AN1088: Designing with an Inverted-F 2.4 GHz PCB Antenna

This document describes an Inverted-F 2.4 GHz PCB antenna designed by Silicon Labs for use with 2.4 GHz wireless chipset designs. The Inverted-F antenna is one of the more commonly used antennas at 2.4 GHz. Silicon Labs provides antenna dimensions in two different substrate thicknesses. PCB antennas are board specific, so you may need to modify the antenna dimensions for your board implementation.

KEY POINTS

- Reference design layout
- Antenna placement and tuning
- Factors affecting antenna performance

1. Overview

One of the main reasons to use a PCB antenna is to reduce cost. Since the antennas are printed directly on the board, they are generally considered to be free. On boards with room to spare, this will be true. On boards that need to grow to account for the increased size of the printed antenna, you must include the added cost of the larger PCB when calculating cost savings.

Well-implemented PCB antennas will have similar performance to that of a ceramic antenna.

Silicon Labs has released the following Inverted-F based Reference Designs:

- EM358x USB Ceramic Balun with Inverted-F PCB Antenna Reference
- EM35xx 2-layer Reference Design with Ceramic Balun and Spiral Inverted-F PCB Antenna
- EFR32MG, EFR32BG, and EFR32FG 2.4 GHz radio board designs

Note: The details included in this application note are based on four legacy 2.4 GHz designs. All of the details contained within this document are applicable to EM3x and EFR32 2.4 GHz designs. The four legacy 2.4 GHz designs used to collect the data contained in this document were:

- EM250 4-Layer Design, Inverted-F Antenna, 0.062″ thick (EM250_REF_DES_LC_LAT_INV-F_62mil.zip)
- EM250 4-Layer Design, Inverted-F Antenna, 0.8mm thick (EM250_REF_DES_LC_LAT_INV-F_0.8mm.zip)
- EM260 4-Layer Design, Inverted-F Antenna, 0.062″ thick (EM260_REF_DES_LC_LAT_INV-F_62mil.zip)
- EM260 4-Layer Design, Inverted-F Antenna, 0.8mm thick (EM260_REF_DES_LC_LAT_INV-F_0.8mm.zip)

2. Layout

PCB antennas are very layout sensitive. For best performance, Silicon Labs recommends following the reference design layouts as closely as possible.

2.1 Key Features

Some key features of the design include the following:

- There are two versions of the layout: for the 62 mil and 0.8 mm board thicknesses
- Feed arm should be fed with a 50 ohm microstrip transmission line (14 mils for an 0.008″ top layer)
- Shorting arm must be shorted to the ground plane, preferably with ground vias
- There should be no ground plane under the antenna
- Ground plane on layers 2 and 4, with stitching vias along the ground edge (however, EFR32 radio boards use ground planes on each layers, where possible)
- The antenna was designed to have a 40 mil clearance between the shorting arm and the board edge, and a 20 mil clearance between the board edge and the antenna trace
- The antenna should be covered with soldermask
- Simulations have shown no benefit to increasing the width of the shorting arm or mitering the bend in the shorting arm

The following figure illustrates the dimensions of the antenna.

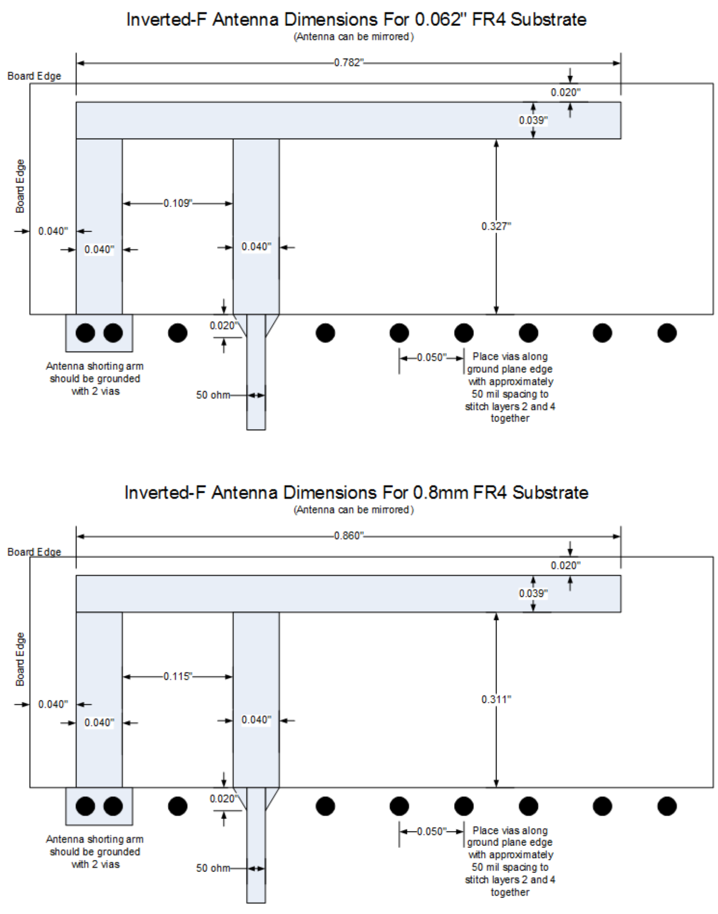


Figure 2.1. Antenna Dimensions

Note: You may need to modify dimensions for your board’s implementation.

2.1.1 Board Stackup

The following figure shows the board stackups used in the designs.

