Application Note

433 to 930-MHz and 2.4-GHz BOM Tunable PCB Antenna

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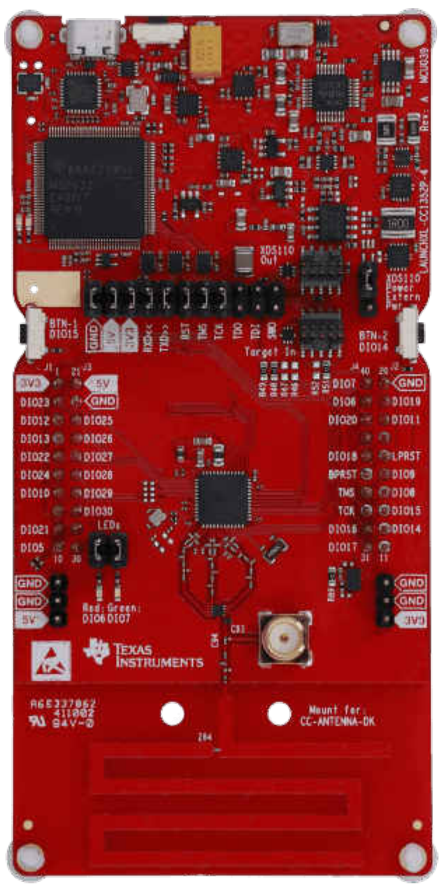
ABSTRACT

This document describes a fixed PCB antenna trace structure that users can configure to operate in two different modes of operation by changing the BOM. Users can tune the antenna for single frequency for operation in 433–MHz, 470–510-MHz, and 868–930-MHz ISM bands; or the antenna can be configured as a dual-band antenna which can operate at one of the given frequencies in addition to 2.4 GHz.

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

Overall size requirements for this antenna are 43 by 25 mm. This is a medium size, low-cost antenna solution. The figure below shows the layout of the PCB monopole antenna with the surface mount external component Z64.



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Trademarks

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Acronyms

Acronym	Definition
AUT	Antenna Under Test
BOM	Bill Of Materials
BW	Bandwidth
CF	Correction Factor
CITA	Cellular Telecommunications Industry Association
DK	Development Kit
DNM	Do Not Mount
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
VNA	Vector Network Analyzer

1 Description of the PCB Antenna

The antenna described in this document is a PCB meander monopole that users can configure by changing the BOM to operate as a single-band antenna or dual-band antenna. The resonance is set by the antenna PCB trace element and the antenna matching components. This allows the antenna to cover a wideband range with one antenna pattern design. The impedance of this antenna depends on the mode used. Referring to Figure 1-1, if the length of L4 is kept as shown, this is beneficial for operation around 433–510 MHz. If L4 is shortened to half the length (19.0 mm), this is beneficial when operating at 868–930 MHz.

The antenna layout is positioned on the top and bottom layer of the board as can be seen in Figure 1-1; 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.

1.1 Implementation of the PCB Meander 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. If a different thickness is used then it could 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. Refer to files included in the LAUNCHXL-CC1352P-4 Reference 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 1-1 and Table 1-1 can be used.

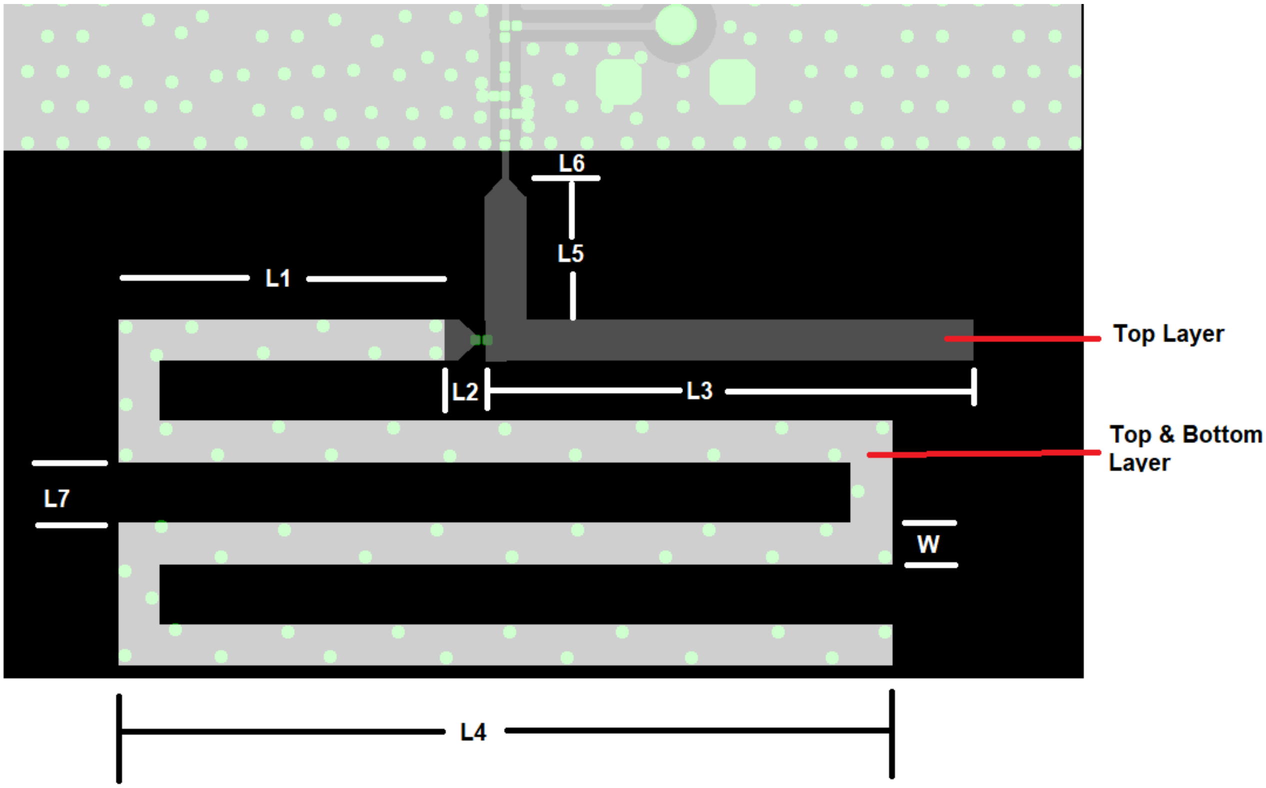

Figure 1-1. LAUNCHXL-CC1352P-4

Table 1-1. Antenna Dimensions

L1	16.0 mm	**L5**	7.0 mm
L2	2.0 mm	**L6**	1.4 mm
L3	24.0 mm	**L7**	3.0 mm
L4	38.0 mm	**W**	2.0 mm

The last antenna segment's optimum length will always be dependent on the geometry of the ground plane. For ground plane sizes smaller than the LAUNCHXL-CC1352P-4 (less than a quarterwave), the optimum length of the last segment could be increased or the antenna match re-calculated for the new ground plane size.

1.2 Matching Network

TI advises users to include an antenna matching network in order to tune and reduce the mismatch losses of the antenna. The geometry of the ground plane affects the impedance of the antenna. The antenna matching network can be used to compensate for detuning caused by encapsulation and other objects in close vicinity of the antenna. The type of antenna matching network depends on the mode of the antenna.

Recommend to use a pi-matching network for single-band mode at the feed point of the antenna. For further information on impedance matching and impedance measurements, see AN058. However, the antenna which is the subject of this app note is a dual-band antenna, designed to simultaneously support 433, 470–510, or 868/915/920-MHz (low-band) and 2.4-GHz (high-band) bands. Therefore, the pi-match is not a recommended solution and instead a LC, CL match network as shown in Figure 1-2 is recommended. This is also the matching network implemented on the LAUNCHXL-CC1352P-4 which is used for testing in this application note.

The LC (Z60 and Z61) part matches the high-band and CL (Z62 and Z63) matches the low-band.

For single-band operations, no 2.4-GHz resonance, Z60 can be replaced with 0 ohm and Z61 left as DNM. Z62 and Z63 can be both an inductor or capacitor in order to match the impedance to 50 ohm.

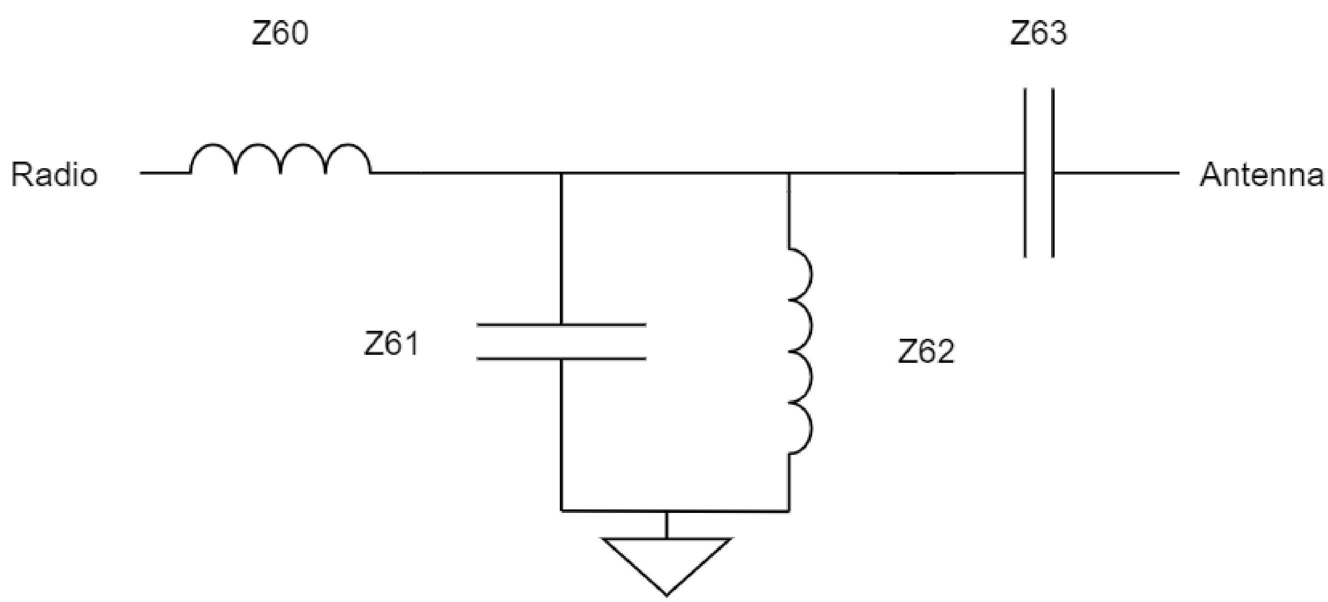

Figure 1-2. LC, CL Match Network for Dual-Band Operations.

2 Test Setup

The hardware used for implementation and testing in this application note is the LAUNCHXL-CC1352P-4 Figure 2-1 as shown in Figure 1-1.

2.1 Radiation Pattern

Figure 2-1 shows how to relate the radiation patterns in this application note to the orientation of the antenna.

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.

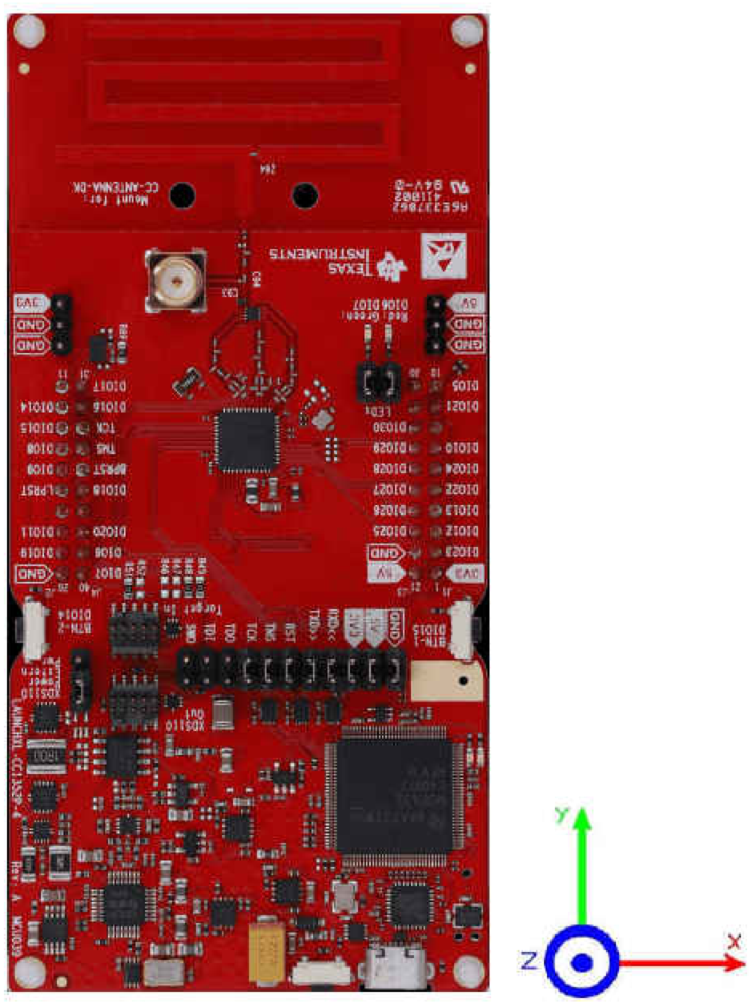

Figure 2-1. XYZ Coordinates for the Antenna Radiation Plots

3 Unmatched Results

3.1 Smith Chart – Natural Impedance without Antenna Match Components

Figure 3-1 shows the Smith chart of the antenna with no antenna match components (Z60: 0 ohm, Z63: 0 ohm, Z61: DNM, Z62: DNM and Z64: 0 ohm).

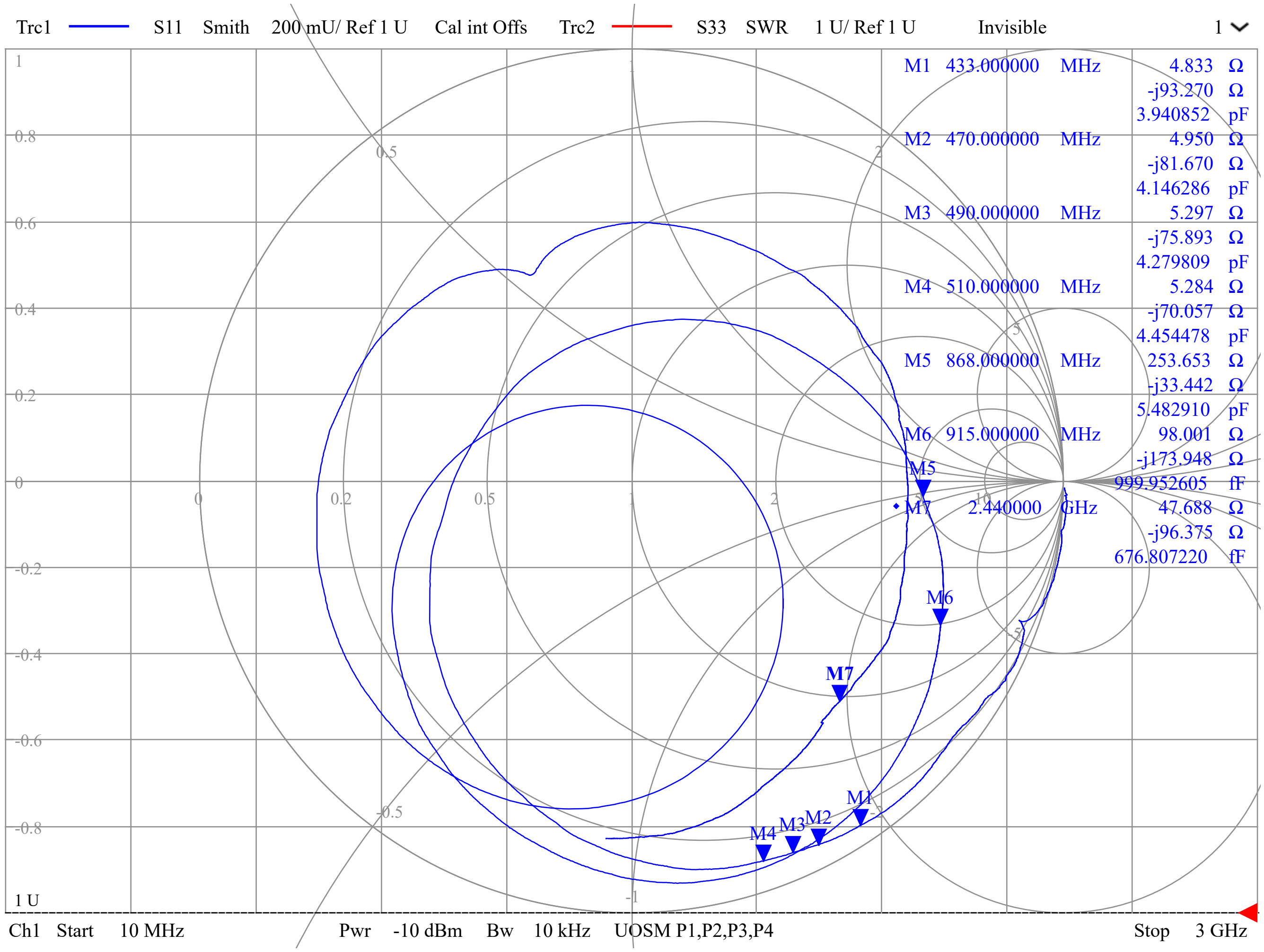

Figure 3-1. Natural Impedance of Antenna with No Antenna Match

3.2 Smith Chart – Impedance with external component Z64

In order two extend the antenna frequency range from 868–930 MHz and 2.4 GHz to support the frequency bands at 433-MHz and 470–510-MHz bands, an additional inductor is required at location Z64. By including the extra inductance Z64, the frequency range can be extended to 433–930 MHz and 2.4 GHz with the same antenna structure; see Figure 3-2. Z64 is not needed for greater than 868 MHz operation but a 0 ohm resistor or capacitor can be used in the Z64 footprint. By changing the value of Z64, the antenna can be made to resonate at different frequencies with the same antenna structure. Frequencies lower than 868 MHz will require an inductance and for frequencies greater than 868 MHz will require a capacitance. For example, a value of 51 nH is recommended for 433 MHz operation; please refer to Table 3-1.

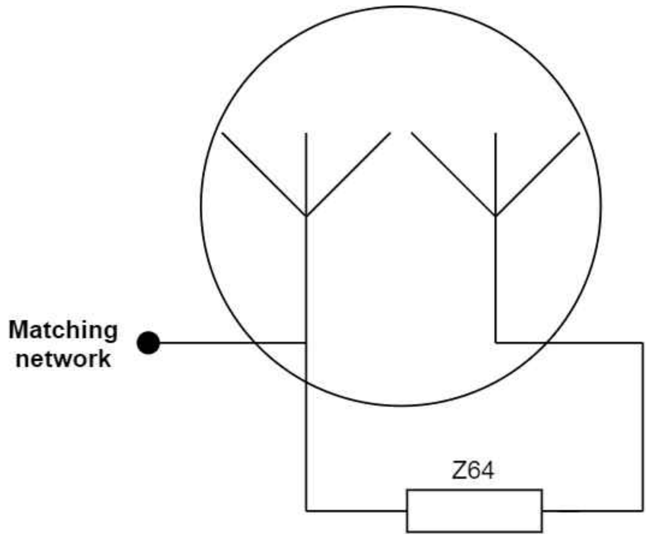

Figure 3-2. Schematic Symbol for Antenna showing Z64

Table 3-1. Z64 recommended component value for the sub-1 GHz ISM Frequency Bands

Frequency [MHz]	Value
433MHz	51 nH
470 MHz	39 nH
490 MHz	33 nH
510MHz	27 nH
892 MHz(1)	2 pF

(1) Compromise with dual-operation at both 868 MHz and 915 MHz

3.2.1 433 MHz Unmatched

Figure 3-3 and Figure 3-4 shows the Smith chart and SWR after placing 51 nH in Z64 to support the 433 MHz frequency (keeping Z60-Z63 unchanged). The SWR at 433 MHz is 1.77 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.

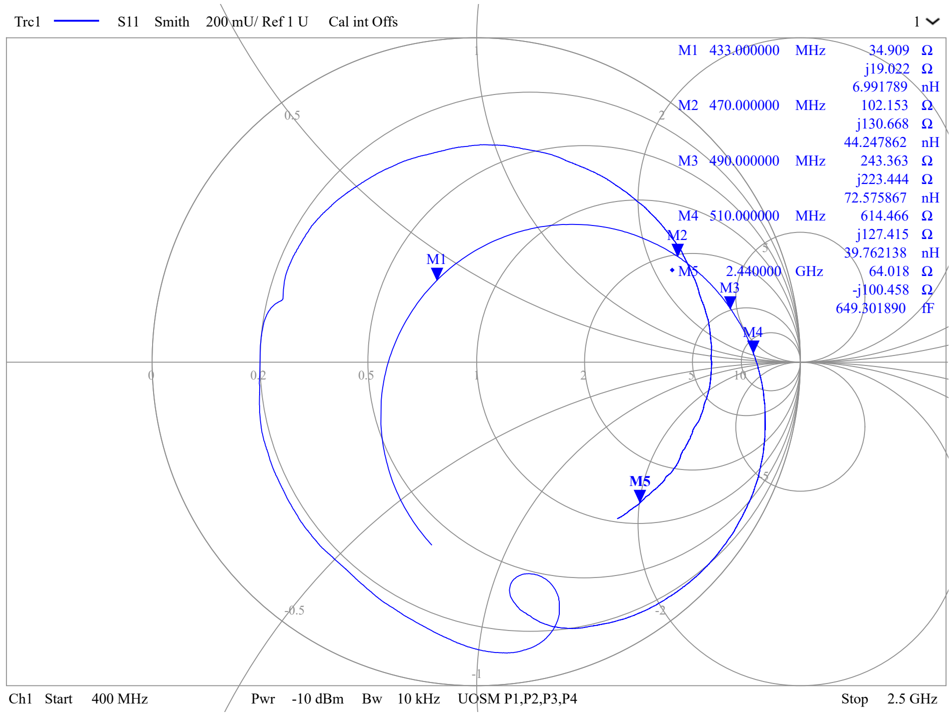

Figure 3-3. Smith Chart After Placing 51 nH at Z64.

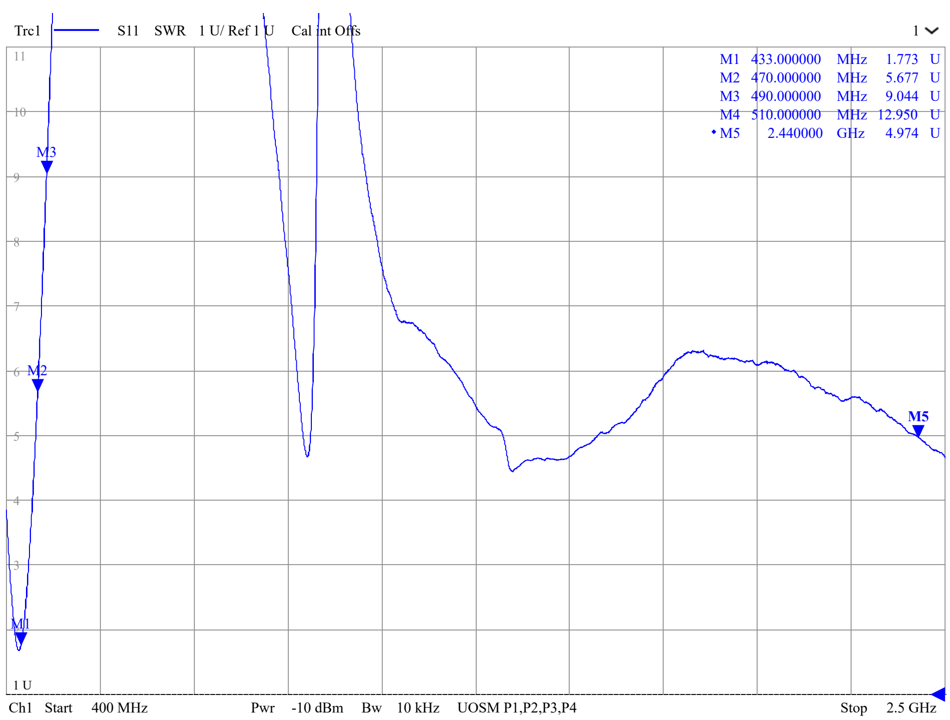

Figure 3-4. SWR After Placing 51 nH at Z64.

3.2.2 470 MHz Unmatched

Figure 3-5 and Figure 3-6 shows the Smith chart and SWR after placing 39 nH in Z64 to support the 470 MHz frequency (keeping Z60-Z63 unchanged). We can see that we don't have a good match with an SWR of 2.05 and therefor matching network is necessary.

