Monopole PCB Antenna with Single or Dual Band Option

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Keywords

- *Single Band Mode (868 MHz, 915 MHz or 920 MHz)*
- *Dual Band Mode (868 MHz & 2440 MHz)*
- *PCB Antenna*
- *Monopole Antenna*
- *Excellent Efficiency*
- *Recommended Antenna Design for 868 MHz, 915 MHz & 920 MHz*
- *OTA Measurements*

1 Introduction

This document describes a PCB antenna that can be configured in two different modes of operation: the antenna can be tuned for a single frequency for operation in the 868 MHz (Europe), 915 MHz (USA) and 920 MHz (Japan) ISM bands; or the antenna can be configured as a dual band antenna which can operate at 868 MHz and 2440 MHz.

This antenna can be used with all transceivers and transmitters from Texas Instruments which operates in these frequency bands.

Overall size requirements for this antenna are 38 x 25 mm. Thus this is a medium size, low cost antenna solution. Figure 1 shows a picture the board being used to develop and characterize this antenna.

This antenna design is one of the several antenna reference designs available on www.ti.com/lpw and is included in the Comprehensive Antenna Selection Guide [6] and the Antenna Selection Quick Guide [7].

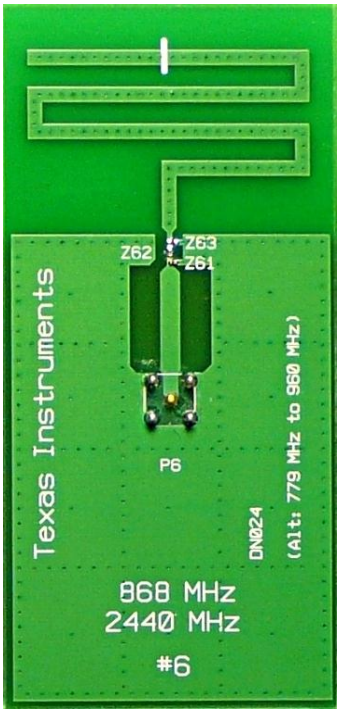

Figure 1. CC-Antenna-DK, Board #6 PCB Monopole Antenna

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2 Abbreviations

AUT	Antenna Under Test
BOM	Bill Of Materials
BW	Bandwidth
CF	Correction Factor
CITA	Cellular Telecommunications Industry Association
DK	Development Kit
EB	Evaluation Board
EIRP	Effective Isotropic Radiated Power
EM	Evaluation Module
ISM	Industrial, Scientific, Medical
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
RF	Radio Frequency
SWR	Standing Wave Ratio
TRP	Total Radiated Power

3 Description of the PCB Antenna

The antenna described in this document is a meandering monopole. The impedance of this antenna depends on the mode used. Referring to Figure 2, if the length of L4 is kept as shown then this is beneficial for the Dual Band Mode. If L4 is shortened to the silkscreen marking, then this is beneficial for the Single Band Mode.

It is recommended to use a pi-matching network at the feed point of the antenna as shown in Figure 2 since the geometry of the ground plane affects the impedance of the antenna. The pi-network can be used to compensate for detuning caused by plastic encapsulation and other objects in close vicinity of the antenna. For further information on impedance matching and impedance measurements, see AN058 [6].

The antenna layout is positioned on the top and bottom layer of the board; this enables a lower resistive loss and gives a slightly wider bandwidth compared to a single sided layout solution. With a single sided layout; the area underneath the antenna can not be used for any other routing so it is more useful to utilize this area to optimize the antenna's performance.

3.1 Implementation of the Meandering Monopole Antenna

To obtain optimum performance it is important to make an exact copy of the antenna dimensions. The antenna was implemented on a 1.6 mm thick FR4 substrate. Since there is no ground plane beneath the antenna the PCB thickness is not critical, but if a different thickness is being used it will be necessary to change the matching network to obtain optimum performance.

One approach to implement the antenna in a PCB CAD tool is to import the antenna layout from a Gerber file. Such a file is included in the CC-Antenna-DK Reference Design [8]. The CC-Antenna-DK contains 16 different board designs [1] and the gerbers from board 6 can be copied for this antenna design.

If the antenna is implemented on a PCB that is wider than the antenna it is important to avoid placing components or having a ground plane close to each side of the antenna. If the CAD tool being used does not support import of Gerber files, Figure 2 and Table 1 can be used.

