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## 915 MHz SINGLE-ENDED ANTENNA MATRIX SELECTION GUIDE

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### 1. Introduction

This report describes the nine  $50\ \Omega$  single-ended antenna types used in the 915 MHz Antenna Matrix (WES0110-01-AMS915-01), which are dedicated to the EZRadio and EZRadioPRO family. Using the development tool, readers can test the performance of the Silicon Labs' RFIC radio family with different types of antennas and find the best solution for the application in terms of shape, size, cost, and expected range.

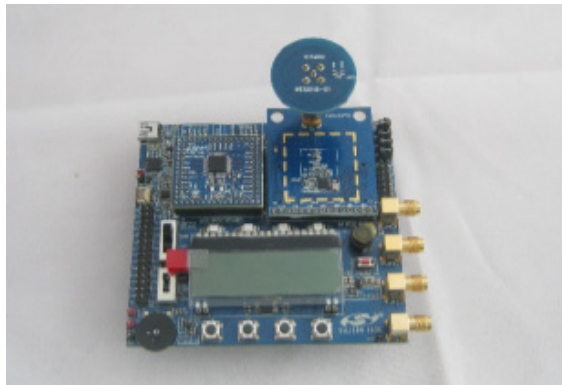
The antenna types in the matrix are selected for the most common application areas in the 915 MHz band. The antennas are optimized and tuned for the antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) structure (Figure 1).

Input impedance, radiation pattern, and antenna gain of every antenna type in the matrix is measured with the above configuration. The outdoor range is also checked using two identical antenna modules at the two sides of the link. The results are given in a separate document containing the measurement report for each antenna type.

In typical customer cases, the antennas are applied without the nearby Pico Board and motherboard, causing them to have no effect. Because all customer applications are different, the right solution may not be found among these particular fixed-size, fixed-form factor Matrix antennas.

For these outlying cases, Silicon Labs recommends to modify/tune the printed ILA (Inverted L Antenna) and the IFA (Inverted F Antenna) types, which are customizable in terms of length and performance. Silicon Labs provides a simple, step-by-step tuning process description in the application note, "AN853: Single-ended Antenna Matrix Design Guide." Use this application note to customize and optimize the performance of these antennas.

The current Matrix is designed for  $50\ \Omega$  single-ended solutions. Another matrix will be devoted for the differential, high-impedance antennas, which are supported by the Si4010 /12/ RFIC family.



**Figure 1. Typical Measurement Configuration—Antenna Board, Pico Board, and Wireless Motherboard**

## 2. General Notes

The following apply:

- EZRadio and EZRadioPRO product family are supported.
- RF Pico Boards equipped with Si4x55, Si4456, or Si446x can be used with these antennas.
- RF connectors are matched to 50  $\Omega$ .
- Boards are equipped with female SMA connectors.
  - Antenna can be connected to the Pico Board using an SMA male-to-male straight adapter.
- MSC-WMB-930 Wireless Motherboard serves as driving interface of the Pico Board (Figure 1).
- For 41 mm wide Pico Boards, the maximum antenna panel width is also 41 mm.
- All PCB antennas are designed to 1.55 m-thick FR4 substrate.

## 3. Antenna Type Description and Typical Applications

A picture of the WES0110-01-AMS915-01 915 MHz Antenna Matrix is shown in Figure 2. 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 ILA (Printed) along the circumference (WES0115-01-APL915P-01).
- Panic Button IFA (Printed) along the circumference (WES0116-01-APF915P-01).
- Printed Meander Monopole (WES0117-01-APN915D-01).
- Small Sized Printed ILA (or optional IFA) in a dedicated small antenna area (WES0118-01-APL915S-01).
- Printed BIFA in a dedicated bigger antenna area (WES0119-01-APB915D-01).

Antenna range is tested with each of the above matrix antennas, and by using a commercially available external whip reference antenna.

