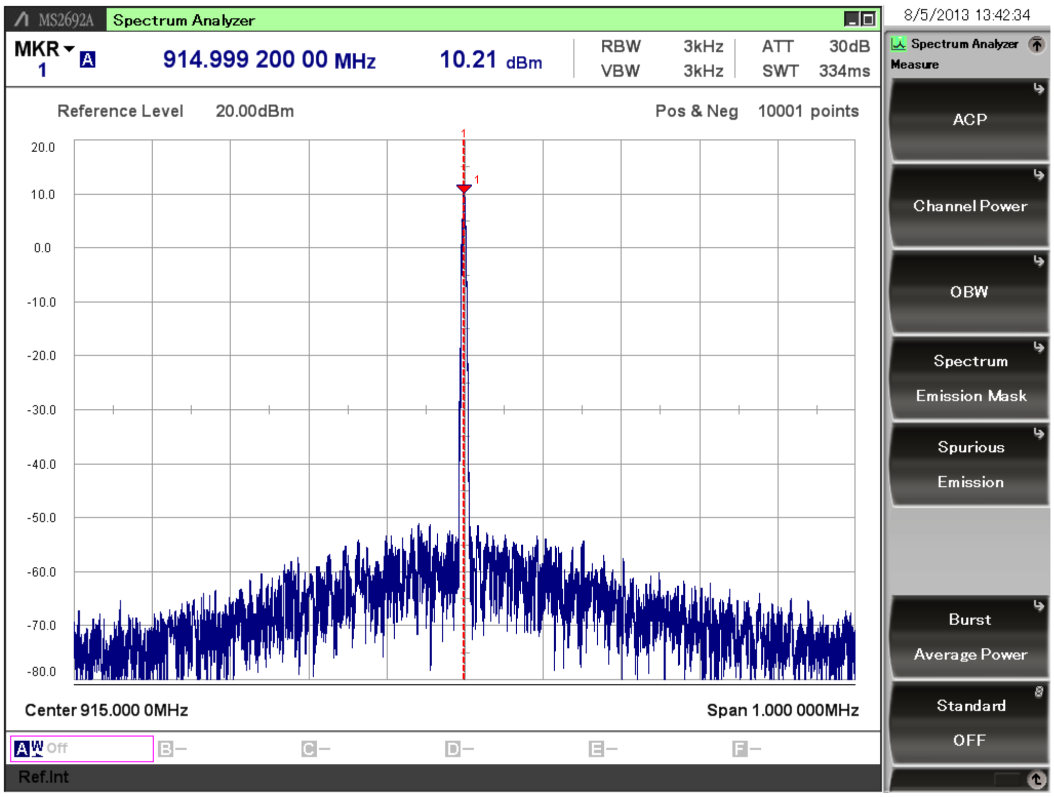


Figure 7. Conducted Measurement Result, 4463-PCE20C915 in a Reduced Power State (0x1C) and V_{DD} (2.6 V).

The measured radiated power maximum is at the XZ cut (Table 2). It is around +9 dBm EIRP, so the maximum gain number is ~–1.2 dBi, as shown in Figure 11.

1.2.4. Radiation Patterns (WES0111-01-APL915M-01)

The radiation patterns of the medium sized printed ILA antenna were measured in an antenna chamber with the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition and with the WMB-930 Wireless Motherboard driving the Pico Board and without any hand effect. Figure 9–Figure 14 show the radiation patterns at the fundamental frequency in the XY, XZ, YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The device under test (DUT) with coordinate system under the radiated measurements is shown in Figure 8. Rotation starts from the X-axe in the XY cut, and begins from the Z-axe in the XZ and YZ cuts.

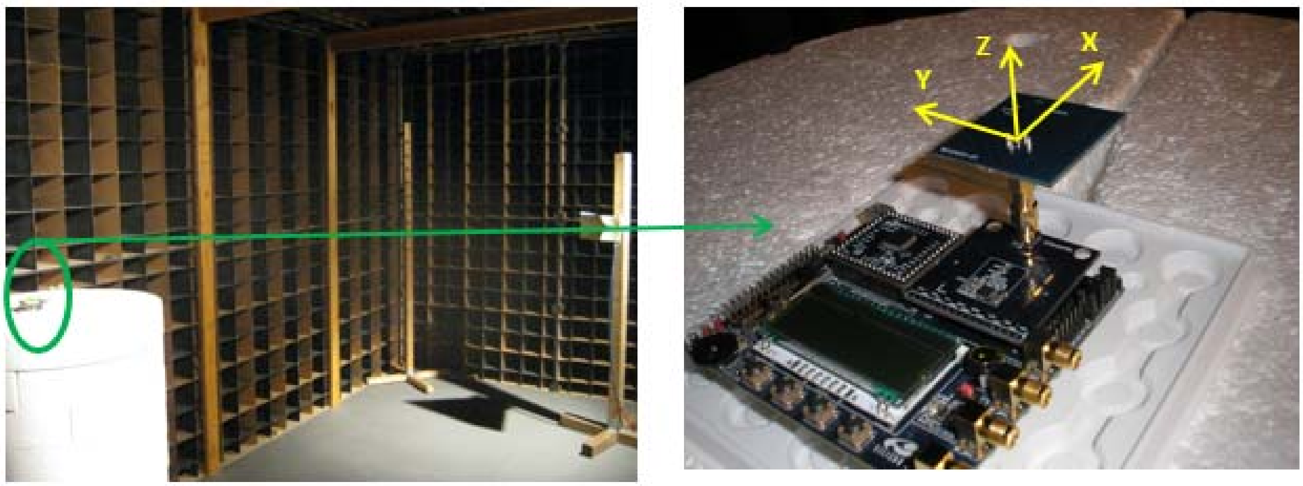


Figure 8. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in Figure 9–Figure 14.

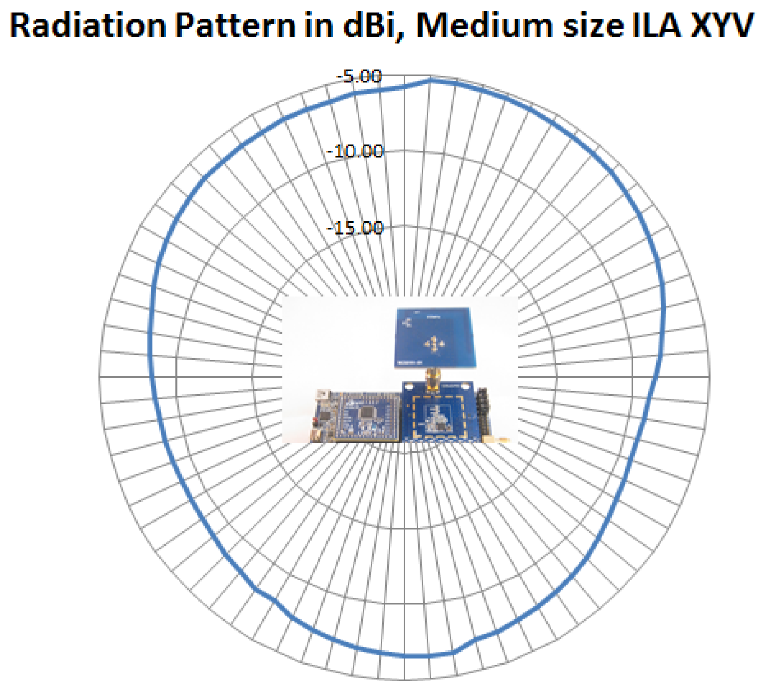


Figure 9. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

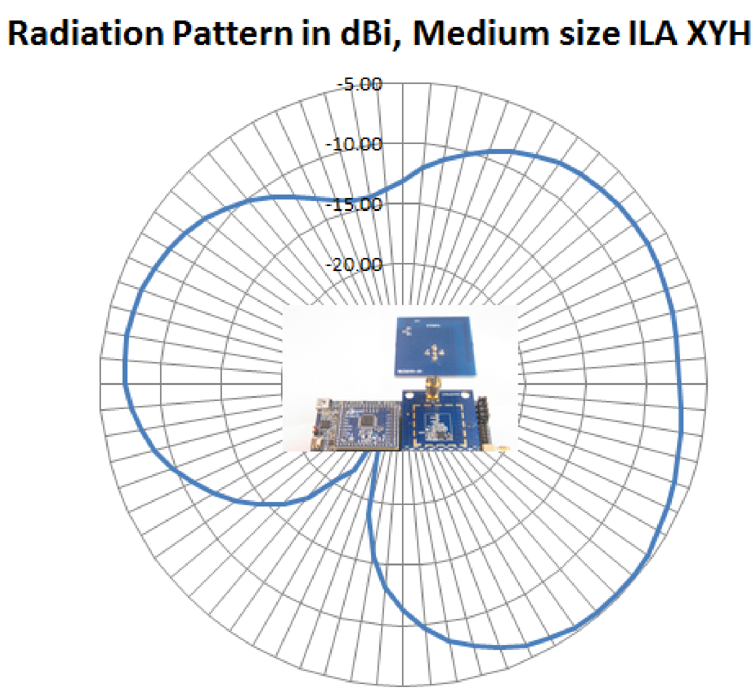


Figure 10. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

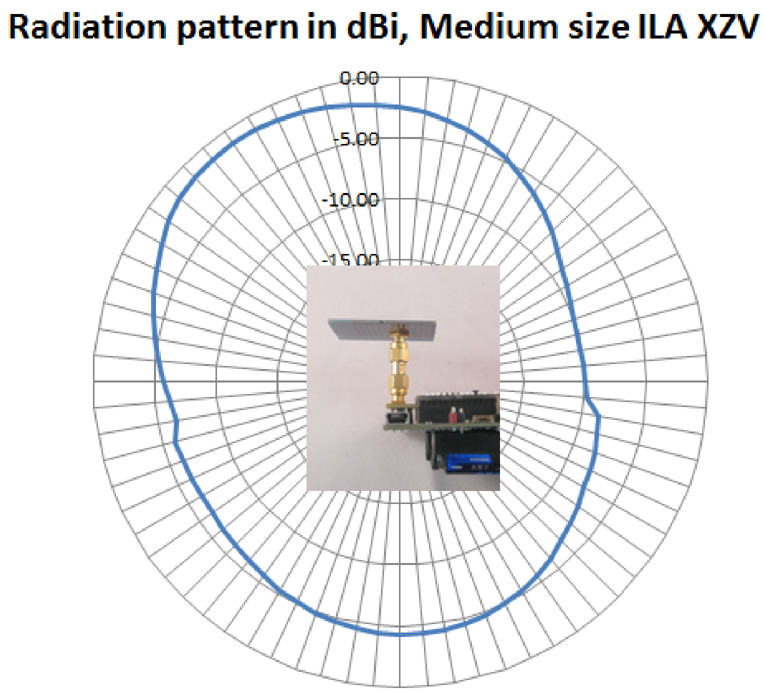


Figure 11. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

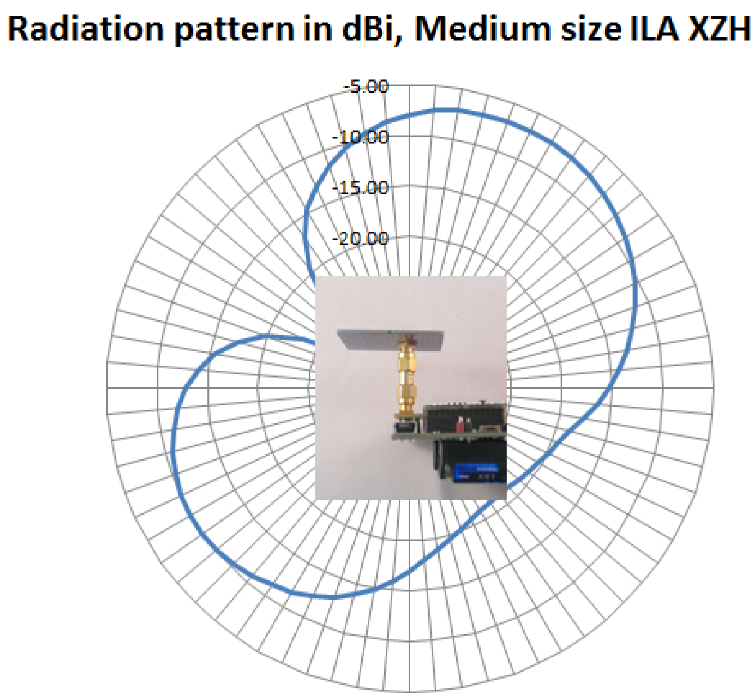


Figure 12. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

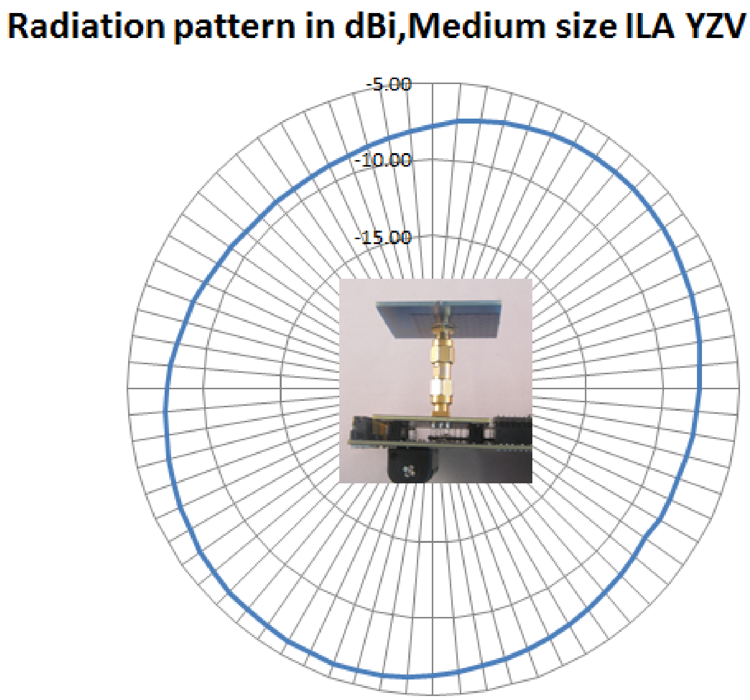


Figure 13. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

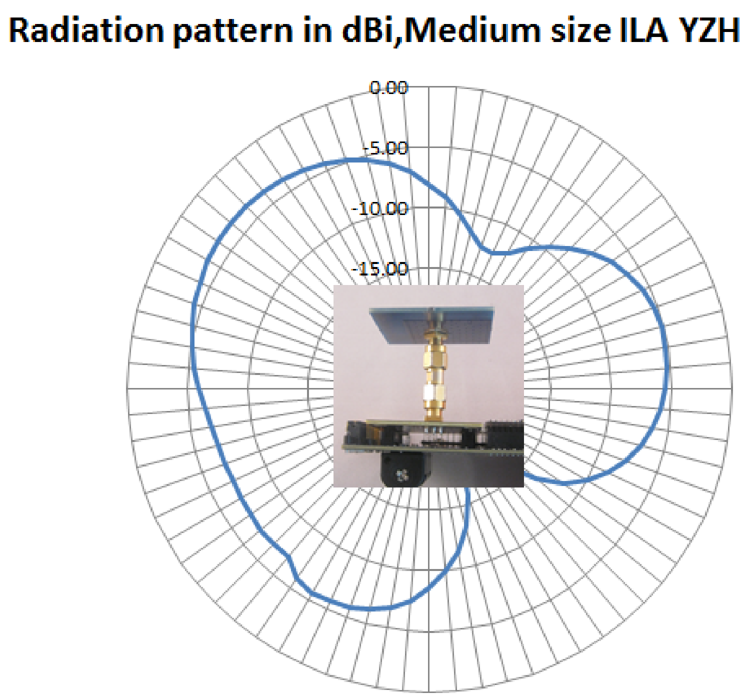


Figure 14. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

1.2.5. Radiated Harmonics (WES0111-01-APL915M-01)

The radiated harmonics of the medium sized printed ILA antenna were also measured in an antenna chamber with the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition and with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20B915 Pico Board was set to a reduced power state (0x1C) and the V_{DD} reduced to 2.6 V to deliver ~10.2 dBm, as shown in Figure 7.The maximum radiated power levels, up to the 10^{th} harmonic, were measured in the XY, XZ, and YZ cut, with both horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 2) with the corresponding standard limits.

The medium sized ILA antenna, driven by the Si4463 class E match at 10 dBm power settings, complies with the FCC harmonic regulations with margin.

Harmonic radiation is likely lower in typical battery-operated final application, where the wireless motherboard is eliminated and the Pico Board is unified with the antenna.

Table 2. Radiated Harmonics, Medium ILA Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	4.88	25.1
XY	V	2^{nd}	1830	–15.31	–49.54	38.6
XY	V	3^{rd}	2745	–41.25	–49.20	8.0
XY	V	4^{th}	3660	–41.25	–48.83	7.6
XY	V	5^{th}	4575	–41.25	–60.11	18.9
XY	V	6^{th}	5490	–15.31	–59.04	48.1
XY	V	7^{th}	6405	–15.31	–56.81	45.8
XY	V	8^{th}	7320	–41.25	–57.19	15.9
XY	V	9^{th}	8235	–41.25	–54.34	13.1
XY	V	10^{th}	9150	–41.25	–52.77	11.5
XY	H	Fund.	915	30.00	4.99	25.0
XY	H	2^{nd}	1830	–15.31	–50.75	39.8
XY	H	3^{rd}	2745	–41.25	–52.41	11.2
XY	H	4^{th}	3660	–41.25	–52.97	11.7
XY	H	5^{th}	4575	–41.25	–60.02	18.8
XY	H	6^{th}	5490	–15.31	–59.47	48.5
XY	H	7^{th}	6405	–15.31	–58.44	47.5
XY	H	8^{th}	7320	–41.25	–57.87	16.6

Table 2. Radiated Harmonics, Medium ILA Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	H	9th	8235	–41.25	–55.47	14.2
XY	H	10th	9150	–41.25	–53.25	12.0
XZ	V	Fund.	915	30.00	9.02	21.0
XZ	V	2nd	1830	–15.31	–46.30	35.3
XZ	V	3rd	2745	–41.25	–49.64	8.4
XZ	V	4th	3660	–41.25	–51.54	10.3
XZ	V	5th	4575	–41.25	–60.22	19.0
XZ	V	6th	5490	–15.31	–61.15	50.2
XZ	V	7th	6405	–15.31	–58.59	47.6
XZ	V	8th	7320	–41.25	–56.28	15.0
XZ	V	9th	8235	–41.25	–54.93	13.7
XZ	V	10th	9150	–41.25	–52.97	11.7
XZ	H	Fund.	915	30.00	3.26	26.7
XZ	H	2nd	1830	–15.31	–50.29	39.3
XZ	H	3rd	2745	–41.25	–52.31	11.1
XZ	H	4th	3660	–41.25	–47.13	5.9
XZ	H	5th	4575	–41.25	–60.61	19.4
XZ	H	6th	5490	–15.31	–59.04	48.1
XZ	H	7th	6405	–15.31	–58.53	47.5
XZ	H	8th	7320	–41.25	–57.33	16.1
XZ	H	9th	8235	–41.25	–54.67	13.4
XZ	H	10th	9150	–41.25	–52.36	11.1
YZ	V	Fund.	915	30.00	4.28	25.7
YZ	V	2nd	1830	–15.31	–49.77	38.8

Table 2. Radiated Harmonics, Medium ILA Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
YZ	V	3rd	2745	–41.25	–50.87	9.6
YZ	V	4th	3660	–41.25	–54.54	13.3
YZ	V	5th	4575	–41.25	–60.53	19.3
YZ	V	6th	5490	–15.31	–58.33	47.4
YZ	V	7th	6405	–15.31	–57.93	46.9
YZ	V	8th	7320	–41.25	–56.98	15.7
YZ	V	9th	8235	–41.25	–54.46	13.2
YZ	V	10th	9150	–41.25	–52.34	11.1
YZ	H	Fund.	915	30.00	6.63	23.4
YZ	H	2nd	1830	–15.31	–48.42	37.4
YZ	H	3rd	2745	–41.25	–49.13	7.9
YZ	H	4th	3660	–41.25	–50.82	9.6
YZ	H	5th	4575	–41.25	–59.76	18.5
YZ	H	6th	5490	–15.31	–58.29	47.3
YZ	H	7th	6405	–15.31	–57.89	46.9
YZ	H	8th	7320	–41.25	–55.84	14.6
YZ	H	9th	8235	–41.25	–53.78	12.5
YZ	H	10th	9150	–41.25	–51.64	10.4

1.2.6. Range Test (WES0111-01-APL915M-01)

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the one-directional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte long packets. The GPS coordinates have been recorded for each spot. The distance between the spots was measured using Google Maps, and results are shown in meters. The range was tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board with reduced (+13 dBm and 0 dBm) power states, and the DUT (as shown in Figure 5.) held by the users hand. The Pico Board was working in a reduced (+13 dBm or 0 dBm) power state during the tests.

The range was tested in a flat land area without obstacles.

During the range test, the following settings have been used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the settings above (Set 1, Set 2, and Set 3), the following range tests are made:

1. Range measurement with the MEDIUM ILA Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the MEDIUM ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the MEDIUM ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the MEDIUM ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the MEDIUM ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE W1063 from Pulse in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE W1063 from Pulse in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE W1063 from Pulse in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 15.

The indoor range test was not performed, due to the lack of a large enough building. But from the TX power and sensitivity data, an indoor range estimation can be given if one assumes a propagation factor of 4.5, which is a typical value in normal office environments. Use the Silicon Labs' range calculator, which can be found here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming a –5.9 dBi antenna gain (front direction, X-axes facing in XY cut) and the setting "Set 1" above (50 kbps, 1% PER, ~13 dBm), the estimated indoor range is 71 m, as is shown in Figure 16. To the maximum antenna gain direction, the indoor range is ~115 m.

Set1	13dBm	50kbps	+/-25kHz
Set2	13dBm	100kbps	+/-50kHz
Set3	0dBm	1.2kbps	+/-1.2kHz

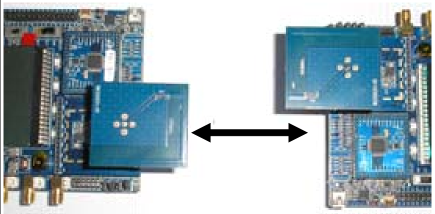
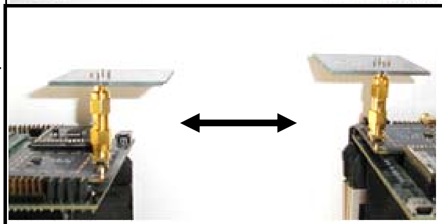
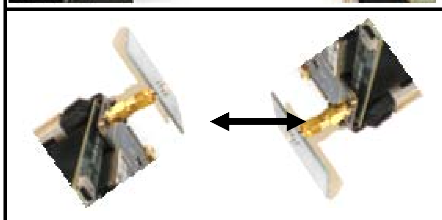
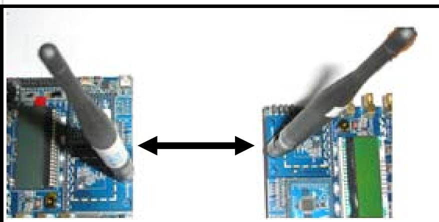
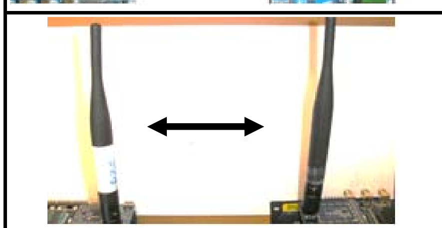
Antenna	Photo	#	Set	Power	Data rate	Deviation	GPS N	GPS E	Distance [m]
Medium Printed ILA					**Base**		**47.152880°**	**19.180930°**	**0.0**
Medium Printed ILA (WES0111)				H pol; Norm. direction					
		1	Set1	13dBm	50kbps	+/-25kHz	47.164650°	19.173080°	**1437.1**
				V pol; Norm. direction					
		2	Set1	13dBm	50kbps	+/-25kHz	47.168360°	19.172550°	**1834.2**
		3	Set2	13dBm	100kbps	+/-50kHz	47.163100°	19.173400°	**1271.1**
		4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.166170°	19.172910°	**1597.4**
				Max. direction w/o hand: XZV 335° //Meas w hand: 270°					
		5	Set1	13dBm	50kbps	+/-25kHz	47.170230°	19.172240°	**2038.0**
W1063				V pol; Norm. direction					
		6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.172010°	**2174.3**
				H pol; Norm. direction					
		8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 15. Outdoor Range Test Result with Two Identical Medium Sized Printed ILA Antennas Connected to the 4463-PCE20C915 Pico Board and to the WMB-930 Wireless Motherboard

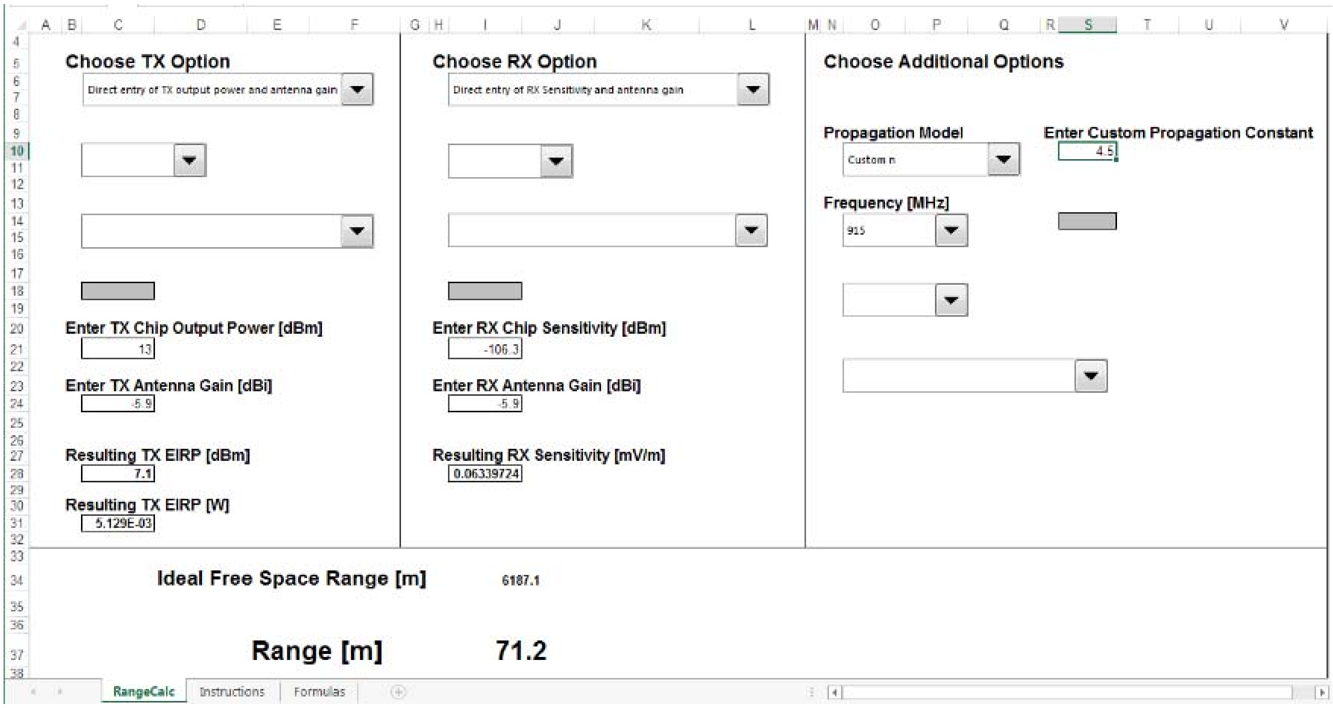


Figure 16. Indoor Range Estimation with Two Identical Medium Sized Printed ILA Antennas Connected to the 4463-PCE20C915 Pico Board and to the WMB-930 Wireless Motherboard

2. Ceramic (Chip) Antenna (WES0112-01-ACM915D-01)

The selected chip antenna is Antenna Factory's ANT-915-CHP-T. For more information, go here:

https://www.linxtechnologies.com/resources/data-guides/ant-xxx-chp-x.pdf

An external matching network (shown in Figure 17) is required at the antenna input to work well at 915 M.

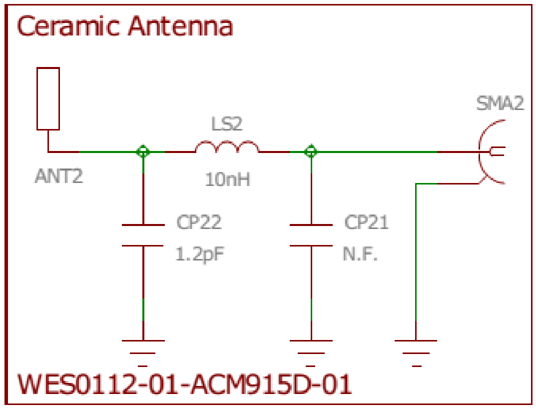


Figure 17. External Matching Network at 915 MHz for the ANT-915-CHP-T Ceramic Antenna

The antenna is shown in Figure 18:

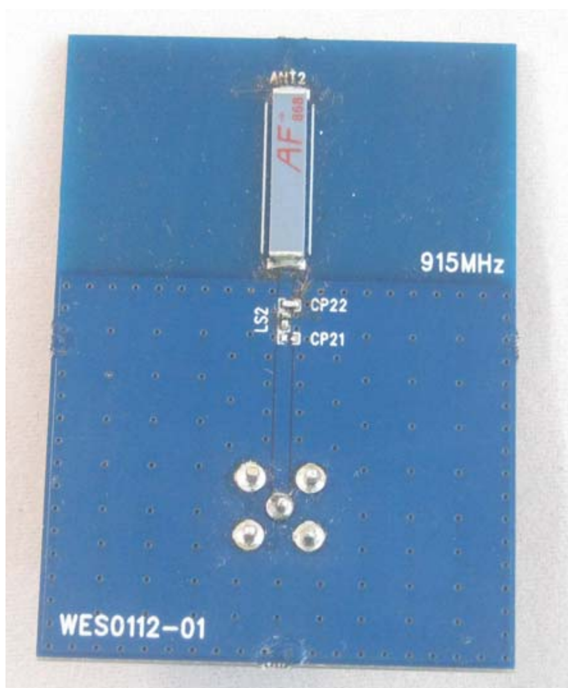


Figure 18. Ceramic (Chip) Antenna, (WES0112-01-ACM915D-01)

2.1. Antenna Impedance (WES0112-01-ACM915D-01)

The impedance measurement setup is shown in Figure 19. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20B915 works in a reduced power state (0x1C with 2.6 V V_{DD} results ~+10.2 dBm, as shown in Figure 22).

During the impedance tuning and range test, the user's hand holds the motherboard. Typical hand position is shown in Figure 20.

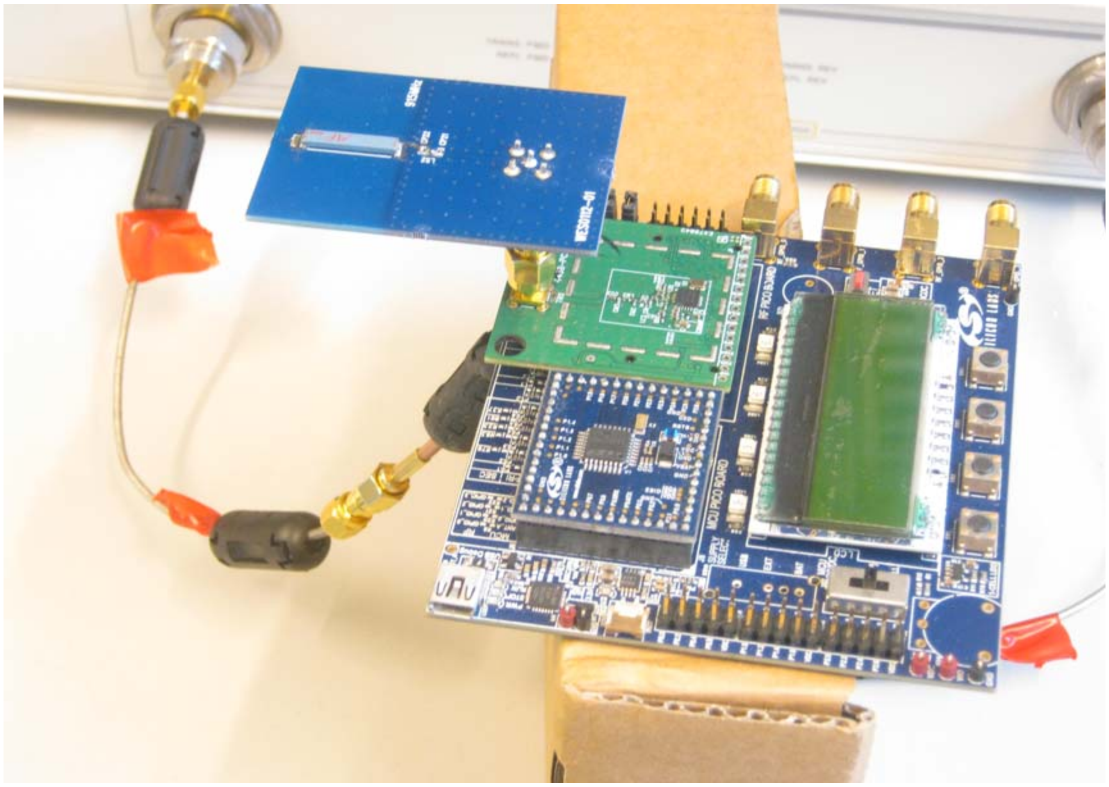


Figure 19. DUT in the Impedance Measurement Setup (WES0112 Ceramic Antenna Board)

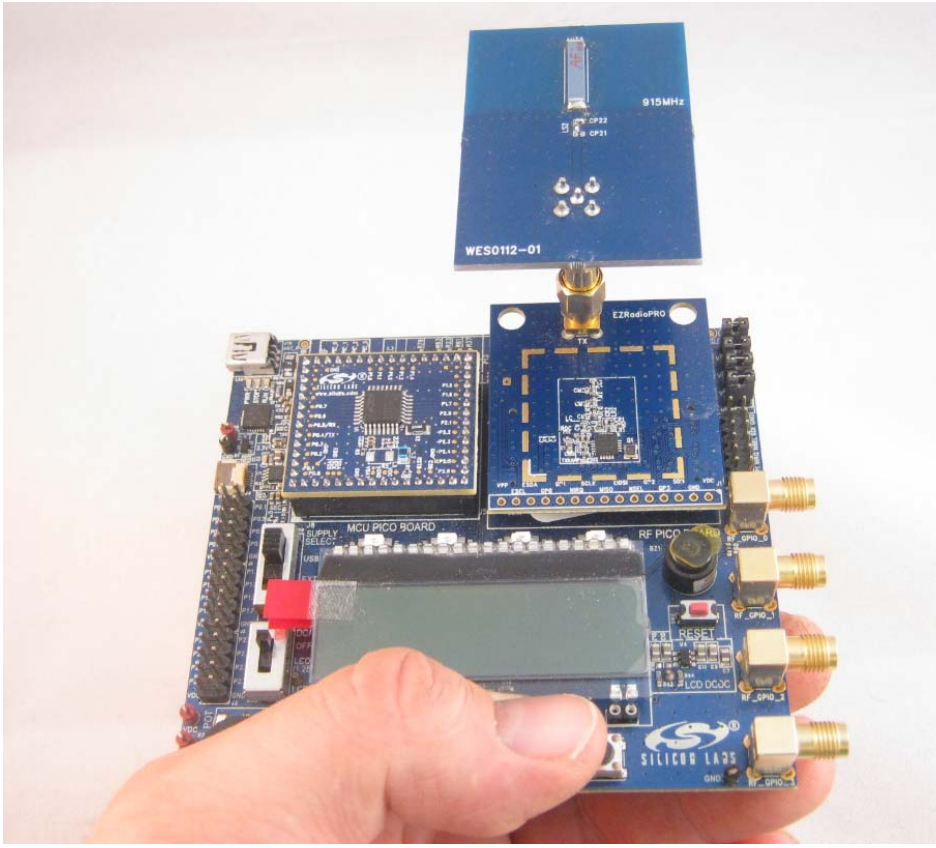


Figure 20. Typical Hand Effect on the Main Board During Impedance and Range Measurement

The measured impedance of the antenna with its external matching network is shown in Figure 21 (up to 3 GHz) with motherboard hand effect.

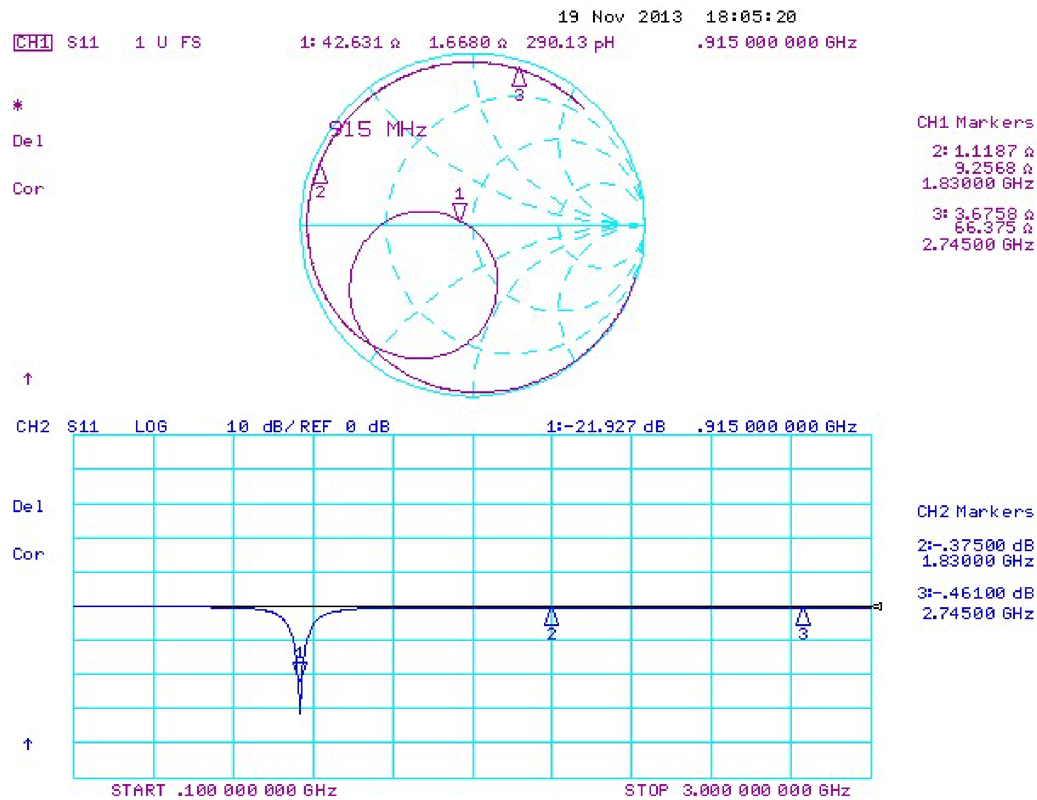


Figure 21. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

2.2. Antenna Gain (WES0112-01-ACM915D-01)

The antenna gain is calculated from both the measured radiated power at the fundamental and from the delivered power to the antenna. In the radiation measurement, the 4463-PCE20C915 Pico Board is set to a reduced (~10.3 dBm) power state and the entire setup is fed by two AA batteries. The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced power state is shown in Figure 22. This method can be effectively applied because the S11 of the antenna is much better than –10 dB so the reflection loss is negligible.