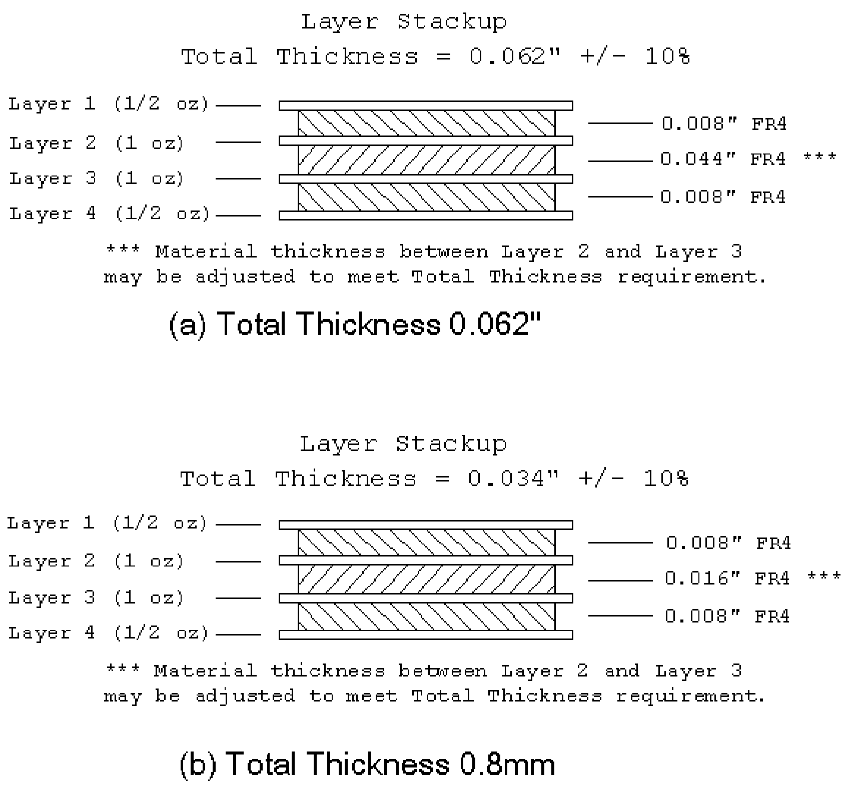


Figure 2.2. Board Stackup

3. Tuning and Antenna

3.1 Antenna Placement

Silicon Labs designed and optimized the Inverted-F reference designs for a 1″-wide PCB board. The ground plane forms an important part of the antenna. The following figure shows the surface currents around the antenna. As you can see, there is significant current running along the ground plane edge. Changing the size of the ground plane will affect performance; most notably, the antenna match will be detuned. For boards that vary in size from the reference design, Silicon Labs recommends the placement shown in the following figure.

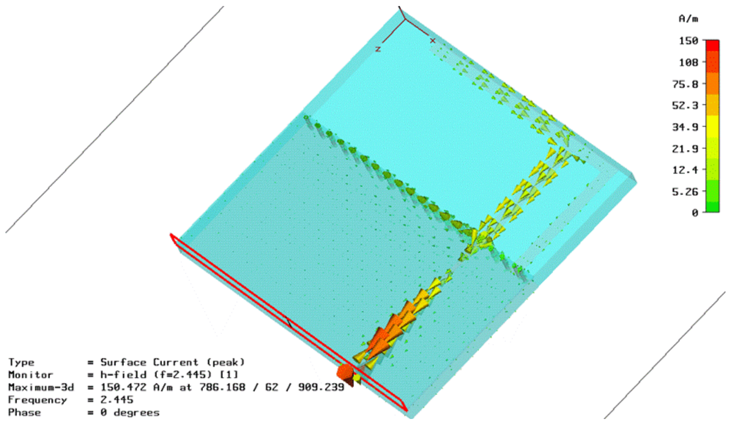


Figure 3.1. Surface Current

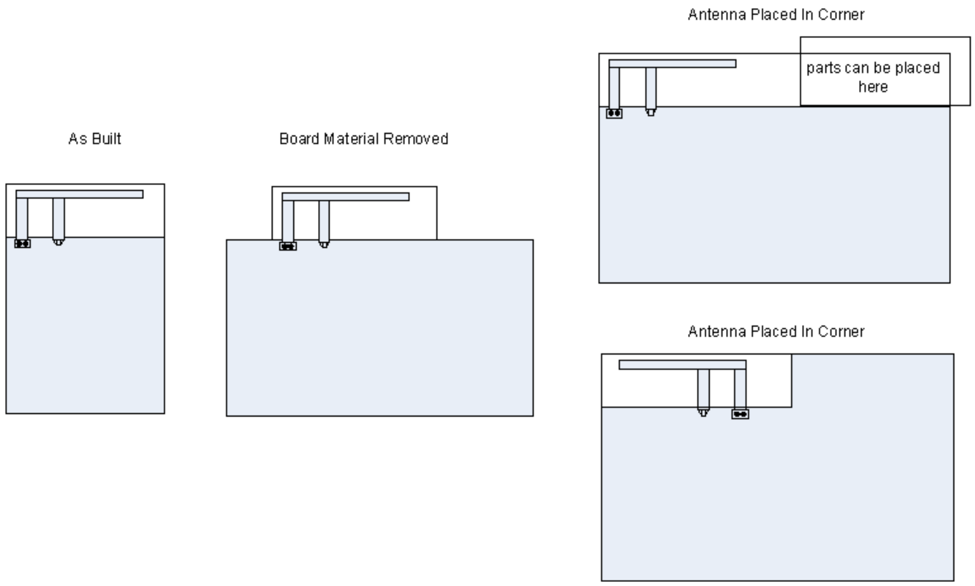


Figure 3.2. Recommended Antenna Placement

3.2 Tuning

Silicon Labs designed the printed antenna to provide a 50-Ohm output. An inverted-F antenna can inherently be matched to 50 ohms without using any external tuning component. However, board size, plastic enclosures, metal shielding, and components in close proximity to the antenna can affect antenna performance. For best performance, the antenna might require tuning that can be realized by two ways:

- Dimension changes in the antenna layout structure, or
- Applying external tuning components.

