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Application Note

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MC1319x Range Performance

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1 Introduction

The MC1319x is a short range, low power, 2.4GHz Industrial, Scientific and Medical (ISM) band transceiver designed to be IEEE® 802.15.4 Standard compliant. Typical intended applications include, but are not limited to the following:

- Remote control and wire replacement in industrial systems such as wireless sensor networks
- Factory automation and motor control
- Energy Management (lighting, HVAC, etc.)
- Asset tracking and monitoring
- Home automation and control (lighting, thermostats, etc.)
- Human interface devices (keyboard, mice, etc.)
- Remote entertainment control
- Wireless toys

The 13192-EVB is an 802.15.4/ZigBee evaluation board based on the MC13192, 2.4GHz transceiver and the MC9S08GT60 MCU. The 13192-EVB provides both serial and USB connectivity to a PC for easy evaluation.

Contents

For improved sensitivity and range evaluations, the 13192-EVB includes the necessary circuitry to enable the MBC13900 Low Noise Amplifier (LNA). It is also equipped with an external SMA connector for an external antenna connection allowing easy connectivity to measurement equipment.

The Sensor Applications Reference Design (SARD) is also an 802.15.4/ZigBee evaluation board based on the MC13192, 2.4GHz transceiver and the MC9S08GT60 MCU. The SARD includes an RS232 port, background debug module for in-circuit hardware debug, the MMA6261Q (X and Y axis) and MMA1260D (Z axis) accelerometers, various switches, and indicator LEDs.

Range performance measurements of the MC1319x on the 13192-EVB and SARD were done in several application environments, and the results are detailed in this application note. The results presented are not meant to guarantee range performance in all possible environments.

2 Sensitivity Performance

Range performance is significantly affected by the sensitivity of the transceiver and the matching to the transceiver on the 13192-EVB. The detailed sensitivity performance of the 13192-EVB is shown in the following section.

2.1 Sensitivity Test Set-Up

This section details the measured sensitivity of the 13192-EVB.

The sensitivity measurements were done with packets of 20 byte length for the PSDU, as defined in the standard. Packet lengths of 6 and 102 bytes were also used for characterization purposes. The detailed sensitivity requirements as defined in the 802.15.4 standard for sensitivity testing are captured in the following quoted text and table taken from reference P802.15.4/D18-6.1.6, 6.5.3.3.

6.5.3.3: "Under the conditions specified in Clause 6.1.6, a compliant device shall be capable of achieving a sensitivity of -85dBm or better."

Clause 6.1.6

Packet error rate (PER)	Average fraction of transmitted packets that are not detected correctly.	• Average measured over random PSDU data.
Receiver sensitivity	Threshold input signal power that yields a specified packet error rate.	• PSDU length = 20 octets. • PER < 1%. • Power measured at antenna terminals. • Interference not present.

The input power level to the receiver was lowered through attenuators until the PER <1% was no longer measured at the receiver. As shown in Figure 1, the test set-up consisted of two 13192-EVBs. The transmitting 13192-EVB was connected through an electronic attenuator to a receiving 13192-EVB. Both of the 13192-EVBs were connected to a laptop with a Universal Serial Bus (USB) cable. The laptop was running the Test Tool with the following PER test scripts:

- PERCoordinator.py
- PERDevice.py

All the PER tests were performed without retransmission.