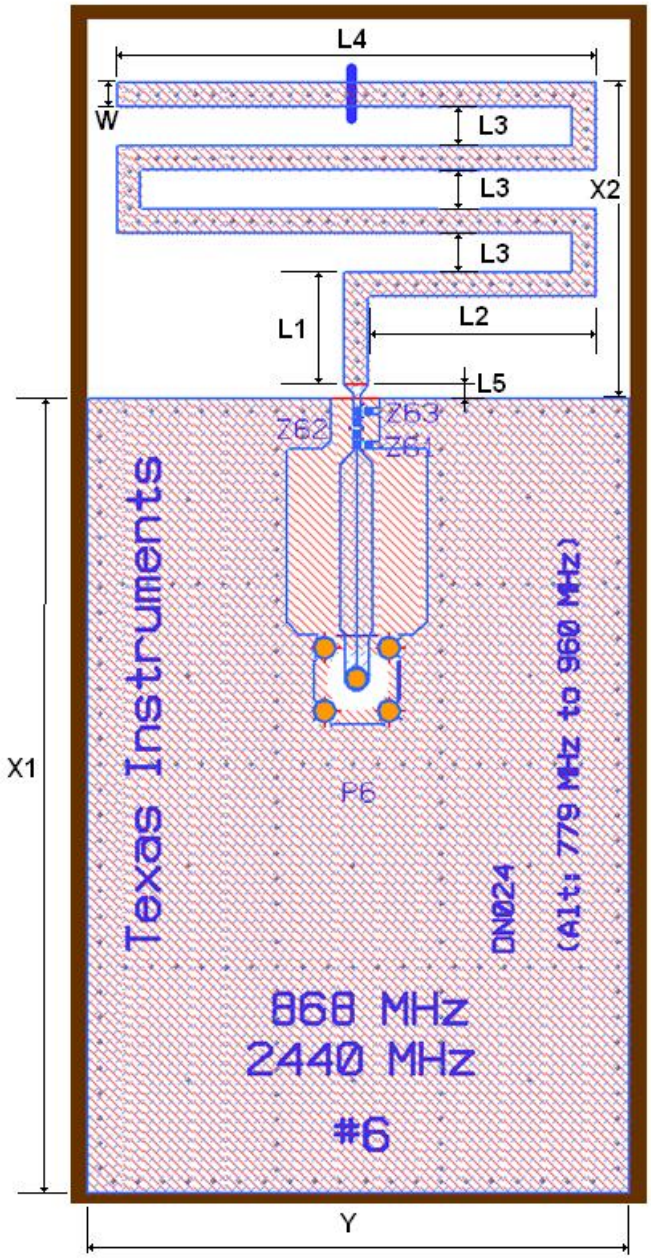

Figure 2. Antenna Dimensions

L1	9.0 mm	**Y**	43.0 mm
L2	18.0 mm	**X1**	63.0 mm
L3	3.0 mm	**X2**	25.0 mm
L4	38.0 mm	**W**	2.0 mm
L5	1.0 mm		

Table 1. Antenna Dimensions

Optimum length for the last antenna segment is dependent on the geometry of the ground plane. The antenna can also be used for 915 & 920 MHz. For larger ground planes L4 would have to be further reduced or the antenna match re-calculated.

4 Results

The CTIA measurement summary results are presented in this section. Note that the performance will be affected by the size and shape of the ground plane.

4.1 Radiation Pattern

Figure 3 and Figure 4 shows how to relate the radiation patterns in this section to the orientation of the antenna. A link to the full measurement report is included in the measurement summary. For reference purposes; measurements have also been performed on the standard whip SMA antennas that are supplied with the EM boards [3], [4].

Note that the size of the ground plane will affect the radiation pattern. Thus implementing this antenna on a board with a different size and shape of the ground plane will most likely affect the radiation pattern.

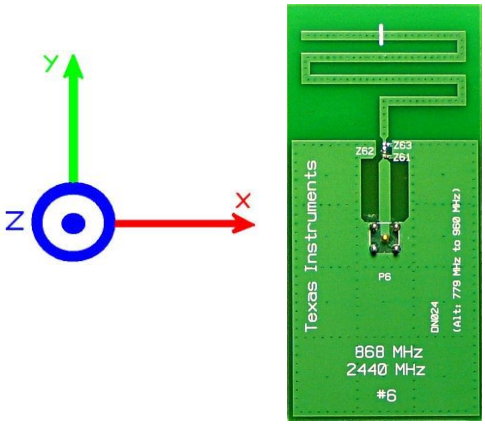

Figure 3. Coordinates for the Radiation Patterns when used as a stand alone board

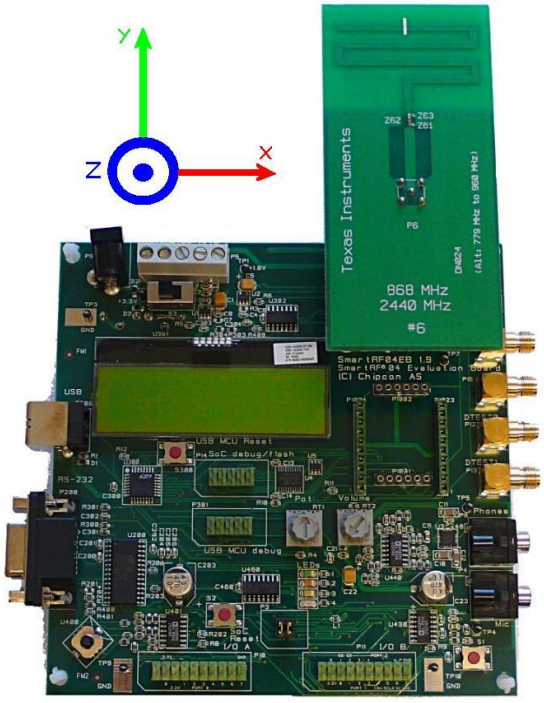

Figure 4. Coordinates for the Radiation Patterns when used with the EM & EB

4.2 Single band Option Design for 868 / 915 / 920 MHz

4.2.1 Antenna Match

4.2.1.1 Smith Chart – No Antenna Match Components

Even with no antenna match components (Z62: 0 ohm), the SWR at 868 MHz is 1.8 and this is a good match (SWR < 2.0) but still recommend inserting the matching components to be able to tune the antenna furthermore if so required due to surroundings may affect the resonance.