The latter is typically the preferred solution when layout modification is not required on a custom design. To accomplish this, Silicon Labs generally recommends reserving SMD placeholders for external antenna tuning components, where the suggested external antenna matching structure is a 3-element PI network. You can achieve a good match using a maximum of two elements (with one series and one shunt component) of the PI network. Any unknown passive impedance can get matched to 50 ohms on this PI network, since all L, C, L-C, C-L combinations can be realized on it and therefore any de-tuning effect can be compensated out.

The following figure shows the values of *L* required for the reference design prototypes. All four designs required *C1/C2* to be unpopulated. Note that every implementation of the antenna design will require different combinations of inductors and capacitors. The *EM260 0.8mm* reference design has the printed inverted-F antenna inherently matched to 50 ohms.

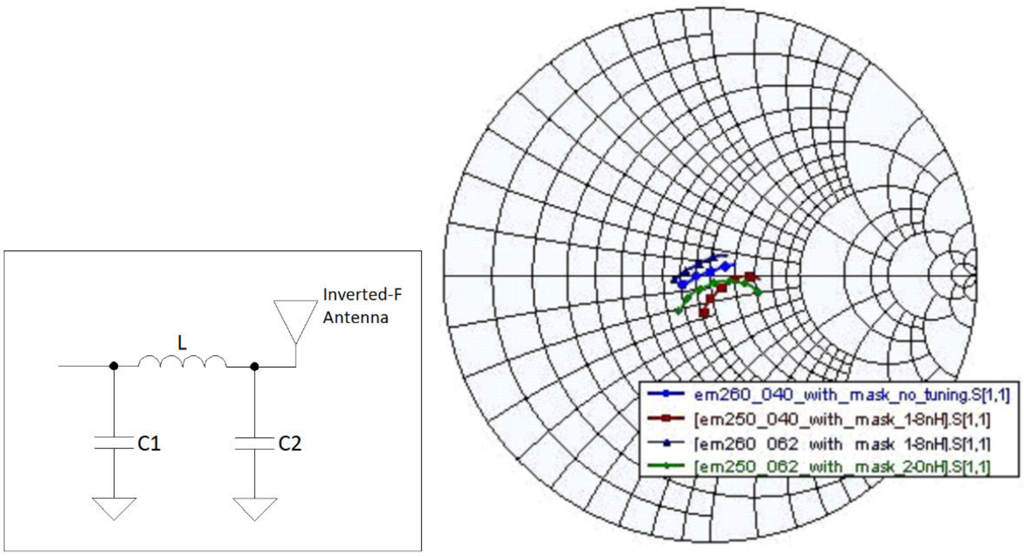


Figure 3.3. Antenna Matching Components

- EM250 62 mil: L = 2.0 nH
- EM260 62 mil: L = 1.8 nH
- EM250 0.8mm: L = 1.8 nH
- EM260 0.8mm: L = 0 ohm
- C1, C2 are not populated

4. Antenna Performance

Silicon Labs designed the antennas using CST Microwave Studio. Antenna gain patterns for two board thicknesses were simulated; the following two figures show this for the 62 mil thick board and for the 0.8 mm board, respectively. The gain shown is the absolute sum of both polarizations. These figures also show the board orientation.