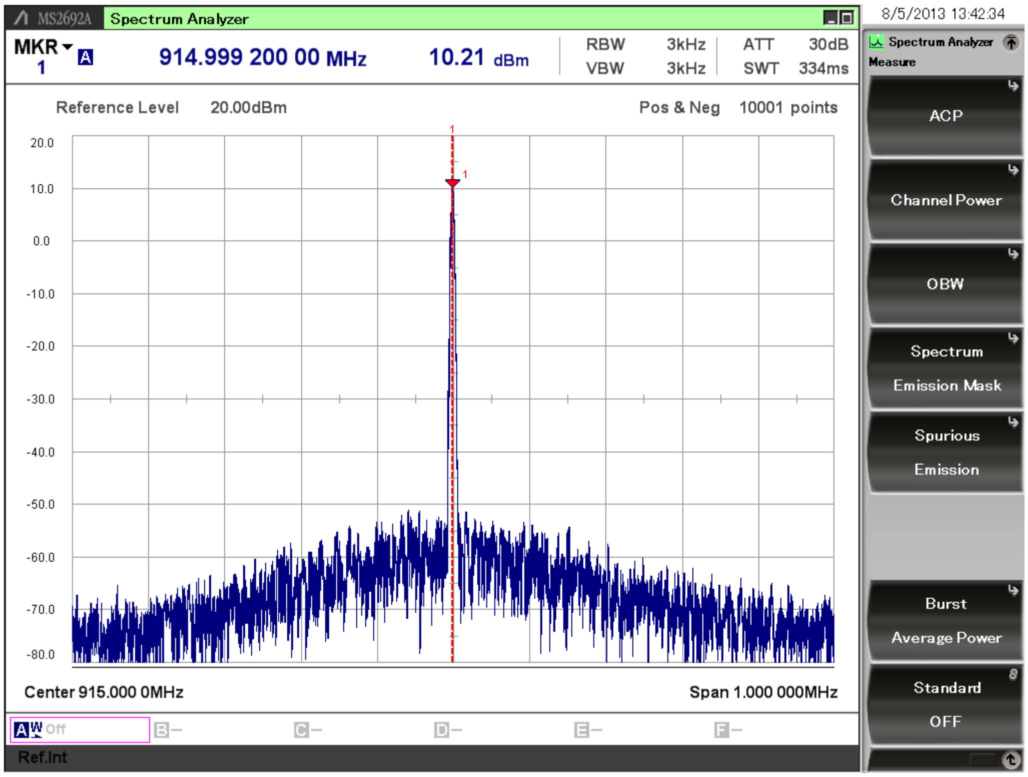


Figure 22. Conducted Measurement Result, 4463-PCE20C915 in a Reduced Power State (0x1C) and V_{DD} (2.6 V).

The measured radiated power maximum is at the XZ cut (Table 3). It is around +4.7 dBm EIRP, so the maximum gain number is ~–5.3 dBi, as shown in Figure 27.

2.3. Radiation Patterns (WES0112-01-ACM915D-01)

Radiation patterns of the ceramic antenna were measured in an antenna chamber with the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition and with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20B915 Pico Board works in a reduced power state (0x1C with 2.6 V_{DD}) and delivers ~10.2 dBm power. Figure 24—Figure 29 show the radiation patterns at the fundamental frequency in the XY, XZ, YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 23. Rotation starts from the X-axe in the XY cut, and begins from the Z-axe in the XZ and YZ cuts.

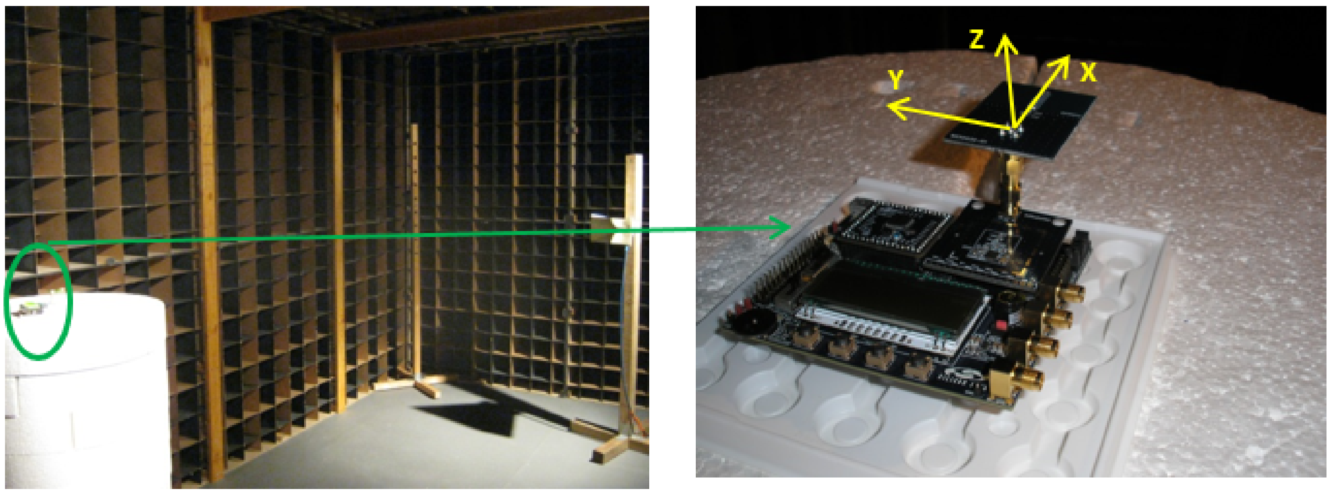


Figure 23. DUT in the Antenna Chamber

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The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 24–Figure 29).

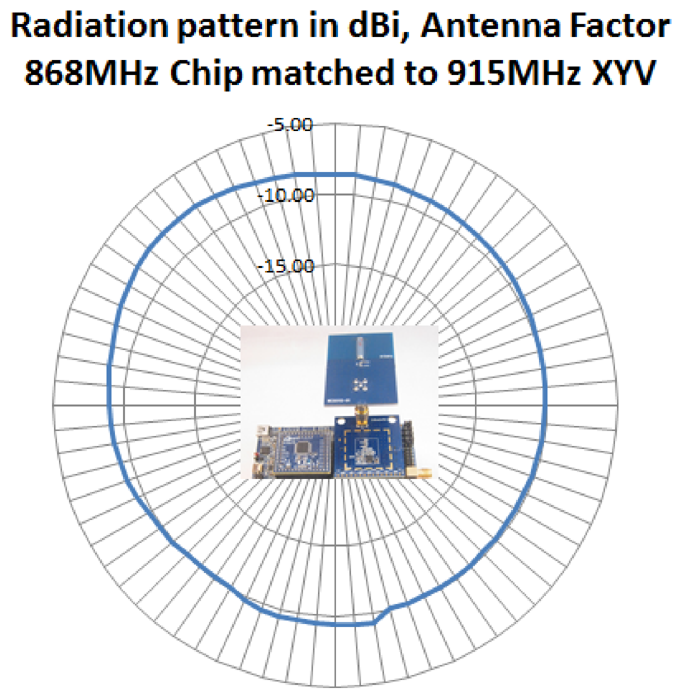


Figure 24. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

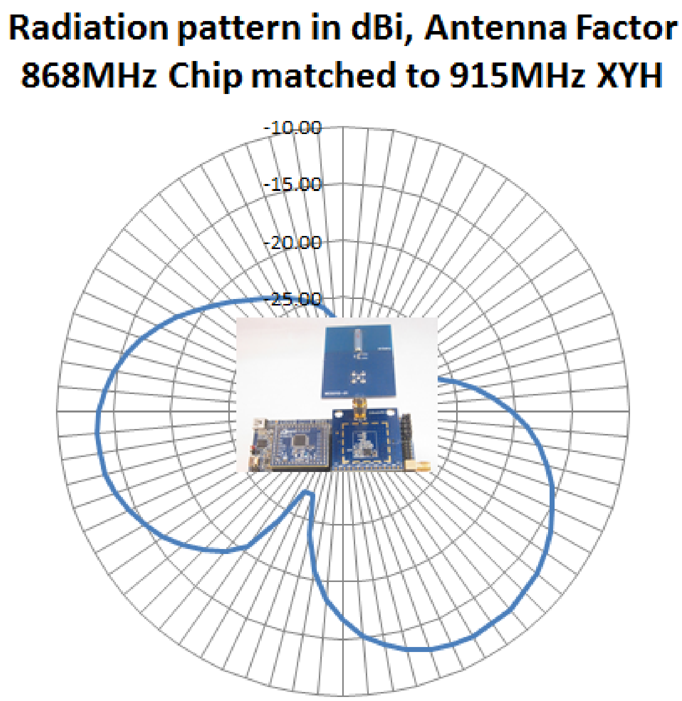


Figure 25. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

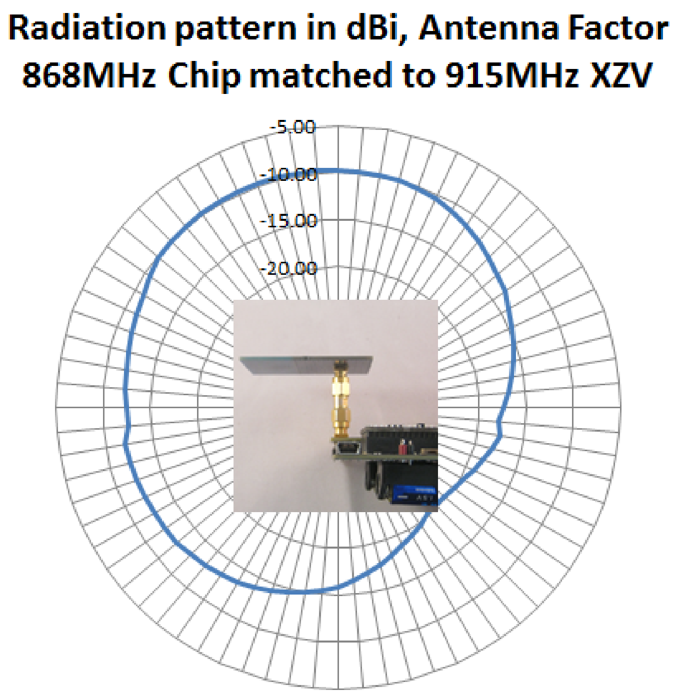


Figure 26. . Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

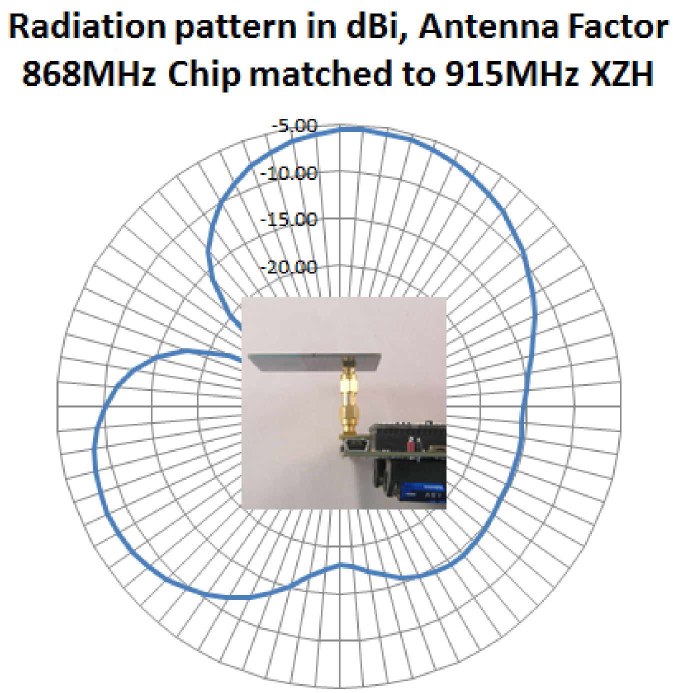


Figure 27. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

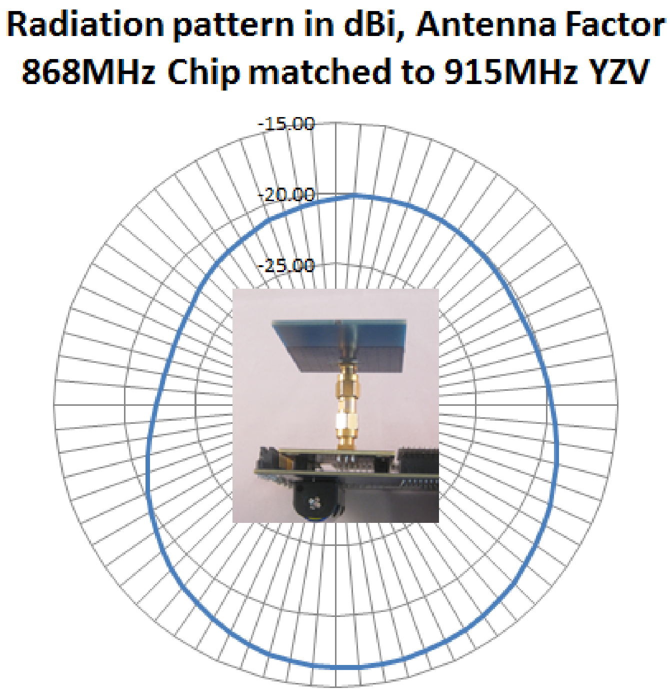


Figure 28. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

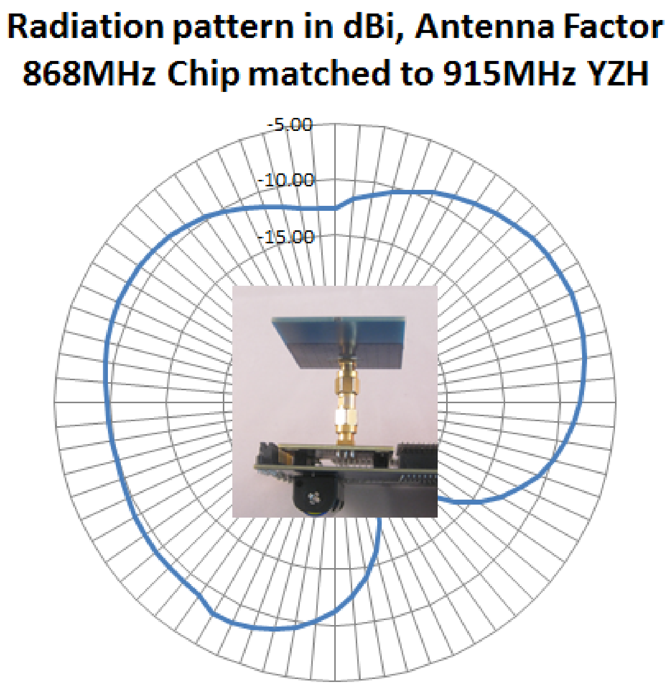


Figure 29. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

2.4. Radiated Harmonics (WES0112-01-ACM915D-01)

The radiated harmonics of the ceramic antenna were also measured in an antenna chamber with the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition and with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20B915 Pico Board works in a reduced power state (0x1C and with 2.6 V V_{DD}) to deliver ~+10.2 dBm to the antenna board. The maximum radiated power levels up to the 10^{th} harmonic were measured in the XY, XZ, and YZ cut, with both the horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 3) with the corresponding standard limits.

The Antenna is FCC compliant with large margin.

Table 3. Radiated Harmonics, Ceramic Antenna Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	2.49	27.5
XY	V	2^{nd}	1830	–15.31	–54.44	39.1
XY	V	3^{rd}	2745	–41.25	–51.68	10.4
XY	V	4^{th}	3660	–41.25	–50.97	9.7
XY	V	5^{th}	4575	–41.25	–60.70	19.5
XY	V	6^{th}	5490	–15.31	–58.92	43.6
XY	V	7^{th}	6405	–15.31	–58.30	43.0
XY	V	8^{th}	7320	–41.25	–57.35	16.1
XY	V	9^{th}	8235	–41.25	–54.14	12.9
XY	V	10^{th}	9150	–41.25	–52.53	11.3
XY	H	Fund.	915	30.00	–2.00	32.0
XY	H	2^{nd}	1830	–15.31	–55.08	39.8
XY	H	3^{rd}	2745	–41.25	–51.31	10.1
XY	H	4^{th}	3660	–41.25	–52.83	11.6
XY	H	5^{th}	4575	–41.25	–60.83	19.6
XY	H	6^{th}	5490	–15.31	–58.63	43.3
XY	H	7^{th}	6405	–15.31	–57.02	41.7
XY	H	8^{th}	7320	–41.25	–57.81	16.6
XY	H	9^{th}	8235	–41.25	–54.36	13.1
XY	H	10^{th}	9150	–41.25	–51.96	10.7

Table 3. Radiated Harmonics, Ceramic Antenna Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XZ	V	Fund.	915	30.00	4.69	25.3
XZ	V	2nd	1830	–15.31	–52.52	37.2
XZ	V	3rd	2745	–41.25	–49.05	7.8
XZ	V	4th	3660	–41.25	–51.47	10.2
XZ	V	5th	4575	–41.25	–60.17	18.9
XZ	V	6th	5490	–15.31	–58.05	42.7
XZ	V	7th	6405	–15.31	–59.13	43.8
XZ	V	8th	7320	–41.25	–57.49	16.2
XZ	V	9th	8235	–41.25	–54.71	13.5
XZ	V	10th	9150	–41.25	–51.60	10.4
XZ	H	Fund.	915	30.00	0.57	29.4
XZ	H	2nd	1830	–15.31	–54.50	39.2
XZ	H	3rd	2745	–41.25	–52.53	11.3
XZ	H	4th	3660	–41.25	–48.17	6.9
XZ	H	5th	4575	–41.25	–61.21	20.0
XZ	H	6th	5490	–15.31	–59.15	43.8
XZ	H	7th	6405	–15.31	–58.44	43.1
XZ	H	8th	7320	–41.25	–57.44	16.2
XZ	H	9th	8235	–41.25	–54.53	13.3
XZ	H	10th	9150	–41.25	–52.99	11.7
YZ	V	Fund.	915	30.00	–6.05	36.1
YZ	V	2nd	1830	–15.31	–61.58	46.3
YZ	V	3rd	2745	–41.25	–50.08	8.8
YZ	V	4th	3660	–41.25	–55.23	14.0

Table 3. Radiated Harmonics, Ceramic Antenna Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
YZ	V	5th	4575	–41.25	–61.67	20.4
YZ	V	6th	5490	–15.31	–58.13	42.8
YZ	V	7th	6405	–15.31	–58.04	42.7
YZ	V	8th	7320	–41.25	–57.64	16.4
YZ	V	9th	8235	–41.25	–54.60	13.3
YZ	V	10th	9150	–41.25	–52.64	11.4
YZ	H	Fund.	915	30.00	3.40	26.6
YZ	H	2nd	1830	–15.31	–51.92	36.6
YZ	H	3rd	2745	–41.25	–50.89	9.6
YZ	H	4th	3660	–41.25	–49.75	8.5
YZ	H	5th	4575	–41.25	–60.20	19.0
YZ	H	6th	5490	–15.31	–58.56	43.3
YZ	H	7th	6405	–15.31	–57.52	42.2
YZ	H	8th	7320	–41.25	–57.17	15.9
YZ	H	9th	8235	–41.25	–53.83	12.6
YZ	H	10th	9150	–41.25	–52.70	11.5

2.5. Range Test (WES0112-01-ACM915D-01)

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the one-directional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte long packets. The GPS coordinates have been recorded for each spot. The distance between the spots were measured using Google Maps, and results are shown in meters. The range shown was tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board working in reduced (~+13 dBm or 0 dBm) power states, and the DUT (as shown in Figure 20.) held by the users hand. The Pico Board worked in a reduced power state (13 dBm or 0 dBm) during the range tests.

The range was tested in a flat land area without obstacles.

During the range tests, the following settings were used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the above settings (Set 1, Set 2, and Set 3) the following range tests are done here:

1. Range measurement with the CERAMIC Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the CERAMIC Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the CERAMIC Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the CERAMIC Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the CERAMIC Antenna Boards—The antenna boards are VERTICALLY polarized and the boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".
9. Reference range measurement with a 915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 3".

The measurement results are summarized in Figure 30.

The indoor range was not measured, due to the lack of a large enough building. But from the TX power and sensitivity data, an estimation can be given if one assumes an indoor propagation factor of 4.5, which is a typical value in normal office environments. Use the Silicon Labs' range calculator, which can be found on the webpage here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming a –8.5 dBi antenna gain (front direction, X-axes facing in XY cut) and the setting "Set 1" (50 kbps, 1% PER, 13 dBm), the estimated indoor range is 54 m, as it is shown in Figure 31. To the maximum antenna gain direction, the indoor range is ~74 m.

Set1	13dBm	50kbps	+/-25kHz
Set2	13dBm	100kbps	+/-50kHz
Set3	0dBm	1.2kbps	+/-1.2kHz

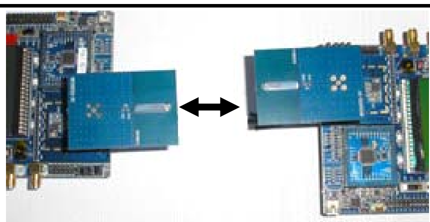
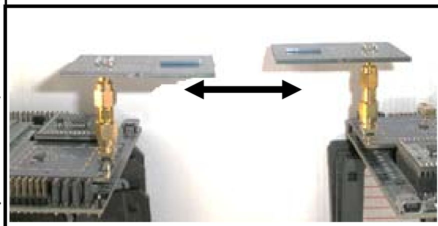
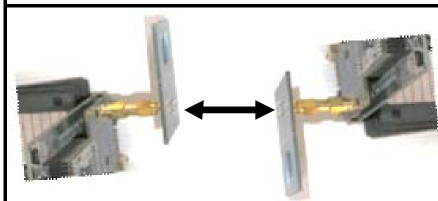
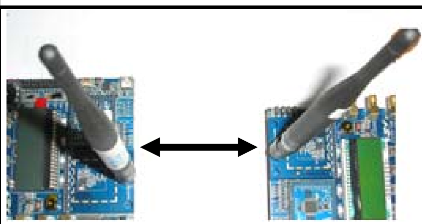
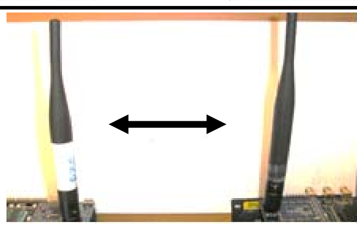
Antenna	Photo	Configuration	No.	Set	Power	Data rate	Deviation	GPS N	GPS E	Distance [m]
Chip Antenna		**Base**						**47.152880°**	**19.180930°**	**0.0**
Chip Antenna (WES0112)		H pol; Norm. direction	1	Set1	13dBm	50kbps	+/-25kHz	47.161710°	19.173620°	**1126.7**
Chip Antenna (WES0112)		V pol; Norm. direction	2	Set1	13dBm	50kbps	+/-25kHz	47.163110°	19.173390°	**1272.4**
			3	Set2	13dBm	100kbps	+/-50kHz	47.161710°	19.173510°	**1130.8**
			4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.163980°	19.173240°	**1364.4**
Chip Antenna (WES0112)		Max. direction: XZH 5°	5	Set1	13dBm	50kbps	+/-25kHz	47.163160°	19.173390°	**1277.4**
W1063		V pol; Norm. direction	6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
			7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	**2174.3**
W1063		H pol; Norm. direction	8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 30. Outdoor Range Test Result with Two Identical Ceramic (Chip) Antennas with the Reduced Power (+13 dBm) 4463-PCE20C915 Pico Board Driven by the WMB-930 Wireless Motherboard

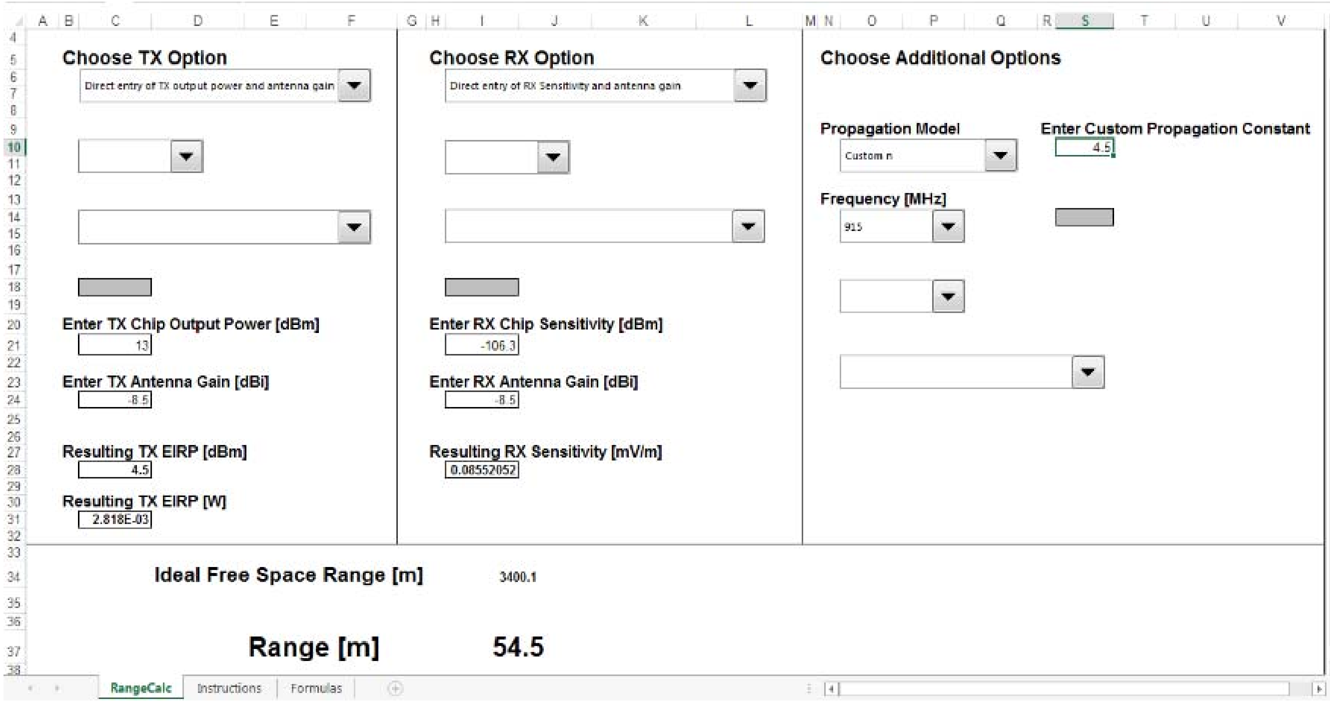


Figure 31. Indoor Range Estimation with Two Identical Ceramic (Chip) Antennas with the Reduced Power (+13 dBm) 4463-PCE20C915 Pico Board Driven by the WMB-930 Wireless Motherboard

3. Small Sized (Wire) Helical Antenna (WES0113-01-AWH915S-01)

The selected helical antenna is Antenna Factor's ANT-915-JJB-RA. For more information, go here:

https://www.linxtechnologies.com/resources/data-guides/ant-915-jjb-xx.pdf

An external matching network (shown in Figure 32) is required at the antenna input.

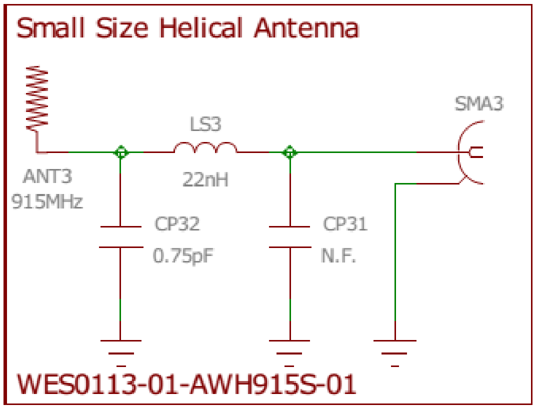


Figure 32. External Matching Network at 915 MHz for the Small Helical Antenna

The antenna is shown in Figure 33.

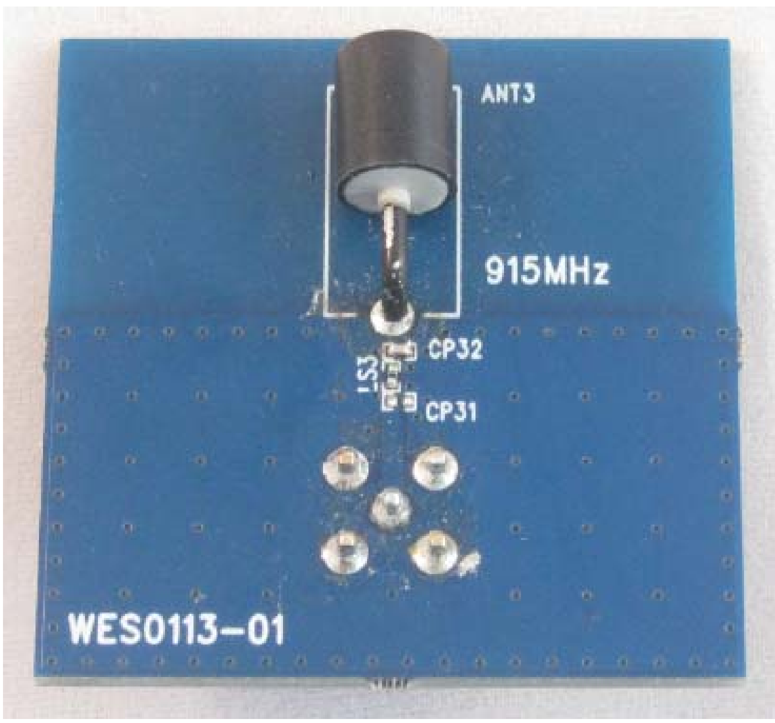


Figure 33. Small Sized Helical Antenna, (WES0113-01-AWH915S-01

3.1. Antenna Impedance (WES0113-01-AWH915S-01)

The impedance measurement setup is shown in Figure 34. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test the user's hand holds the motherboard. Typical hand position is shown in Figure 35.

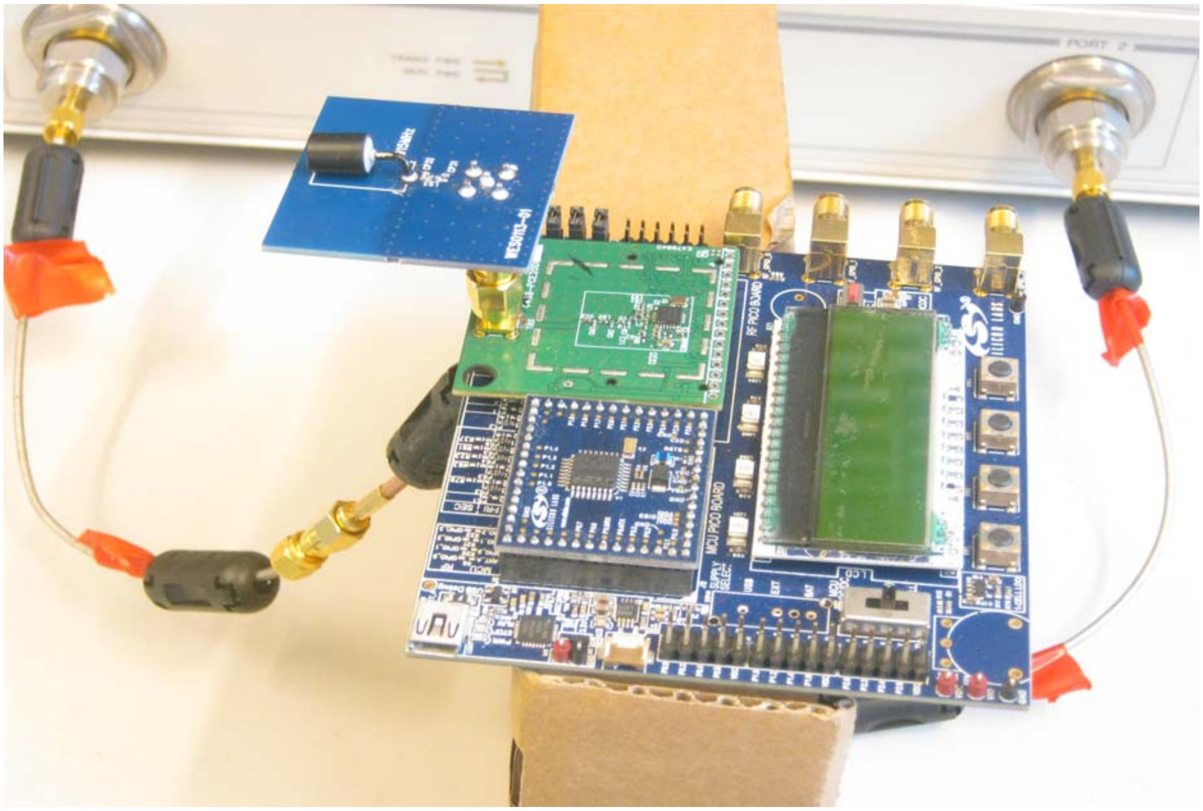


Figure 34. DUT in the Impedance Measurement Setup with the WES0113-01-AWH915S-01 Small Helical Antenna Board

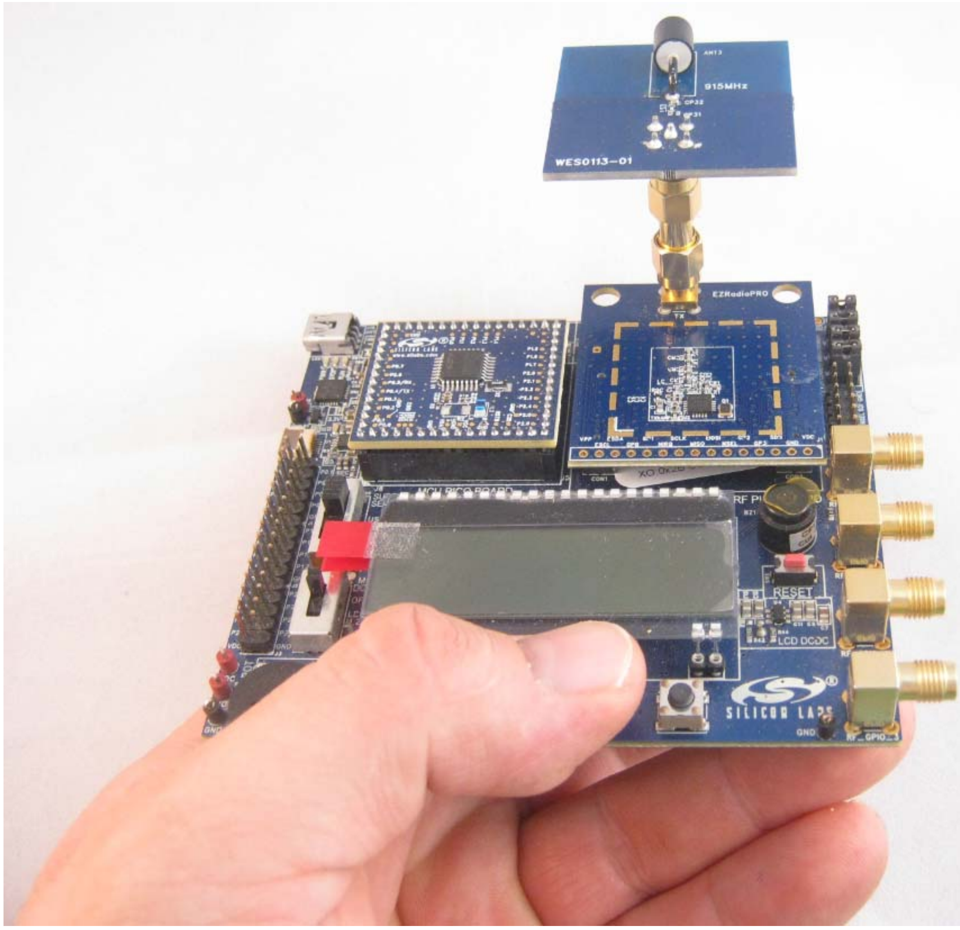


Figure 35. Typical Hand Effect on the Main Board During Impedance and Range Measurement WES0113-01-AWH915S-01 Small Helical Antenna Board

The measured impedance of the antenna with its external matching network is shown in Figure 36 (up to 3 GHz) with motherboard hand effect.

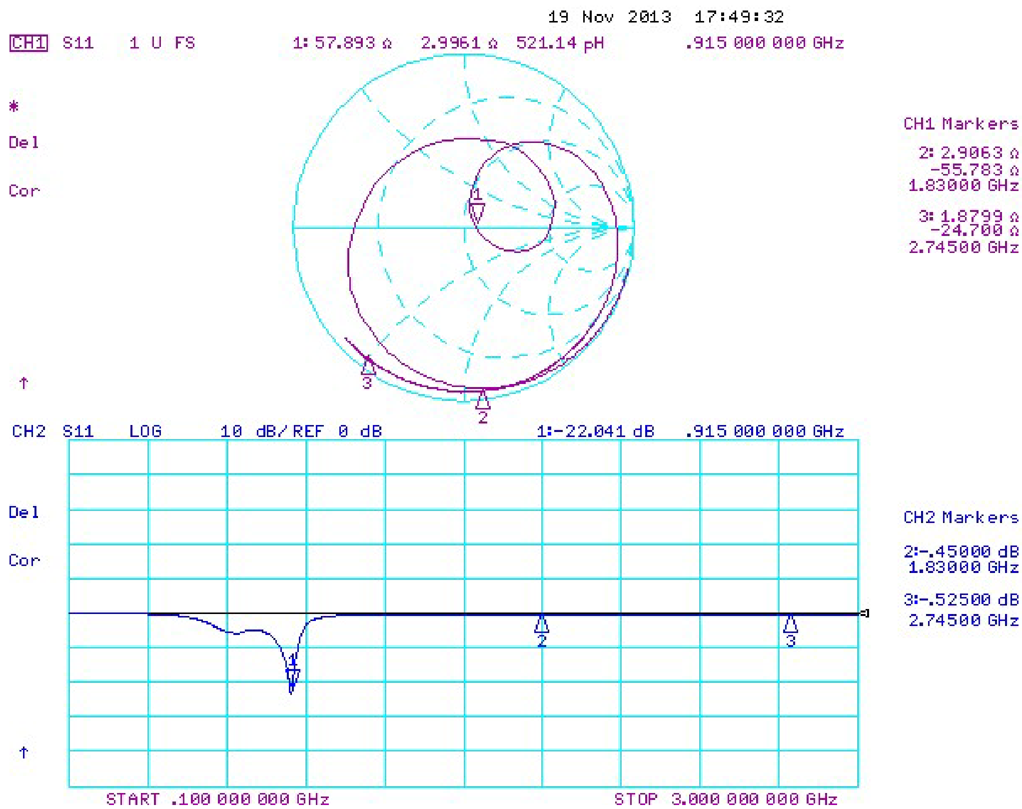


Figure 36. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

3.2. Antenna Gain (WES0113-01-AWH915S-01)

The antenna gain is calculated from both the measured radiated power at the fundamental and from the delivered power to the antenna by the 4463-PCE20C915 Pico Board. In the radiation measurement, the 4463-PCE20C915 Pico Board is set to reduced power state (0x1C results ~+10.2 dBm at 2.6 V_{DD}), and the entire setup is fed by two AA batteries. The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced (~10 dBm) power state is shown in Figure 37. This method can be effectively applied because the S11 of the antenna is much better than –10 dB, so the reflection loss is negligible.