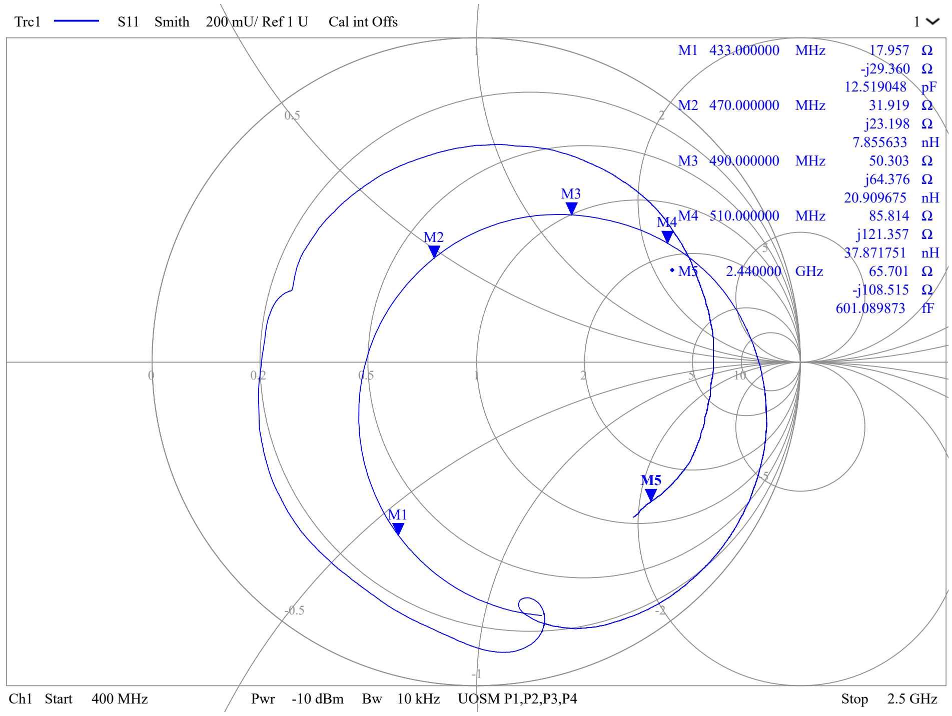

Figure 3-5. Smith Chart After Placing 39 nH at Z64

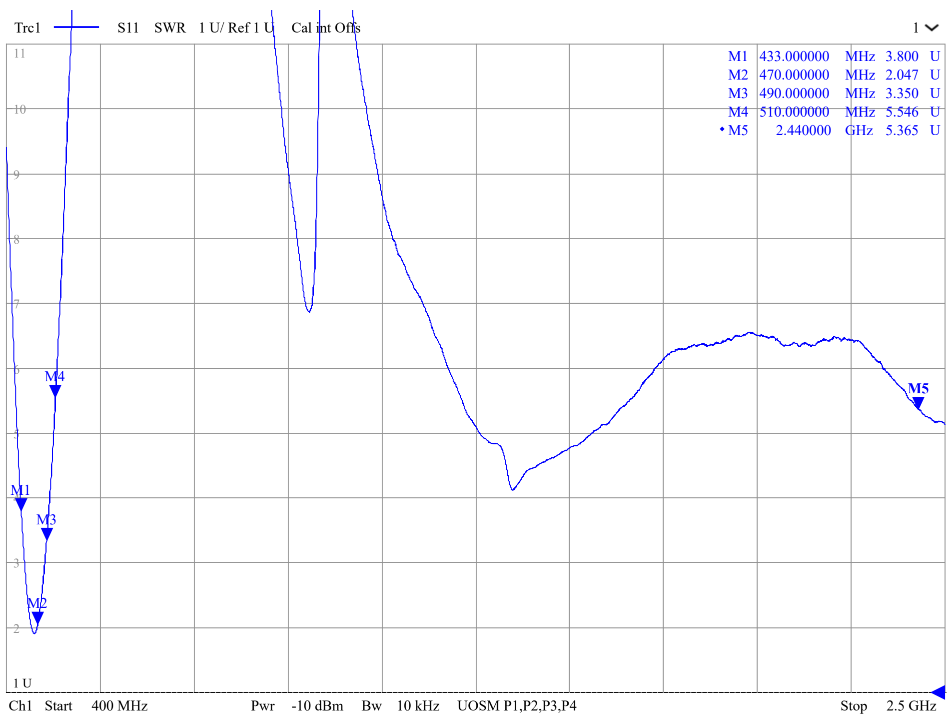

Figure 3-6. SWR After Placing 39 nH at Z64

3.2.3 490 MHz Unmatched

Figure 3-7 and Figure 3-8 shows the Smith chart and SWR after placing 33 nH in Z64 to support the 490 MHz frequency (keeping Z60-Z63 unchanged). We can see that we don't have a good match with an SWR of 2.20 and therefor matching network is necessary.

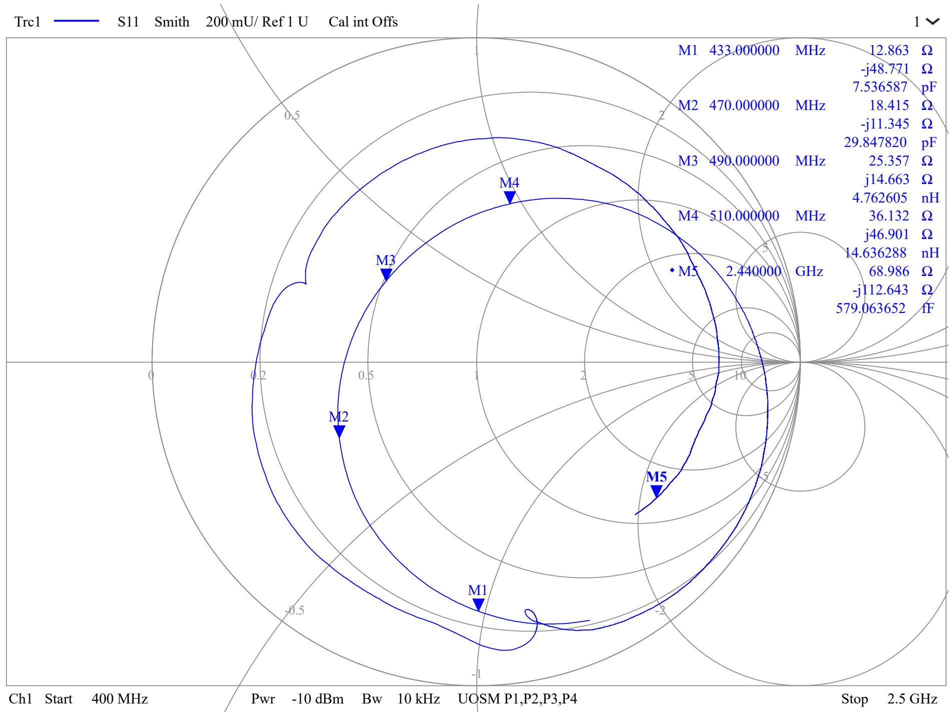

Figure 3-7. Smith Chart After Placing 33 nH at Z64.

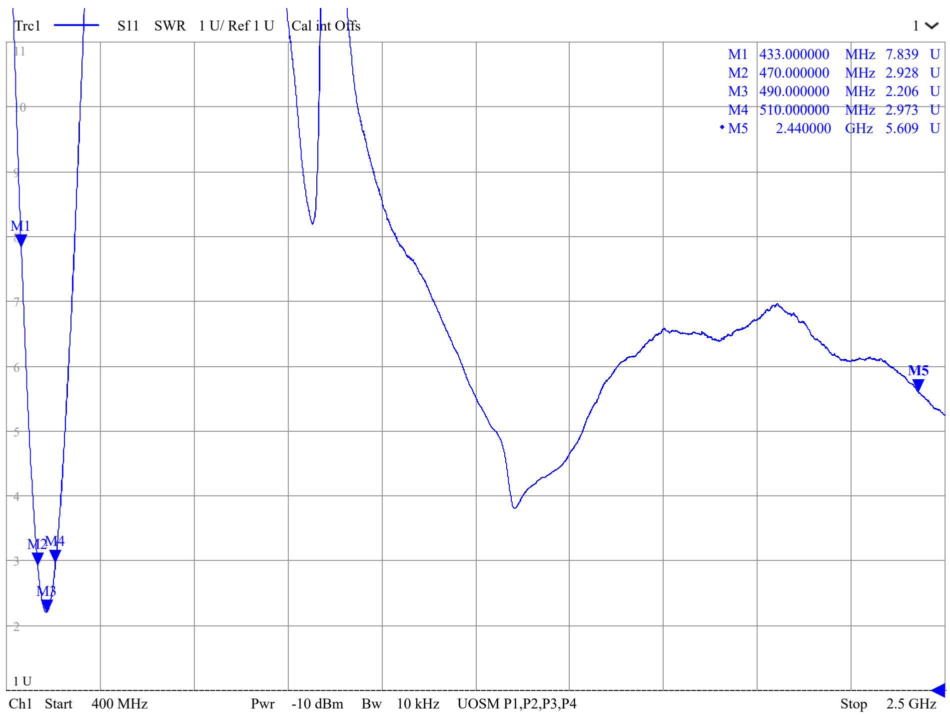

Figure 3-8. SWR After Placing 33 nH at Z64.

3.2.4 510 MHz Unmatched

Figure 3-9 and Figure 3-10 shows the Smith chart and SWR after placing 27 nH in Z64 to support the 510-MHz frequency (keeping Z60–Z63 unchanged). We can see that we don't have a good match with an SWR of 2.26 and therefore matching network is necessary.

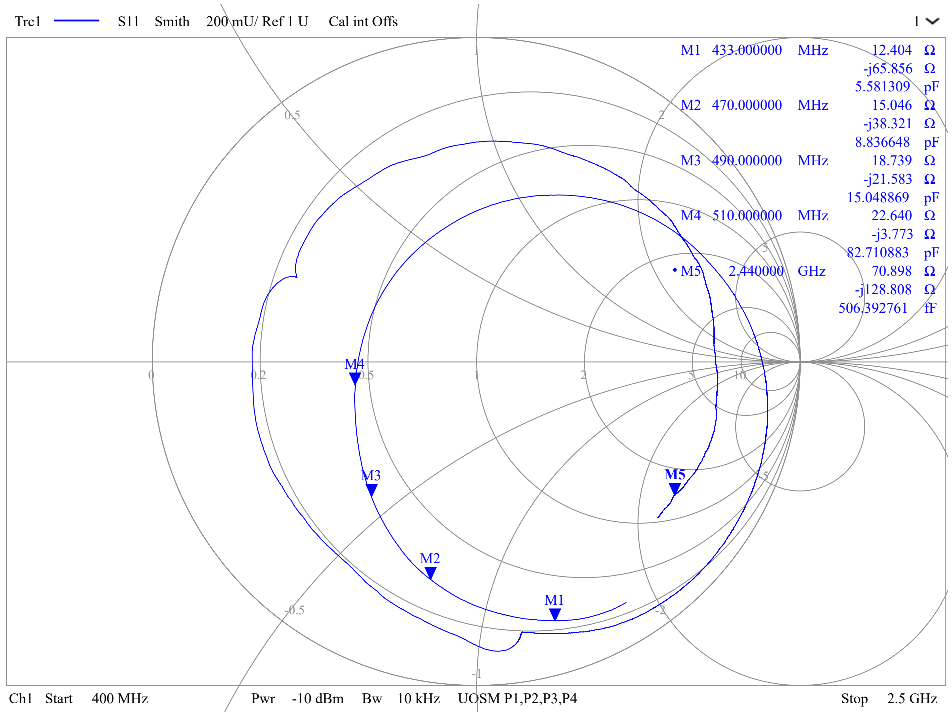

Figure 3-9. Smith chart when placing 27 nH at Z64

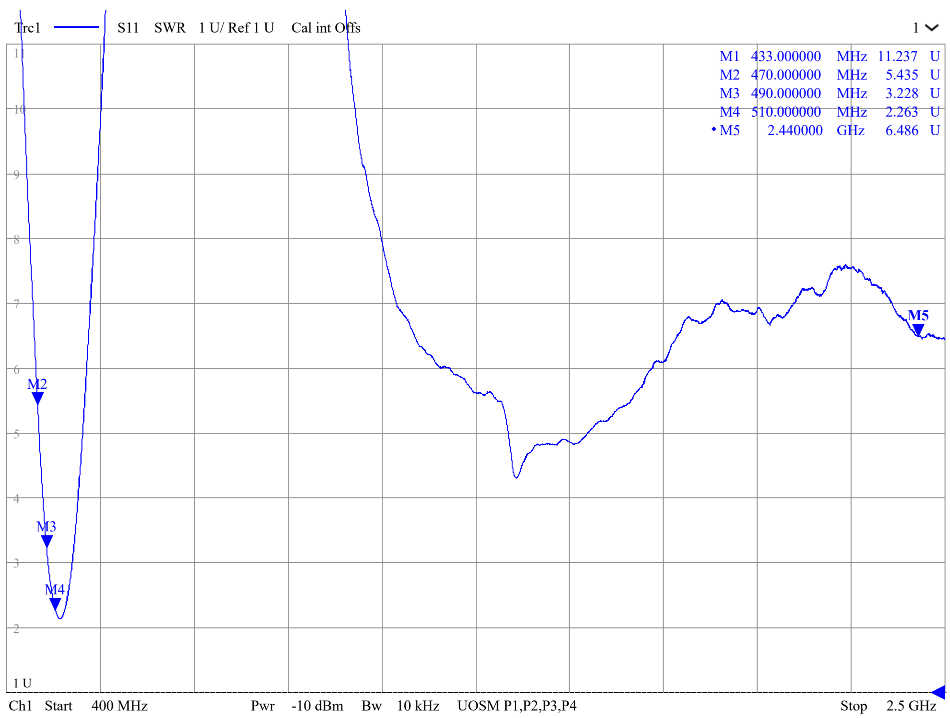

Figure 3-10. SWR after placing 27 nH at Z64

3.2.5 868/915 MHz Unmatched

Figure 3-11 and Figure 3-12 shows the Smith chart and SWR after placing 2 pF capacitor on Z64 to support the 868/915 MHz frequency (keeping Z60–Z63 unchanged). Since the bandwidth of the antenna is great enough to support both 868 and 915 MHz the resonance of the antenna was tuned for ((915+896) / 2 ≈) 892 MHz.

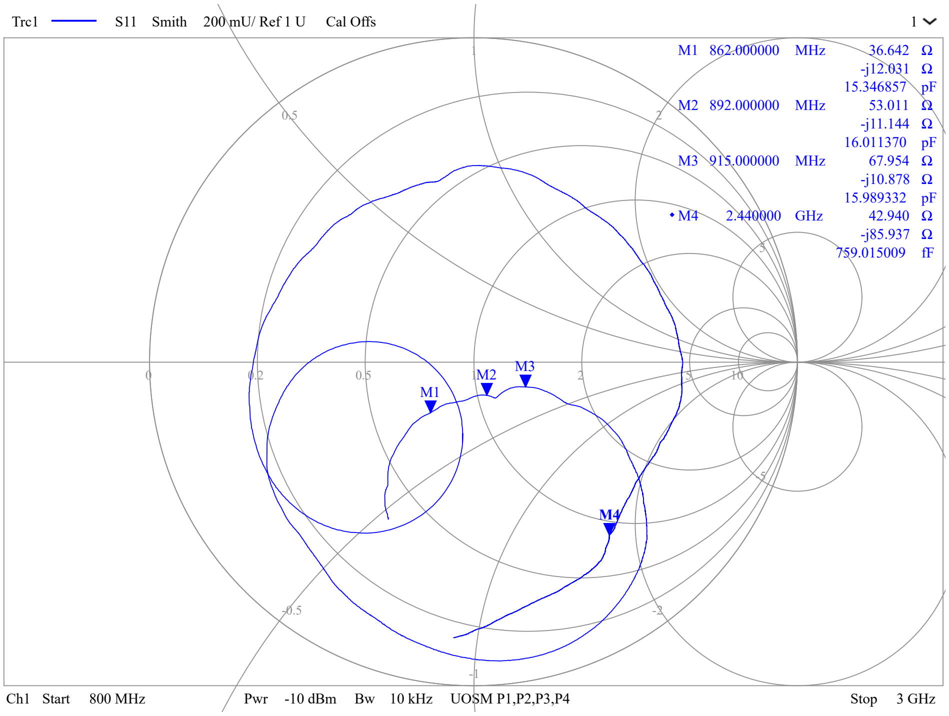

Figure 3-11. Smith Chart After placing a 2-pF Capacitor on Z64.

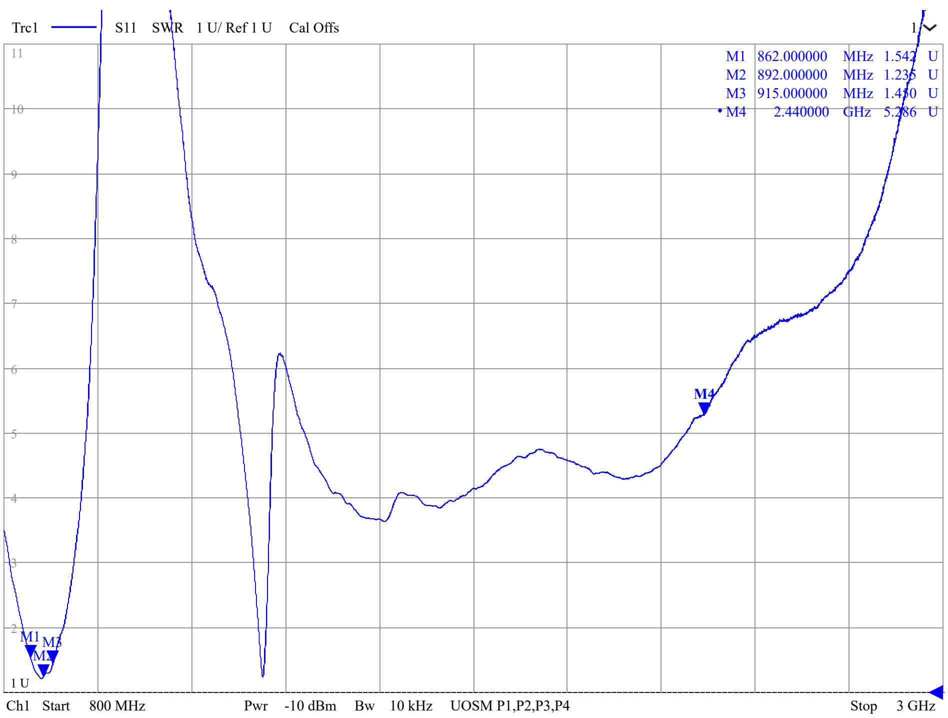

Figure 3-12. SWR After Placing a 2-pF Capacitor on Z64.

4 Single-Band Matching and Result

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.

When matching the antenna to 50 ohm a Smith chart tool will give a good indication on the component values needed to match the antenna. However, there will be a deviation between the theoretical impedance given by the Smith chart and realized value. Therefore, further tuning might be necessary in order to archive a good match.

4.1 433-MHz Smith chart, SWR, Bandwidth, and Efficiency

Figure 4-1 shows the theoretical Smith chart for matching the antenna for single-band 433 MHz with a theoretical SWR of 1.026.

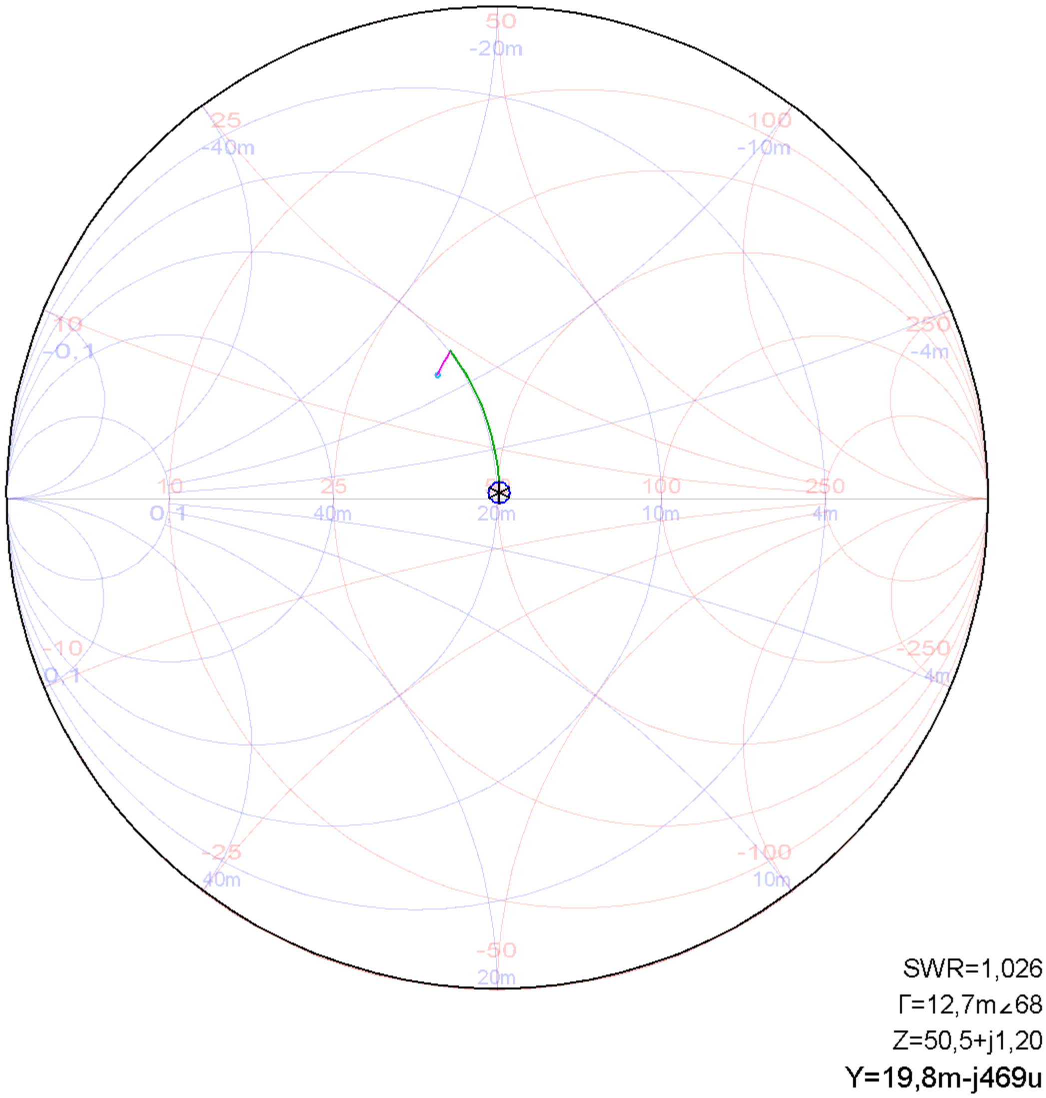

Figure 4-1. Theoretical Smith Chart for Single-Band 433-MHz Matching

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 4-2 and Figure 4-3 shows the resulting impedance and SWR which at 1.05 is less than the threshold for a good match of SWR < 2.0. Table 4-1 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 4-3 to be 444.78-422 = 22.78 MHz.

Table 4-1. Matching Network BOM for 433-MHz Single-Band Operations.

Ref. Designator	Murata Part Number	Value
Z60		0 Ω
Z61		DNM
Z62	GRM0335C1H4R3CA01	4.7 pF
Z63	LQP03TN2N0B02	2 nH
Z64	LQP03TN51NH02	51 nH

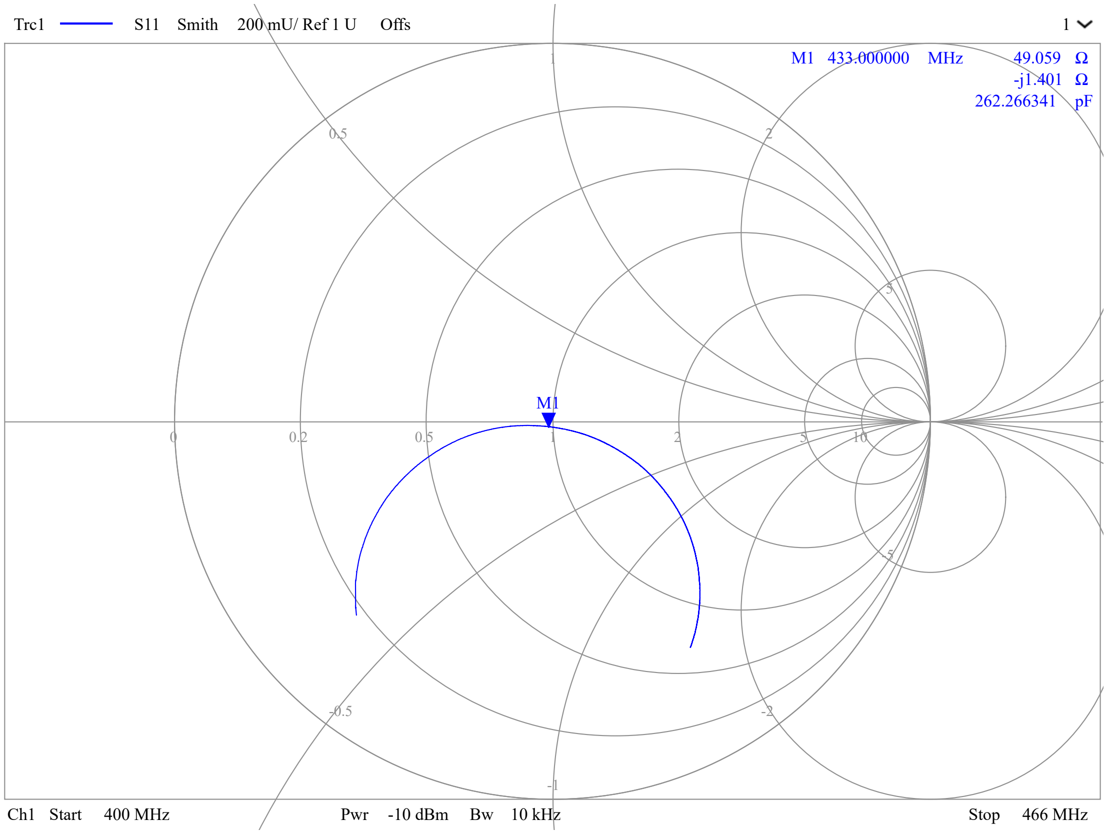

Figure 4-2. Smith Chart of Antenna Matched for 433-MHz Single Band

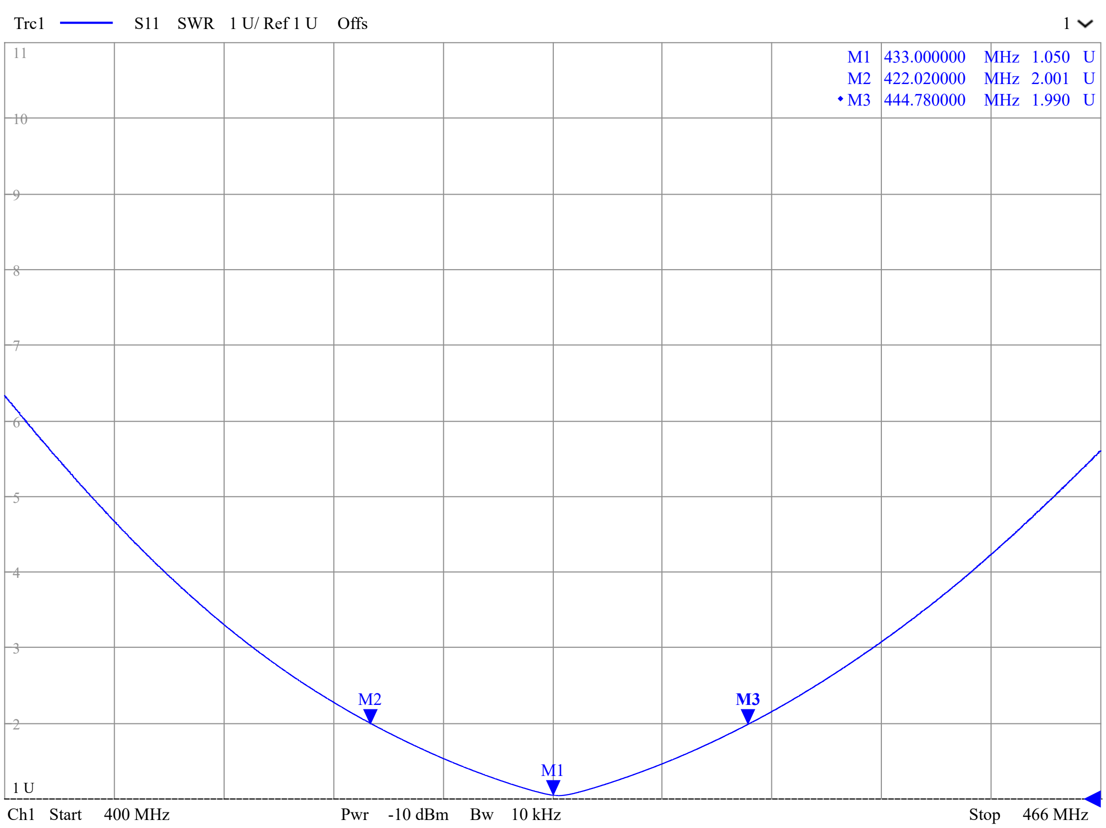

Figure 4-3. SWR Measurement of 433-MHz and Bandwidth at SWR < 2

Figure 4-4 shows the radiation pattern of the antenna matched for 433 MHz radiating at 13 dBm 433 MHz. The figure shows a TRP of 5.25 dBm, this with a measured conducted output power of 12.42 dBm gives us an efficiency of 19.19%.

