Application Note
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Designing with an Inverted-F PCB Antenna

For the EM250 and EM260 Platforms

This document describes an Inverted-F PCB antenna designed by Ember for use with both the EM250 and EM260. The Inverted-F antenna is one of the more commonly used antennas at 2.4 GHz. Ember 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.

Contents

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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.

Ember has released the following Inverted-F based Reference Designs:

- 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)

Layout

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

Key features

Some key features of the design include the following:

- There are two versions of the layout: for the 62 mil and 0.8mm 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 two 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
- No ground pour on layer 1
- 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

Figure 1 illustrates the dimensions of the antenna.

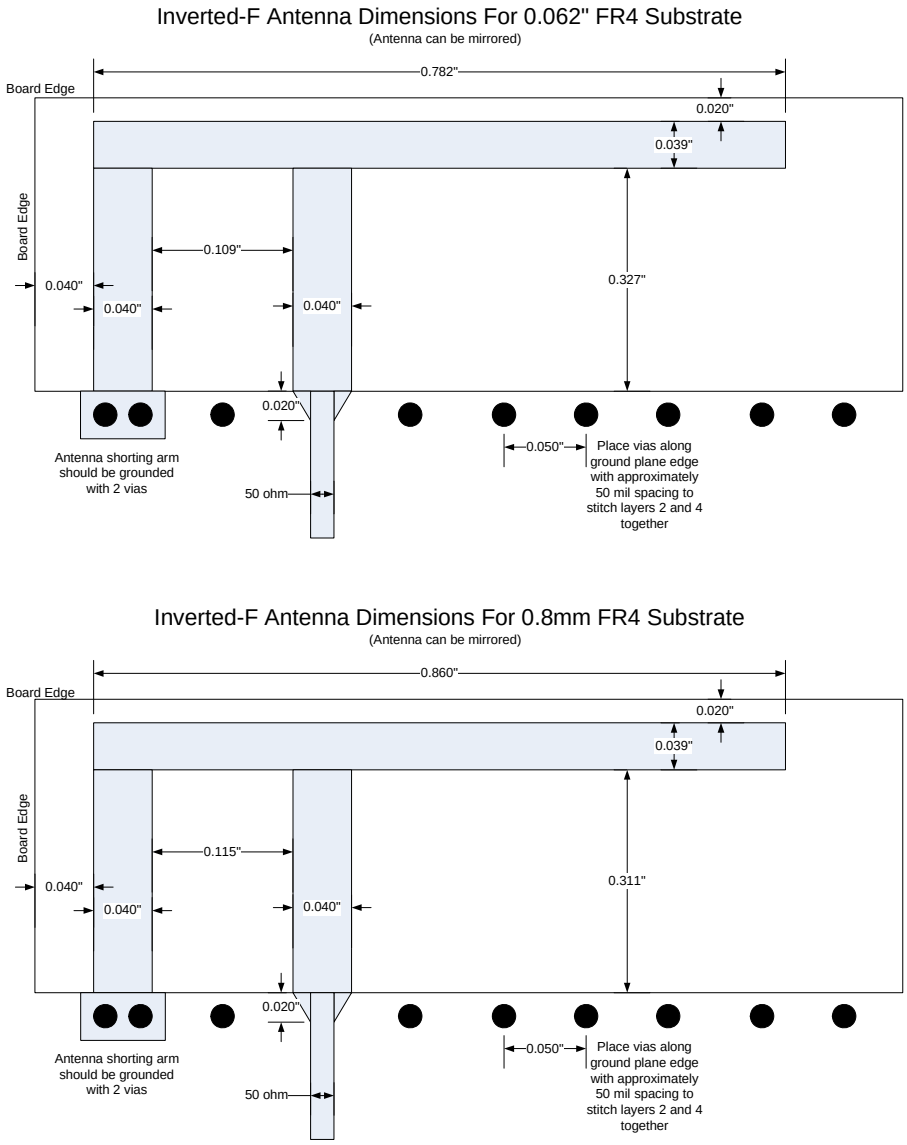


Figure 1. Antenna dimensions

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

Board stackup

Figure 2 shows the board stackups used in the designs.