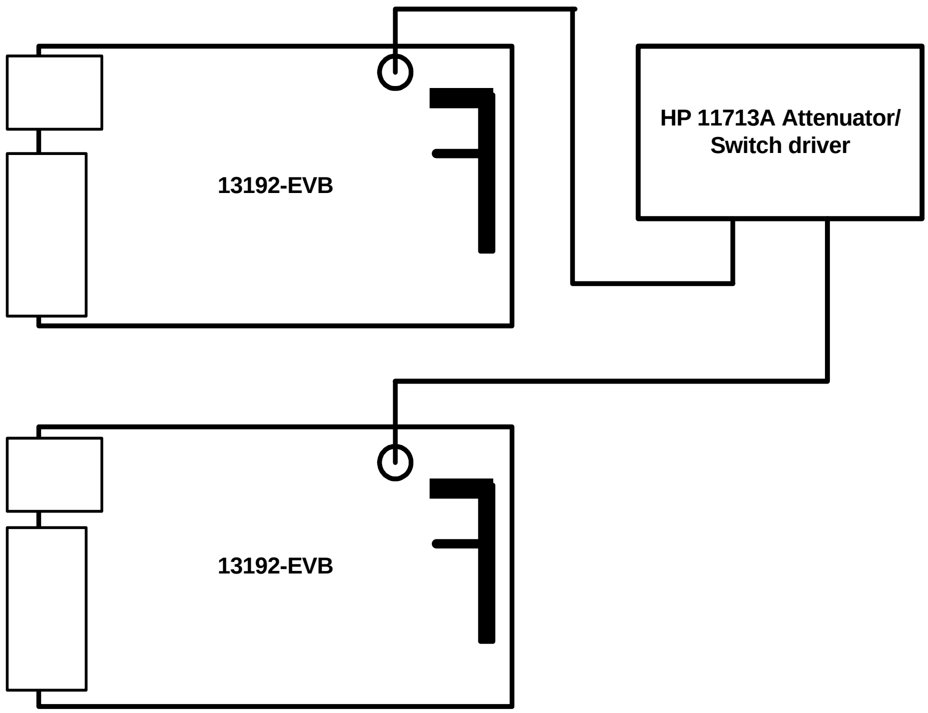

Figure 1. 13192-EVB Test Set-Up for Sensitivity

2.2 Sensitivity Measurement Results

The 13192-EVB has an on-board LNA. Sensitivity measurements were performed with the LNA enabled and bypassed. The 13192-EVB schematic information is available at the Freescale ZigBee web-site, www.freescale.com/zigbee. The results are as shown in Figure 2 and Figure 3.