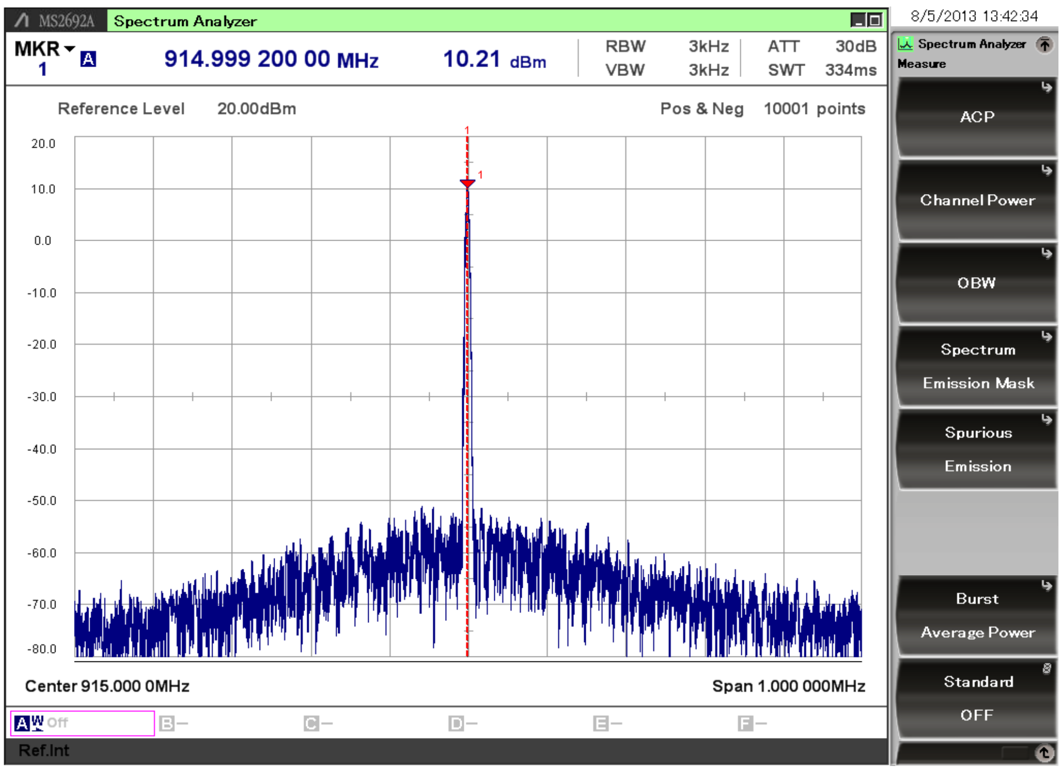


Figure 37. Conducted Measurement Result, 4463-PCE20C915 in ~10 dBm Power State

The measured radiated power maximum is at the XZ cut (Table 4). It is around +5.9 dBm EIRP, so the maximum gain number is ~–4.3 dBi as it is shown in Figure 41.

3.3. Radiation Patterns

The radiation patterns of the small sized helical antenna were measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition and with the WMB-930 Wireless Motherboard driving the Pico Board. Figure 39–Figure 44 show the radiation patterns at the fundamental frequency in the XY, XZ,and YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 38. Rotation starts from the X-axe in the XY cut, and begins from the Z-axe in the XZ and YZ cuts.

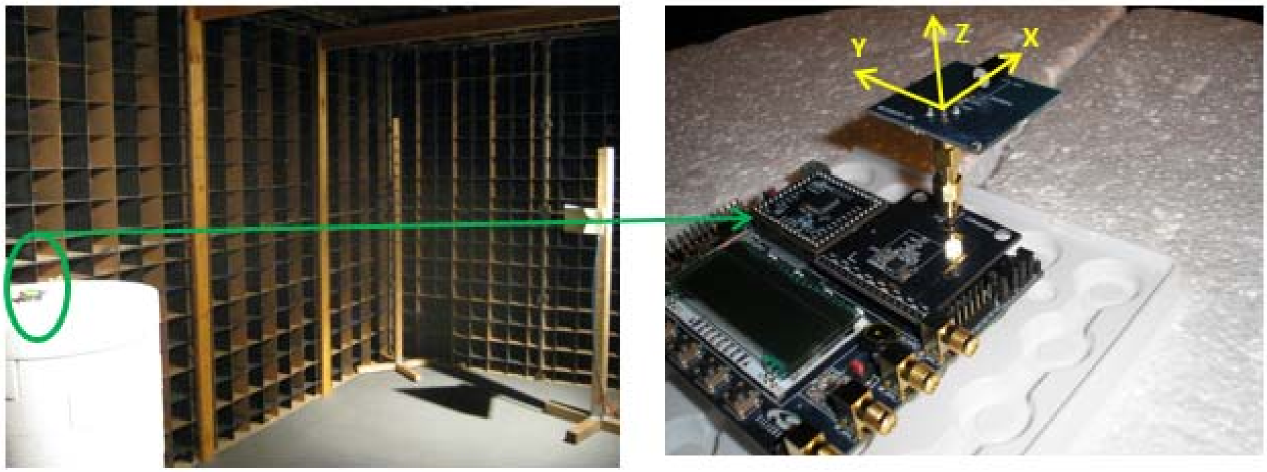


Figure 38. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 39–Figure 44).

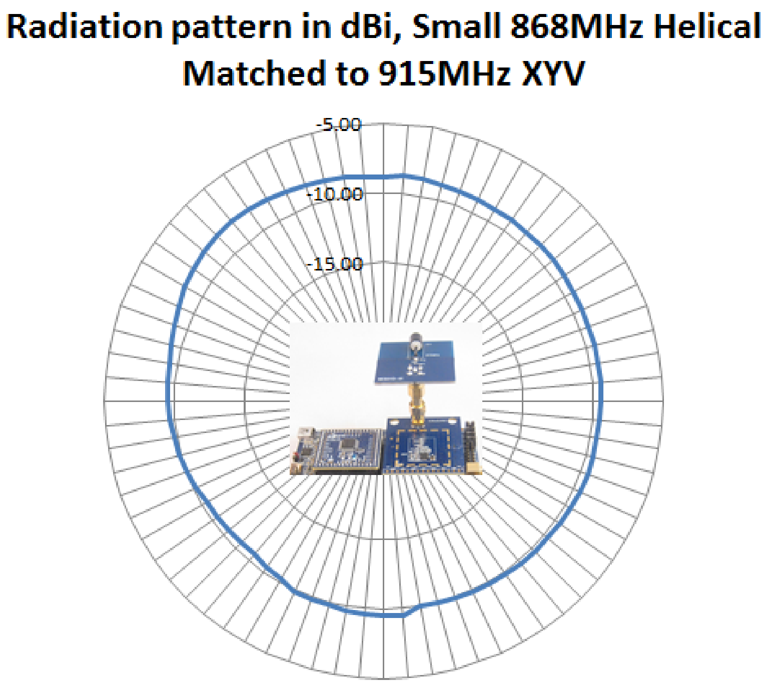


Figure 39. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

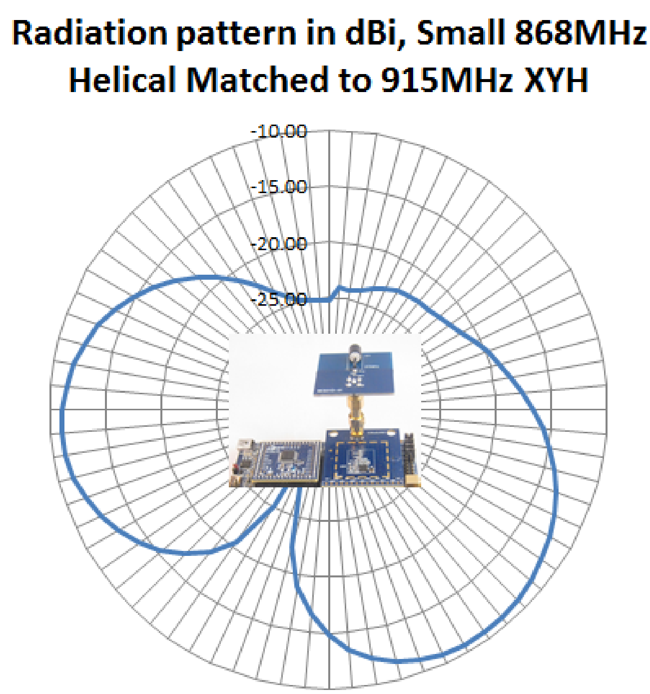


Figure 40. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

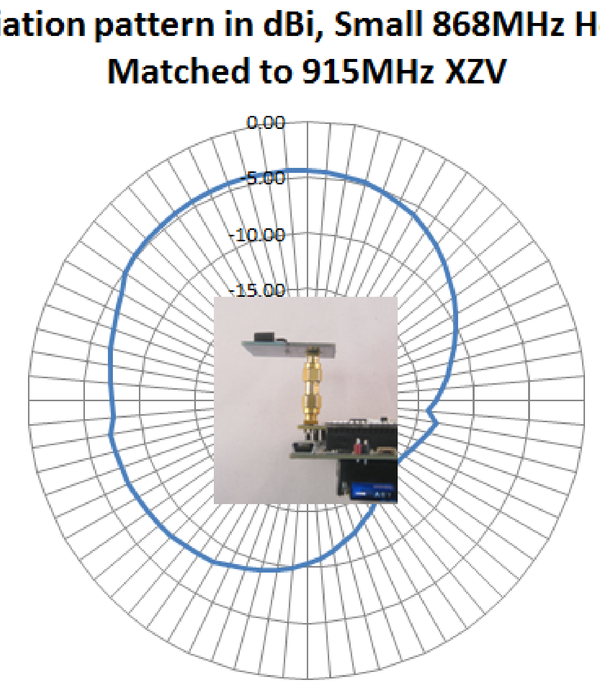


Figure 41. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

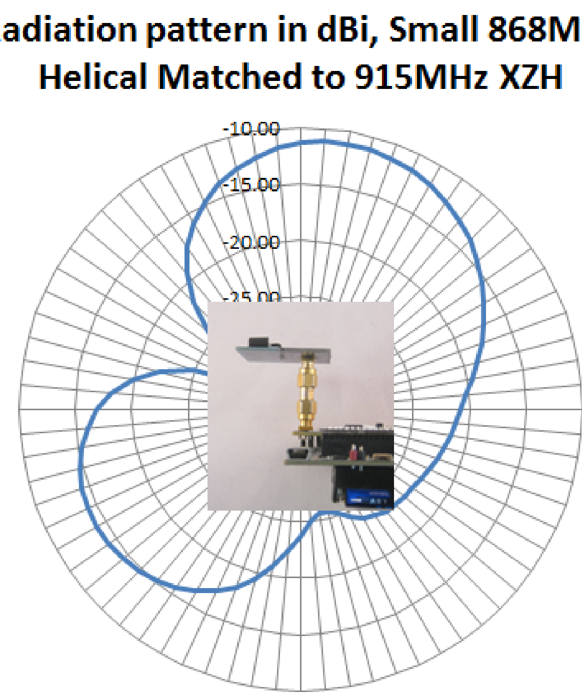


Figure 42. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

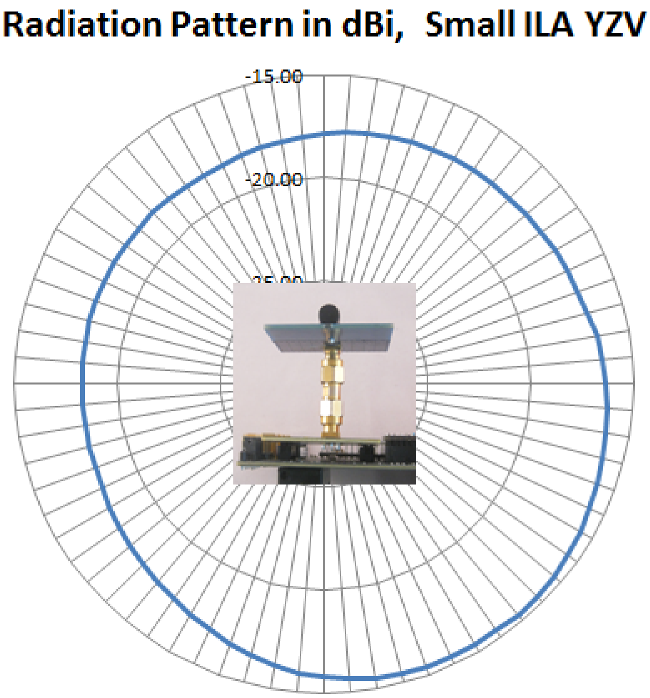


Figure 43. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

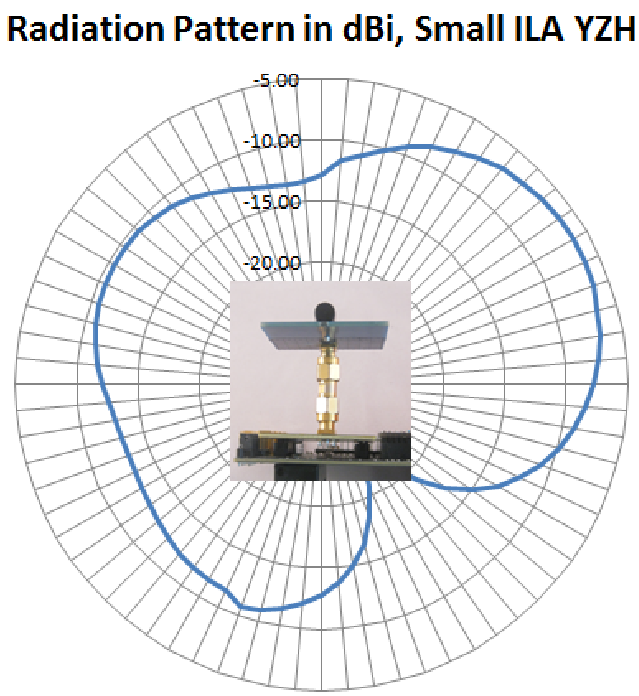


Figure 44. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

3.4. Radiated Harmonics

The radiated harmonics of the small sized helical antenna were also measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition and with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20C915 Pico Board works in a reduced power state (0x1C) and at 2.6 V_{DD} to have ~+10.2 dBm power delivered to the antenna board. The maximum radiated power levels up to the 10th harmonic were measured in the XY, XZ, and YZ cut, with both horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 4) with the corresponding standard limits.

The Antenna is FCC compliant with a large margin.

Table 4. Radiated Harmonics, Small Sized Helical ILA Antenna Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	2.12	27.9
XY	V	2nd	1830	–14.08	–50.10	36.0
XY	V	3rd	2745	–41.25	–50.96	9.7
XY	V	4th	3660	–41.25	–50.86	9.6
XY	V	5th	4575	–41.25	–61.44	20.2
XY	V	6th	5490	–14.08	–58.81	44.7
XY	V	7th	6405	–14.08	–58.31	44.2
XY	V	8th	7320	–41.25	–55.89	14.6
XY	V	9th	8235	–41.25	–54.37	13.1
XY	V	10th	9150	–41.25	–53.04	11.8
XY	H	Fund.	915	30.00	–0.43	30.4
XY	H	2nd	1830	–14.08	–54.94	40.9
XY	H	3rd	2745	–41.25	–50.57	9.3
XY	H	4th	3660	–41.25	–52.18	10.9
XY	H	5th	4575	–41.25	–61.88	20.6
XY	H	6th	5490	–14.08	–58.83	44.7
XY	H	7th	6405	–14.08	–57.99	43.9
XY	H	8th	7320	–41.25	–56.71	15.5
XY	H	9th	8235	–41.25	–54.62	13.4

Table 4. Radiated Harmonics, Small Sized Helical ILA Antenna Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	H	10th	9150	–41.25	–52.29	11.0
XZ	V	Fund.	915	30.00	5.92	24.1
XZ	V	2nd	1830	–14.08	–51.40	37.3
XZ	V	3rd	2745	–41.25	–50.14	8.9
XZ	V	4th	3660	–41.25	–51.58	10.3
XZ	V	5th	4575	–41.25	–61.59	20.3
XZ	V	6th	5490	–14.08	–58.29	44.2
XZ	V	7th	6405	–14.08	–58.63	44.5
XZ	V	8th	7320	–41.25	–55.49	14.2
XZ	V	9th	8235	–41.25	–53.82	12.6
XZ	V	10th	9150	–41.25	–51.90	10.7
XZ	H	Fund.	915	30.00	–0.84	30.8
XZ	H	2nd	1830	–14.08	–48.65	34.6
XZ	H	3rd	2745	–41.25	–52.89	11.6
XZ	H	4th	3660	–41.25	–47.94	6.7
XZ	H	5th	4575	–41.25	–59.39	18.1
XZ	H	6th	5490	–14.08	–58.96	44.9
XZ	H	7th	6405	–14.08	–58.79	44.7
XZ	H	8th	7320	–41.25	–57.46	16.2
XZ	H	9th	8235	–41.25	–54.25	13.0
XZ	H	10th	9150	–41.25	–52.88	11.6
YZ	V	Fund.	915	30.00	–3.81	33.8
YZ	V	2nd	1830	–14.08	–55.91	41.8

Table 4. Radiated Harmonics, Small Sized Helical ILA Antenna Board Connected to the Reduced Power (~+10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP	Measured radiated power in EIRP [dBm]	Margin [dB]
YZ	V	3rd	2745	–41.25	–49.22	8.0
YZ	V	4th	3660	–41.25	–55.01	13.8
YZ	V	5th	4575	–41.25	–60.62	19.4
YZ	V	6th	5490	–14.08	–59.42	45.3
YZ	V	7th	6405	–14.08	–58.33	44.2
YZ	V	8th	7320	–41.25	–57.08	15.8
YZ	V	9th	8235	–41.25	–52.61	11.4
YZ	V	10th	9150	–41.25	–52.19	10.9
YZ	H	Fund.	915	30.00	3.35	26.6
YZ	H	2nd	1830	–14.08	–51.57	37.5
YZ	H	3rd	2745	–41.25	–49.93	8.7
YZ	H	4th	3660	–41.25	–49.07	7.8
YZ	H	5th	4575	–41.25	–61.02	19.8
YZ	H	6th	5490	–14.08	–59.03	44.9
YZ	H	7th	6405	–14.08	–58.26	44.2
YZ	H	8th	7320	–-41.25	–56.79	15.5
YZ	H	9th	8235	–41.25	–51.24	10.0
YZ	H	10th	9150	–41.25	–52.65	11.4

3.5. Range Test

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the one-directional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte long packets. The GPS coordinates have been recorded for each spot. The distance between the spots was measured using Google Maps, and results are shown in meters. The range tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board with reduced power states (+13 dBm and 0 dBm), and the DUT (shown in Figure 34) held by the users hand. The Pico Board worked in a reduced power state (+13 dBm or 0 dBm) during the range tests.

The range was tested in a flat land area without obstacles.

During the range test, the following settings were used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the above settings (Set 1, Set 2, and Set 3) the following range tests are done here:

1. Range measurement with the SMALL HELICAL Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the SMALL HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the SMALL HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the SMALL HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the SMALL HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 45.

The indoor range was not measured, due to the lack of a large enough building. But from the TX power and sensitivity data, an estimation can be given if one assumes an indoor propagation factor of 4.5, which is a typical value in normal office environments. Use the Silicon Labs' range calculator which can be found on the webpage here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming a –8.5 dBi antenna gain (front direction, X-axes facing) and the setting "Set 1" (50 kbps, 1% PER, 13 dBm), the estimated indoor range is 81 m, as it is shown in Figure 46. To the maximum antenna gain direction, the indoor range is ~55 m.

Set	Power	Data rate	Deviation
Set1	13dBm	50kbps	+/-25kHz
Set2	13dBm	100kbps	+/-50kHz
Set3	0dBm	1.2kbps	+/-1.2kHz

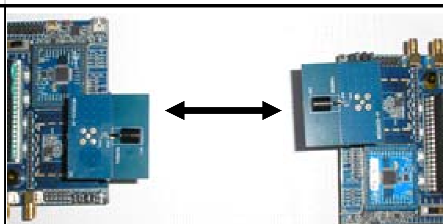
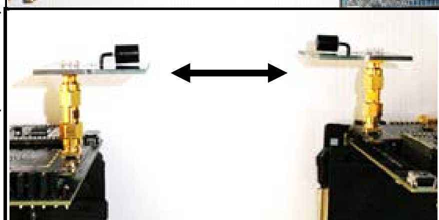
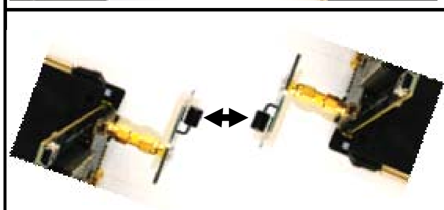
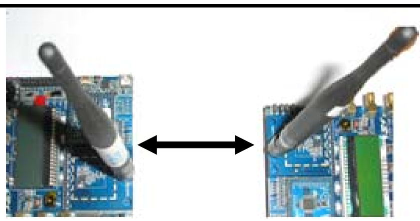
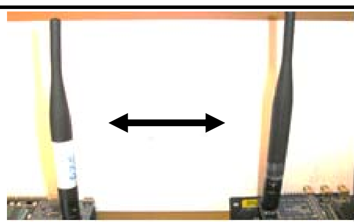
Antenna	Setup	#	Set	Power	Data rate	Deviation	GPS N	GPS E	Distance [m]
Small Helical					**Base**		**47.152880°**	**19.180930°**	**0.0**
Small Helical (WES0113)	 H pol; Norm. direction	1	Set1	13dBm	50kbps	+/-25kHz	47.161170°	19.173690°	**1072.1**
Small Helical (WES0113)	 V pol; Norm. direction	2	Set1	13dBm	50kbps	+/-25kHz	47.162820°	19.173360°	**1244.7**
		3	Set2	13dBm	100kbps	+/-50kHz	47.161580°	19.173630°	**1113.8**
		4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.162330°	19.173490°	**1191.9**
Small Helical (WES0113)	 Max. direction w/o hand: XZV 340° //Meas w hand: 250°	5	Set1	13dBm	50kbps	+/-25kHz	47.164620°	19.173150°	**1431.8**
W1063	 V pol; Norm. direction	6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	**2174.3**
W1063	 H pol; Norm. direction	8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 45. Outdoor Range Test Result with Two Identical Small Sized Helical Antennas with Reduced Rower (~+13 dBm and 0 dBm) 4463-PCE20C915 Pico Board Driven by the WMB-930 Wireless Motherboard

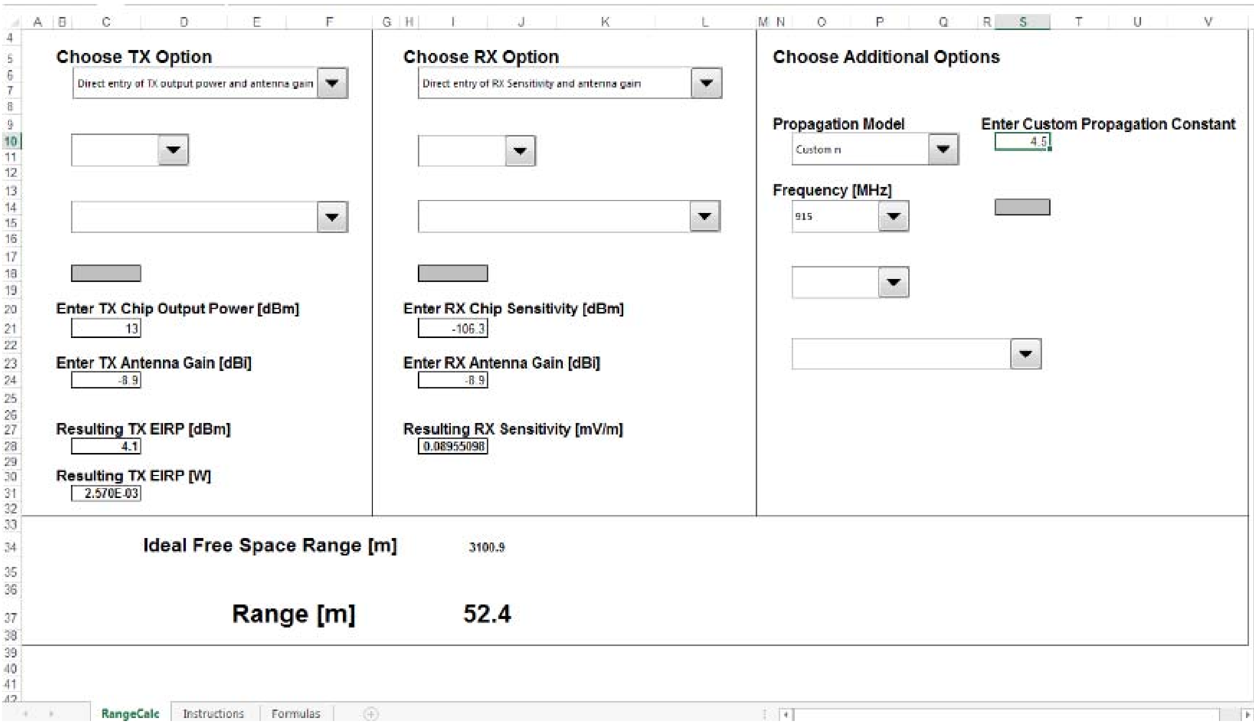


Figure 46. Indoor Range Estimation with Two Identical Ceramic (Chip) Antennas with Reduced Power (~+13 dBm) 4463-PCE20C915 Pico Board Driven by the WMB-930 Wireless Motherboard

4. Medium Sized (Wire) Helical Antenna (WES0114-01-AWH915M-01)

The selected helical antenna is Antenna Factor's ANT-916-HETH. For more information, go here:

https://www.linxtechnologies.com/resources/data-guides/ant-xxx-hexx.pdf

An external matching network (shown in Figure 47) is required at the antenna input.

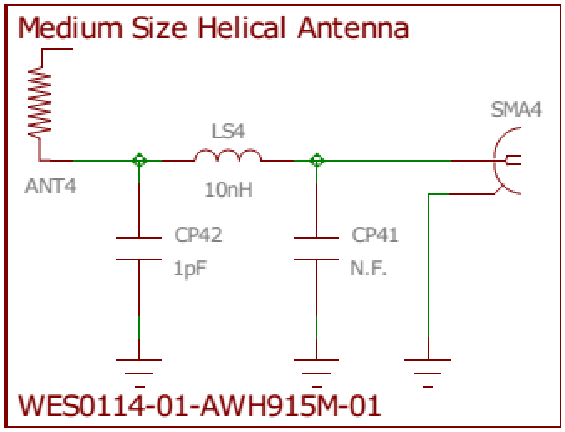


Figure 47. External Matching Network at 915 M for the Medium Helical Antenna

The antenna is shown in Figure 48:

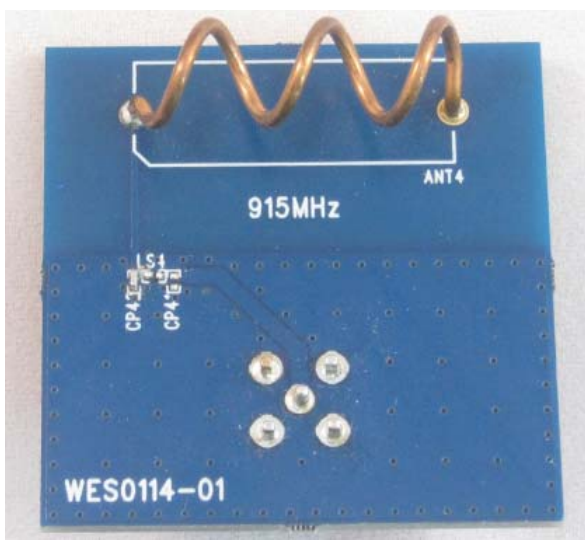


Figure 48. Medium Sized Helical Antenna

4.1. Antenna Impedance (WES0114-01-AWH915M-01)

The impedance measurement setup is shown in Figure 49. In the case of the Medium Sized Helical Antenna, the board is connected to a 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test, the user's hand holds the motherboard. Typical hand position is shown in Figure 50.

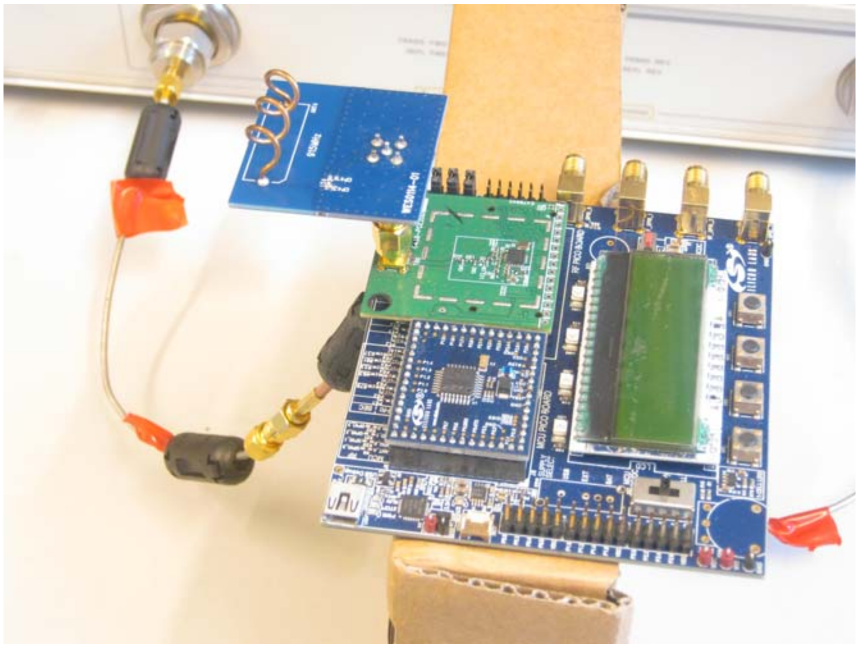


Figure 49. DUT in the Impedance Measurement Setup (Medium Sized Helical Antenna Board [WES0114-01-AWH915M-01])

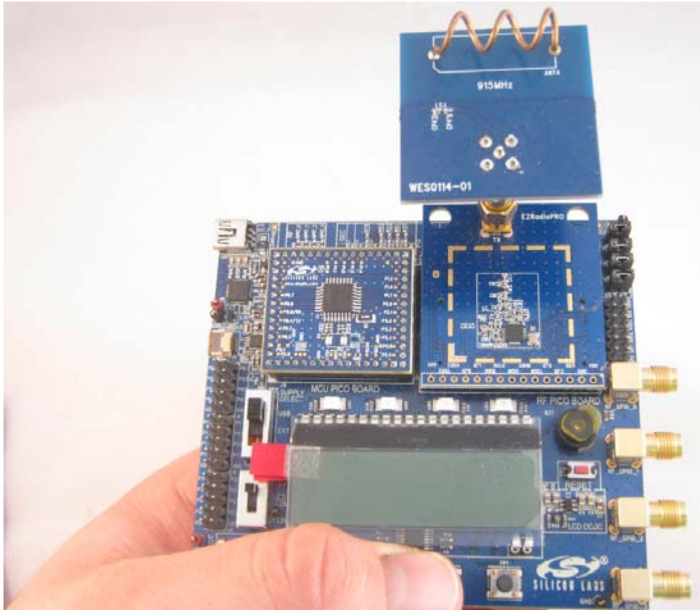


Figure 50. Typical Hand Effect on the Main Board During Impedance and Range Measurement (Medium Sized Helical Antenna Board [WES0114-01-AWH915M-01])

The measured impedance of the antenna with its external matching network is shown in Figure 51 (up to 3 GHz) with motherboard hand effect.

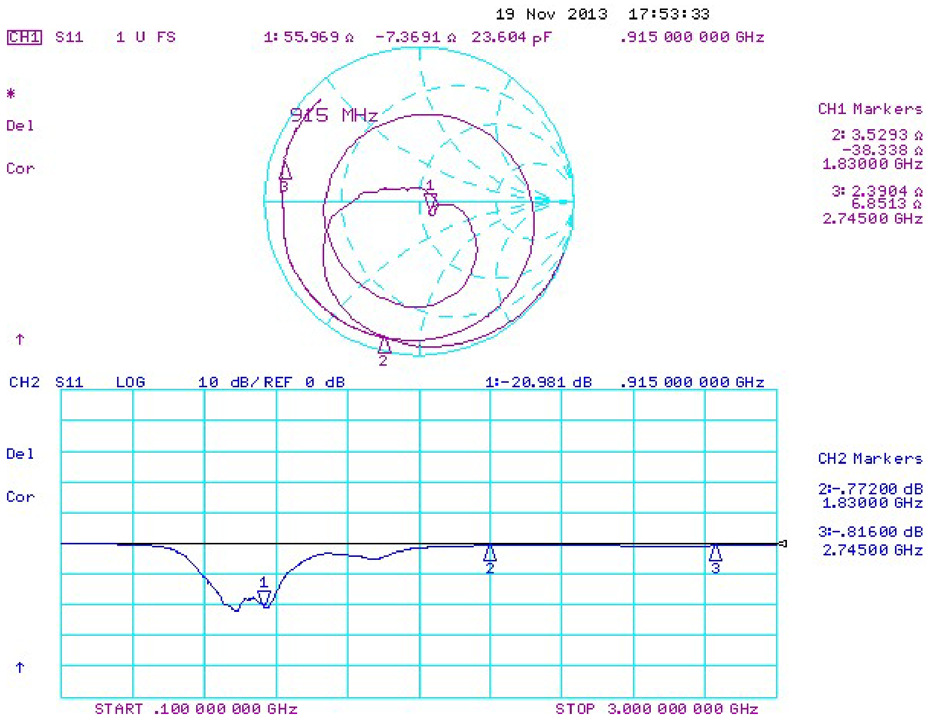


Figure 51. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

4.2. Antenna Gain (WES0114-01-AWH915M-01)

The antenna gain is calculated from both the measured radiated power at the fundamental and from the delivered power to the antenna, determined by conducted SA measurements on the 50 Ω termination (shown in Figure 52). This method can be effectively applied because the S11 of the antenna is much better than –10 dB, so the reflection is negligible.

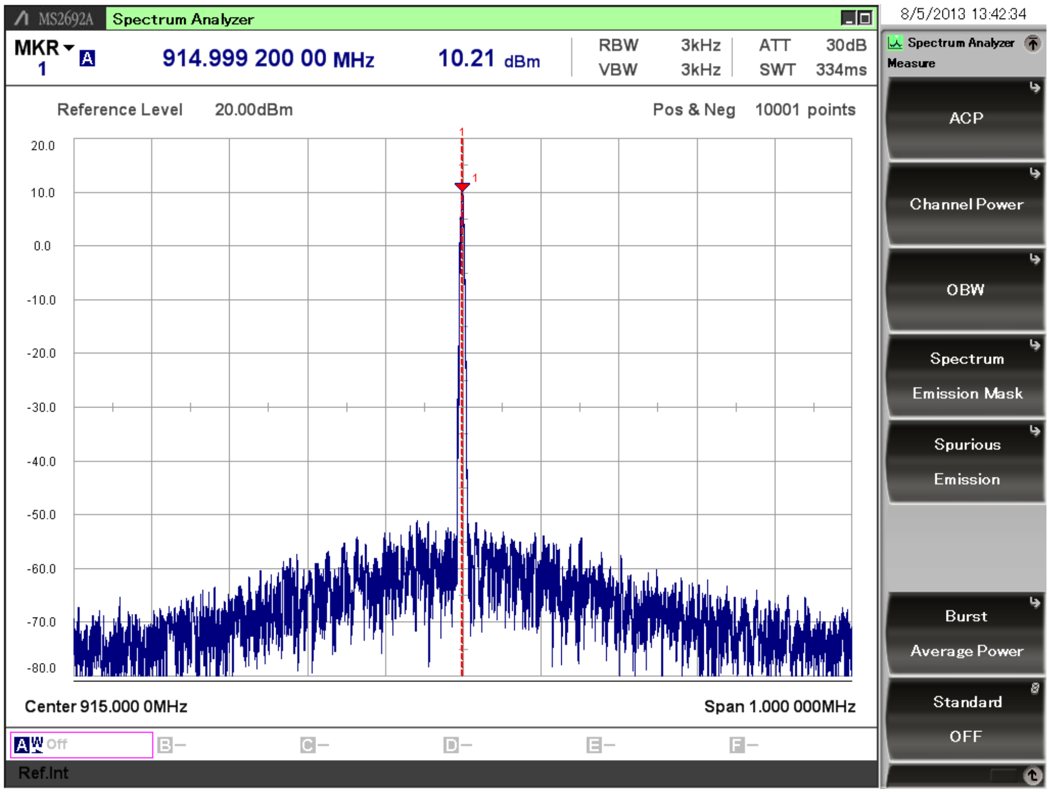


Figure 52. Conducted Measurement Result, 4463-PCE20C915M in a Reduced Power State (0x1C and 2.6 V V_{DD}) with ~+10.2 dBm

The measured radiated power maximum is at the XZ cut (Table 5). It is around 10.4 dBm EIRP, so the maximum gain number is ~+0.2 dBi, as it is shown in Figure 56.

4.3. Radiation Patterns (WES0114-01-AWH915M-01)

The radiation patterns of the medium sized helical antenna were measured in an antenna chamber using the 4463-PCE20C915 Pico Board in a reduced power state (~+10.2 dBm) connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. Figure 54—Figure 59 show the radiation patterns at the fundamental frequency in the XY, XZ, YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 53. In the XY cut the rotation starts from the X-axe, while in the XZ and YZ cuts it starts from the Z-axe.

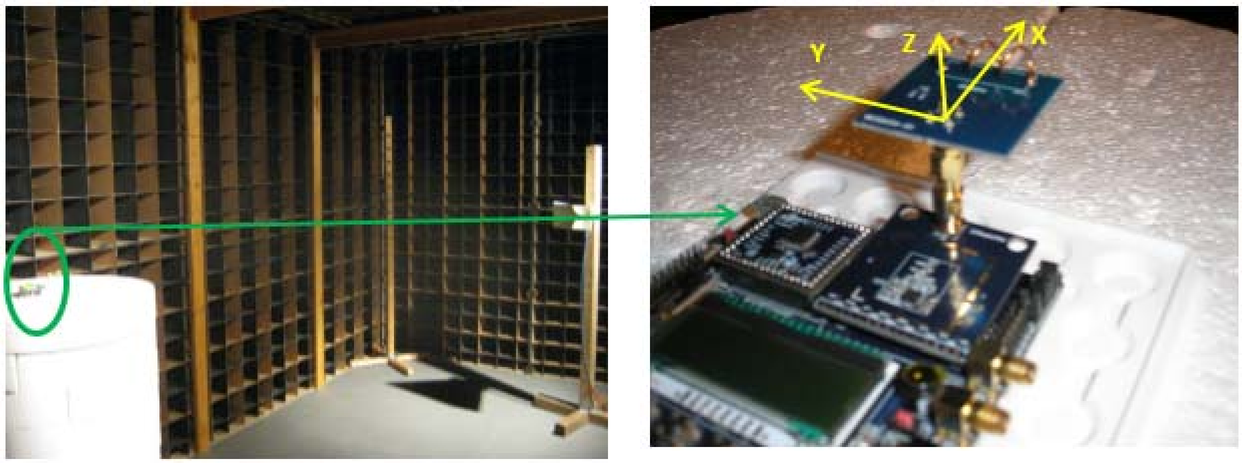


Figure 53. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 54—Figure 59).