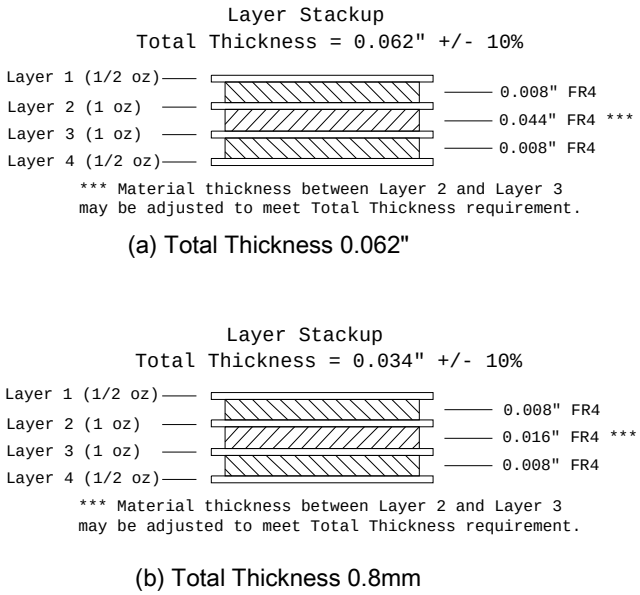


Figure 2. Board stackup

Tuning and Antenna

Antenna placement

Ember designed and optimized the Inverted-F reference designs for a 1″-wide PCB board. The ground plane forms an important part of the antenna. Figure 3 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, Ember recommends the placement shown in Figure 4.

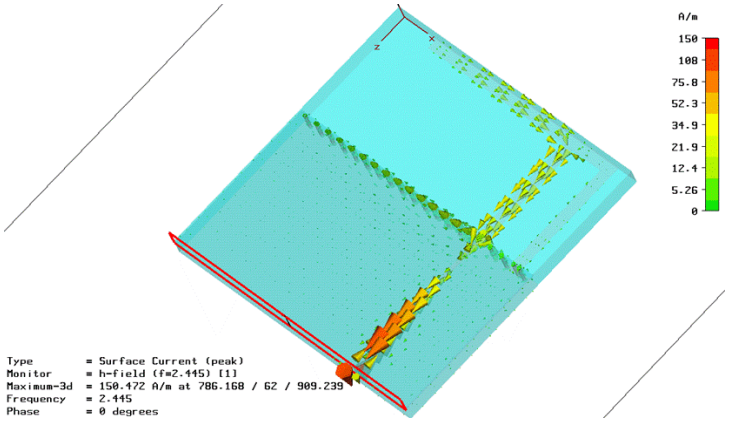


Figure 3. Surface current

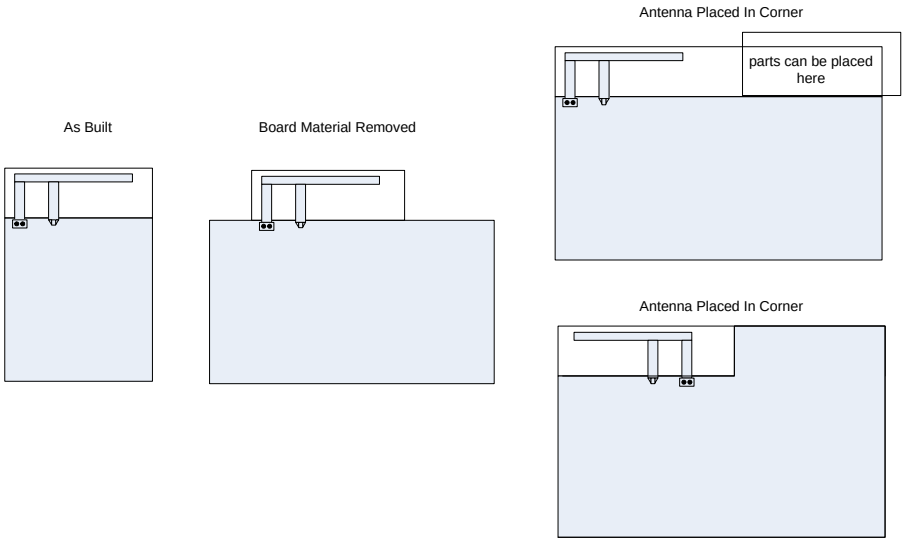
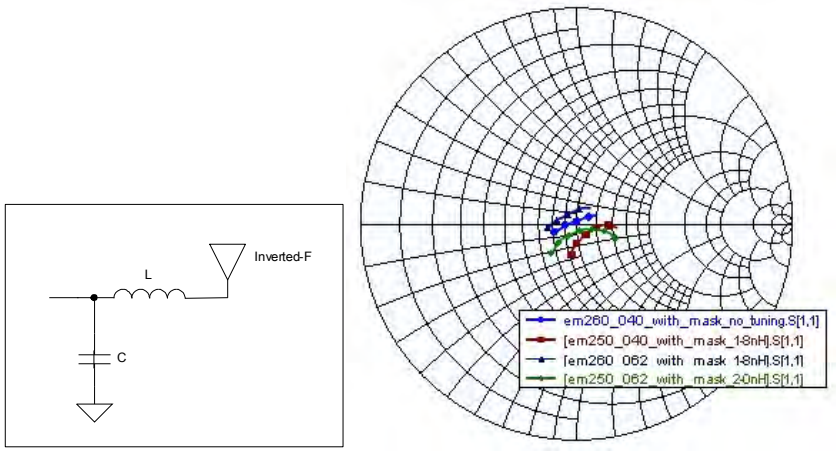