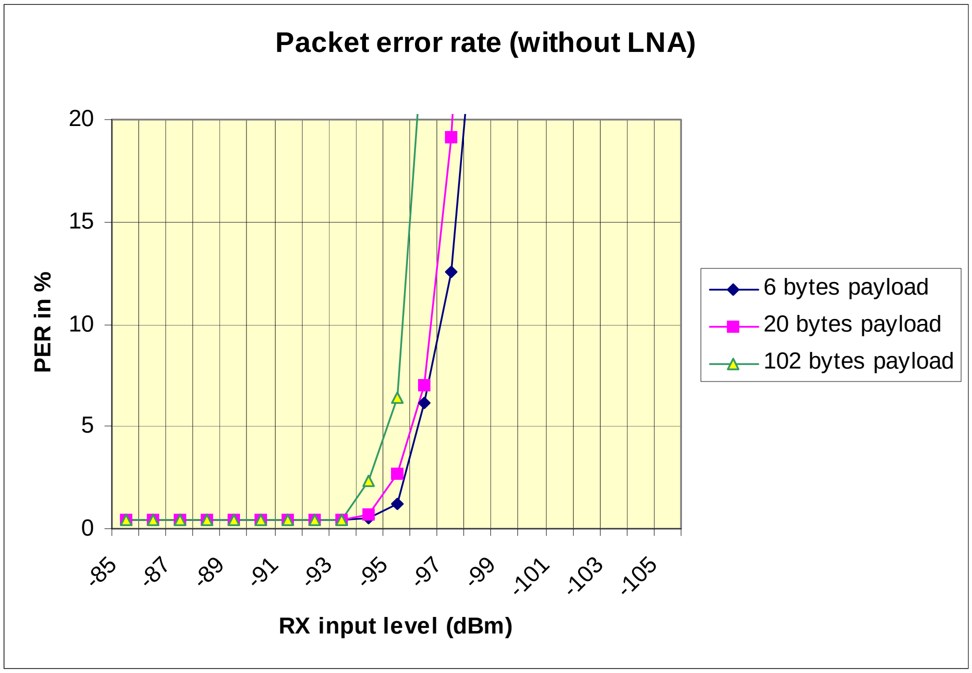

Figure 2. PER without LNA = -95dBm

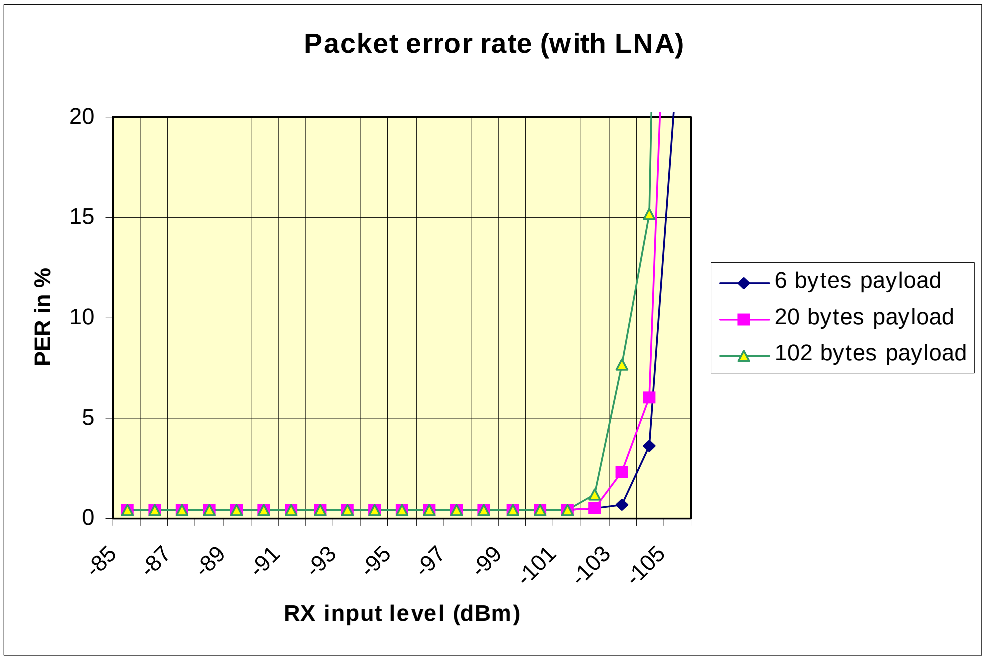

Figure 3. PER with LNA = -103dBm

3 Transmitting Antenna

In addition to the sensitivity of the receiver, the transmitting antenna characteristics also significantly impact the range performance. The radiation patterns of the F-antenna printed on the 13192-EVB are shown in Figure 4 and Figure 5. The radiation patterns of the dipole antenna printed on the Sensor Application Reference Design Board (SARD) are shown in Figure 6 and Figure 7. The radiation patterns are for the board orientations (top view) as shown to the right of the polar graph. In Figure 4 and Figure 6 the boards are lying flat on the pedestal (horizontal pattern), and in Figure 5 and Figure 7 the boards are lying on their long side (vertical pattern). The measurements are performed with the transceiver set to maximum output power, which results in approximately +2dBm at the antenna plane of the boards.

The output power of the MC1319x internal PA may be adjusted at register 12, bits 0:7. For nominal output power, which is default at reset, register 12, bits 0:7 are at BC (hex). For maximum output power, register 12, bits 0:7 are set to FF (hex). More detailed information on the PA register and other registers is available in the appropriate MC1319x Reference Manual, which can be found at the Freescale ZigBee web-site, www.freescale.com/zigbee.