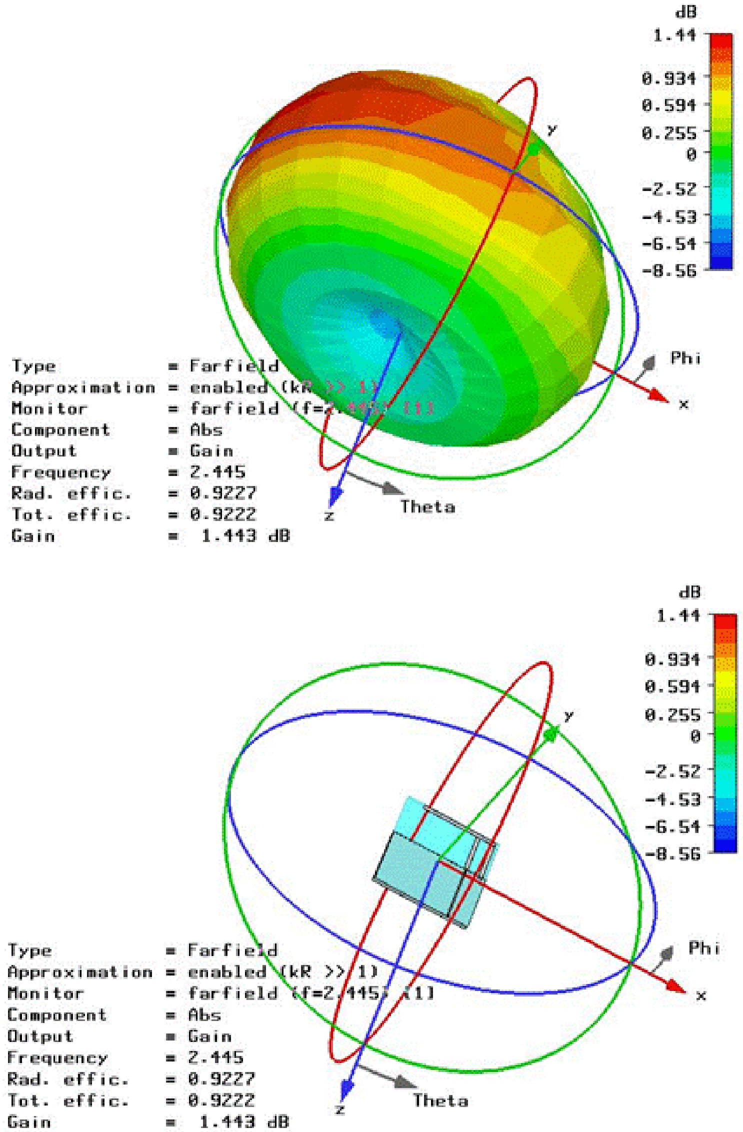


Figure 4.1. Simulation of Gain Pattern for the 62 mil Antenna

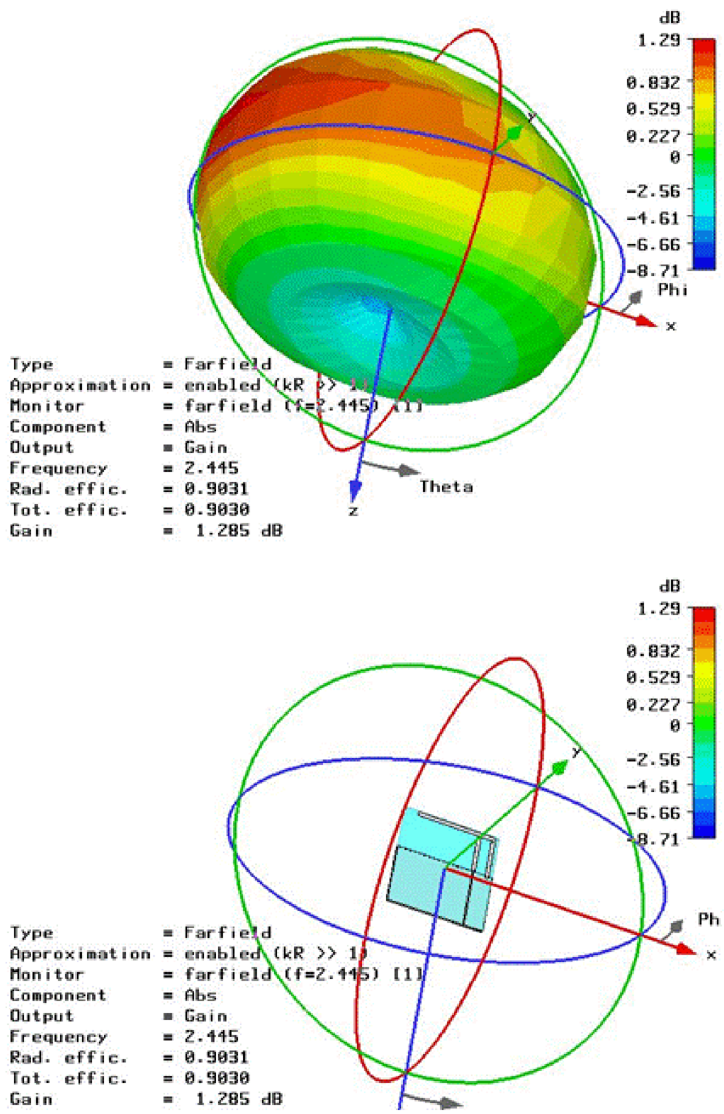


Figure 4.2. Simulation of Gain Pattern for the 0.8 mm Antenna

4.1 Effects of Manufacturing Variations

Silicon Labs designed both antennas to have enough excess bandwidth to maintain performance over manufacturing tolerances. The following figure shows that a good match can still be maintained when varying the dielectric constant between 4.3 and 4.8 and the board thickness by +/-3 mils.