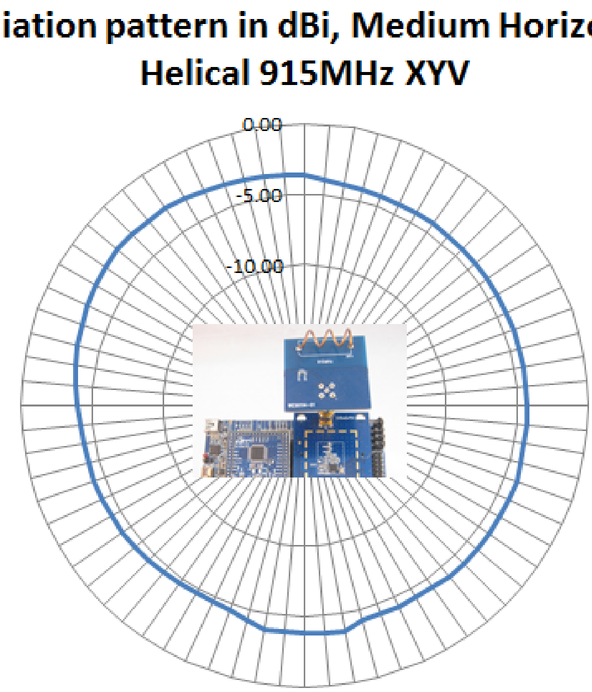


Figure 54. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

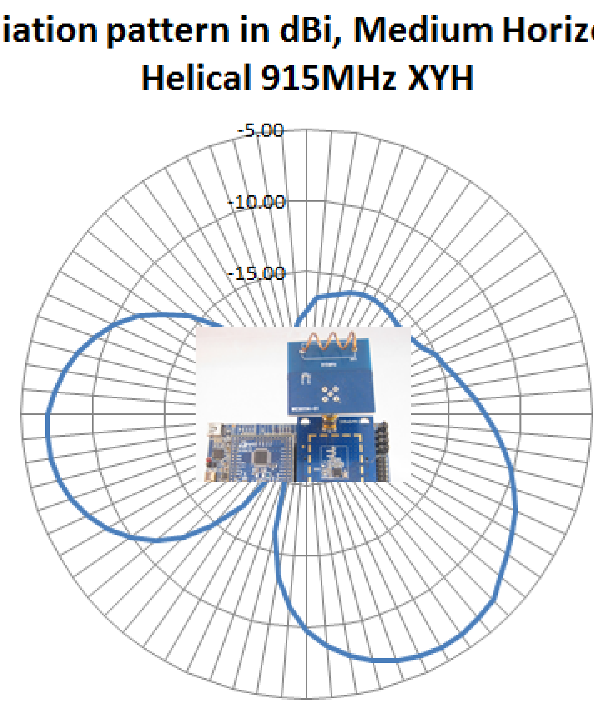


Figure 55. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

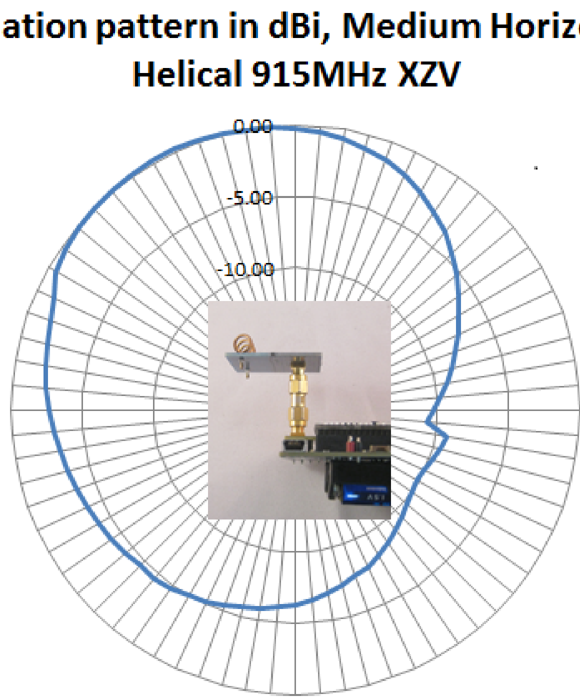


Figure 56. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

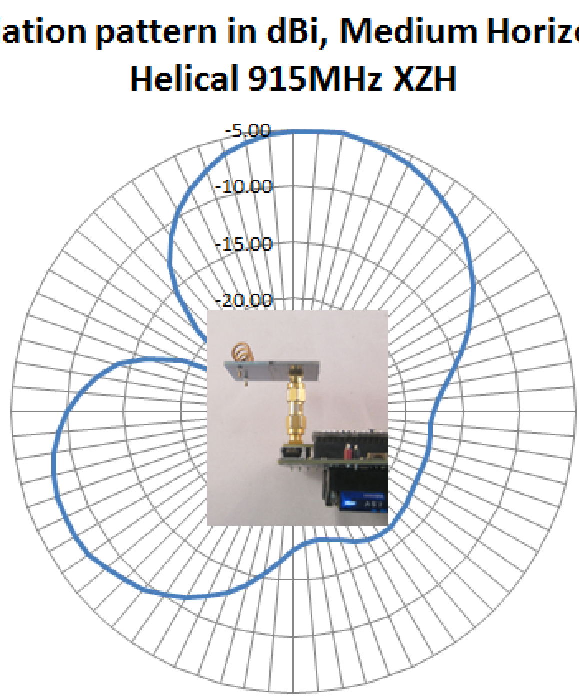


Figure 57. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

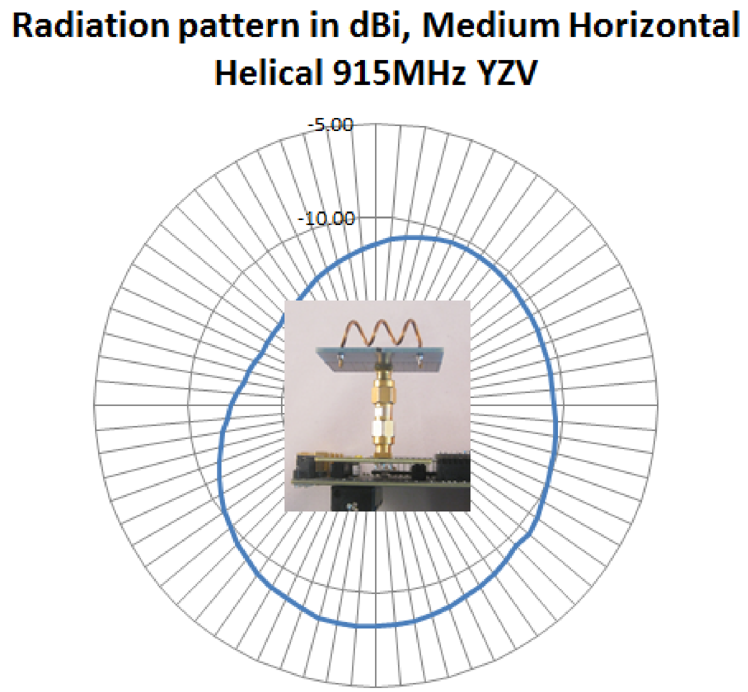


Figure 58. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

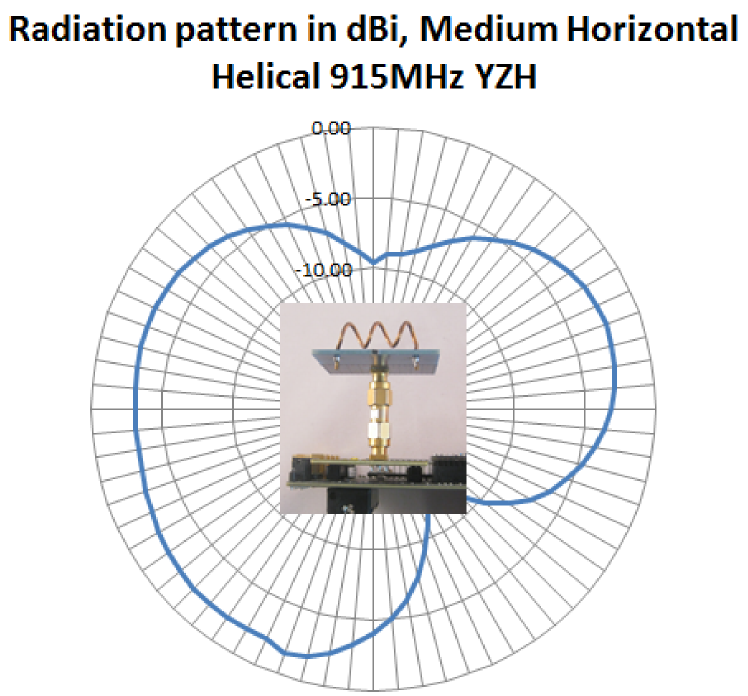


Figure 59. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

4.4. Radiated Harmonics (WES0114-01-AWH915M-01)

The radiated harmonics of the medium size helical antenna were also measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20C915 Pico Board works in a reduced power state (~+10.2 dBm, power state 0x1C, 2.6 V V_{DD}). The maximum radiated power levels up to the 10^{th} harmonic were measured in the XY, XZ, and YZ cut, with both horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 5) with the corresponding standard limits.

The Antenna is FCC compliant, with large enough margin.

Table 5. Radiated Harmonics, Medium Helical Antenna Board Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	7.41	22.6
XY	V	2^{nd}	1830	–9.61	–50.35	40.7
XY	V	3^{rd}	2745	–41.25	–51.16	9.9
XY	V	4^{th}	3660	–41.25	–52.01	10.8
XY	V	5^{th}	4575	–41.25	–60.47	19.2
XY	V	6^{th}	5490	–9.61	–59.16	49.5
XY	V	7^{th}	6405	–9.61	–56.67	47.1
XY	V	8^{th}	7320	–41.25	–57.36	16.1
XY	V	9^{th}	8235	–41.25	–55.97	14.7
XY	V	10^{th}	9150	–41.25	–52.35	11.1
XY	H	Fund.	915	30.00	4.14	25.9
XY	H	2^{nd}	1830	–9.61	–45.10	35.5
XY	H	3^{rd}	2745	–41.25	–52.03	10.8
XY	H	4^{th}	3660	–41.25	–53.37	12.1
XY	H	5^{th}	4575	–41.25	–60.74	19.5
XY	H	6^{th}	5490	–9.61	–58.31	48.7
XY	H	7^{th}	6405	–9.61	–58.37	48.8
XY	H	8^{th}	7320	–41.25	–57.48	16.2
XY	H	9^{th}	8235	–41.25	–56.24	15.0
XY	H	10^{th}	9150	–41.25	–52.38	11.1

Table 5. Radiated Harmonics, Medium Helical Antenna Board Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XZ	V	Fund.	915	30.00	10.39	19.6
XZ	V	2nd	1830	–9.61	–50.86	41.3
XZ	V	3rd	2745	–41.25	–50.24	9.0
XZ	V	4th	3660	–41.25	–52.71	11.5
XZ	V	5th	4575	–41.25	–61.14	19.9
XZ	V	6th	5490	–9.61	–59.16	49.6
XZ	V	7th	6405	–9.61	–56.61	47.0
XZ	V	8th	7320	–41.25	–57.60	16.4
XZ	V	9th	8235	–41.25	–55.46	14.2
XZ	V	10th	9150	–41.25	–52.40	11.1
XZ	H	Fund.	915	30.00	5.21	24.8
XZ	H	2nd	1830	–9.61	–44.16	34.6
XZ	H	3rd	2745	–41.25	–55.23	14.0
XZ	H	4th	3660	–41.25	–49.03	7.8
XZ	H	5th	4575	–41.25	–60.06	18.8
XZ	H	6th	5490	–9.61	–58.52	48.9
XZ	H	7th	6405	–9.61	–56.95	47.3
XZ	H	8th	7320	–41.25	–57.99	16.7
XZ	H	9th	8235	–41.25	–55.13	13.9
XZ	H	10th	9150	–41.25	–52.57	11.3
YZ	V	Fund.	915	30.00	1.98	28.0
YZ	V	2nd	1830	–9.61	–41.26	31.7
YZ	V	3rd	2745	–41.25	–49.76	8.5
YZ	V	4th	3660	–41.25	–55.16	13.9

Table 5. Radiated Harmonics, Medium Helical Antenna Board Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
YZ	V	5th	4575	–41.25	–60.50	19.3
YZ	V	6th	5490	–9.61	–59.15	49.5
YZ	V	7th	6405	–9.61	–56.47	46.9
YZ	V	8th	7320	–41.25	–56.50	15.2
YZ	V	9th	8235	–41.25	–55.43	14.2
YZ	V	10th	9150	–41.25	–52.24	11.0
YZ	H	Fund.	915	30.00	8.72	21.3
YZ	H	2nd	1830	–9.61	–49.98	40.4
YZ	H	3rd	2745	–41.25	–51.51	10.3
YZ	H	4th	3660	–41.25	–50.84	9.6
YZ	H	5th	4575	–41.25	–61.22	20.0
YZ	H	6th	5490	–9.61	–59.29	49.7
YZ	H	7th	6405	–9.61	–57.75	48.1
YZ	H	8th	7320	–41.25	–56.41	15.2
YZ	H	9th	8235	–41.25	–54.59	13.3
YZ	H	10th	9150	–41.25	–50.98	9.7

4.5. Range Test (WES0114-01-AWH915M-01)

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the one-directional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte packet length. The GPS coordinates have been recorded for each spot. The distance between the spots were measured using Google Maps, and results are shown in meters. The range was tested between two identical units with the WMB-930 Wireless Motherboard, reduced power 4463-PCE20C915 Pico Board, and the DUT (as shown in Figure 50) held by the users hand.

The range was tested in a flat land area without obstacles.

During the range test, the following settings were used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the above settings (Set 1, Set 2, and Set 3) the following range tests are done here:

1. Range measurement with the MEDIUM HELICAL Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the MEDIUM HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the MEDIUM HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the MEDIUM HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the MEDIUM HELICAL Antenna Boards—The antenna boards are VERTICALLY polarized and the boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 60.

The indoor range test was not performed, due to the lack of a large enough building. But from the TX power and sensitivity data, an indoor range estimation can be given if one assumes a propagation factor of 4.5, which is a typical value in normal office environments. Use Silicon Labs' range calculator, which can be found here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming a ~–3.7 dBi antenna gain (front direction, X-axes facing, XY cut) and the setting "Set 1" (50 kbps, 1% PER, 13 dBm), the estimated indoor range is 81 m as shown in Figure 61. If the boards are facing with the direction of maximum radiation, the indoor range increases to ~121 m.

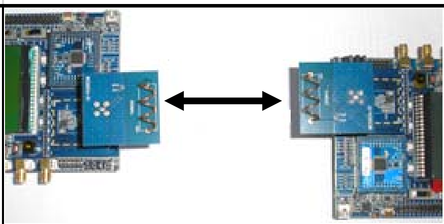
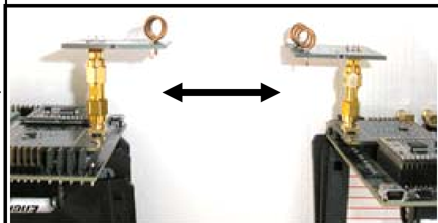
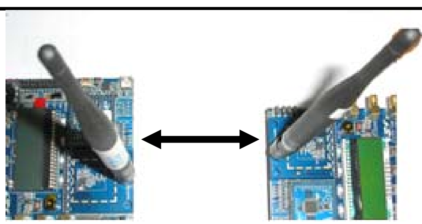
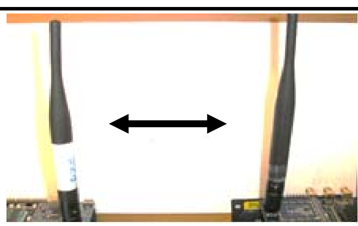
		Set1	13dBm	50kbps	+/-25kHz				
		Set2	13dBm	100kbps	+/-50kHz				
		Set3	0dBm	1.2kbps	+/-1.2kHz		**GPS**		**Distance [m]**
							N	**E**	
	Medium Helical				**Base**		**47.152880°**	**19.180930°**	**0.0**
Medium Helical (WES0114)				H pol; Norm. direction					
							GPS		
							N	E	
		1	Set1	13dBm	50kbps	+/-25kHz	47.165190°	19.172980°	**1495.0**
				V pol; Norm. direction					
							GPS		
							N	E	
		2	Set1	13dBm	50kbps	+/-25kHz	47.168570°	19.172500°	**1857.4**
		3	Set2	13dBm	100kbps	+/-50kHz	47.166110°	19.172900°	**1591.5**
		4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.166580°	19.172830°	**1641.9**
				Max. direction w/o hand: XZV 330°					
							GPS		
							N	E	
		5	Set1	13dBm	50kbps	+/-25kHz	TBD	TBD	**TBD**
W1063				V pol; Norm. direction					
							GPS		
							N	E	
		6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	**2174.3**
				H pol; Norm. direction					
							GPS		
							N	E	
		8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 60. Outdoor Range Test Result with Two Identical Medium Sized Helical Antennas with the 4463-PCE20C915 Pico Board Working in Reduced Power States Driven by the WMB-930 Wireless Motherboard

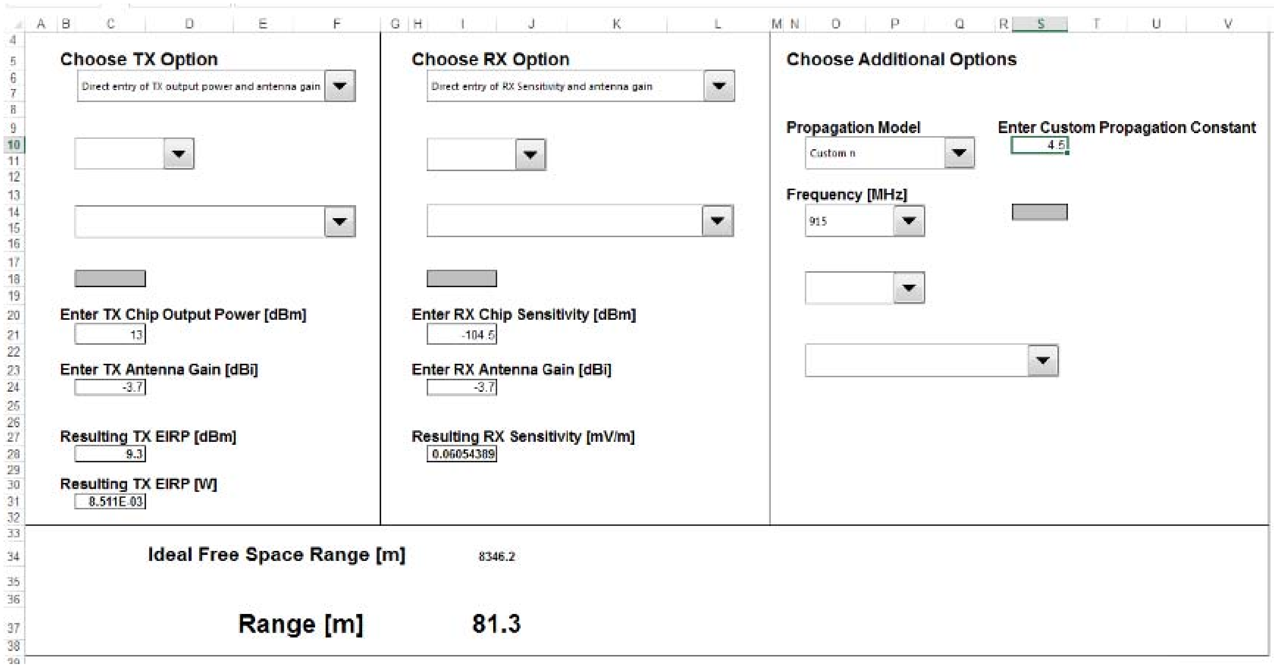


Figure 61. Indoor Range Estimation with Two Identical Medium Sized Helical Antennas and with the 4463-PCE20C915 Pico Board Working in Reduced Power State, Driven by the WMB-930 Wireless Motherboard

5. Panic Button IFA (Printed) Along the Circumference (WES0115-01-APF915P-01)

The Panic Button IFA antenna has the following characteristics:

- The antenna trace width is 0.5 mm.
- The distance between the antenna trace outer edge and the PCB cutting edge is 1.5 mm.
- The distance between the antenna trace inner edge and ground metal is 2 mm.
- No capacitance (Ctop) at the end of the antenna is required.
- No parallel capacitance or any other matching element at the antenna input is required. Only a series 0 Ω is used to connect the antenna as it is shown in Figure 62.

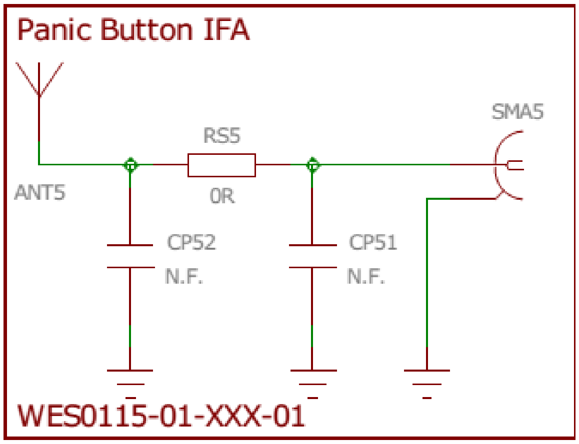


Figure 62. 0 Ω Connection of the Panic Button IFA Antenna at 915 M

The antenna is shown in Figure 63:

Figure 63. Panic Button IFA Antenna (WES0115-01-APF915P-01)

5.1. Antenna Impedance (WES0115-01-APF915P-01)

The impedance measurement setup is shown in Figure 64. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test, the user's hand holds the motherboard. Typical hand position is shown in Figure 65.

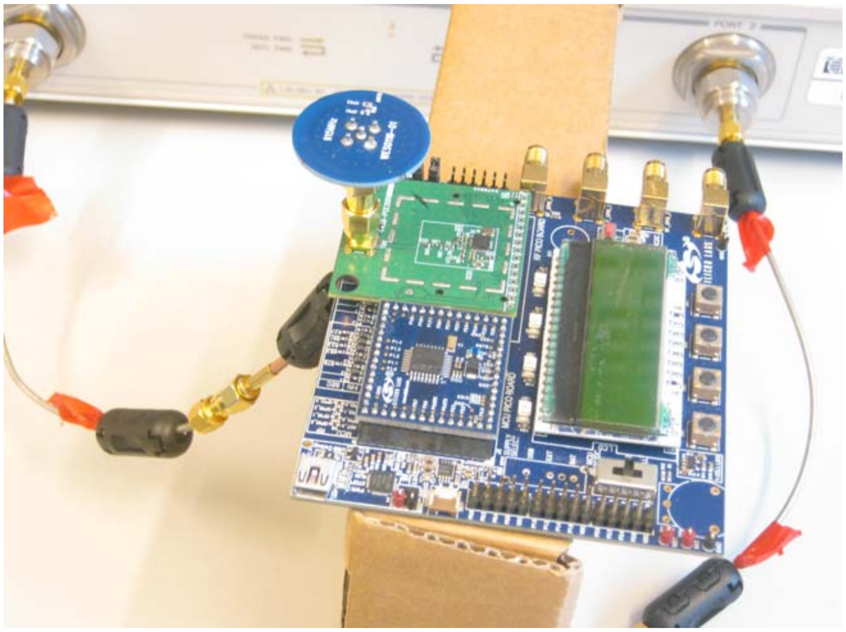


Figure 64. DUT (Panic Button IFA, WES0115-01-APF915P-01) in the Impedance Measurement Setup

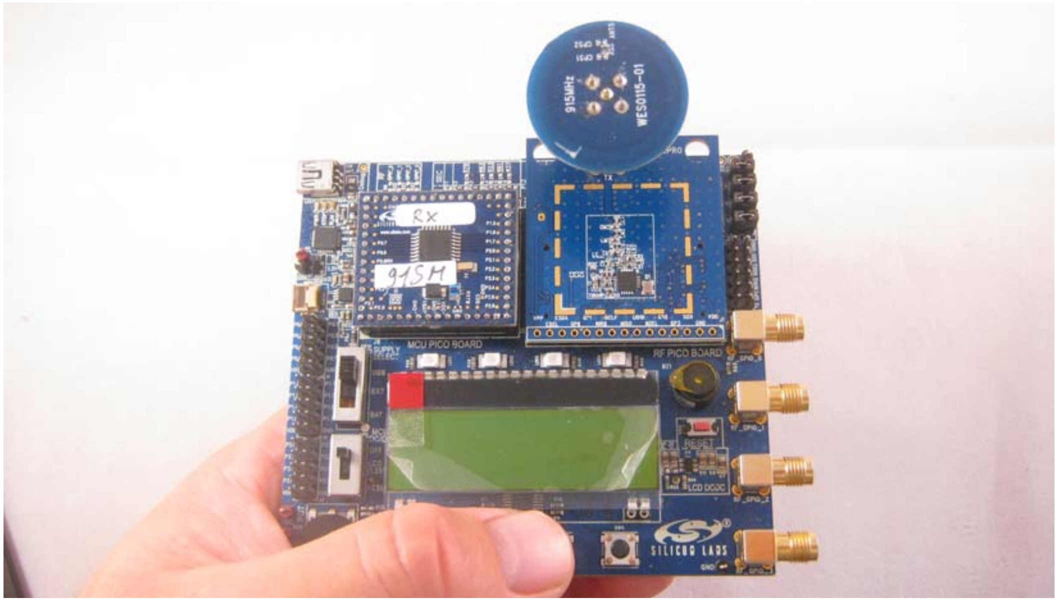


Figure 65. Typical Hand Effect on the Main Board During Impedance and Range Measurement (Panic Button IFA Antenna Board)

The measured impedance of the antenna with its external matching network is shown in Figure 66 (up to 3 GHz) with motherboard hand effect.

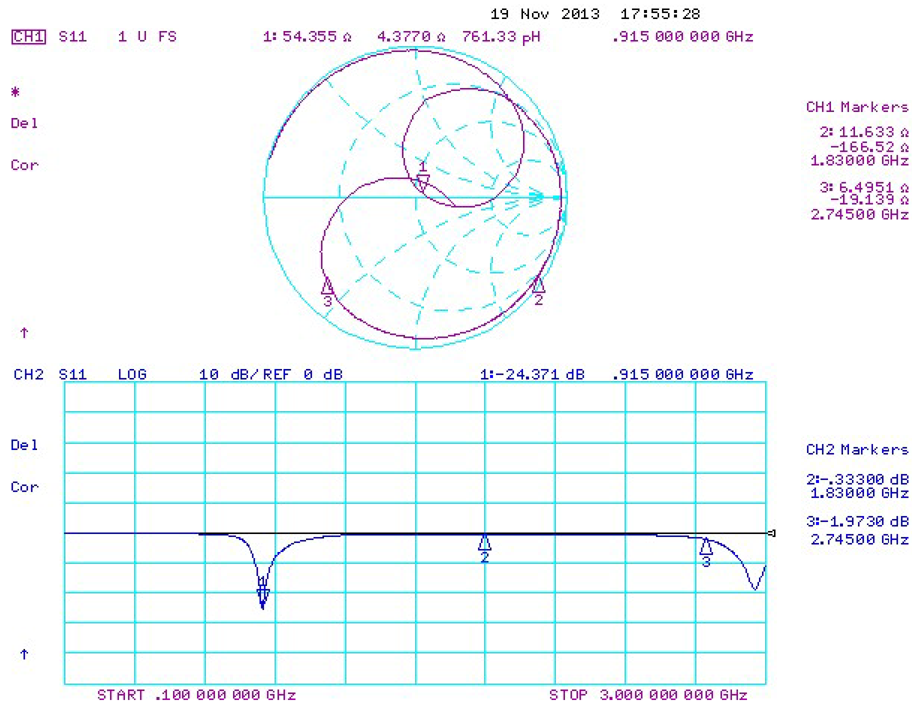


Figure 66. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

5.2. Antenna Gain (WES0115-01-APF915P-01)

The antenna gain is calculated from the measured radiated power at the fundamental and from the delivered power to the antenna. In the radiation measurement the 4463-PCE20C915 Pico Board is set to reduced (~10.3 dBm, power state 0x1C with 2.6 V V_{DD}) power state and the entire setup is fed by two AA batteries. The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced (~10 dBm) power state is shown in Figure 67. This method can be effectively applied because the S11 of the antenna is much better than –10 dB, so the reflection is negligible.

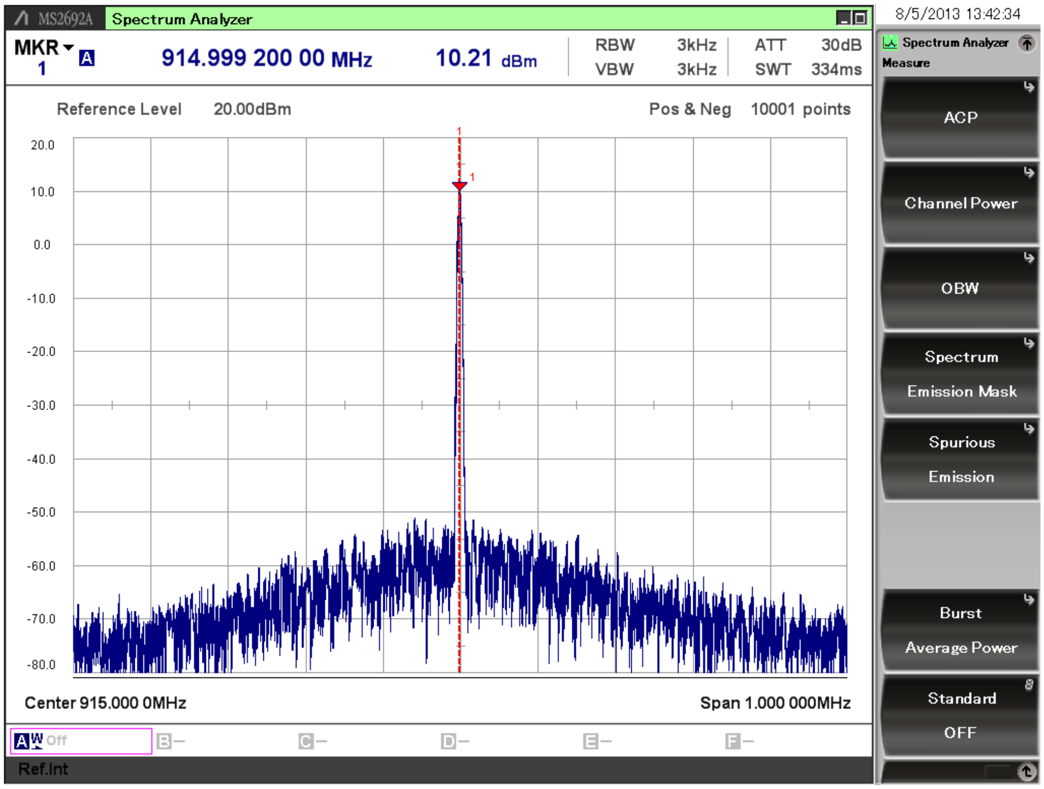


Figure 67. Conducted Measurement Result, 4463-PCE20C915 in a Reduced (~10 dBm) Power State (0x1C and 2.6 V V_{DD})

The measured radiated power maximum is at the XZ cut (Table 6). It is around 7.7 dBm EIRP, so the maximum gain number is ~–2.5 dBi, as shown in Figure 71.

This gain number is surprisingly high for a panic button antenna. It should be emphasized that in typical panic button applications the grounding environment and the strength of the hand effect is different. In real panic button applications (instead of the SMA connector, SMA male-male transition, Pico Board and wireless motherboard), only a lithium coin battery is applied and the achievable antenna gain is much weaker.

Also, in wrist applications the very close parallel hand has a strong detuning effect. In these applications, further impedance tuning of the antenna is required, and the radiation efficiency degrades strongly. Refer to the application note, "AN853: Single-ended Antenna Matrix Design Guide".

5.3. Radiation Patterns (WES0115-01-APF915P-01)

The radiation patterns of the small IFA antenna were measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. Figure 69—Figure 74 show the radiation patterns at the fundamental frequency in the XY, XZ, and YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 68. Rotation starts from the X-axe in the XY cut, and starts from the Z-axe in the XZ and YZ cuts.

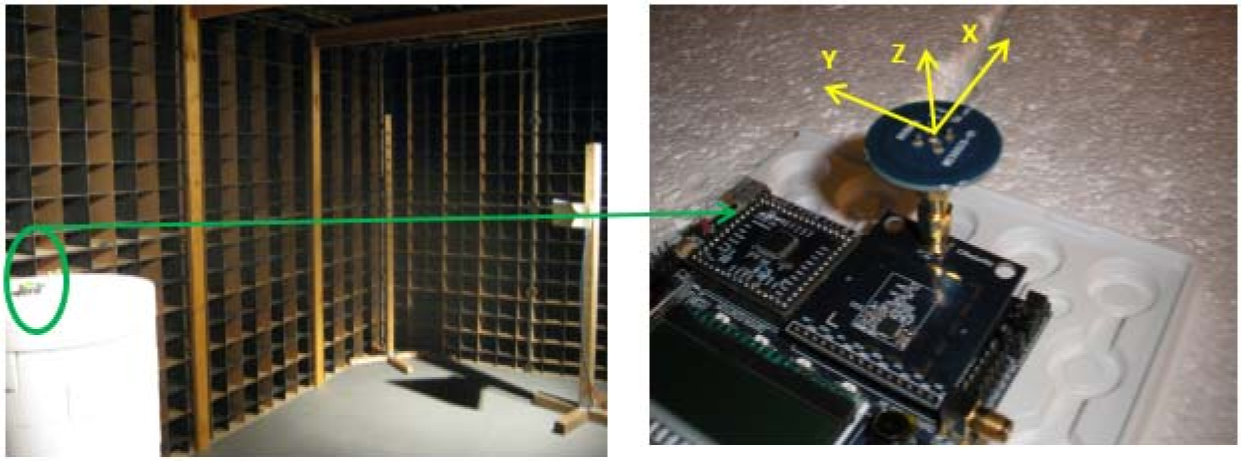


Figure 68. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 69–Figure 74).