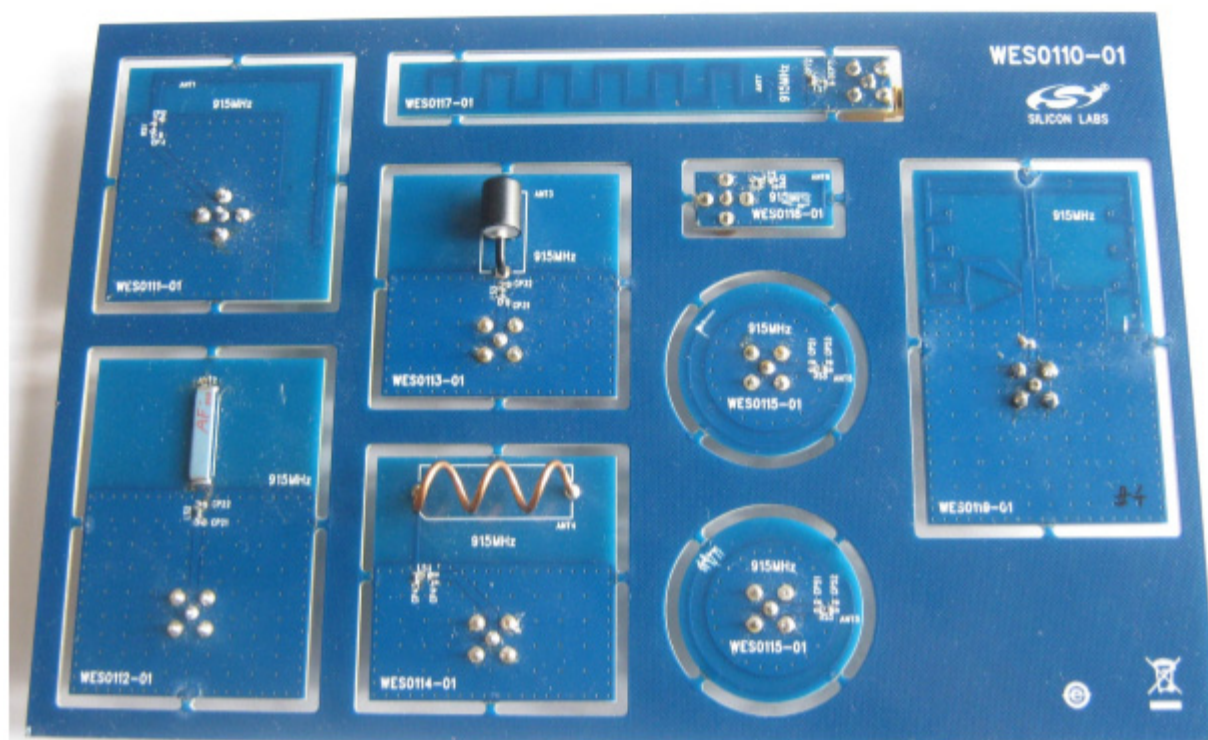


Figure 2. Picture of the WES0110-01-AMS915-01 915 MHz Antenna Matrix Board

## 3.1. Typical Applications of the Antenna Types

Each antenna type described in this section has advantages and disadvantages relative to context and intended use.

### 3.1.1. Medium Sized Printed ILA (or Optionally IFA) Around the PCB Circumference (WES0111-01-APL915M-01)

This is a low-cost, printed monopole antenna. This type uses a narrow PCB strip around the PCB circumference as the antenna area, thereby saving significant space. The drawback of this solution is the reduced gain, especially if the antenna trace is close to the ground metal of the circuitry.

The maximum gain of the realized antenna is  $-1$  dBi with the antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) structure. The gain of the antenna board alone is not measured.

This antenna type is sensitive to hand effect, so bench tuning with hand in place is required. But hand effect can also improve radiation if the hand covers only the circuit area.

Due to these properties, this antenna type is frequently used in key fobs, where the range requirement is usually moderate. The picture of the antenna and its input matching structure are shown in Figure 3.