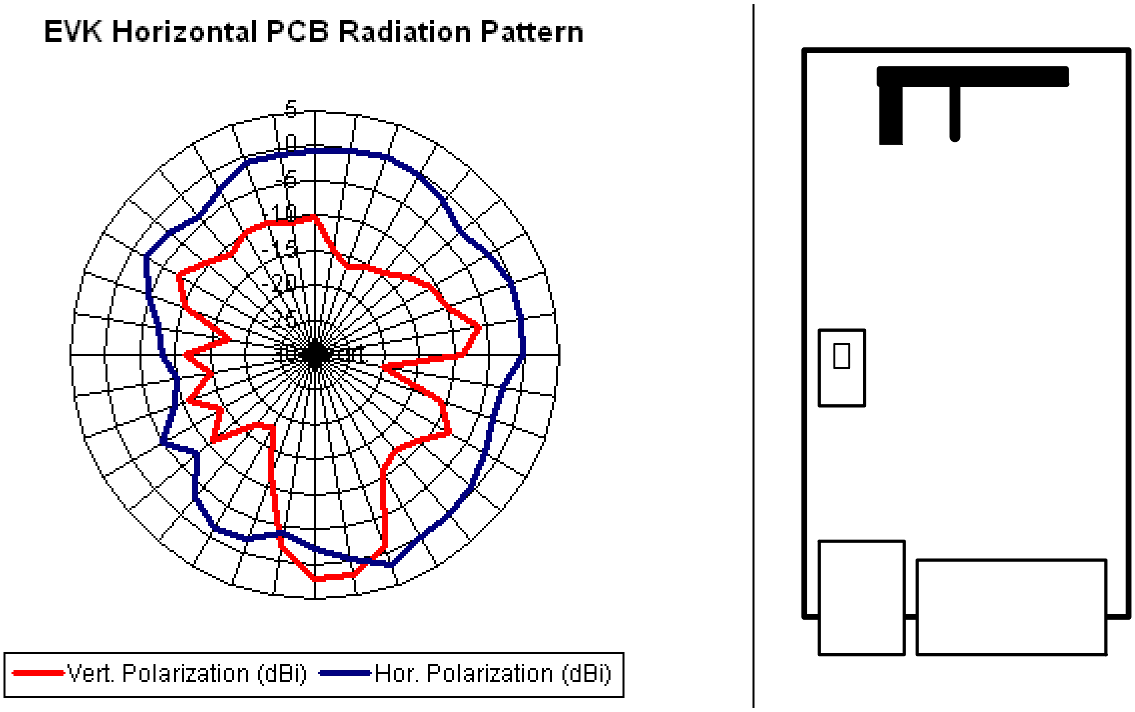

Figure 4. 13192-EVB Horizontal PCB Radiation Pattern

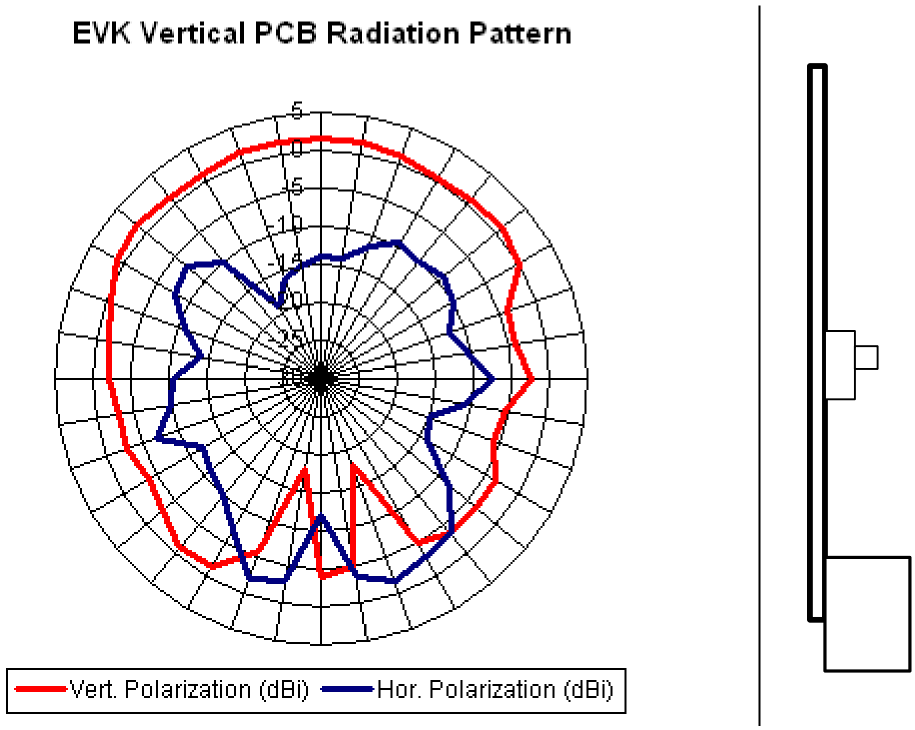

Figure 5. 13192-EVB Vertical PCB Radiation Pattern

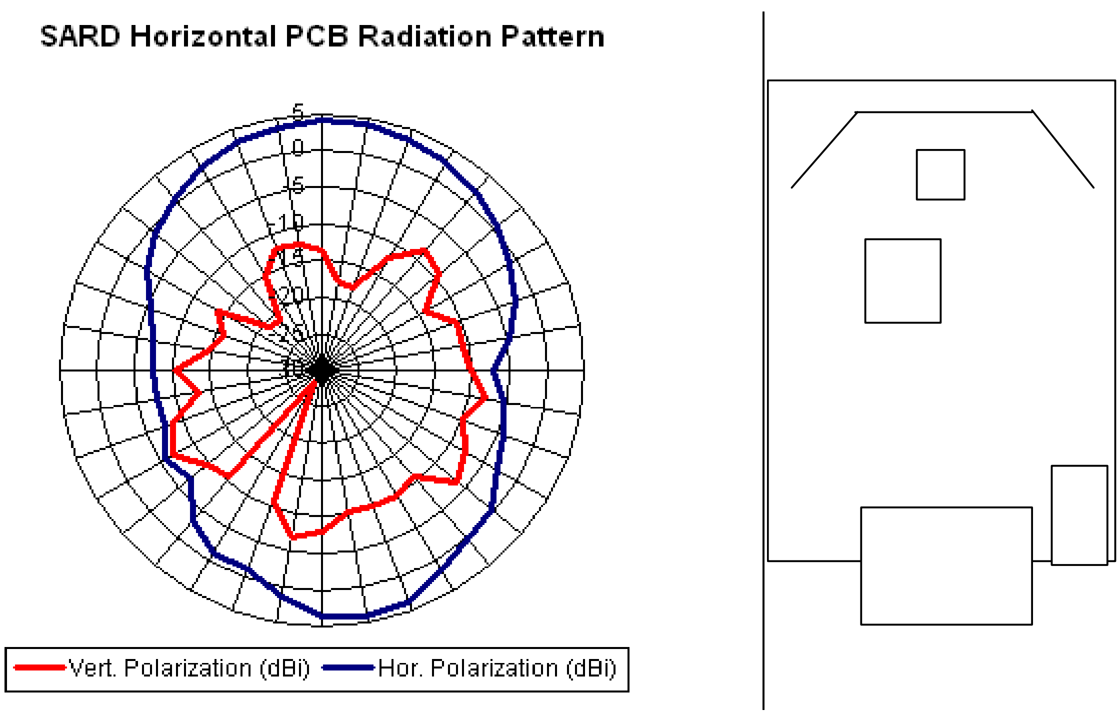

Figure 6. SARD Horizontal PCB Radiation Pattern

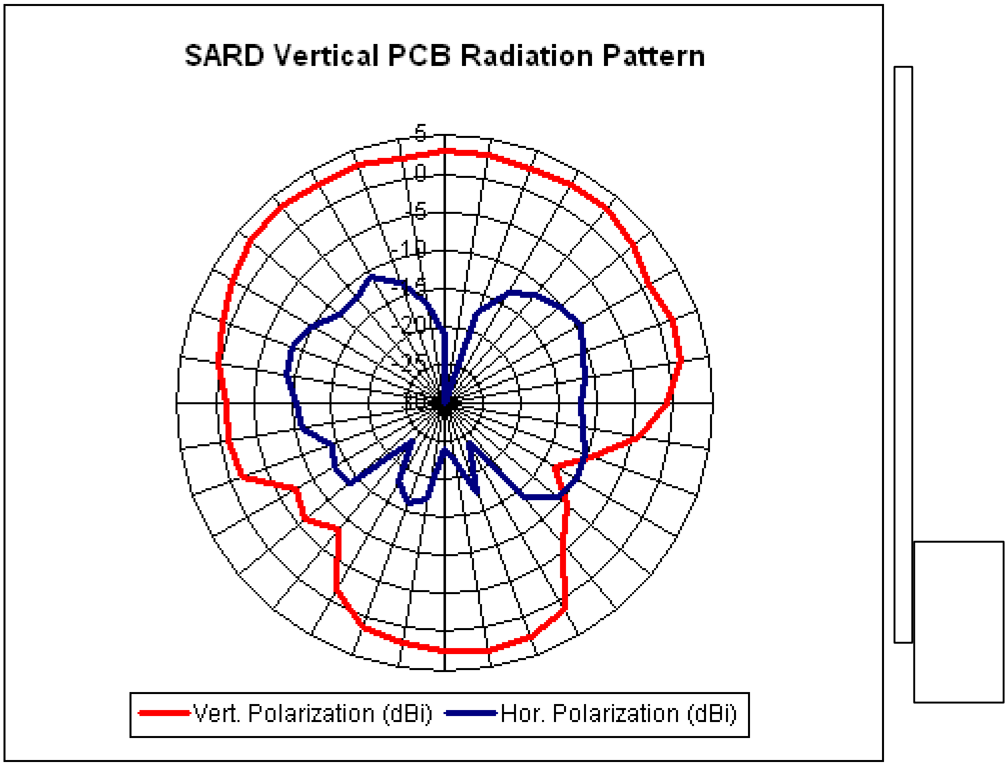

Figure 7. SARD Vertical PCB Radiation Pattern

4 Range Models

The measured antenna radiation patterns are useful when applying range models. The following three variables should be known when applying the simplest of the range models, the path loss formula:

1. The power received at the receiver input.
2. The power delivered by the transmitter into the antenna.
3. The gains of the transmitter and receiver antennas.

The path loss formula calculates the free space propagation loss, and these calculations are compared to actual measurements in Section 5.3, “Range Summary”. When the antennas are assumed to have unity gain, the path loss formula reduces to:

