CC-Antenna-DK and Antenna Measurements Summary

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Keywords

- *169 MHz (136 – 240 MHz) Antenna*
- *315 MHz (273 – 348 MHz) Antenna*
- *433 MHz (387 – 510 MHz) Antenna*
- *868 MHz (779 – 960 MHz) Antenna*
- *915 MHz (779 – 960 MHz) Antenna*
- *2440 MHz Antenna*
- *PCB Antenna*
- *Wire Antenna*
- *Ceramic Chip Antenna*
- *CC-Antenna-DK*
- *Dual Band Antenna (868 & 2440 MHz)*
- *Mitsubishi Chip Antenna*
- *Pulse Chip Antenna*
- *Helical Wire Antenna*
- *Pulse Helical Wire Antenna*

1 Introduction

The main purpose of the CC-Antenna-DK is to ease the decision for which type of low cost antenna can be implemented as well as give an estimation of the performance that can be achieved.

The frequency range of the antennas is from 136 MHz to 2480 MHz. The A4 sized PCB panel contains 16 different boards; 13 antenna designs and 3 boards for calibration purposes. Each board has been v-cut and can be snapped out of the PCB panel.

All antennas are tuned for connecting to an EM board on the EB platform. A matching network is used on each antenna design so the antenna boards can matched for other GND sizes than the EB board.

Additionally, the ambition with this document is to collect the various antenna measurements that have been performed and to compare the results obtained in an overview format. Terminology, antenna characteristics, fundamentals of antenna design, and measurement procedures are covered in the Antenna Selection Guide [18]. For each antenna, a CTIA measurement summary is provided in this report with a link to the full measurement CTIA report. DN6xx is designated for CTIA measurement reports.

Choosing the correct antenna for the application is crucial if the optimum range is to be achieved. Similarly, for a given distance, the power can be reduced on the transmitter side if the optimum antenna is chosen.

Antennas are categorized under the operating frequency (169 MHz, 315 MHz, 433 MHz, 868 / 915 MHz or 2.44 GHz) and then the type of antenna (PCB Antennas, Chip Antennas, and Wire Antennas). The main focus is on PCB, Wire and Chip antennas, since these are mainly used in high volume products.

Table of Contents

2 Abbreviations

BOM	Bill Of Materials
BW	Bandwidth
DK	Development Kit
DUT	Device Under Test
EB	Evaluation Board
EIRP	Effective Isotropic Radiated Power
EM	Evaluation Module
CITA	Cellular Telecommunications Industry Association
NC	Not Connected
NHPRP	Near Horizon Partial Radiated Power
NHPRP45	Near Horizon Partial Radiated Power within 45 degrees angle
OTA	Over The Air
PCB	Printed Circuit Board
SWR	Standing Wave Ratio
TRP	Total Radiated Power

3 CC-Antenna-DK Rev 1.0.0.

3.1 Board Description

The CC-Antenna-DK PCB panel contains 16 different boards; 13 antenna designs and 3 boards for calibration purposes. Each board has been v-cut and can be snapped out of the PCB panel, shown in Figure 1.

Each board has a height of 95 mm and a width of 20 mm to 45 mm. The PCB is 1.6 mm thick and has a dielectric of 4.2.

The schematic (PDF), layout (PDF and gerbers), PCB stack-up (PDF) are provided in the CC-Antenna-DK documentation in the zip file [19].

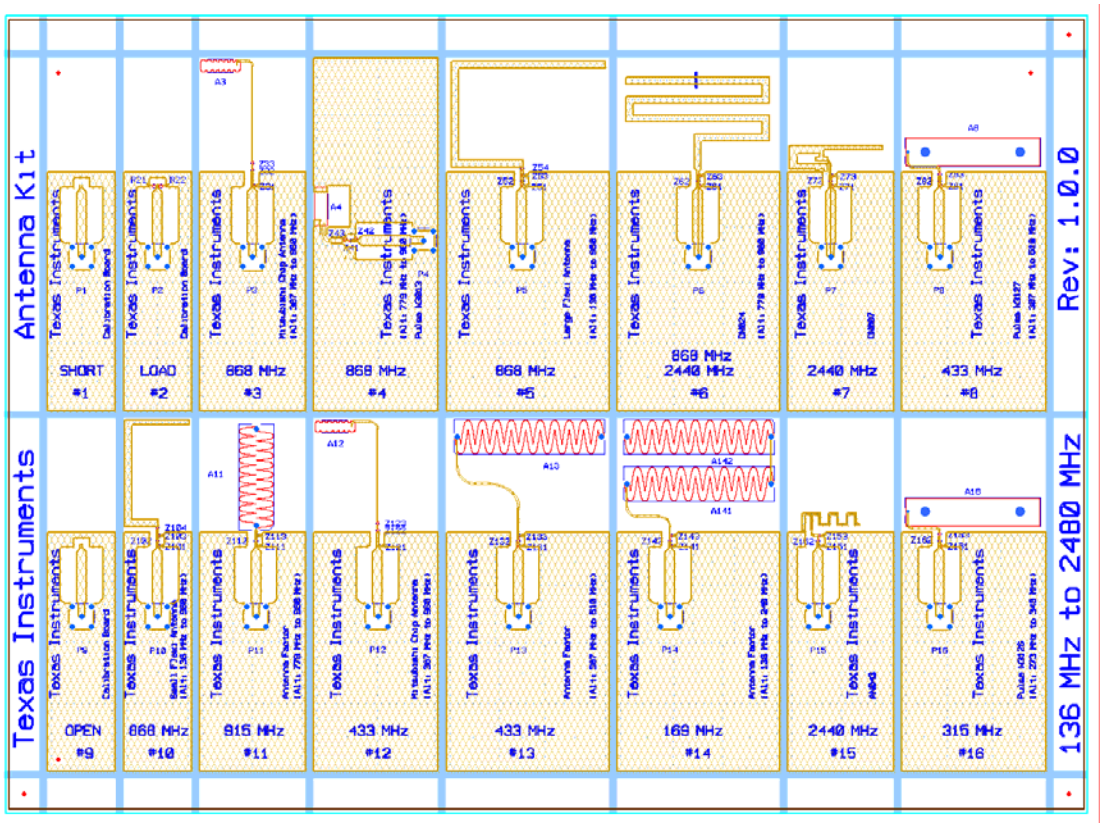

Figure 1: CC-Antenna-DK Board Showing Top Metal Layer, Silkscreen and V-cut Track

All Low Power Wireless chips have their own specific reference designs. Each reference design is implemented on an Evaluation Module (EM). Figure 2 shows a typical EM that is used for CC2500 ref design.

Figure 2. Picture of CC2500 Evaluation Module (EM)

The EM board is inserted onto the main Evaluation Board platform so the reference design implemented on the EM can be evaluated. The EM board is inserted onto the top, right side of the SmartRF04EB board as can be seen in Figure 3.

Figure 3. Picture of SmartRF04EB Evaluation Board (EB)

All antennas have been measured and tuned for connecting to an EM board inserted onto an EB board unless other specified; this is illustrated in Figure 4.

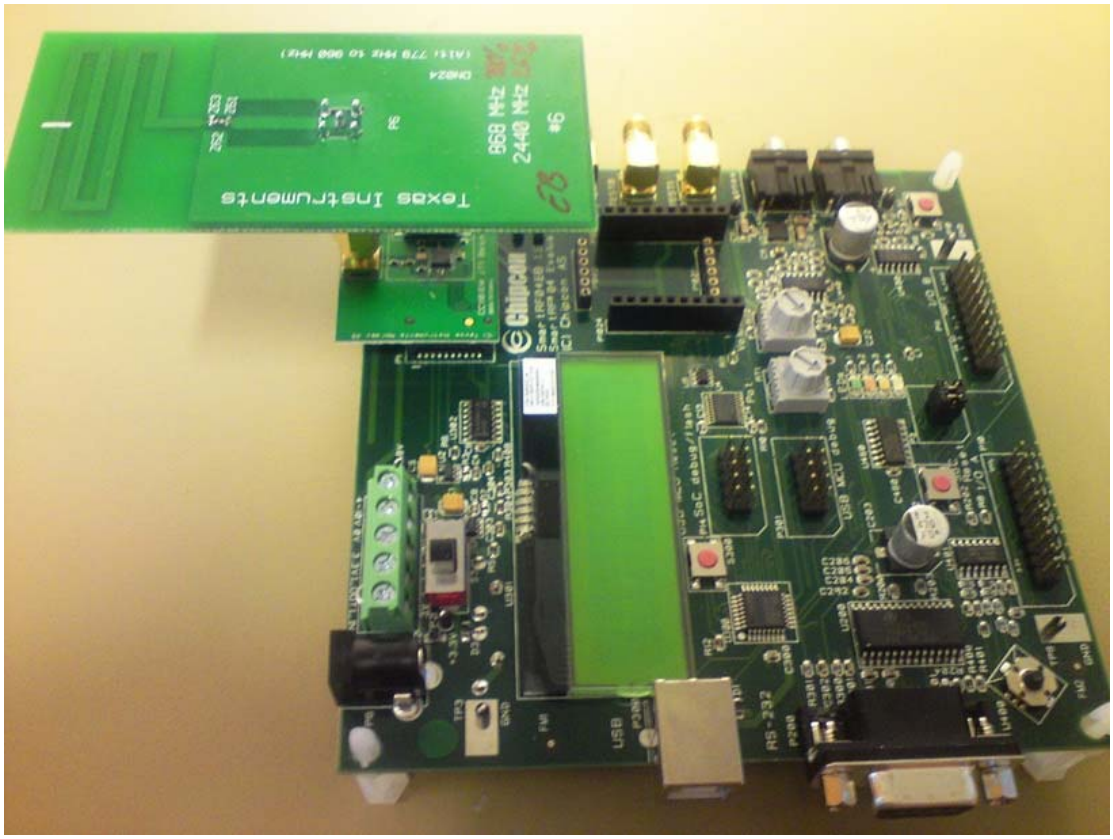

Figure 4: Connectivity of Antenna Board #6 to a CC1101 EM Board on the EB Platform

A matching network is used on each antenna design so the antenna boards can matched for other GND sizes than the EB board, refer to Figure 5.

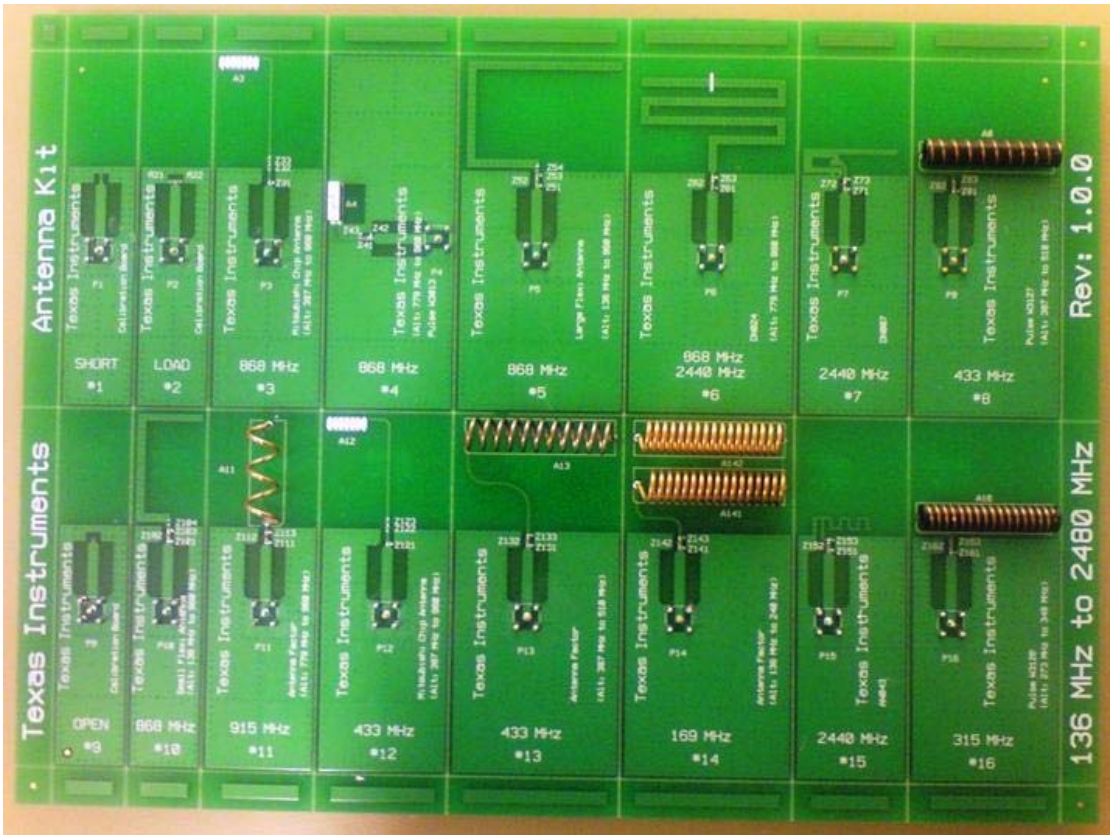

Figure 5: CC-Antenna-DK Panel Picture

Sections 3.1.1 to 3.1.16 show the top metal layer in blue and the bottom layer in red.

The efficiency of the antenna (>868 MHz) is normally increased when used as a stand alone board. The lower frequencies (<433 MHz) require a larger GND plane / antenna to achieve high total radiated power (TRP).

Two types of antenna (board 6, 3.1.6 and board 7, 3.1.7) have been chosen to illustrate that the TRP is increased when used as a stand alone compared to using the antennas on the EM & EB platform.

3.1.1 Board #1: "Short" Calibration Board

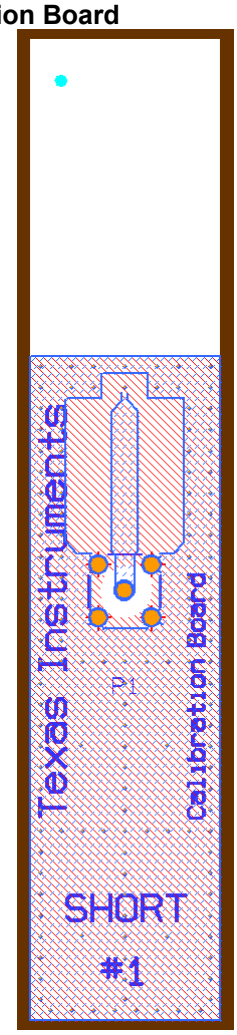

Figure 6: Board #1 – "Short" Calibration Board

Size	Width (mm)	Height (mm)
PCB Board	20	95
GND	18	63

BOM	Ref. Designator	Part Number	Value
	-	-	-

Table 1: PCB Size and BOM for Board #1 – "Short" Calibration Board

Three boards have been provided for calibration purposes; OPEN (3.1.9), SHORT (3.1.1), and 50 ohm LOAD (3.1.2). These boards are mainly used when working with a network analyzer.

3.1.2 Board #2: "Load" Calibration Board

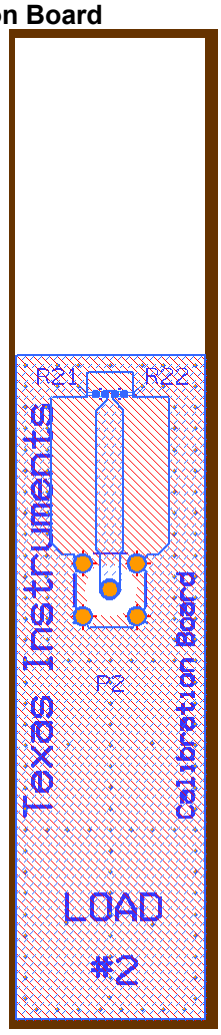

Figure 7: Board #2 – "Load" Calibration Board

Size	Width (mm)	Height (mm)
PCB Board	20	95
GND	18	63

BOM	Ref. Designator	Koa Part Number	Value
	R21	RK73H1ETTP1000F	100 ohm
	R22	RK73H1ETTP1000F	100 ohm

Table 2: PCB Size and BOM for Board #2 – "Load" Calibration Board

Three boards have been provided for calibration purposes; OPEN (3.1.9), SHORT (3.1.1), and 50 ohm LOAD (3.1.2). These boards are mainly used when working with a network analyzer.

3.1.3 Board #3: Mitsubishi Chip Antenna – 868 MHz

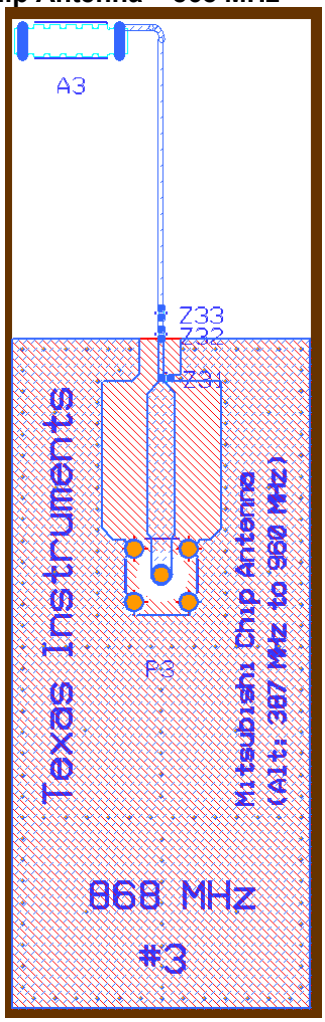

Figure 8: Board #3: Mitsubishi Chip Antenna – 868 MHz

Size	Width (mm)	Height (mm)
PCB Board	30	95
GND	28	63

BOM	Ref. Designator	Part Number	Value
	A3	MITSUBISHI AMD1103-ST01T	-
	Z31	NC	-
	Z32	Murata LQG15HS22NJ02D	22 nH
	Z33	KOA RK73Z1ETTP	0 ohm

Table 3: PCB Size and BOM for Board #3: Mitsubishi Chip Antenna – 868 MHz

Pros: Good BW and easy to match.