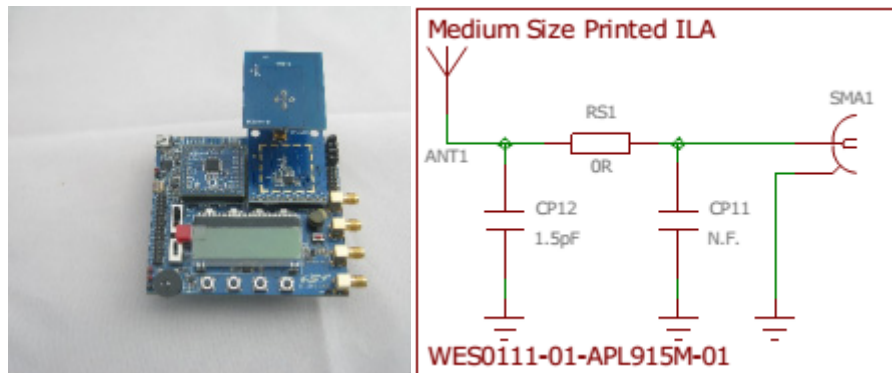


Figure 3. Medium Sized Printed ILA (WES0111-01-APL915M-01)

### 3.1.2. Ceramic (Chip) Antenna (WES0112-01-ACM915D-01)

This type of antenna usually requires a relatively large circuit area with the gaps filled in with ground metal. This antenna type is a very good, high-gain, smaller alternative to any printed antenna. However, the cost of the chip antenna is higher. It is typically used in set-top boxes and AMRs where the slight additional cost can be tolerated.

Chip antennas are usually realized on high epsilon dielectric, so the hand effect has less influence, unless the PCB circuitry area (with ground metal) is small. In these cases, the hand increases the small ground size and thus changes (usually improves) the radiation. Due to this, with small PCB sizes, bench tuning of the impedance with hand is also required.

Despite the advantages, chip antennas are not generally used in key fobs because of their relatively higher price.

The antenna used in the matrix is the ANT-868-CHP-T type from Antenna Factor. With the applied antenna PCB ground size, this antenna requires a two-element external matching network at the input to work at 915 M (Figure 4). The maximum gain of the realized antenna board is  $-5.3$  dBi with the antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) structure.

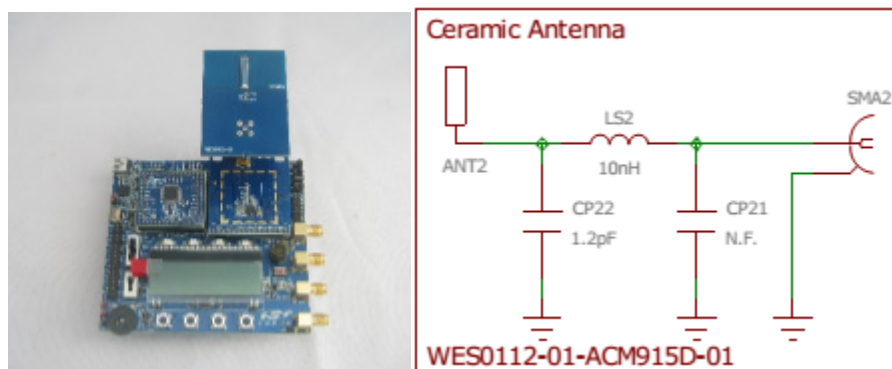


Figure 4. Ceramic Chip Antenna (WES0112-01-ACM915D-01)

### 3.1.3. Small Sized (Wire) Helical Antenna Parallel with the PCB (WES0113-01-AWH915S-01)

This antenna is a popular, very small, low-cost alternative to the external whip antenna, but it has a significantly lower gain because the antenna length is much shorter. This type of antenna is typically used in set-top boxes, AMRs, alarm systems, and key fobs.