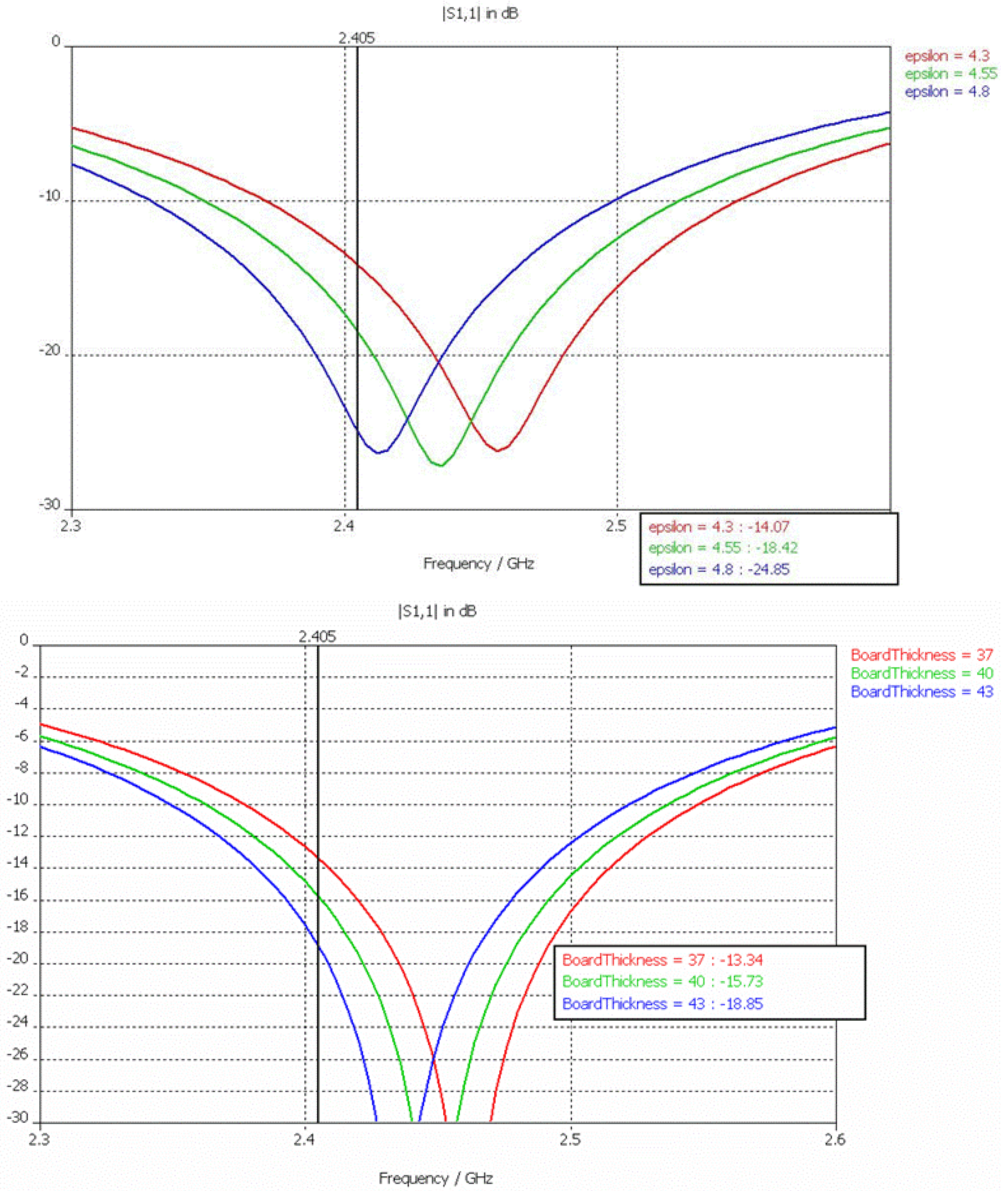


Figure 4.3. Effects of Manufacturing Tolerances

4.2 Measured Antenna Patterns

Silicon Labs measured antenna patterns for eight prototype boards—two each of 62 mils and 0.8mm for both the EM250 and EM260—in a 5 meter anechoic chamber. Patterns in three orthogonal planes were measured for both polarizations. The following figures illustrate these patterns for EM250 62 mil boards, EM260 62 mil boards, EM250 0.8 mm boards, and EM260 0.8 mm boards, respectively.