Path loss = 10NLog10(f) + 10NLog10(d) +32.44dB

Where:

- N is the path loss coefficient
- f is the frequency in MHz
- d is the distance in km

The free space model is only valid for distances that are in the far-field region of the transmitting antenna. With this equation, under ideal conditions, the path loss is calculated with N=2. When the transmission channel is non-ideal, the typical path loss coefficient values are 2.05-2.5 for line of sight and 3.0-4.0 for indoor environments/no line of sight. The non-ideal characteristics of the transmission channel result in the transmitting wave producing reflection, diffraction, and/or scattering.

Reflection occurs when the transmitted wave encounters an object of large dimension as compared to its wavelength. Examples of commonly found large obstructions are buildings, large walls, and the ground. Some of the energy of the wave may be transmitted or absorbed into the obstruction and the remaining energy will be reflected off of the medium’s surface. The energy of the transmitted and reflected waves is a function of the geometry and material properties of the obstruction and the amplitude, phase, and polarization of the incident wave.

Diffraction occurs when the surface of the obstruction has sharp edges producing secondary waves that in effect bend around the obstruction. Like reflection, diffraction is affected by the physical properties of the obstruction and the incident wave characteristics. In situations where the receiver is heavily obstructed, the diffracted waves may have sufficient strength to produce a useful signal.

Scattering occurs when the transmitted wave encounters a large quantity of small dimension objects such as lamp posts, bushes, and trees. The reflected energy in a scattering situation is spread in all directions.