The small helical antenna used in the Matrix is the ANT-868-JJB-RA from Antenna Factor. Due to the small size of the antenna PCB (ground), to have matching at 915 MHz an additional external matching network is required at the antenna input (Figure 5). The helical monopole is sensitive to hand effect, and even if only the circuit (ground) area of the antenna PCB is touched, this will cause the ground size around the antenna to change. Due to hand effect, the modification (or elimination) of the external matching network is required in the vicinity of a hand.

The maximum gain of the realized antenna board is  $-4.1$  dBi with the antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) structure.

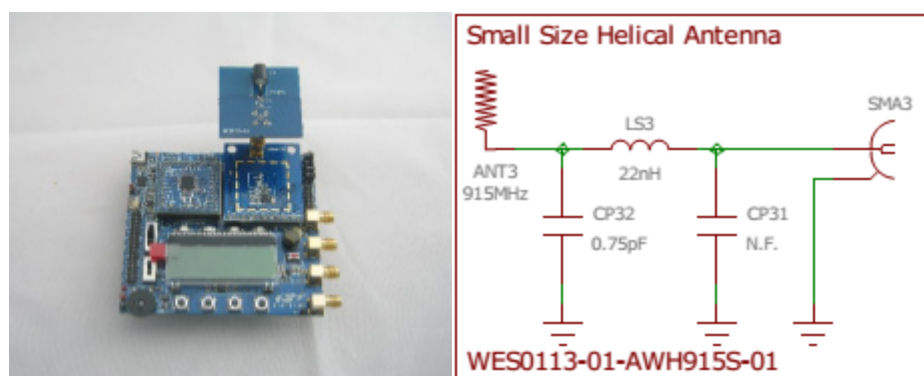


Figure 5. Small Sized (Wire) Helical Antenna (WES0113-01-AWH915S-01)

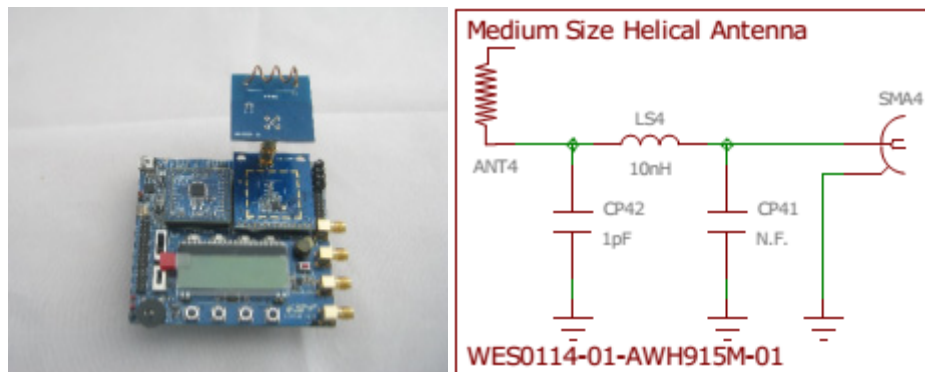
### 3.1.4. Medium Sized (Wire) Helical Antenna (WES0114-01-AWH915M-01)

This type of antenna is a popular, small, low-cost, wire alternative to the external whip antenna, but the gain is still slightly lower due to the shorter length. However, the gain with the medium helical antenna is much better than with the small helical antenna. This type of antenna is typically used in key fobs, set-top boxes, AMRs, and alarm systems.

In this matrix, the ANT-916-HETH type from the Antenna Factor is selected with a two-element external matching (Figure 6) at the antenna input to tune it to 915 MHz.

The maximum gain of the realized antenna board is +0.4 dBi with the antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) structure.

The helical monopole is sensitive to hand effect, which is true even if only the circuit (ground) area of the PCB is touched and the ground size is small. In this case, the ground size around the antenna changes (the radiation usually improves). Because of hand effect, further tuning of the matching network is necessary.