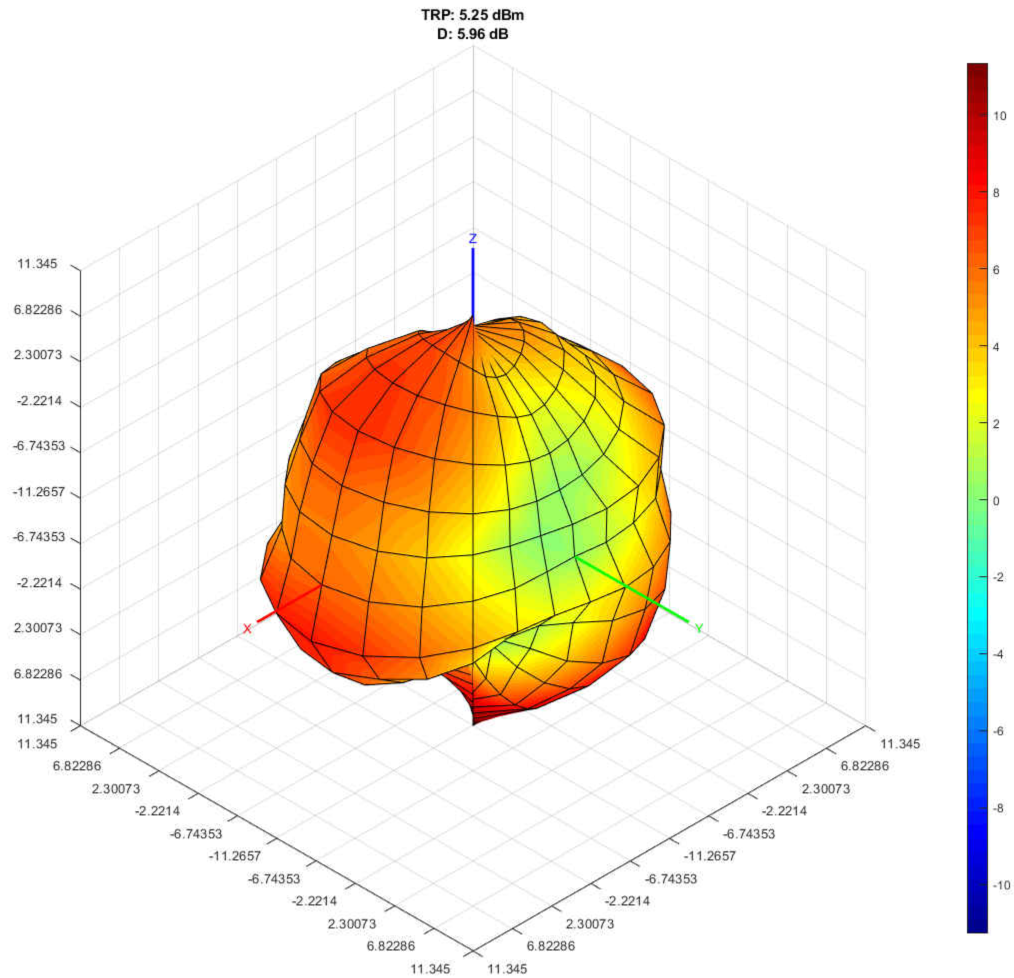

Figure 4-4. Radiation Pattern of Antenna Matched for 433-MHz Radiating with 13 dBm 433-MHz Setting

4.2 470-MHz Smith chart, SWR, Bandwidth, and Efficiency

Figure 4-5 shows the theoretical Smith chart for matching the antenna for single-band 470 MHz with a theoretical SWR of 1.025

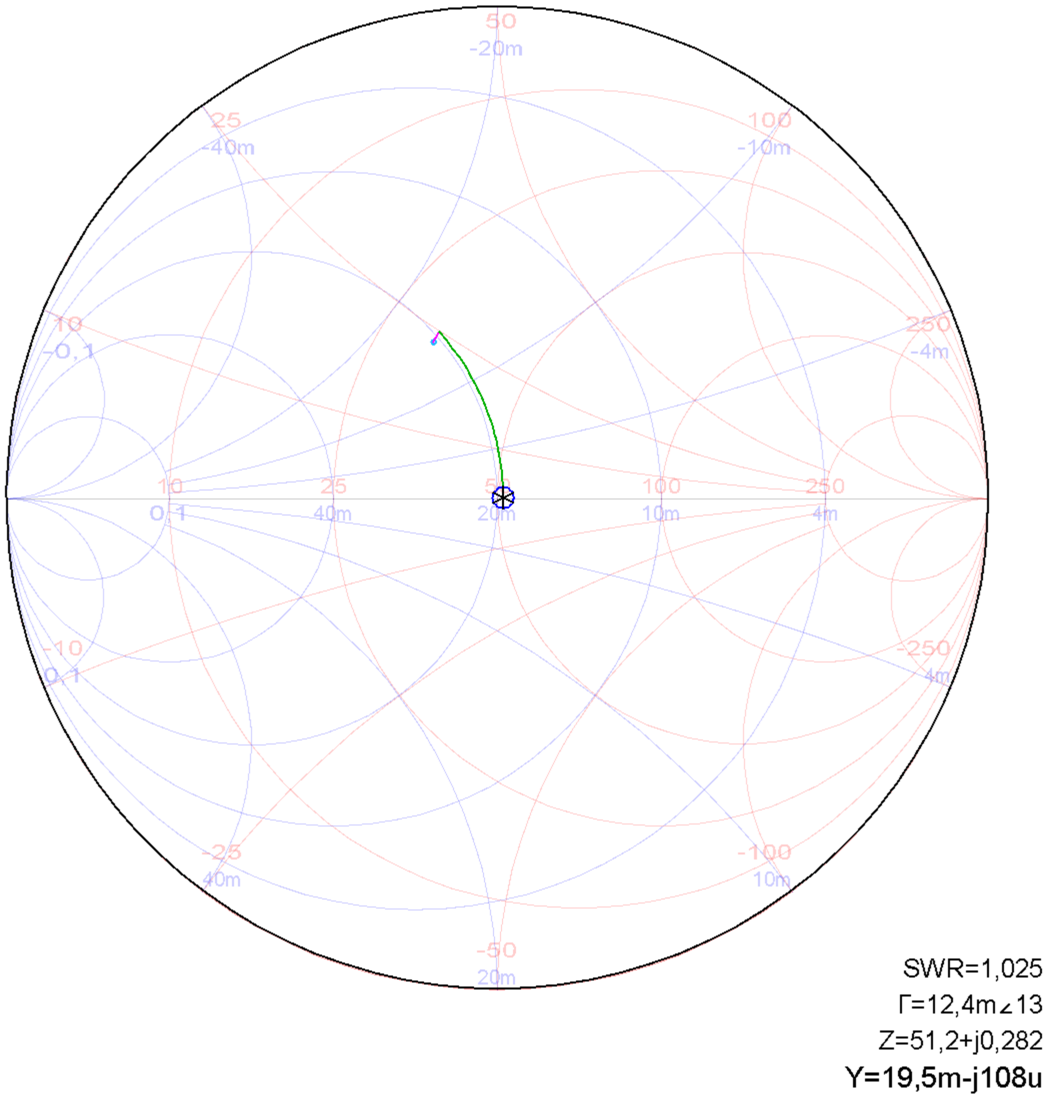

Figure 4-5. Theoretical Smith Chart for Single-Band 470-MHz Matching

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 4-6 and Figure 4-7 shows the resulting impedance and SWR which at 1.074 is less than the threshold for a good match of SWR < 2.0. Table 4-2 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 4-7 to be 490-465 = 25 MHz.

Table 4-2. Matching Network BOM for 470-MHz Single-Band Operations

Ref. Designator	Murata Part Number	Value
Z60		0 Ω
Z61		DNM
Z62	GRM0335C1H5R1CA01	5.1 pF
Z63	LQP03TN6N2B02	6.2 nH
Z64	LQP03TN39NH02	39 nH

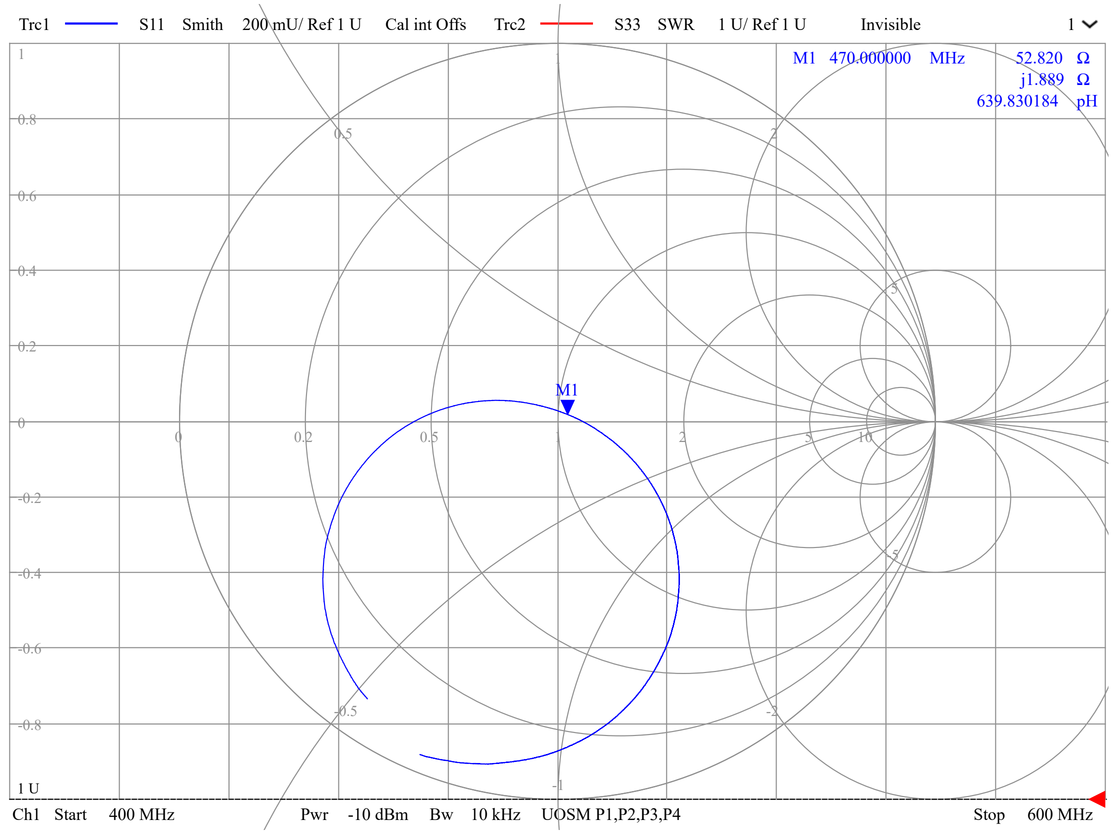

Figure 4-6. Smith Chart of Antenna Matched for 470-MHz Single Band.

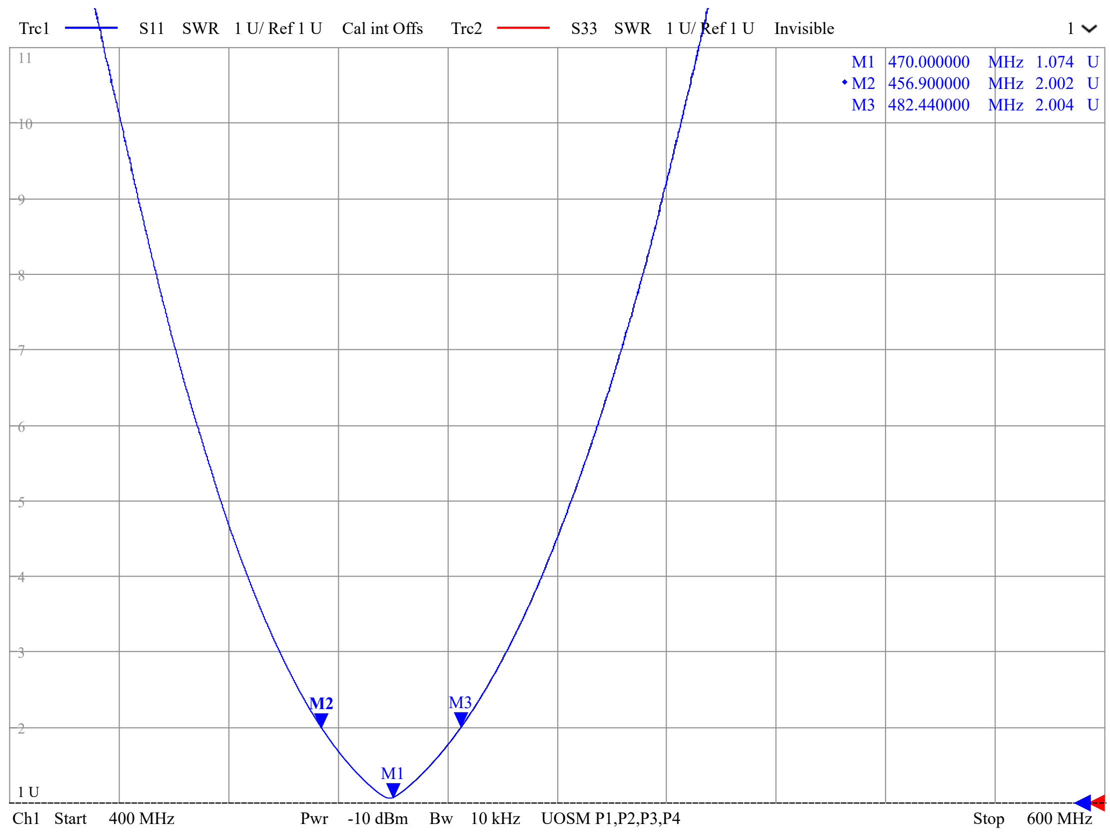

Figure 4-7. SWR Measurement of 470 MHz and Bandwidth at SWR < 2

Figure 4-8 shows the radiation pattern of the antenna matched for 470 MHz radiating at 13 dBm 470 MHz. The figure shows a TRP of 8.06 dBm, this with a measured conducted output power of 12.65 dBm gives us an efficiency of 34.8%.

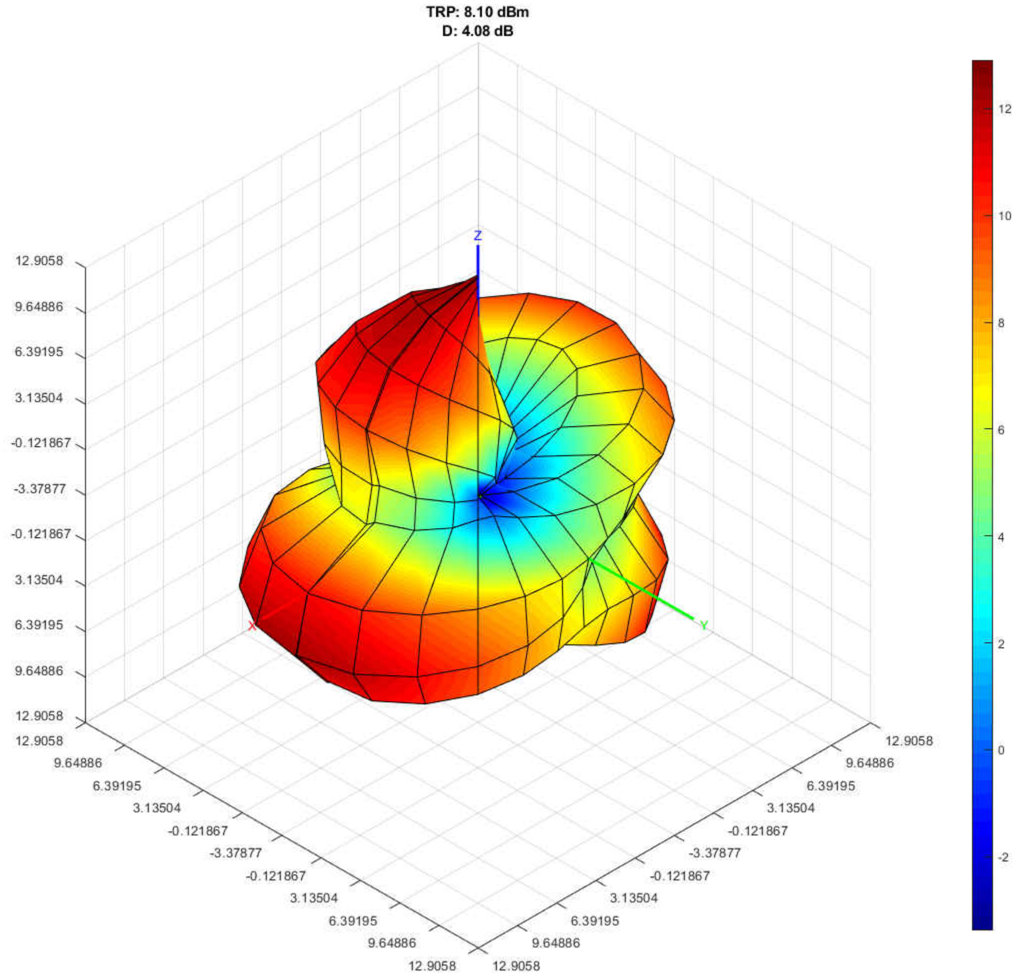

Figure 4-8. Radiation Pattern of the Antenna Matched for 470-MHz Radiating with 13 dBm 470-MHz Setting

4.3 490-MHz Smith Chart, SWR, Bandwidth, and Efficiency

Figure 4-9 shows the theoretical Smith chart for matching the antenna for single-band 470 MHz with a theoretical SWR of 1.017.

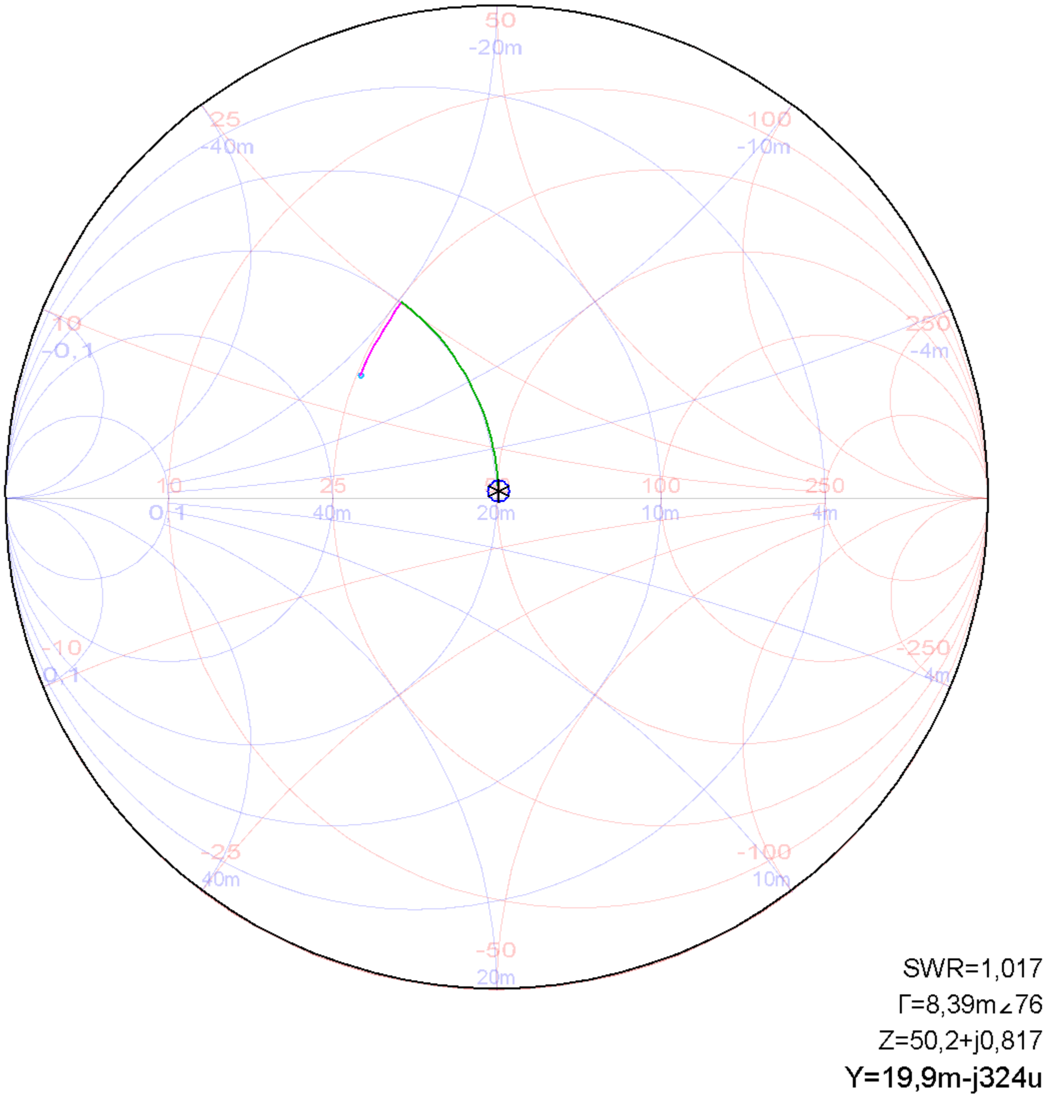

Figure 4-9. Theoretical Smith Chart for Single-Band 490 MHz Matching

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 4-10 and Figure 4-11 shows the resulting impedance and SWR which at 1.05 is less than the threshold for a good match of SWR < 2.0. Table 4-3 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 4-11 to be 503.3-478.5 =24.8 MHz.