4.2.1 Antenna Patterns for EM250 62 mil Boards

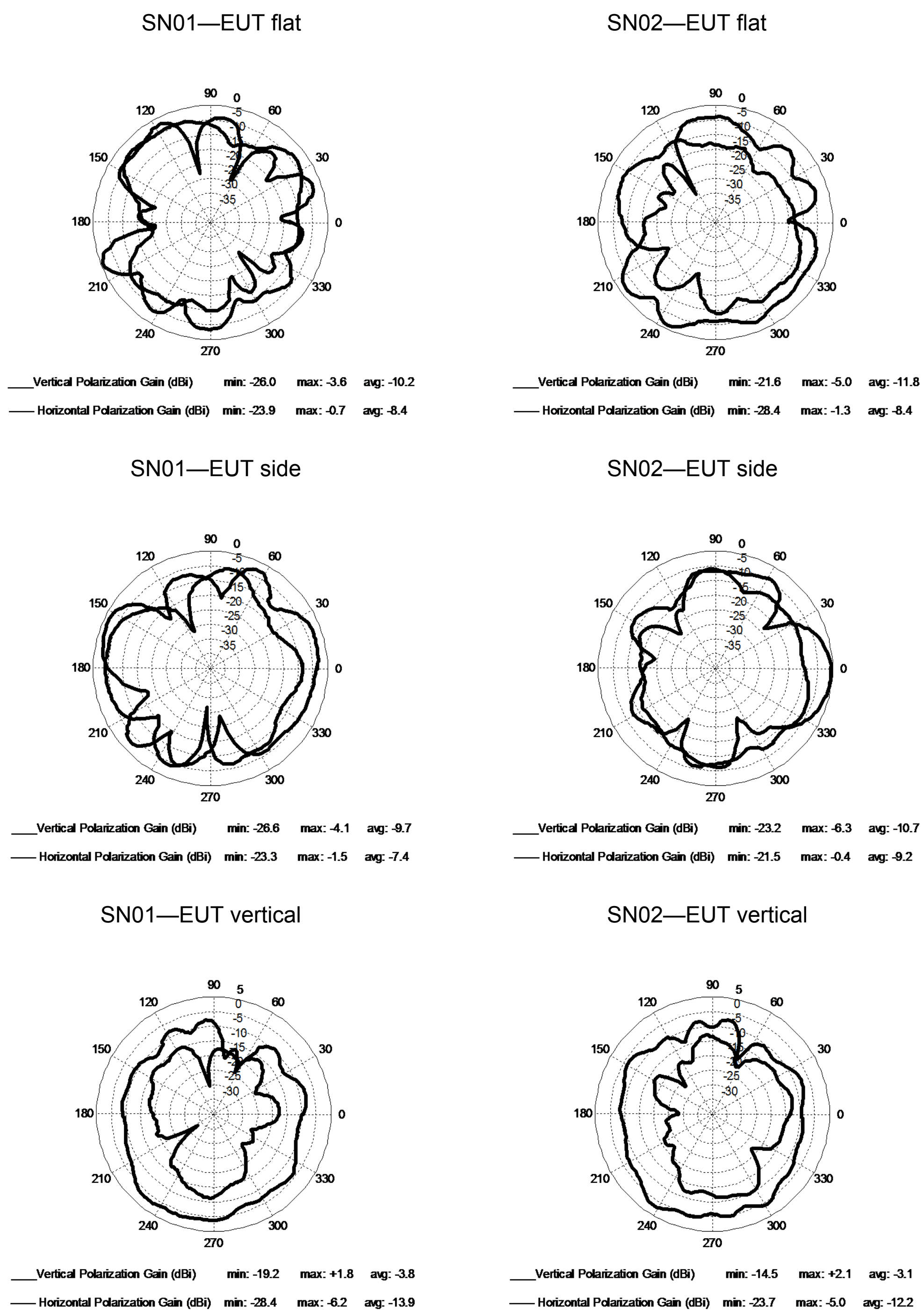


Figure 4.4. Measured Antenna Patterns for EM250 62 mil Boards

4.2.2 Antenna Patterns for EM260 62 mil Boards

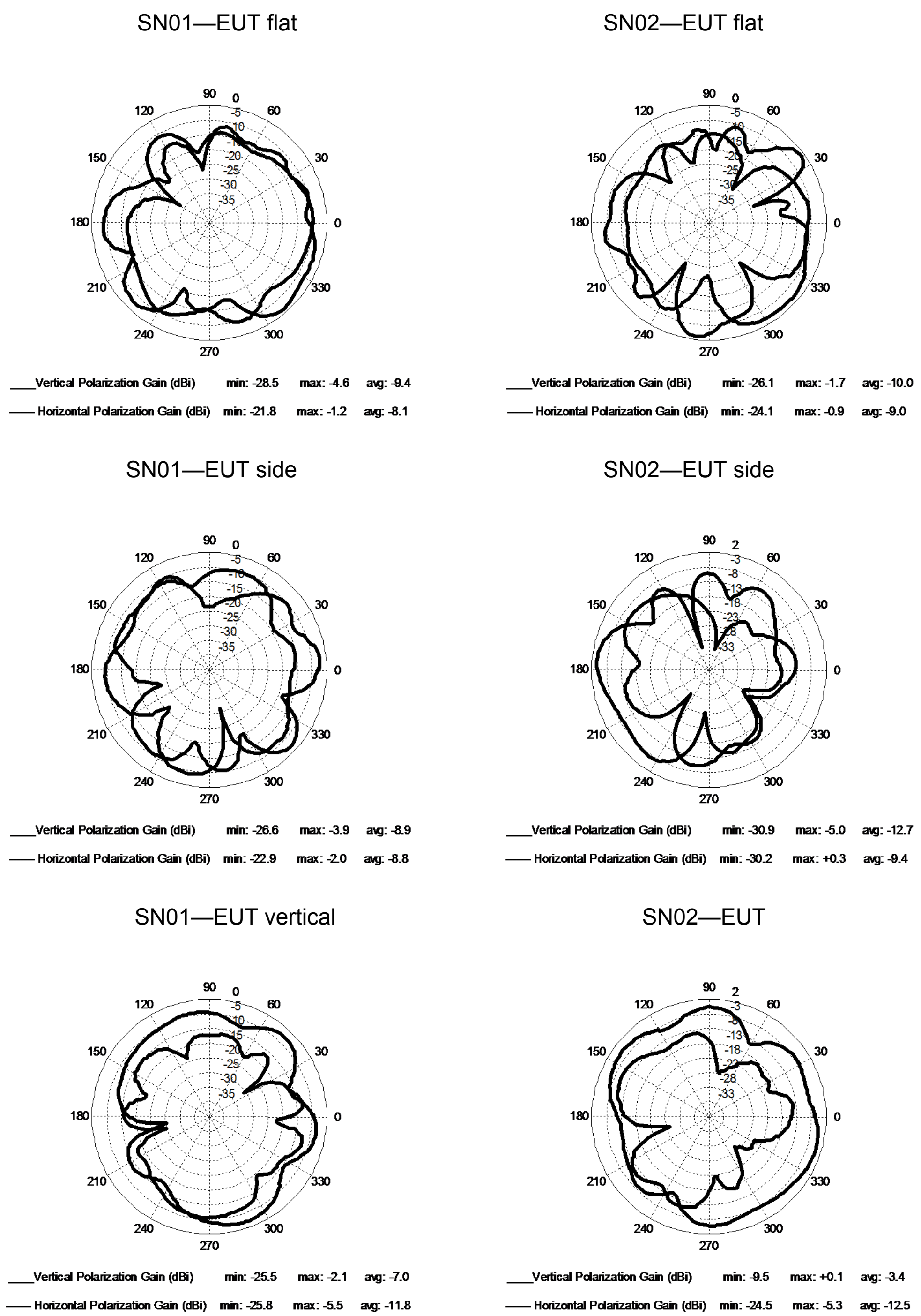
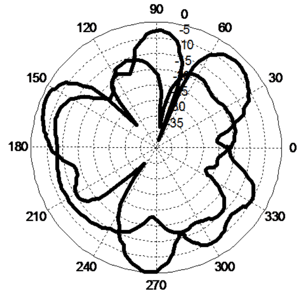