**Figure 6. Medium Sized (Wire) Helical Antenna (WES0114-01-AWH915M-01)**

### 3.1.5. Panic Button ILA (WES0115-01-APL915P-01) and Panic Button IFA (WES0116-01-APF915P-01) Along the Circumference

This is a very low-cost, small monopole type of antenna. Typically, this antenna trace fully surrounds the small circuitry along the PCB edge, which allows them to have the highest possible radiation efficiency and make impedance tuning easier.

These antennas are basically the same as the first antenna type (WES0111-01-APL915M-01). The antenna trace also runs along the PCB circumference, but the PCB is significantly smaller.

Due to the very small sizes, the gain is low, especially at low frequency bands. However, this is not the case with the measured antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) configuration, as the large ground metallization of the additional boards increases the gain. The maximum gain of the Panic ILA and IFA is  $\sim -1.5$  to  $-2.3$  dBi.

The Small Panic Button antenna board alone has a much lower gain, typically  $-6$  to  $-8$  dBi.

These antennas are mostly used in wristband panic button applications, where strong hand effect exists. As these antennas are sensitive to hand effect as well, further tuning is required in the presence of the human body.

In wristband applications the antenna is usually positioned parallel with the hand, and held very close to the body. Because of positioning, the body effect further degrades the radiation. Fortunately, the range requirement is also very low in typical applications (within a room or a small FET).

The main difference between the ILA and IFA is that the ILA needs a parallel matching capacitor (4.7 pF here) at the input, while the IFA is inherently matched. However, the post-tuning of the ILA is easier. In the application note, "AN853: Single-ended Antenna Matrix Design Guide," Silicon Labs provides a detailed description of the tuning process, for both the ILA and IFA antennas. The panic button antennas given in this Matrix are tuned without hand effect but with the large additional boards, so the range achieved with them is much better than what one could see in a real application with the hand effect.

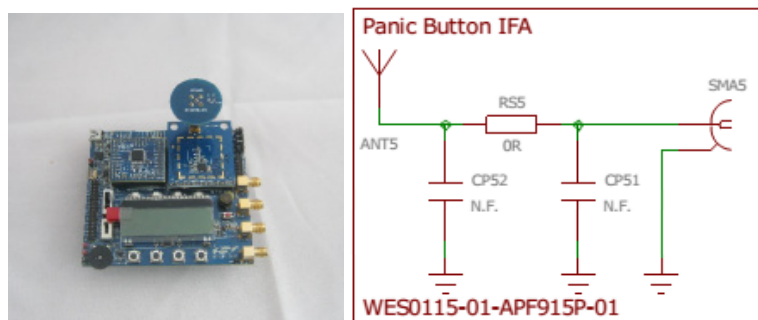


Figure 7. Panic Button ILA (WES0115-01-APL915P-01)

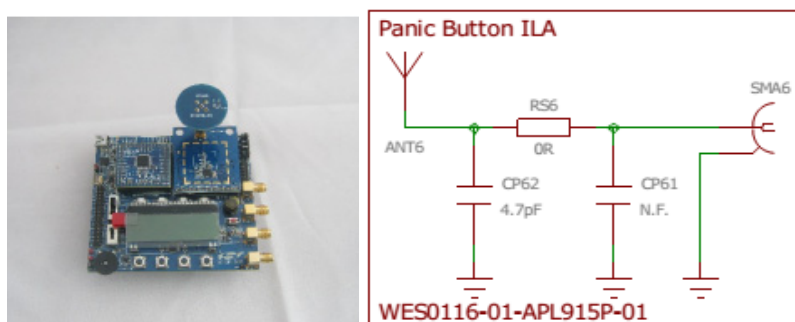


Figure 8. Panic Button IFA (WES0116-01-APF915P-01)

### 3.1.6. Printed Meander Monopole (WES0117-01-APN915D-01)

This type is a low-cost, smaller, printed alternative of the external whip antenna, but it requires a separate antenna area, which is larger than the space required by other typical printed antennas (ILA or IFA, around the PCB circumference or by a wire helical antenna). However, the meander antenna has a higher gain.