Table 4-3. Matching Network BOM for 490-MHz Single-Band Operations

Ref. Designator	Murata Part Number	Value
Z60		0 Ω
Z61		DNM
Z62	GRM0335C1H6R2CA01	6.2 pF
Z63	LQP03TN6N2H02	6.2 nH
Z64	LQP03TN33NH02	33 nH

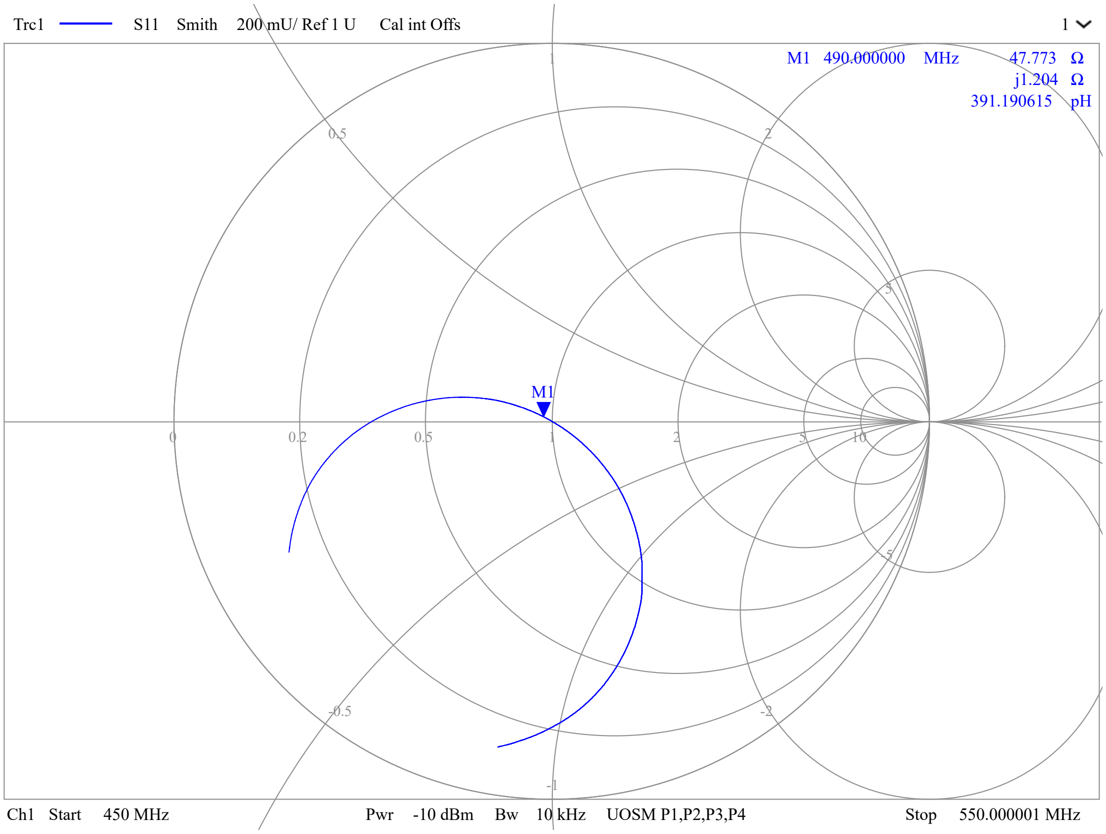

Figure 4-10. Smith Chart of Antenna Matched for 490-MHz Single Band

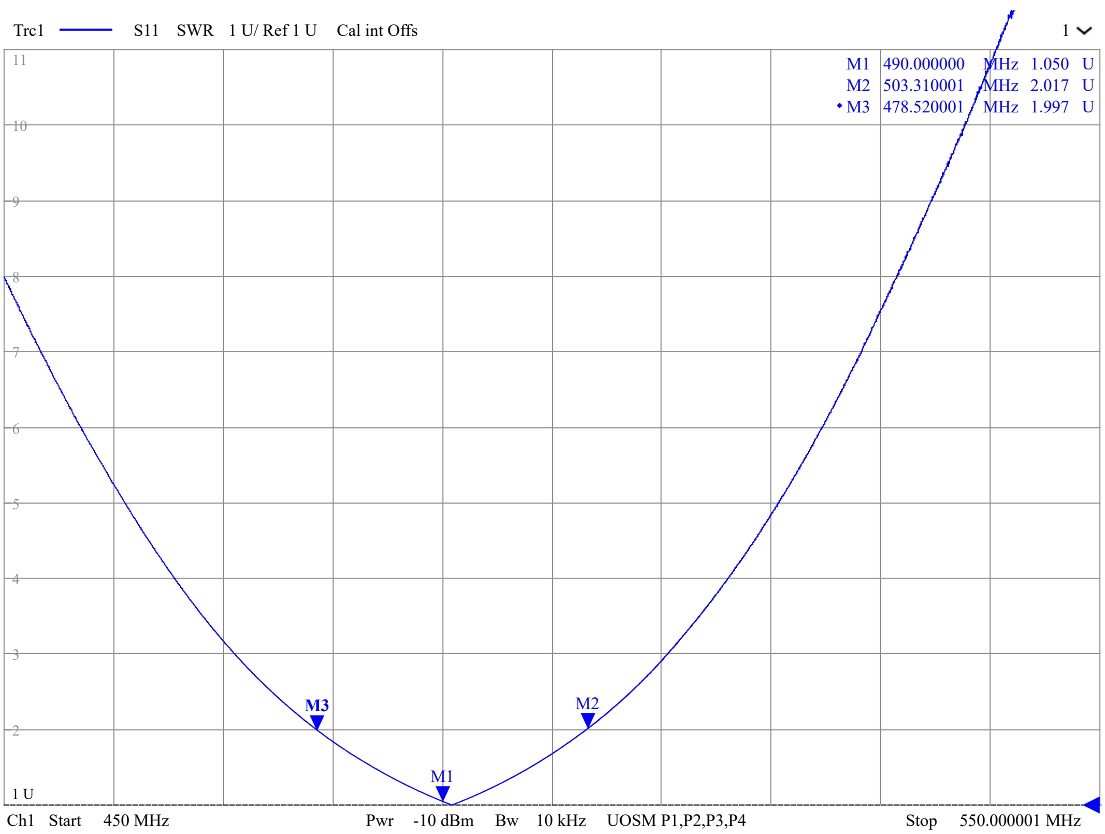

Figure 4-11. SWR Measurement of 490 MHz and Bandwidth at SWR < 2

Figure 4-12 shows the radiation pattern of the antenna matched for 490 MHz radiating at 13 dBm 490 MHz. The figure shows a TRP of 7.72 dBm, this with a measured conducted output power of 12.17 dBm gives us an efficiency of 35.89%.

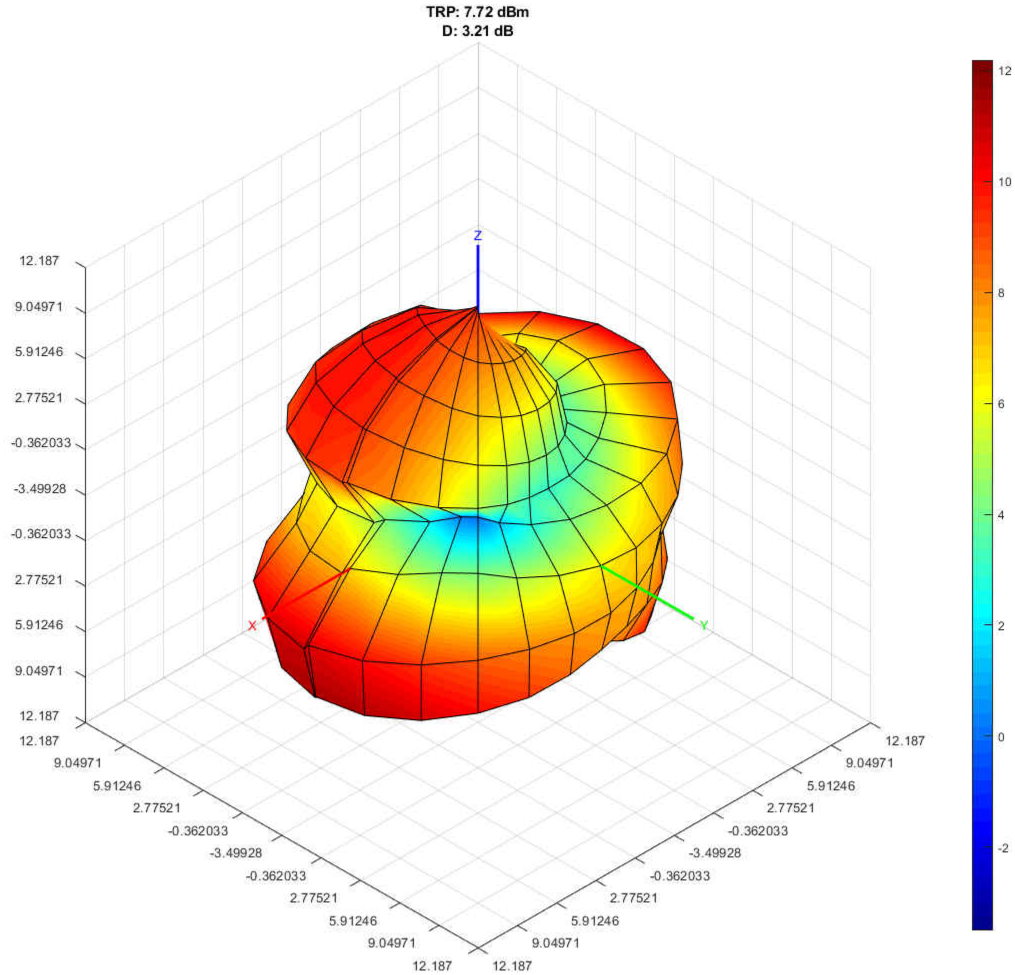

Figure 4-12. Radiation Pattern of the Antenna Matched for 490-MHz Radiating with 13 dBm 490-MHz Setting

4.4 510-MHz Smith Chart, SWR, Bandwidth, and Efficiency

Figure 4-13 shows the theoretical Smith chart for matching the antenna for single-band 470 MHz with a theoretical SWR of 1.017.

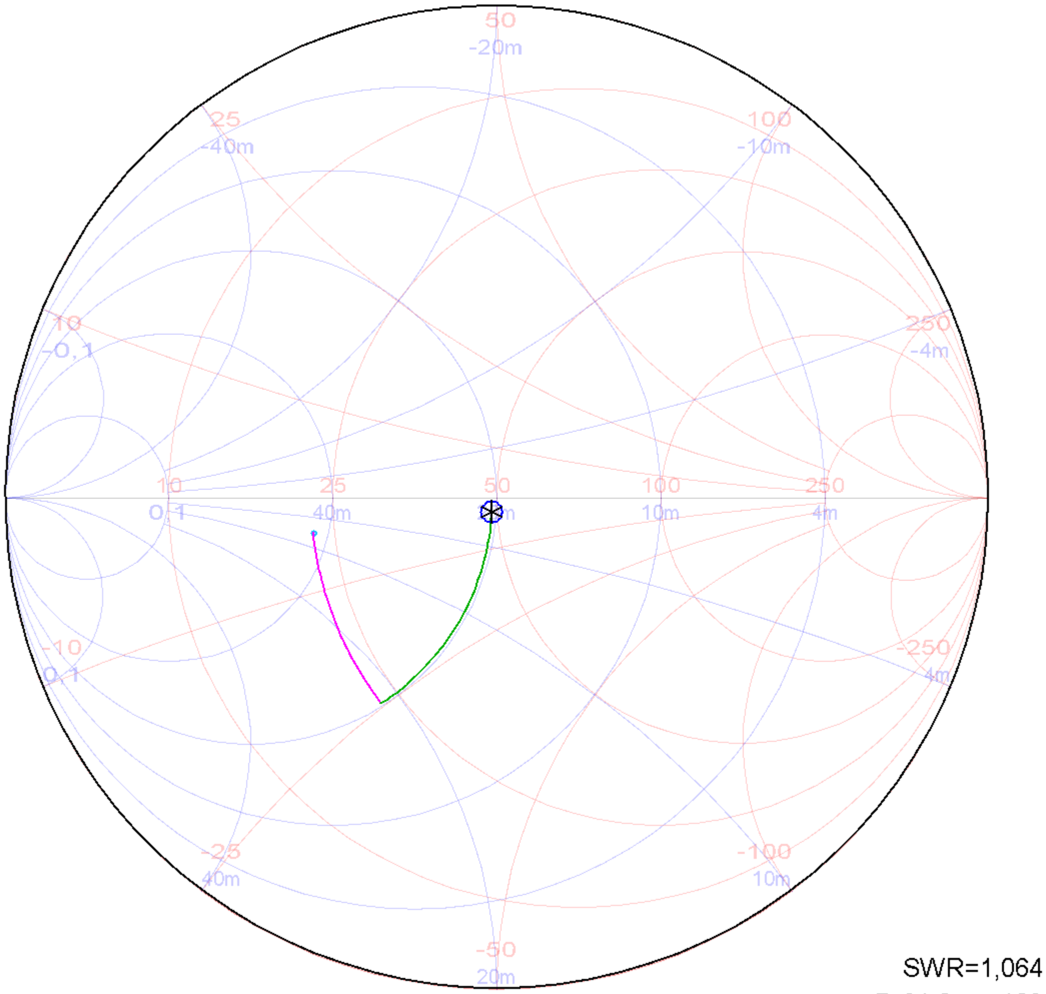

Figure 4-13. Theoretical Smith Chart for Single-Band 510-MHz Matching

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 4-14 and Figure 4-15 shows the resulting impedance and SWR which at 1.302 is less than the threshold for a good match of SWR < 2.0. Table 4-4 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 4-15 to be 529-500 = 29 MHz

Table 4-4. Matching Network BOM for 510-MHz Single-Band Operations

Ref. Designator	Murata Part Number	Value
Z60		0 Ω
Z61		DNM
Z62	GRM0335C1H8R2CA01	8.3 pF
Z63	LQP03TN11NH02	11 nH
Z64	LQP03TN27NH02	27 nH

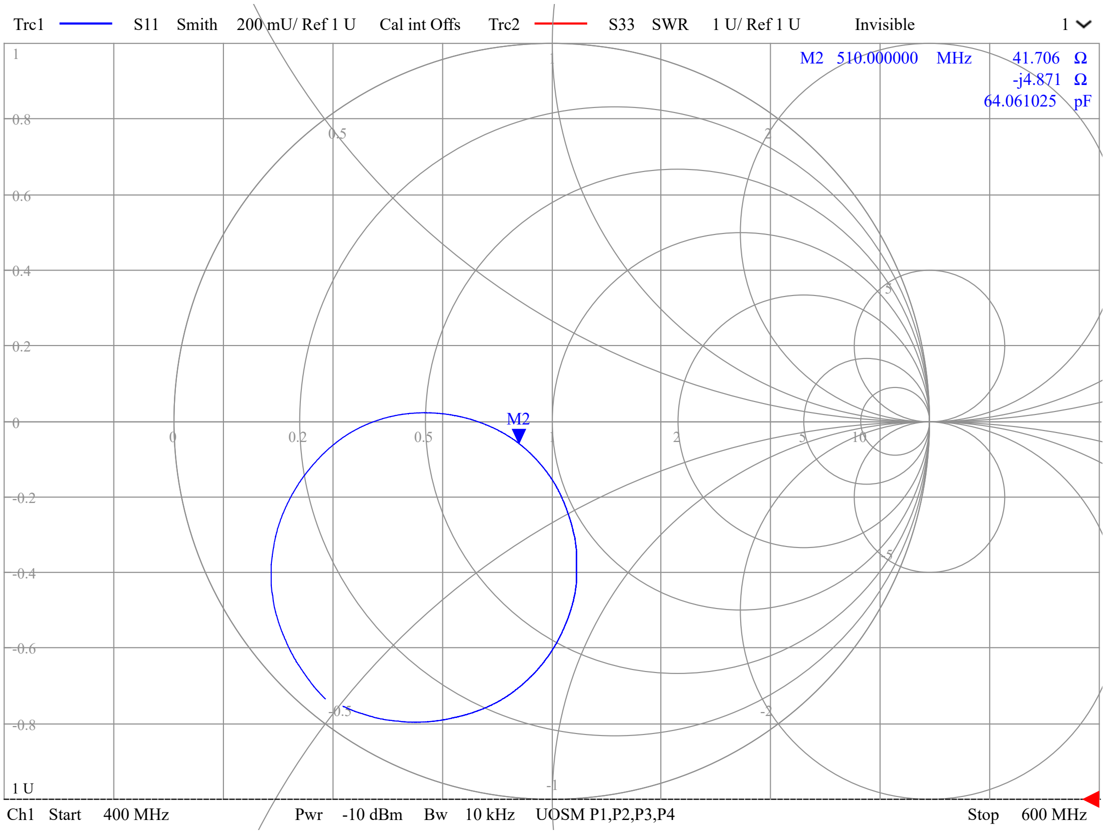

Figure 4-14. Smith Chart of Antenna Matched For 510-MHz Single Band

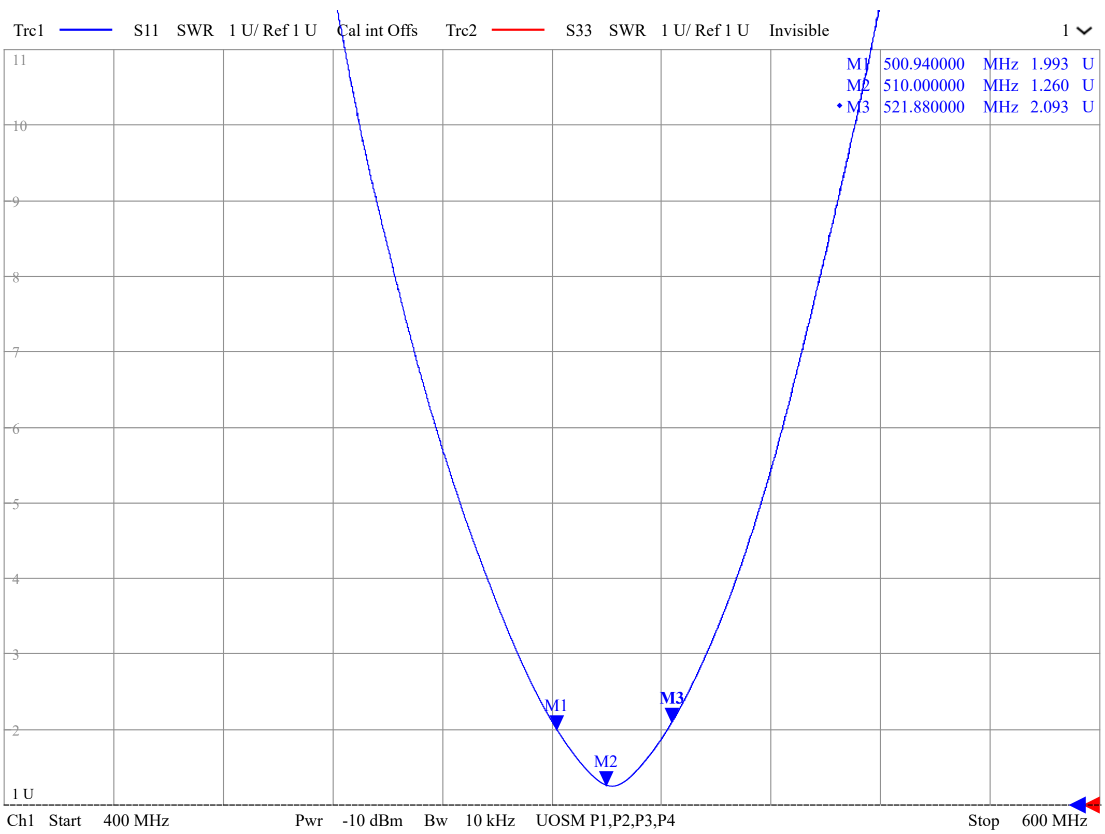

Figure 4-15. SWR Measurement of 510 MHz And Bandwidth at SWR < 2

Figure 4-16 shows the radiation pattern of the antenna matched for 510 MHz radiating at 13 dBm 510 MHz. The figure shows a TRP of 6.94 dBm, this with a measured conducted output power of 11.77 dBm gives us an efficiency of 32.9%.

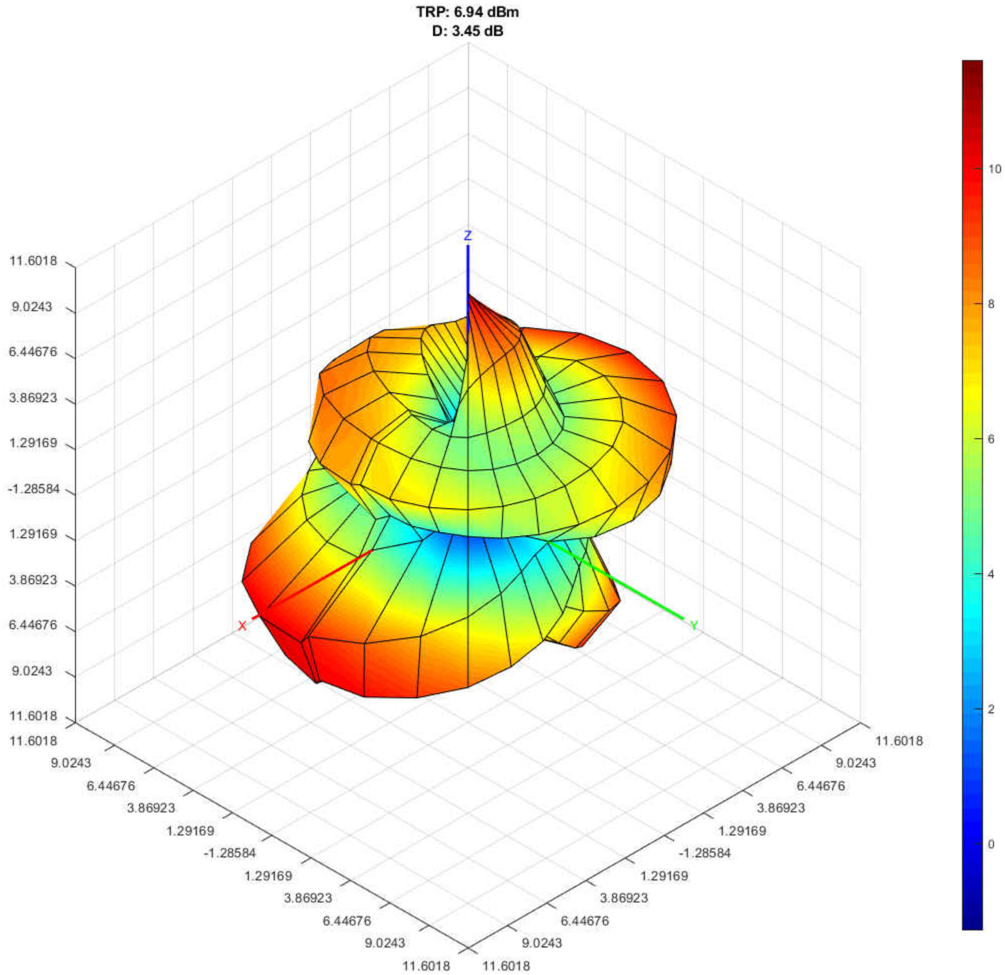

Figure 4-16. Radiation Pattern of the Antenna Matched for 510-MHz Radiating with 13 dBm 510-MHz Setting

4.5 868/915-MHz Smith Chart, SWR, Bandwidth, and Efficiency

As mentioned earlier in Section 3.2.5 the bandwidth of the antenna is sufficient to achieve a good match for 868 MHz and 915 MHz simultaneously. Hence we only need one matching network for both frequencies, and therefore tune the antenna for ((915+896) / 2 ≈) 892 MHz.

Figure 4-17 shows the theoretical Smith chart for matching the antenna for single-band 892 MHz with a theoretical SWR of 1.065.

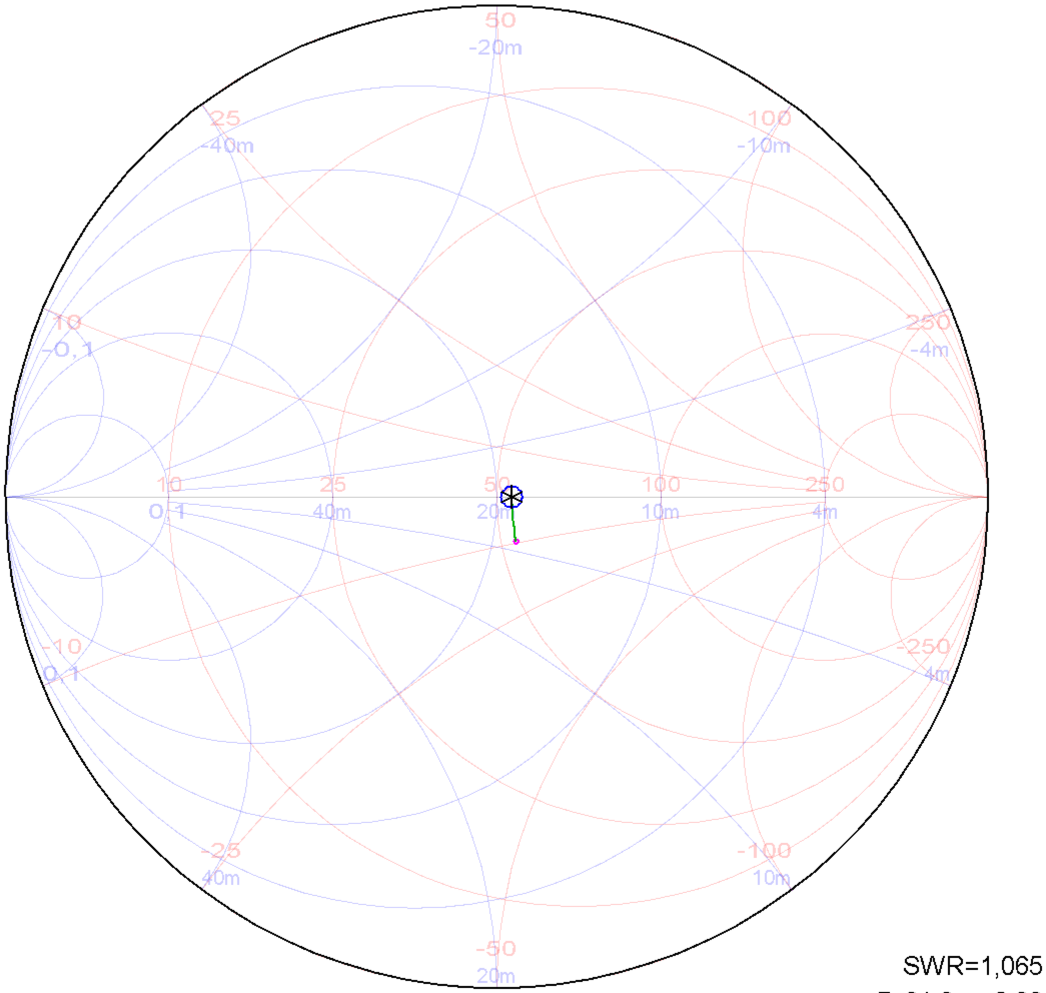

Figure 4-17. Theoretical Smith Chart for Single-Band 892-MHz Matching

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 4-18 and Figure 4-19 shows the resulting impedance and SWR which at 1.225 is less than the threshold for a good match of SWR < 2.0. Table 4-5 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 4-19 to be 941.16-845.8 = 95.81 MHz.