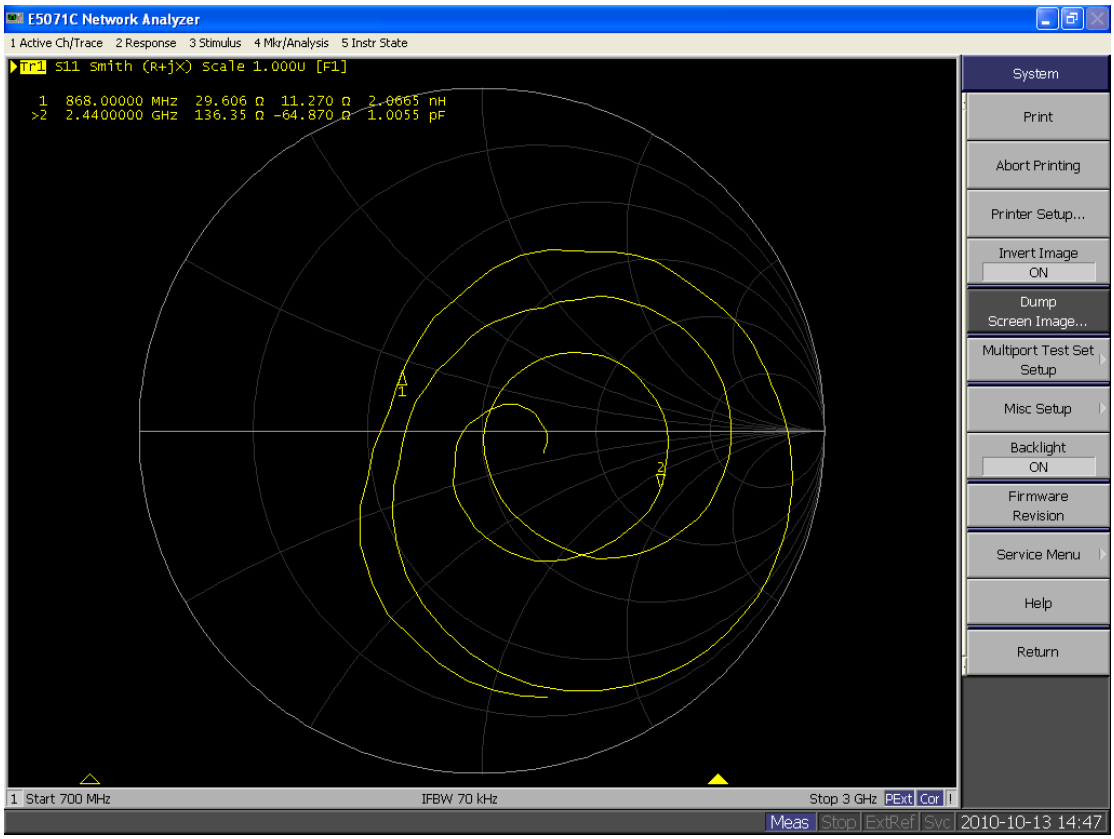

Figure 5: Start Match Value with 0 ohm resistor

4.2.1.2 Theoretical Smith Chart Match

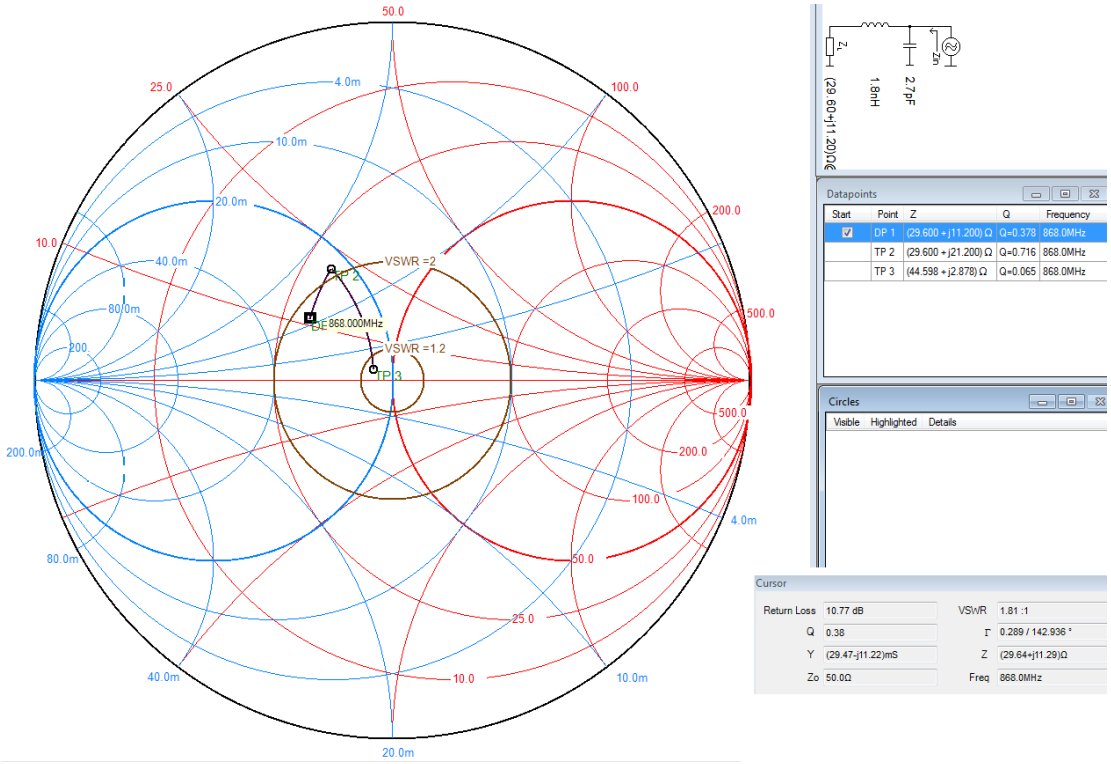

Figure 6: Antenna Match – 868 MHz

With a series 1.8nH inductor (Z62) and a shunt capacitor (Z61), the match theoretically should be improved to SWR of 1.1. The BOM used for this match can be found in Table 2.