If the meander antenna is put on a separate PCB, it works best if the antenna PCB is perpendicular to the circuit PCB, or to a large ground metal. The maximum gain of the realized antenna board is  $-1.7$  dBi with the antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) structure.

The meander antenna is sensitive to hand effect. As usual, the hand can improve radiation if the hand only covers the circuit area.

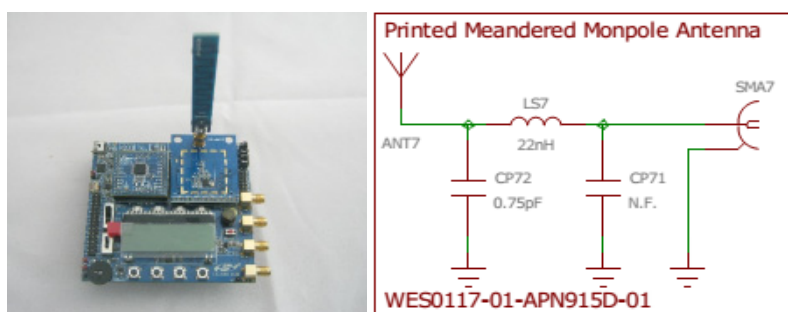


Figure 9. Printed Meander Monopole (WES0117-01-APN915D-01)

### 3.1.7. Small Sized Printed ILA (or Optionally IFA) in Dedicated Small Antenna Area (WES0118-01-APL915S-01)

This type of antenna is typically used in dongles and key fobs, where a limited-size, separated antenna area is available, and where there is not enough space along the PCB circumference for a good antenna. The gain is limited, but the presence of a nearby hand or a large amount of metal (computer chassis) can improve gain significantly if only the circuit area of the PCB is covered. The best situation is if the hand or ground metal is perpendicular to the antenna plane.

The maximum gain of the realized antenna board is  $-3.4$  dBi with the antenna PCB + Pico Board + motherboard (MSC-WMB-930 Wireless Motherboard) structure.

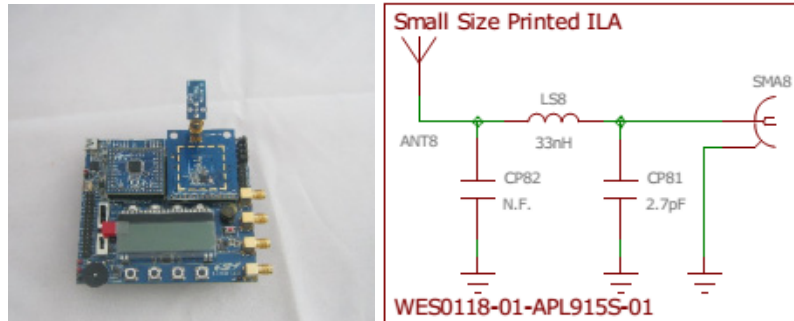


Figure 10. Small Sized Printed ILA (or Optionally IFA) in Dedicated Small Antenna Area (WES0118-01-APL915S-01)

### 3.1.8. Balanced IFA (BIFA) on Larger Separate Antenna Area (WES0119-01-APB915D-01)

Due to its bigger size, this antenna type has good gain. The biggest advantage is that the radiation pattern is not influenced too much by the PCB ground size and shape, due to the balanced operation of the antenna. (The BIFA antenna is differential, and a printed balun is used at the input to connect it to the  $50 \Omega$  single-ended Pico Board input/output). Because of this, the performance of the BIFA antenna is nearly the same without the Pico Board and motherboard. The maximum gain is  $+0.8$  dBi, which is fairly high.

Another advantage of the BIFA antenna is that it mostly radiates in the direction of the antenna's symmetrical axis. (More precisely, it radiates mainly along a plane which includes the symmetrical axis and is perpendicular to the antenna PCB.)

Unfortunately, the BIFA is sensitive to hand effect if the antenna traces are directly touched. But it is not sensitive if only the ground (circuit) part of the PCB is touched.