Table 4-5. Matching Network BOM for 892-MHz Single-Band Operations

Ref. Designator	Murata Part Number	Value
Z60		0 Ω
Z61		DNM
Z62		DNM
Z63		0 Ω
Z64	GRM0335C1H2R0CA01	2 pF

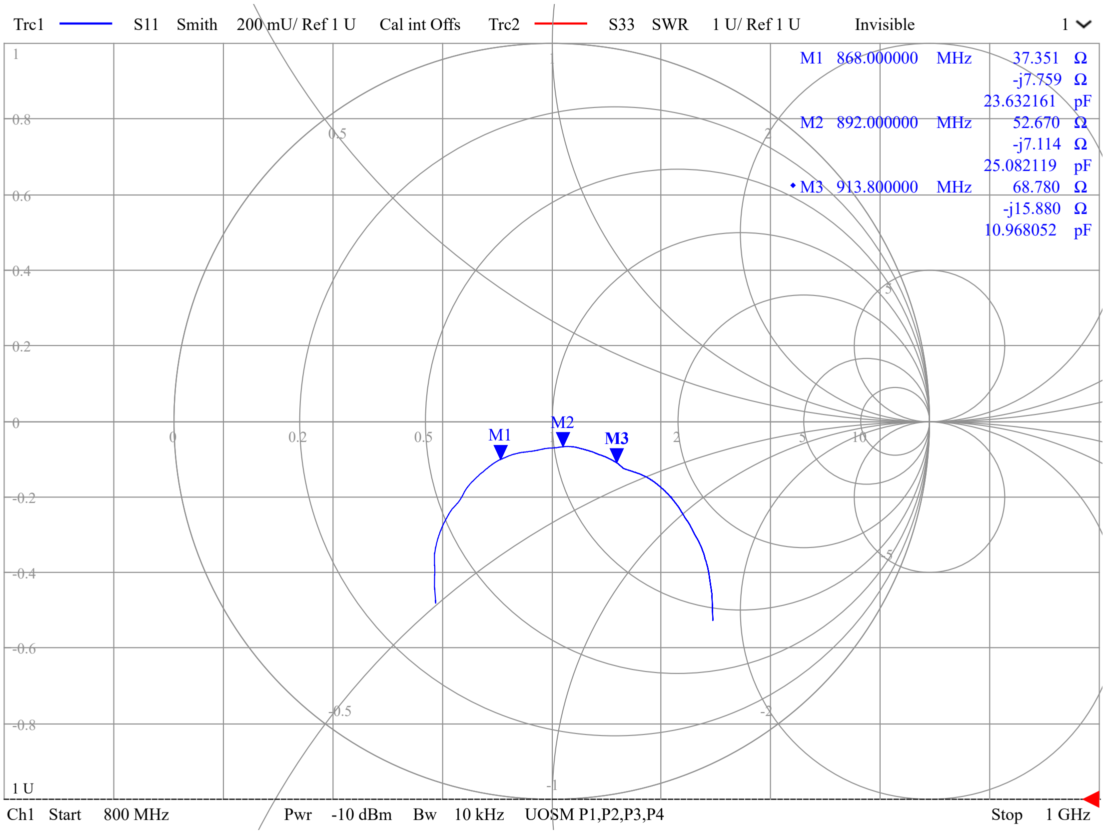

Figure 4-18. Smith Chart Measurement of 868, 892, and 915 MHz

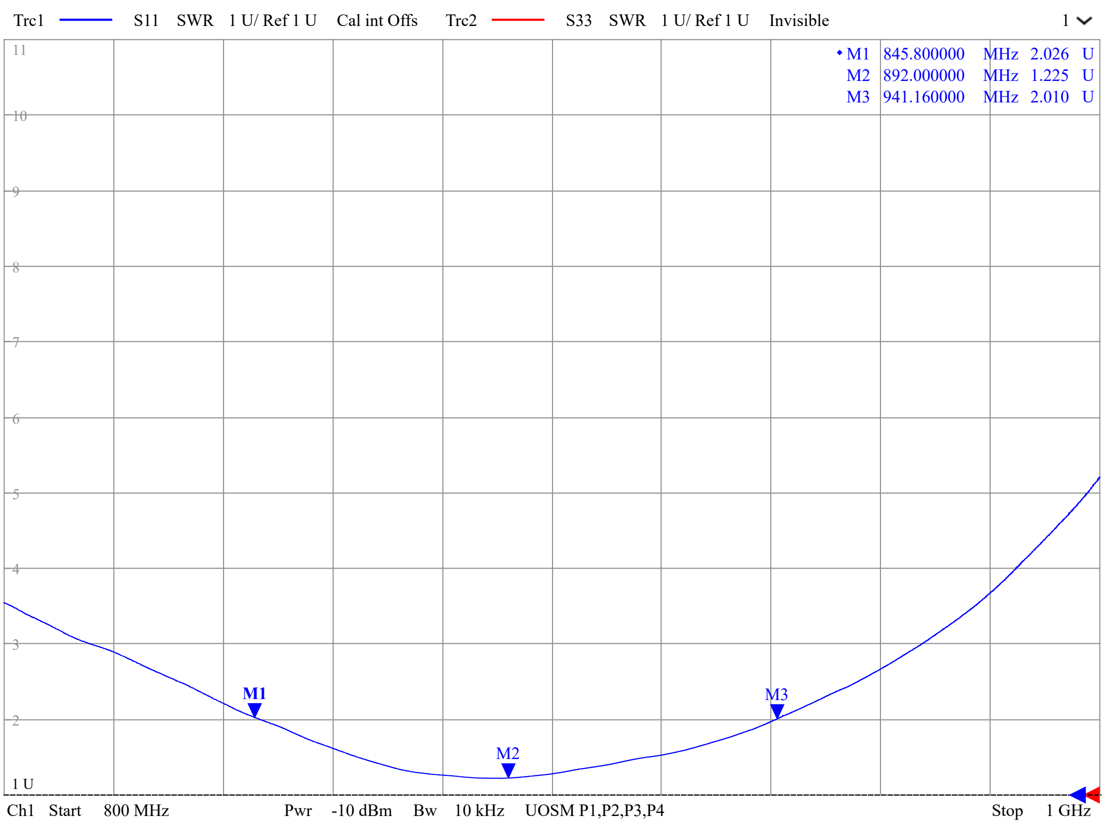

Figure 4-19. SWR Measurement of 892-MHz And Bandwidth at SWR < 2

Figure 4-20 and Figure 4-21 shows the radiation pattern of the antenna matched for 892 MHz radiating at 13 dBm 868/915 MHz. Table 4-6 shows the TRP and efficiency for the antenna with the given matching network

Table 4-6. TRP and Efficiency for 868/915 MHz

	Figure 38	Figure 39
Frequency	868 MHz	915 MHz
Power setting	13 dBm	13 dBm
Conducted output power	11.89 dBm	12.83 dBm
TRP	10.51 dBm	12.71 dBm
Efficiency	72.78 %	97.27 %

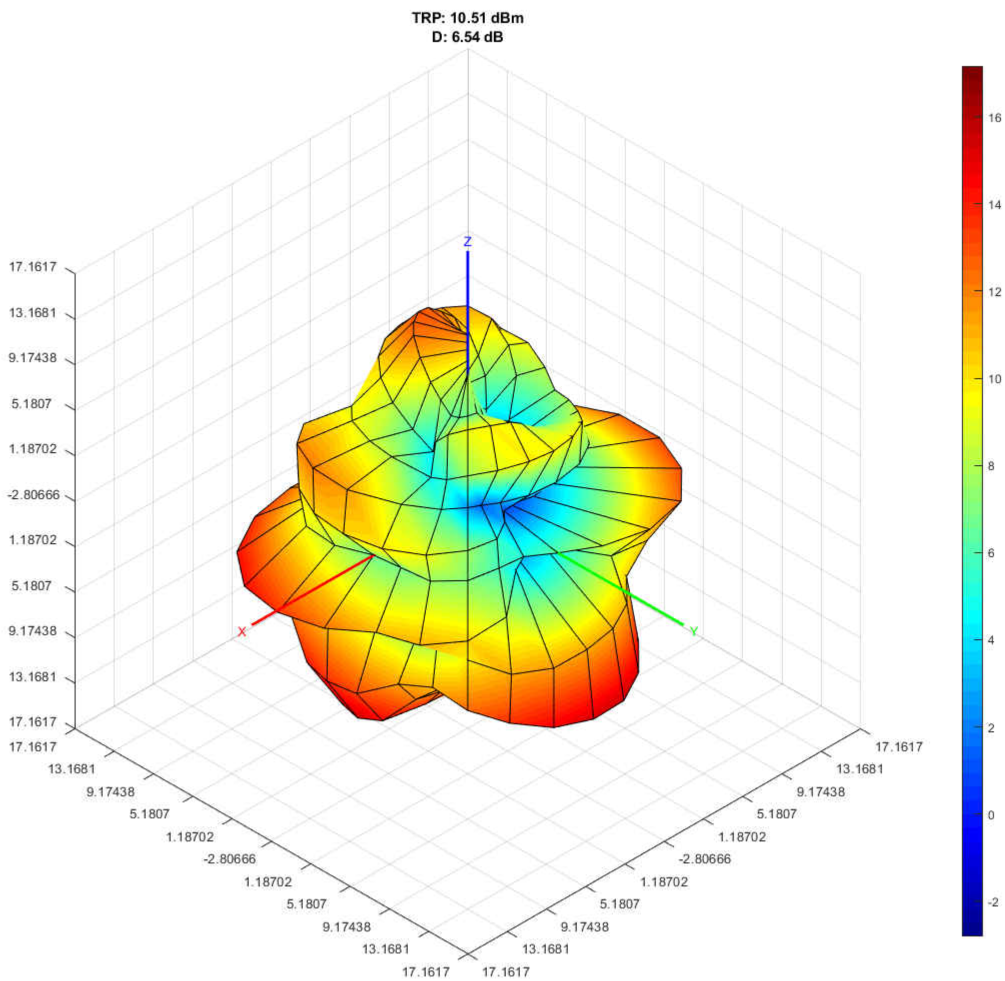

Figure 4-20. Radiation Pattern of the Antenna Matched for 892-MHz Radiating with 13 dBm 868-MHz Setting

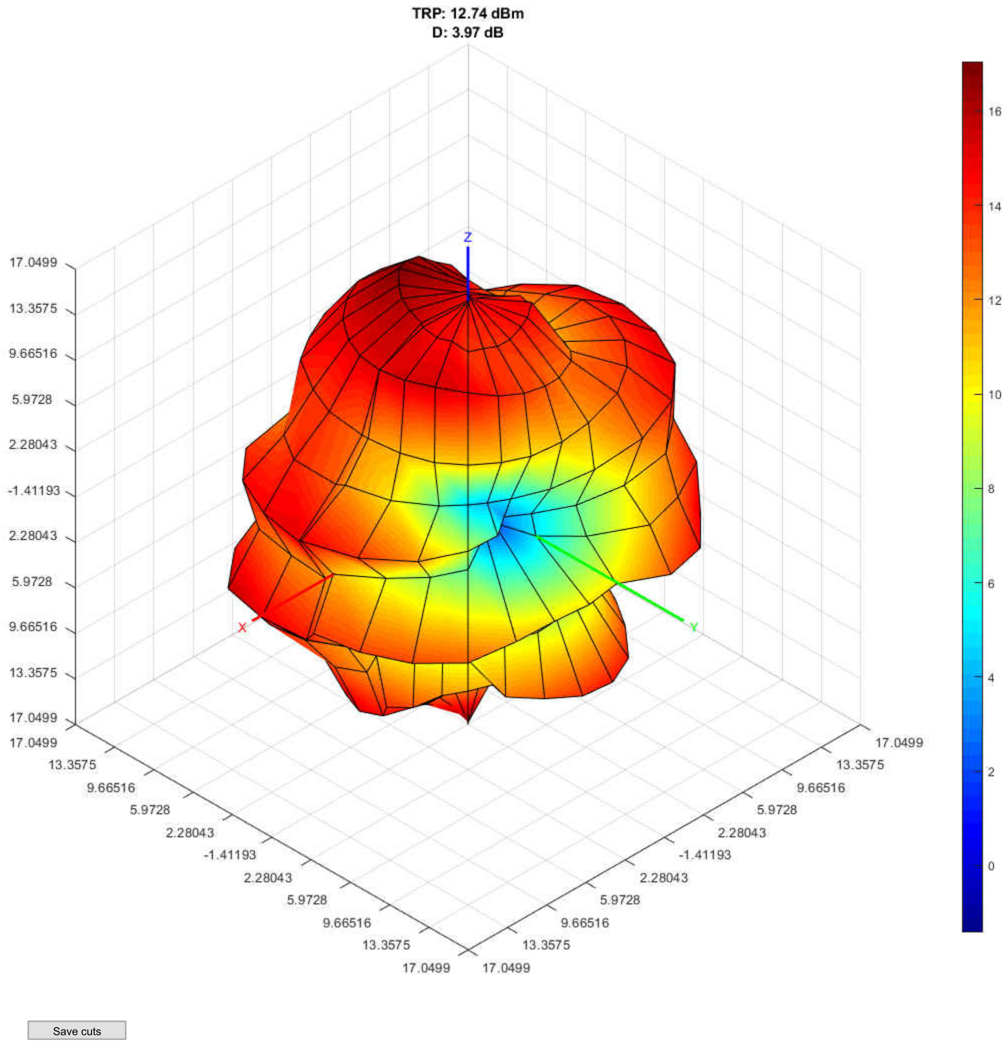

Figure 4-21. Radiation Pattern of the Antenna Matched for 892-MHz Radiating with 13 dBm 868-MHz Setting

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Note

If either 868 or 915 MHz is preferred over the other, the antenna can be tuned towards either frequency. This would increase the efficiency and bandwidth of the frequency.

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5 Dual Band Matching and 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.

As mentioned earlier, the antenna supports dual band operations with 2440 MHz in addition to either 433, 490-510 or 868/915 MHz. The tricky part with dual-band matching is to have a good match (SWR < 2) for both bands. The steps used is this app note are the following:

1. Use a Smith chart tool to match the low-band using only Z62 and Z63
2. Use a Smith chart tool to match the high-band by adding Z60 and Z61
3. Tune the values of the components until an acceptable SWR/Impedance is achieved
4. Test the matched using S11 on a VNA
5. Correct for deviation from the theoretical Smith chart in the high- and low- band

5.1 433-MHz and 2440-MHz Smith Chart, SWR, Bandwidth, and Efficiency

Figure 5-1 and Figure 5-2 show the theoretical Smith chart for matching the antenna for dual-band 433 and 2440 MHz with a theoretical SWR of 1.033 and 1.028.

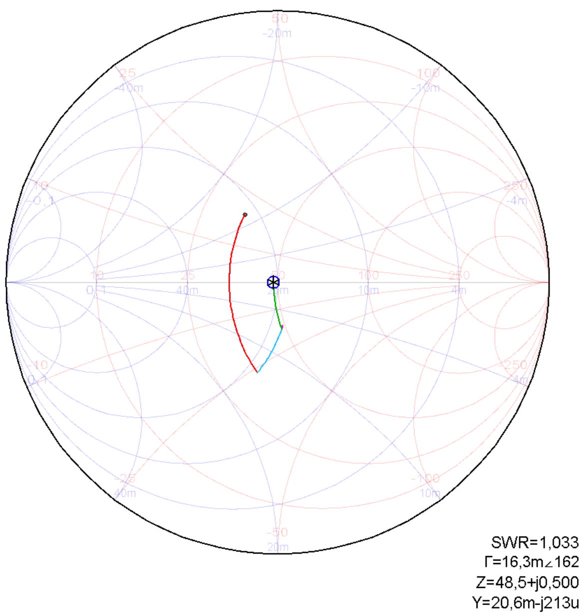

Figure 5-1. Theoretical Smith Chart for Dual-Band 433-MHz Match

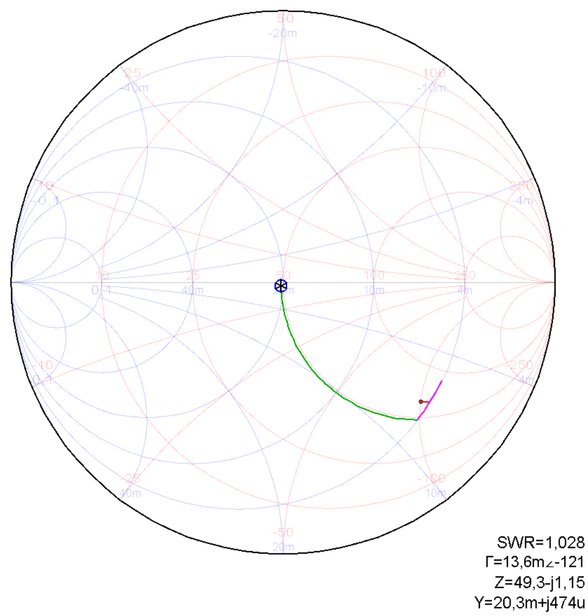

Figure 5-2. Theoretical Smith Chart for Dual-Band 2440-MHz Match

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 5-3 and Figure 5-4 shows the resulting impedance and SWR which at 1.113 for 433 MHz and 1.201 for 2440 MHz is less than the threshold for a good match of SWR < 2.0. Table 5-1 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 5-4 to be 445.6 - 421.6 = 24 MHz for 433 MHz and 2570-2320 = 250 MHz for 2440 MHz.

Table 5-1. Matching Network BOM for 433 and 2440-MHz Dual-Band Operations

Ref. Designator	Murata Part Number	Value
Z60	LQP03TN6N8H02	6.8 nH
Z61		DNM
Z62	LQP03TN47NH02	47 nH
Z63	GRM0335C1H8R2CA01	8.2 pF
Z64	LQP03TN51NH02	51 nH

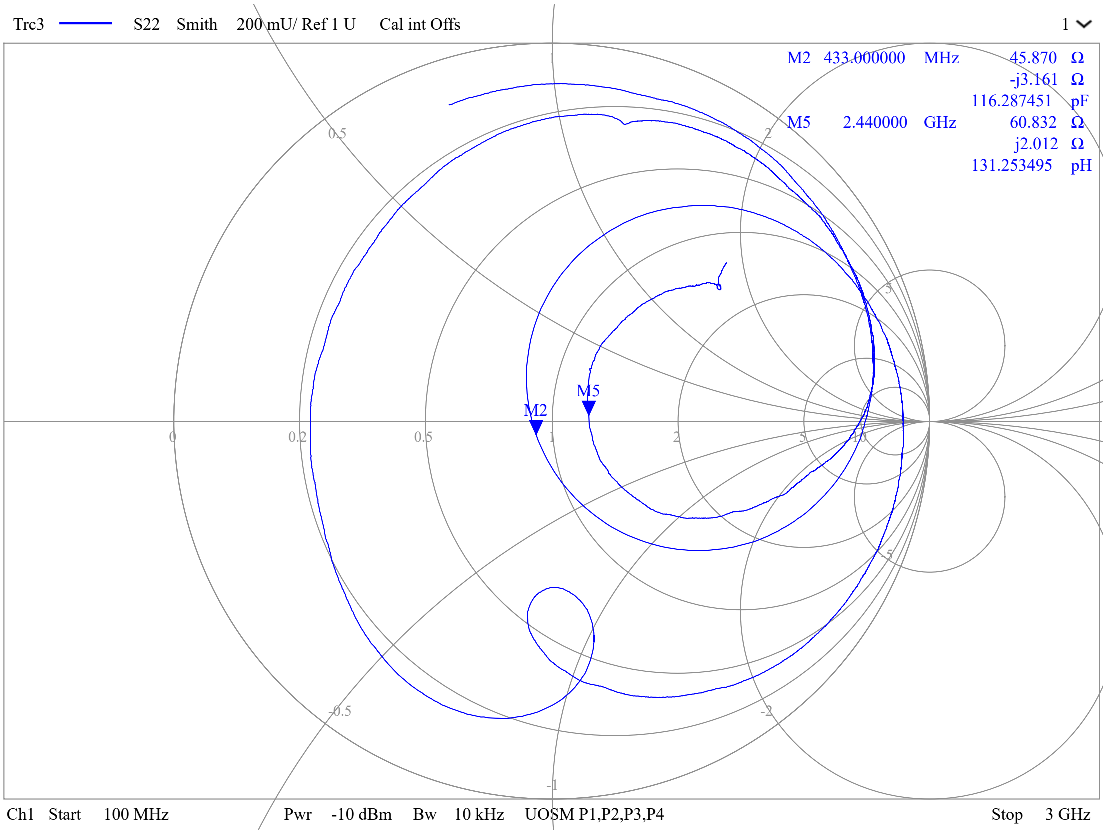

Figure 5-3. Smith Chart Measurement of Dual Band 433 MHz and 2.4 GHz

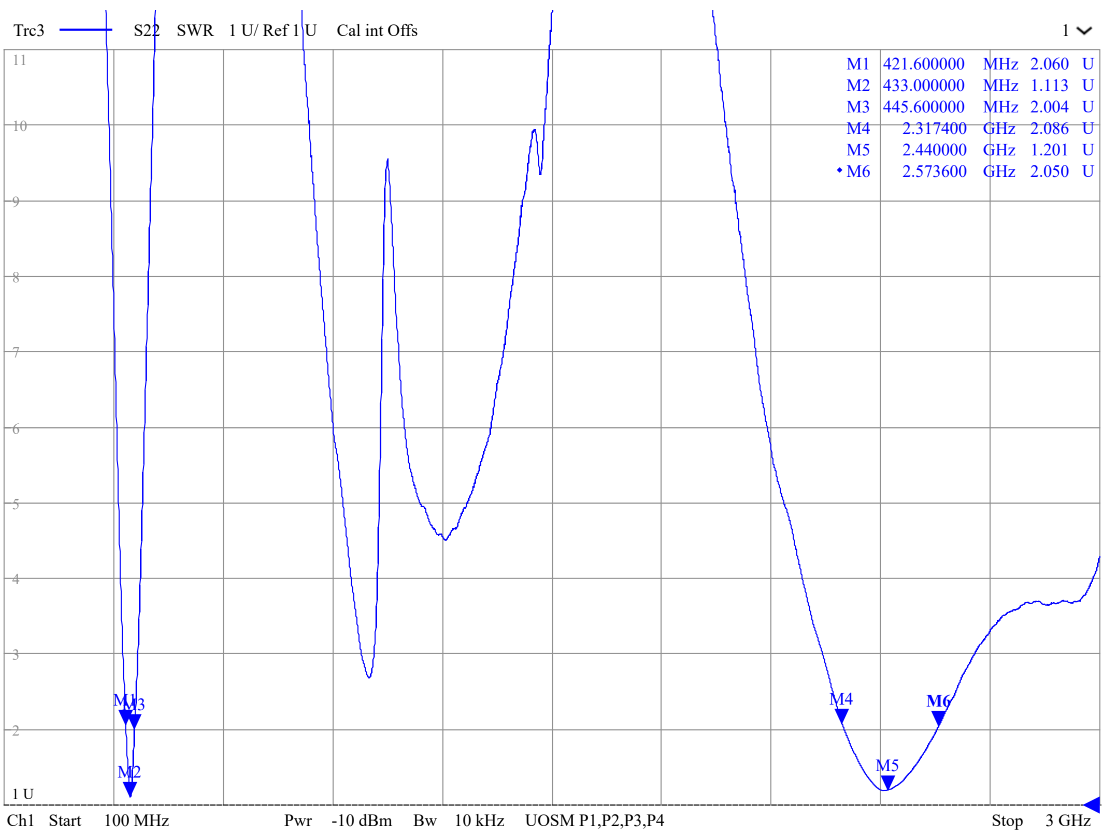

Figure 5-4. SWR Measurement of Dual Band 433 MHz, 2.4 GHz, and Bandwidth at SWR < 2

Figure 5-5 and Figure 5-6 shows the radiation pattern of the antenna at 433 and 2440 MHz. Table 5-2 shows the TRP and efficiency for the antenna with the given matching network.