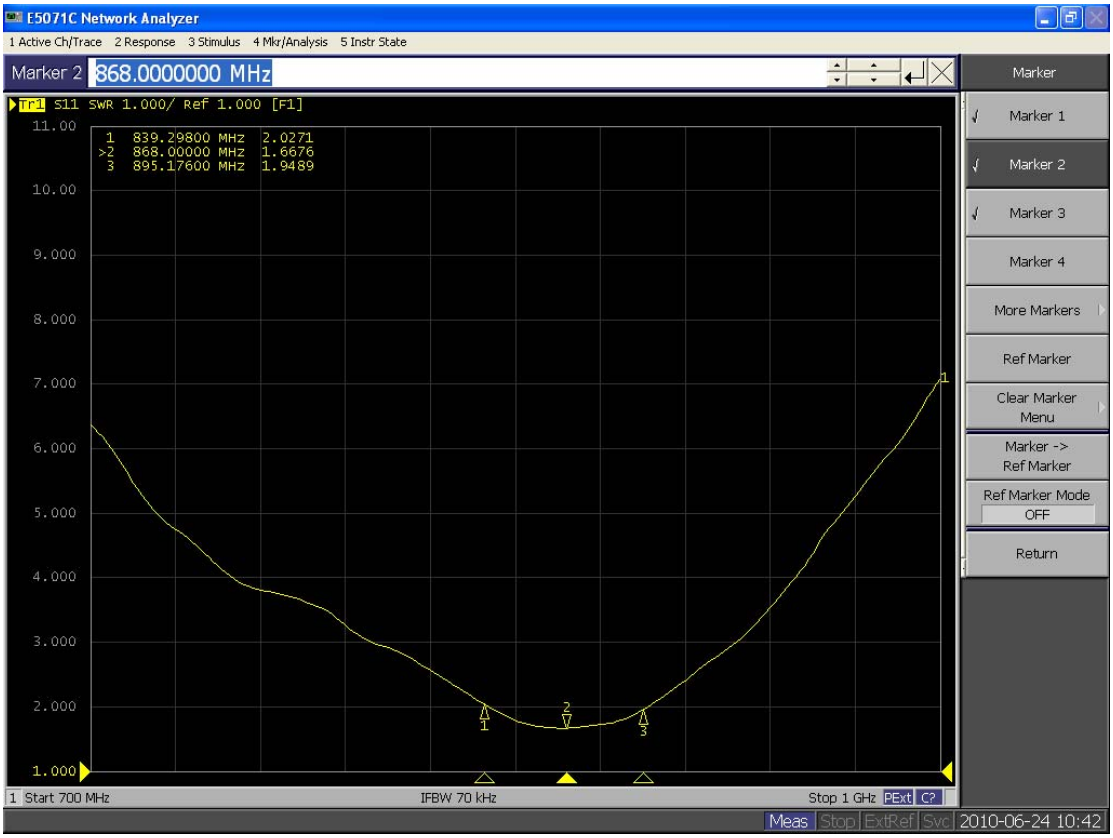

Figure 9: 56 MHz Bandwidth Measurement @ SWR of 2.0

3.1.4 Board #4: Pulse Chip Antenna – 868 MHz

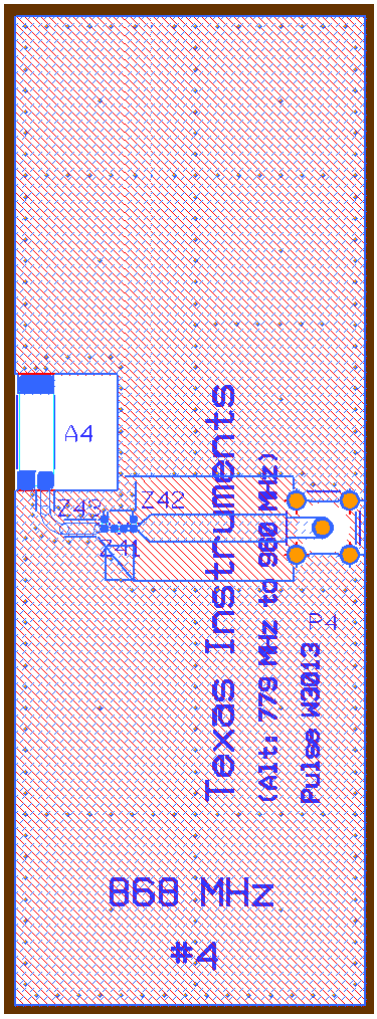

Figure 10: Board #4: Pulse Chip Antenna – 868 MHz

Size	Width (mm)	Height (mm)
PCB Board	35	95
GND	33	93

BOM	Ref. Designator	Part Number	Value
	A4	PULSE W3013	-
	Z41	KOA RK73Z1ETTP	0 ohm
	Z42	NC	-
	Z43	Murata GRM1555C1H8R2CZ01D	8.2 pF

Table 4: PCB Size and BOM for Board #4: Pulse Chip Antenna – 868 MHz

Pros: Ability to place the antenna in the middle of a GND plane at the edge of the board instead of the traditional placement at top corner of a board. Good TRP efficiency when matched correctly.

Cons: Difficult to match with external discrete network. The main matching parameter is the distance to the GND around the antenna. If this distance is incorrect, then a new PCB spin is required to tune the antenna to the desired frequency. Low BW.

For the CC-Antenna-DK Rev 1.0.0 PCB, the antenna chip had to be moved towards the open GND cavity slightly to get the resonance at 868 MHz. When the antenna was centered on its pads, the resonance was around 859 MHz. This will be retuned for future revisions of the CC-Antenna-DK.

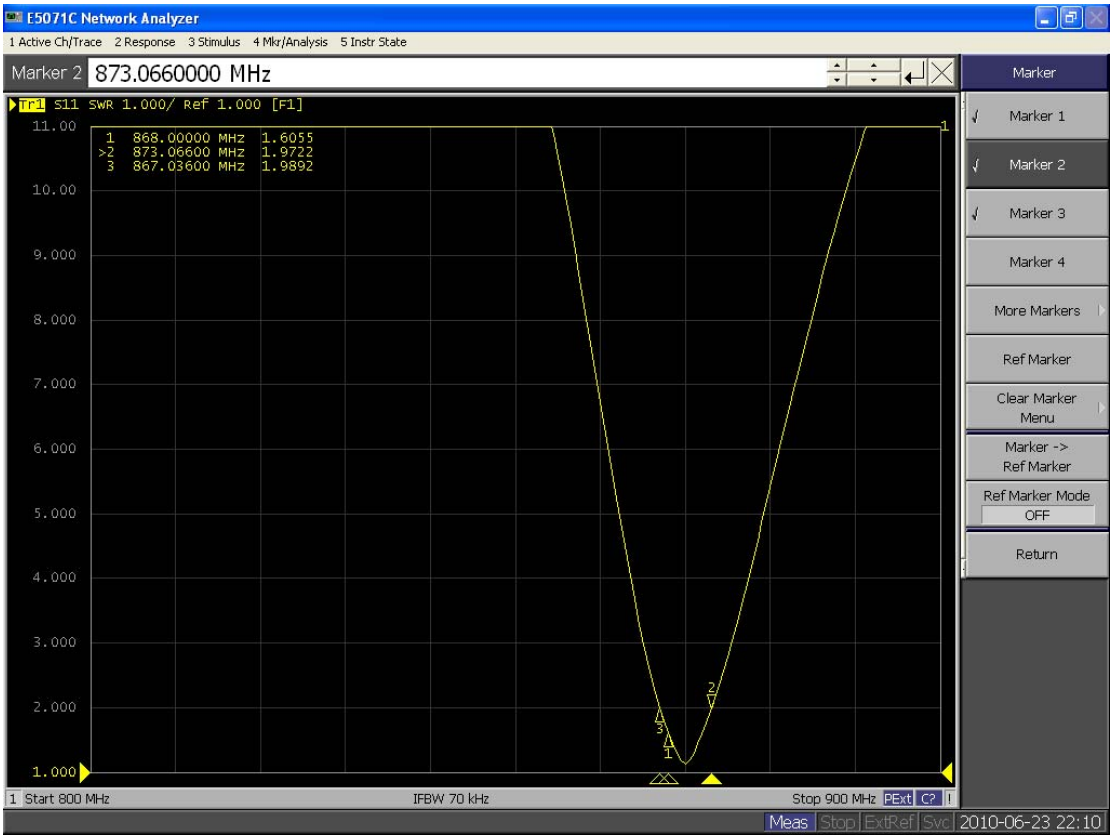

Figure 11: 6 MHz Bandwidth Measurement @ SWR of 2.0

3.1.5 Board #5: Large Flexi Antenna – 868 MHz

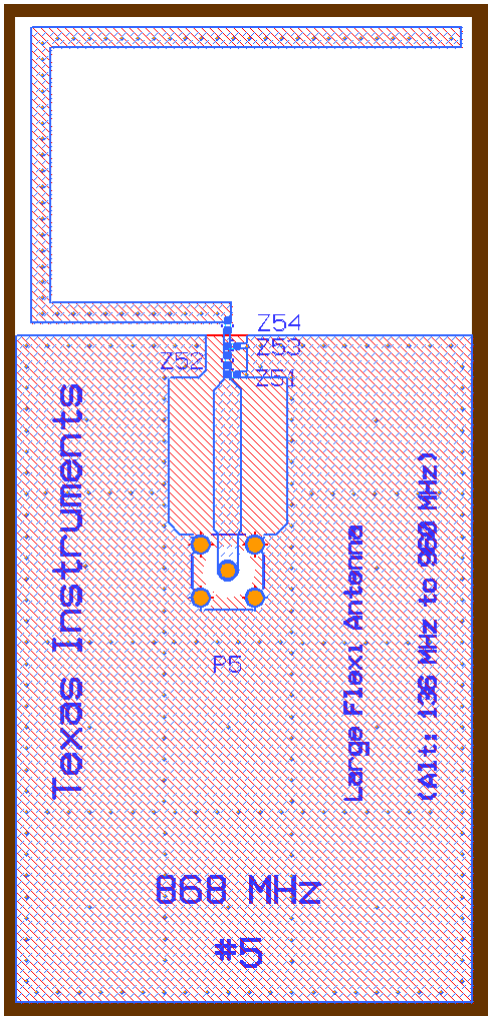

Figure 12: Board #5: Large Flexi Antenna – 868 MHz

Size	Width (mm)	Height (mm)
PCB Board	45	95
GND	43	63

BOM	Ref. Designator	Part Number	Value
	Z51	Murata GRM1555C1H6R2CZ01D	6.2 pF
	Z52	Murata LQG15HS5N6S02D	5.6 nH
	Z53	NC	-
	Z54	KOA RK73Z1ETTP	0 ohm

Table 5: PCB Size and BOM for Board #5: Large Flexi Antenna – 868 MHz

Pros: No simulations required providing that a network analyzer is available for tuning of the antenna via the match network. Reasonable BW performance and good TRP efficiency.

Cons: Usage of discrete components in antenna matching is compulsory.

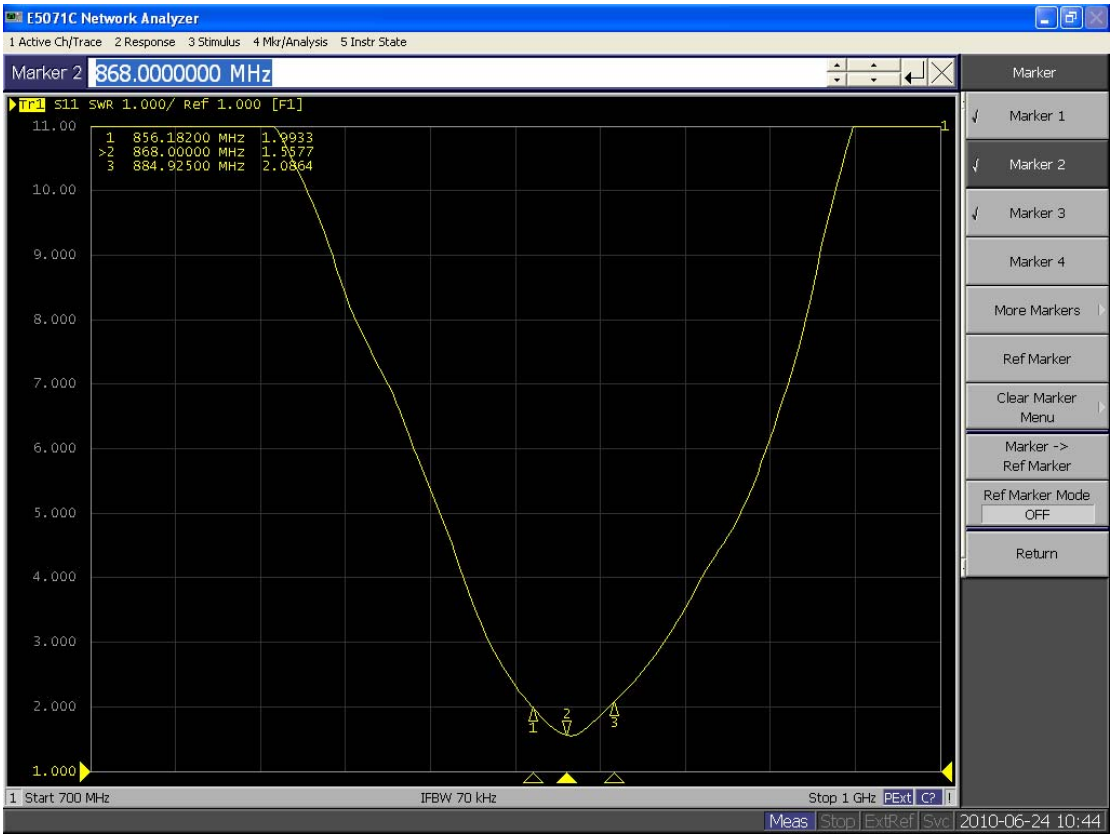

Figure 13: 29 MHz Bandwidth Measurement of @ SWR of 2.0

This type of antenna basically shows that for a given available area a trace length which is shorter than a quarter wave length of the desired frequency can be matched by adding inductance to the antenna feed point.

This antenna has not been simulated, yet the TRP results are good and equal the other antennas performances at this frequency. Board 10 (3.1.10) is similar concept but for a smaller board size.

3.1.6 Board #6: Dual Band Antenna – 868 MHz & 2440 MHz

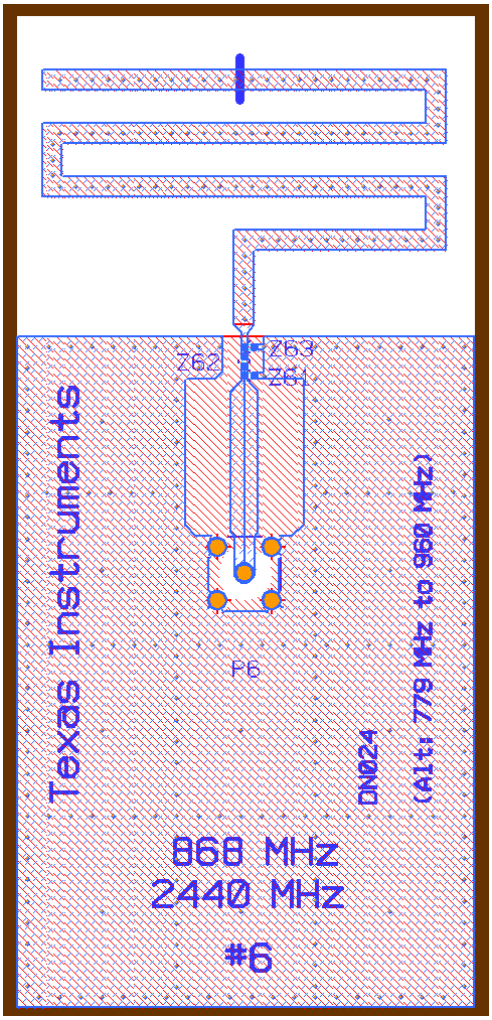

Figure 14: Board #6: Dual Band Antenna – 868 MHz & 2440 MHz

Size	Width (mm)	Height (mm)
PCB Board	45	95
GND	43	63

BOM	Ref. Designator	Murata Part Number	Value
	Z61	LQG15HS10NJ02D	10 nH
	Z62	GRM1555C1H2R7CZ01D	2.7 pF
	Z63	NC	-

Table 6: PCB Size and BOM for Board #6: Dual Band Antenna – 868 MHz & 2440 MHz

Pros: Dual band, 868 MHz and 2440 MHz. Excellent TRP for both 868 MHz and 2440 MHz. Good BW at 868 MHz and excellent BW at 2440 MHz.