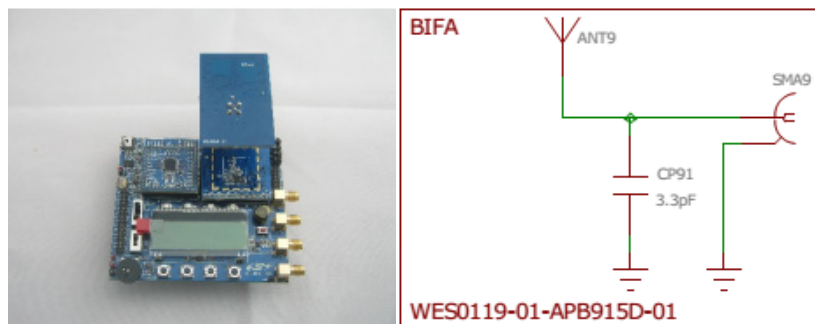


Figure 11. Balanced IFA (BIFA) (WES0119-01-APB915D-01)



## 4. Documentation:

The application note, “AN848: 915 MHz Single-ended Antenna Matrix Measurement Reports” contains a separate detailed description and documentation of each antenna type, which includes:

- Antenna match schematic (if one exists)
- Top and bottom layout
- Picture
- Measured impedance
- Measured antenna gain
- Measured radiation pattern
- Harmonic radiation (up to the 10<sup>th</sup> harmonic)
- Range measurements

The documentation for each antenna includes a manufacturing pack which may be downloaded from the respective web page ([www.silabs.com](http://www.silabs.com)).

## 5. Range Measurements

Two outdoor range tests are done:

- Outdoor range test with two units using the reference monopole (whip).
- Outdoor range test between two identical units using the investigates antenna board.

During measurements, the range number (in meters) is extracted from Google Map distance plot (outdoors).