Figure 4.5. Measured Antenna Patterns for EM260 62 mil Boards

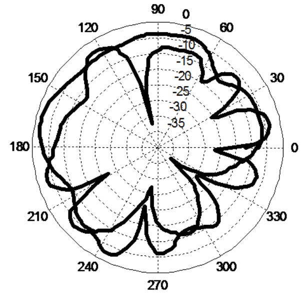
4.2.3 Antenna Patterns for EM250 0.8 mm Boards

SN01—EUT flat



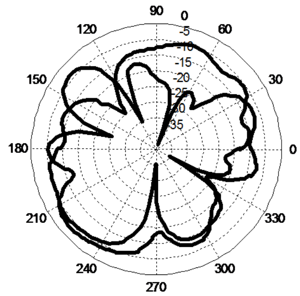
___Vertical Polarization Gain (dBi) min: -33.4 max: -6.5 avg: -13.2
—— Horizontal Polarization Gain (dBi) min: -37.5 max: -0.2 avg: -9.6

SN02—EUT flat



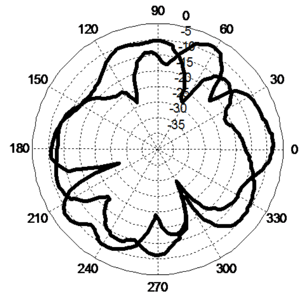
___Vertical Polarization Gain (dBi) min: -34.6 max: -1.8 avg: -9.7
—— Horizontal Polarization Gain (dBi) min: -32.4 max: -2.6 avg: -9.4

SN01—EUT side



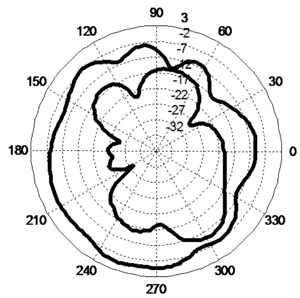
___Vertical Polarization Gain (dBi) min: -35.4 max: -4.1 avg: -10.8
—— Horizontal Polarization Gain (dBi) min: -38.7 max: -2.8 avg: -11.2

SN02—EUT side



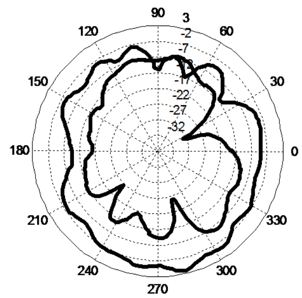
___Vertical Polarization Gain (dBi) min: -23.4 max: -5.2 avg: -10.2
—— Horizontal Polarization Gain (dBi) min: -28.2 max: -2.8 avg: -10.4

SN01—EUT vertical



___Vertical Polarization Gain (dBi) min: -12.3 max: +0.5 avg: -4.2
—— Horizontal Polarization Gain (dBi) min: -28.5 max: -4.9 avg: -14.6

SN02—EUT vertical



___Vertical Polarization Gain (dBi) min: -12.0 max: +2.0 avg: -4.3
—— Horizontal Polarization Gain (dBi) min: -28.0 max: -5.8 avg: -12.2