Table 5-2. TRP and Efficiency for 433 and 2440 MHz Dual Band Antenna Match

	Figure 43	Figure 44
Frequency	433 MHz	2440 MHz
Power setting	13 dBm	10 dBm
Conducted output power	12.42 dBm	9.15 dBm
TRP	6 dBm	8.56 dBm
Efficiency	22.8 %	87.3 %

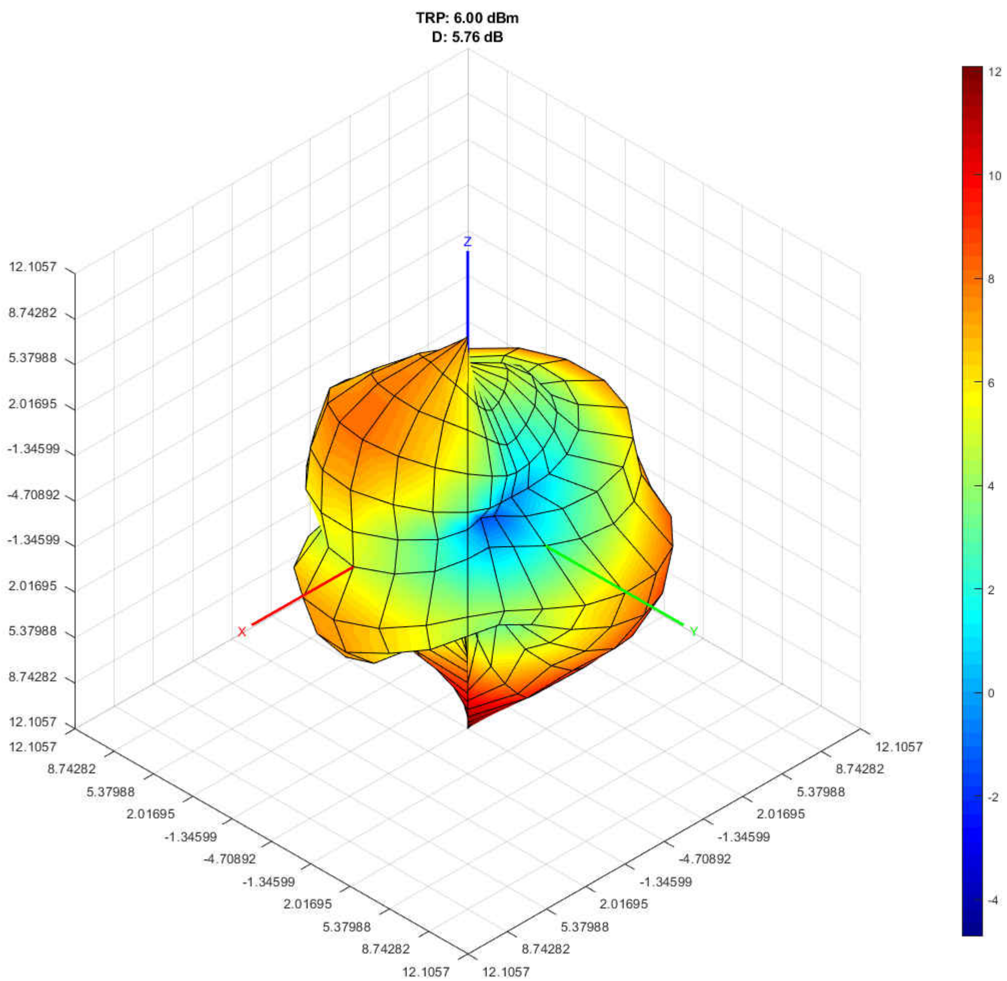

Figure 5-5. Radiation Pattern of the Antenna Matched for Dual-Band 433 and 2440-MHz Radiating with 13-dBm 433-MHz Setting

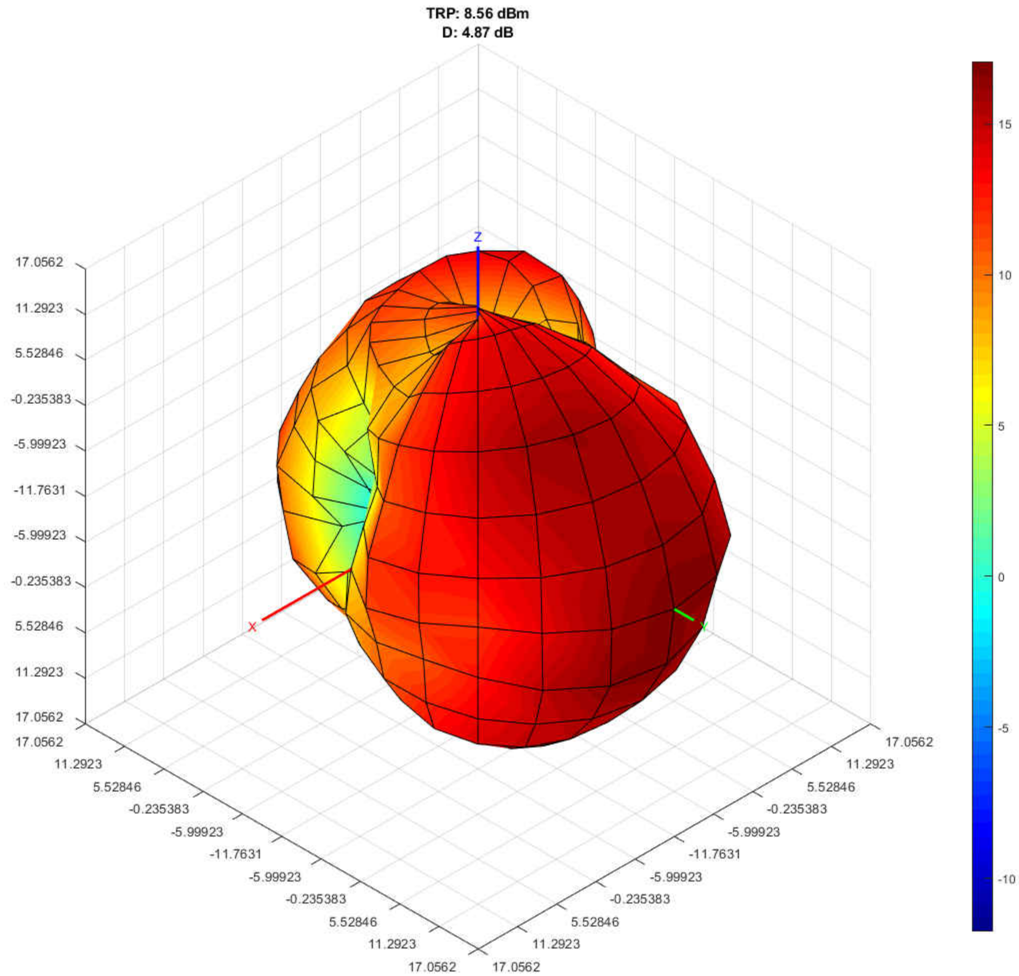

Figure 5-6. Radiation Pattern of the Antenna Matched for Dual-Band 433 and 2440-MHz Radiating with 10-dBm 2440-MHz Setting

5.2 470-MHz and 2440-MHz Smith Chart, SWR, Bandwidth and Efficiency

Figure 5-7 and Figure 5-8 shows the theoretical Smith chart for matching the antenna for dual-band 470 and 2440 MHz with a theoretical SWR of 1.023 and 1.047.

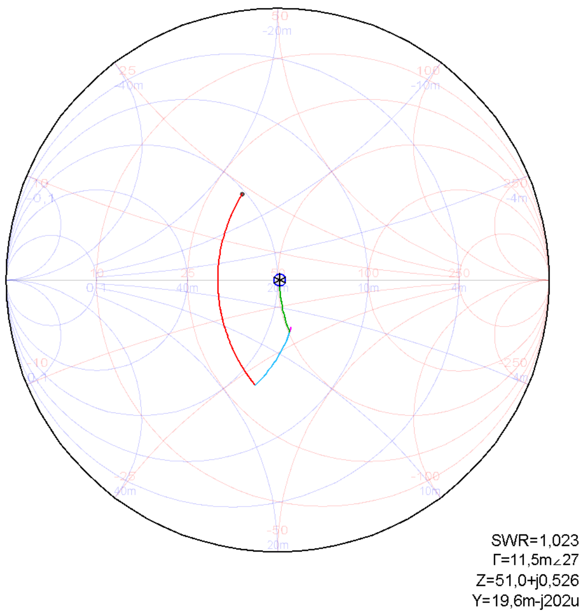

Figure 5-7. Theoretical Smith Chart for Dual Band 470-MHz Match

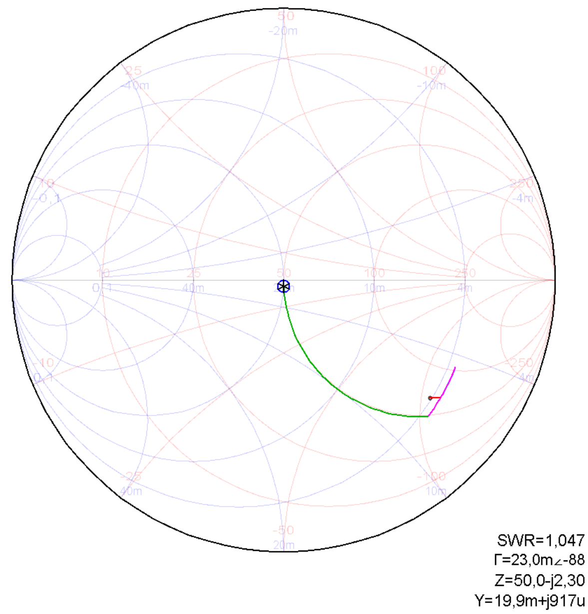

Figure 5-8. Theoretical Smith Chart for Dual Band 2440-MHz Match

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 5-9 and Figure 5-10 shows the resulting impedance and SWR which at 1.201 for 470 MHz and 1.278 for 2440 MHz is less than the threshold for a good match of SWR < 2.0. Table 5-3 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 5-10 to be 484-459 = 25 MHz for 470 MHz and 2556-2290 = 266 MHz for 2440 MHz.

Table 5-3. Matching Network BOM for 470 and 2440-MHz Dual-Band Operations

Ref. Designator	Murata Part Number	Value
Z60	LQP03TN6N2H02	6.2 nH
Z61	GRM0335C1HR10WA01	0.1 pF
Z62	LQP03TN36NH02	36 nH
Z63	GGRM0335C1H7R5CA01	7.5 pF
Z64	LQP03TN39NH02	39 nH

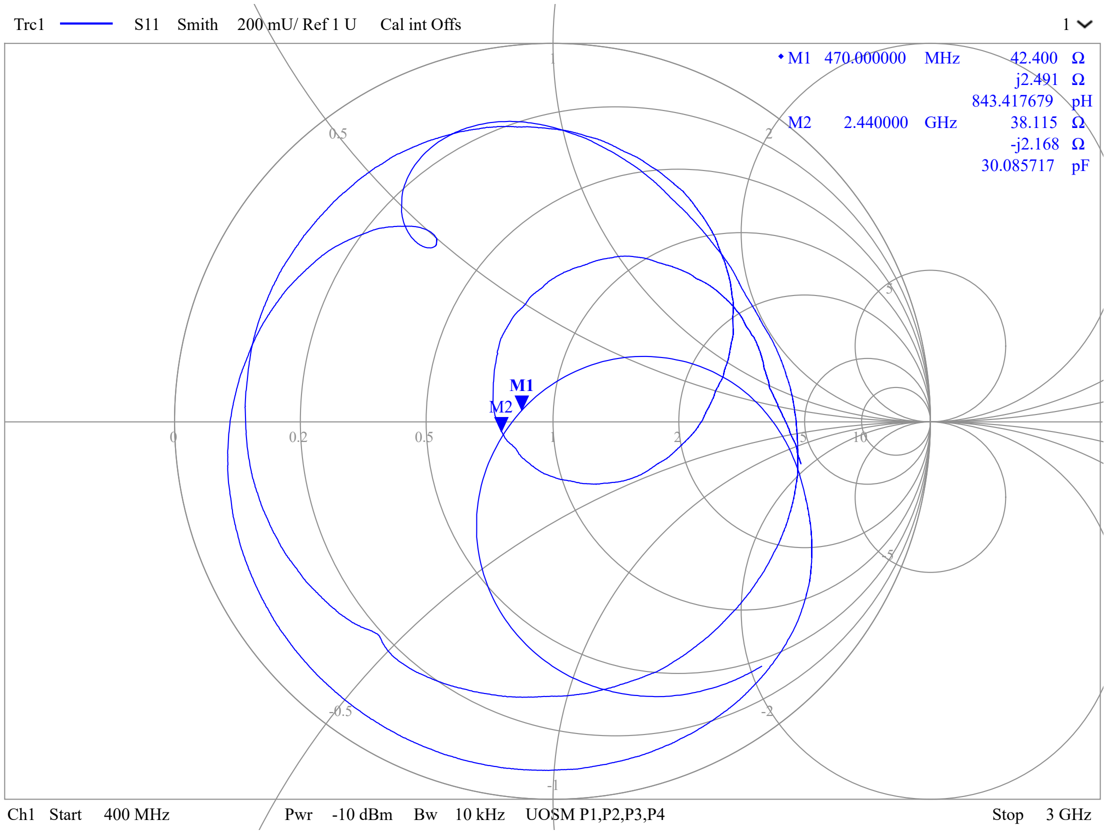

Figure 5-9. Smith Chart Measurement of Dual Band 470 MHz and 2.4 GHz

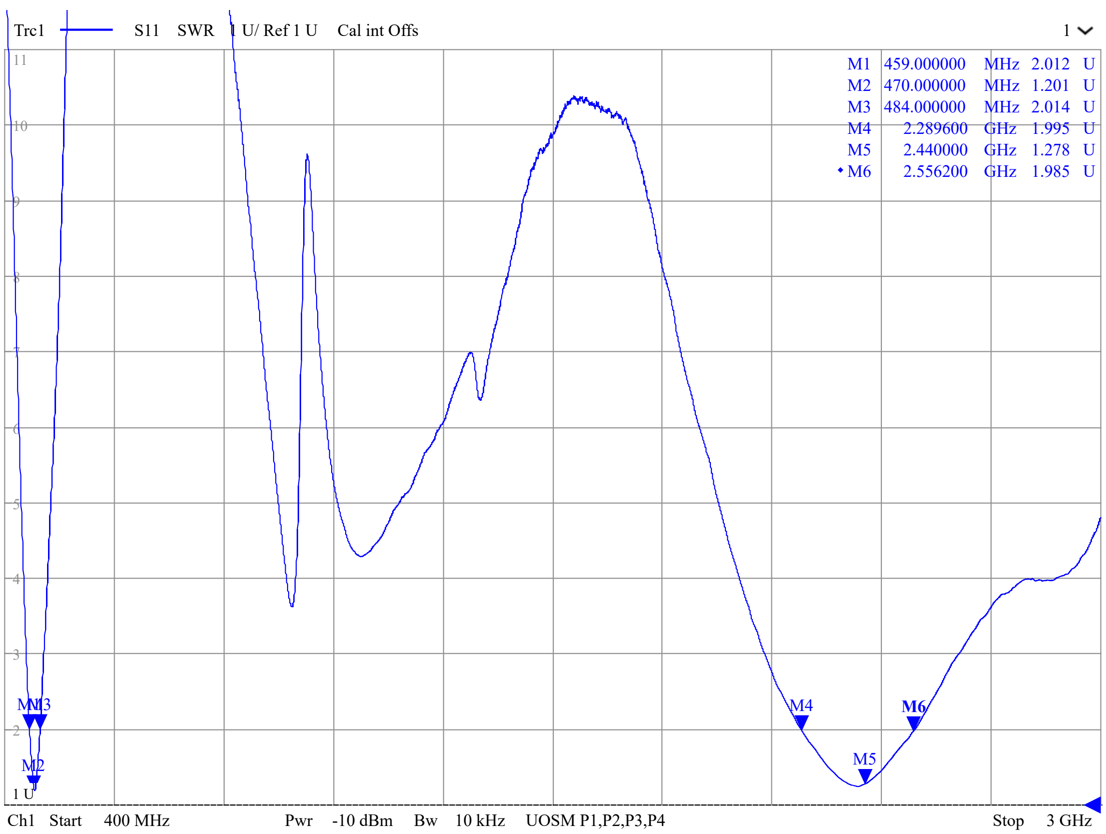

Figure 5-10. SWR Measurement of Dual-Band 470 MHz, 2.4 GHz, and Bandwidth at SWR < 2

Figure 5-11 and Figure 5-12 shows the radiation pattern of the antenna at 470 and 2440 MHz. Table 5-4 shows the TRP and efficiency for the antenna with the given matching network.

Table 5-4. TRP and Efficiency for 470 and 2440-MHz Dual-Band Antenna Match

	Figure 43	Figure 44
Frequency	470 MHz	2440 MHz
Power setting	13 dBm	10 dBm
Conducted output power	12.65 dBm	9.15 dBm
TRP	7.26 dBm	8.19 dBm
Efficiency	28.9 %	80.2 %

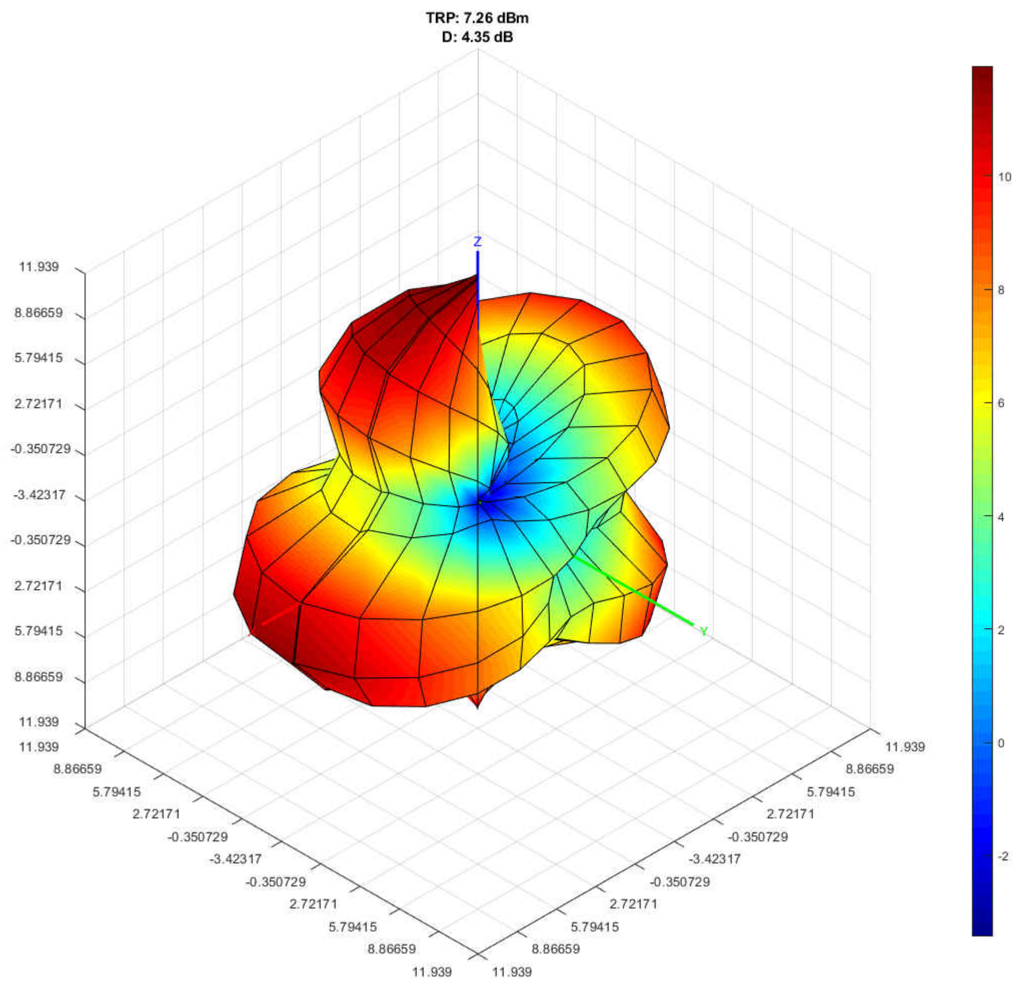

Figure 5-11. Radiation Pattern of the Antenna Matched for Dual-Band 470 and 2440-MHz Radiating with 13-dBm 470-MHz Setting

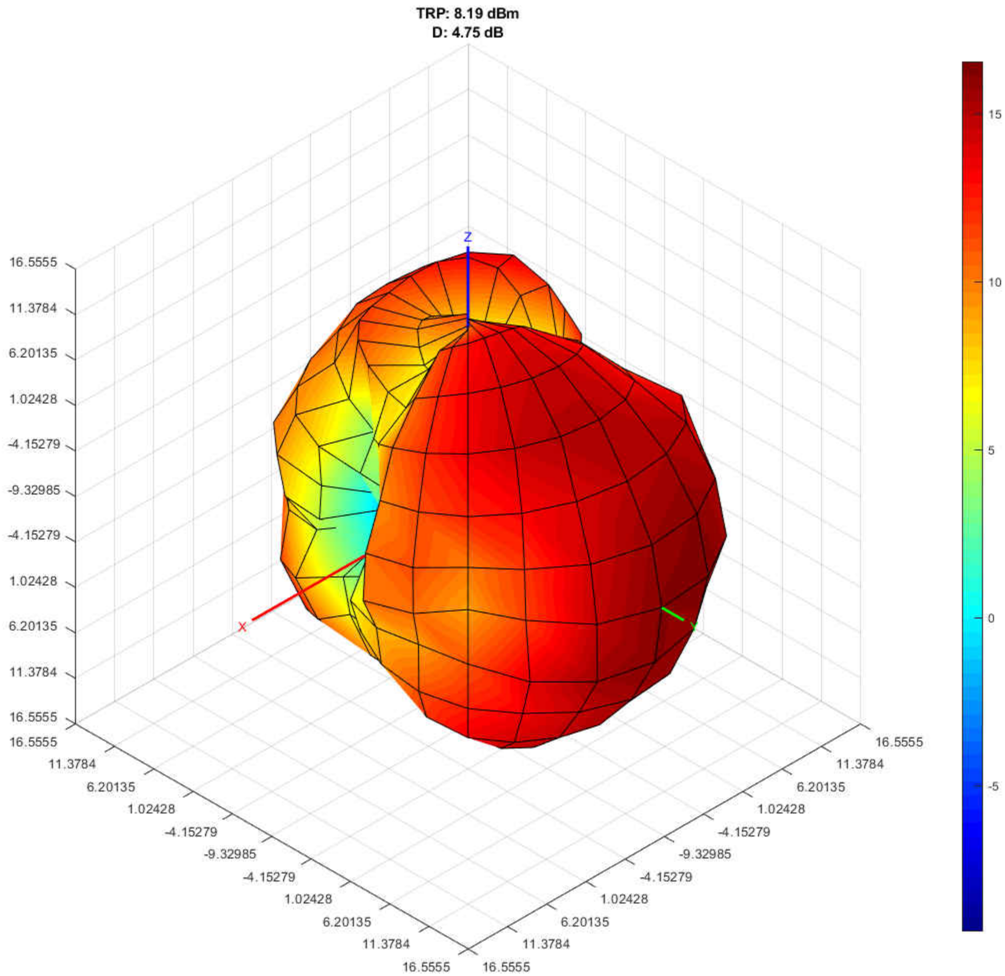

Figure 5-12. Radiation Pattern of the Antenna Matched for Dual-Band 470 and 2440-MHz Radiating with 10-dBm 2440-MHz Setting

5.3 490 MHz and 2440 MHz Smith Chart, SWR, Bandwidth and Efficiency

Figure 5-13 and Figure 5-14 show the theoretical Smith chart for matching the antenna for dual-band 490 and 2440 MHz with a theoretical SWR of 1.008 and 1.005.

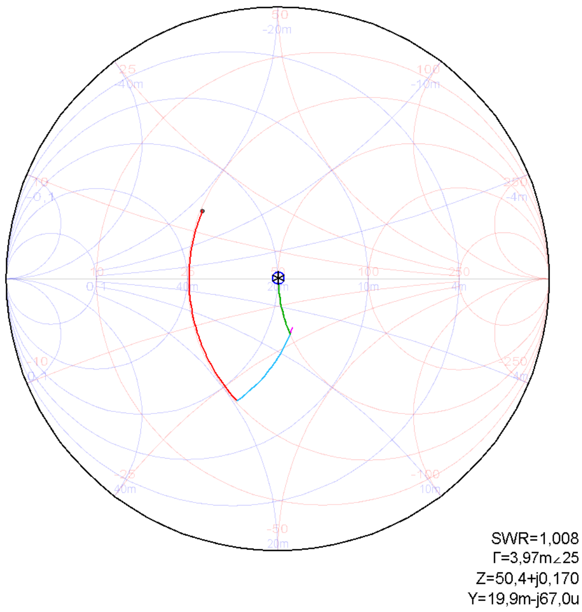

Figure 5-13. Theoretical Smith Chart for Dual Band 490-MHz Match

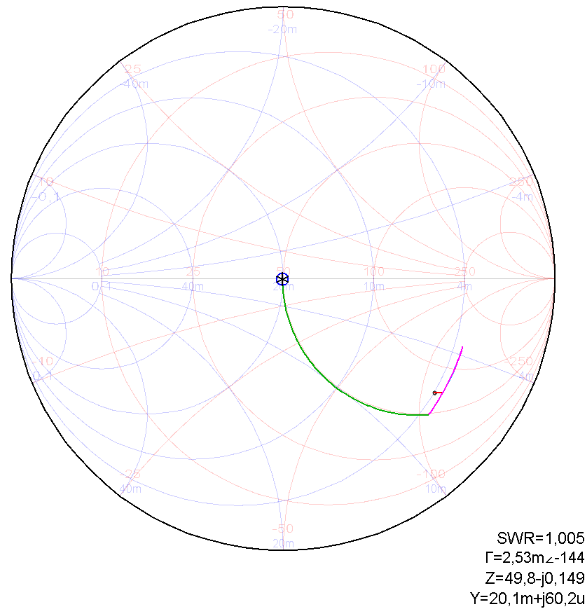

Figure 5-14. Theoretical Smith Chart for Dual-Band 2440-MHz Match

Further tuning of the antenna resonance was needed after realizing the theoretical match. Figure 5-15 and Figure 5-16 shows the resulting impedance and SWR, which at 1.078 for 490 MHz and 1.277 for 2440 MHz is less than the threshold for a good match of SWR < 2.0. Table 5-5 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 5-16 to be 506 – 478.2 = 27.8 MHz for 490 MHz and 2567-2333 = 234 MHz for 2440 MHz.