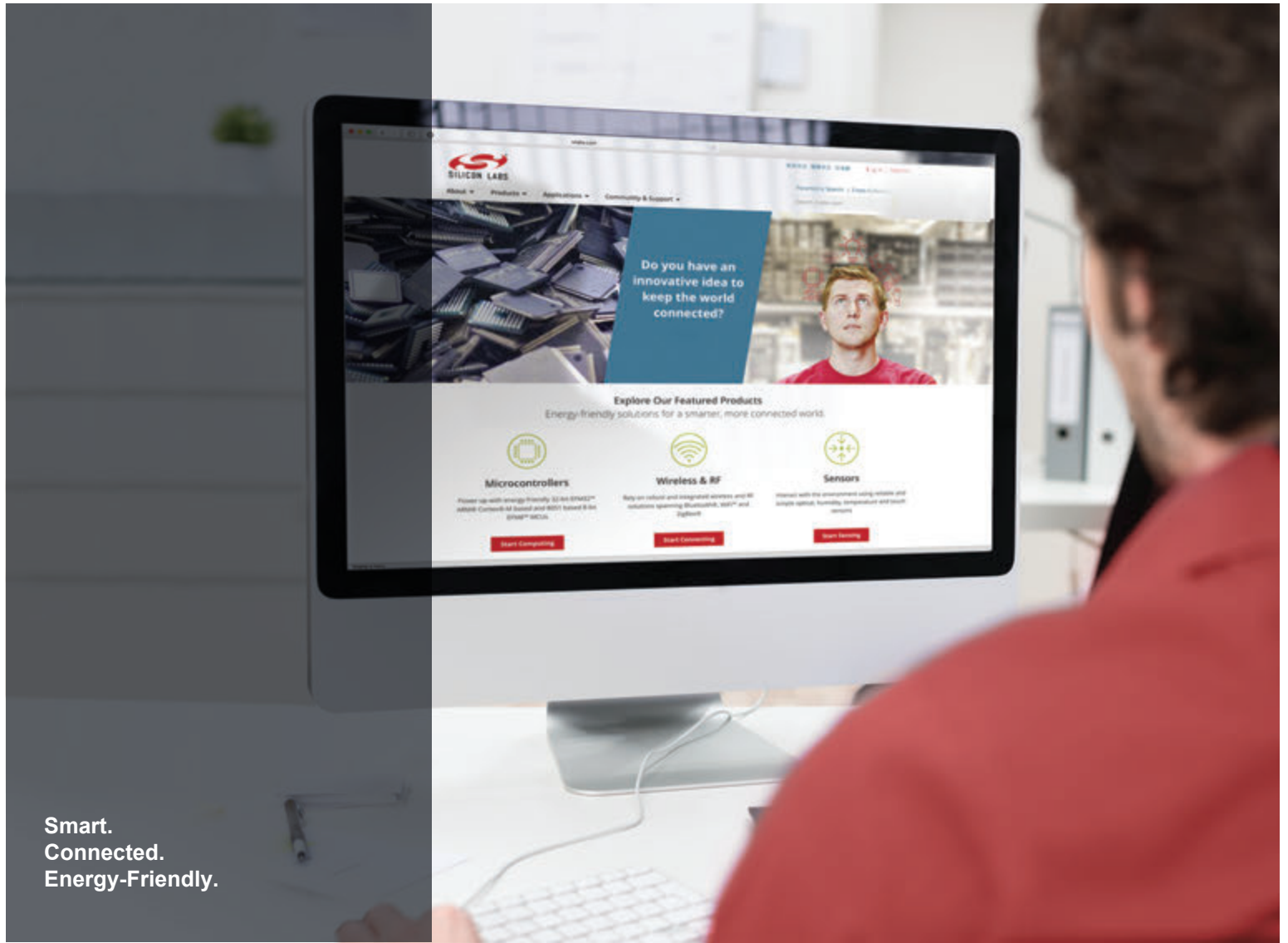
The used link parameters during the test are: 9.6 kbps bit rate, 30 kHz (2-level GFSK, H=6.25) deviation, and 10 dBm output power. Standard Pico Board packet error test firmware is used.

In the test site, strong GSM interference is present.

The given ranges below are measured to the maximum radiation direction of the antennas. More details can be found in application note “AN848: 915 MHz Single-ended Antenna Matrix Measurement Reports.”

**Table 1. Range Measurement Results**

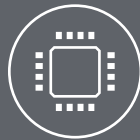
No.	Name	Ant. gain max. [dBi]	RX GPS Coordinates TX:N 47.15288°, E 19.18093°	Max. Outdoor Range [m]
#1	Reference Whip - Pulse W1063	+1	N 47.165420°, E 19.17292	1520
#2	Medium Sized Printed ILA (around the PCB interference) (WES0111-01-APL915M-01)	-1.2	N 47.17023°, E 19.17224°	2038
#3	Ceramic (Chip) Antenna (WES0112-01-ACM915D-01)	-5.3	N 47.16316°, E 19.17339°	1277
#4	Small Sized (Wire) Helical Antenna (WES0113-01-ACM915D-01)	-4.3	N 47.16462°, E 19.17315°	1432
#5	Medium Sized (Wire) Helical Antenna (WES0114-01-AWH915M-01)	+0.2	N 47.16857°, E 19.1725°	1857
#6	Panic Button IFA (WES0115-01-APF915P-01)	-2.5	N 47.17059°, E 19.17217°	2078
#7	Panic Button ILA (WES0116-01-APL915P-01)	-1.8	N 47.16996°, E 19.17227°	2009
#8	Printed Meander Monopole (WES0117-01-APN915D-01)	-1.9	N 47.17065°, E 19.17236°	2080
#9	Small Sized Printed ILA (WES0118-01-APL915S-01)	-3.6	N 47.16483°, E 19.17311°	1454
#10	Printed BIFA (WES0119-01-APB915D-01)	+0.5	N 47.17081°, E 19.17204°	2104



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