Figure 4. Recommended antenna placement

Tuning

Ember designed the antenna to provide a 50-Ohm output. However, board size, plastic enclosures, metal shielding, and components in close proximity to the antenna can affect antenna performance. For best performance, the antenna will require tuning. You can achieve a good match with one series and one shunt component. Figure 5 shows the values of *L* required for the reference design prototypes. All four designs required *C* to be unpopulated. Note that every implementation of the antenna design will require different combinations of inductors and capacitors.



- 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
- C is not populated

Figure 5. Antenna matching components

Antenna Performance

Antenna pattern simulations

Ember designed the antennas using CST Microwave Studio. Antennas for two board thicknesses were simulations of the antenna gain patterns; Figure 6 shows this for the 62 mil thick board and Figure 7 for the 0.8mm board. The gain shown is the absolute sum of both polarizations. These figures also show the board orientation.

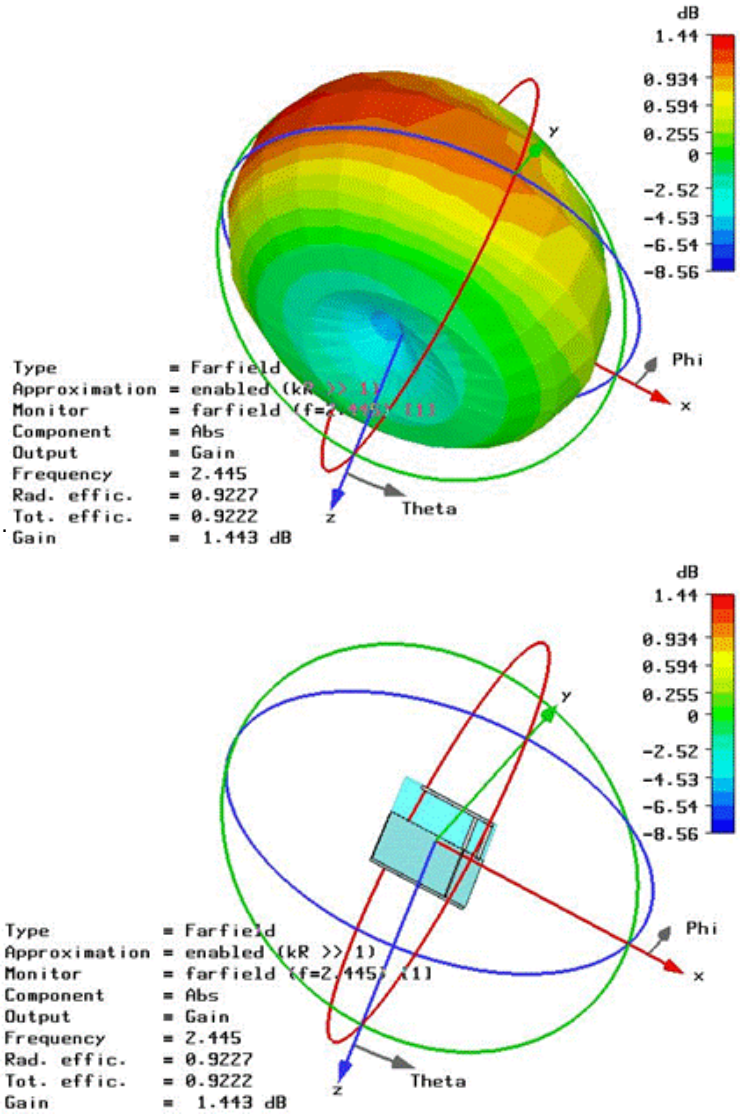


Figure 6. Simulation of gain pattern for the 62 mil antenna

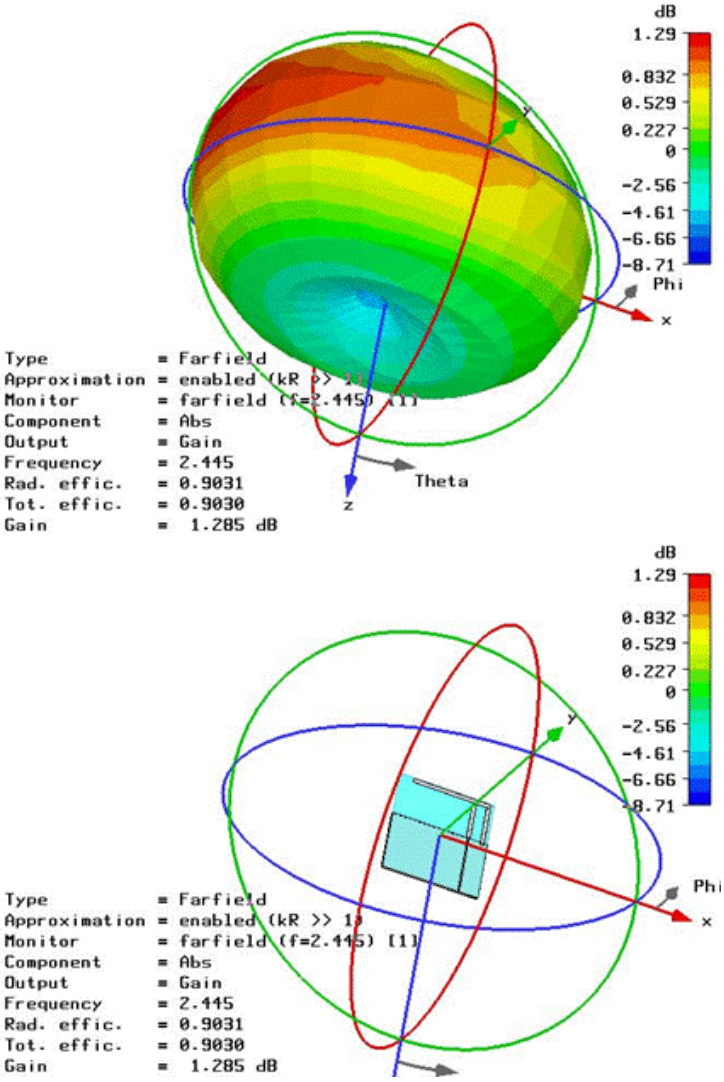


Figure 7. Simulation of gain pattern for the 0.8mm antenna

Effects of manufacturing variations

Ember designed both antennas to have enough excess bandwidth to maintain performance over manufacturing tolerances. Figure 8 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.