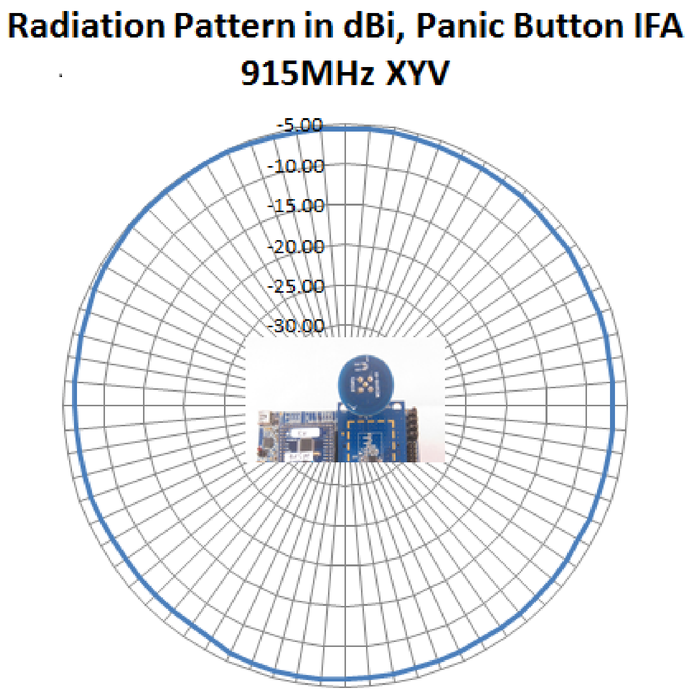


Figure 69. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

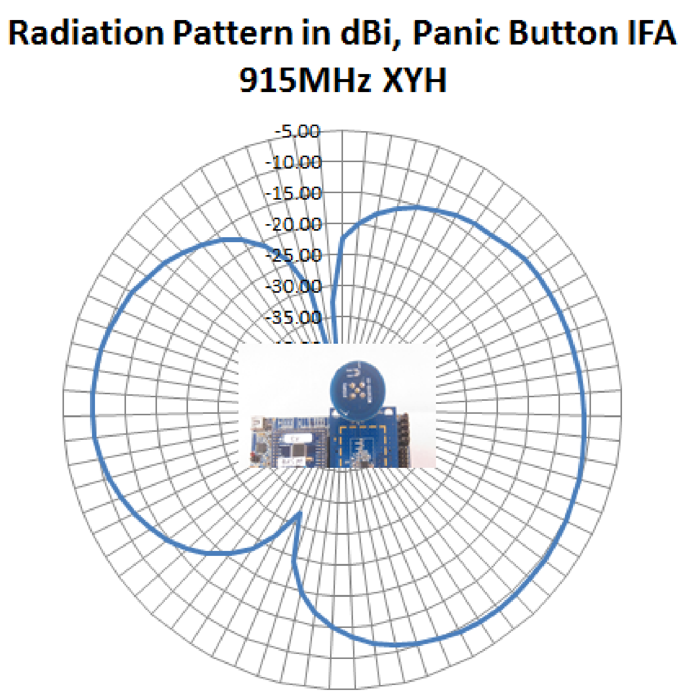


Figure 70. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

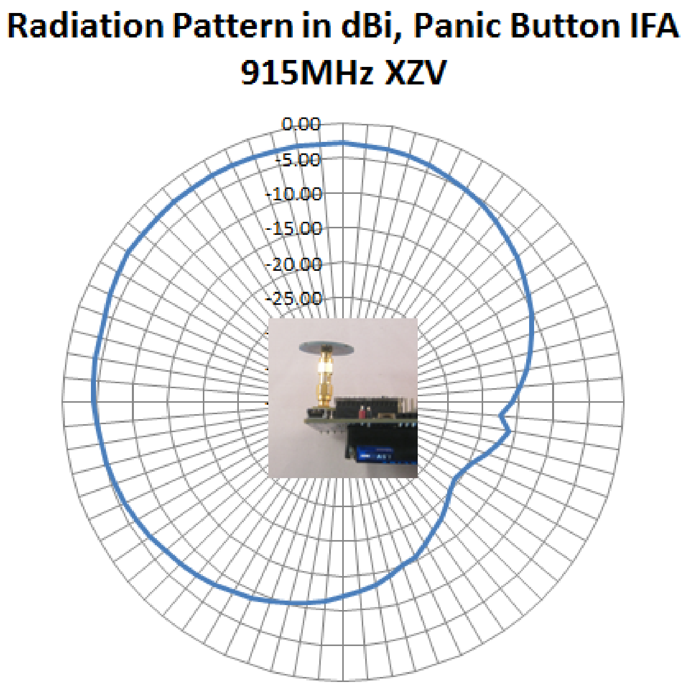


Figure 71. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

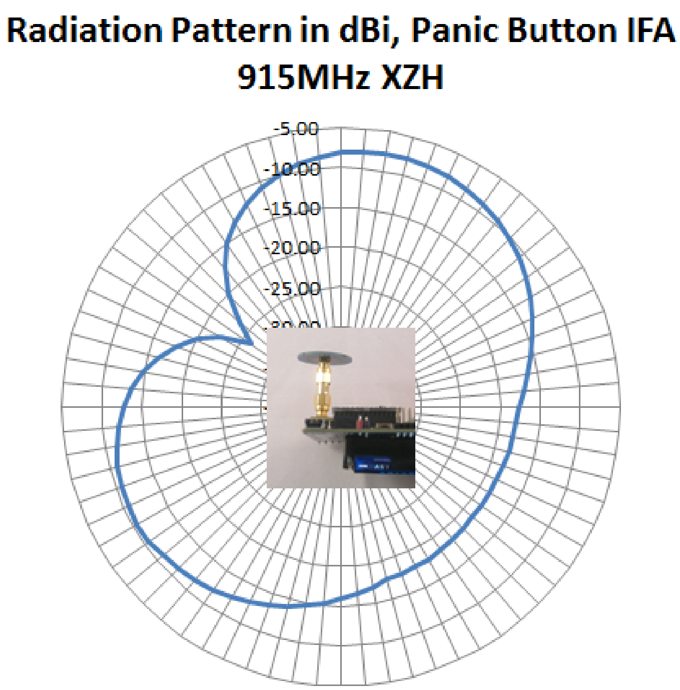


Figure 72. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

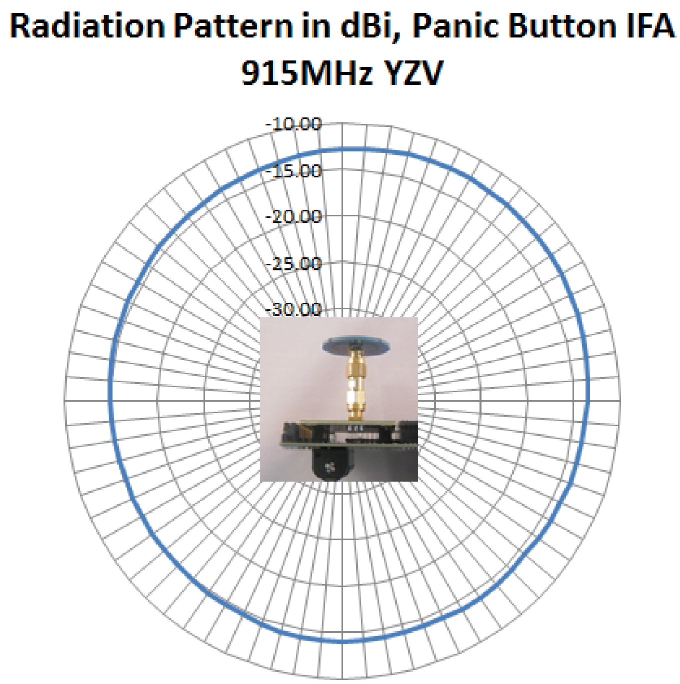


Figure 73. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

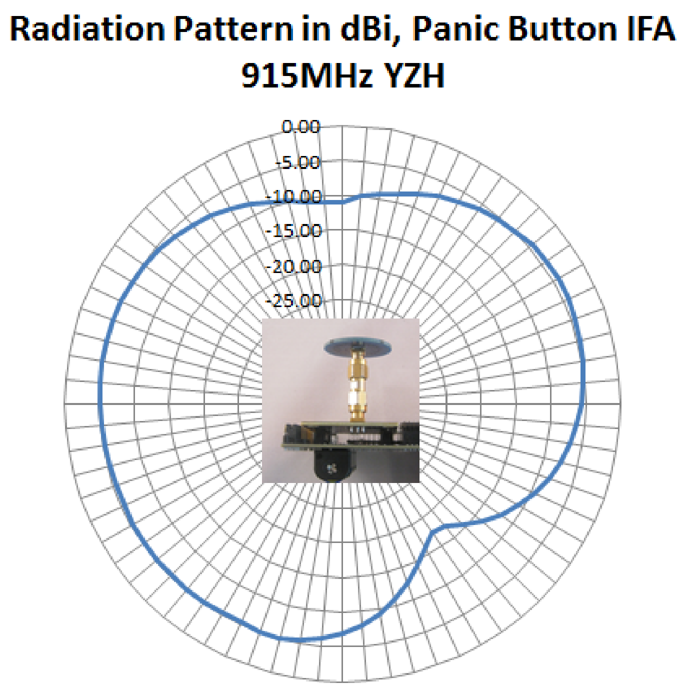


Figure 74. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

5.4. Radiated Harmonics (WES0115-01-APF915P-01)

The radiated harmonics of the small Panic IFA antenna were also measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20C915 Pico Board works in a reduced power state (~+10.2 dBm). The maximum radiated power levels up to the 10th harmonic were measured in the XY, XZ, and YZ cut. with both horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 6) with the corresponding standard limits.

The small sized panic button IFA antenna driven by the Si4463 Class E match at reduced (~10 dBm) power state complies with the FCC harmonic regulations.

Table 6. Radiated Harmonics, Panic Button IFA Board Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	4.98	25.0
XY	V	2nd	1830	–12.29	–53.13	40.8
XY	V	3rd	2745	–41.25	–50.90	9.7
XY	V	4th	3660	–41.25	–50.77	9.5
XY	V	5th	4575	–41.25	–61.00	19.7
XY	V	6th	5490	–12.29	–58.88	46.6
XY	V	7th	6405	–12.29	–58.31	46.0
XY	V	8th	7320	–41.25	–56.85	15.6
XY	V	9th	8235	–41.25	–53.66	12.4
XY	V	10th	9150	–41.25	–51.35	10.1
XY	H	Fund.	915	30.00	1.05	28.9
XY	H	2nd	1830	–12.29	–55.51	43.2
XY	H	3rd	2745	–41.25	–49.23	8.0
XY	H	4th	3660	–41.25	–51.62	10.4
XY	H	5th	4575	–41.25	–61.48	20.2
XY	H	6th	5490	–12.29	–57.99	45.7
XY	H	7th	6405	–12.29	–57.81	45.5
XY	H	8th	7320	–41.25	–55.46	14.2
XY	H	9th	8235	–41.25	–55.23	14.0

Table 6. Radiated Harmonics, Panic Button IFA Board Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XY	H	10th	9150	–41.25	–52.27	11.0
XZ	V	Fund.	915	30.00	7.71	22.3
XZ	V	2nd	1830	–12.29	–54.10	41.8
XZ	V	3rd	2745	–41.25	–50.25	9.0
XZ	V	4th	3660	–41.25	–51.33	10.1
XZ	V	5th	4575	–41.25	–61.66	20.4
XZ	V	6th	5490	–12.29	–57.70	45.4
XZ	V	7th	6405	–12.29	–59.25	47.0
XZ	V	8th	7320	–41.25	–56.80	15.5
XZ	V	9th	8235	–41.25	–55.20	13.9
XZ	V	10th	9150	–41.25	–51.34	10.1
XZ	H	Fund.	915	30.00	2.41	27.6
XZ	H	2nd	1830	–12.29	–54.07	41.8
XZ	H	3rd	2745	–41.25	–51.93	10.7
XZ	H	4th	3660	–41.25	–47.21	6.0
XZ	H	5th	4575	–41.25	–60.41	19.2
XZ	H	6th	5490	–12.29	–59.73	47.4
XZ	H	7th	6405	–12.29	–58.66	46.4
XZ	H	8th	7320	–41.25	–56.81	15.6
XZ	H	9th	8235	–41.25	–53.60	12.3
XZ	H	10th	9150	–41.25	–52.07	10.8
YZ	V	Fund.	915	30.00	–2.06	32.1
YZ	V	2nd	1830	–12.29	–59.38	47.1
YZ	V	3rd	2745	–41.25	–47.58	6.3

Table 6. Radiated Harmonics, Panic Button IFA Board Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
YZ	V	4th	3660	–41.25	–51.23	10.0
YZ	V	5th	4575	–41.25	–60.81	19.6
YZ	V	6th	5490	–12.29	–57.73	45.4
YZ	V	7th	6405	–12.29	–58.06	45.8
YZ	V	8th	7320	–41.25	–57.44	16.2
YZ	V	9th	8235	–41.25	–54.31	13.1
YZ	V	10th	9150	–41.25	–51.33	10.1
YZ	H	Fund.	915	30.00	6.09	23.9
YZ	H	2nd	1830	–12.29	–53.76	41.5
YZ	H	3rd	2745	–41.25	–50.45	9.2
YZ	H	4th	3660	–41.25	–48.66	7.4
YZ	H	5th	4575	–41.25	–59.51	18.3
YZ	H	6th	5490	–12.29	–58.77	46.5
YZ	H	7th	6405	–12.29	–57.47	45.2
YZ	H	8th	7320	–41.25	–56.57	15.3
YZ	H	9th	8235	–41.25	–50.92	9.7
YZ	H	10th	9150	–41.25	–52.82	11.6

5.5. Range Test

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the one-directional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte long packets. The GPS coordinates have been recorded for each spot. The distance between the spots was measured using Google Maps, and the results are shown in meters. The range was tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board, and the DUT (as shown in Figure 65.) held by the users hand. The 4463PCE20C915 Pico Board worked in a properly reduced power state (either +13 or 0 dBm).

The range was tested in a flat land area without obstacles.

During the range test, the following settings (Set 1, Set 2, and Set 3) were used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the above settings the following range tests were done here:

1. Range measurement with the PANIC BUTTON IFA Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the PANIC BUTTON IFA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the PANIC BUTTON IFA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the PANIC BUTTON IFA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the PANIC BUTTON IFA Antenna Boards—The antenna boards are VERTICALLY polarized and boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 75.

Note: These range test results are valid with the above configuration and with moderate hand effect. In normal battery-operated, small push-button applications, where there is no large GND (motherboard) close to the antenna and where the antenna is usually very close to the user's hand, the achievable range is most likely much shorter.

The indoor range test was not performed, due to the lack of a large enough building. But from the TX power and sensitivity data, an indoor range estimation can be given if one assumes a propagation factor of 4.5, which is a typical value in normal office environments. Use the Silicon Labs' range calculator, which can be found here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming a –5.6 dBi antenna gain (front direction, X-axes facing) and the setting "Set 1" (50 kbps, 1% PER, 13 dBm), the estimated indoor range is 73 m, as shown in Figure 76. If the antennas are facing with the direction of maximum radiation, the indoor range increases to ~101 m.

Set1	13dBm	50kbps	+/-25kHz
Set2	13dBm	100kbps	+/-50kHz
Set3	0dBm	1.2kbps	+/-1.2kHz

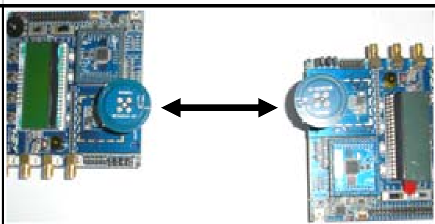
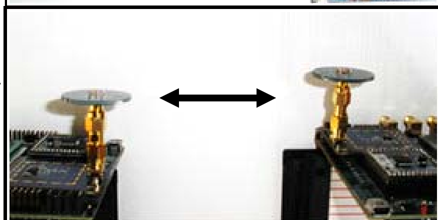
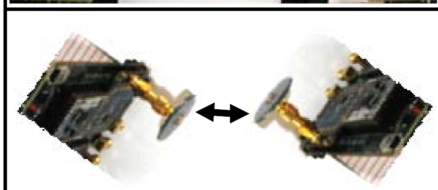
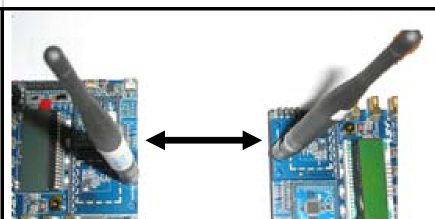
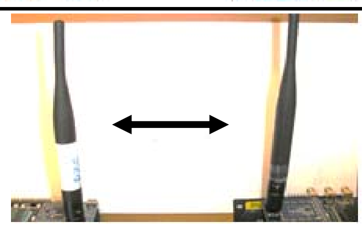
							GPS		**Distance [m]**
							N	**E**	
	Panic Button IFA				**Base**		**47.152880°**	**19.180930°**	**0.0**
Panic Button IFA (WES0115)				H pol; Norm. direction					
							GPS		
							N	E	
		1	Set1	13dBm	50kbps	+/-25kHz	47.164970°	19.173100°	**1468.9**
				V pol; Norm. direction					
							GPS		
							N	E	
		2	Set1	13dBm	50kbps	+/-25kHz	47.167340°	19.172700°	**1724.1**
		3	Set2	13dBm	100kbps	+/-50kHz	47.166370°	19.172980°	**1616.0**
		4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.165140°	19.173040°	**1488.1**
				Max. direction w/o hand: XZV 325° //Meas w hand: 235°					
							GPS		
							N	E	
		5	Set1	13dBm	50kbps	+/-25kHz	47.170590°	19.172170°	**2077.7**
W1063				V pol; Norm. direction					
							GPS		
							N	E	
		6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	**2174.3**
				H pol; Norm. direction					
							GPS		
							N	E	
		8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 75. Outdoor Range Test Result with Two Identical IFA Panic Button Antennas with the 4463-PCE20C915 Pico Board Working in a Reduced Power (+13 or 0 dBm) State Driven by the WMB-930 Wireless Motherboard

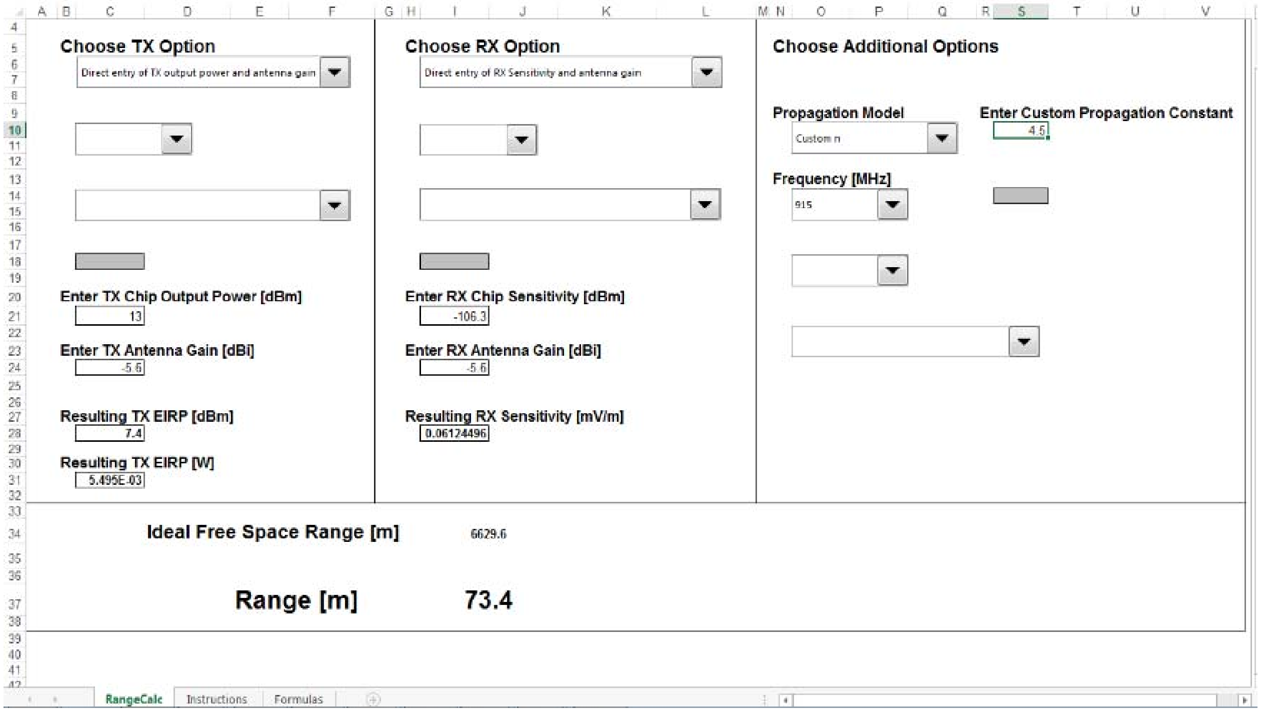


Figure 76. Indoor Range Estimation with Two Identical IFA Panic Button Antennas and with the 4463-PCE20C915 Pico Board Working in a Reduced Power (~+13 dBm) State Driven by the WMB-930 Wireless Motherboard

6. Panic Button ILA (Printed) Along the Circumference (WES0116-01-APL915P-01)

The Panic Button ILA antenna has the following characteristics:

- The antenna trace width is 0.5 mm.
- The distance between the antenna trace outer edge and the PCB cutting edge is 1.5 mm.
- The distance between the antenna trace inner edge and ground metal is 2 mm.
- External matching network (shown in Figure 77) is required at the antenna input.

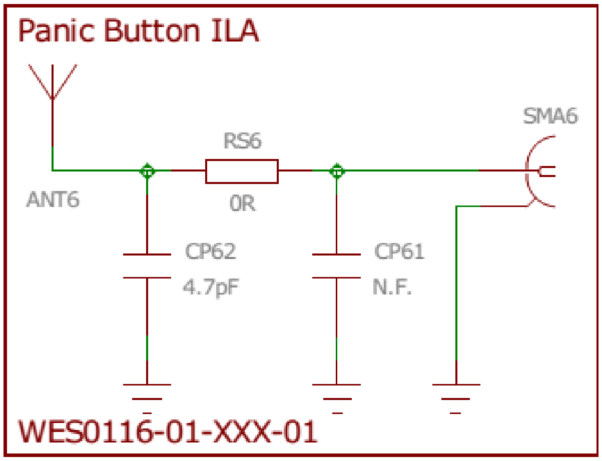


Figure 77. External Matching Network at 915 MHz for the Panic Button ILA Antenna

The antenna is shown in Figure 78:

Figure 78. Small ILA Antenna for Panic Button Applications

6.1. Antenna Impedance (WES0116-01-APL915P-01)

The impedance measurement setup is shown in Figure 79. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test the user's hand holds the motherboard. Typical hand position is shown in Figure 80.

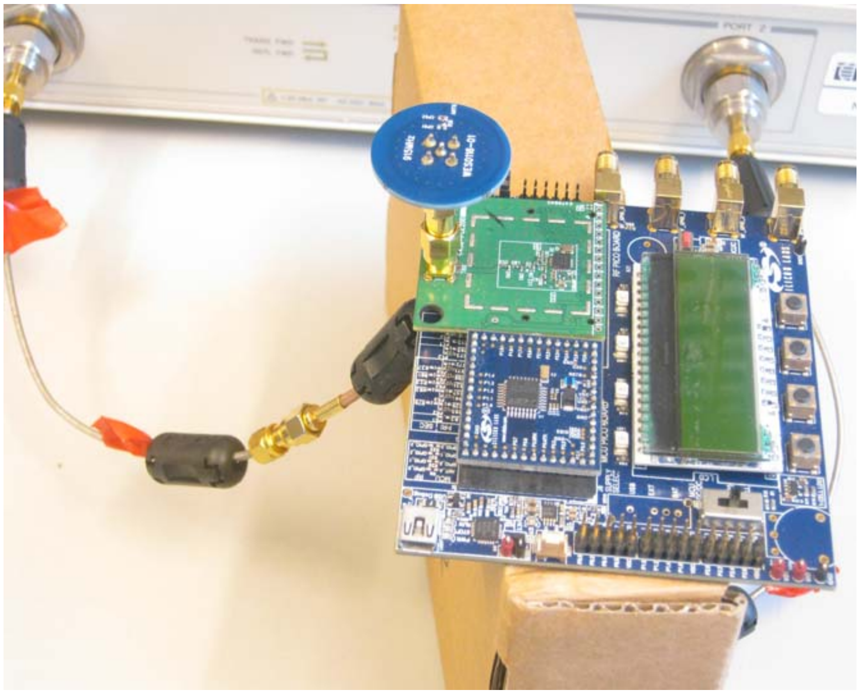


Figure 79. DUT (WES0116-01-APL915P-01) in the Impedance Measurement Setup

Figure 80. Typical Hand Effect on the Main Board During Impedance and Range Measurement (Panic Button ILA)

The measured impedance of the antenna with its external matching network is shown in Figure 81 (up to 3 GHz) with motherboard hand effect.

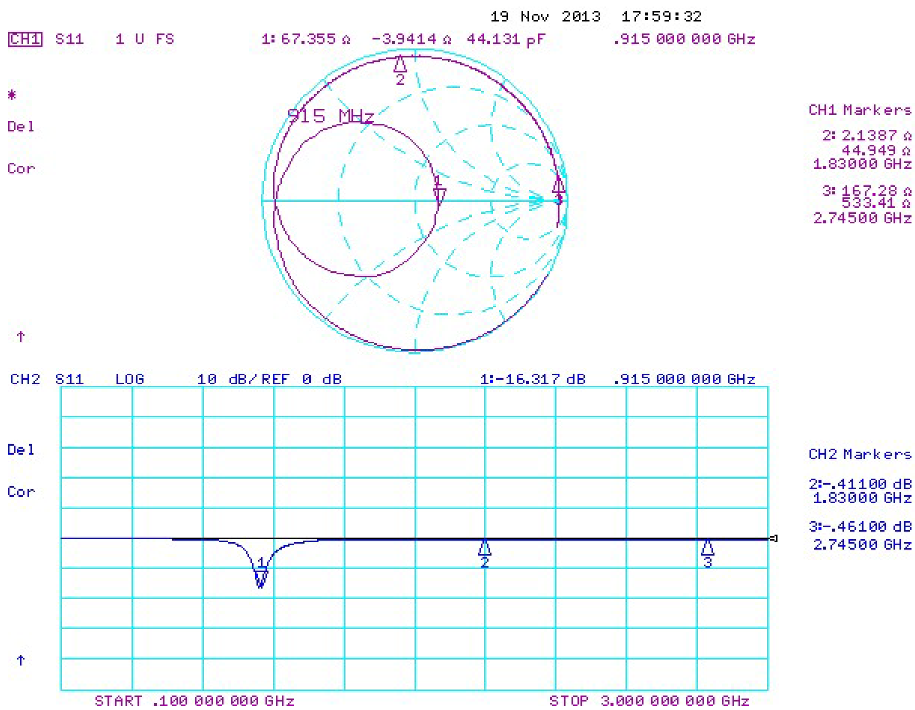


Figure 81. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

6.2. Antenna Gain (WES0116-01-APL915P-01)

The antenna gain is calculated from the measured radiated power at the fundamental and from the delivered power to the antenna. In the radiation measurement, the 4463-PCE20C915 Pico Board is set to reduced power state (~+10.2 dBm, state 0x1C) and the entire setup is fed by two AA batteries (V_{DD} is set to 2.6 V). The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced (~10 dBm) power state is shown in Figure 82. This method can be effectively applied because the S11 of the antenna is much better than –10 dB, so the reflection loss is negligible.

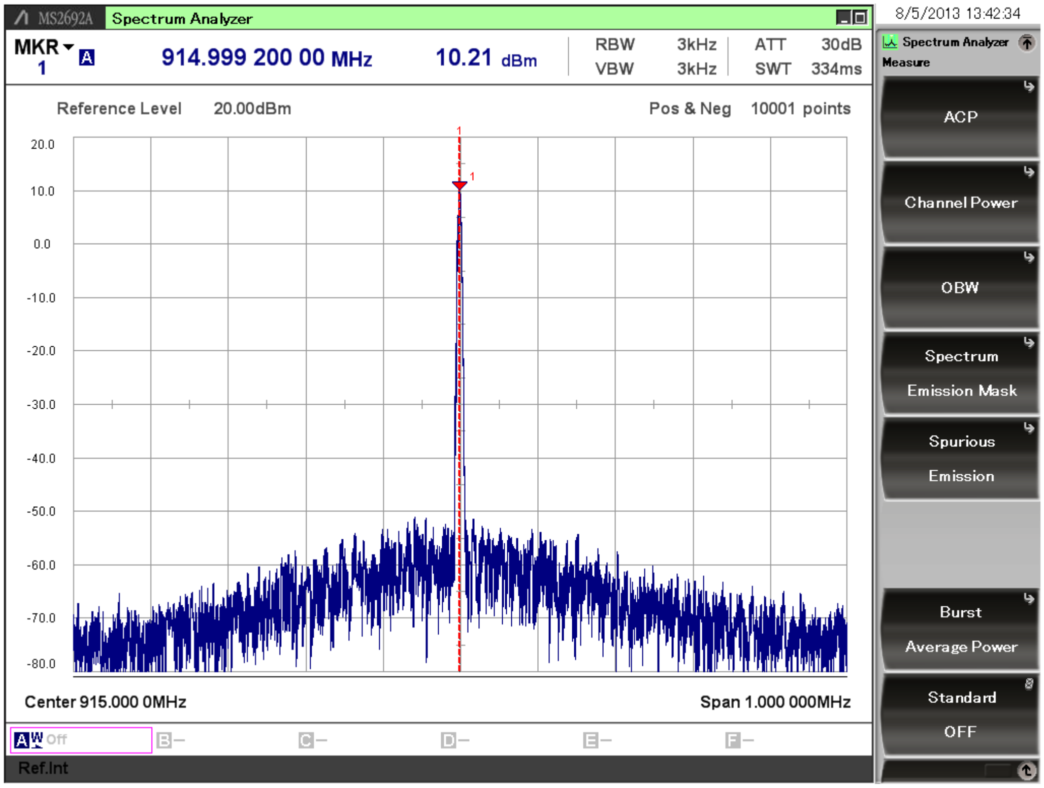


Figure 82. Conducted Measurement Result, 4463-PCE20C915 in Reduced (~10 dBm) Power State

The measured radiated power maximum is at the XZ cut (Table 7). It is around 8.4 dBm EIRP, so the maximum gain number is ~–1.8 dBi, as shown in Figure 86.

This gain number is surprisingly high for a panic button antenna. It should be emphasized that in typical panic button applications the grounding environment and the strength of the hand effect is different. In real panic button applications (instead of the SMA connector, SMA male-male transition, Pico Board and wireless motherboard) only a lithium coin battery is applied and the achievable antenna gain is much weaker.

Also, in wrist applications the very close parallel hand has a strong detuning effect. In these applications further impedance tuning of the antenna is required and the radiation efficiency degrades strongly. Refer to the application note, “AN853: Single-ended Antenna Matrix Design Guide”.

6.3. Radiation Patterns (WES0116-01-APL915P-01)

The radiation patterns of the Panic Button ILA antenna were measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. Figure 84—Figure 89 show the radiation patterns at the fundamental frequency in the XY, XZ, YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 83. Rotation starts from the X-axe in the XY cut, and begins from the Z-axe in the XZ and YZ cuts.

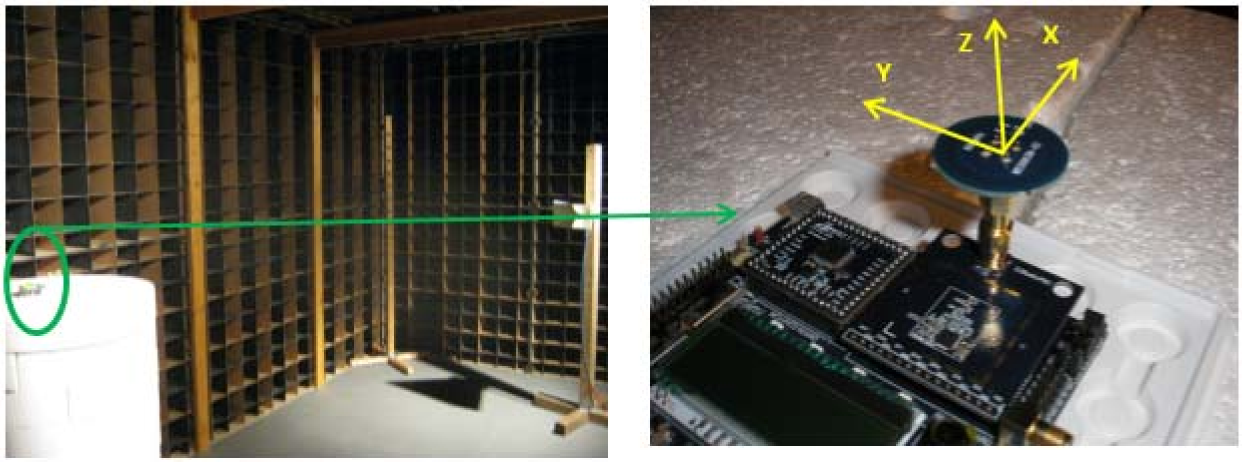


Figure 83. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 84–Figure 89).

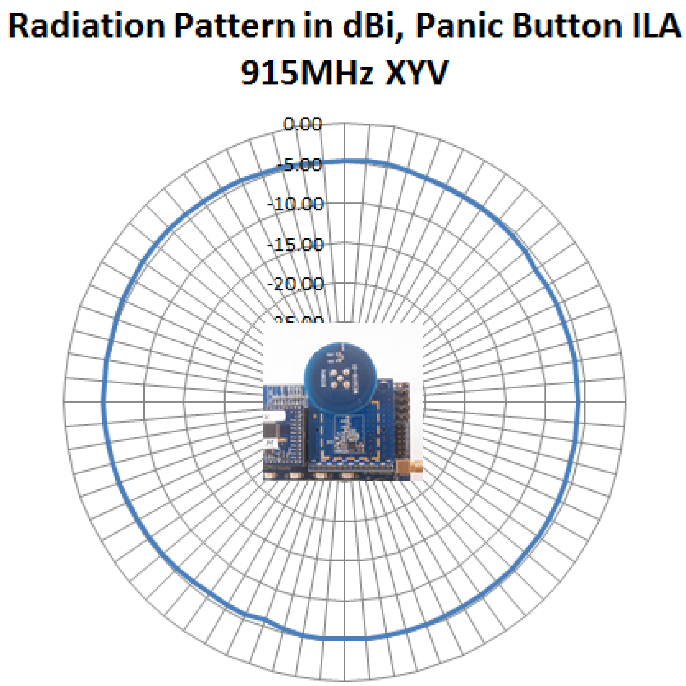


Figure 84. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

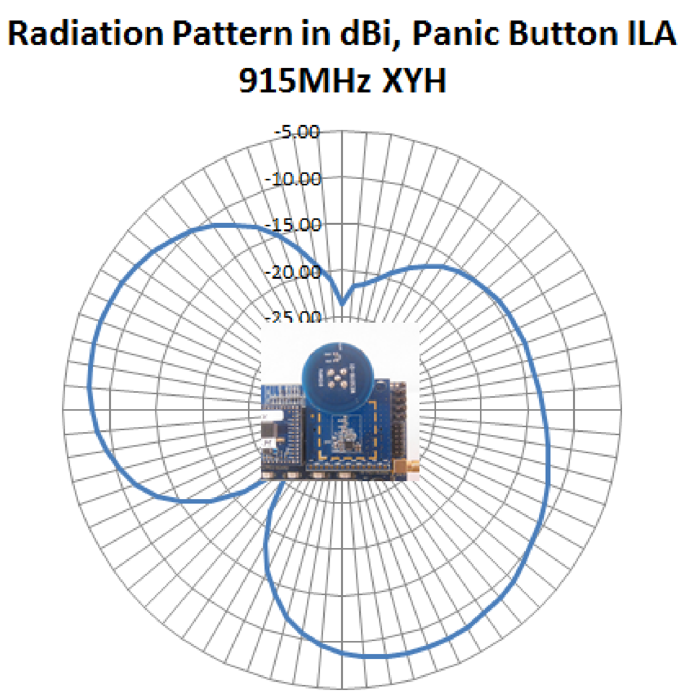


Figure 85. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

Radiation Pattern in dBi, Panic Button ILA
915MHz XZV

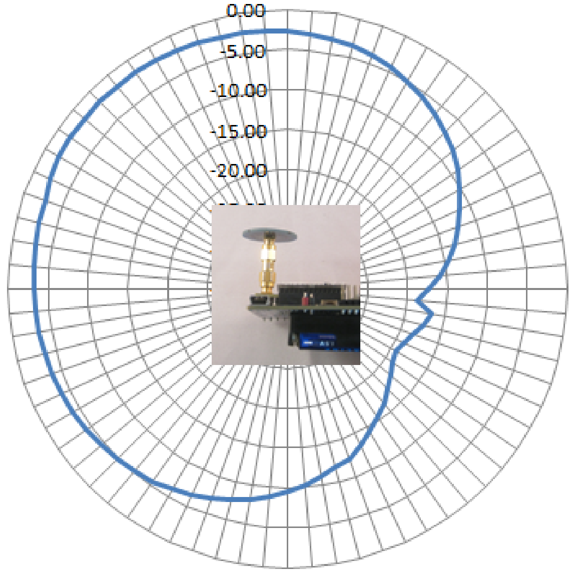


Figure 86. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

Radiation Pattern in dBi, Panic Button ILA
915MHz XZH

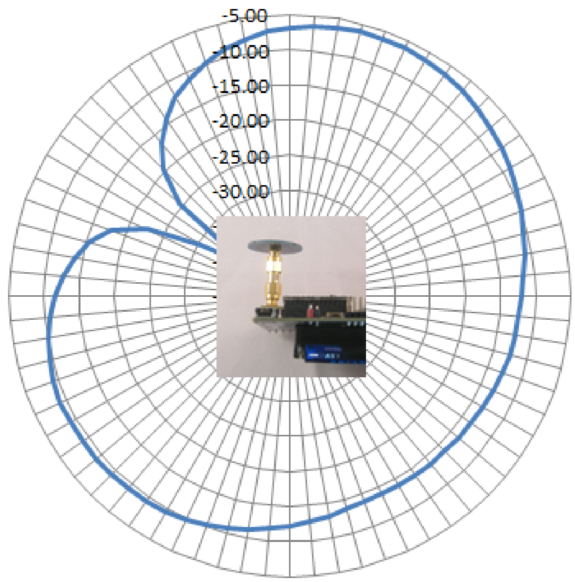


Figure 87. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

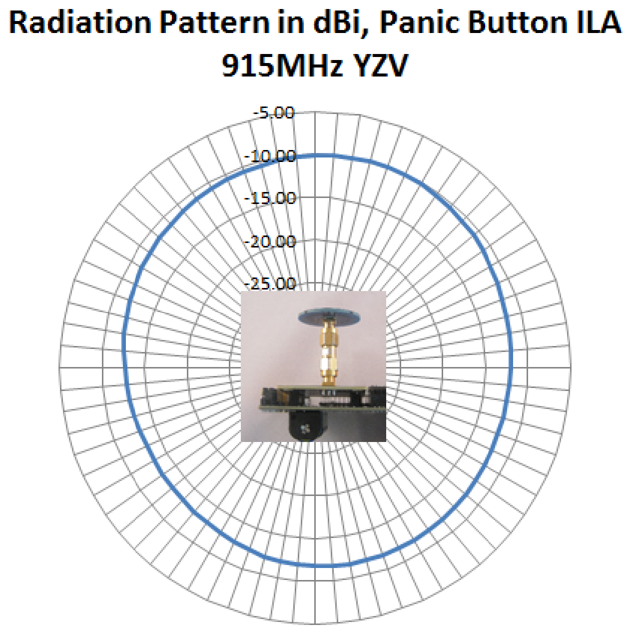


Figure 88. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

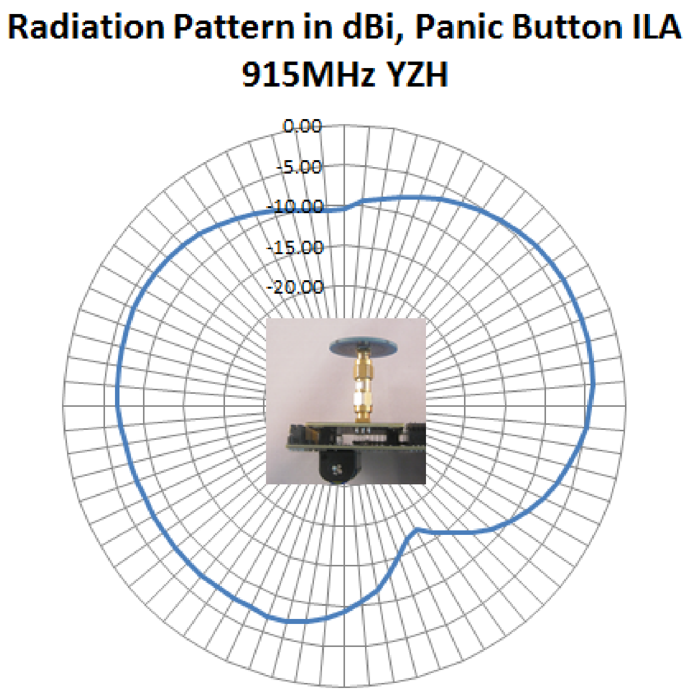


Figure 89. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

6.4. Radiated Harmonics (WES0116-01-APL915P-01)

The radiated harmonics of the small ILA antenna were also measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20C915 board works in a reduced power (~+10.2 dBm) state (0x1C, V_{DD} is 2.6 V). The maximum radiated power levels up to the 10^{th} harmonic were measured in the XY, XZ, and YZ cut, with both the horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 7) together with the corresponding standard limits.

The small sized panic button ILA antenna driven by the Si4463 class E match in reduced (~10 dBm) power state complies with the FCC harmonic regulations.