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

BOM	Ref. Designator	Murata Part Number	Value
	Z61	GRM1555C1H2R7CZ01D	2.7 pF
	Z62	LQG15HS1N8S02D	1.8 nH
	Z63	NC	-

Table 2: BOM for Board #6: Single Band Antenna – 868 MHz

To confirm the theoretical match, the impedance is measured again and was the match could be confirmed as shown in Figure 7 with a SWR of 1.1.

Note that the match for this Single Mode configuration is good at 868 MHz and poor at 2.4 GHz.

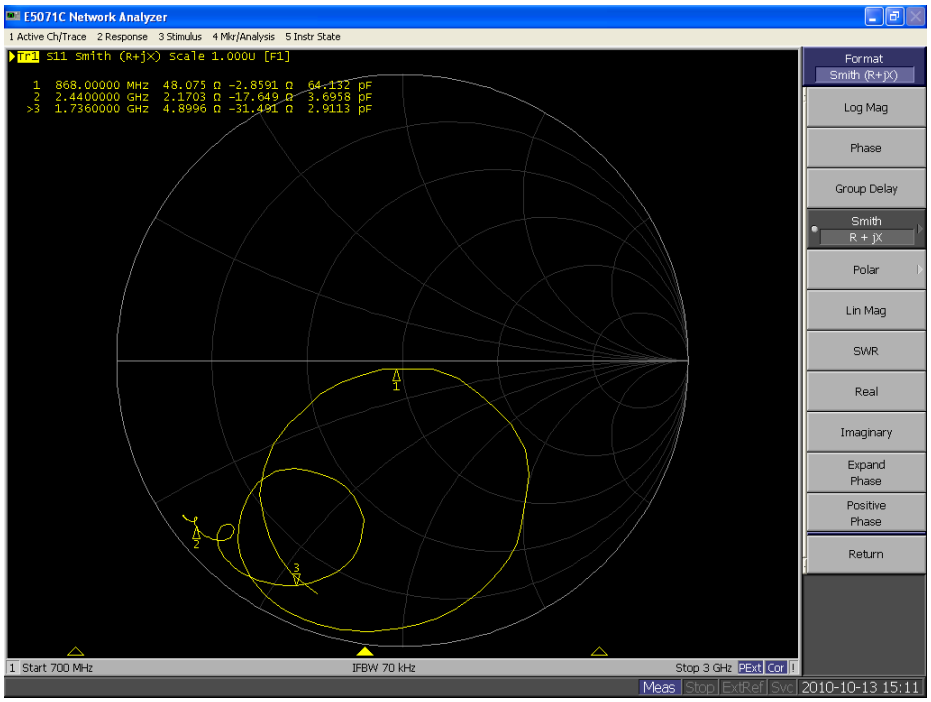

Figure 7: Matched Antenna at 868 MHz

4.2.2 Bandwidth

As can be seen from Figure 8, the bandwidth with a SWR of 2.0 (-10 dB RL) is 913 MHz – 825 MHz = 88 MHz.

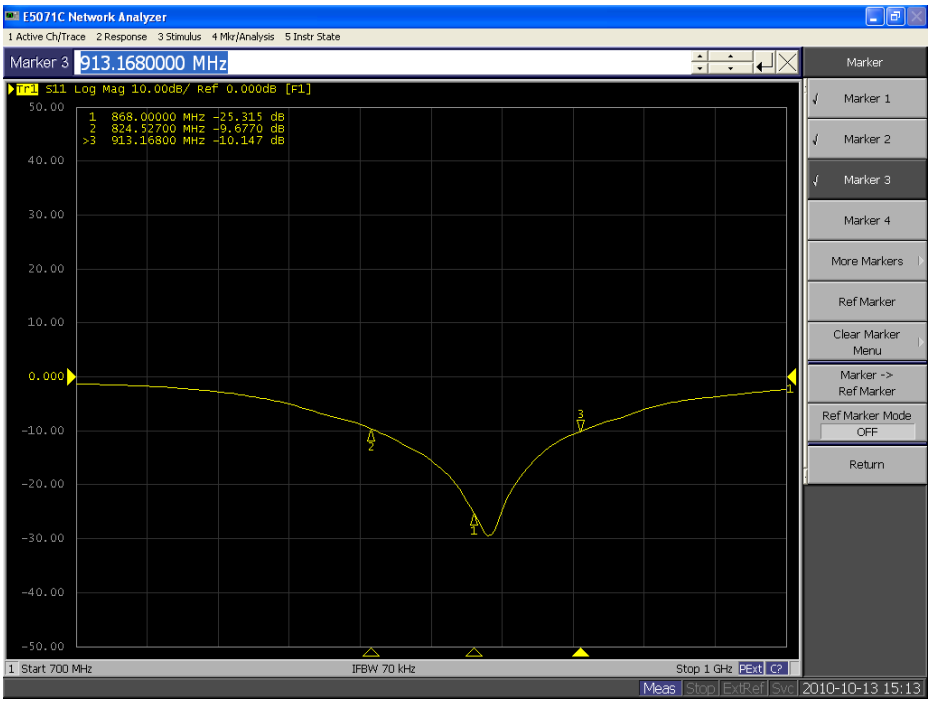

Figure 8: 88 MHz Bandwidth Measurement (868 MHz) @ SWR of 2.0

4.3 Dual band Option Design for 868 & 2440 MHz

4.3.1 Antenna Match

4.3.1.1 Smith Chart – No Antenna Match Components

With no antenna match components (Z62: 0 ohm), at 868 MHz the match is poor with SWR 2.9 and excellent at 2.44 GHz with SWR 1.2. The match needs to be improved at 868 MHz with the matching network.