Table 5-5. Matching Network BOM for 490 and 2440-MHz Dual-Band Operations

Ref. Designator	Murata Part Number	Value
Z60	LQP03TN6N8H02	6.8 nH
Z61	GRM0335C1HR10WA01	0.1 pF
Z62	LQP03TN24NH02	24 nH
Z63	GRM0335C1H100JA01	10 pF
Z64	LQP03TN33NH02	33 nH

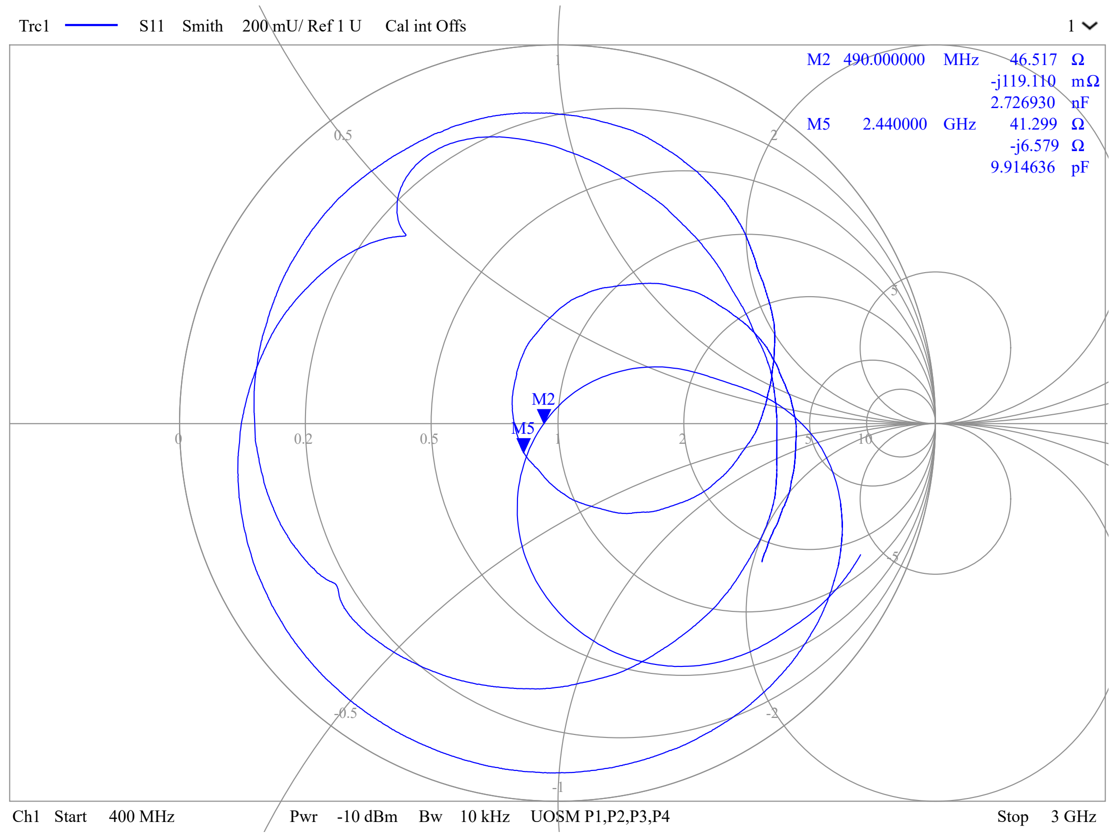

Figure 5-15. Smith Chart Measurement of Dual Band 490 MHz and 2.4 GHz

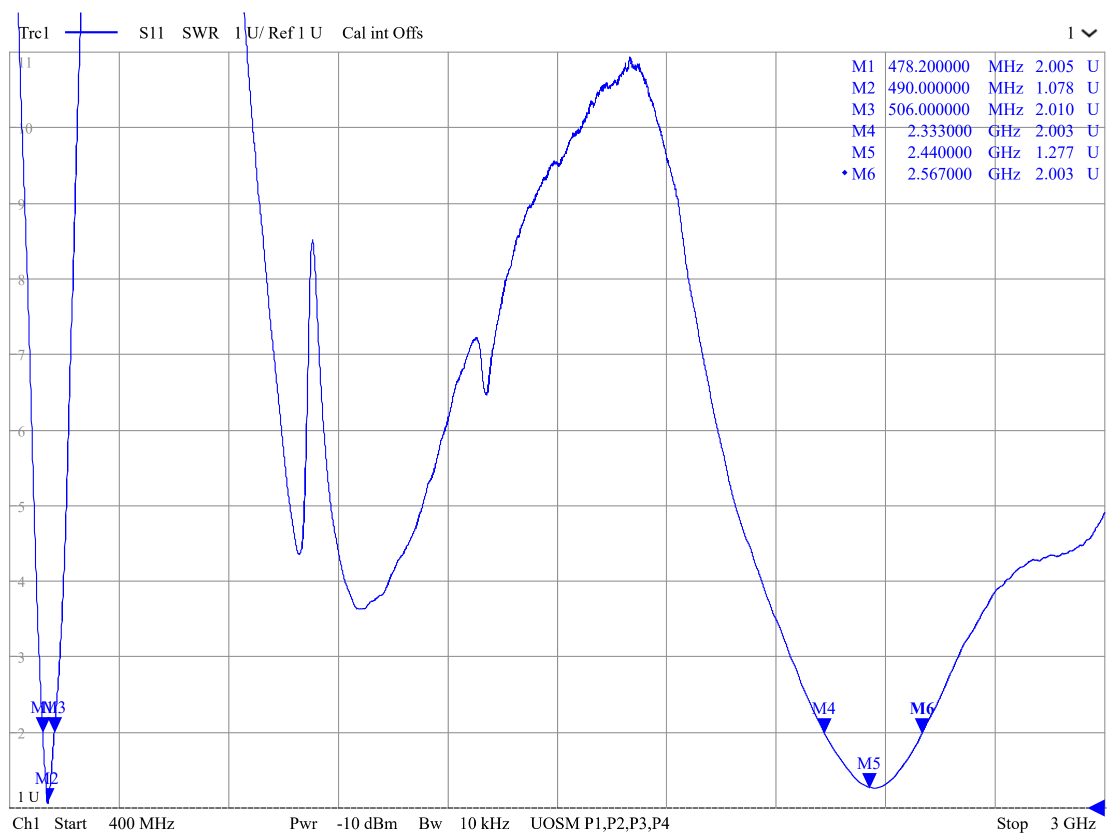

Figure 5-16. SWR Measurement of Dual Band 490 MHz, 2.4 GHz, and Bandwidth at SWR < 2

Figure 5-17 and Figure 5-18 shows the radiation pattern of the antenna at 490 and 2440 MHz. Table 5-6 shows the TRP and efficiency for the antenna with the given matching network.

Table 5-6. TRP and Efficiency for 490 and 2440-MHz Dual-Band Antenna Match

	Figure 43	Figure 44
Frequency	490 MHz	2440 MHz
Power setting	13 dBm	10 dBm
Conducted output power	12.17 dBm	9.15 dBm
TRP	7.12 dBm	8.58 dBm
Efficiency	31.6 %	76.38 %

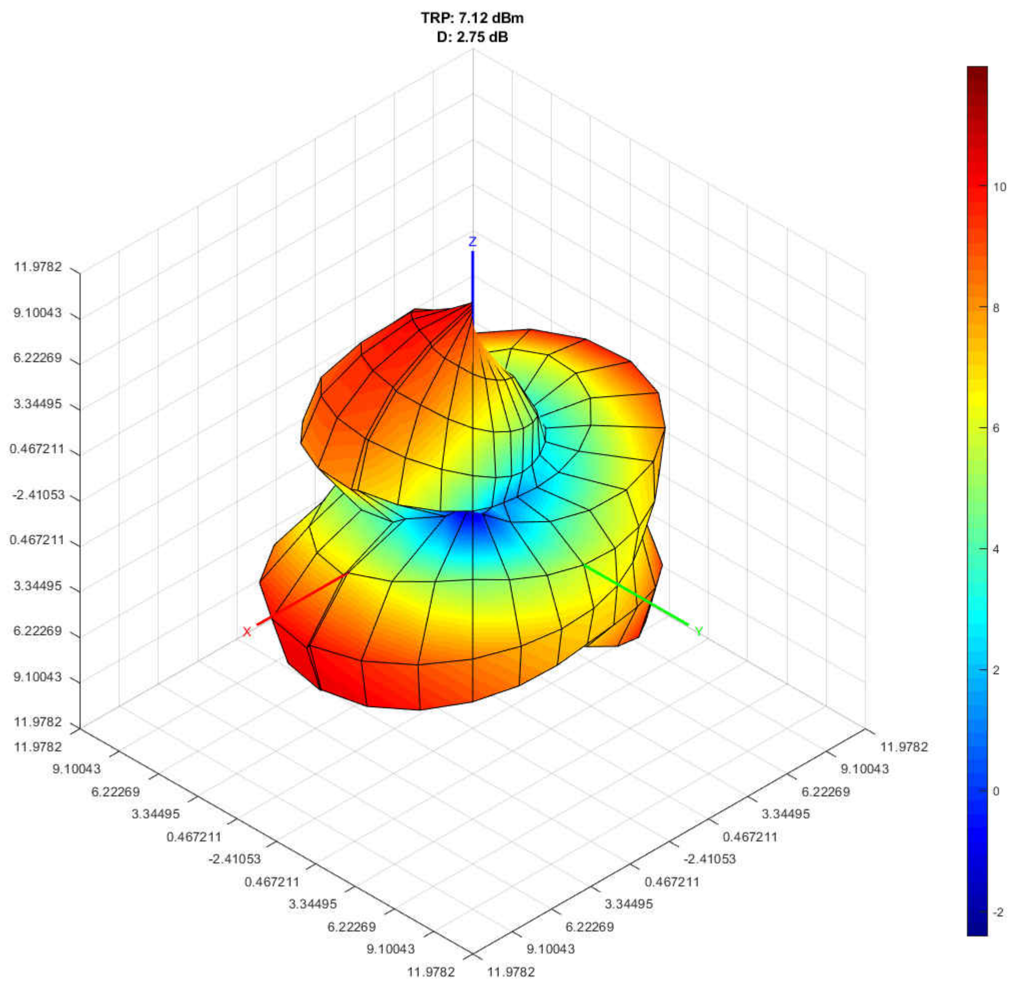

Figure 5-17. Radiation Pattern of the Antenna Matched for Dual-Band 490 and 2440 MHz Radiating with 13 dBm 490 MHz Setting

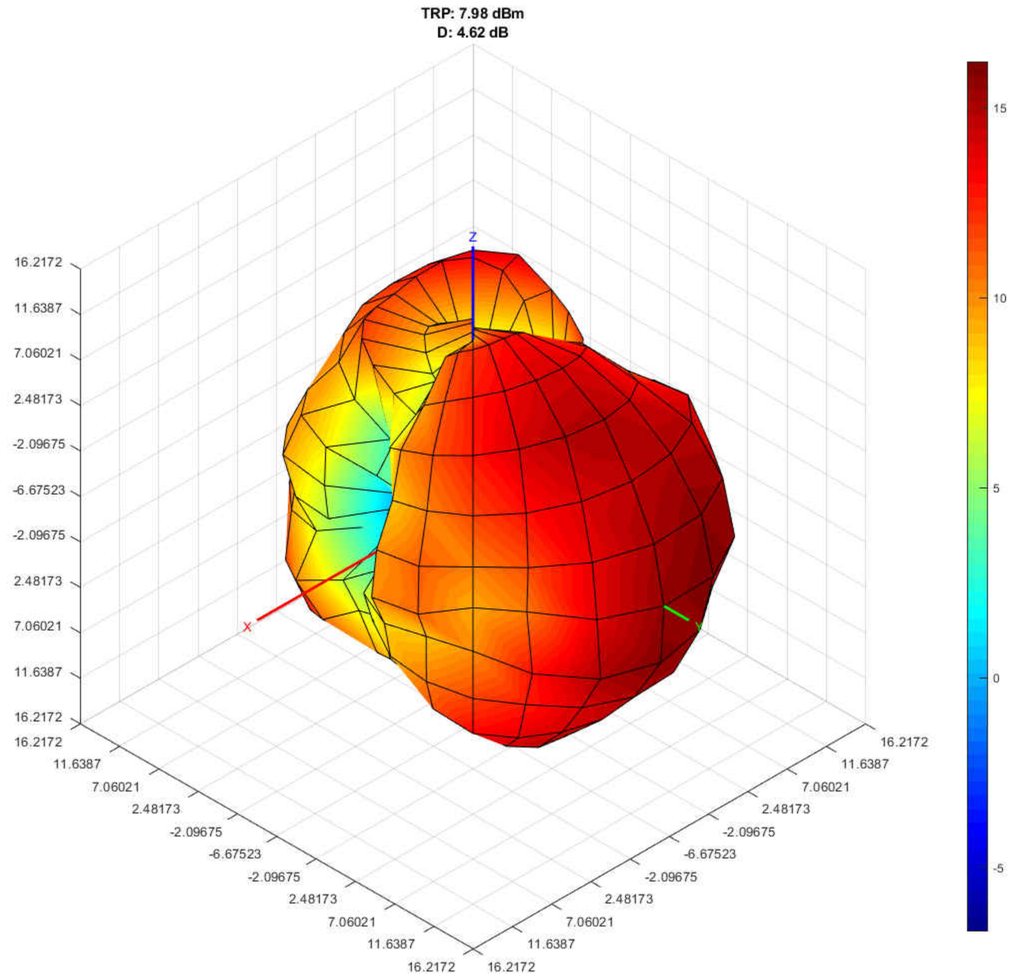

Figure 5-18. Radiation Pattern of the Antenna Matched for Dual-Band 490 and 2440-MHz Radiating with 10-dBm 2440-MHz Setting

5.4 510-MHz and 2440-MHz Smith Chart, SWR, Bandwidth, and Efficiency

Figure 5-19 and Figure 5-20 shows the theoretical Smith chart for matching the antenna for dual-band 510 and 2440 MHz with a theoretical SWR of 1.031 and 1.000.

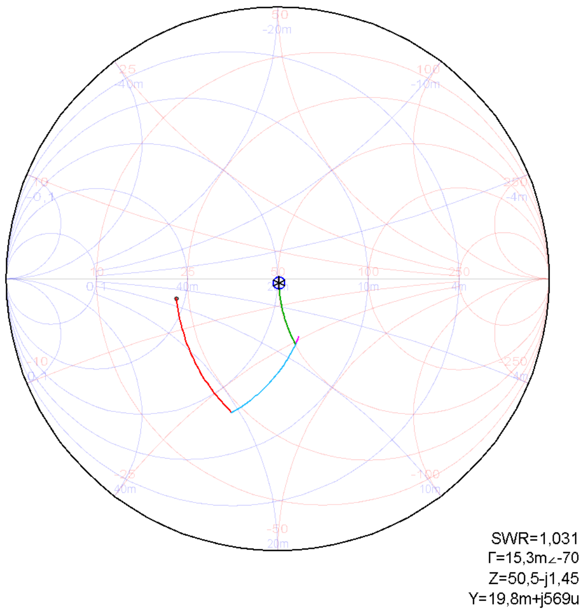

Figure 5-19. Theoretical Smith Chart for Dual Band 510 MHz Match

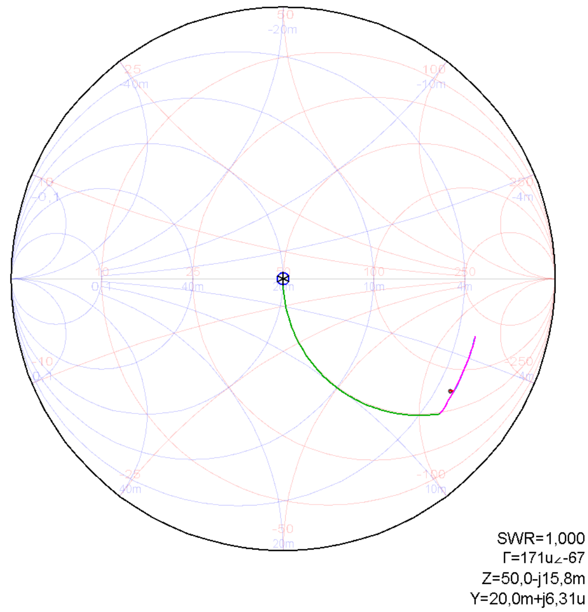

Figure 5-20. Theoretical Smith Chart for Dual Band 2440 MHz Match

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. in Figure 5-21 and Figure 5-22 shows the resulting impedance and SWR which at 1.110 for 510 MHz and 1.098 for 2440 MHz is less than the threshold for a good match of SWR < 2.0. Table 5-7 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 5-22 to be 522.4 – 497.8 = 24.6 MHz for 510 MHz and 2531-2325 = 206 MHz for 2440 MHz.

Table 5-7. Matching Network BOM for 510 and 2440-MHz Dual-Band Operations

Ref. Designator	Murata Part Number	Value
Z60	LQP03TN7N5H02	7.5 nH
Z61	GRM0335C1HR20BA01	0.2 pF
Z62	LQP03TN18NH02	18 nH
Z63	GRM0335C1H180JA01	18 pF
Z64	LQP03TN27NH02	27 nH

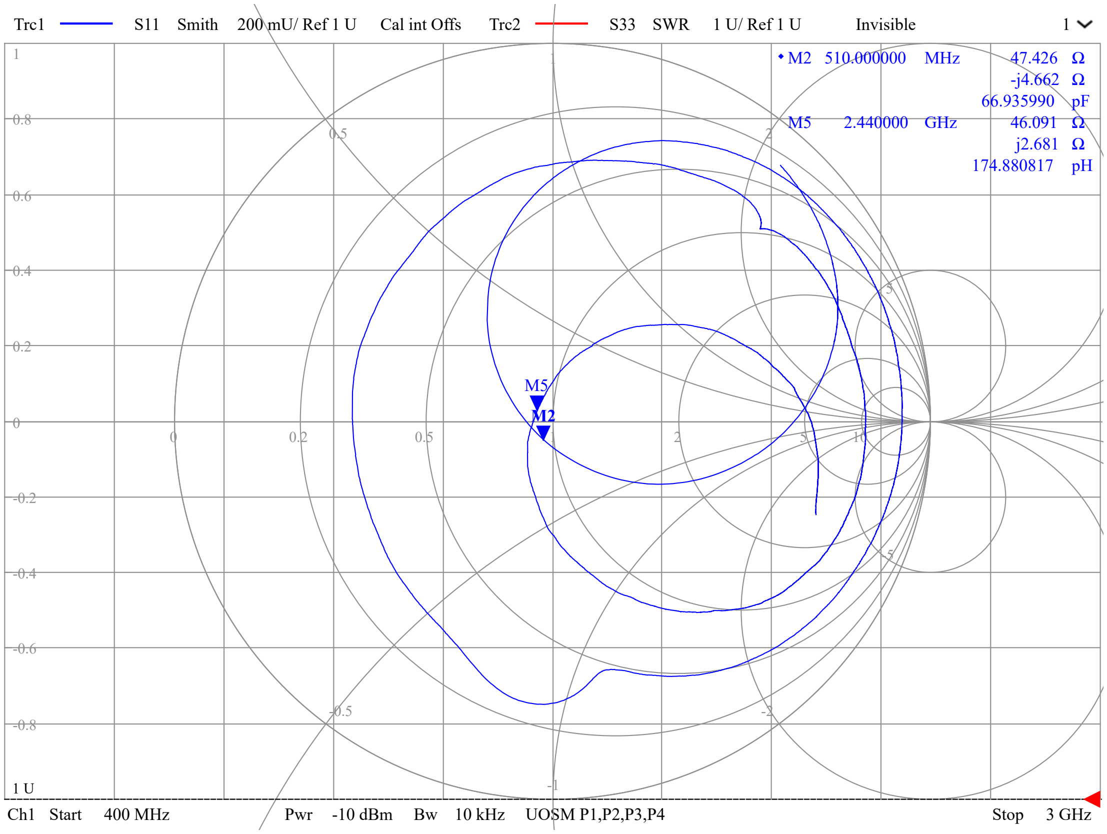

Figure 5-21. Smith Chart Measurement of Dual Band 510 MHz and 2.4 GHz

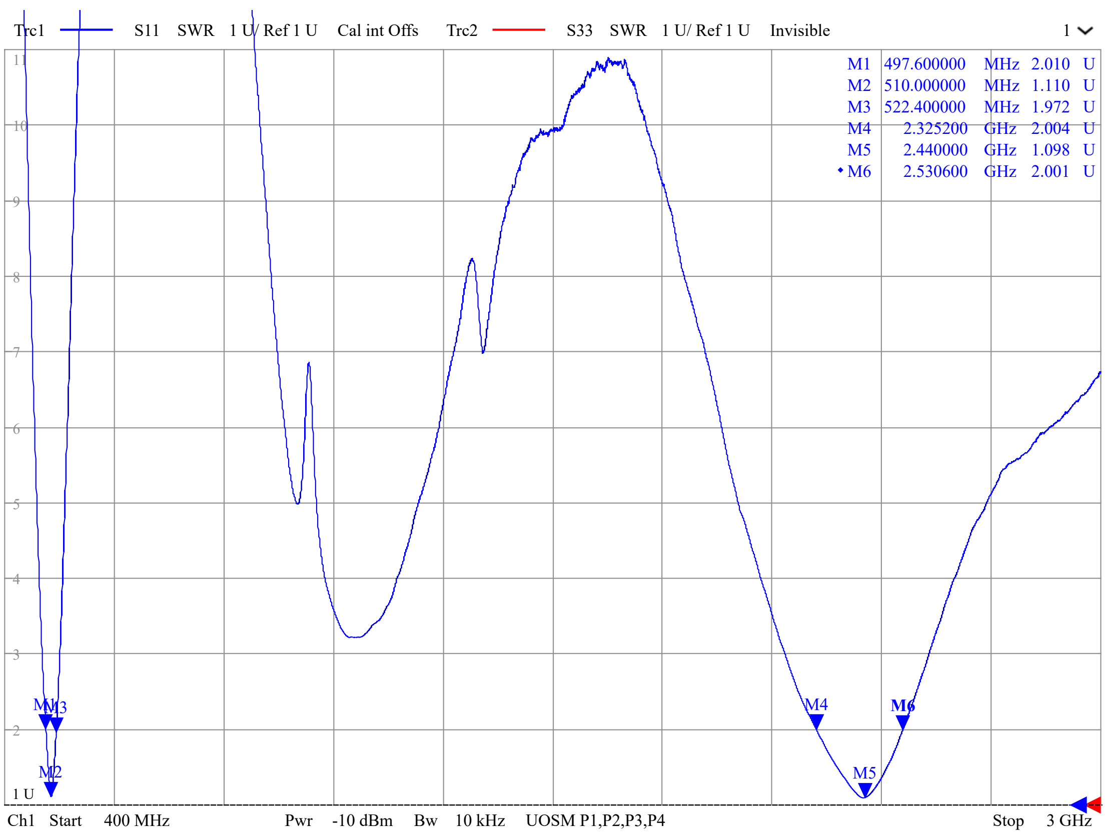

Figure 5-22. SWR Measurement of Dual Band 510 MHz, 2.4 GHz, and Bandwidth at SWR < 2

Figure 5-23 and Figure 5-24 shows the radiation pattern of the antenna at 510 and 2440 MHz. Table 5-8 shows the TRP and efficiency for the antenna with the given matching network.

Table 5-8. TRP and Efficiency for 510 and 2440-MHz Dual-Band Antenna Match

	Figure 43	Figure 44
Frequency	510 MHz	2440 MHz
Power setting	13 dBm	10 dBm
Conducted output power	11.77 dBm	9.15 dBm
TRP	5.8 dBm	12 dBm
Efficiency	25.3 %	84.1 %

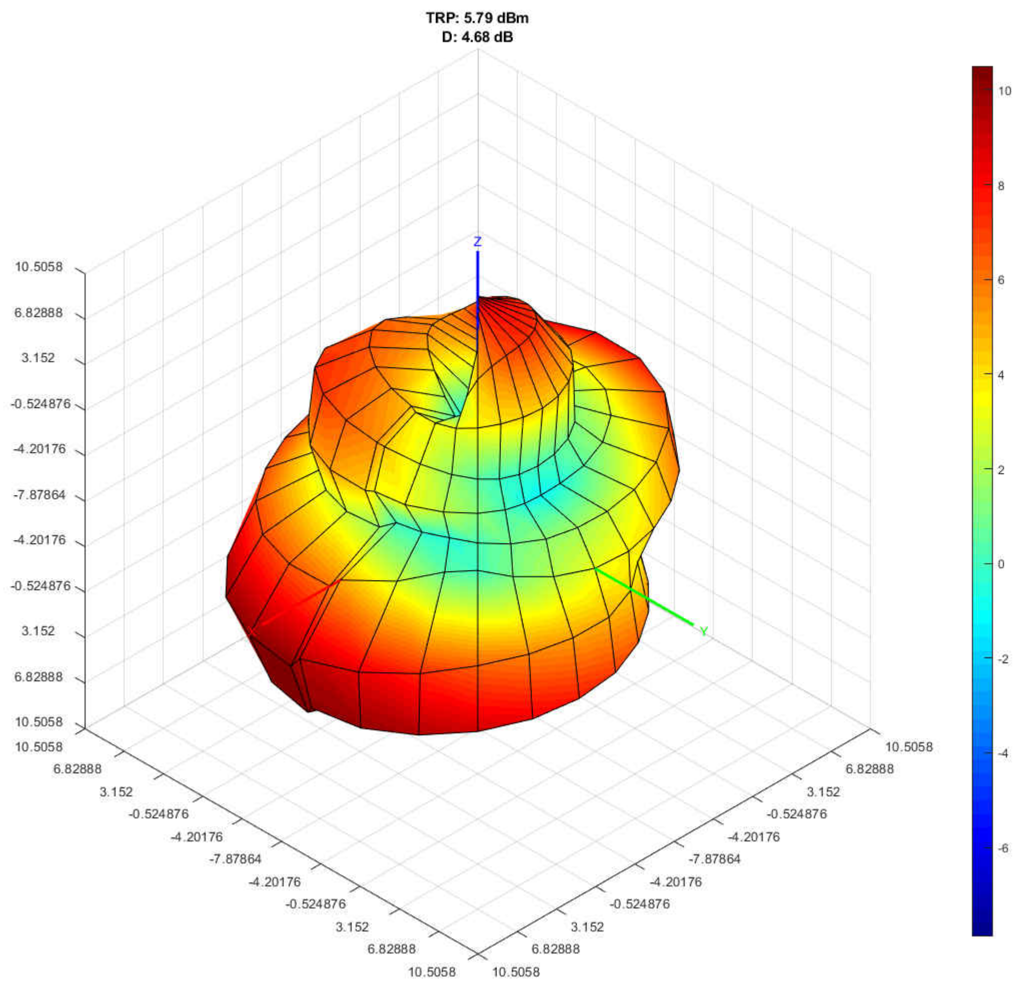

Figure 5-23. Radiation Pattern of the Antenna Matched for Dual-Band 510 and 2440-MHz Radiating with 13-dBm 510-MHz Setting

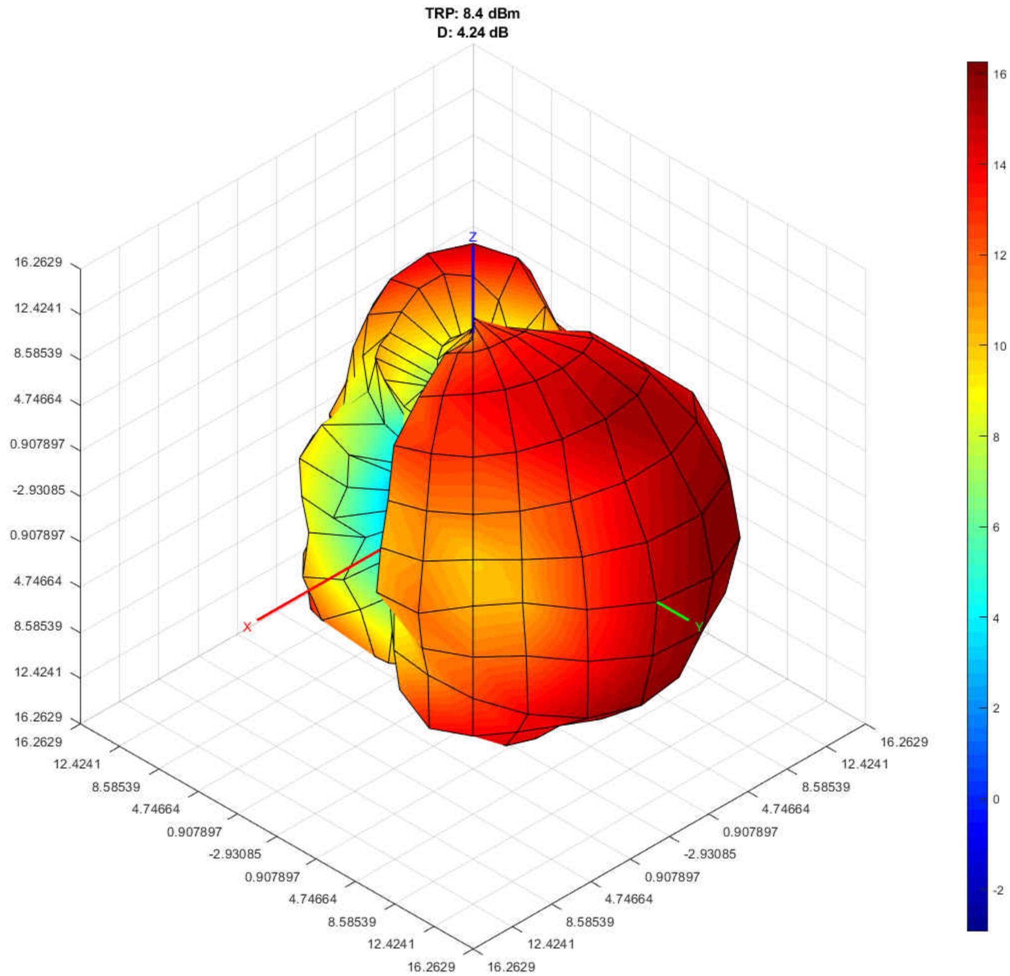

Figure 5-24. Radiation Pattern of the Antenna Matched for Dual-Band 510 and 2440-MHz Radiating with 10-dBm 2440-MHz Setting

5.5 868/915 and 2440-MHz Smith Chart, SWR, Bandwidth, and Efficiency

Figure 5-25 and Figure 5-26 show the theoretical Smith chart for matching the antenna for dual-band 892 and 2440 MHz with a theoretical SWR of 1.136 and 1.052.