Other factors that may affect range performance, in addition to the antenna radiation patterns of the transmitter and receiver, are:

- Antenna losses
- Multi-path
- Interference of other propagating signals
- Background noise

All of these factors randomly combine to create extremely complex scenarios. Various indoor and outdoor propagation models have been created to address the problem. Outdoor propagation models that predict path loss over irregular terrain are

- Longley-Rice Model
- Durkin Model
- Okumura Model

Refer to "*Wireless Communication: Principles and Practice*", [1] for more detail on these models.

5 Range Test

As explained in Section 4, "Range Models", terrain heavily impacts wave propagation. Range tests were performed in a variety of outdoor environments to provide a basic understanding of the range performance that is capable with the MC1319x. The chosen environments included Line of Sight (LOS) on level terrain, LOS on uneven terrain, and obstructed (OBS) line of sight on level terrain. Other variables whose impact on range was measured were:

- Antenna orientation ("standing" or "flat")
- Output power of the 13192-EVB (max or default)
- LNA (enabled or bypassed)
- Antenna (F or dipole).

For the dipole measurements, the SARD board was used. The 13192-EVB and SARD board schematic information is available at the Freescale ZigBee web-site, www.freescale.com/zigbee.

5.1 Range Test Set-Up

The range tests consisted of an 13192-EVB or SARD board transmitting packets to a receiving 13192-EVB or SARD board, respectively. Both transmitting and receiving boards were positioned about 1.2 meters (4 feet) above ground and were connected to a laptop through a USB cable. The Test Tool with two PER scripts, PERCoordinator.py and PERDevice.py, and the SMAC Range Demo Plus software were both used to measure range performance. Both software programs correlated closely, therefore, software selection was determined to not be a factor in range performance. For all outdoor testing, conditions were sunny and temperatures were mild.

5.2 Measurement Results

The measurements results are summarized in Table 1. The details of the level and uneven terrains are shown in Figure 8, Figure 9, Figure 10 and Figure 11.

Table 1. Range Measurement Results

Board Type	Antenna Type	Antenna Position	Output Power (dBi)	LNA Status	View	Terrain	Range (meters)
13192-EVB	F	Standing	+2	Bypassed	LOS	Uneven	1000
13192-EVB	F	Standing	+2	Bypassed	LOS	Level	425
13192-EVB	F	Flat	+2	Bypassed	LOS	Level	350
13192-EVB	F	Flat	+2	Bypassed	Obstructed	Level	245
13192-EVB	F	Standing	-2	Bypassed	LOS	Uneven	700
13192-EVB	F	Standing	-2	Enabled	LOS	Uneven	1100
13192-EVB	F	Standing	+2	Enabled	LOS	Uneven	1350
SARD	Dipole	Flat	+2	N/A	LOS	Level	230