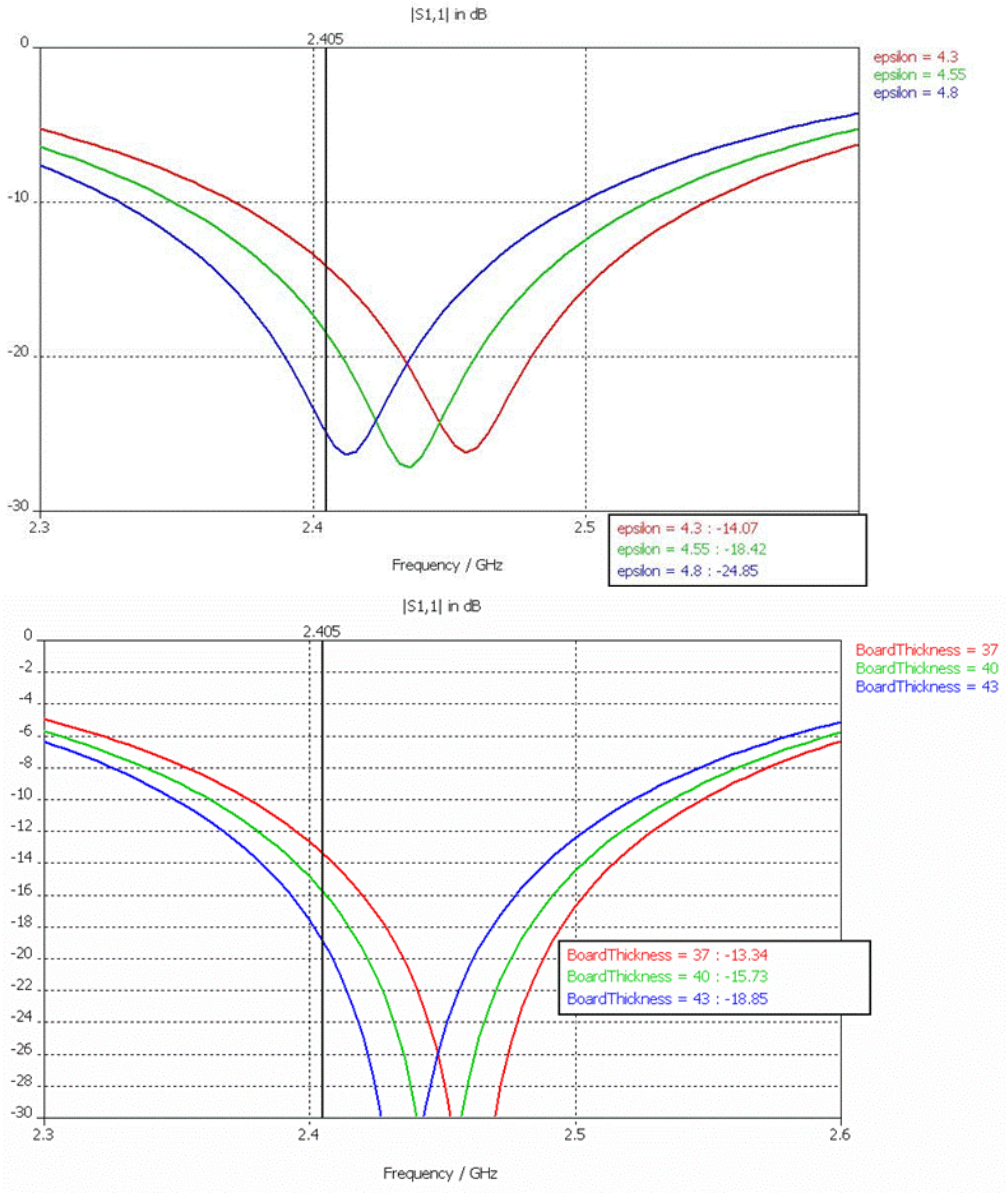


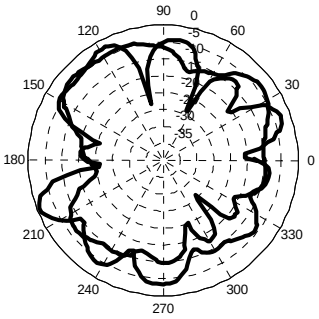
Figure 8. Effects of manufacturing tolerances

Measured antenna patterns

Ember 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. Figure 9 illustrates these patterns for EM250 62 mil boards, Figure 10 for EM260 62 mil boards, Figure 11 for EM250 0.8mm boards, and Figure 12 for EM260 0.8mm boards.