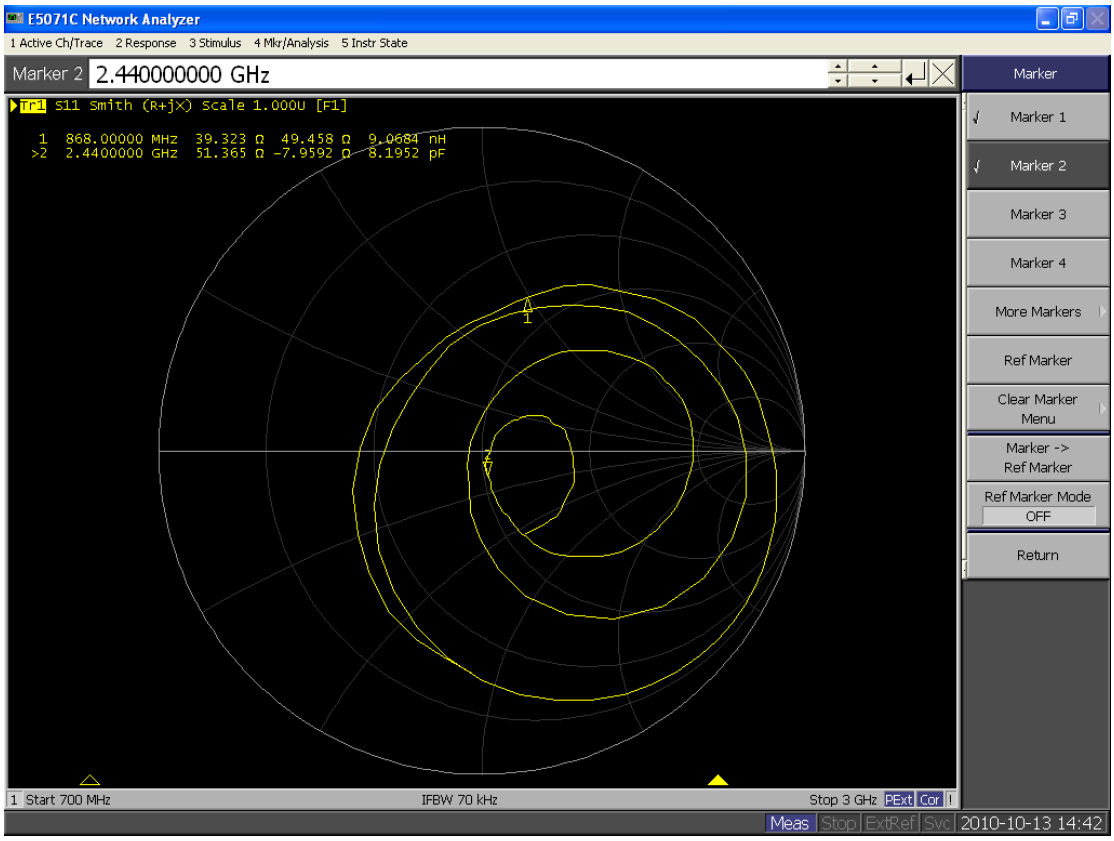

Figure 9: Start Match Value with 0 ohm resistor

The tricky part is to have a good match at both 868 MHz and 2.44 GHz. A series capacitor was chosen at 3.9 pF; theoretically the new match at 868 MHz should be improved to SWR 1.3 and at 2.44 GHz the new match will be slightly worse from the original value but still with a good SWR 1.6. The match value at 2.44 GHz is a compromise because of the shared match value used at 868 MHz. The effects of the theoretical match values can be seen in Figure 10 and Figure 11.