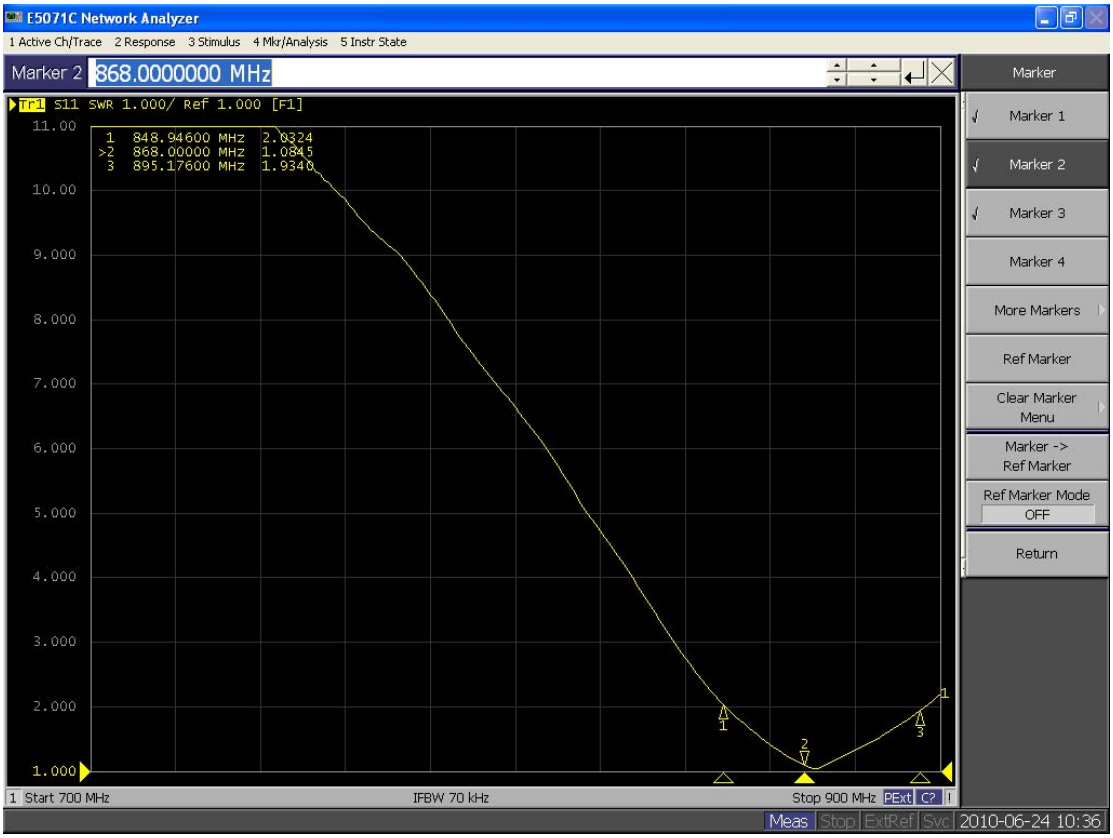

Figure 15: 46 MHz Bandwidth Measurement (868 MHz) @ SWR of 2.0

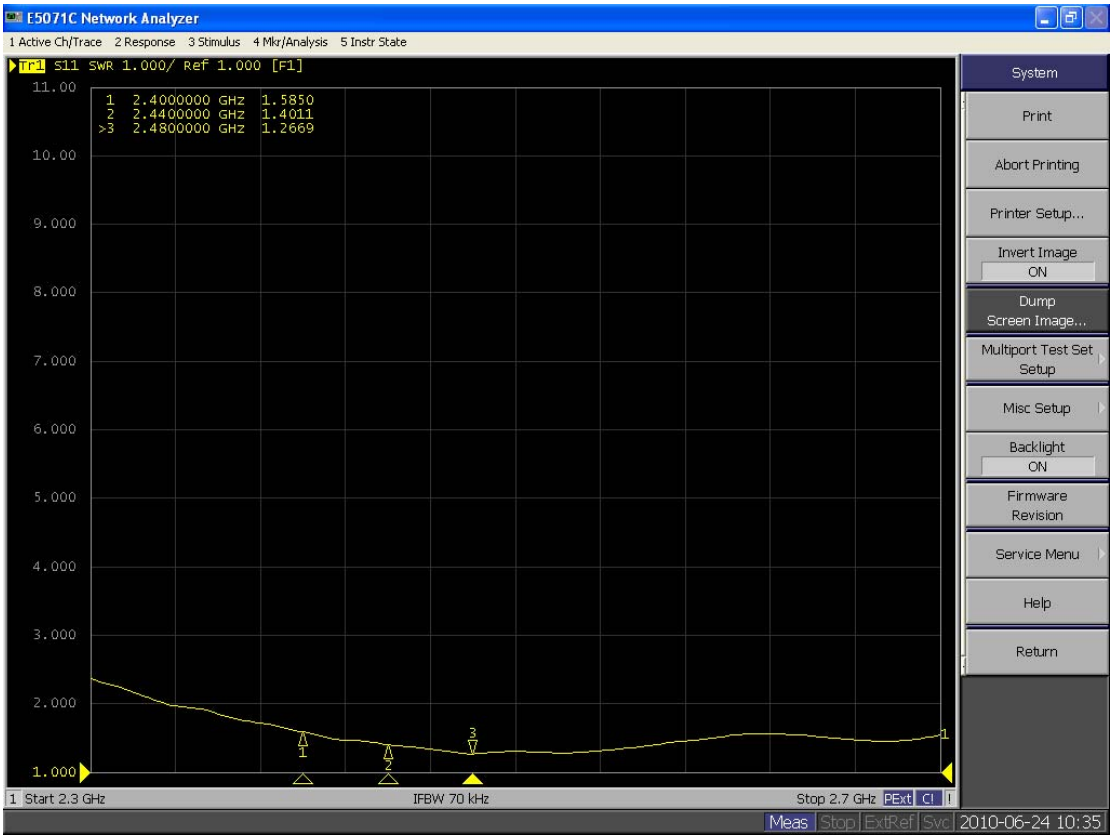

Figure 16: 2400 MHz to 2480 MHz Bandwidth Measurement

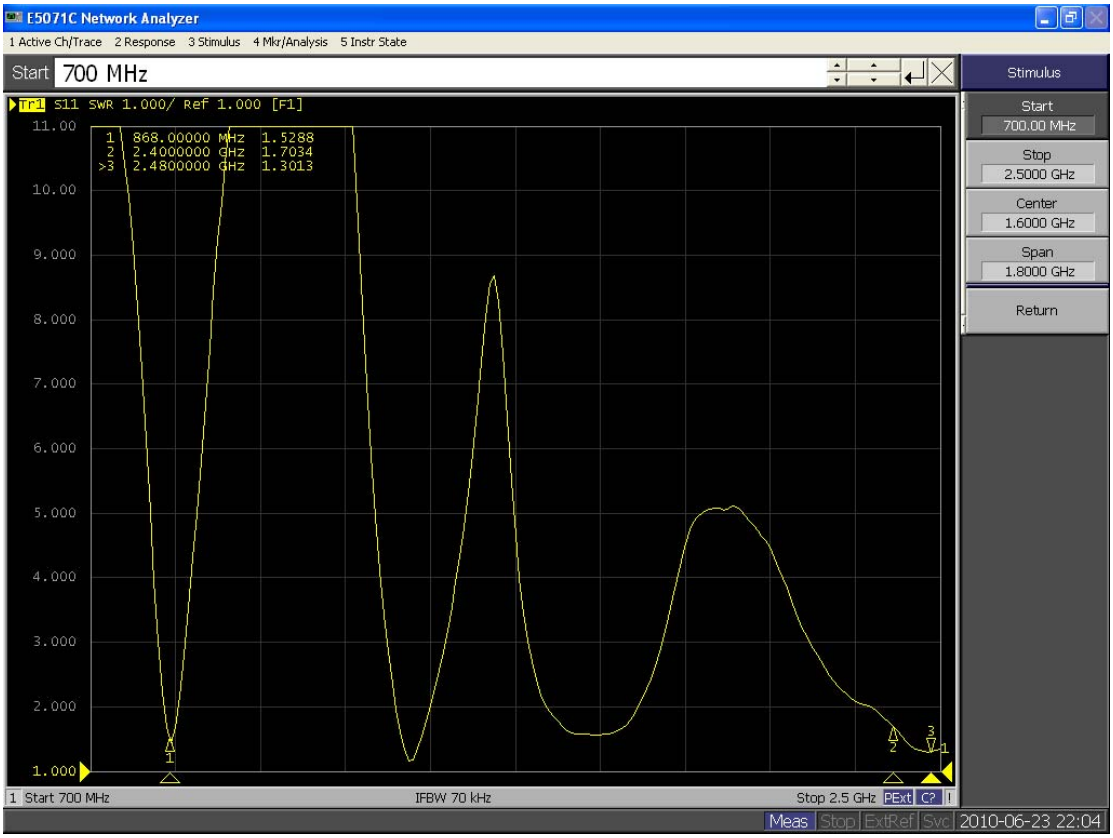

Figure 17: 700 MHz to 2500 MHz Wideband Measurement

3.1.7 Board #7: Inverted F-Antenna – 2440 MHz

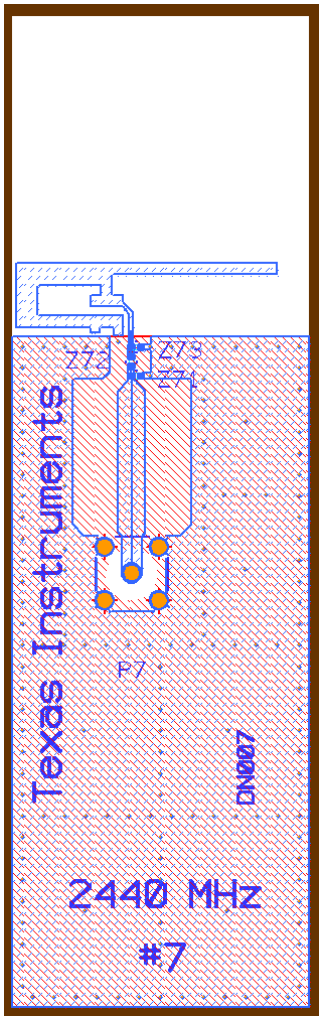

Figure 18: Board #7: Inverted F-Antenna – 2440 MHz

Size	Width (mm)	Height (mm)
PCB Board	30	95
GND	28	63

BOM	Ref. Designator	Koa Part Number	Value
	Z71	NC	-
	Z72	RK73Z1ETTP	0 ohm
	Z73	NC	-

Table 7: PCB Size and BOM for Board #7: Inverted F-Antenna – 2440 MHz

Pros: Excellent BW and excellent TRP efficiency.

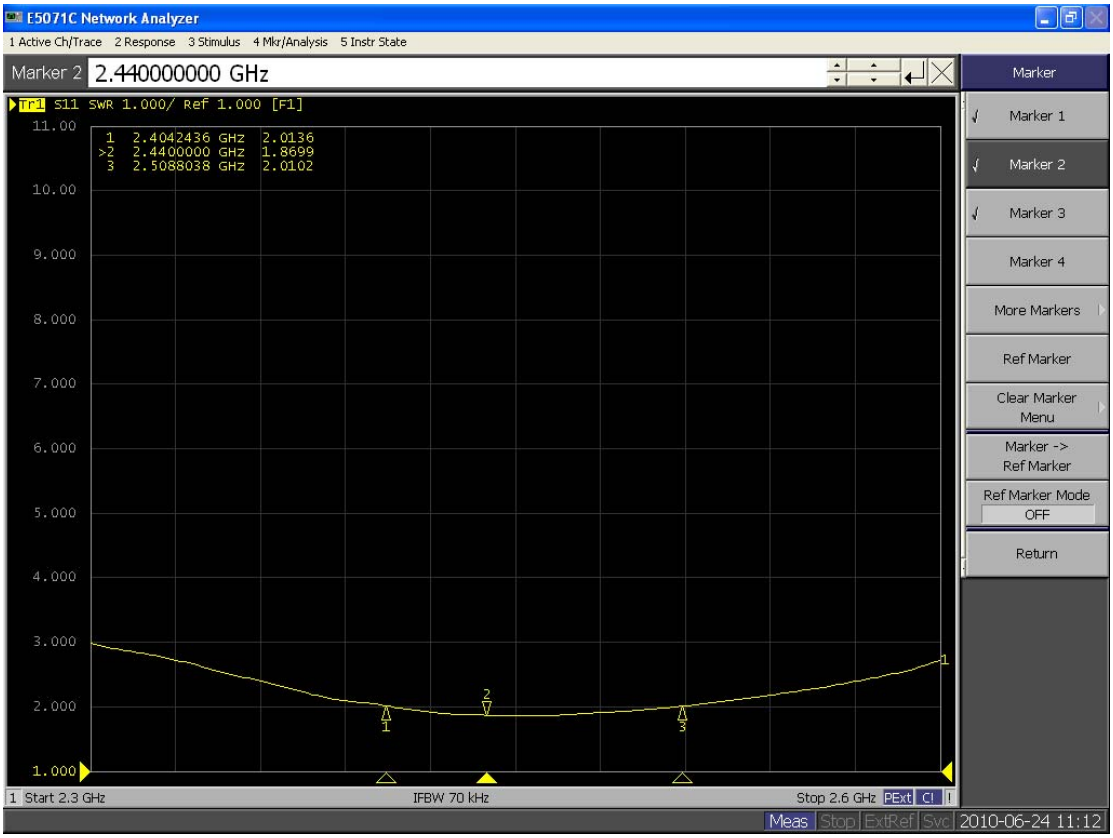

Figure 19: SWR Measurement at 2400 MHz, 2440 MHz & 2480 MHz

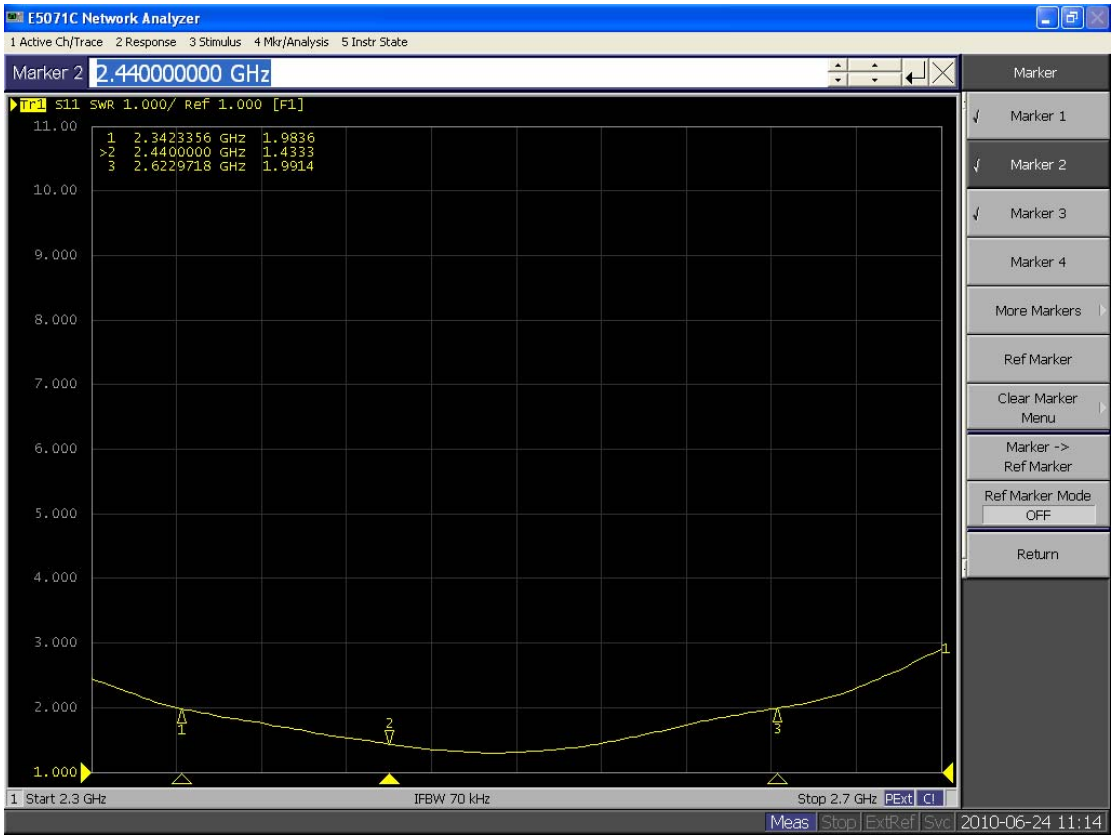

Figure 20: 280 MHz Bandwidth Measurement (stand alone, 2440 MHz) @ SWR of 2.0

3.1.8 Board #8: Pulse Helical Wire Antenna – 433 MHz

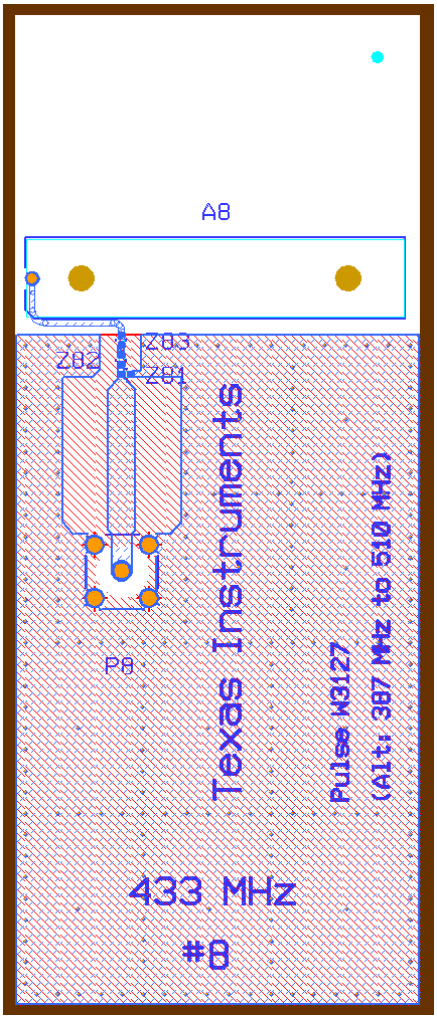

Figure 21: Board #8: Pulse Helical Wire Antenna – 433 MHz

Size	Width (mm)	Height (mm)
PCB Board	40	95
GND	38	63

BOM	Ref. Designator	Part Number	Value
	A8	PULSE W3127	-
	Z81	Murata GRM1555C1H7R5CZ01D	7.5 pF
	Z82	Murata LQG15HS22NJ02D	22 nH
	Z83	KOA RK73Z1ETTP	0 ohm

Table 8: PCB Size and BOM for Board #8: Pulse Helical Wire Antenna – 433 MHz

Pros: Compact design at 433 MHz. TRP efficiency can be improved if antenna is moved further away from GND plane edge. Good robust mechanical design compared to wire antenna.