Antenna patterns for EM250 62 mil boards

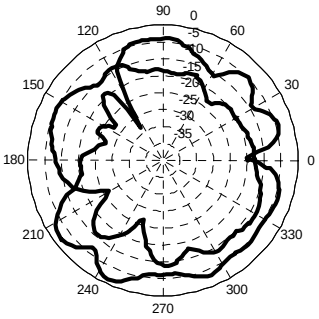
SN01—EUT flat



____Vertical Polarization Gain (dBi) min: -26.0 max: -3.6 avg: -10.2

------- Horizontal Polarization Gain (dBi) min: -23.9 max: -0.7 avg: -8.4

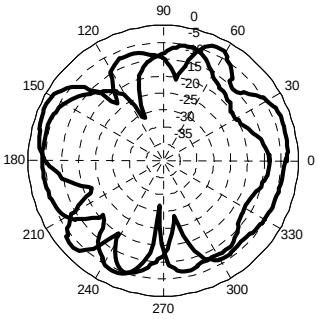
SN02—EUT flat



____Vertical Polarization Gain (dBi) min: -21.6 max: -5.0 avg: -11.8

------- Horizontal Polarization Gain (dBi) min: -28.4 max: -1.3 avg: -8.4

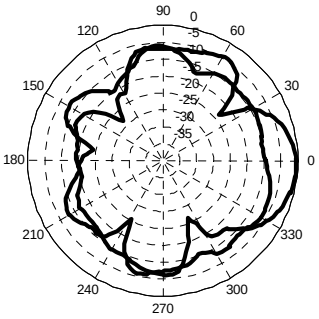
SN01—EUT side



____Vertical Polarization Gain (dBi) min: -26.6 max: -4.1 avg: -9.7

------- Horizontal Polarization Gain (dBi) min: -23.3 max: -1.5 avg: -7.4

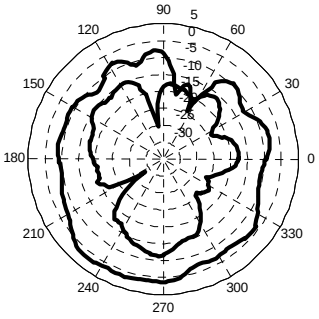
SN02—EUT side



____Vertical Polarization Gain (dBi) min: -23.2 max: -6.3 avg: -10.7

------- Horizontal Polarization Gain (dBi) min: -21.5 max: -0.4 avg: -9.2

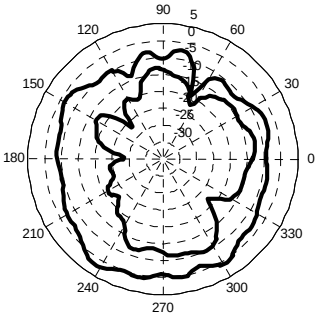
SN01—EUT vertical



____Vertical Polarization Gain (dBi) min: -19.2 max: +1.8 avg: -3.8

------- Horizontal Polarization Gain (dBi) min: -28.4 max: -6.2 avg: -13.9

SN02—EUT vertical



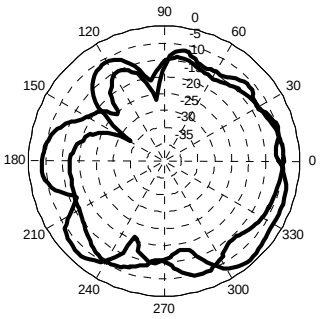
____Vertical Polarization Gain (dBi) min: -14.5 max: +2.1 avg: -3.1