4.3.1.2 Theoretical Smith Chart Match

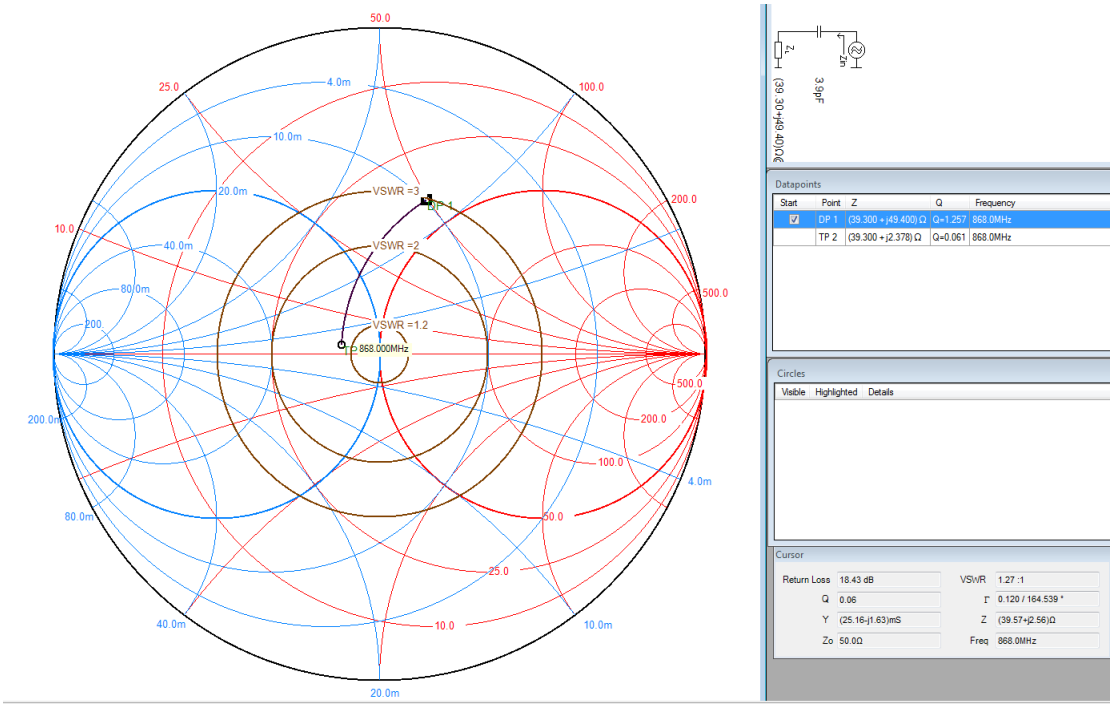

Figure 10: Antenna Match – 868 MHz

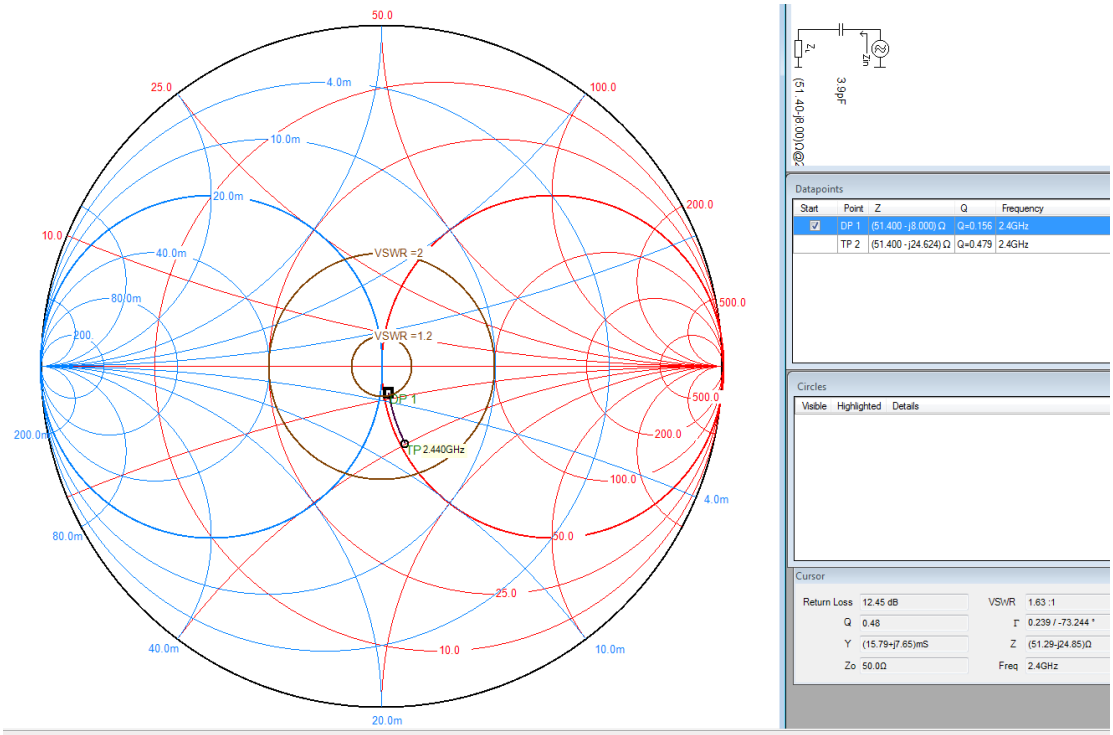

Figure 11: Antenna Match – 2.44 GHz

With a series 3.9 pF capacitor (Z62), the BOM used for this match can be found in Table 3.

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

BOM	Ref. Designator	Murata Part Number	Value
	Z61	NC	-
	Z62	GRM1555C1H3R9CZ01D	3.9 pF
	Z63	NC	-

Table 3: BOM for Board #6: Dual Band Antenna – 868 MHz & 2.4 GHz

To confirm the theoretical match, the impedance is measured again and was the match could be confirmed as shown in Figure 12 with a SWR 1.2 for 868 MHz and SWR 1.6 for 2.44 GHz.

Note that the match for this Dual Mode configuration is good at both 868 MHz and 2.4 GHz.