Figure 8. Picture of Uneven Terrain

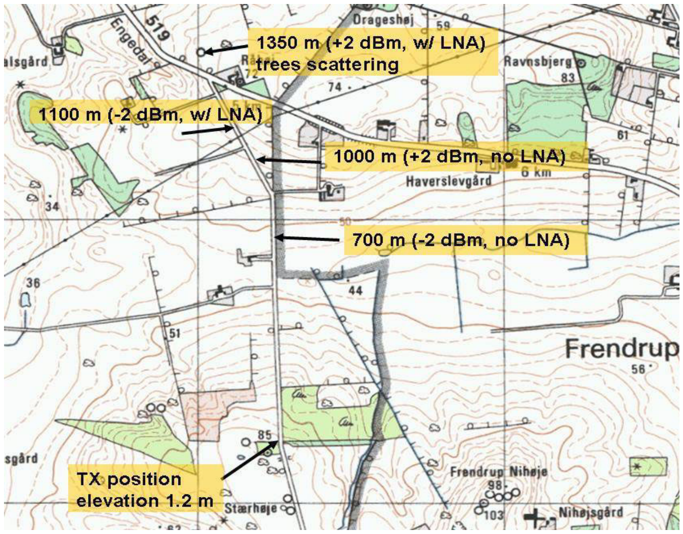

Figure 9. Map of Uneven Terrain

Figure 10. Picture of Level Terrain

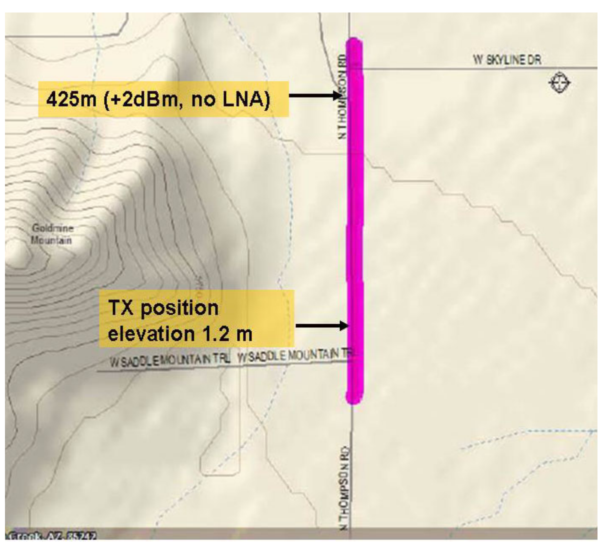

Figure 11. Map of Level Terrain

5.3 Range Summary

The range measurements detailed in Section 4, “Range Models” quantify the improvements made by the following factors:

- Orientating the antenna in the upright position
- Setting the maximum internal PA output power to maximum
- Using an LNA
- Designing the application board with an F antenna
- Setting the transmitter in the line of sight of the receiver

The range measurements also show that the terrain profiles have a considerable affect on range performance. In the examples presented in Section 5.2, “Measurements Results” the difference between the two terrains selected was 575 meters.

The uneven terrain results were compared to the calculated values predicted by the free-space model. The following values were used for the calculations:

- Optimum antenna gain: 2.5dBi
- RX sensitivity without LNA: -95dBm
- RX sensitivity with LNA: -103dBm
- TX power, default: -2dBm
- TX power, maximum: 2dBm

The results from the uneven terrain tested on an 13192-EVB versus the calculated values are shown in Table 2.

Table 2. Uneven Terrain Measured vs. Calculated Results

Results Type	-2dBm, no LNA	+2dBm, no LNA	-2dBm, with LNA	+2dBm, with LNA
Calculated	650 m	1000 m	2000 m	3000 m
Measured	700 m	1000 m	1100 m	1350 m

The calculated versus measured results demonstrate the limitations of the free-space model. The results of the uneven versus level terrain would be better modeled with a path loss coefficient of 2.1 and 2.2, respectively. Better predictions of range performance would be possible with the range models mentioned in Section 4, “Range Models”.

Range results and path loss calculations are useful in determining link budgets. For example, the 13192-EVB demonstrated the capability to reach 700 to 1000 meters without the use of the on-board LNA. The useful range, defined as the range with exceptional coverage, is predicted to be in the order of 100 to 200 meters when applying the fading or link margin. The useful range was calculated with the following equation:

$$L = Ptx + Gtx - Prx + Grx - M$$

Where:

- L is the acceptable path loss in dB
- Ptx is the transmitter output power in dBm
- Gtx is the transmitter antenna gain in dBi
- Prx is the receiver sensitivity in dBm
- Grx is the receiver antenna gain in dBi
- M is the fading margin in dB

The link margin, is defined as the margin in dB above the receiver sensitivity level required to ensure reliable radio connection between the transmitter and receiver. In optimum conditions (antennas are perfectly aligned, no multi-path or reflections exists, and there are no losses) the necessary link margin would be 0dB. In real world conditions, the link margins are typically in the range of 15 to 25dB.

References

1. Theodore S. Rappaport, *Wireless Communication: Principles and Practice*, Upper Saddle River, NJ: Prentice Hall, 1996.

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