------- Horizontal Polarization Gain (dBi) min: -23.7 max: -5.0 avg: -12.2

Figure 9. Measured antenna patterns for EM250 62 mil boards

Antenna patterns for EM260 62 mil boards

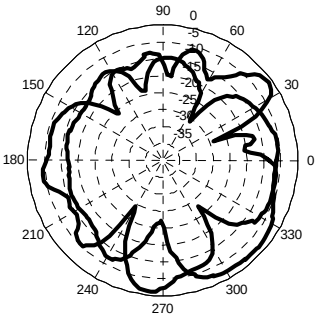
SN01—EUT flat



____Vertical Polarization Gain (dBi) min: -28.5 max: -4.6 avg: -9.4

------- Horizontal Polarization Gain (dBi) min: -21.8 max: -1.2 avg: -8.1

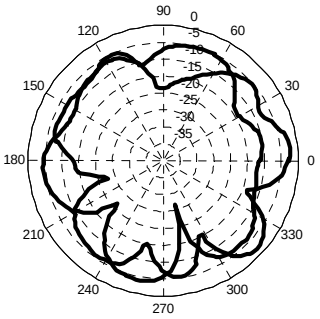
SN02—EUT flat



____Vertical Polarization Gain (dBi) min: -26.1 max: -1.7 avg: -10.0

------- Horizontal Polarization Gain (dBi) min: -24.1 max: -0.9 avg: -9.0

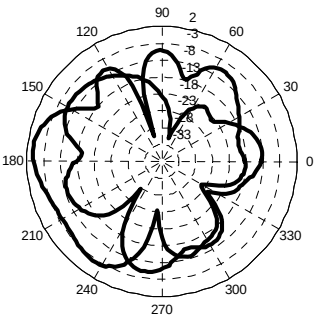
SN01—EUT side



____Vertical Polarization Gain (dBi) min: -26.6 max: -3.9 avg: -8.9

------- Horizontal Polarization Gain (dBi) min: -22.9 max: -2.0 avg: -8.8

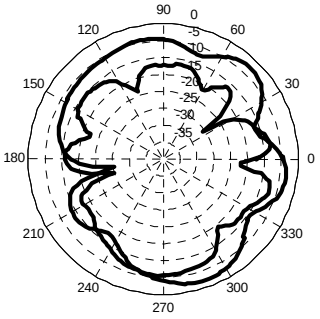
SN02—EUT side



____Vertical Polarization Gain (dBi) min: -30.9 max: -5.0 avg: -12.7

------- Horizontal Polarization Gain (dBi) min: -30.2 max: +0.3 avg: -9.4

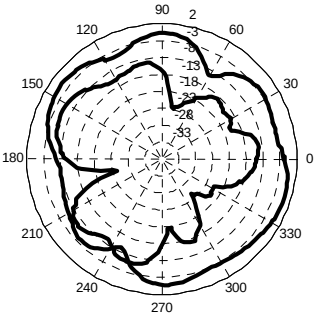
SN01—EUT vertical



____Vertical Polarization Gain (dBi) min: -25.5 max: -2.1 avg: -7.0

------- Horizontal Polarization Gain (dBi) min: -25.8 max: -5.5 avg: -11.8

SN02—EUT



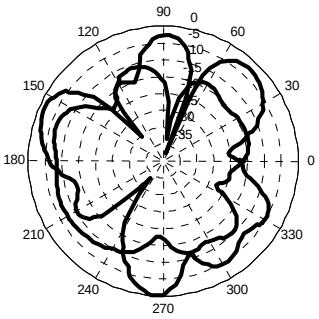
____Vertical Polarization Gain (dBi) min: -9.5 max: +0.1 avg: -3.4