Table 7. Radiated Harmonics, Panic Button ILA Antenna Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	5.98	24.0
XY	V	2^{nd}	1830	–11.57	–56.24	44.7
XY	V	3^{rd}	2745	–41.25	–50.77	9.5
XY	V	4^{th}	3660	–41.25	–50.16	8.9
XY	V	5^{th}	4575	–41.25	–60.22	19.0
XY	V	6^{th}	5490	–11.57	–59.31	47.7
XY	V	7^{th}	6405	–11.57	–56.31	44.7
XY	V	8^{th}	7320	–41.25	–56.37	15.1
XY	V	9^{th}	8235	–41.25	–54.34	13.1
XY	V	10^{th}	9150	–41.25	–51.62	10.4
XY	H	Fund.	915	30.00	2.79	27.2
XY	H	2^{nd}	1830	–11.57	–58.56	47.0
XY	H	3^{rd}	2745	–41.25	–50.38	9.1
XY	H	4^{th}	3660	–41.25	–52.79	11.5
XY	H	5^{th}	4575	–41.25	–60.41	19.2
XY	H	6^{th}	5490	–11.57	–59.01	47.4
XY	H	7^{th}	6405	–11.57	–58.29	46.7
XY	H	8^{th}	7320	–41.25	–57.05	15.8
XY	H	9^{th}	8235	–41.25	–54.93	13.7

Table 7. Radiated Harmonics, Panic Button ILA Antenna Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XY	H	10th	9150	–41.25	–52.58	11.3
XZ	V	Fund.	915	30.00	8.43	21.6
XZ	V	2nd	1830	–11.57	–55.59	44.0
XZ	V	3rd	2745	–41.25	–50.31	9.1
XZ	V	4th	3660	–41.25	–51.08	9.8
XZ	V	5th	4575	–41.25	–61.51	20.3
XZ	V	6th	5490	–11.57	–58.40	46.8
XZ	V	7th	6405	–11.57	–58.31	46.7
XZ	V	8th	7320	–41.25	–57.23	16.0
XZ	V	9th	8235	–41.25	–54.82	13.6
XZ	V	10th	9150	–41.25	–52.88	11.6
XZ	H	Fund.	915	30.00	4.14	25.9
XZ	H	2nd	1830	–11.57	–54.74	43.2
XZ	H	3rd	2745	–41.25	–53.23	12.0
XZ	H	4th	3660	–41.25	–48.41	7.2
XZ	H	5th	4575	–41.25	–62.09	20.8
XZ	H	6th	5490	–11.57	–59.31	47.7
XZ	H	7th	6405	–11.57	–57.90	46.3
XZ	H	8th	7320	–41.25	–55.87	14.6
XZ	H	9th	8235	–41.25	–53.59	12.3
XZ	H	10th	9150	–41.25	–52.97	11.7
YZ	V	Fund.	915	30.00	0.20	29.8
YZ	V	2nd	1830	–11.57	–59.52	47.9
YZ	V	3rd	2745	–41.25	–48.05	6.8

Table 7. Radiated Harmonics, Panic Button ILA Antenna Connected to the Reduced Power (~10.2 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
YZ	V	4th	3660	–41.25	–52.57	11.3
YZ	V	5th	4575	–41.25	–60.76	19.5
YZ	V	6th	5490	–11.57	–58.53	47.0
YZ	V	7th	6405	–11.57	–57.93	46.4
YZ	V	8th	7320	–41.25	–56.67	15.4
YZ	V	9th	8235	–41.25	–54.50	13.3
YZ	V	10th	9150	–41.25	–52.84	11.6
YZ	H	Fund.	915	30.00	6.69	23.3
YZ	H	2nd	1830	–11.57	–55.17	43.6
YZ	H	3rd	2745	–41.25	–50.83	9.6
YZ	H	4th	3660	–41.25	–50.69	9.4
YZ	H	5th	4575	–41.25	–60.30	19.0
YZ	H	6th	5490	–11.57	–58.53	47.0
YZ	H	7th	6405	–11.57	–56.20	44.6
YZ	H	8th	7320	–41.25	–56.32	15.1
YZ	H	9th	8235	–41.25	–52.38	11.1
YZ	H	10th	9150	–41.25	–52.61	11.4

6.5. Range Test (WES0116-01-APL915P-01)

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the bidirectional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten-byte packet length. The GPS coordinates have been recorded for each spot. The distance between the spots were measured using Google Maps, and results are shown in meters. The range was tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board, and the DUT (as shown in Figure 81.) held by the users hand. The 4463-PCE20C915 Pico Board worked in a properly reduced power state (either +13 dBm or 0 dBm).

The range was tested in a flat land area without obstacles.

During the range test, the following settings were used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the above settings (Set 1, Set 2, and Set 3) the following range tests are done here:

1. Range measurement with the PANIC BUTTON ILA Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the PANIC BUTTON ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the PANIC BUTTON ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the PANIC BUTTON ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the PANIC BUTTON ILA Antenna Boards—The antenna boards are VERTICALLY polarized and boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 90.

Note: These range test results are valid with the above configuration and with moderate hand effect. In normal battery-operated, small push-button applications, where there is no large GND (motherboard) close to the antenna and where the antenna is usually very close to the user's hand, the achievable range is most likely much shorter.

The indoor range test was not performed, due to the lack of a large enough building. But from the TX power and sensitivity data, an indoor range estimation can be given if one assumes a propagation factor of 4.5, which is a typical value in normal office environments. Using the Silicon Labs' range calculator, which can be found here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming –4.8 dBi antenna gain (front direction, X-axes facing) and the setting "Set 1" (50 kbps, 1% PER, 13 dBm), the estimated indoor range is 80 m, as shown in Figure 91. If the boards are facing with the direction of radiation maximum, the indoor range is ~108 m.

Set1	13dBm	50kbps	+/-25kHz
Set2	13dBm	100kbps	+/-50kHz
Set3	0dBm	1.2kbps	+/-1.2kHz

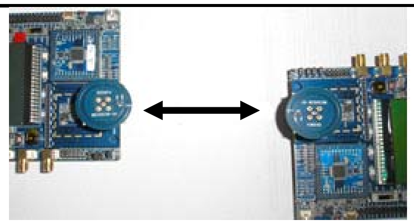
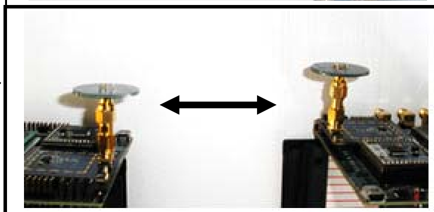
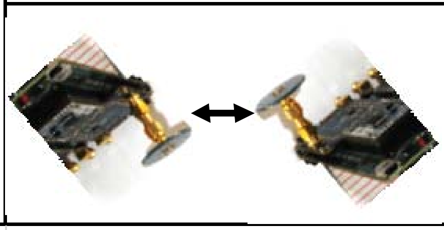
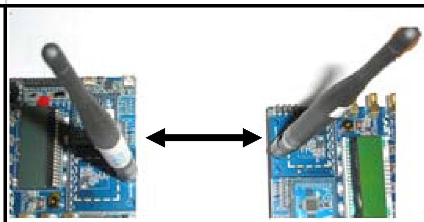
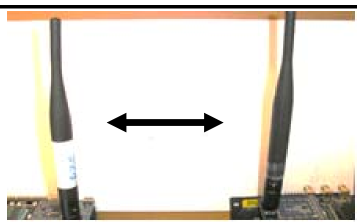
							GPS		**Distance [m]**
							N	**E**	
	Panic Button ILA				**Base**		**47.152880°**	**19.180930°**	**0.0**
Panic Button ILA (WES0116)				H pol; Norm. direction					
							GPS		
							N	E	
		1	Set1	13dBm	50kbps	+/-25kHz	47.164470°	19.173170°	**1416.0**
				V pol; Norm. direction					
							GPS		
							N	E	
		2	Set1	13dBm	50kbps	+/-25kHz	47.165910°	19.172850°	**1572.4**
		3	Set2	13dBm	100kbps	+/-50kHz	47.162900°	19.173400°	**1251.2**
		4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.161740°	19.173610°	**1130.0**
				Max. direction w/o hand: XZV 310° //Meas w hand: 240°					
							GPS		
							N	E	
		5	Set1	13dBm	50kbps	+/-25kHz	47.169960°	19.172270°	**2008.9**
W1063				V pol; Norm. direction					
							GPS		
							N	E	
		6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	**2174.3**
				H pol; Norm. direction					
							GPS		
							N	E	
		8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 90. Outdoor Range Test Result with Two Identical ILA Panic Button Antennas with the 4463-PCE20C915 Pico Board Working in a Reduced Power (~10.2 dBm) State Driven by the WMB-930 Wireless Motherboard

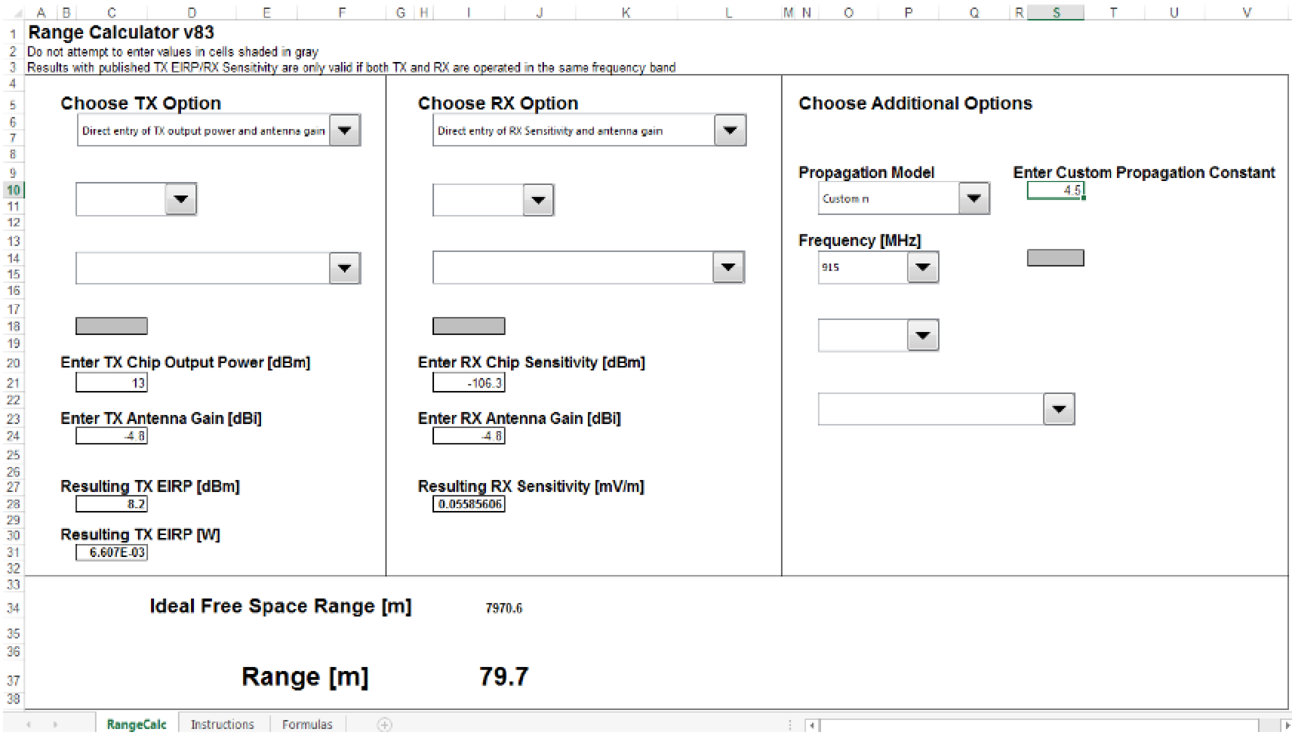


Figure 91. Indoor Range Estimation with Two Identical ILA Panic Button Antennas and with the 4463-PCE20C915 Pico Board Working in a Reduced (~+13 dBm) Power State Driven by the WMB-930 Wireless Motherboard

7. Printed Meander Monopole (WES0117-01-APN915D-01)

For the Printed Meander Monopole, an external matching network (shown in Figure 92) is required at the antenna input.

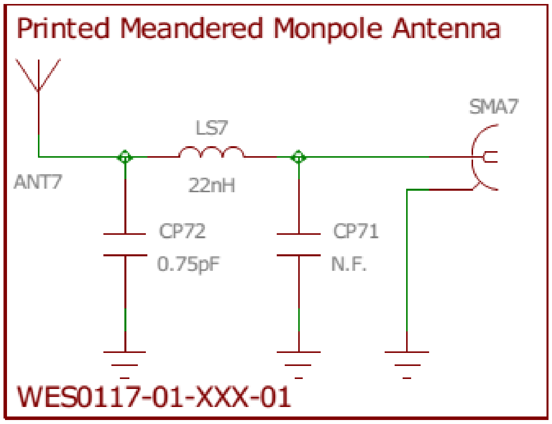


Figure 92. External Matching Network at 915 M for the Printed Meander Antenna

The antenna is shown in Figure 93:

Figure 93. Printed Meander Monopole Antenna

7.1. Antenna Impedance (WES0117-01-APN915D-01)

The measurement setup is shown in Figure 94. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test, the user’s hand holds the motherboard. Typical hand position is shown in Figure 95.

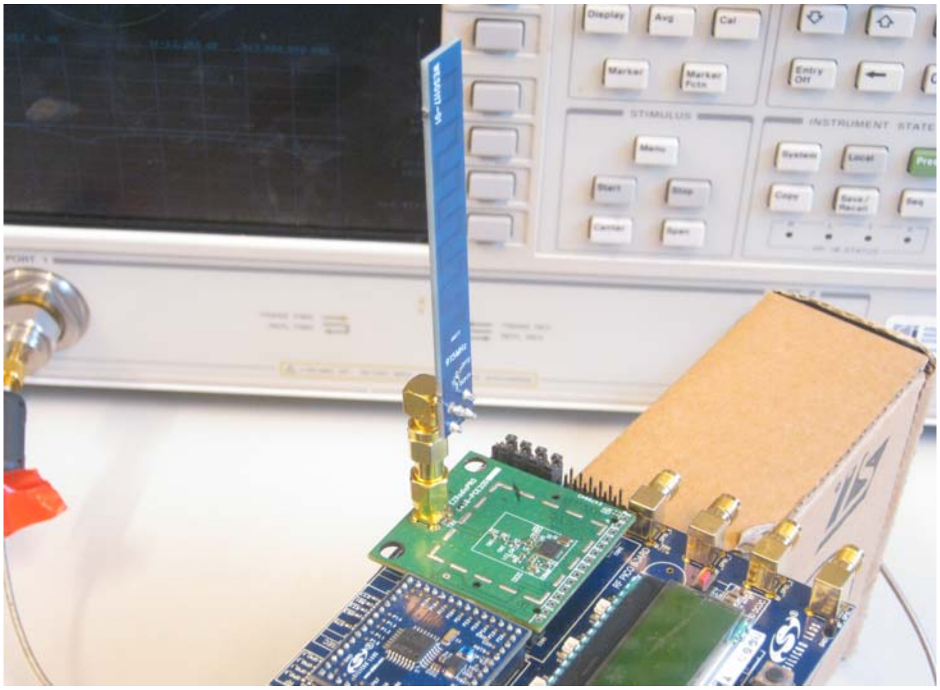


Figure 94. DUT (WES0117-01-APN915D-01) in the Impedance Measurement Setup

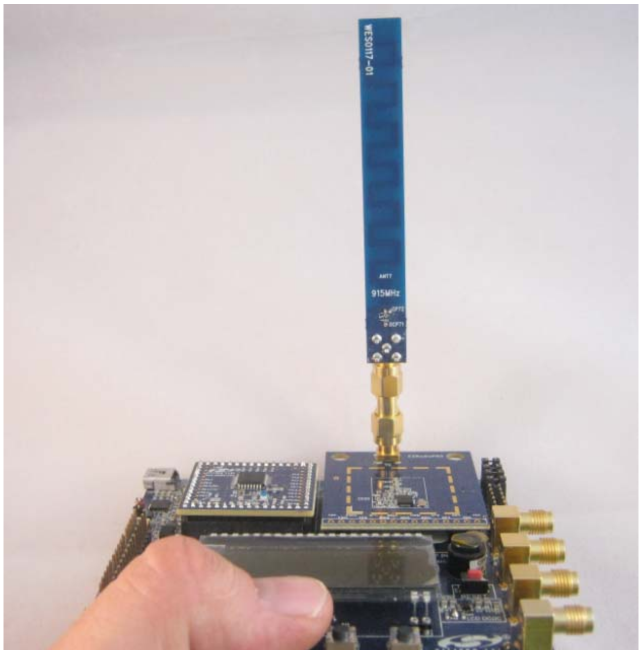


Figure 95. Typical Hand Effect on the Main Board During Impedance and Range Measurement (Printed Meander Board)

The measured impedance of the antenna with its external matching network is shown in Figure 96 (up to 3 GHz) with motherboard hand effect.

\

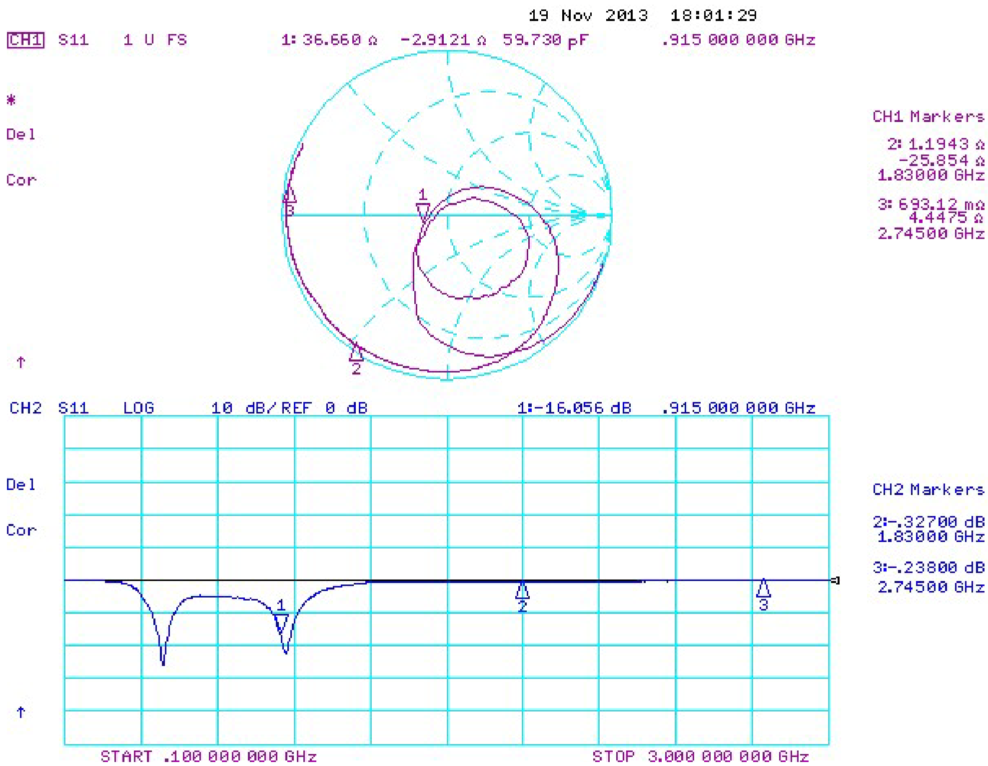


Figure 96. Measured Impedance (up to 3 GHz) with Hand Effect on the WMB-930 Motherboard

7.2. Antenna Gain (WES0117-01-APN915D-01)

The antenna gain is calculated from the measured radiated power at the fundamental and from the delivered power to the antenna. In the radiation measurement, the 4463-PCE20C915 Pico Board is set to reduced (~+10.2 dBm) power state (0x1C), and the entire setup is fed by two AA batteries (V_{DD} is set to 2.6 V). The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced (~10 dBm) power state is shown in Figure 97. This method can be effectively applied because the S11 of the antenna is much better than –10 dB, so the reflection is negligible.

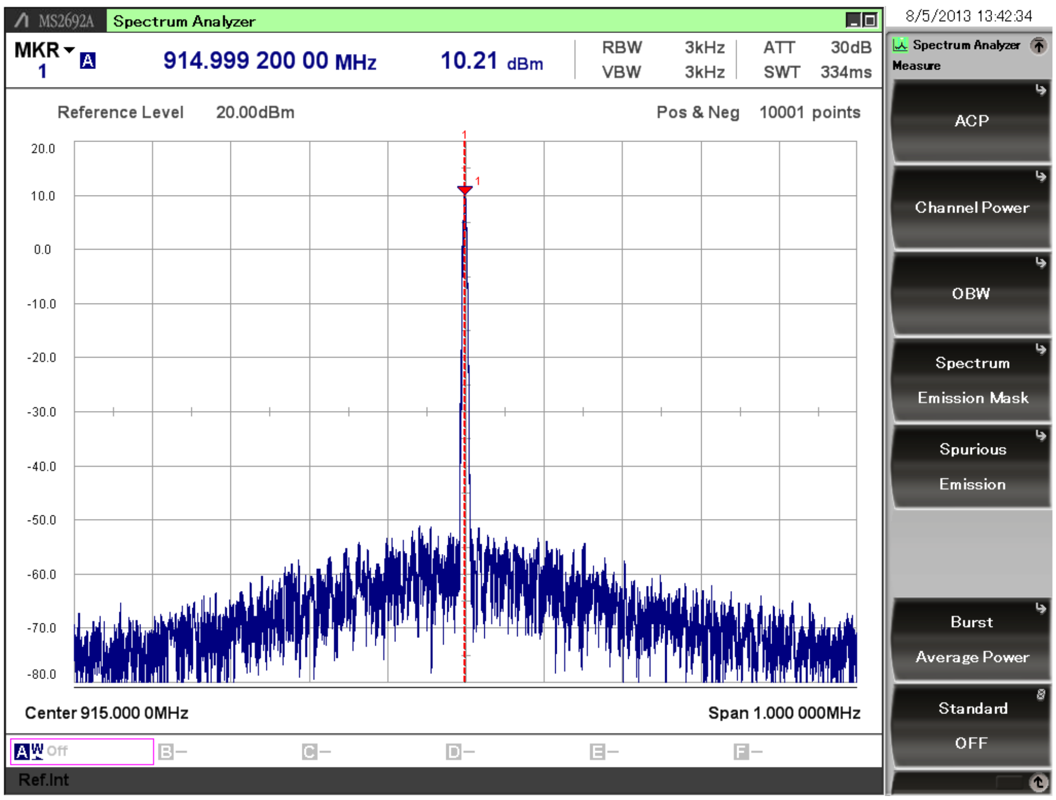


Figure 97. Conducted Measurement Result, 4463-PCE20C915 in Reduced (~10 dBm) Power State

The measured radiated power maximum is at the XY cut (Table 8). It is around 8.3 dBm EIRP, so the maximum gain number is ~–1.9 dBi, as shown in Figure 98.

7.3. Radiation Patterns (WES0117-01-APN915D-01)

The radiation patterns of the printed meander antenna were measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. Figure 99—Figure 104 show the radiation patterns at the fundamental frequency in the XY, XZ, and YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 98. Rotation starts from the X-axe in the XY cut, and from the Z-axe in the XZ and YZ cuts.

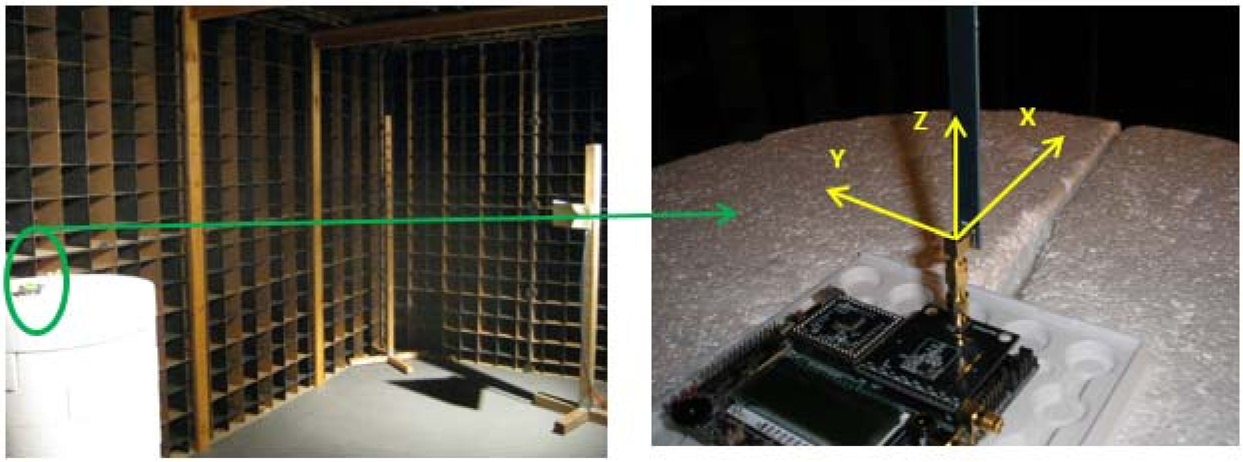


Figure 98. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 99–Figure 104).

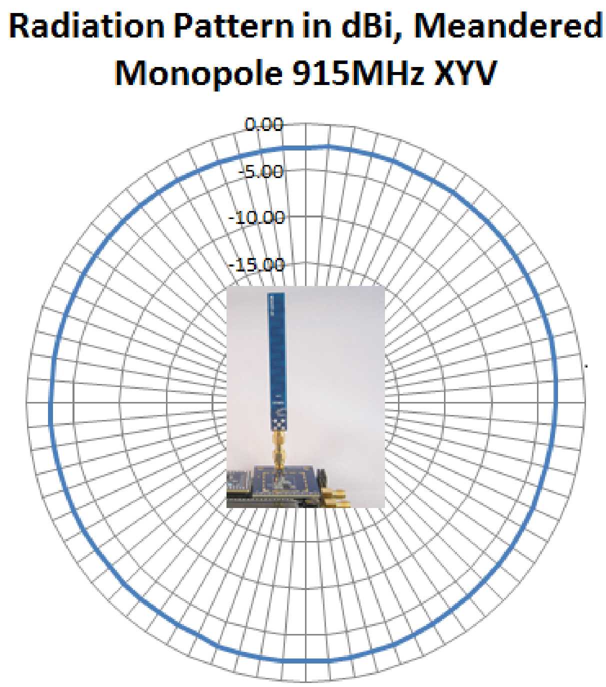


Figure 99. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

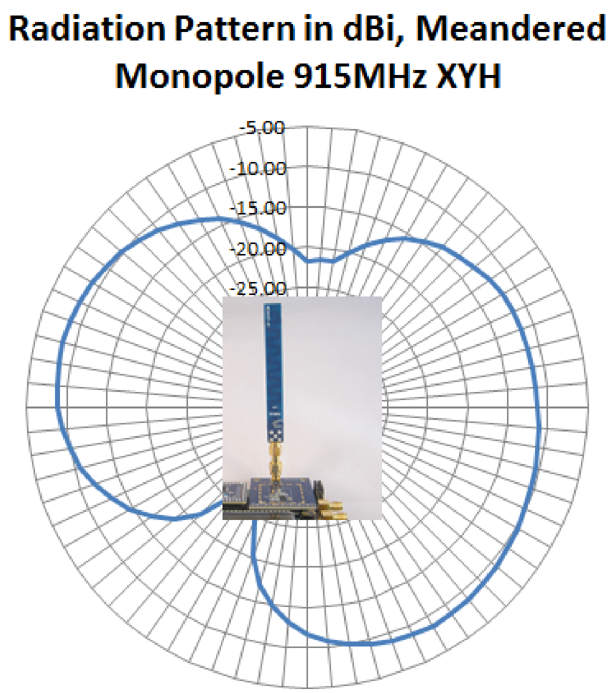


Figure 100. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

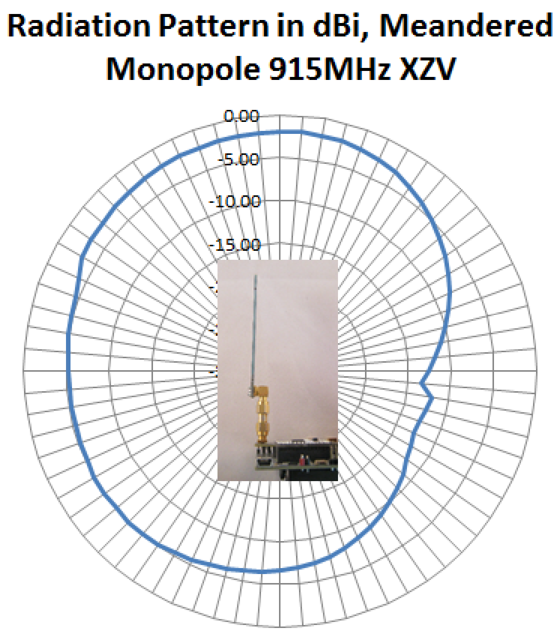


Figure 101. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

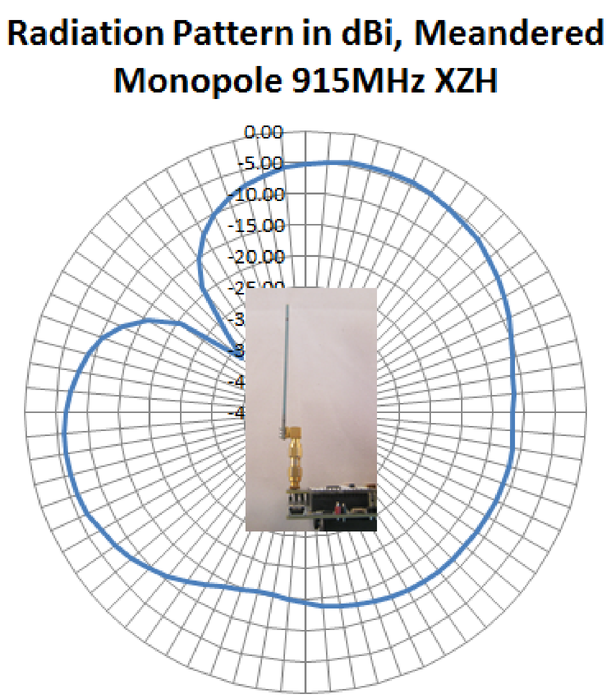


Figure 102. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

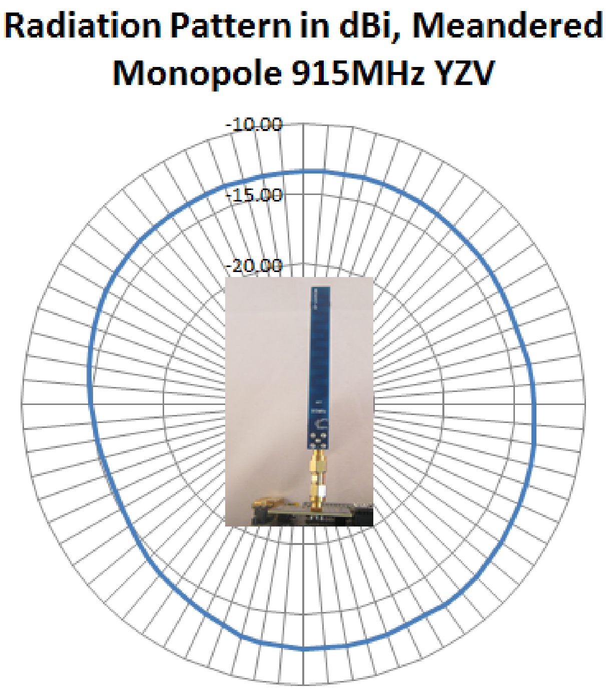


Figure 103. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

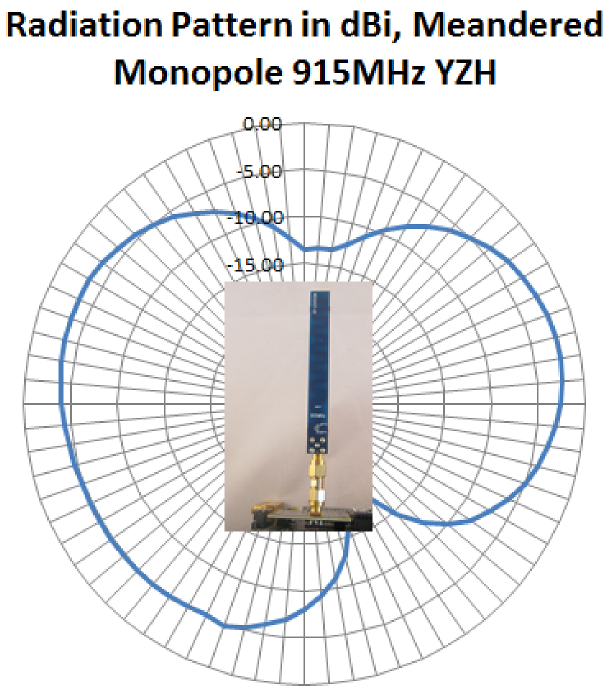


Figure 104. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

7.4. Radiated Harmonics (WES0117-01-APN915D-01)

The radiated harmonics of the printed meander antenna were also measured in an antenna chamber using the 4461-PCE14D915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. The 4463-PCE20C915 board works in a reduced power (~+10.2 dBm) state (0x1C, V_{DD} is 2.6 V). The maximum radiated power levels up to the 10^{th} harmonic were measured in the XY, XZ, and YZ cut, both with horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 8) with the corresponding standard limits.

This Antenna is FCC compliant.

Table 8. Radiated Harmonics, Printed Meander Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	8.12	21.9
XY	V	2^{nd}	1830	–11.68	–50.54	38.9
XY	V	3^{rd}	2745	–41.25	–50.91	9.7
XY	V	4^{th}	3660	–41.25	–51.16	9.9
XY	V	5^{th}	4575	–41.25	–61.12	19.9
XY	V	6^{th}	5490	–11.68	–57.53	45.9
XY	V	7^{th}	6405	–11.68	–57.07	45.4
XY	V	8^{th}	7320	–41.25	–56.30	15.1
XY	V	9^{th}	8235	–41.25	–54.95	13.7
XY	V	10^{th}	9150	–41.25	–52.86	11.6
XY	H	Fund.	915	30.00	1.71	28.3
XY	H	2^{nd}	1830	–11.68	–53.86	42.2
XY	H	3^{rd}	2745	–41.25	–50.90	9.6
XY	H	4^{th}	3660	–41.25	–51.19	9.9
XY	H	5^{th}	4575	–41.25	–60.98	19.7
XY	H	6^{th}	5490	–11.68	–58.66	47.0
XY	H	7^{th}	6405	–11.68	–58.67	47.0
XY	H	8^{th}	7320	–41.25	–57.07	15.8
XY	H	9^{th}	8235	–41.25	–55.19	13.9
XY	H	10^{th}	9150	–41.25	–53.08	11.8

Table 8. Radiated Harmonics, Printed Meander Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XZ	V	Fund.	915	30.00	8.32	21.7
XZ	V	2nd	1830	–11.68	–50.01	38.3
XZ	V	3rd	2745	–41.25	–51.13	9.9
XZ	V	4th	3660	–41.25	–53.21	12.0
XZ	V	5th	4575	–41.25	–61.42	20.2
XZ	V	6th	5490	–11.68	–59.37	47.7
XZ	V	7th	6405	–11.68	–57.98	46.3
XZ	V	8th	7320	–41.25	–57.42	16.2
XZ	V	9th	8235	–41.25	–54.32	13.1
XZ	V	10th	9150	–41.25	–51.94	10.7
XZ	H	Fund.	915	30.00	5.76	24.2
XZ	H	2nd	1830	–11.68	–49.97	38.3
XZ	H	3rd	2745	–41.25	–51.84	10.6
XZ	H	4th	3660	–41.25	–48.44	7.2
XZ	H	5th	4575	–41.25	–59.01	17.8
XZ	H	6th	5490	–11.68	–58.67	47.0
XZ	H	7th	6405	–11.68	–58.64	47.0
XZ	H	8th	7320	–41.25	–57.11	15.9
XZ	H	9th	8235	–41.25	–54.45	13.2
XZ	H	10th	9150	–41.25	–53.01	11.8
YZ	V	Fund.	915	30.00	–2.25	32.2
YZ	V	2nd	1830	–11.68	–53.03	41.4
YZ	V	3rd	2745	–41.25	–49.97	8.7
YZ	V	4th	3660	–41.25	–55.72	14.5

Table 8. Radiated Harmonics, Printed Meander Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
YZ	V	5th	4575	–41.25	–60.48	19.2
YZ	V	6th	5490	–11.68	–59.64	48.0
YZ	V	7th	6405	–11.68	–58.18	46.5
YZ	V	8th	7320	–41.25	–57.15	15.9
YZ	V	9th	8235	–41.25	–54.36	13.1
YZ	V	10th	9150	–41.25	–53.05	11.8
YZ	H	Fund.	915	30.00	7.97	22.0
YZ	H	2nd	1830	–11.68	–49.92	38.2
YZ	H	3rd	2745	–41.25	–49.27	8.0
YZ	H	4th	3660	–41.25	–49.31	8.1
YZ	H	5th	4575	–41.25	–58.69	17.4
YZ	H	6th	5490	–11.68	–58.16	46.5
YZ	H	7th	6405	–11.68	–56.96	45.3
YZ	H	8th	7320	–41.25	–56.01	14.8
YZ	H	9th	8235	–41.25	–53.96	12.7
YZ	H	10th	9150	–41.25	–52.79	11.5

7.5. Range Test(WES0117-01-APN915D-01)

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the one-directional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte packet length. The GPS coordinates have been recorded for each spot. The distance between the spots was measured using Google Maps, and results are shown in meters. The range was tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board, and the DUT (shown in Figure 94) held by the users hand. The 4463-PCE20C915 Pico Board works in a properly reduced power state (either +13 dBm or 0 dBm).

The range was tested in a flat land area without obstacles.

During the range test, the following settings have been used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the above settings (Step 1, Step 2, and Step 3) the following range tests were done:

1. Range measurement with the PRINTED MEANDER Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the PRINTED MEANDER Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the PRINTED MEANDER Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the PRINTED MEANDER Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the PRINTED MEANDER Antenna Boards—The antenna boards are VERTICALLY polarized and the boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 105.

The indoor range was not measured, due to the lack of a large enough building. But from the TX power and sensitivity data, an indoor range estimation can be given if one assumes an indoor propagation factor of 4.5, which is a typical value in normal office environments. Use the Silicon Labs' range calculator, which can be found here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming –2.6 dBi antenna gain (front direction, X-axes facing) and the setting "Set 1" (50 kbps, 1% PER, 13 dBm), the estimated indoor range is 100 m, as shown in Figure 106. If the boards are facing with the direction of maximum radiation, then the indoor range increases to ~107 m.