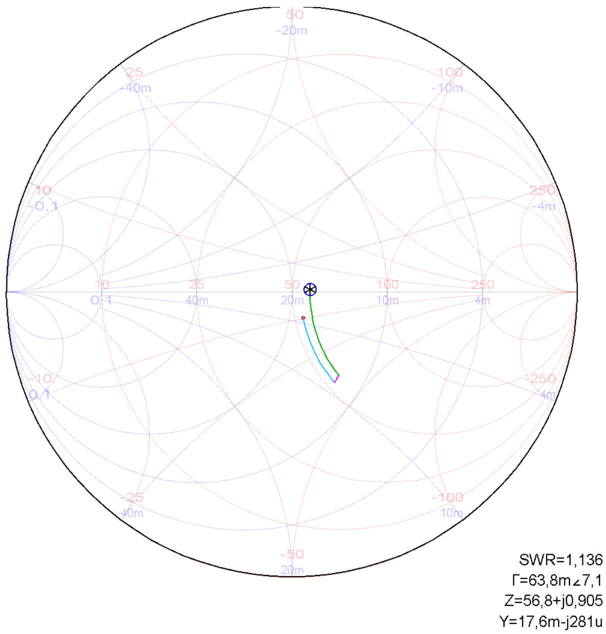

Figure 5-25. Theoretical Smith Chart for Dual-Band 892-MHz Match

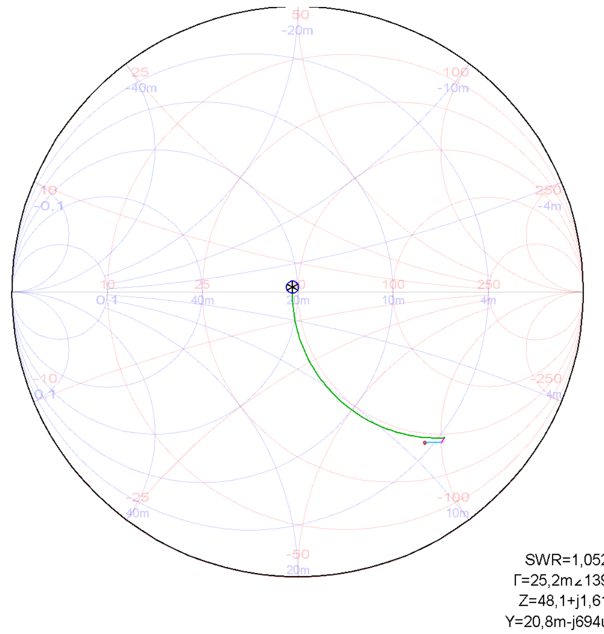

Figure 5-26. Theoretical Smith Chart for Dual-Band 2440-MHz Match

Further tuning of the resonance of the antenna was needed after realizing the theoretical match. Figure 5-27 and Figure 5-28 shows the resulting impedance and SWR which at 1.083 for 892 MHz and 1.239 for 2440 MHz is less than the threshold for a good match of SWR < 2.0. Table 5-9 shows the BOM with components used to relies the matching network given in Figure 1-2.

The bandwidth of the antenna defined by SWR < 2.0 can be seen in Figure 5-28 to be 956.8-847.2 = 109.6 MHz for 892 MHz and 2611-2296 = 315 MHz for 2440 MHz.

Table 5-9. Matching Network BOM for 868/915 and 2440-MHz Dual-Band Operations

Ref. Designator	Murata Part Number	Value
Z60	LQP03TN6N8H02	6.8 nH
Z61		DNM
Z62	LQP03TNR22H02	220 nH
Z63	GRM0335C1H6R2BA01	6.2 pF
Z64	GRM0335C1H2R0BA01	2 nH

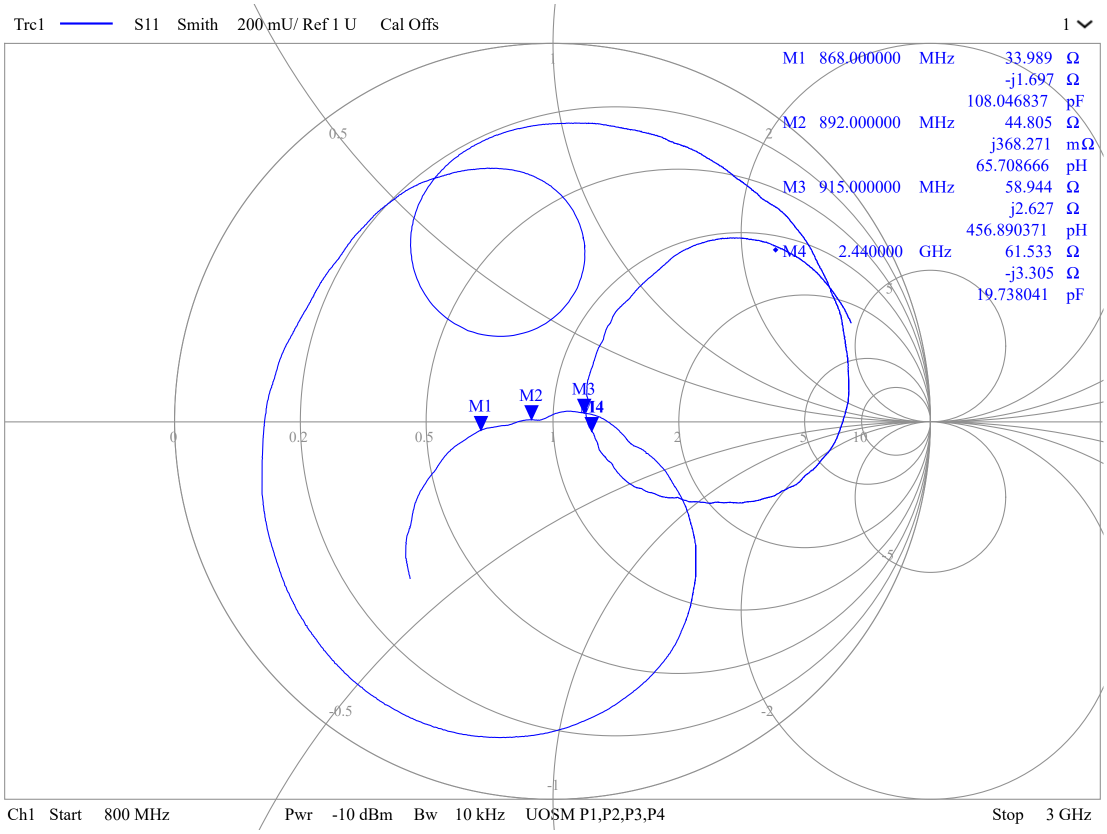

Figure 5-27. Smith Chart Measurement of Dual Band 868/915 MHz and 2.4 GHz

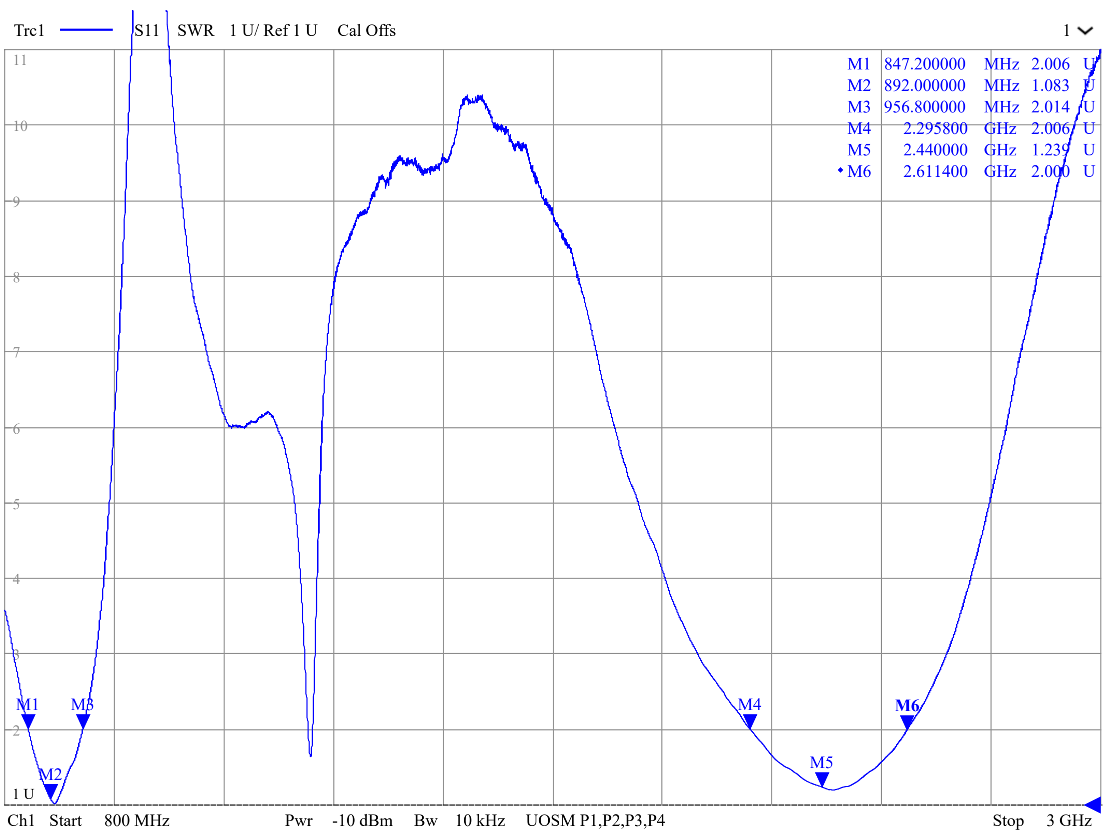

Figure 5-28. SWR Measurement of Dual Band 868/915 MHz, 2.4 GHz, and Bandwidth at SWR < 2

Figure 5-29, Figure 5-30, and Figure 5-31 shows the radiation pattern of the antenna at 868, 915 and 2440 MHz. Table 5-10 shows the TRP and efficiency for the antenna with the given matching network.

Table 5-10. TRP and Efficiency for 868/915 and 2440-MHz Dual-Band Antenna Match

	Figure 43	Figure 65	Figure 44
Frequency	868 MHz	915 MHz	2440 MHz
Power setting	13 dBm	13 dBm	10 dBm
Conducted output power	12.17 dBm	13.23 dBm	9.15 dBm
TRP	9.84 dBm	13.1 dBm	11.98 dBm
Efficiency	62.4 %	97.05 %	83.75 %

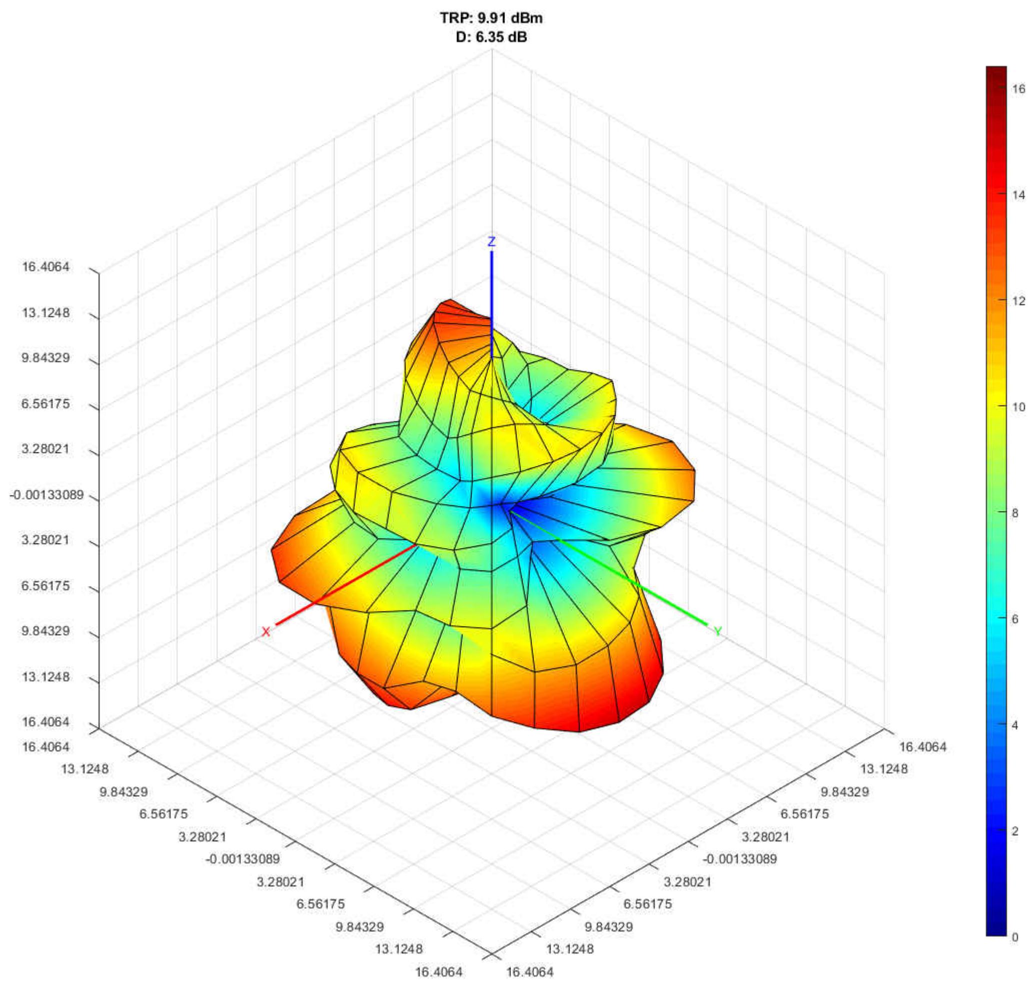

Figure 5-29. Radiation Pattern of the Antenna Matched for Dual-Band 868/915 and 2440-MHz Radiating with 13-dBm 868-MHz Setting

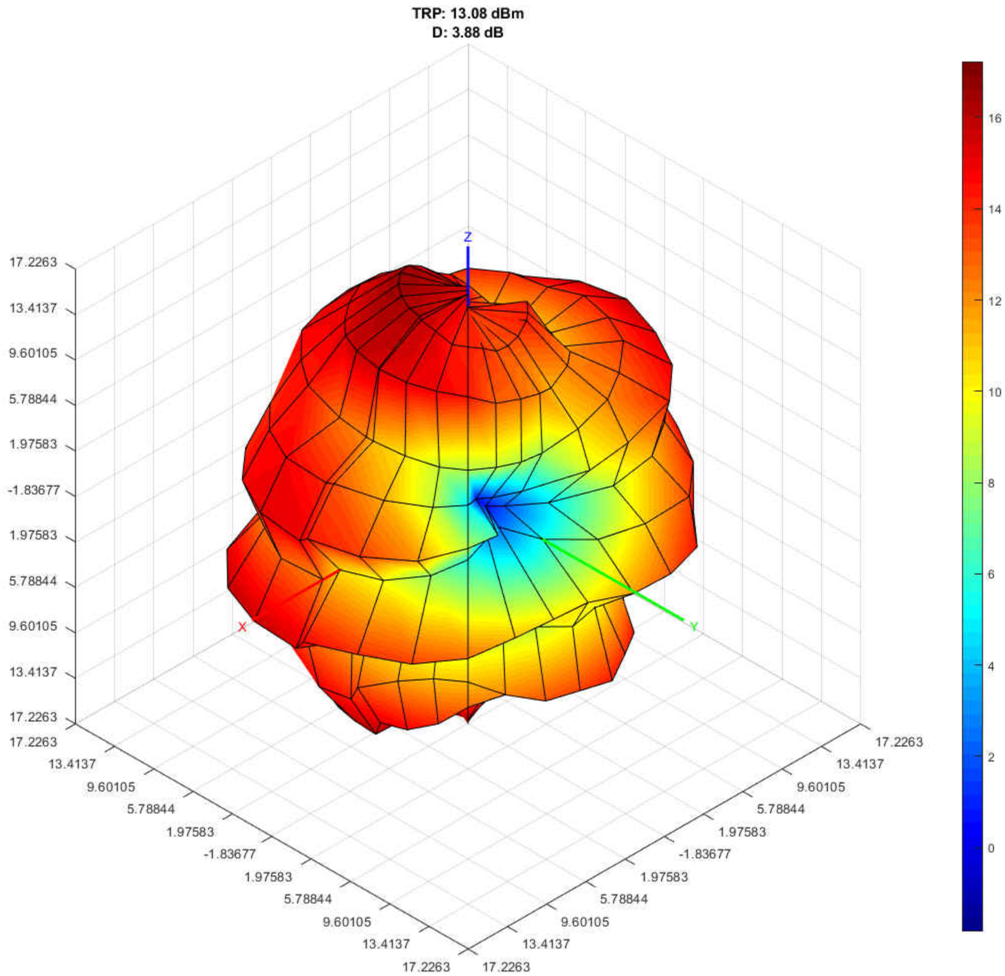

Figure 5-30. Radiation Pattern of the Antenna Matched for Dual-Band 868/915 and 2440-MHz Radiating with 13-dBm 915-MHz Setting

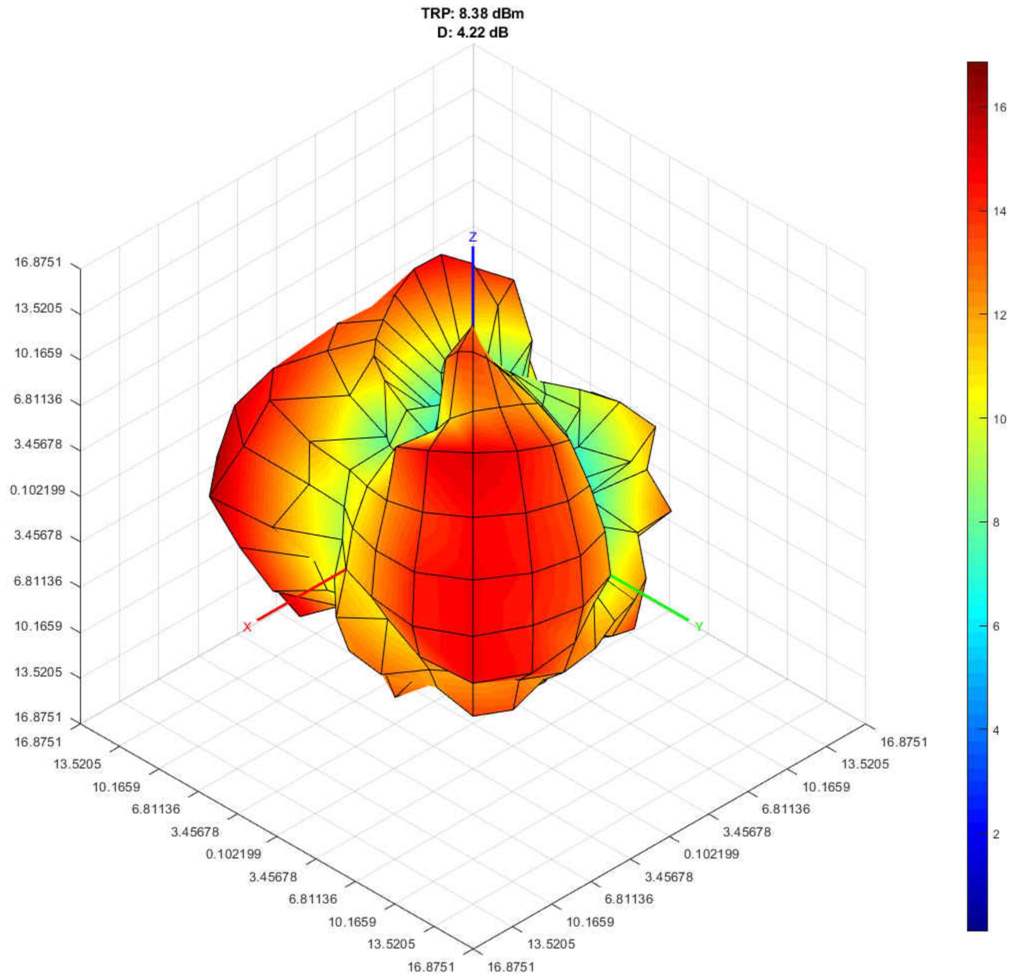

Figure 5-31. Radiation Pattern of the Antenna Matched for Dual-Band 868/915 and 2440-MHz Radiating with 10-dBm 2440-MHz Setting

6 Summary - Bill of Materials and Results

Table 6-1. BOM summary for all modes and frequencies

Frequency	Mode	Z60	Z61	Z62	Z63	Z64
433 MHz	Single	0 Ω	DNM	4.7 pF	2 nH	51 nH
	Dual	6.8 nH	DNM	47 nH	8.2 pF	51 nH
470 MHz	Single	0 Ω	DNM	5.1 pF	6.2 nH	39 nH
	Dual	6.2 nH	0.1 pF	36 nH	7.5 pF	39 nH
490 MHz	Single	0 Ω	DNM	6.2 pF	6.2 nH	33 nH
	Dual	6.8 nH	0.1 nH	24 nH	10 pF	33 nH
510 MHz	Single	0 Ω	DNM	8.2 pF	11 nH	27 nH
	Dual	7.5 nH	0.2 pF	18 nH	18 pF	27 nH
862/915 MHz	Single	0 ohm	DNM	0 Ω	DNM	2 pF
	Dual	6.8 nH	DNM	220 nH	6.2 pF	2 pF

Table 6-2. Efficiency and Bandwidth Summary for all modes and frequencies

Frequency	Mode	Efficiency [%]		Bandwidth [MHz]	
		Low-band	High-band	Low-band	High-band
433 MHz	Single	19.2%		22.8 MHz	
	Dual	22.8%	87.3%	24 MHz	250 MHz
470 MHz	Single	34.8%		25 MHz	
	Dual	28.9%	80.2%	25 MHz	266 MHz
490 MHz	Single	35.9%		24.8 MHz	
	Dual	31.6%	76.4%	27.8 MHz	234 MHz
510 MHz	Single	32.9%		29 MHz	
	Dual	25.3%	84.1%	24.6 MHz	206 MHz
862/915 MHz	Single	72.8% / 97.3%		95.8 MHz	
	Dual	62.4% / 97.1%	83.8%	109.6 MHz	315 MHz

7 Conclusion

The antenna in this application note can be used in two different modes: single-band operation or dual-band operation. When configured as single-band mode, users can configure the antenna through thematching network and Z64 to operate at a single ISM frequency between 433 MHz and 930 MHz. Users can configure the antenna in dual-band mode then the ISM frequency operation can be between 433–930 MHz and also 2.4 GHz. All modes of operation have shown a high transmitted radiated efficiency while maintaining a wide bandwidth.

The antenna design including the antenna matching network can easily be adapted to a specific ISM frequency with the option of single-band or dual-band operation. This is an advantage for designs that require just one PCB antenna structure to cover several bands by just changing the BOM. Even frequencies lower than 433 MHz can be supported, if the Z64 component is increased furthermore.

The dual-band mode is ideal when the radio solution works at sub-1 GHz ISM frequency and 2.4 GHz. When using the dual-band mode it is important that the 3rd harmonic of the 868 MHz (2.604 GHz) antenna is below the regulatory limits since the 2.4 GHz antenna (2.74 GHz to 2.38 GHz) will also radiate the 3rd harmonic.

TI recommends following the antenna dimensions as shown in Figure 1-1; Size of the antenna is 43 x 25 mm. The maximum gain is approximately 3 to 5 dBi, which is typical for a monopole antenna.

S11 measurements 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.

8 References

- LAUNCHXL-CC1352P-4
- LAUNCHXL-CC1352P1
- LAUNCHXL-CC1312R1