------- Horizontal Polarization Gain (dBi) min: -24.5 max: -5.3 avg: -12.5

Figure 10. Measured antenna patterns for EM260 62 mil boards

Antenna patterns for EM250 0.8mm boards

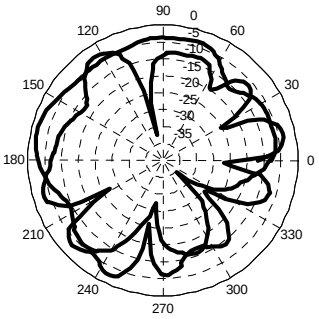
SN01—EUT flat



____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

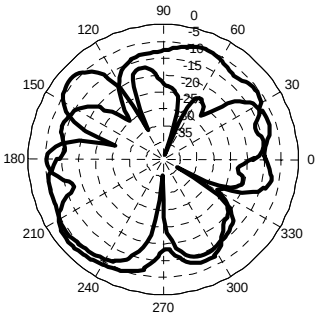
SN02—EUT flat



____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

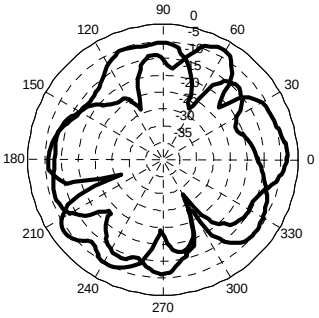
SN01—EUT side



____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

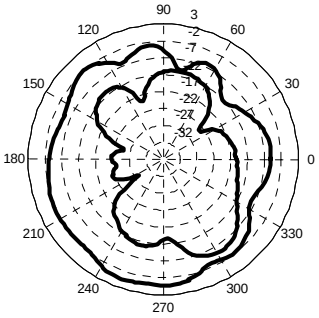
SN02—EUT side



____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

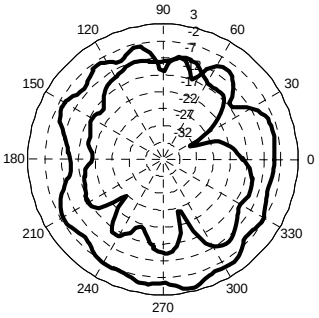
SN01—EUT vertical



____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



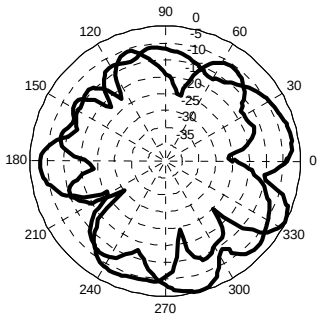
____Vertical Polarization Gain (dBi) min: -12.0 max: +2.0 avg: -4.3

------- Horizontal Polarization Gain (dBi) min: -28.0 max: -5.8 avg: -12.2

Figure 11**.** Measured antenna patterns for EM250 0.8mm boards

Antenna patterns for EM260 0.8mm boards

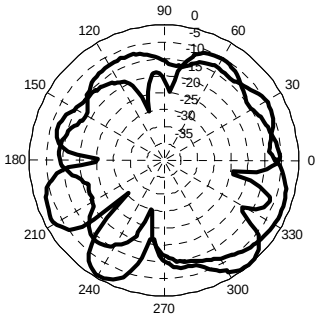
SN01—EUT flat



____Vertical Polarization Gain (dBi) min: -21.4 max: -0.2 avg: -9.3

------- Horizontal Polarization Gain (dBi) min: -25.0 max: -0.3 avg: -8.7

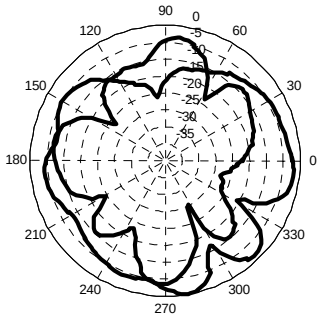
SN02—EUT flat



____Vertical Polarization Gain (dBi) min: -25.0 max: -1.9 avg: -9.2

------- Horizontal Polarization Gain (dBi) min: -25.8 max: -0.0 avg: -8.7

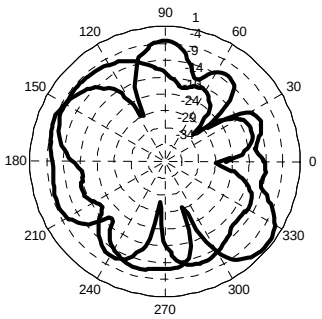
SN01—EUT side



____Vertical Polarization Gain (dBi) min: -25.3 max: -3.4 avg: -12.2

------- Horizontal Polarization Gain (dBi) min: -21.0 max: -0.1 avg: -6.9

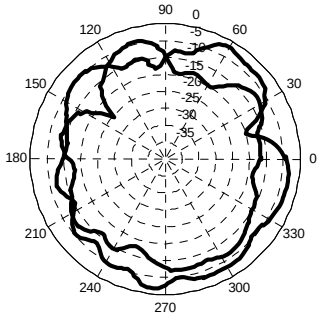
SN02—EUT side



____Vertical Polarization Gain (dBi) min: -27.2 max: -4.8 avg: -11.9

------- Horizontal Polarization Gain (dBi) min: -24.5 max: +0.1 avg: -8.3

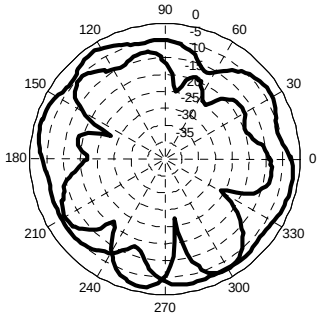
SN01—EUT vertical



____Vertical Polarization Gain (dBi) min: -15.0 max: -1.5 avg: -6.2

------- Horizontal Polarization Gain (dBi) min: -20.6 max: -4.2 avg: -10.1

SN02—EUT vertical



____Vertical Polarization Gain (dBi) min: -12.8 max: -1.6 avg: -4.6

------- Horizontal Polarization Gain (dBi) min: -22.7 max: -1.6 avg: -10.7

Figure 12. Measured antenna patterns for EM260 0.8mm boards

After Reading This Document

If you have questions about the information described in this document, please contact an Ember support representative at support@ember.com.

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