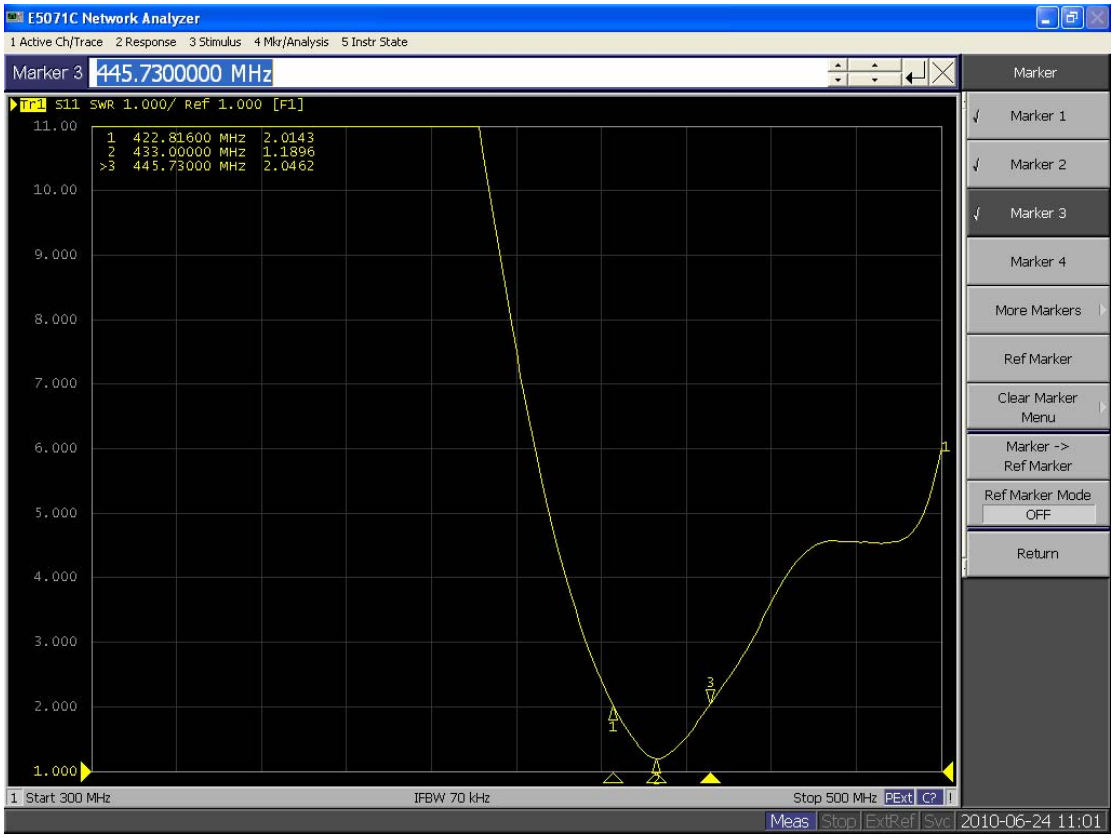

Figure 22: 23 MHz Bandwidth Measurement (433 MHz) of @ SWR of 2.0

3.1.9 Board #9: "Open" Calibration Board

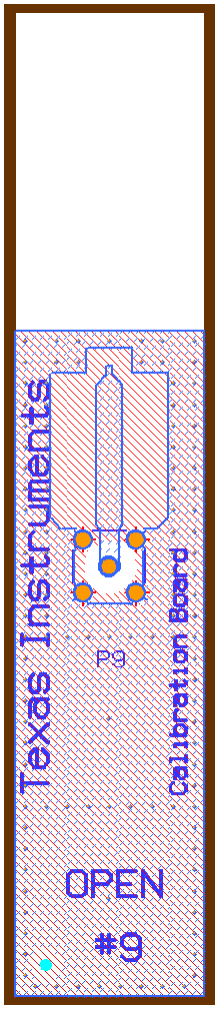

Figure 23: Board #9 – "Open" Calibration Board

Size	Width (mm)	Height (mm)
PCB Board	20	95
GND	18	63

BOM	Ref. Designator	Part Number	Value
	-	-	-

Table 9: PCB Size and BOM for Board #9 – "Open" Calibration Board

Three boards have been provided for calibration purposes; OPEN (3.1.9), SHORT (3.1.1), and 50 ohm LOAD (3.1.2). These boards are mainly used when working with a network analyzer.

3.1.10 Board #10: Small Flexi Antenna – 868 MHz

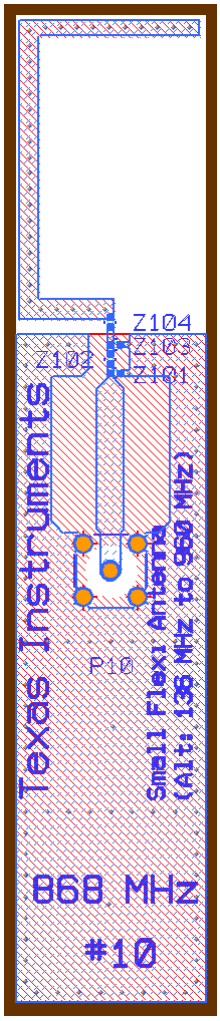

Figure 24: Board #10: Small Flexi Antenna – 868 MHz

Size	Width (mm)	Height (mm)
PCB Board	20	95
GND	18	63

BOM	Ref. Designator	Part Number	Value
	Z101	Murata LQG15HS10NJ02D	10 nH
	Z102	Murata LQG15HS12NJ02D	12 nH
	Z103	NC	-
	Z104	KOA RK73Z1ETTP	0 ohm

Table 10: PCB Size and BOM for Board #10: Small Flexi Antenna – 868 MHz

Pros: No simulations required providing that a network analyzer is available for tuning of the antenna via the match network. Good BW performance and good TRP efficiency.

Cons: Usage of discrete components in antenna matching is compulsory.

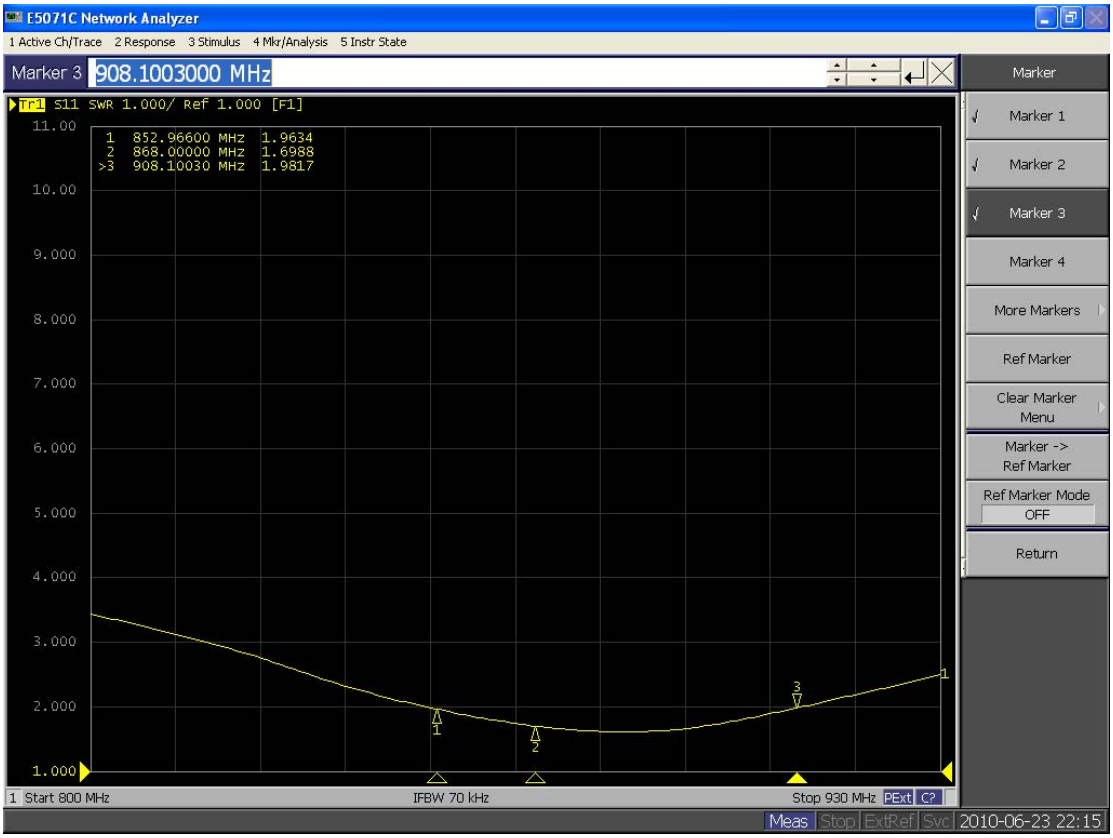

Figure 25: 56 MHz Bandwidth Measurement (868 MHz) @ SWR of 2.0

This type of antenna basically shows that for a given available area a trace length which is shorter than a quarter wave length of the desired frequency can be matched by adding inductance to the antenna feed point.

This antenna has not been simulated, yet the TRP results are good and equal the other antennas performances at this frequency. Board 5 (3.1.5) is similar concept but for a larger board size.

3.1.11 Board #11: Helical Wire Antenna – 915 MHz

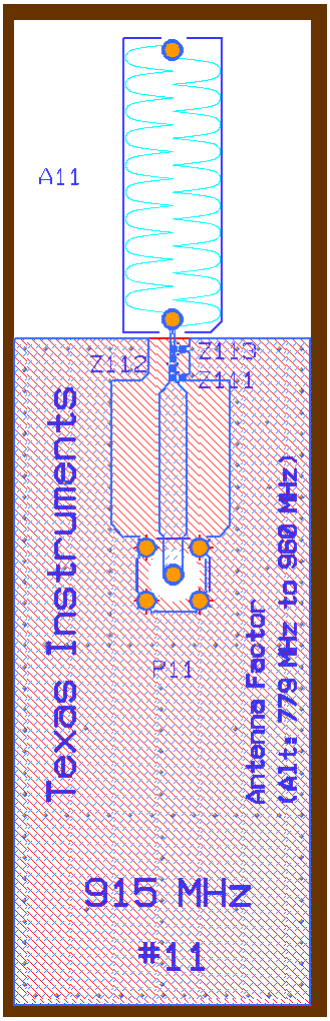

Figure 26: Board #11: Helical Wire Antenna – 915 MHz

Size	Width (mm)	Height (mm)
PCB Board	30	95
GND	28	63

BOM	Ref. Designator	Part Number	Value
	A11	ANTENNA FACTOR ANT-916-HETH	-
	Z111	NC	-
	Z112	Murata LQG15HS18NJ02D	18 nH
	Z113	Murata LQG15HS27NJ02D	27 nH

Table 11: PCB Size and BOM for Board #11: Helical Wire Antenna – 915 MHz

Pros: Good TRP efficiency, compact design and strong mechanical design.

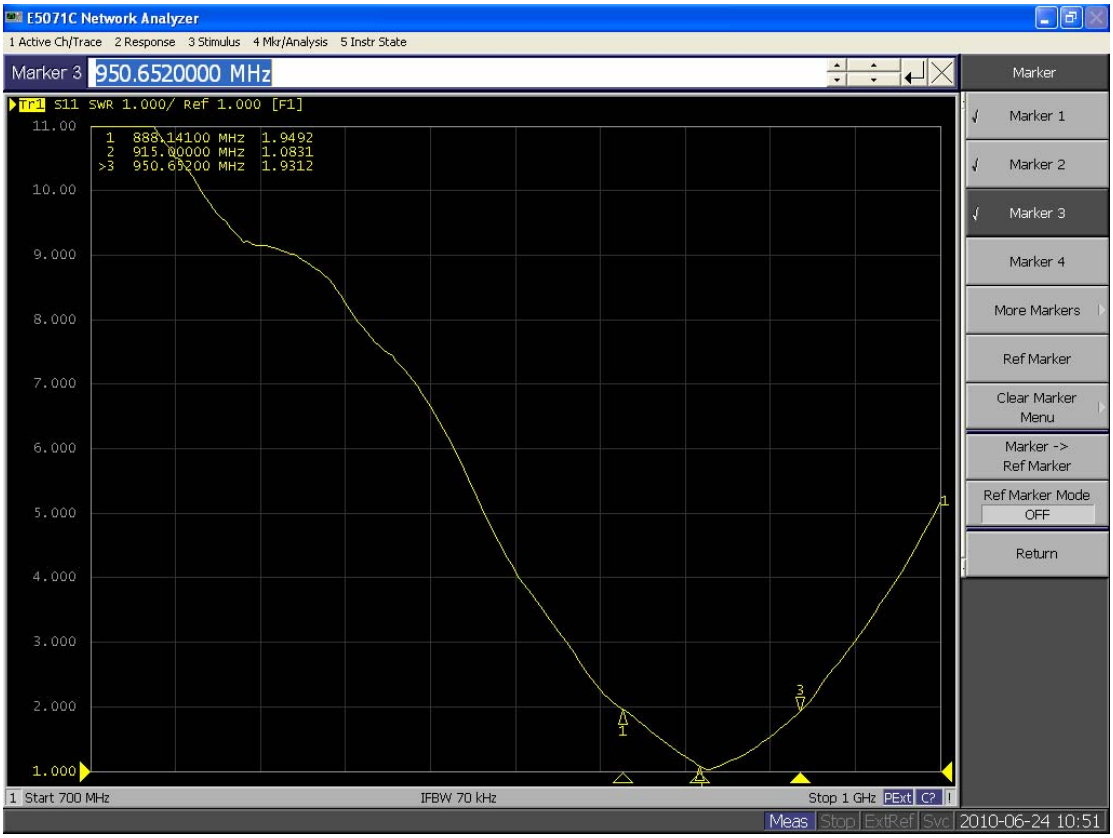

Figure 27: 62 MHz Bandwidth Measurement (915 MHz) @ SWR of 2.0

3.1.12 Board #12: Mitsubishi Chip Antenna – 433 MHz

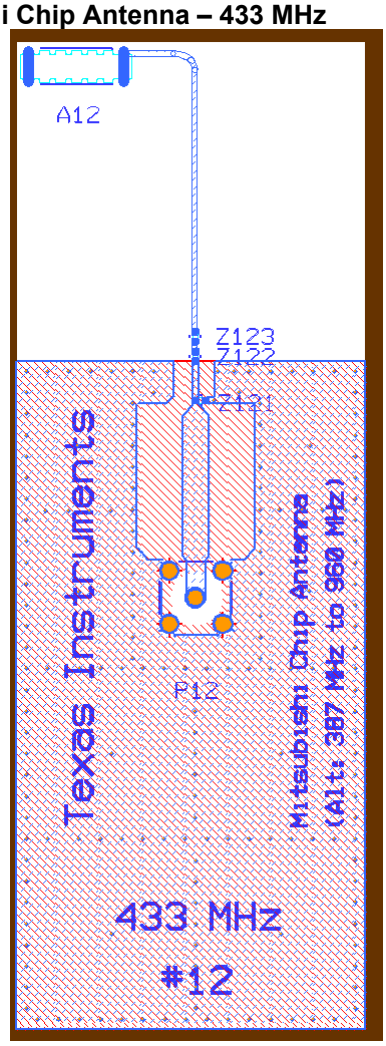

Figure 28: Board #12: Mitsubishi Chip Antenna – 433 MHz

Size	Width (mm)	Height (mm)
PCB Board	35	95
GND	33	63

BOM	Ref. Designator	Murata Part Number	Value
	A12	MITSUBISHI AMD1103-ST01T	-
	Z121	NC	-
	Z122	Murata LQG15HS68NJ02	68 nH
	Z123	Murata LQG15HS39NJ02D	39 nH

Table 12: PCB Size and BOM for Board #12: Mitsubishi Chip Antenna – 433 MHz

Pros: Good BW and easy to match.