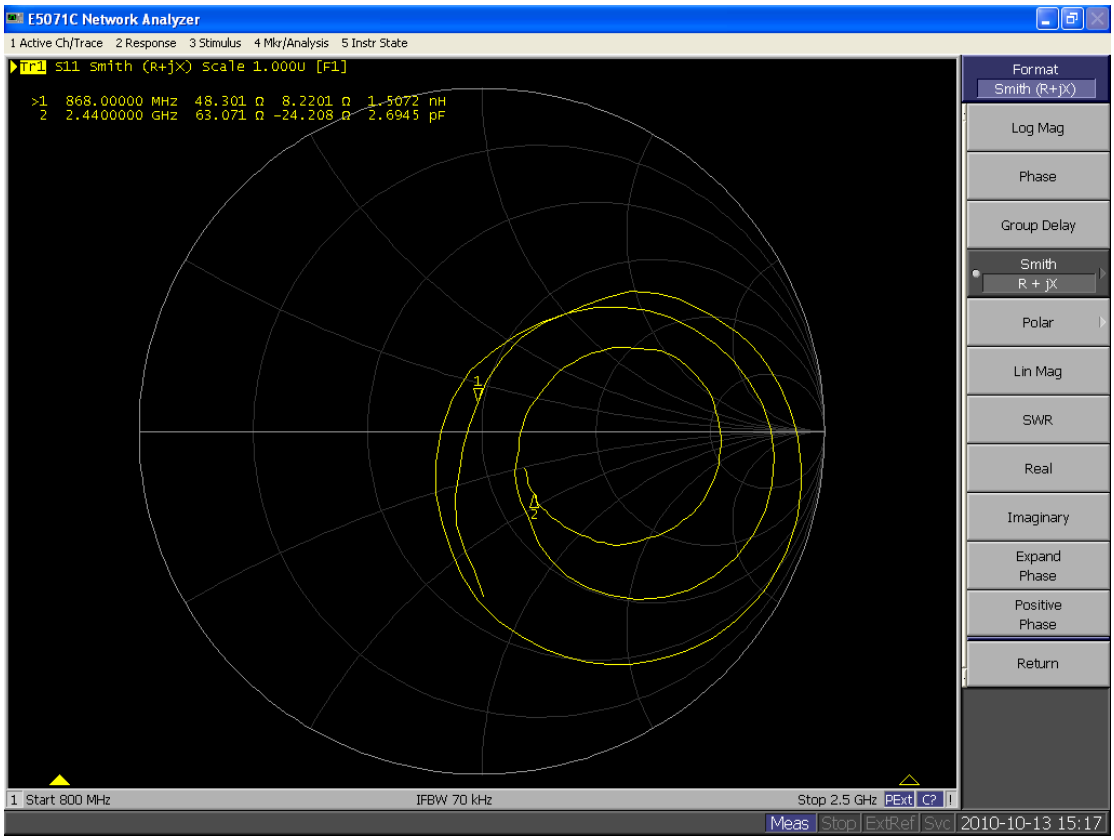

Figure 12: Matched Antenna at 868 MHz and 2.44 GHz

4.3.2 Bandwidth

As can be seen from Figure 13, the bandwidth with a SWR of 2.0 (-10 dB RL) at 868 MHz is 893 MHz – 820 MHz = 73 MHz and at 2.4 GHz is 2740 MHz – 2386 MHz = 354 MHz.

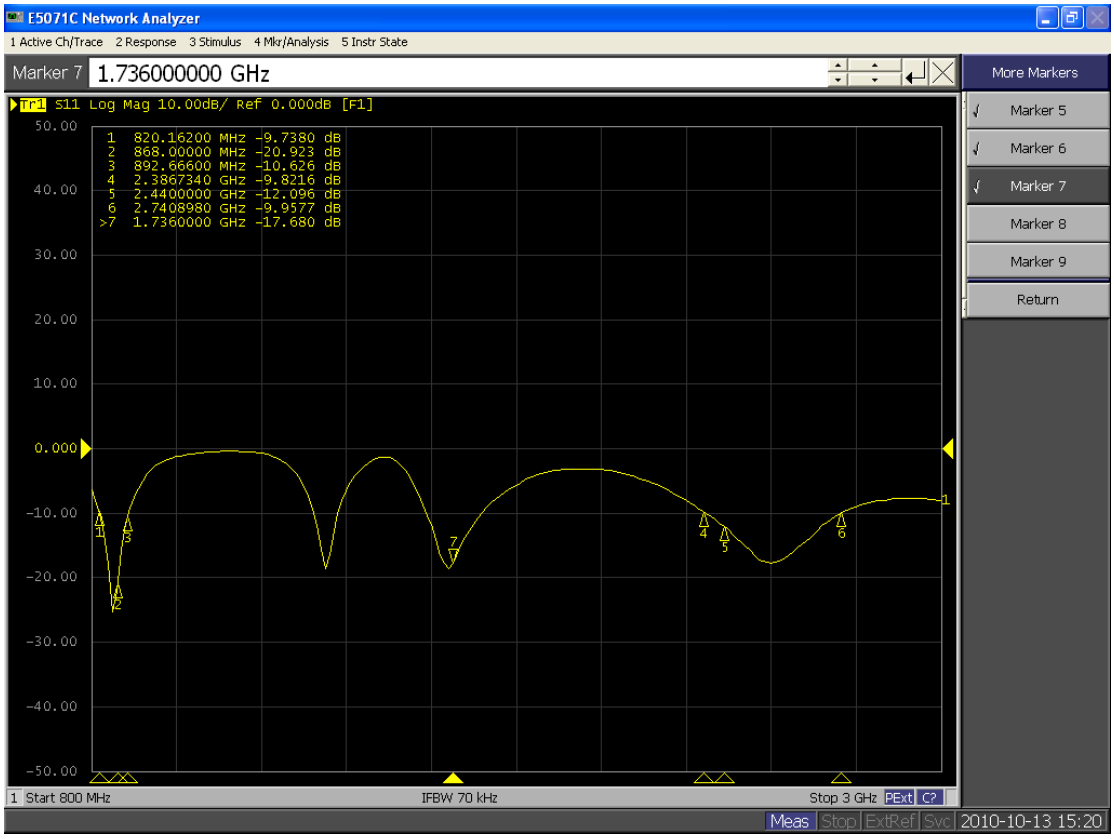

Figure 13: 73 MHz (868 MHz) & 354 MHz (2.4 GHz) Bandwidth Measurement @ SWR of 2.0

4.4 OTA Measurement Summary

Table 4 summarizes the OTA measurements reports from the antenna configured as a Single Band Mode Antenna and as a Dual Band Antenna. The full version of the CTIA OTA report can be found in DN616 [5].