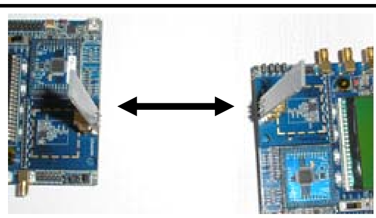
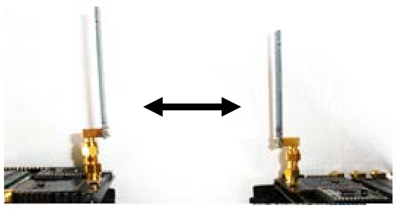
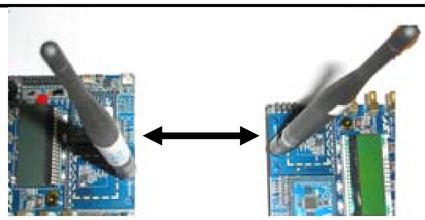
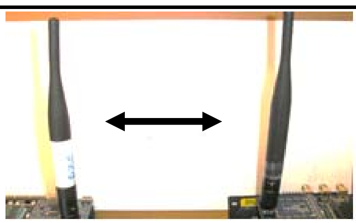
		Set1	13dBm	50kbps	+/-25kHz				
		Set2	13dBm	100kbps	+/-50kHz				
		Set3	0dBm	1.2kbps	+/-1.2kHz		GPS		Distance [m]
							N	E	
	Meandered Monopole				Base		47.152880°	19.180930°	0.0
Meandered Monopole (WES0117)				H pol; Norm. direction					
							GPS		
							N	E	
		1	Set1	13dBm	50kbps	+/-25kHz	47.169710°	19.172520°	1976.5
		2	Set2	100kbps	100kbps	+/-50kHz	47.16564	19.17291	1543.0
		3	Set3	0dBm	1.2kbps	+/-1.2kHz	47.16615	19.17281	1598.2
				V pol; Norm. direction					
							GPS		
							N	E	
		4	Set1	13dBm	50kbps	+/-25kHz	47.170650°	19.172360°	2079.5
				Max. direction w/o hand: XZH 0°					
							GPS		
							N	E	
		5	Set1	13dBm	50kbps	+/-25kHz	TBD	TBD	TBD
W1063				V pol; Norm. direction					
							GPS		
							N	E	
		6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	2459.8
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	2174.3
				H pol; Norm. direction					
							GPS		
							N	E	
		8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	2695.4

Figure 105. Outdoor Range Test Result with Two Identical Printed Meander Monopole Antennas with the 4463-PCE20C915 Pico Board Working in a Reduced Power (~10.2 dBm) State Driven by the WMB-930 Wireless Motherboard

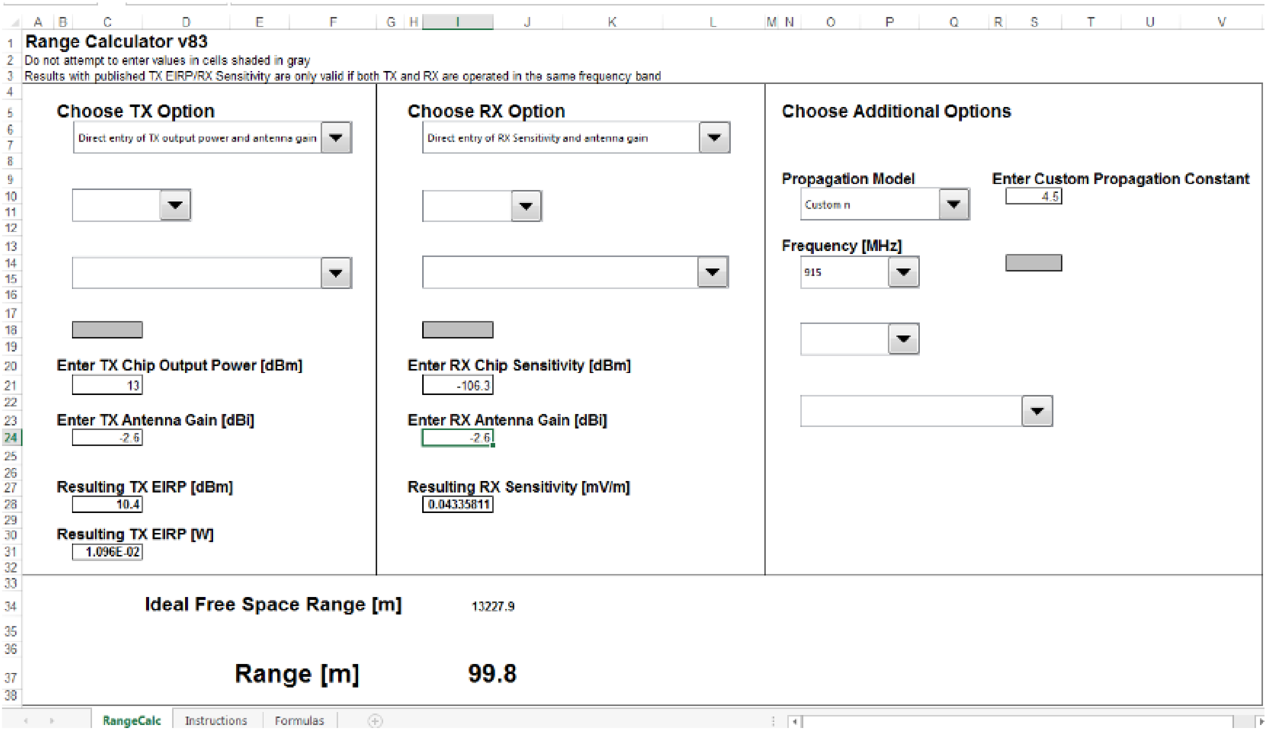


Figure 106. Indoor Range Estimation with Two Identical Printed Meander Monopole Antennas with the 4463-PCE20C915 Pico Board Working in a Reduced (~+13 dBm) Power State Driven by the WMB-930 Wireless Motherboard

8. Small Sized Printed ILA Antenna (WES0118-01-APL915S-01)

The Small Sized Printed ILA antenna has the following characteristics:

- The distance between the antenna trace outer edge and the PCB cutting edge is 1.5 mm.
- The size of the separated PCB antenna area is 10x10 mm.
- An external matching network (shown in Figure 107) is required at the antenna input.

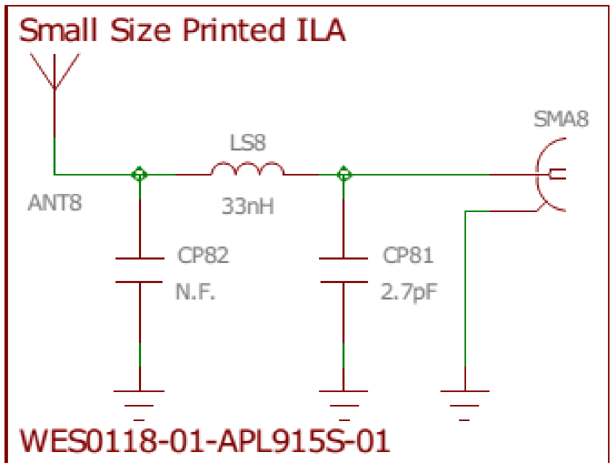


Figure 107. External Antenna Matching Network at 915 M for the Small ILA Antenna

The antenna is shown in Figure 108.

Figure 108. Small Sized Printed ILA Antenna

8.1. Antenna Impedance (WES0118-01-APL915S-01)

The impedance measurement setup is shown in Figure 109. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test, the user’s hand holds the motherboard. A typical hand position is shown in Figure 110.

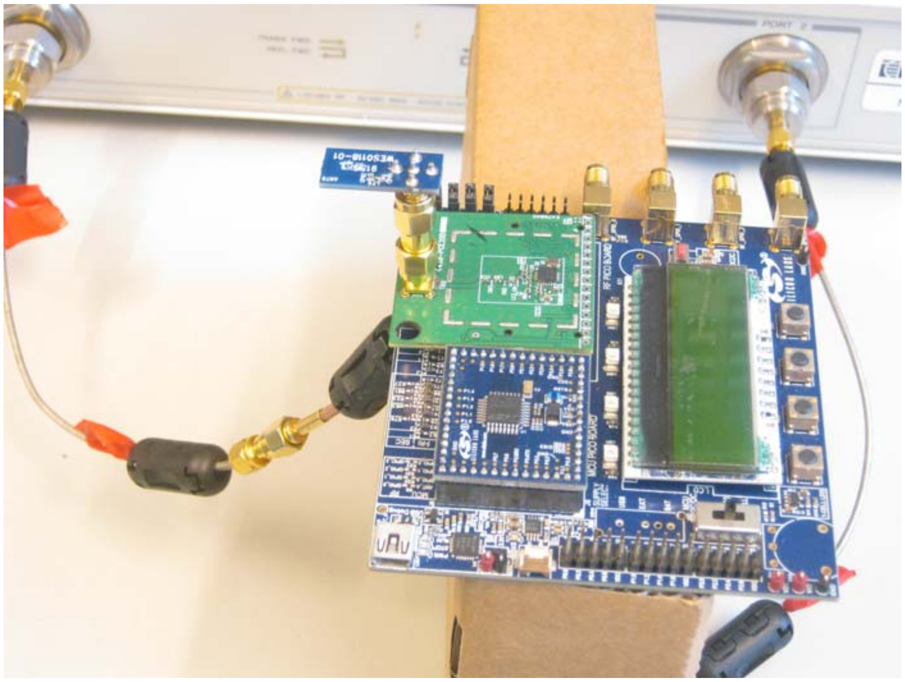


Figure 109. DUT (WES0118-01-APL915S-01) in the Impedance Measurement Setup

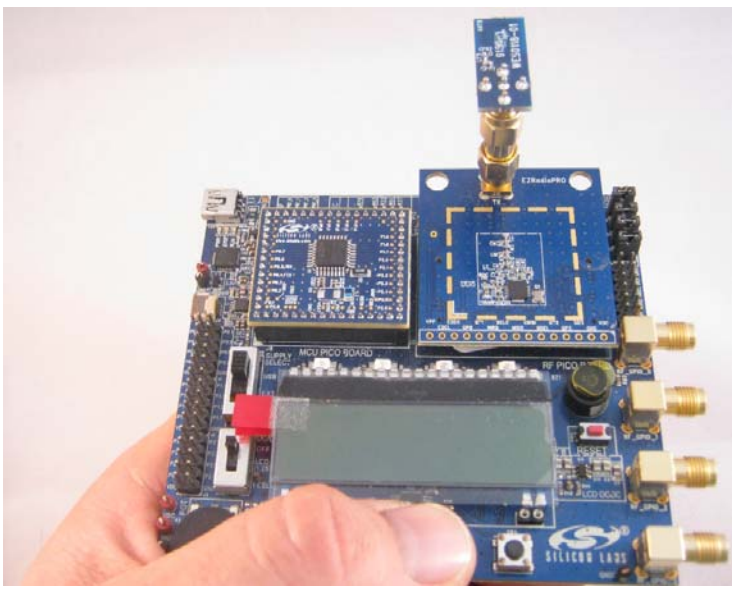


Figure 110. Typical Hand Effect on the Main Board During Impedance and Range Measurement (Small Sized Printed ILA Antenna Board)

The measured impedance of the antenna with its external matching network is shown in Figure 111 (up to 3 GHz) with motherboard hand effect.

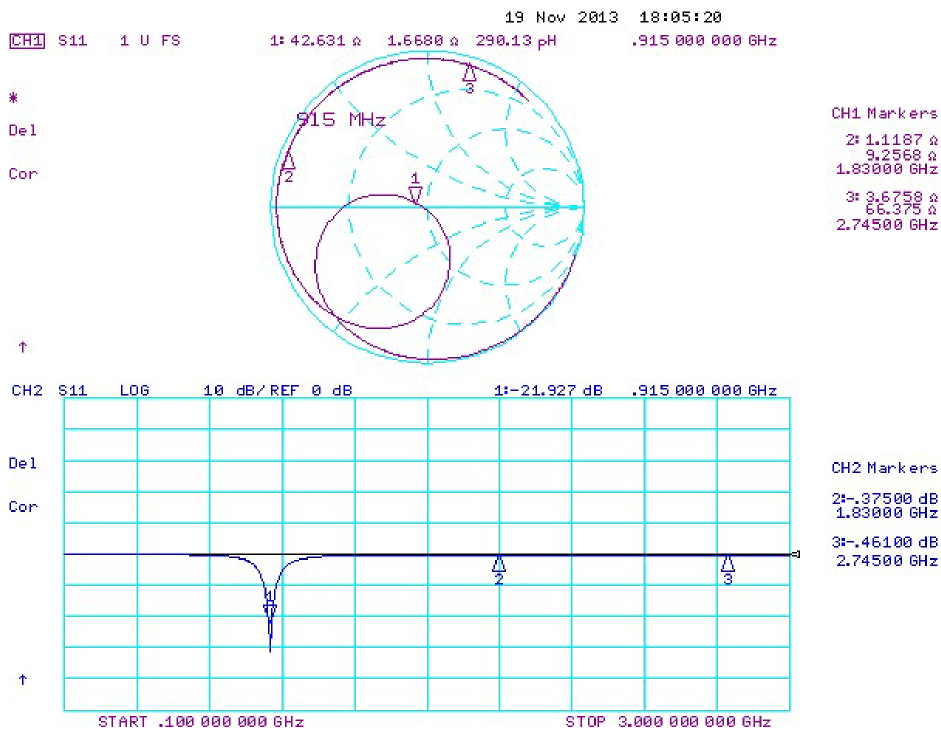


Figure 111. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

8.2. Antenna Gain (WES0118-01-APL915S-01)

The antenna gain is calculated from the measured radiated power at the fundamental and from the delivered power to the antenna. In the radiation measurement, the 4463-PCE20C915 Pico Board is set to reduced (~+10.2 dBm) power state (0x1C) and the entire setup is fed by two AA batteries (V_{DD} is set to 2.6 V). The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced (~10 dBm) power state is shown in Figure 112. This method can be effectively applied because the S11 of the antenna is much better than –10 dB so the reflection is negligible.

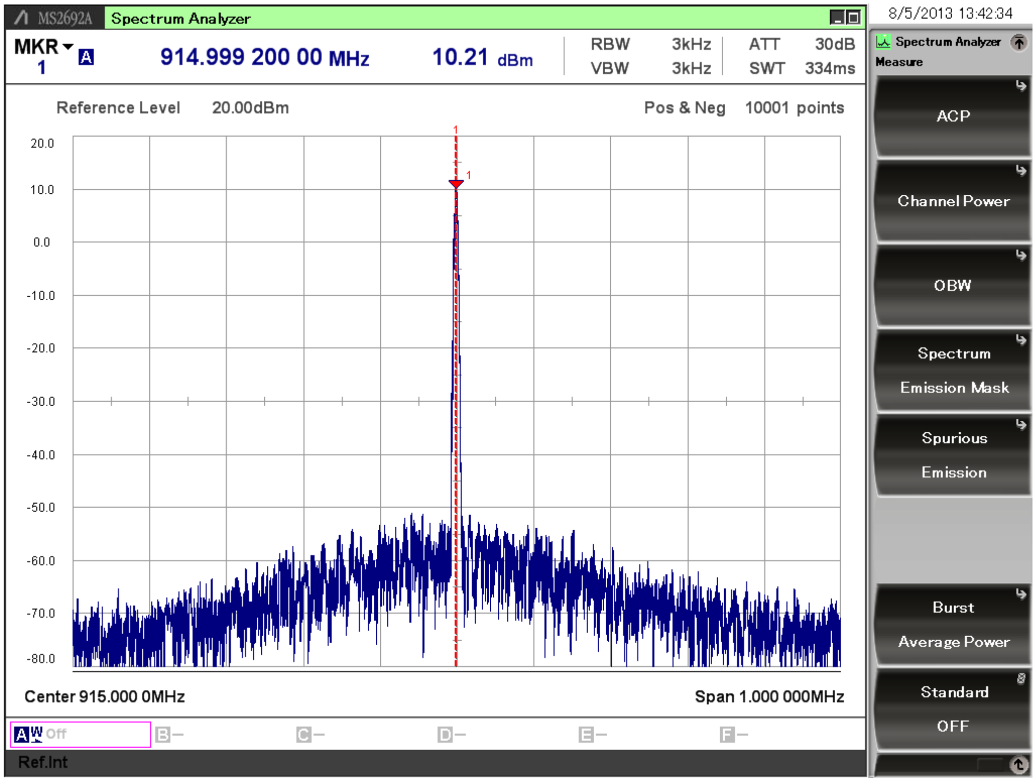


Figure 112. Conducted Measurement Result, 4463-PCE20C915 in a Reduced (~10 dBm) Power State

The measured radiated power maximum is at the XZ cut (Table 9). It is around +6.6 dBm EIRP, so the maximum gain number is ~–3.6 dBi, as shown in Figure 116.

This gain number is surprisingly high for such a small antenna. It should be emphasized that in typical, small remote applications, the grounding environment and the strength of the hand effect is different. Without the SMA connector, the SMA male-male transition, the Pico Board, and the wireless motherboard, the achievable antenna gain is much weaker.

8.3. Radiation Patterns (WES0118-01-APL915S-01)

The radiation patterns of the small sized printed ILA antenna were measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. Figure 114—Figure 119 show the radiation patterns at the fundamental frequency in the XY, XZ, and YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 113. Rotation starts from the X-axe in the XY cut, and from the Z-axe in the XZ and YZ cuts.

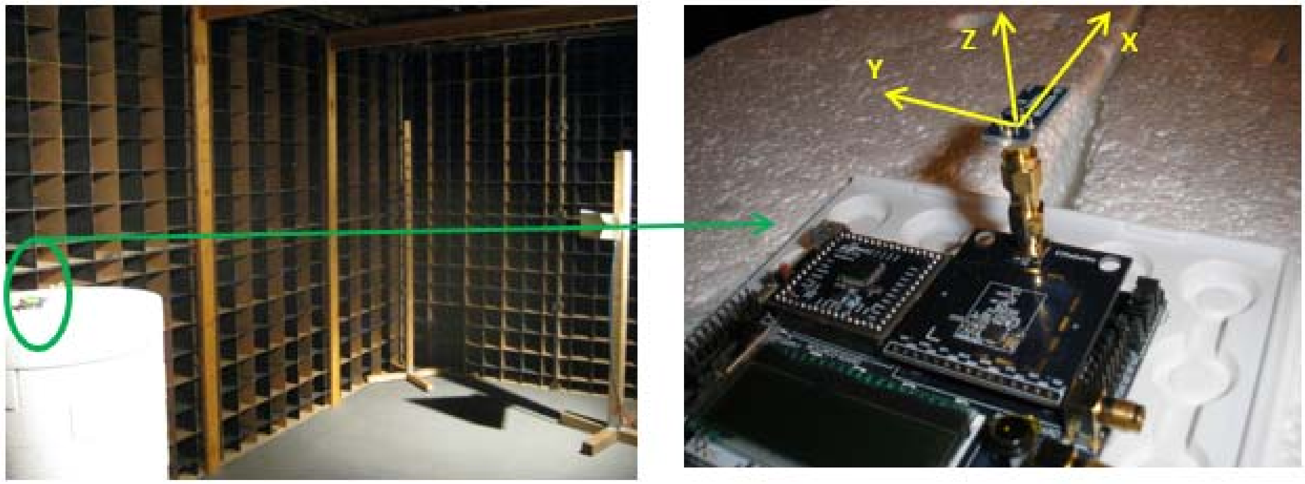


Figure 113. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 114–Figure 119).

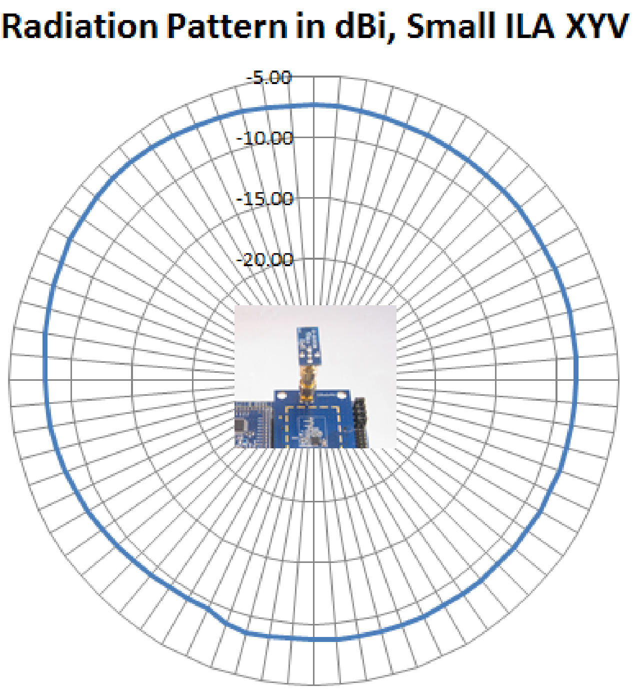


Figure 114. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

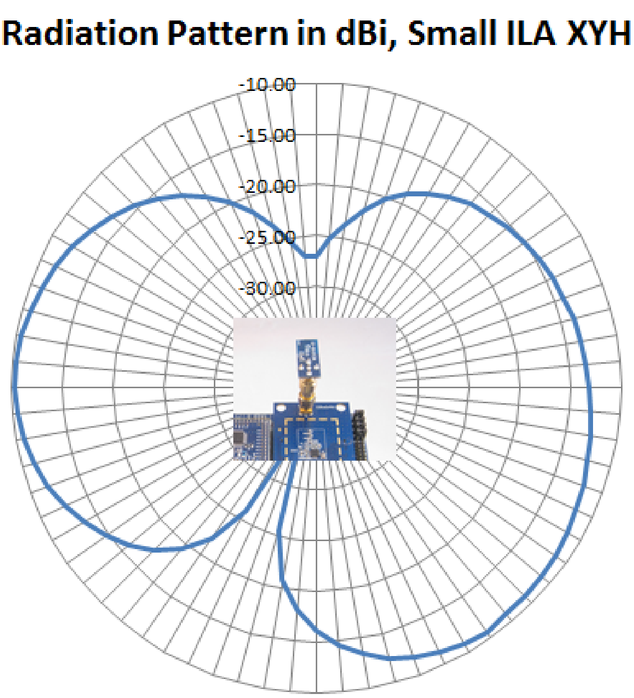


Figure 115. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

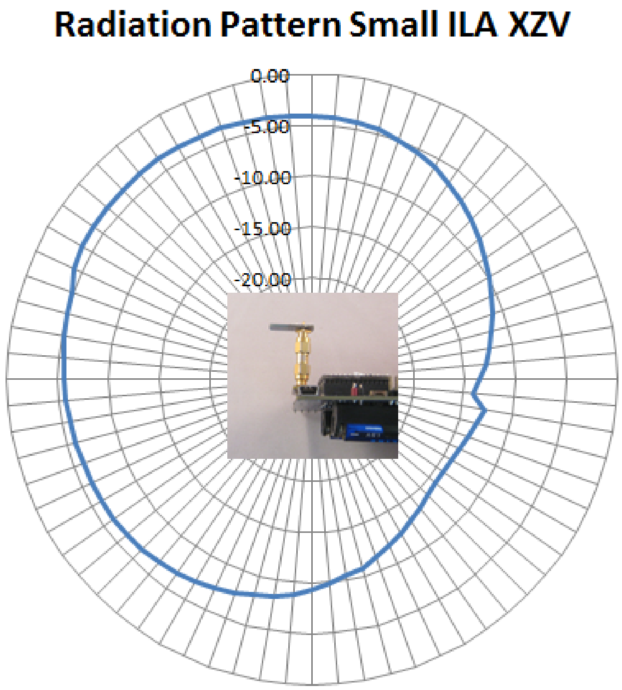


Figure 116. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

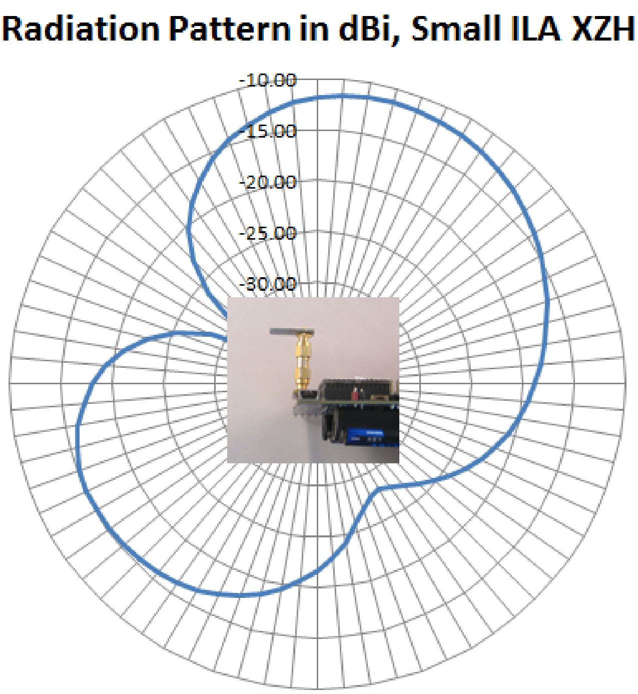


Figure 117. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

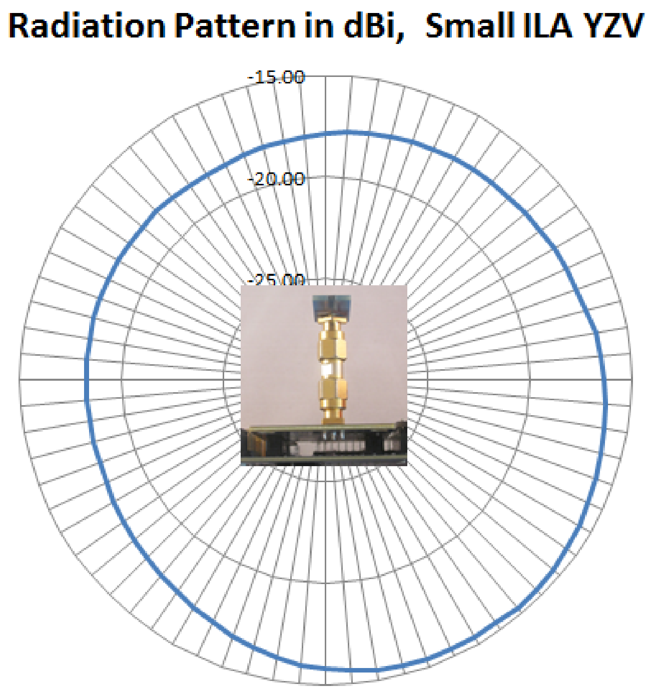


Figure 118. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

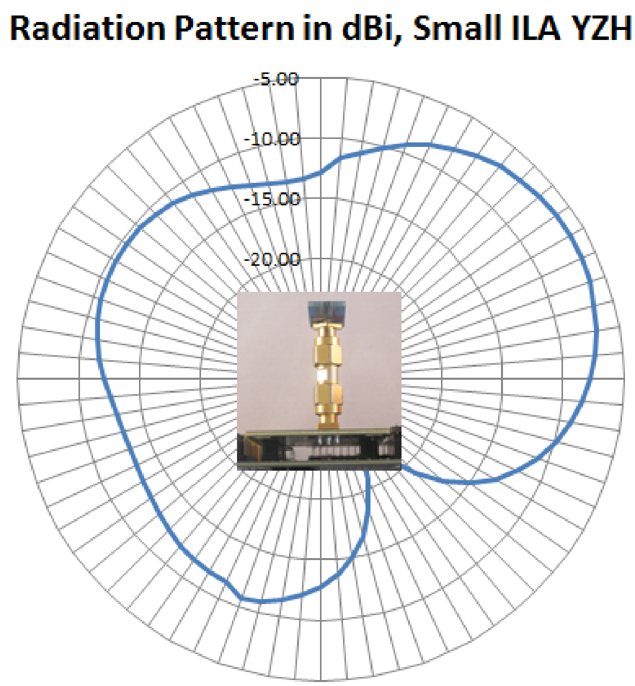


Figure 119. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

8.4. Radiated Harmonics (WES0118-01-APL915S-01)

The radiated harmonics of the small sized printed ILA antenna were also measured in an antenna chamber, using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board working in a reduced power (~+10.2 dBm) state (0x1C, V_{DD} is 2.6 V). The maximum radiated power levels up to the 10th harmonic were measured in the XY, XZ, and YZ cut, with both horizontal and vertical polarized receiver antenna. The results are shown in the following EIRP table (Table 9) with the corresponding standard limits.

The small sized ILA antenna driven by the Si4463 class E match in reduced (~10 dBm) power state complies with the FCC harmonic regulations with margin.

Table 9. Radiated Harmonics, Small ILA Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	3.58	26.4
XY	V	2nd	1830	–15.31	–53.92	40.5
XY	V	3rd	2745	–41.25	–51.26	10.0
XY	V	4th	3660	–41.25	–50.89	9.6
XY	V	5th	4575	–41.25	–60.54	19.3
XY	V	6th	5490	–15.31	–58.60	45.2
XY	V	7th	6405	–15.31	–56.51	43.1
XY	V	8th	7320	–41.25	–56.87	15.6
XY	V	9th	8235	–41.25	–52.18	10.9
XY	V	10th	9150	–41.25	–52.11	10.9
XY	H	Fund.	915	30.00	–0.09	30.1
XY	H	2nd	1830	–15.31	–56.52	43.1
XY	H	3rd	2745	–41.25	–49.66	8.4
XY	H	4th	3660	–41.25	–51.03	9.8
XY	H	5th	4575	–41.25	–61.59	20.3
XY	H	6th	5490	–15.31	–59.18	45.7
XY	H	7th	6405	–15.31	–57.84	44.4
XY	H	8th	7320	–41.25	–57.64	16.4
XY	H	9th	8235	–41.25	–55.02	13.8

Table 9. Radiated Harmonics, Small ILA Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
XY	H	10th	9150	–41.25	–52.59	11.3
XZ	V	Fund.	915	30.00	6.57	23.4
XZ	V	2nd	1830	–15.31	–57.45	44.0
XZ	V	3rd	2745	–41.25	–50.56	9.3
XZ	V	4th	3660	–41.25	–53.31	12.1
XZ	V	5th	4575	–41.25	–60.77	19.5
XZ	V	6th	5490	–15.31	–59.32	45.9
XZ	V	7th	6405	–15.31	–58.91	45.5
XZ	V	8th	7320	–41.25	–57.37	16.1
XZ	V	9th	8235	–41.25	–54.62	13.4
XZ	V	10th	9150	–41.25	–52.34	11.1
XZ	H	Fund.	915	30.00	–1.24	31.2
XZ	H	2nd	1830	–15.31	–54.95	41.5
XZ	H	3rd	2745	–41.25	–53.18	11.9
XZ	H	4th	3660	–41.25	–47.76	6.5
XZ	H	5th	4575	–41.25	–61.11	19.9
XZ	H	6th	5490	–15.31	–59.39	46.0
XZ	H	7th	6405	–15.31	–57.31	43.9
XZ	H	8th	7320	–41.25	–56.79	15.5
XZ	H	9th	8235	–41.25	–53.28	12.0
XZ	H	10th	9150	–41.25	–51.96	10.7
YZ	V	Fund.	915	30.00	–5.06	35.1
YZ	V	2nd	1830	–15.31	–58.88	45.5
YZ	V	3rd	2745	–41.25	–49.38	8.1

Table 9. Radiated Harmonics, Small ILA Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured Radiated Power in EIRP [dBm]	Margin [dB]
YZ	V	4th	3660	–41.25	–53.07	11.8
YZ	V	5th	4575	–41.25	–59.65	18.4
YZ	V	6th	5490	–15.31	–59.26	45.8
YZ	V	7th	6405	–15.31	–58.29	44.9
YZ	V	8th	7320	–41.25	–56.94	15.7
YZ	V	9th	8235	–41.25	–53.07	11.8
YZ	V	10th	9150	–41.25	–51.85	10.6
YZ	H	Fund.	915	30.00	4.02	26.0
YZ	H	2nd	1830	–15.31	–54.48	41.1
YZ	H	3rd	2745	–41.25	–49.36	8.1
YZ	H	4th	3660	–41.25	–49.66	8.4
YZ	H	5th	4575	–41.25	–59.97	18.7
YZ	H	6th	5490	–15.31	–58.82	45.4
YZ	H	7th	6405	–15.31	–56.43	43.0
YZ	H	8th	7320	–41.25	–56.45	15.2
YZ	H	9th	8235	–41.25	–51.21	10.0
YZ	H	10th	9150	–41.25	–52.90	11.6

8.5. Range Test (WES0118-01-APL915S-01)

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers where the bidirectional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte packet length. The GPS coordinates have been recorded for each spot. The distance between the spots was measured using Google Maps, and results are shown in meters. The range was tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board, and the DUT (as shown in Figure 110) held by the users hand. The 4463-PCE20C915 Pico Board worked in a properly reduced power state (either +13 dBm or 0 dBm).

The range was tested in a flat land area without obstacles.

During the range test, the following settings have been used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Using the above settings (Set 1, Set 2, and Set 3) the following range tests are done here:

1. Range measurement with the SMALL SIZE ILA Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the SMALL SIZE ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the SMALL SIZE ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the SMALL SIZE ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the SMALL SIZE ILA Antenna Boards—The antenna boards are VERTICALLY polarized and the boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 120.

Note: These range test results are valid with the above configuration and with moderate hand effect. In normal battery-operated, remote applications, where there is no large GND (motherboard) close to the antenna and where the antenna is usually very close to the user's hand, the achievable range is most likely much shorter.

The indoor range test was not performed, due to the lack of a large enough building. But from the TX power and sensitivity data, an indoor range estimation can be given if one assumes a propagation factor of 4.5, which is a typical value in normal office environments. Use the Silicon Labs' range calculator, which can be found here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming –7.4 dBi antenna gain (front direction, X-axes facing) and the setting "Set 1" (50 kbps, 1% PER, 13 dBm), the estimated indoor range is 60 m, as shown in Figure 121. If the boards are facing with the direction of maximum radiation, the indoor range increases to 90 m.

Set1	13dBm	50kbps	+/-25kHz
Set2	13dBm	100kbps	+/-50kHz
Set3	0dBm	1.2kbps	+/-1.2kHz

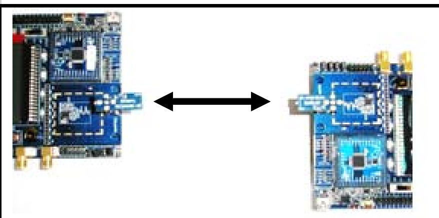
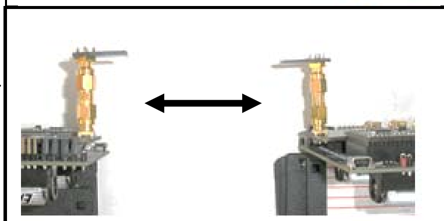
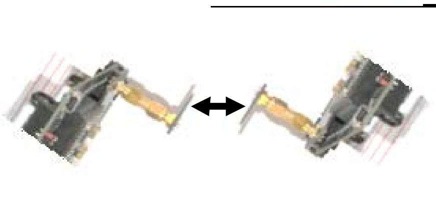
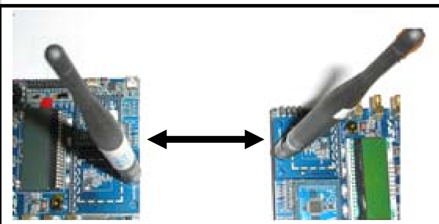
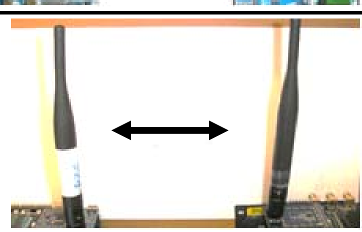
							GPS		Distance [m]
							N	E	
	Small Printed ILA				**Base**		**47.152880°**	**19.180930°**	**0.0**
Small Printed ILA (WES0118)				H pol; Norm. direction					
							GPS		
							N	E	
		1	Set1	13dBm	50kbps	+/-25kHz	47.161860°	19.173600°	**1142.0**
				V pol; Norm. direction					
							GPS		
							N	E	
		2	Set1	13dBm	50kbps	+/-25kHz	47.161270°	19.173610°	**1084.8**
		3	Set2	13dBm	100kbps	+/-50kHz	47.159130°	19.174030°	**869.0**
		4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.160740°	19.173780°	**1027.7**
				Max. direction w/o hand: XZV 325° //Meas w hand: 240°					
							GPS		
							N	E	
		5	Set1	13dBm	50kbps	+/-25kHz	47.164830°	19.173110°	**1454.4**
W1063				V pol; Norm. direction					
							GPS		
							N	E	
		6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	**2174.3**
				H pol; Norm. direction					
							GPS		
							N	E	
		8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 120. Outdoor Range Test Result with Two Identical Small Sized Printed ILA Antennas with the 4463-PCE20C915 Pico Board Working in a Reduced Power (~10.2 dBm) State Driven by the WMB-930 Wireless Motherboard

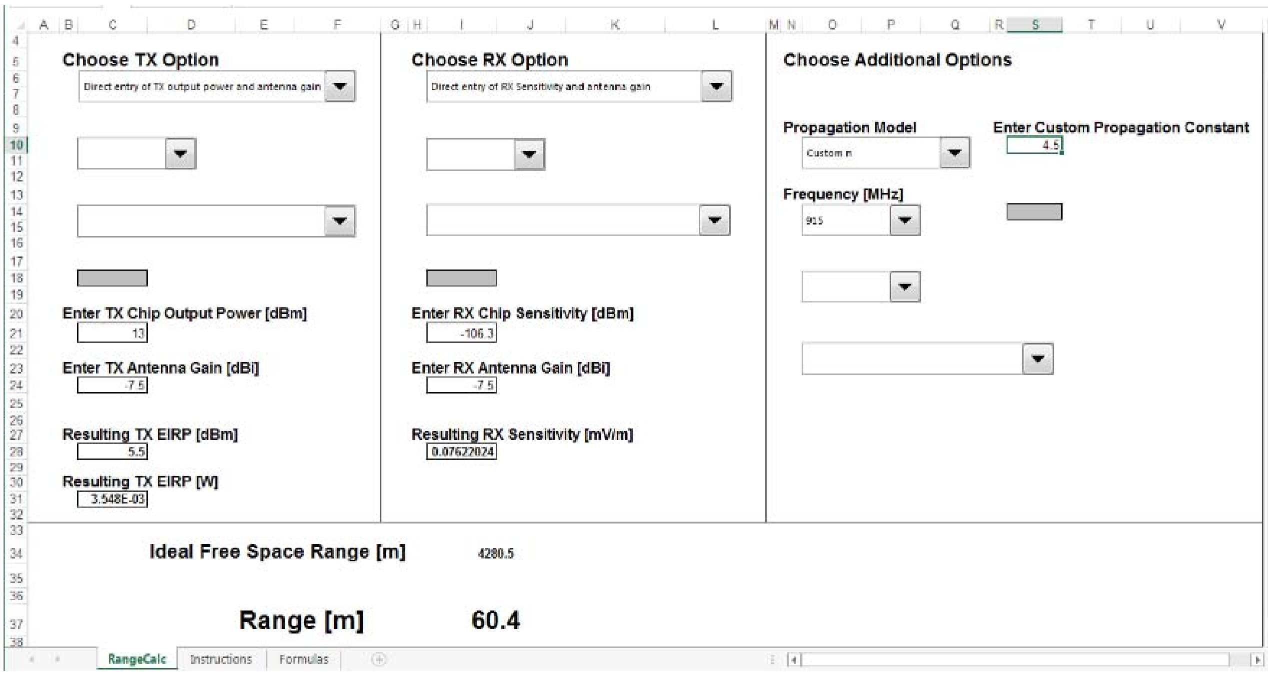


Figure 121. Indoor Range Estimation with Two Identical Small Sized Printed ILA Antennas and with the 4461-PCE14D915 Pico Board Working in a Reduced (~+13 dBm) Power State Driven by the WMB-930 Wireless Motherboard

9. Printed BIFA (WES0119-01-APB915D-01)

For the Printed BIFA antenna, an external matching network (shown in Figure 122) is required at the antenna input.

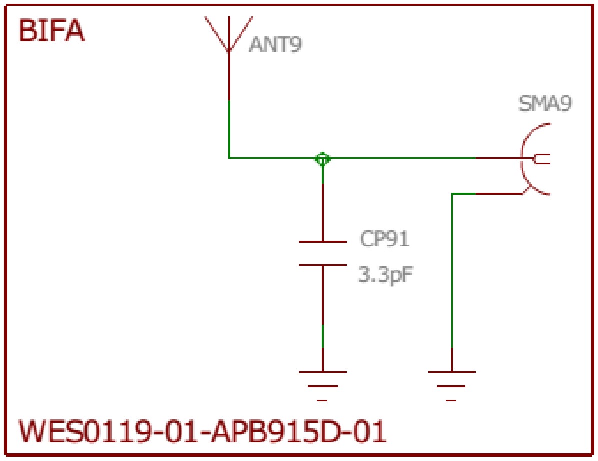


Figure 122. External Matching Network at 915 MHz for the BIFA Antenna

The antenna is shown in Figure 123.

Figure 123. Printed BIFA Antenna

9.1. Antenna Impedance (WES0119-01-APB915D-01)

The impedance measurement setup is shown in Figure 124. The antenna board is connected to the 4460-PCE10D915 Pico Board through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board.

During the impedance tuning and range test, the user's hand holds the motherboard. A typical hand position is shown in Figure 125.