Cons: Generally, it is difficult to achieve high TRP efficiencies with a chip antenna at 433 MHz.

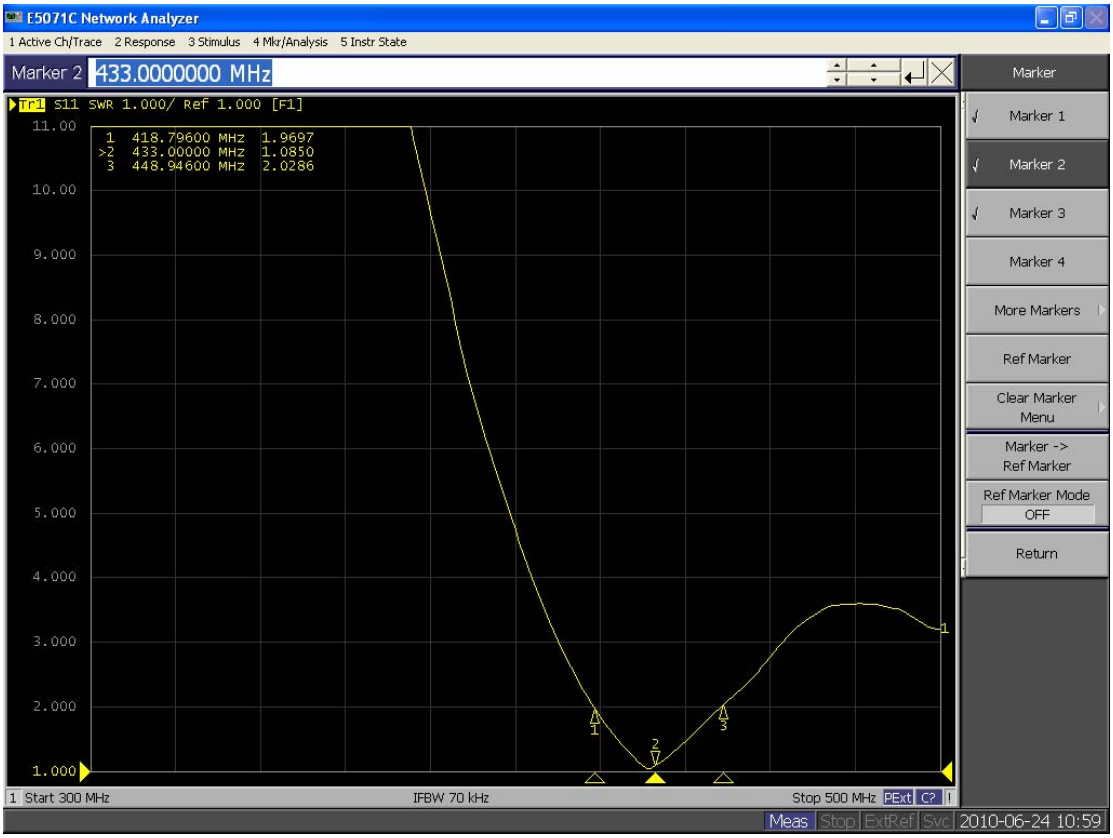

Figure 29: 30 MHz Bandwidth Measurement (433 MHz) @ SWR of 2.0

3.1.13 Board #13: Antenna Factor Helical Wire Antenna – 433 MHz

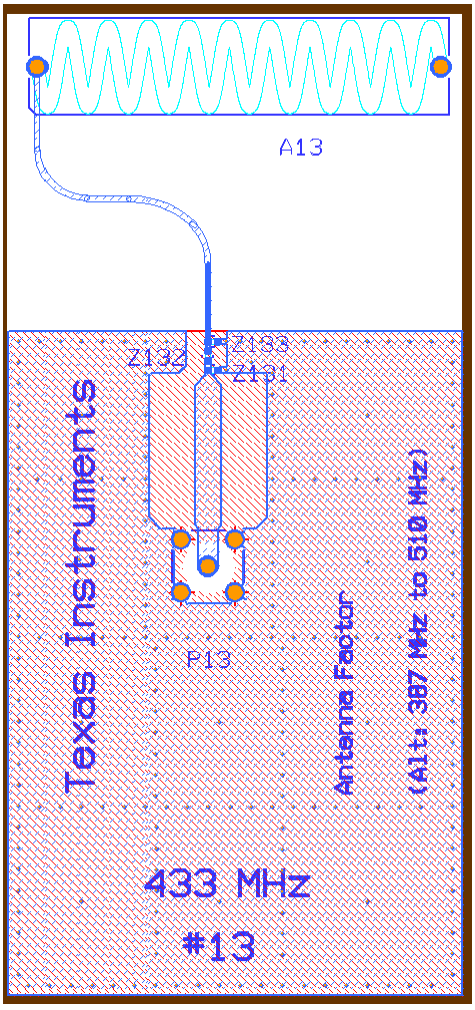

Figure 30: Board #13: Antenna Factor Helical Wire Antenna – 433 MHz

Size	Width (mm)	Height (mm)
PCB Board	45	95
GND	43	63

BOM	Ref. Designator	Part Number	Value
	A13	ANTENNA FACTOR ANT-433-HETH	-
	Z131	NC	-
	Z132	Murata LQG15HS27NJ02D	27 nH
	Z133	Murata GRM1555C1H5R6CZ01D	5.6 pF

Table 13: PCB Size and BOM for Board #13: Antenna Factor Helical Wire Antenna – 433 MHz

Pros: Good TRP efficiency, compact design and strong mechanical design.

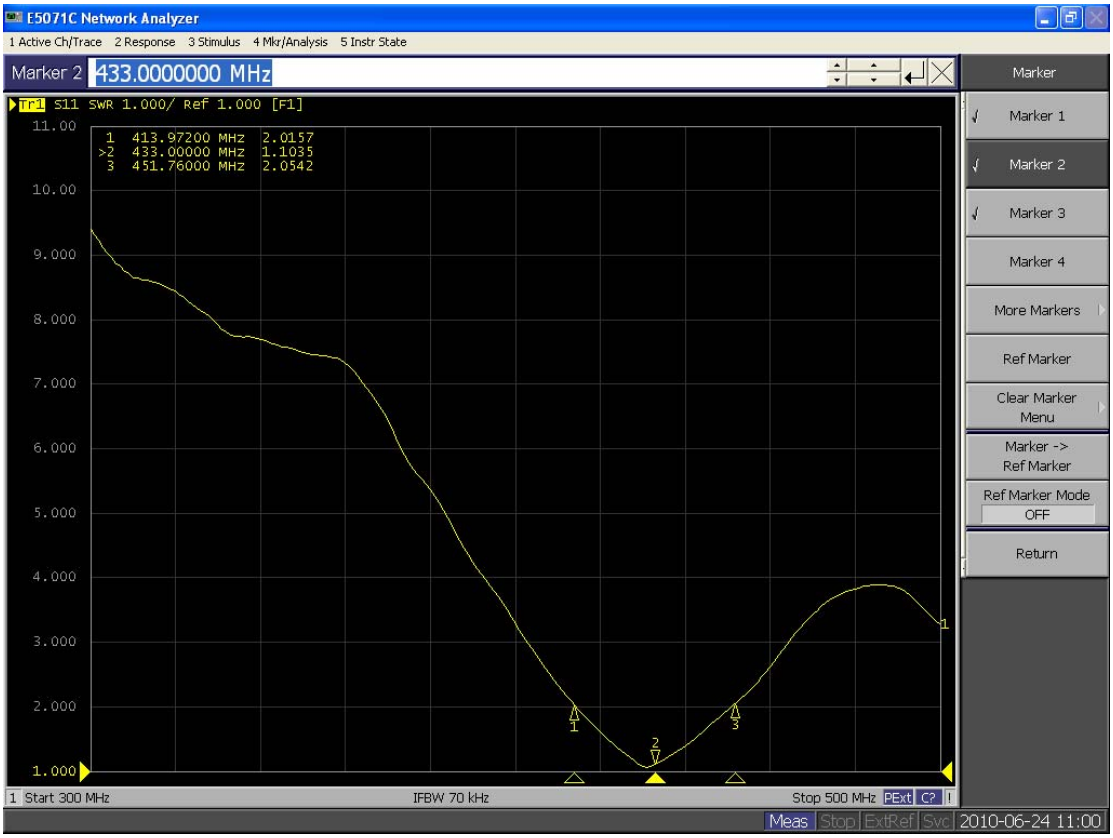

Figure 31: 38 MHz Bandwidth Measurement (433 MHz) @ SWR of 2.0

3.1.14 Board #14: Antenna Factor Helical Wire Antenna – 169 MHz

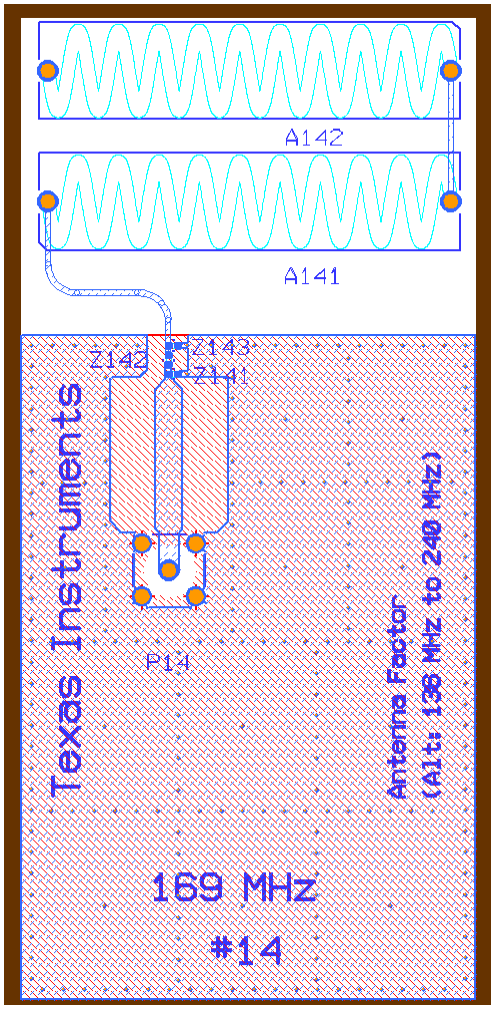

Figure 32: Board #14: Antenna Factor Helical Wire Antenna – 169 MHz

Size	Width (mm)	Height (mm)
PCB Board	45	95
GND	43	63

BOM	Ref. Designator	Part Number	Value
	A141	ANTENNA FACTOR ANT-315-HETH	-
	A142	ANTENNA FACTOR ANT-315-HETH	-
	Z141	NC	-
	Z142	Murata LQG15HS47NJ02D	47 nH
	Z143	Murata LQG15HSR10J02	100 nH

Table 14: PCB Size and BOM for Board #14: Antenna Factor Helical Wire Antenna – 169 MHz

Pros: Compact antenna design for 169 MHz.

Cons: Small BW and low TRP efficiency due to the physical size of the antenna.

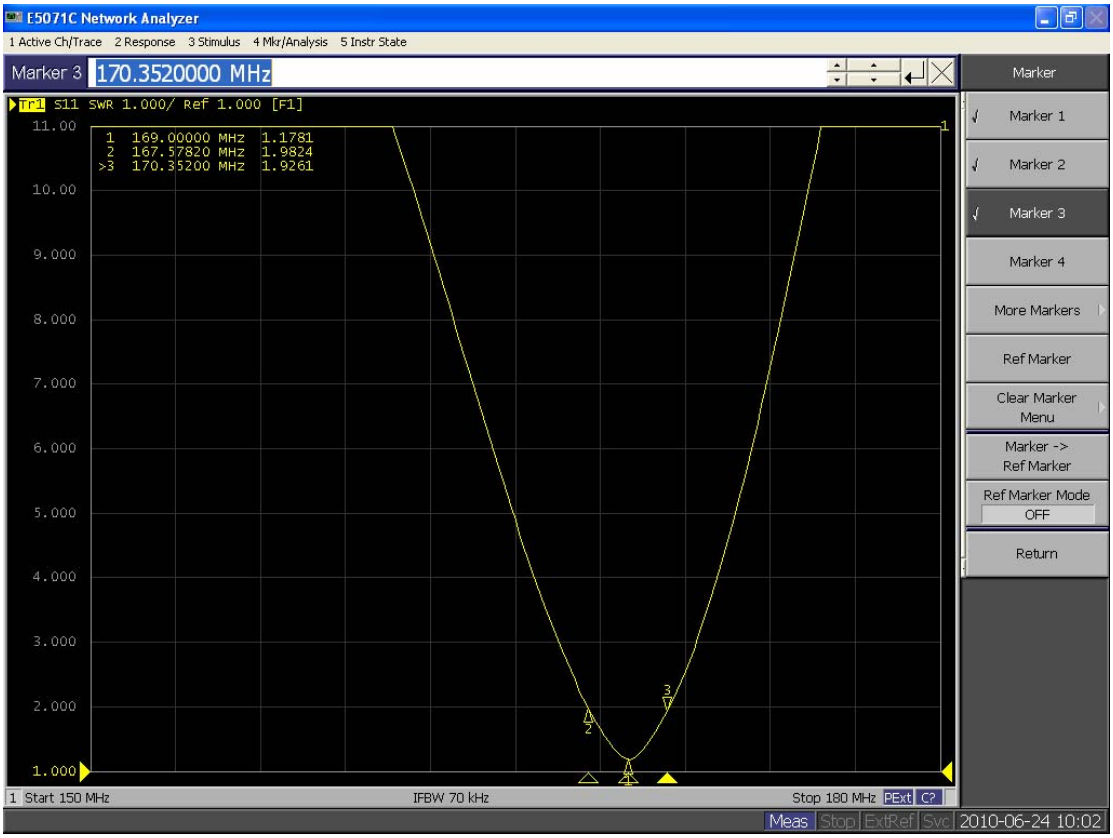

Figure 33: 3 MHz Bandwidth Measurement (169 MHz) @ SWR of 2.0

3.1.15 Board #15: Meandered Antenna – 2440 MHz

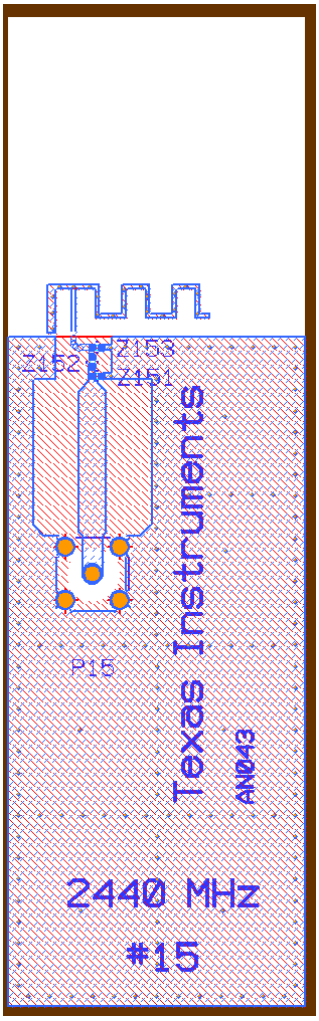

Figure 34: Board #15: Meandered Antenna – 2440 MHz

Size	Width (mm)	Height (mm)
PCB Board	30	95
GND	28	63

BOM	Ref. Designator	Part Number	Value
	Z151	NC	-
	Z152	KOA RK73Z1ETTP	0 ohm
	Z153	Murata GRM1555C1H1R2CZ01D	1.2 pF

Table 15: PCB Size and BOM for Board #15: Meandered Antenna – 2440 MHz

Pros: Compact antenna design at 2.44 GHz with satisfactorily BW.

Cons: Difficult to match and if board size is available it is better to use board 7 (13.1.7) instead.