Figure 4.6. Measured Antenna Patterns for EM250 0.8 mm Boards

4.2.4 Antenna Patterns for EM260 0.8 mm Boards

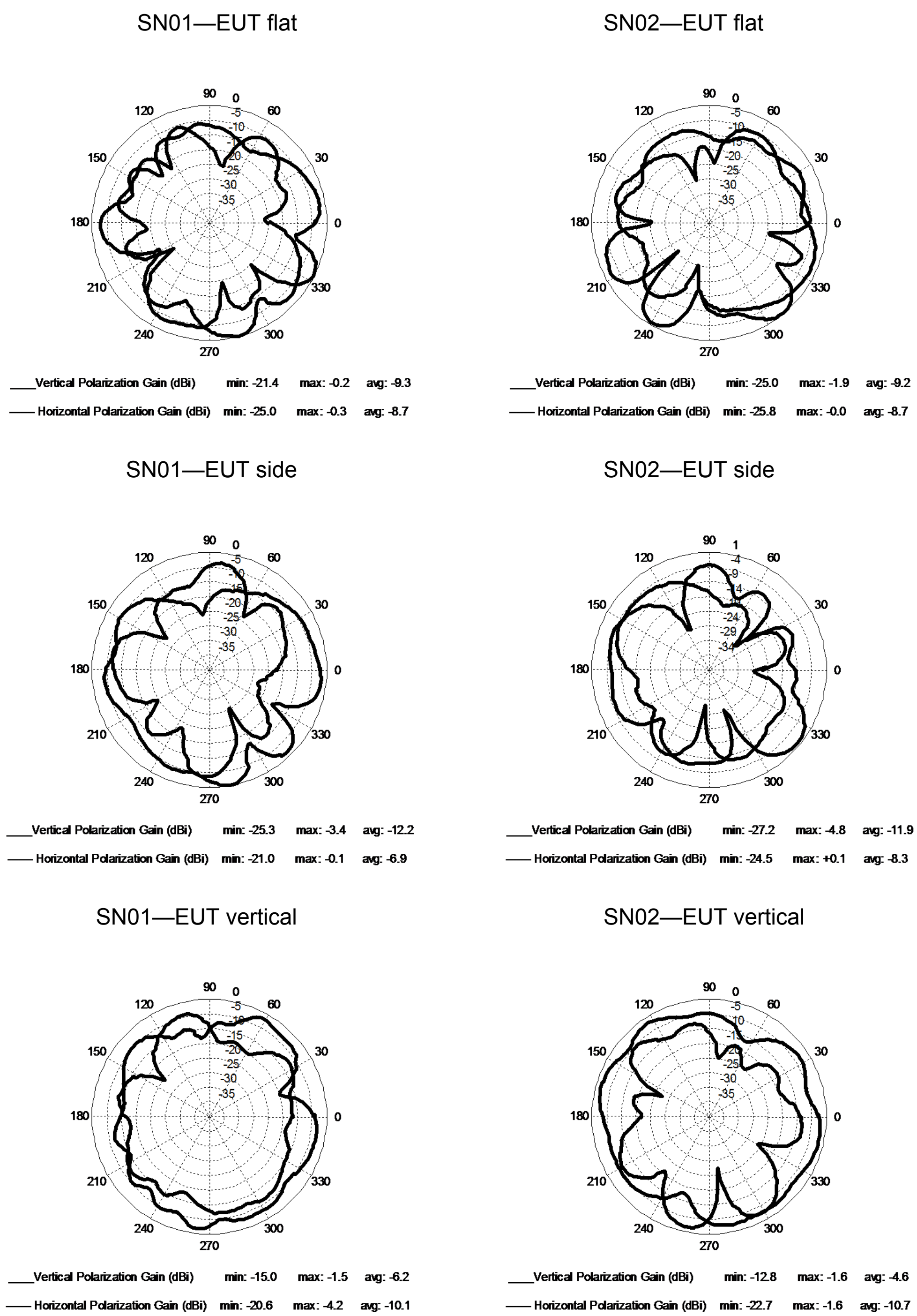
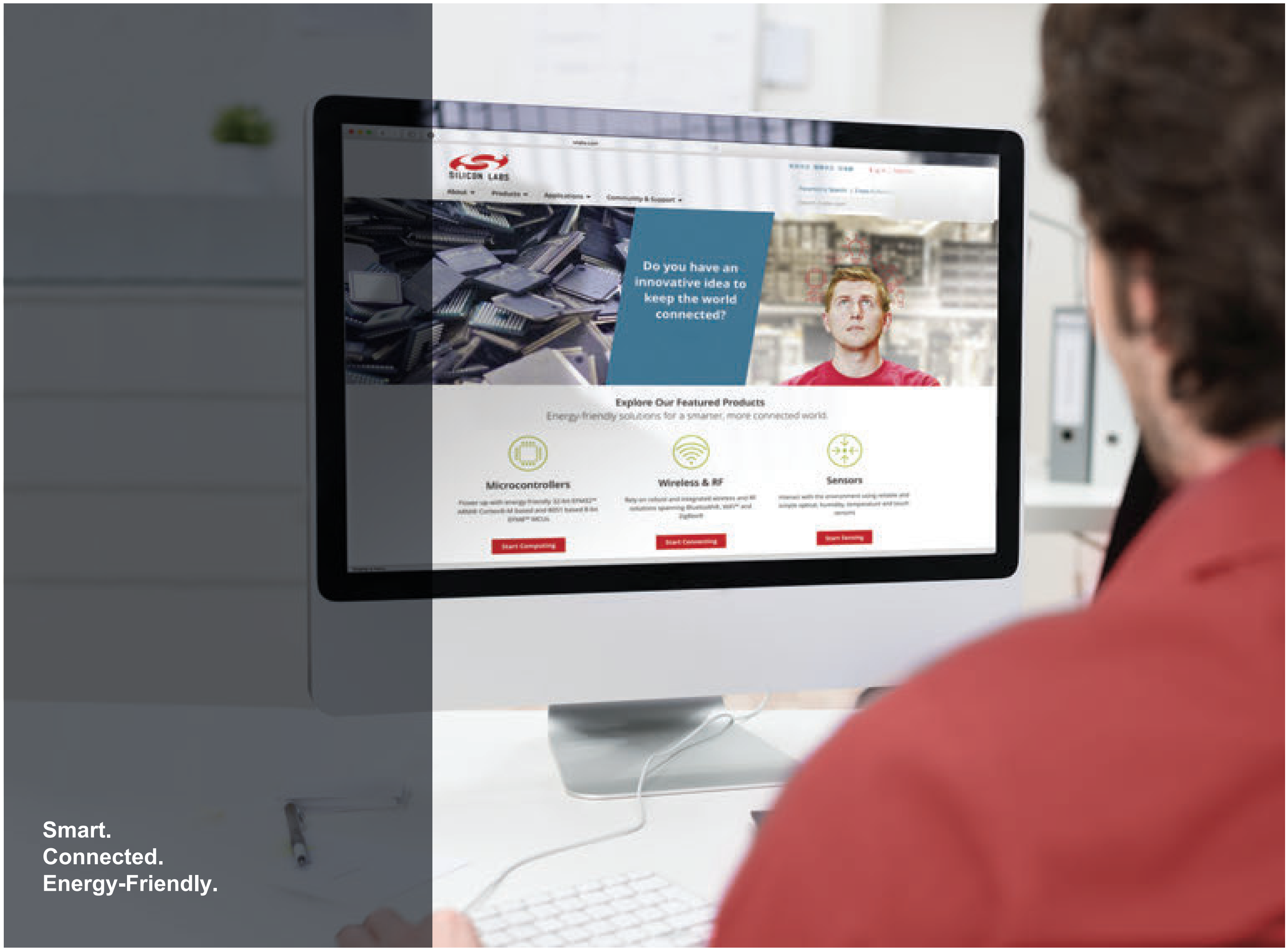


Figure 4.7. Measured Antenna Patterns for EM260 0.8 mm Boards

5. After Reading this Document

If you have questions about the information described in this document, please contact support at https://www.silabs.com/support.



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