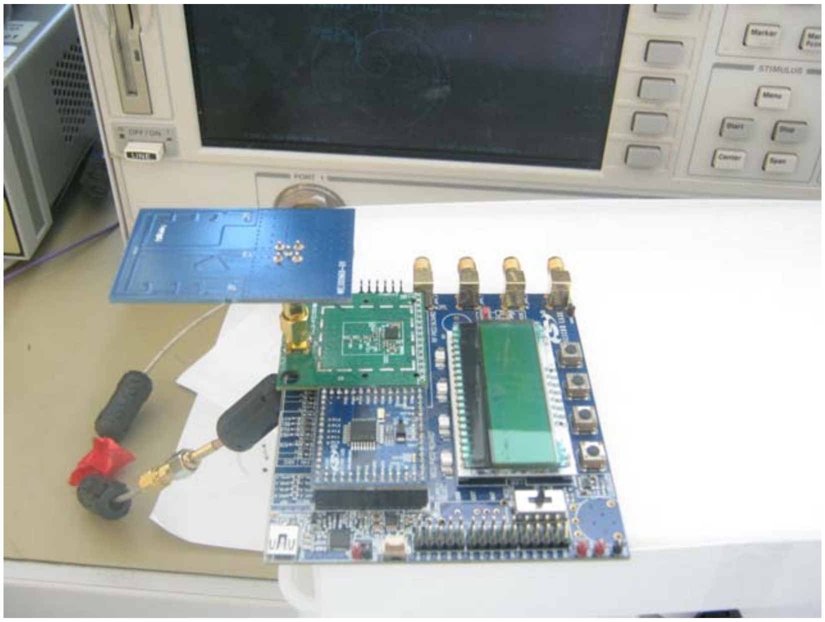


Figure 124. (WES0119-01-APB915D-01) DUT in the Impedance Measurement Setup

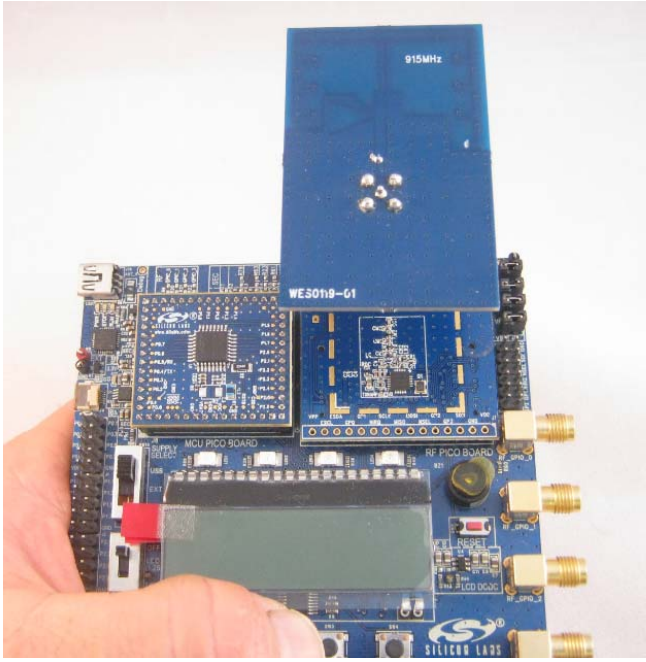


Figure 125. Typical Hand Effect on the Main Board During Impedance and Range Measurement (BIFA Antenna Board)

The measured impedance of the antenna with its external matching network is shown in Figure 126 (up to 3 GHz) with motherboard hand effect.

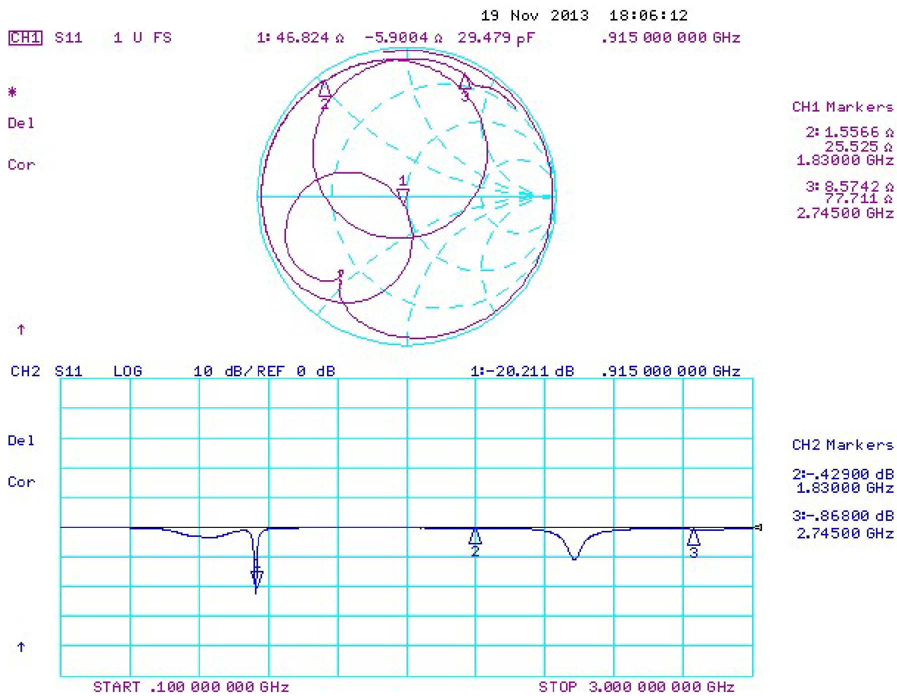


Figure 126. Measured Impedance (up to 3 GHz) with Hand Effect on the Main Board

9.2. Antenna Gain (WES0119-01-APB915D-01)

The antenna gain is calculated from the measured radiated power at the fundamental and from the delivered power to the antenna. In the radiation measurement, the 4463-PCE20C915 Pico Board is set to a reduced (~+10.2 dBm) power state (0x1C) and the entire setup is fed by two AA batteries (V_{DD} is set to 2.6 V). The conducted SA measurement result of the 4463-PCE20C915 Pico Board in this reduced (~10 dBm) power state is shown in Figure 127. This method can be effectively applied because the S11 of the antenna is much better than –10 dB, so the reflection loss is negligible.

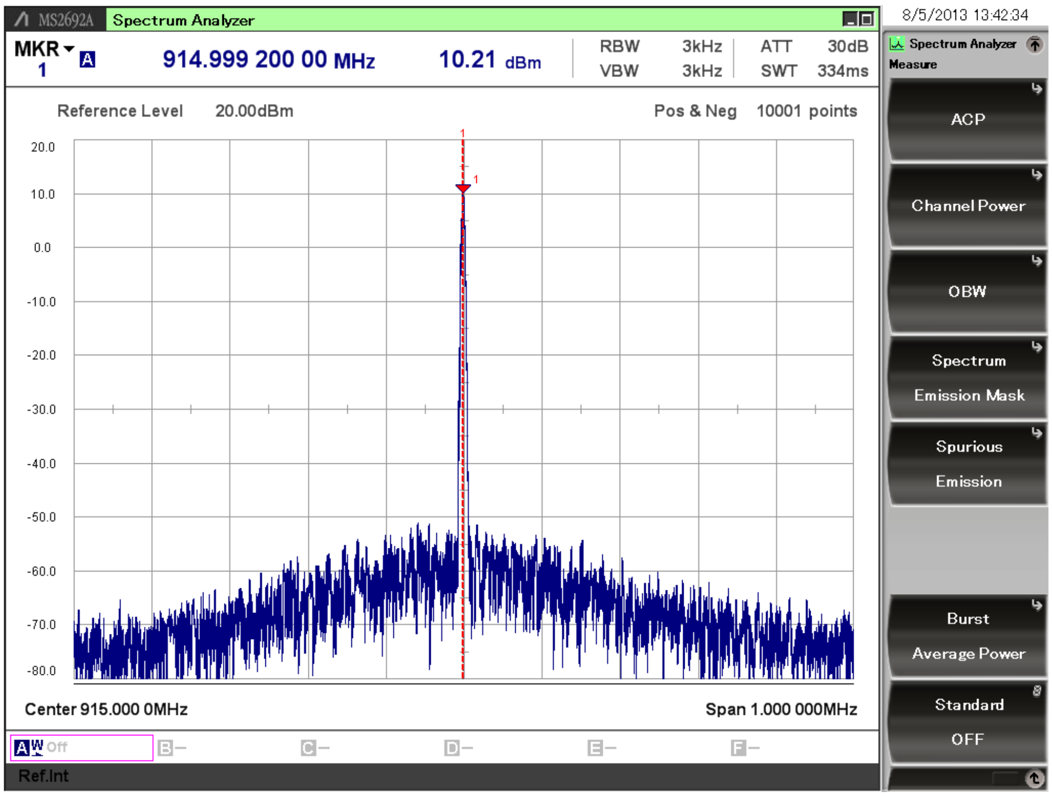


Figure 127. Conducted Measurement Result, 4463-PCE20C915 in Reduced (~10.2 dBm) State

The measured radiated power maximum is at the ZY cut (Table 10). It is around 10.7 dBm EIRP, so the maximum gain number is ~0.5 dBi ,as shown in Figure 131.

9.3. Radiation Patterns (WES0119-01-APB915D-01)

Radiation patterns of the printed BIFA antenna were measured in an antenna chamber using the 4463-PCE20C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board. Figure 129—Figure 134 show the radiation patterns at the fundamental frequency in the XY, XZ, and YZ cut, with both horizontal and vertical receiver antenna polarization. The rotator was stepped in five degrees to record the radiation pattern in 360 degrees.

The DUT with coordinate system under the radiated measurements is shown in Figure 128. Rotation starts from the X-axe in the XY cut, and from the Z-axe in the XZ and YZ cuts.

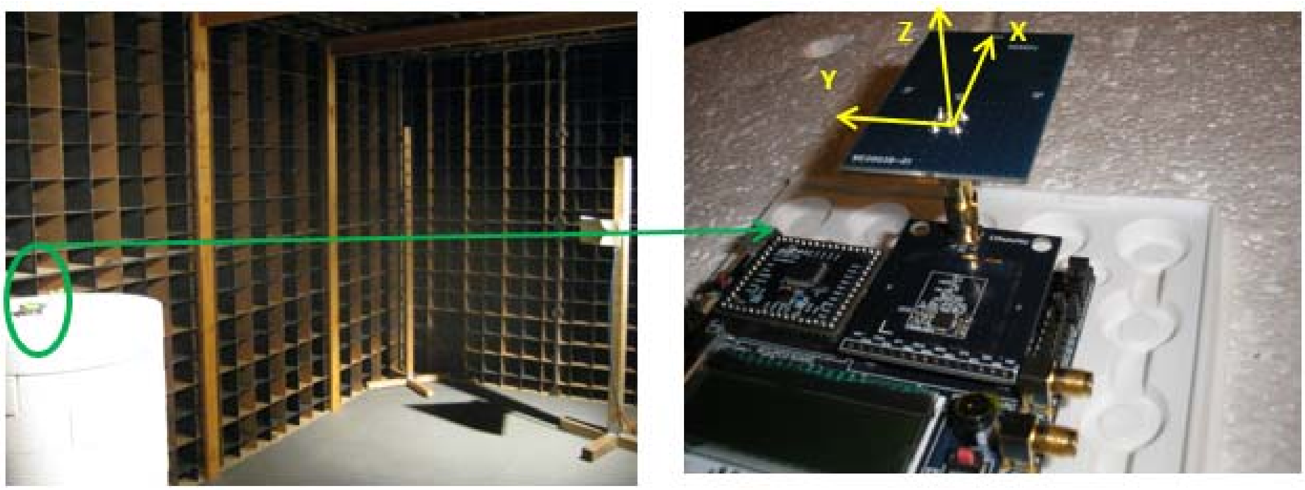


Figure 128. DUT in the Antenna Chamber

The measured radiation patterns (antenna gain in dBi) are shown in the following six figures (Figure 129–Figure 134).

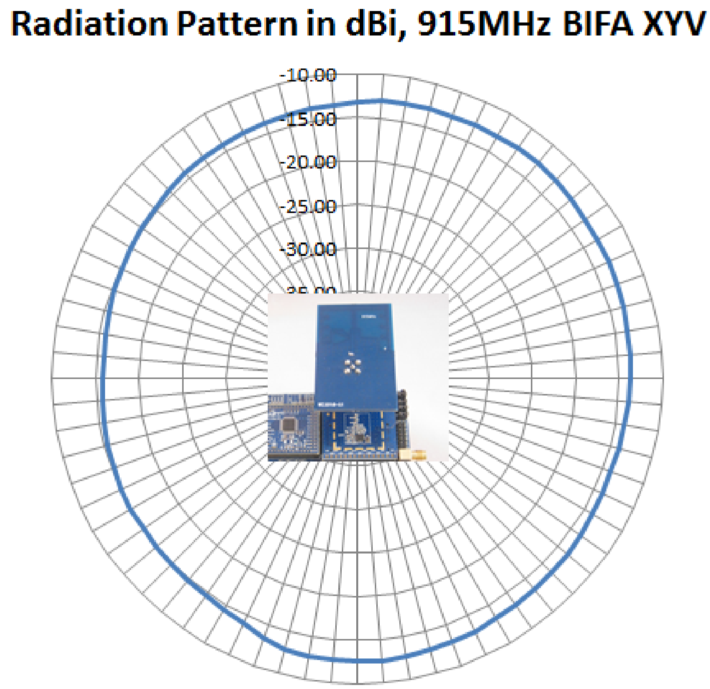


Figure 129. Radiation Pattern in the XY Cut with Vertical Receiver Antenna Polarization

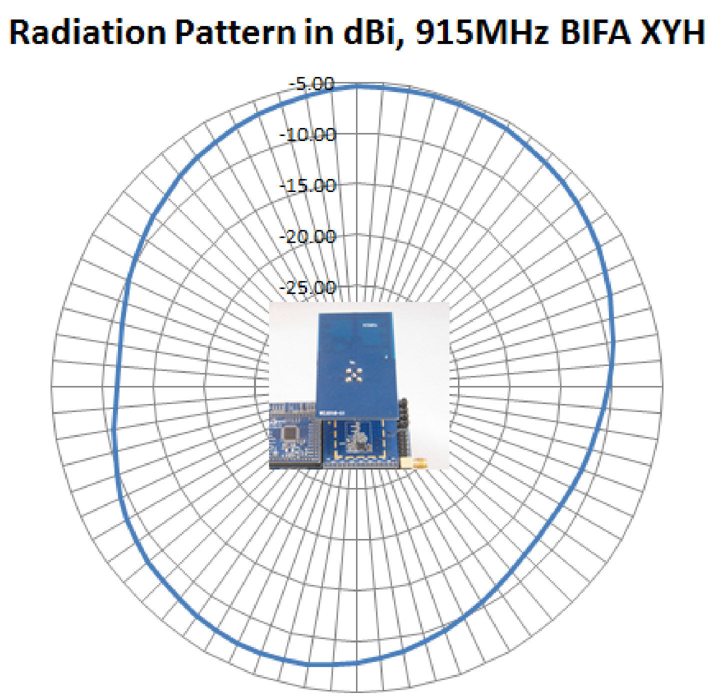


Figure 130. Radiation Pattern in the XY Cut with Horizontal Receiver Antenna Polarization

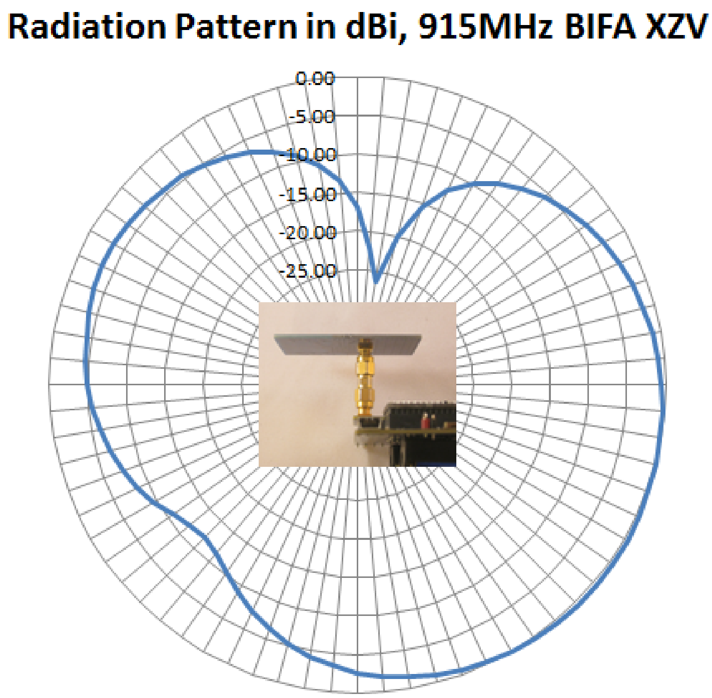


Figure 131. Radiation Pattern in the XZ Cut with Vertical Receiver Antenna Polarization

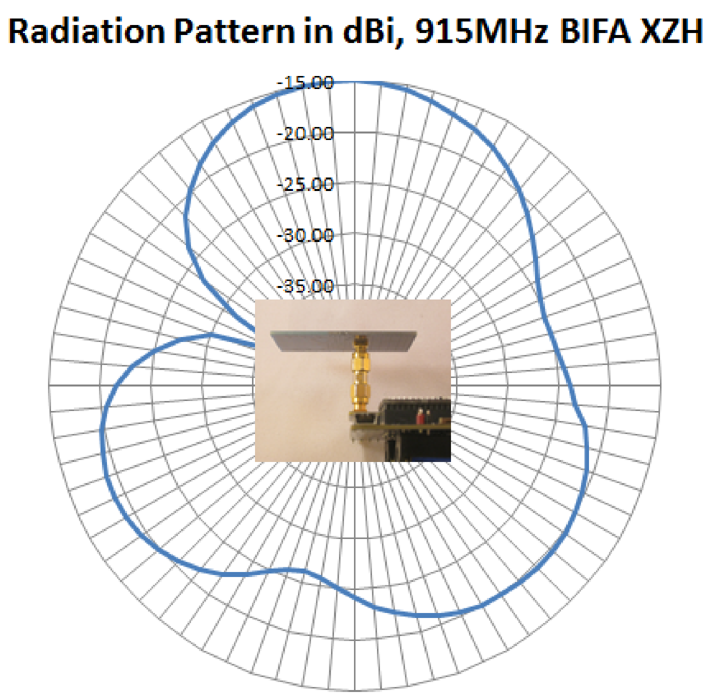


Figure 132. Radiation Pattern in the XZ Cut with Horizontal Receiver Antenna Polarization

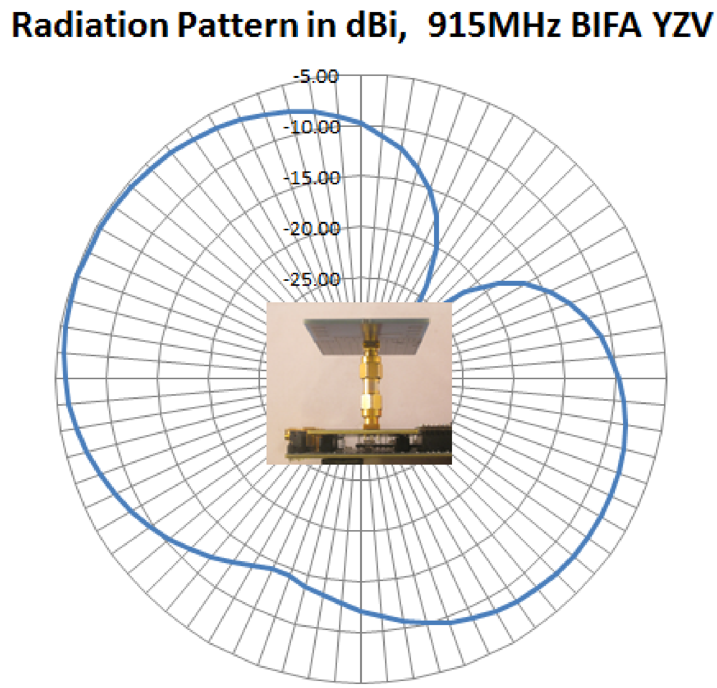


Figure 133. Radiation Pattern in the YZ Cut with Vertical Receiver Antenna Polarization

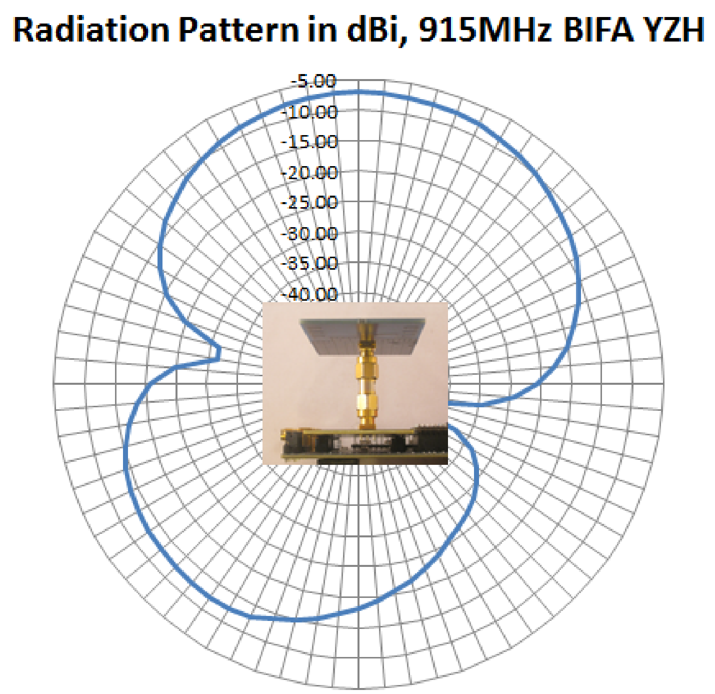


Figure 134. Radiation Pattern in the YZ Cut with Horizontal Receiver Antenna Polarization

9.4. Radiated Harmonics (WES0119-01-APB915D-01)

The radiated harmonics of the BIFA antenna were also measured in an antenna chamber using the 4463-PCE10C915 Pico Board connected through a male-to-male SMA transition with the WMB-930 Wireless Motherboard driving the Pico Board works in a reduced power (~+10.2 dBm) state (0x1C, V_{DD} is 2.6 V). The maximum radiated power levels up to the 10th harmonic were measured in the XY, XZ and YZ cut, with both horizontal and vertical polarized receiver antenna. Results are shown in the following EIRP table (Table 10) with the corresponding standard limits.

The BIFA antenna driven by the Si4463 10 dBm class E match (4463-PCE20C915 Pico Board) complies with the FCC harmonic regulations.

Table 10. Radiated Harmonics, BIFA Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	V	Fund.	915	30.00	–2.29	32.3
XY	V	2nd	1830	–15.31	–52.90	43.6
XY	V	3rd	2745	–41.25	–50.27	9.0
XY	V	4th	3660	–41.25	–49.03	7.8
XY	V	5th	4575	–41.25	–56.50	15.2
XY	V	6th	5490	–15.31	–53.60	44.3
XY	V	7th	6405	–15.31	–53.72	44.5
XY	V	8th	7320	–41.25	–52.03	10.8
XY	V	9th	8235	–41.25	–50.17	8.9
XY	V	10th	9150	–41.25	–47.25	6.0
XY	H	Fund.	915	30.00	4.82	25.2
XY	H	2nd	1830	–15.31	–53.93	44.7
XY	H	3rd	2745	–41.25	–53.28	12.0
XY	H	4th	3660	–41.25	–51.82	10.6
XY	H	5th	4575	–41.25	–56.90	15.7
XY	H	6th	5490	–15.31	–53.90	44.6
XY	H	7th	6405	–15.31	–53.43	44.2
XY	H	8th	7320	–41.25	–52.19	10.9
XY	H	9th	8235	–41.25	–50.29	9.0

Table 10. Radiated Harmonics, BIFA Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
XY	H	10th	9150	–41.25	–47.21	6.0
XZ	V	Fund.	915	30.00	10.74	19.3
XZ	V	2nd	1830	–15.31	–55.50	46.2
XZ	V	3rd	2745	–41.25	–50.91	9.7
XZ	V	4th	3660	–41.25	–53.71	12.5
XZ	V	5th	4575	–41.25	–57.05	15.8
XZ	V	6th	5490	–15.31	–53.92	44.7
XZ	V	7th	6405	–15.31	–52.88	43.6
XZ	V	8th	7320	–41.25	–52.04	10.8
XZ	V	9th	8235	–41.25	–49.60	8.3
XZ	V	10th	9150	–41.25	–47.19	5.9
XZ	H	Fund.	915	30.00	–4.71	34.7
XZ	H	2nd	1830	–15.31	–51.20	41.9
XZ	H	3rd	2745	–41.25	–52.08	10.8
XZ	H	4th	3660	–41.25	–47.70	6.5
XZ	H	5th	4575	–41.25	–56.47	15.2
XZ	H	6th	5490	–15.31	–53.84	44.6
XZ	H	7th	6405	–15.31	–53.91	44.6
XZ	H	8th	7320	–41.25	–52.38	11.1
XZ	H	9th	8235	–41.25	–50.15	8.9
XZ	H	10th	9150	–41.25	–46.92	5.7
YZ	V	Fund.	915	30.00	4.94	25.1
YZ	V	2nd	1830	–15.31	–54.98	45.7
YZ	V	3rd	2745	–41.25	–51.93	10.7

Table 10. Radiated Harmonics, BIFA Antenna Board Connected to the Reduced Power (~10 dBm) 4463-PCE20C915, and Driven by the WMB-930 Wireless Motherboard (Continued)

Cut.	Pol.	Freq.	f [MHz]	FCC (15.247) limit in EIRP [dBm]	Measured radiated power in EIRP [dBm]	Margin [dB]
YZ	V	4th	3660	–41.25	–50.34	9.1
YZ	V	5th	4575	–41.25	–57.73	16.5
YZ	V	6th	5490	–15.31	–53.59	44.3
YZ	V	7th	6405	–15.31	–53.42	44.2
YZ	V	8th	7320	–41.25	–51.76	10.5
YZ	V	9th	8235	–41.25	–50.11	8.9
YZ	V	10th	9150	–41.25	–47.35	6.1
YZ	H	Fund.	915	30.00	3.21	26.8
YZ	H	2nd	1830	–15.31	–57.29	48.0
YZ	H	3rd	2745	–41.25	–53.09	11.8
YZ	H	4th	3660	–41.25	–52.44	11.2
YZ	H	5th	4575	–41.25	–57.62	16.4
YZ	H	6th	5490	–15.31	–53.52	44.3
YZ	H	7th	6405	–15.31	–53.38	44.1
YZ	H	8th	7320	–41.25	–51.31	10.1
YZ	H	9th	8235	–41.25	–49.50	8.2
YZ	H	10th	9150	–41.25	–47.48	6.2

9.5. Range Test (WES0119-01-APB915D-01)

The available range was measured using the Range Test Demo. This application is supplied with the standard development kits for EZRadioPRO®. The target of this measurement is to find the distance between the transceivers, where the bidirectional PER (Packet Error Rate, number of lost packets) is not more than 1% at each side with ten byte long packets. The GPS coordinates have been recorded for each spot. The distance between the spots was measured using Google Maps, and results are shown in meters. The range was tested between two identical units with the WMB-930 Wireless Motherboard, 4463-PCE20C915 Pico Board, and the DUT (as shown in Figure 125) held by the users hand. The 4463-PCE20C915 Pico Board worked in a properly reduced power state (either +13 dBm or 0 dBm).

The range was tested in a flat land area without obstacles.

During the range test, the following settings have been used:

- Set 1: Txpow=13 dBm, 50 kbps, 25 kHz dev., RXBW=103.06 kHz (sens ~–106.3 dBm)
- Set 2: Txpow=13 dBm, 100 kbps, 50 kHz dev., RXBW=206.12 kHz (sens ~–103.4 dBm)
- Set 3: Txpow=0 dBm, 1.2 kbps, 1.2 kHz dev., RXBW=7.15 kHz (sens ~–118 dBm)

Two outdoor range tests are performed.

Using the above settings (Set 1, Set 2, and Set 3) the following range tests are done here:

1. Range measurement with the BIFA Antenna Boards—The antenna boards are HORIZONTALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
2. Range measurement with the BIFA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 1".
3. Range measurement with the BIFA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 2".
4. Range measurement with the BIFA Antenna Boards—The antenna boards are VERTICALLY polarized and the X-axes are facing each other (i.e., normal usage position). The applied setting is "Set 3".
5. Range measurement with the BIFA Antenna Boards—The antenna boards are VERTICALLY polarized and the boards are facing each other in their direction of maximum radiation. The applied setting is "Set 1".
6. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 1".
7. Reference range measurement with two 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in VERTICAL polarization using the setting denoted by "Set 3".
8. Reference range measurement with a 868/915 MHz REFERENCE MONOPOLE (W1063 from Pulse) in HORIZONTAL polarization using the setting denoted by "Set 1".

The measurement results are summarized in Figure 135.

The indoor range test was not performed, due to the lack of a large enough building. But from the TX power and sensitivity data, an indoor range estimation can be given if one assumes a propagation factor of 4.5, which is a typical value in normal office environments. Use the Silicon Labs' range calculator, which can be found here:

http://www.silabs.com/support/pages/document-library.aspx?p=Wireless&f=EZRadioPRO&pn=Si4460

Assuming –5.5 dBi antenna gain (front direction, X-axes facing) and the setting "Set 1" (50 kbps, 1% PER, 14 dBm), the estimated indoor range is 74 m, as shown in Figure 136. If the boards are facing with the direction of maximum radiation, the indoor range increases to 137 m.

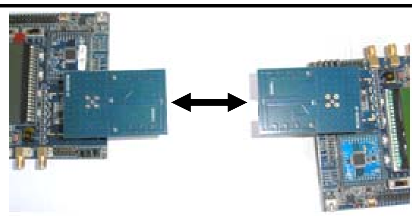
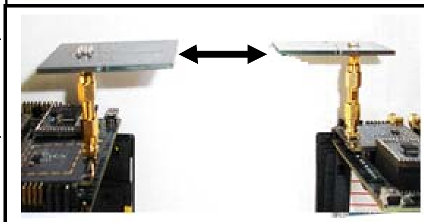
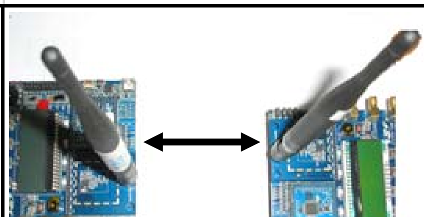
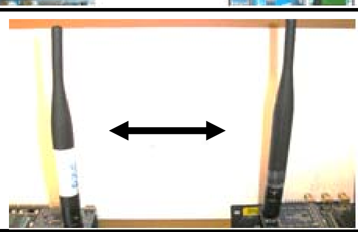
		Set1	13dBm	50kbps	+/-25kHz				
		Set2	13dBm	100kbps	+/-50kHz				
		Set3	0dBm	1.2kbps	+/-1.2kHz		**GPS**		**Distance [m]**
							N	**E**	
	BIFA				**Base**		**47.152880°**	**19.180930°**	**0.0**
BIFA (WES0119)				H pol; Norm. direction					
							GPS		
							N	E	
		1	Set1	13dBm	50kbps	+/-25kHz	47.170810°	19.172040°	**2104.0**
				V pol; Norm. direction					
							GPS		
							N	E	
		2	Set1	13dBm	50kbps	+/-25kHz	47.168090°	19.172560°	**1805.8**
		3	Set2	13dBm	100kbps	+/-50kHz	47.166350°	19.172780°	**1619.6**
		4	Set3	0dBm	1.2kbps	+/-1.2kHz	47.166630°	19.172810°	**1647.6**
				Max. direction w/o hand: XZV 125°					
							GPS		
							N	E	
		5	Set1	13dBm	50kbps	+/-25kHz	TBD	TBD	**TBD**
W1063				V pol; Norm. direction					
							GPS		
							N	E	
		6	Set1	13dBm	50kbps	+/-25kHz	47.174060°	19.171540°	**2459.8**
		7	Set3	0dBm	1.2kbps	+/-1.2kHz	47.171470°	19.17201	**2174.3**
				H pol; Norm. direction					
							GPS		
							N	E	
		8	Set1	13dBm	50kbps	+/-25kHz	47.176200°	19.171200°	**2695.4**

Figure 135. Outdoor Range Test Result with Two Identical Printed BIFA Antennas with the 4463-PCE20C915 Pico Board Working in a Reduced Power (~10.2 dBm) State Driven by the WMB-930 Wireless Motherboard

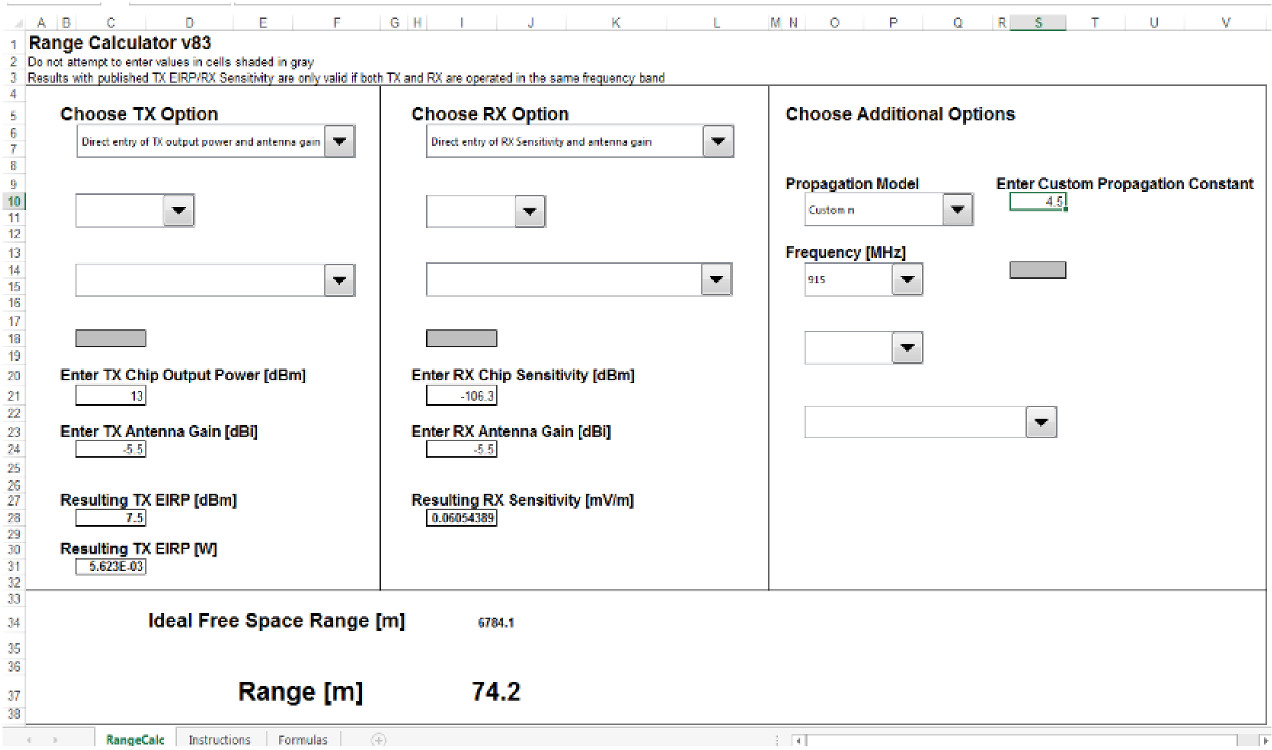
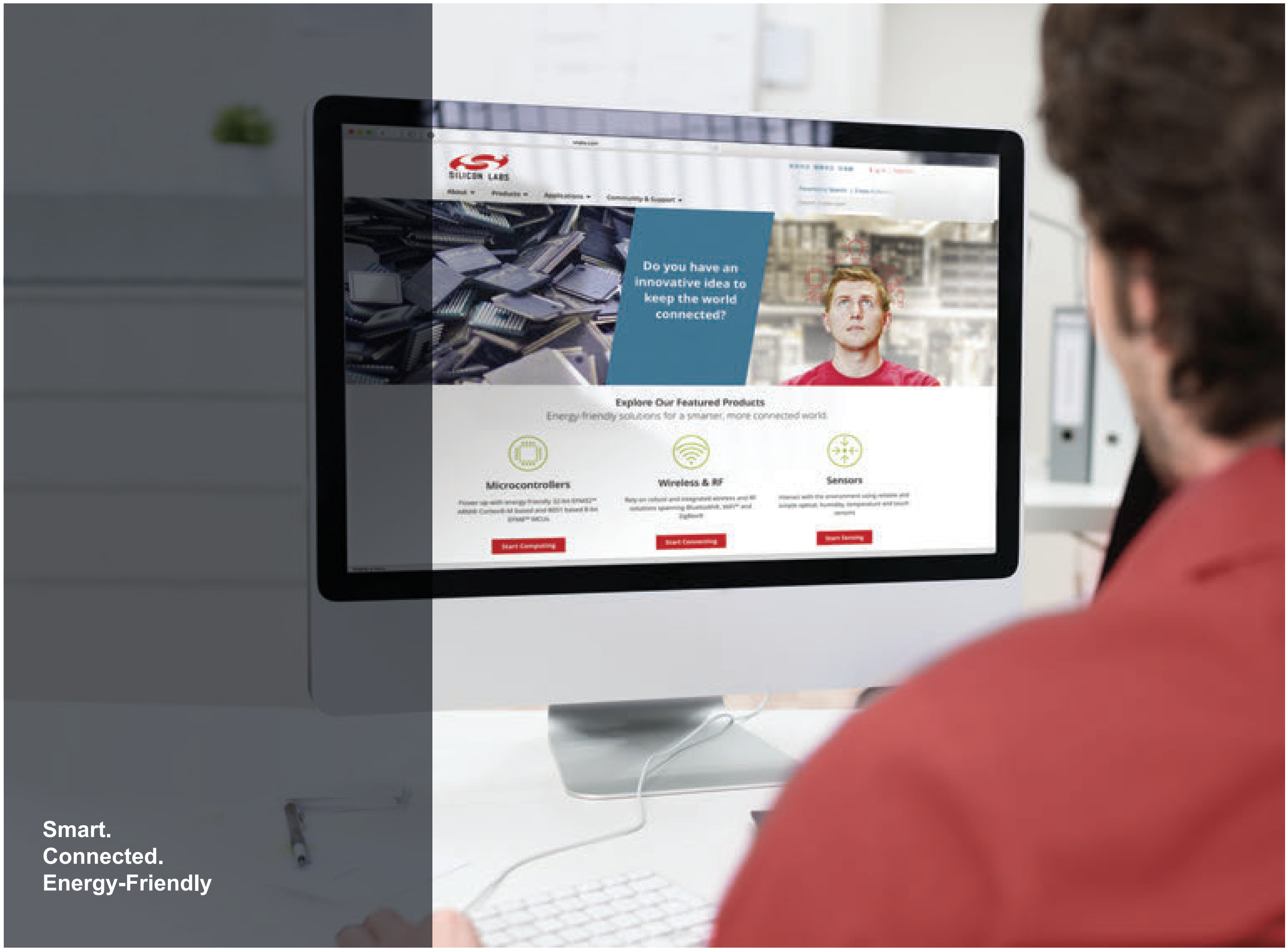


Figure 136. Indoor Range Estimation with Two Identical Printed BIFA Antennas and with the 4463-PCE20C915 Pico Board Working in a Reduced (~+13 dBm) Power State Driven by the WMB-930 Wireless Motherboard



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