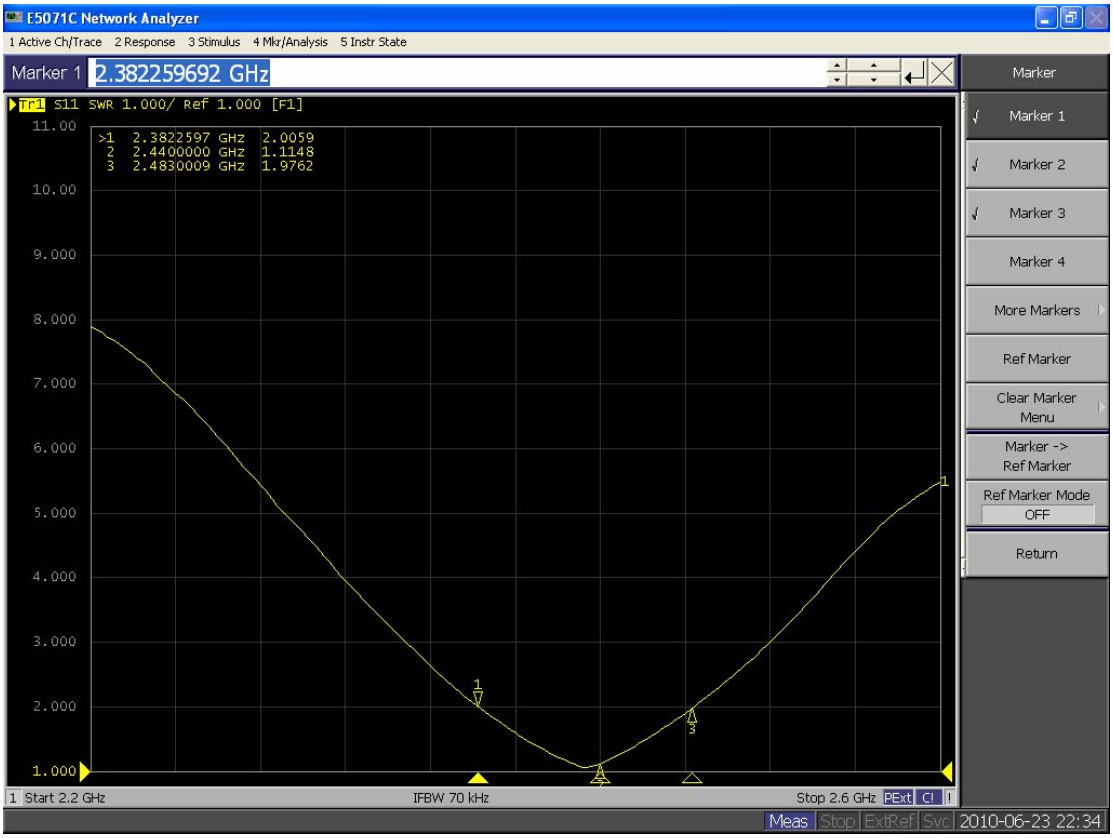

Figure 35: 101 MHz Bandwidth Measurement (2440 MHz) @ SWR of 2.0

3.1.16 Board #16: Pulse Helical Wire Antenna – 315 MHz

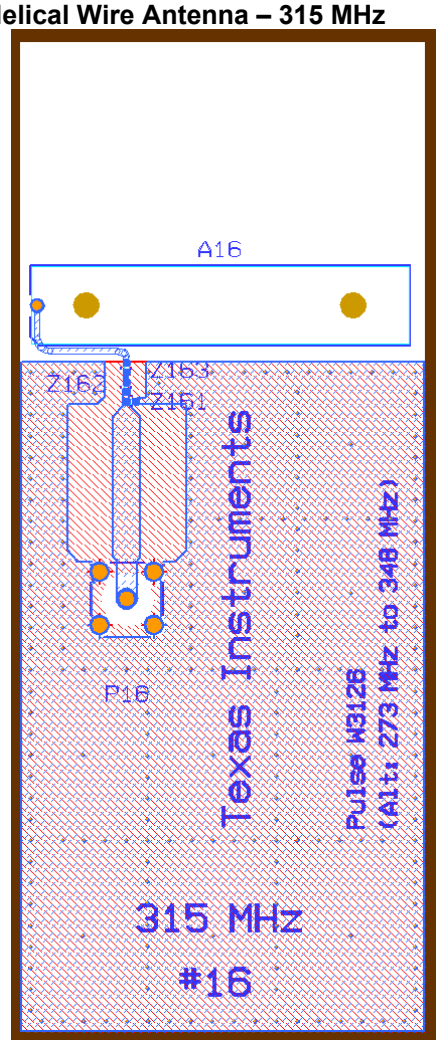

Figure 36: Board #16: Pulse Helical Wire Antenna – 315 MHz

Size	Width (mm)	Height (mm)
PCB Board	40	95
GND	38	63

BOM	Ref. Designator	Part Number	Value
	A16	PULSE W3126	-
	Z161	Murata GRM1555C1H220JZ01D	22 pF
	Z162	Murata LQG15HS22NJ02D	22 nH
	Z163	Murata LQG15HS4N7S02D	4.7 nH

Table 16: PCB Size and BOM for Board #16: Pulse Helical Wire Antenna – 315 MHz

Pros: Compact antenna design for 315 MHz and mechanically robust design.

Cons: BW.

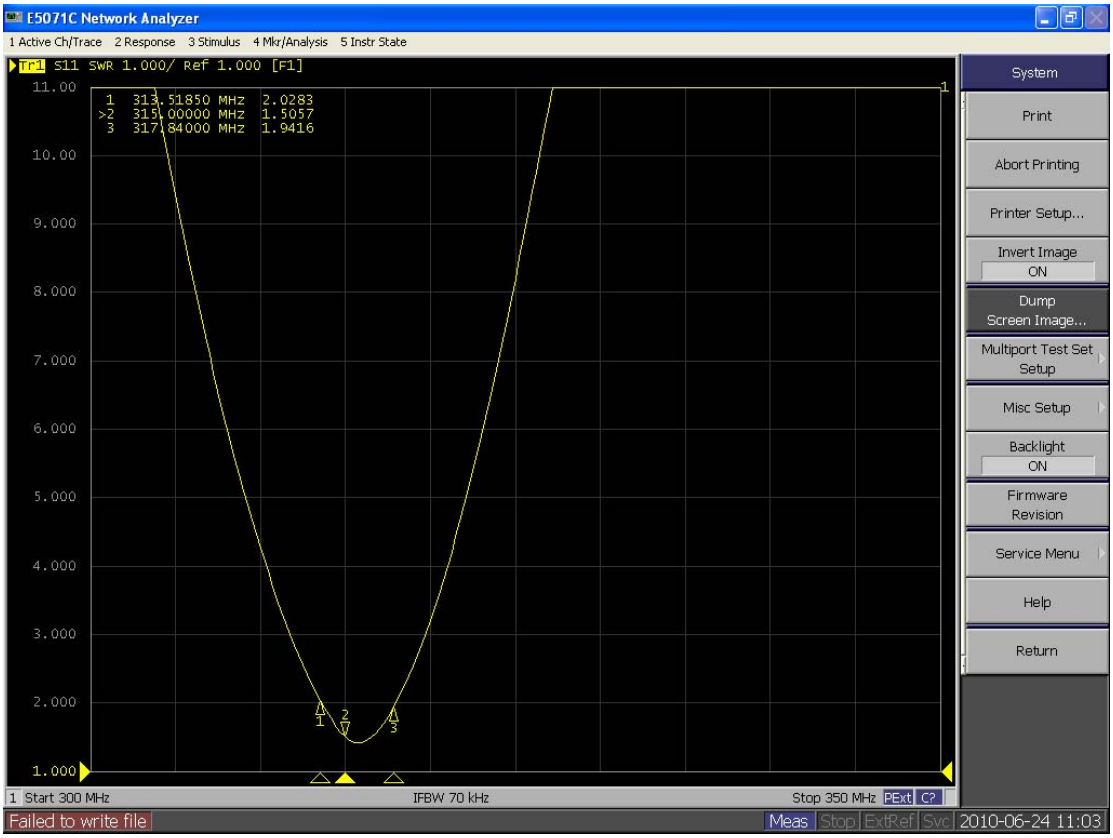

Figure 37: 4 MHz Bandwidth Measurement (315 MHz) @ SWR of 2.0

4 Antenna Measurement Summary

4.1 Over-The-Air (OTA) Testing

OTA testing provides a more accurate testing for wireless devices in order to be able to determine the antenna characteristics of the final product. Traditionally, the antenna radiation patterns were stated as horizontal and vertical polarizations in XY, XZ & YZ planes. This information is still useful, but for the majority of wireless devices, the polarization and positioning is usually unknown and makes comparing antennas difficult.

The testing is performed in an anechoic chamber and the transmitted power is recorded in a dual polarized antenna. The DUT is fixed onto the turn arm which is on the turn table. The turn table rotates from 0 to 180 degrees and the turn arm is rotated 360 degrees so a 3D radiation diagram can illustrate the spatial distributions.

The hardware part of the test system is based on the R&S TS8991 and the software is EMC32. Within the EMC32 program, a standard CTIA OTA report is generated from the test suite that is performed and the main results obtained are:

- Total Radiated Power, TRP (dBm)
- Peak EIRP (dBm)
- Directivity (dBi)
- Efficiency (%)
- Gain (dBi)
- NHPRP

Total Radiated Power (TRP) is calculated by integrating the power measured for the complete rotation of the DUT.

Peak Effective Isotropic Radiated Power (EIRP) is the maximum value that is measured.

Directivity is the difference from the Peak EIRP and TRP.

Efficiency is the difference between the TRP and the input power delivered to the DUT. This data is presented in both dB and in percentage.

Gain is the sum of Efficiency and Directivity.

NHPRP is the Near Horizon Partial Radiated Power that is specified for 45 degrees (NHPRP45), 30 degrees (NHPRP30) and 22.5 degrees (NHPRP22.5).

4.1.1 XYZ Co-ordinates for Antenna Diagrams

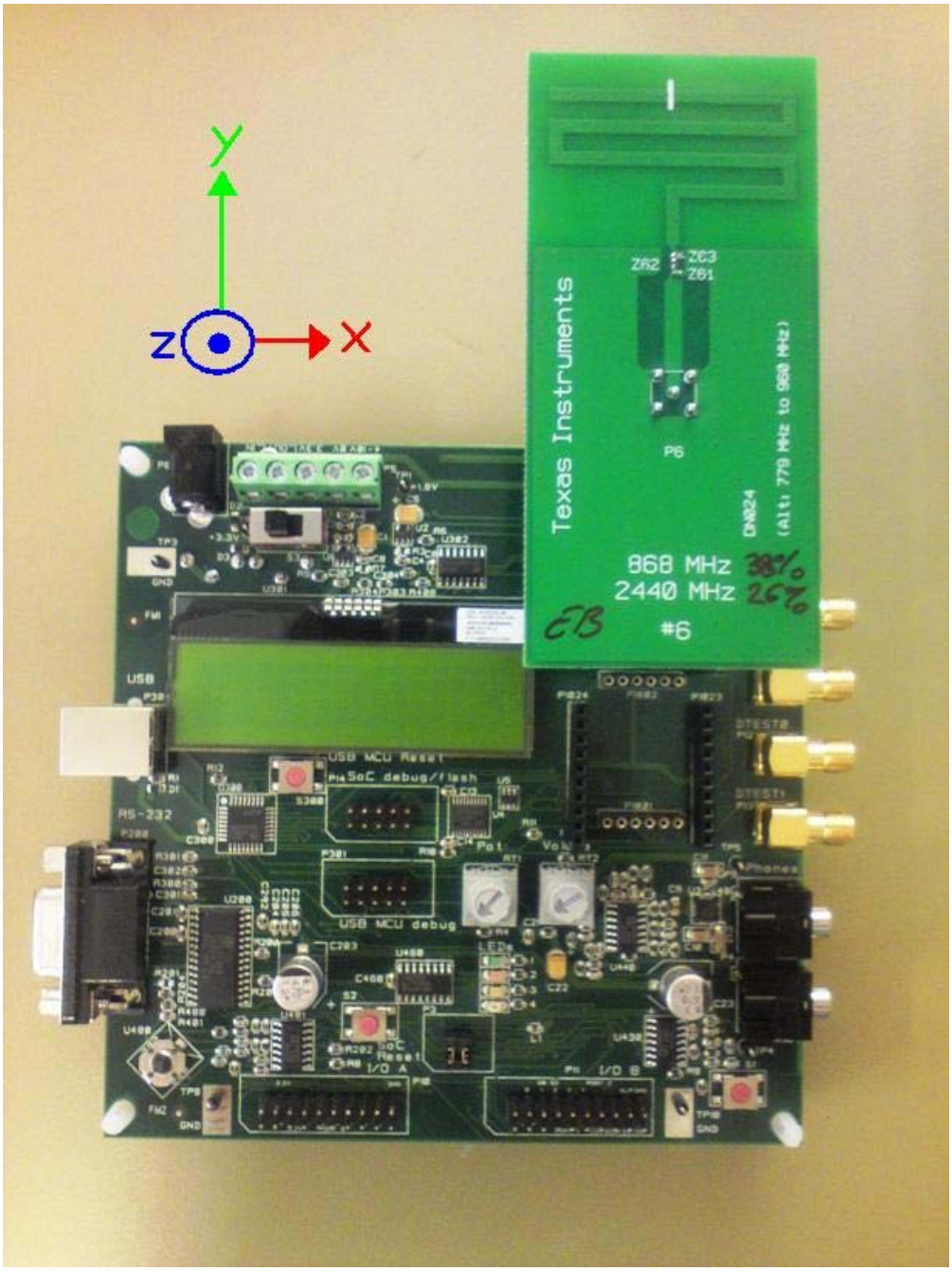

Figure 38: Antenna Board XYZ Coordinate Orientation

Figure 38 illustrates the XYZ coordinates for all the measurements performed in the antenna chamber. Board number 6 is shown in Figure 38. The antenna board is switched between the various antennas on the CC-Antenna-DK but positioning is kept in the same position.

4.2 169 MHz Band

These antennas can be used in the frequency band of 136 MHz – 240 MHz. 169 MHz was chosen so the characteristics of the antenna can be compared.

4.2.1 PCB Antennas (169 MHz)

Not recommended due to physical size

4.2.2 Chip Antennas (169 MHz)

Not recommended due to poor performance for compact designs.

4.2.3 Wire Antennas (169 MHz)

	Board 14 (3.1.14) (169 MHz)
Full CTIA Report	DN610
Test Description	**Test Result**
Total Radiated Power	-11.62 dBm
Peak EIRP	-8.91 dBm
Directivity	2.71 dBi
Efficiency	-11.62 dB
Efficiency	6.89 %
Gain	-8.91 dBi
NHPRP 45°	-12.68 dBm
NHPRP 45° / TRP	-1.07 dB
NHPRP 45° / TRP	78.25 %
NHPRP 30°	-14.10 dBm
NHPRP 30° / TRP	-2.48 dB
NHPRP 30° / TRP	56.50 %
NHPRP 22.5°	-15.29 dBm
NHPRP 22.5° / TRP	-3.67 dB
NHPRP 22.5° / TRP	42.92 %
UHRP	-14.62 dBm
UHRP / TRP	-3.01 dB
UHRP / TRP	50.05 %
LHRP	-14.63 dBm
LHRP / TRP	-3.01 dB
LHRP / TRP	49.95 %
Front/Back Ratio	2.52
PhiBW	177.9 deg
PhiBW Up	95.0 deg
PhiBW Down	82.9 deg
ThetaBW	125.8 deg
ThetaBW Up	83.7 deg
ThetaBW Down	42.1 deg
Boresight Phi	315 deg
Boresight Theta	45 deg
Maximum Power	-8.91 dBm
Minimum Power	-31.21 dBm
Average Power	-12.43 dBm
Max/Min Ratio	22.30 dB
Max/Avg Ratio	3.52 dB
Min/Avg Ratio	-18.78 dB
Best Single Value	-11.12 dBm
Best Position	Phi = 285 deg; Theta = 45 deg; Pol = Hor

Table 17: 169 MHz Wire Antennas

4.3 Antenna Efficiency Summary (169 MHz)

Ranking	Description	TRP Efficiency [%]
1	Board 14 (3.1.14)	6.89 %

Table 18: TRP (169 MHz)

4.4 315 MHz Band

These antennas can be used in the frequency band of 273 MHz – 348 MHz. 315 MHz was chosen so the characteristics of the antenna can be compared.

4.4.1 PCB Antennas (315 MHz)

Not recommended due to physical size.

4.4.2 Chip Antennas (315 MHz)

Not recommended due to poor performance for compact designs.

4.4.3 Wire Antennas (315 MHz)

	Board 16 (3.1.16) (315 MHz)
Full CTIA Report	DN612
Test Description	**Test Result**
Total Radiated Power	-8.28 dBm
Peak EIRP	-5.21 dBm
Directivity	3.07 dBi
Efficiency	-8.28 dB
Efficiency	14.85 %
Gain	-5.21 dBi
NHPRP 45°	-9.76 dBm
NHPRP 45° / TRP	-1.48 dB
NHPRP 45° / TRP	71.18 %
NHPRP 30°	-10.96 dBm
NHPRP 30° / TRP	-2.68 dB
NHPRP 30° / TRP	54.00 %
NHPRP 22.5°	-12.01 dBm
NHPRP 22.5° / TRP	-3.73 dB
NHPRP 22.5° / TRP	42.35 %
UHRP	-11.20 dBm
UHRP / TRP	-2.91 dB
UHRP / TRP	51.12 %
LHRP	-11.39 dBm
LHRP / TRP	-3.11 dB
LHRP / TRP	48.88 %
Front/Back Ratio	3.98
PhiBW	206.1 deg
PhiBW Up	98.8 deg
PhiBW Down	107.4 deg
ThetaBW	77.9 deg
ThetaBW Up	47.4 deg
ThetaBW Down	30.5 deg
Boresight Phi	210 deg
Boresight Theta	150 deg
Maximum Power	-5.21 dBm
Minimum Power	-25.71 dBm
Average Power	-8.15 dBm
Max/Min Ratio	20.50 dB
Max/Avg Ratio	2.94 dB
Min/Avg Ratio	-17.56 dB
Best Single Value	-5.92 dBm
Best Position	Phi = 225 deg; Theta = 150 deg; Pol = Ver

Table 19: 315 MHz Wire Antennas

4.5 Antenna Efficiency Summary (315 MHz)

Ranking	Description	TRP Efficiency [%]
1	Board 16 (3.1.16)	14.85 %

Table 20: TRP (315 MHz)

4.6 433 MHz Band

These antennas can be used in the frequency band of 387 MHz – 510 MHz. 433MHz was chosen so the characteristics of the antenna can be compared.