	Board 6 Single Band Mode (868 MHz)	**Board 6 Dual Band Mode (868 MHz)**	**Board 6 Dual Band Mode (2440 MHz)**
Full CTIA Report	DN616	DN616	DN616
Test Description	**Test Result**	**Test Result**	**Test Result**
Total Radiated Power	-0.10 dBm	-0.25 dBm	-0.21 dBm
Peak EIRP	5.05 dBm	4.85 dBm	3.35 dBm
Directivity	5.15 dBi	5.09 dBi	3.56 dBi
Efficiency	-0.10 dB	-0.25 dB	-0.21 dB
Efficiency	**97.67 %**	**94.48 %**	**95.35 %**
Gain	5.05 dBi	4.85 dBi	3.35 dBi
NHPRP 45°	-2.77 dBm	-2.87 dBm	-1.92 dBm
NHPRP 45° / TRP	-2.67 dB	-2.62 dB	-1.71 dB
NHPRP 45° / TRP	54.13 %	54.65 %	67.38 %
NHPRP 30°	-4.79 dBm	-4.85 dBm	-3.72 dBm
NHPRP 30° / TRP	-4.69 dB	-4.61 dB	-3.51 dB
NHPRP 30° / TRP	33.97 %	34.61 %	44.54 %
NHPRP 22.5°	-6.05 dBm	-6.10 dBm	-4.98 dBm
NHPRP 22.5° / TRP	-5.94 dB	-5.85 dB	-4.77 dB
NHPRP 22.5° / TRP	25.44 %	25.98 %	33.35 %
UHRP	-3.75 dBm	-3.94 dBm	-3.25 dBm
UHRP / TRP	-3.65 dB	-3.69 dB	-3.04 dB
UHRP / TRP	43.18 %	42.75 %	49.62 %
LHRP	-2.56 dBm	-2.67 dBm	-3.18 dBm
LHRP / TRP	-2.45 dB	-2.42 dB	-2.98 dB
LHRP / TRP	56.82 %	57.25 %	50.38 %
Front/Back Ratio	3.78	3.28	1.39
PhiBW	293.4 deg	300.3 deg	91.9 deg
PhiBW Up	212.0 deg	230.8 deg	39.7 deg
PhiBW Down	81.5 deg	69.5 deg	52.2 deg
ThetaBW	75.5 deg	59.9 deg	119.4 deg
ThetaBW Up	34.2 deg	20.6 deg	102.8 deg
ThetaBW Down	41.3 deg	39.3 deg	16.6 deg
Boresight Phi	135 deg	120 deg	90 deg
Boresight Theta	180 deg	180 deg	45 deg
Maximum Power	5.05 dBm	4.85 dBm	3.35 dBm
Minimum Power	-11.70 dBm	-11.84 dBm	-7.53 dBm
Average Power	1.12 dBm	0.96 dBm	-0.03 dBm
Max/Min Ratio	16.75 dB	16.69 dB	10.88 dB
Max/Avg Ratio	3.93 dB	3.89 dB	3.38 dB
Min/Avg Ratio	-12.82 dB	-12.80 dB	-7.50 dB
Best Single Value	4.24 dBm	4.15 dBm	2.62 dBm
Best Position	Phi = 105 deg; Theta = 165 deg; Pol = Hor	Phi = 90 deg; Theta = 165 deg; Pol = Hor	Phi = 75 deg; Theta = 60 deg; Pol = Ver

Table 4: Measurement Summary for both Single and Dual Band Mode

5 Conclusion

The antenna in this design note can be used in two different modes. When configured as Single Band Mode, this is ideal for 868 MHz, 915 MHz or 920 MHz operation. The antenna can also be configured in Dual Band Mode then the operation can also be at 868 MHz and 2.4 GHz. All modes of operation have a Transmitted Radiated Efficiency > 90 % and still maintaining a wide bandwidth [5].

The Dual Band Mode is ideal when the radio solution is working at both 868 MHz and 2.4 GHz. When using the Dual Band Mode it is important to keep the 3rd harmonic of the 868 MHz (2.604 GHz) underneath the regulatory limits since the 2.4 GHz antenna (2.74 GHz to 2.38 GHz) will also radiate the 3rd harmonic as well. If the reference design of the radio is followed, then the harmonic levels are well within the regulatory standards.

It is recommended to follow the antenna dimensions as shown in Figure 2, size of the antenna is 38 x 25 mm. The maximum gain is approximately 3 to 5 dBi which is typical for a monopole antenna.

Measurements of reflection show that the center frequency is dependent on the size of the ground plane, but this is easily compensated for by adjusting the antenna length or the antenna match network.

6 References

[1] DN031 (SWRA328.PDF) – CC-Antenna-DK Documentation and Antenna Measurements Summary

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

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

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

[5] DN616 (SWRA345.PDF) - CC-Antenna-DK, board #6 as stand alone in Single & Dual Mode

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

[7] DN035 (SWRA351.PDF) – Antenna Selection Quick Guide

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

7 Document History

Revision	Date	Description/Changes
SWRA227E	2013.02.22	Updated with OTA CTIA Measurements and Dual-Band Option Mode
SWRA227D	2009.08.20	Added CC430 to list of devices
SWRA227C	2009.07.15	Corrected link to CC1110EM Meander Antenna Reference Design
SWRA227B	2009.04.14	Added EB to Abbreviations. Cosmetic changes
SWRA227A	2009.03.17	Updated with 955 MHz. Removed logo from header
SWRA227	2007.04.16	Initial release.

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