4.6.1 PCB Antennas (433 MHz)

Not recommended due to physical size but using concepts such as the stub antenna design (Board #5: Large Flexi Antenna – 868 MHz and Board #10: Small Flexi Antenna – 868 MHz) good performances can be achievable in a small size.

4.6.2 Chip Antennas (433 MHz)

Not strongly recommended due to poorer performance for compact designs.

	Board 12 (3.1.12) (433 MHz)
Full CTIA Report	DN608
Test Description	**Test Result**
Total Radiated Power	-8.34 dBm
Peak EIRP	-3.48 dBm
Directivity	4.86 dBi
Efficiency	-8.34 dB
Efficiency	14.67 %
Gain	-3.48 dBi
NHPRP 45°	-10.42 dBm
NHPRP 45° / TRP	-2.08 dB
NHPRP 45° / TRP	61.97 %
NHPRP 30°	-12.32 dBm
NHPRP 30° / TRP	-3.98 dB
NHPRP 30° / TRP	39.99 %
NHPRP 22.5°	-13.60 dBm
NHPRP 22.5° / TRP	-5.26 dB
NHPRP 22.5° / TRP	29.78 %
UHRP	-11.34 dBm
UHRP / TRP	-3.00 dB
UHRP / TRP	50.10 %
LHRP	-11.36 dBm
LHRP / TRP	-3.02 dB
LHRP / TRP	49.90 %
Front/Back Ratio	5.57
PhiBW	230.4 deg
PhiBW Up	81.6 deg
PhiBW Down	148.8 deg
ThetaBW	50.5 deg
ThetaBW Up	29.7 deg
ThetaBW Down	20.8 deg
Boresight Phi	345 deg
Boresight Theta	150 deg
Maximum Power	-3.48 dBm
Minimum Power	-26.89 dBm
Average Power	-7.75 dBm
Max/Min Ratio	23.41 dB
Max/Avg Ratio	4.27 dB
Min/Avg Ratio	-19.14 dB
Best Single Value	-4.25 dBm
Best Position	Phi = 300 deg; Theta = 150 deg; Pol = Hor

Table 21: 433 MHz Ceramic Chip Antennas

4.6.3 Wire Antennas (433 MHz)

	Board 8 (3.1.8) (433 MHz)	Board 13 (3.1.13) (433 MHz)
Full CTIA Report	DN605	DN609
Test Description	**Test Result**	**Test Result**
Total Radiated Power	-7.07 dBm	-5.93 dBm
Peak EIRP	-2.51 dBm	-1.15 dBm
Directivity	4.56 dBi	4.78 dBi
Efficiency	-7.07 dB	-5.93 dB
Efficiency	19.62 %	25.53 %
Gain	-2.51 dBi	-1.15 dBi
NHPRP 45°	-9.04 dBm	-7.94 dBm
NHPRP 45° / TRP	-1.97 dB	-2.01 dB
NHPRP 45° / TRP	63.53 %	62.99 %
NHPRP 30°	-10.84 dBm	-9.79 dBm
NHPRP 30° / TRP	-3.77 dB	-3.86 dB
NHPRP 30° / TRP	41.99 %	41.13 %
NHPRP 22.5°	-12.09 dBm	-11.05 dBm
NHPRP 22.5° / TRP	-5.01 dB	-5.12 dB
NHPRP 22.5° / TRP	31.52 %	30.75 %
UHRP	-9.97 dBm	-8.93 dBm
UHRP / TRP	-2.89 dB	-3.00 dB
UHRP / TRP	51.37 %	50.17 %
LHRP	-10.20 dBm	-8.96 dBm
LHRP / TRP	-3.13 dB	-3.03 dB
LHRP / TRP	48.63 %	49.83 %
Front/Back Ratio	5.21	5.57
PhiBW	235.5 deg	227.9 deg
PhiBW Up	77.3 deg	98.7 deg
PhiBW Down	158.2 deg	129.2 deg
ThetaBW	63.5 deg	48.3 deg
ThetaBW Up	41.2 deg	27.8 deg
ThetaBW Down	22.4 deg	20.5 deg
Boresight Phi	360 deg	330 deg
Boresight Theta	150 deg	150 deg
Maximum Power	-2.51 dBm	-1.15 dBm
Minimum Power	-25.91 dBm	-23.39 dBm
Average Power	-6.57 dBm	-5.42 dBm
Max/Min Ratio	23.40 dB	22.24 dB
Max/Avg Ratio	4.06 dB	4.27 dB
Min/Avg Ratio	-19.34 dB	-17.97 dB
Best Single Value	-3.15 dBm	-1.70 dBm
Best Position	Phi = 315 deg; Theta = 150 deg; Pol = Hor	Phi = 315 deg; Theta = 150 deg; Pol = Hor

Table 22: 433 MHz Wire Antennas

4.7 Antenna Efficiency Summary (433 MHz)

Ranking	Description	TRP Efficiency [%]
1	Board 13 (3.1.13)	25.53 %
2	Board 8 (3.1.8)	19.62 %
3	Board 12 (3.1.12)	14.67 %

Table 23: TRP (433 MHz)

4.8 868 / 915 / 955 MHz Band

These antennas can be used in the frequency band of 779 MHz – 960 MHz. 868 MHz & 915 MHz were chosen so the characteristics of the antenna can be compared.

4.8.1 PCB Antennas (868 – 955 MHz)

	Board 5 (3.1.5) (868 MHz)	Board 6 (3.1.6) (868 MHz)	Board 6 (3.1.6) (868 MHz) Stand Alone	Board 10 (3.1.10) (868 MHz)	Board 10 (3.1.10) (915 MHz)
Full CTIA Report	DN602	DN603	DN616	DN606	DN606
Test Description	**Test Result**	**Test Result**	**Test Result**	**Test Result**	**Test Result**
Total Radiated Power	-1.95 dBm	-1.95 dBm	-0.43 dBm	-2.82 dBm	-1.98 dBm
Peak EIRP	3.46 dBm	3.61 dBm	5.16 dBm	1.38 dBm	2.87 dBm
Directivity	5.41 dBi	5.55 dBi	5.59 dBi	4.20 dBi	4.85 dBi
Efficiency	-1.95 dB	-1.95 dB	-0.43 dB	-2.82 dB	-1.98 dB
Efficiency	63.78 %	63.89 %	90.51 %	52.29 %	63.39 %
Gain	3.46 dBi	3.61 dBi	5.16 dBi	1.38 dBi	2.87 dBi
NHPRP 45°	-3.81 dBm	-3.85 dBm	-3.13 dBm	-4.63 dBm	-4.08 dBm
NHPRP 45° / TRP	-1.86 dB	-1.90 dB	-2.70 dB	-1.81 dB	-2.10 dB
NHPRP 45° / TRP	65.17 %	64.57 %	53.71 %	65.93 %	61.72 %
NHPRP 30°	-5.69 dBm	-5.73 dBm	-5.19 dBm	-6.28 dBm	-5.86 dBm
NHPRP 30° / TRP	-3.73 dB	-3.79 dB	-4.76 dB	-3.47 dB	-3.88 dB
NHPRP 30° / TRP	42.32 %	41.83 %	33.46 %	44.99 %	40.89 %
NHPRP 22.5°	-7.01 dBm	-7.03 dBm	-6.56 dBm	-7.52 dBm	-7.18 dBm
NHPRP 22.5° / TRP	-5.05 dB	-5.08 dB	-6.12 dB	-4.70 dB	-5.20 dB
NHPRP 22.5° / TRP	31.23 %	31.02 %	24.41 %	33.85 %	30.23 %
UHRP	-4.38 dBm	-4.21 dBm	-4.23 dBm	-5.48 dBm	-3.92 dBm
UHRP / TRP	-2.43 dB	-2.26 dB	-3.79 dB	-2.67 dB	-1.94 dB
UHRP / TRP	57.19 %	59.39 %	41.76 %	54.12 %	64.02 %
LHRP	-5.64 dBm	-5.86 dBm	-2.78 dBm	-6.20 dBm	-6.42 dBm
LHRP / TRP	-3.69 dB	-3.91 dB	-2.35 dB	-3.38 dB	-4.44 dB
LHRP / TRP	42.81 %	40.61 %	58.24 %	45.88 %	35.98 %
Front/Back Ratio	1.52	2.40	3.80	4.16	3.88
PhiBW	151.9 deg	157.9 deg	154.9 deg	234.9 deg	344.9 deg
PhiBW Up	43.3 deg	49.1 deg	88.8 deg	168.2 deg	102.4 deg
PhiBW Down	108.5 deg	108.8 deg	66.1 deg	66.8 deg	242.5 deg
ThetaBW	83.1 deg	90.5 deg	57.3 deg	52.4 deg	84.3 deg
ThetaBW Up	53.1 deg	60.5 deg	21.4 deg	52.4 deg	39.9 deg
ThetaBW Down	30.0 deg	30.0 deg	36.0 deg	0.0 deg	44.3 deg
Boresight Phi	330 deg	330 deg	120 deg	240 deg	240 deg
Boresight Theta	30 deg	30 deg	180 deg	0 deg	15 deg
Maximum Power	3.46 dBm	3.61 dBm	5.16 dBm	1.38 dBm	2.87 dBm
Minimum Power	-17.74 dBm	-15.71 dBm	-12.81 dBm	-7.43 dBm	-12.95 dBm
Average Power	-1.49 dBm	-1.40 dBm	0.60 dBm	-2.32 dBm	-1.08 dBm
Max/Min Ratio	21.20 dB	19.32 dB	17.97 dB	8.81 dB	15.81 dB
Max/Avg Ratio	4.94 dB	5.01 dB	4.56 dB	3.70 dB	3.95 dB
Min/Avg Ratio	-16.25 dB	-14.31 dB	-13.41 dB	-5.11 dB	-11.86 dB
Best Single Value	2.70 dBm	3.19 dBm	4.31 dBm	-0.12 dBm	2.07 dBm
Best Position	Phi = 345 deg; Theta = 45 deg; Pol = Ver	Phi = 345 deg; Theta = 45 deg; Pol = Ver	Phi = 100 deg; Theta = 180 deg; Pol = Hor	Phi = 285 deg; Theta = 30 deg; Pol = Hor	Phi = 285 deg; Theta = 15 deg; Pol = Hor

Table 24: 868 / 915 / 955 MHz PCB Antennas

4.8.2 Chip Antennas (868 – 955 MHz)

	Board 3 (3.1.3) (868 MHz)	Board 3 (3.1.3) (915 MHz)	Board 4 (3.1.4) (868 MHz)
Full CTIA Report	DN600	DN600	DN601
Test Description	**Test Result**	**Test Result**	**Test Result**
Total Radiated Power	-3.25 dBm	-3.20 dBm	-2.05 dBm
Peak EIRP	1.73 dBm	1.65 dBm	1.81 dBm
Directivity	4.98 dBi	4.85 dBi	3.86 dBi
Efficiency	-3.25 dB	-3.20 dB	-2.05 dB
Efficiency	47.34 %	47.81 %	62.39 %
Gain	1.73 dBi	1.65 dBi	1.81 dBi
NHPRP 45°	-5.10 dBm	-5.28 dBm	-3.84 dBm
NHPRP 45° / TRP	-1.86 dB	-2.07 dB	-1.80 dB
NHPRP 45° / TRP	65.23 %	62.05 %	66.14 %
NHPRP 30°	-6.89 dBm	-7.10 dBm	-5.54 dBm
NHPRP 30° / TRP	-3.64 dB	-3.90 dB	-3.49 dB
NHPRP 30° / TRP	43.27 %	40.76 %	44.74 %
NHPRP 22.5°	-8.14 dBm	-8.41 dBm	-6.82 dBm
NHPRP 22.5° / TRP	-4.89 dB	-5.21 dB	-4.77 dB
NHPRP 22.5° / TRP	32.42 %	30.15 %	33.37 %
UHRP	-5.58 dBm	-5.42 dBm	-4.80 dBm
UHRP / TRP	-2.34 dB	-2.21 dB	-2.75 dB
UHRP / TRP	58.38 %	60.07 %	53.06 %
LHRP	-7.05 dBm	-7.19 dBm	-5.33 dBm
LHRP / TRP	-3.81 dB	-3.99 dB	-3.28 dB
LHRP / TRP	41.62 %	39.93 %	46.94 %
Front/Back Ratio	3.47	4.53	1.72
PhiBW	154.5 deg	319.5 deg	86.8 deg
PhiBW Up	56.9 deg	225.7 deg	34.3 deg
PhiBW Down	97.5 deg	93.8 deg	52.5 deg
ThetaBW	79.4 deg	74.3 deg	120.0 deg
ThetaBW Up	49.4 deg	37.5 deg	60.0 deg
ThetaBW Down	30.0 deg	36.8 deg	60.0 deg
Boresight Phi	315 deg	240 deg	345 deg
Boresight Theta	30 deg	15 deg	60 deg
Maximum Power	1.73 dBm	1.65 dBm	1.81 dBm
Minimum Power	-10.56 dBm	-19.75 dBm	-10.38 dBm
Average Power	-2.71 dBm	-2.34 dBm	-1.60 dBm
Max/Min Ratio	12.28 dB	21.40 dB	12.19 dB
Max/Avg Ratio	4.44 dB	3.98 dB	3.41 dB
Min/Avg Ratio	-7.85 dB	-17.41 dB	-8.79 dB
Best Single Value	0.77 dBm	1.19 dBm	1.56 dBm
Best Position	Phi = 285 deg; Theta = 30 deg; Pol = Hor	Phi = 270 deg; Theta = 30 deg; Pol = Hor	Phi = 345 deg; Theta = 60 deg; Pol = Ver

Table 25: 868 / 915 / 955 MHz Chip Antennas

4.8.3 Wire Antennas (868 – 955 MHz)

	Board 11 (3.1.11) (915 MHz)	Nearson Whip Dipole (868 MHz)	Nearson Whip Dipole (915 MHz)
Full CTIA Report	DN607	DN613	DN613
Test Description	**Test Result**	**Test Result**	**Test Result**
Total Radiated Power	-1.64 dBm	-1.52 dBm	-0.50 dBm
Peak EIRP	3.52 dBm	1.42 dBm	2.71 dBm
Directivity	5.16 dBi	2.94 dBi	3.21 dBi
Efficiency	-1.64 dB	-1.52 dB	-0.50 dB
Efficiency	68.52 %	70.49 %	89.09 %
Gain	3.52 dBi	1.42 dBi	2.71 dBi
NHPRP 45°	-3.87 dBm	-2.34 dBm	-1.24 dBm
NHPRP 45° / TRP	-2.23 dB	-0.82 dB	-0.73 dB
NHPRP 45° / TRP	59.82 %	82.83 %	84.46 %
NHPRP 30°	-5.76 dBm	-3.39 dBm	-2.33 dBm
NHPRP 30° / TRP	-4.12 dB	-1.88 dB	-1.83 dB
NHPRP 30° / TRP	38.73 %	64.92 %	65.60 %
NHPRP 22.5°	-7.08 dBm	-4.47 dBm	-3.50 dBm
NHPRP 22.5° / TRP	-5.44 dB	-2.95 dB	-3.00 dB
NHPRP 22.5° / TRP	28.57 %	50.73 %	50.14 %
UHRP	-3.86 dBm	-4.22 dBm	-2.76 dBm
UHRP / TRP	-2.22 dB	-2.70 dB	-2.25 dB
UHRP / TRP	59.98 %	53.65 %	59.52 %
LHRP	-5.62 dBm	-4.86 dBm	-4.43 dBm
LHRP / TRP	-3.98 dB	-3.34 dB	-3.93 dB
LHRP / TRP	40.02 %	46.35 %	40.48 %
Front/Back Ratio	4.39	1.35	1.86
PhiBW	321.2 deg	360.0 deg	360.0 deg
PhiBW Up	231.5 deg	360.0 deg	360.0 deg
PhiBW Down	89.7 deg	360.0 deg	360.0 deg
ThetaBW	74.2 deg	79.7 deg	42.5 deg
ThetaBW Up	36.4 deg	39.3 deg	20.5 deg
ThetaBW Down	37.7 deg	40.4 deg	22.0 deg
Boresight Phi	240 deg	45 deg	105 deg
Boresight Theta	15 deg	90 deg	75 deg
Maximum Power	3.52 dBm	1.42 dBm	2.71 dBm
Minimum Power	-20.50 dBm	-10.36 dBm	-10.76 dBm
Average Power	-0.57 dBm	-2.17 dBm	-1.40 dBm
Max/Min Ratio	24.02 dB	11.79 dB	13.47 dB
Max/Avg Ratio	4.08 dB	3.60 dB	4.11 dB
Min/Avg Ratio	-19.93 dB	-8.19 dB	-9.36 dB
Best Single Value	2.98 dBm	0.80 dBm	2.48 dBm
Best Position	Phi = 270 deg; Theta = 30 deg; Pol = Hor	Phi = 30 deg; Theta = 90 deg; Pol = Hor	Phi = 150 deg; Theta = 75 deg; Pol = Hor

Table 26: 868 / 915 / 955 MHz Wire Antennas

4.9 Antenna Efficiency Summary on EB (868 – 955 MHz)

Ranking	Description	TRP Efficiency [%]
1	Nearson Whip Antenna	89.09 %
2	Board 11 (3.1.11)	68.52 %
3	Board 6 (3.1.6)	63.89 %
4	Board 5 (3.1.5)	63.78 %
5	Board 10 (3.1.10)	63.39 %
6	Board 4 (3.1.4)	62.39 %
7	Board 3 (3.1.3)	47.81 %

Table 27: TRP (868 – 955 MHz)

4.10 Antenna Efficiency Summary – Stand Alone (868 – 955 MHz)

Ranking	Description	TRP Efficiency [%]
1	Board 6 (3.1.6)	90.51 %

Table 28: TRP (868 – 955 MHz)

4.11 2.4 GHz Band

This antenna can be used in the frequency band of 2400 MHz – 2480 MHz. 2440 MHz was chosen so the characteristics of the antenna can be compared.

4.11.1 PCB Antennas (2.4 GHz)

	Board 6 (3.1.6) (2440 MHz) Stand Alone	Board 7 (3.1.7) (2440 MHz) Stand Alone	Board 7 (3.1.7) (2400 MHz)	Board 7 (3.1.7) (2440 MHz)	Board 7 (3.1.7) (2480 MHz)
Full CTIA Report	DN616	DN615	DN604	DN604	DN604
Test Description	**Test Result**	**Test Result**	**Test Result**	**Test Result**	**Test Result**
Total Radiated Power	-0.63 dBm	-0.26 dBm	-0.99 dBm	-1.82 dBm	-1.90 dBm
Peak EIRP	3.83 dBm	5.89 dBm	5.44 dBm	4.51 dBm	4.12 dBm
Directivity	4.45 dBi	6.15 dBi	6.43 dBi	6.33 dBi	6.03 dBi
Efficiency	-0.63 dB	-0.26 dB	-0.99 dB	-1.82 dB	-1.90 dB
Efficiency	86.60 %	94.17 %	79.68 %	65.74 %	64.53 %
Gain	3.83 dBi	5.89 dBi	5.44 dBi	4.51 dBi	4.12 dBi
NHPRP 45°	-2.21 dBm	-2.07 dBm	-2.82 dBm	-3.68 dBm	-3.60 dBm
NHPRP 45° / TRP	-1.58 dB	-1.81 dB	-1.83 dB	-1.85 dB	-1.70 dB
NHPRP 45° / TRP	69.42 %	65.90 %	65.62 %	65.27 %	67.64 %
NHPRP 30°	-3.95 dBm	-3.93 dBm	-4.54 dBm	-5.37 dBm	-5.27 dBm
NHPRP 30° / TRP	-3.32 dB	-3.67 dB	-3.56 dB	-3.55 dB	-3.37 dB
NHPRP 30° / TRP	46.51 %	42.95 %	44.09 %	44.20 %	46.04 %
NHPRP 22.5°	-5.22 dBm	-5.07 dBm	-5.80 dBm	-6.59 dBm	-6.49 dBm
NHPRP 22.5° / TRP	-4.59 dB	-4.81 dB	-4.81 dB	-4.77 dB	-4.58 dB
NHPRP 22.5° / TRP	34.73 %	33.05 %	33.01 %	33.38 %	34.81 %
UHRP	-3.96 dBm	-3.65 dBm	-2.44 dBm	-3.27 dBm	-3.47 dBm
UHRP / TRP	-3.34 dB	-3.39 dB	-1.45 dB	-1.45 dB	-1.56 dB
UHRP / TRP	46.40 %	45.81 %	71.63 %	71.68 %	69.74 %
LHRP	-3.33 dBm	-2.92 dBm	-6.46 dBm	-7.30 dBm	-7.09 dBm
LHRP / TRP	-2.71 dB	-2.66 dB	-5.47 dB	-5.48 dB	-5.19 dB
LHRP / TRP	53.60 %	54.19 %	28.37 %	28.32 %	30.26 %
Front/Back Ratio	3.27	16.57	9.96	11.10	13.23
PhiBW	105.6 deg	118.1 deg	173.3 deg	171.5 deg	174.3 deg
PhiBW Up	62.6 deg	87.9 deg	137.2 deg	55.2 deg	51.9 deg
PhiBW Down	43.0 deg	30.2 deg	36.1 deg	116.3 deg	122.4 deg
ThetaBW	46.5 deg	32.0 deg	76.8 deg	41.0 deg	46.0 deg
ThetaBW Up	14.0 deg	11.1 deg	41.3 deg	24.0 deg	23.4 deg
ThetaBW Down	32.5 deg	20.8 deg	35.4 deg	17.0 deg	22.6 deg
Boresight Phi	245 deg	30 deg	45 deg	135 deg	135 deg
Boresight Theta	140 deg	150 deg	45 deg	30 deg	30 deg
Maximum Power	3.83 dBm	5.89 dBm	5.44 dBm	4.51 dBm	4.12 dBm
Minimum Power	-14.02 dBm	-12.15 dBm	-14.54 dBm	-13.88 dBm	-12.04 dBm
Average Power	-0.59 dBm	0.72 dBm	-0.84 dBm	-1.75 dBm	-1.92 dBm
Max/Min Ratio	17.85 dB	18.04 dB	19.98 dB	18.39 dB	16.16 dB
Max/Avg Ratio	4.42 dB	5.17 dB	6.28 dB	6.25 dB	6.04 dB
Min/Avg Ratio	-13.43 dB	-12.87 dB	-13.70 dB	-12.13 dB	-10.12 dB
Best Single Value	3.62 dBm	5.34 dBm	4.75 dBm	3.63 dBm	3.56 dBm
Best Position	Phi = 90 deg; Theta = 80 deg; Pol = Ver	Phi = 270 deg; Theta = 180 deg; Pol = Hor	Phi = 30 deg; Theta = 60 deg; Pol = Ver	Phi = 105 deg; Theta = 30 deg; Pol = Hor	Phi = 105 deg; Theta = 30 deg; Pol = Hor

Table 29: 2440 MHz PCB Antennas

	Board 15 (3.1.15) (2400 MHz)	Board 15 (3.1.15) (2440 MHz)	Board 15 (3.1.15) (2480 MHz)	Board 6 (3.1.6) (2440 MHz)
Full CTIA Report	DN611	DN611	DN611	DN603
Test Description	**Test Result**	**Test Result**	**Test Result**	**Test Result**
Total Radiated Power	-1.70 dBm	-1.71 dBm	-1.97 dBm	-1.17 dBm
Peak EIRP	4.33 dBm	4.09 dBm	3.66 dBm	3.36 dBm
Directivity	6.03 dBi	5.81 dBi	5.63 dBi	4.53 dBi
Efficiency	-1.70 dB	-1.71 dB	-1.97 dB	-1.17 dB
Efficiency	67.59 %	67.42 %	63.57 %	76.43 %
Gain	4.33 dBi	4.09 dBi	3.66 dBi	3.36 dBi
NHPRP 45°	-3.56 dBm	-3.61 dBm	-3.69 dBm	-2.69 dBm
NHPRP 45° / TRP	-1.85 dB	-1.90 dB	-1.72 dB	-1.53 dB
NHPRP 45° / TRP	65.24 %	64.55 %	67.33 %	70.38 %
NHPRP 30°	-5.29 dBm	-5.36 dBm	-5.41 dBm	-4.37 dBm
NHPRP 30° / TRP	-3.59 dB	-3.65 dB	-3.44 dB	-3.20 dB
NHPRP 30° / TRP	43.77 %	43.15 %	45.30 %	47.89 %
NHPRP 22.5°	-6.55 dBm	-6.61 dBm	-6.65 dBm	-5.60 dBm
NHPRP 22.5° / TRP	-4.85 dB	-4.90 dB	-4.68 dB	-4.43 dB
NHPRP 22.5° / TRP	32.71 %	32.37 %	34.00 %	36.06 %
UHRP	-3.24 dBm	-3.20 dBm	-3.58 dBm	-3.47 dBm
UHRP / TRP	-1.54 dB	-1.48 dB	-1.62 dB	-2.30 dB
UHRP / TRP	70.18 %	71.04 %	68.93 %	58.88 %
LHRP	-6.96 dBm	-7.09 dBm	-7.04 dBm	-5.03 dBm
LHRP / TRP	-5.26 dB	-5.38 dB	-5.08 dB	-3.86 dB
LHRP / TRP	29.82 %	28.96 %	31.07 %	41.12 %
Front/Back Ratio	9.89	8.60	10.41	2.37
PhiBW	171.4 deg	188.0 deg	183.2 deg	87.3 deg
PhiBW Up	129.7 deg	75.9 deg	50.8 deg	30.7 deg
PhiBW Down	41.7 deg	112.1 deg	132.4 deg	56.6 deg
ThetaBW	80.0 deg	45.9 deg	55.8 deg	41.8 deg
ThetaBW Up	39.9 deg	24.9 deg	27.6 deg	26.3 deg
ThetaBW Down	40.1 deg	21.0 deg	28.2 deg	15.5 deg
Boresight Phi	45 deg	120 deg	135 deg	105 deg
Boresight Theta	45 deg	30 deg	30 deg	45 deg
Maximum Power	4.33 dBm	4.09 dBm	3.66 dBm	3.36 dBm
Minimum Power	-11.30 dBm	-11.41 dBm	-12.11 dBm	-13.80 dBm
Average Power	-1.41 dBm	-1.53 dBm	-1.85 dBm	-1.58 dBm
Max/Min Ratio	15.63 dB	15.50 dB	15.77 dB	17.16 dB
Max/Avg Ratio	5.74 dB	5.62 dB	5.52 dB	4.94 dB
Min/Avg Ratio	-9.89 dB	-9.88 dB	-10.25 dB	-12.22 dB
Best Single Value	3.68 dBm	2.88 dBm	3.23 dBm	2.60 dBm
Best Position	Phi = 30 deg; Theta = 60 deg; Pol = Ver	Phi = 90 deg; Theta = 30 deg; Pol = Hor	Phi = 30 deg; Theta = 60 deg; Pol = Ver	Phi = 105 deg; Theta = 45 deg; Pol = Ver

Table 30: 2440 MHz PCB Antennas Continued

4.11.2 Chip Antennas (2.4 GHz)

There is a large range of chip antennas available at 2.4 GHz which have reasonable performance. The drawback with ceramic chip antennas at this frequency is that the performance of PCB antennas is very good and compact. If board space for a PCB antenna is not available, then a ceramic antenna is a good option.

4.11.3 Wire Antennas (2.4 GHz)

	2.4 GHz Kit Antenna (2400 MHz)	**2.4 GHz Kit Antenna (2440 MHz)**	**2.4 GHz Kit Antenna (2480 MHz)**
Full CTIA Report	DN614	DN614	DN614
Test Description	**Test Result**	**Test Result**	**Test Result**
Total Radiated Power	-0.63 dBm	-0.39 dBm	-1.18 dBm
Peak EIRP	3.10 dBm	2.84 dBm	1.86 dBm
Directivity	3.72 dBi	3.23 dBi	3.04 dBi
Efficiency	-0.63 dB	-0.39 dB	-1.18 dB
Efficiency	86.56 %	91.32 %	76.23 %
Gain	3.10 dBi	2.84 dBi	1.86 dBi
NHPRP 45°	-1.65 dBm	-1.37 dBm	-2.13 dBm
NHPRP 45° / TRP	-1.02 dB	-0.97 dB	-0.95 dB
NHPRP 45° / TRP	78.99 %	79.96 %	80.40 %
NHPRP 30°	-2.98 dBm	-2.70 dBm	-3.34 dBm
NHPRP 30° / TRP	-2.35 dB	-2.30 dB	-2.17 dB
NHPRP 30° / TRP	58.22 %	58.85 %	60.73 %
NHPRP 22.5°	-4.09 dBm	-3.83 dBm	-4.43 dBm
NHPRP 22.5° / TRP	-3.46 dB	-3.44 dB	-3.25 dB
NHPRP 22.5° / TRP	45.06 %	45.34 %	47.33 %
UHRP	-2.92 dBm	-2.82 dBm	-3.41 dBm
UHRP / TRP	-2.30 dB	-2.43 dB	-2.23 dB
UHRP / TRP	58.92 %	57.16 %	59.88 %
LHRP	-4.49 dBm	-4.08 dBm	-5.14 dBm
LHRP / TRP	-3.86 dB	-3.68 dB	-3.97 dB
LHRP / TRP	41.08 %	42.84 %	40.12 %
Front/Back Ratio	7.01	4.82	3.40
PhiBW	191.8 deg	215.3 deg	291.6 deg
PhiBW Up	135.7 deg	167.7 deg	88.0 deg
PhiBW Down	56.0 deg	47.5 deg	203.7 deg
ThetaBW	37.9 deg	92.1 deg	59.9 deg
ThetaBW Up	15.5 deg	60.8 deg	37.2 deg
ThetaBW Down	22.4 deg	31.3 deg	22.6 deg
Boresight Phi	165 deg	255 deg	30 deg
Boresight Theta	45 deg	60 deg	75 deg
Maximum Power	3.10 dBm	2.84 dBm	1.86 dBm
Minimum Power	-13.86 dBm	-12.33 dBm	-14.19 dBm
Average Power	-1.56 dBm	-1.37 dBm	-2.16 dBm
Max/Min Ratio	16.96 dB	15.17 dB	16.05 dB
Max/Avg Ratio	4.66 dB	4.20 dB	4.03 dB
Min/Avg Ratio	-12.30 dB	-10.97 dB	-12.02 dB
Best Single Value	2.92 dBm	2.40 dBm	1.71 dBm
Best Position	Phi = 180 deg; Theta = 45 deg; Pol = Hor	Phi = 255 deg; Theta = 60 deg; Pol = Hor	Phi = 30 deg; Theta = 75 deg; Pol = Hor

Table 31: 2440 MHz PCB Antennas Continued

4.12 Antenna Efficiency Summary on EB (2.4 GHz)

Ranking	Description	TRP Efficiency [%]
1	2.4 GHz Whip Antenna	91.32 %
2	Board 7 (3.1.7)	79.68 %
3	Board 6 (3.1.6)	76.43 %
4	Board 15 (3.1.15)	67.59 %

Table 32: TRP (2.4 GHz)

4.13 Antenna Efficiency Summary – Stand Alone (2.4GHz)

Ranking	Description	TRP Efficiency [%]
1	Board 7 (3.1.7)	94.17 %
2	Board 6 (3.1.6)	86.60 %

Table 33: TRP (2.4 GHz)

5 Conclusion

TRP efficiencies have been presented from 94% at 2.4 GHz to 7% at 169 MHz. The TRP efficiencies ≤ 433 MHz are not in the region of the efficiencies presented at ≥ 868 MHz. This is mainly due to the wavelength at the lower frequencies is much larger, refer to Table 34. The size of the EB is approx 12 x 12 cm.

Frequency (MHz)	λ / 4 (cm)	Highest Recorded TRP Efficiency (%)
2440	3.1	94.17 %
915 / 868	8.2 / 8.6	90.51 %
433	17.3	25.53 %
315	23.8	14.85 %
169	44.4	6.89 %

Table 34: Highest Recorded TRP Efficiencies (%)

The choice of antenna is not so straight forward; the operating frequency, GND size and available space for the antenna and mechanical surroundings effect the decision process of which antenna should be used.

For a given physical size of board, PCB antennas can be an optimum choice at ≥ 868 MHz whereas at ≤ 433 MHz, a helical wire antenna might be the best option. The TRP efficiency will be reduced at the lower frequency and this has to be taken into account when calculating the link budget and expected range.

There is no one antenna that fits all applications but hopefully this CC-Antenna-DK will help in determining which antenna type should be the best solution for your application.

6 References

[1] DN600 (SWRA329.PDF) – Full CTIA Measurement Report for board 3

[2] DN601 (SWRA330.PDF) – Full CTIA Measurement Report for board 4

[3] DN602 (SWRA331.PDF) – Full CTIA Measurement Report for board 5

[4] DN603 (SWRA332.PDF) – Full CTIA Measurement Report for board 6

[5] DN604 (SWRA333.PDF) – Full CTIA Measurement Report for board 7

[6] DN605 (SWRA334.PDF) – Full CTIA Measurement Report for board 8

[7] DN606 (SWRA335.PDF) – Full CTIA Measurement Report for board 10

[8] DN607 (SWRA336.PDF) – Full CTIA Measurement Report for board 11

[9] DN608 (SWRA337.PDF) – Full CTIA Measurement Report for board 12

[10] DN609 (SWRA338.PDF) – Full CTIA Measurement Report for board 13

[11] DN610 (SWRA339.PDF) – Full CTIA Measurement Report for board 14

[12] DN611 (SWRA340.PDF) – Full CTIA Measurement Report for board 15

[13] DN612 (SWRA341.PDF) – Full CTIA Measurement Report for board 16

[14] DN613 (SWRA342.PDF) - Standard Whip Antenna for 868 MHz & 915 MHz EM boards

[15] DN614 (SWRA343.PDF) - Standard Whip Antenna for 2.4 GHz EM boards

[16] DN615 (SWRA344.PDF) - Board 7 as stand alone (without EM or EB board)

[17] DN616 (SWRA345.PDF) - Board 6 as stand alone (without EM or EB board)

[18] AN058 (SWRA161.PDF) – Antenna Selection Guide

[19] CC-Antenna-DK Rev 1.0.0. Reference Design (SWRR070.ZIP)

7 General Information

7.1 Document History

Revision	Date	Description/Changes
SWRA328	2010.08.26	Initial release.

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