Final Project

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ECE 391 Transmission Lines Final Project Report

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Abstract

This project utilized the content covered over the course of 10 weeks in ECE 391 Transmission Lines to design four specific impedance matching networks. Each separate task had a different network to match the same load that was randomly assigned. The assigned load was $31\,\Omega$ resistor in series with a $5\,\mathrm{nH}$ inductor. The specific design frequency for this network is $3.8\,\mathrm{GHz}$. Each task used a combination of numerical calculations, Smith Chart analysis, and ADS simulation for verification. The source impedance is $50\,\Omega$ for each task. The desired outcome of this project is to have a strong understanding of the different ways to match a load to the source impedance in order to have a reflection coefficient as close to zero as possible. The other learning outcome is the differences between different matching networks and how the bandwidth changes with different types of matching networks. Key findings include that lumped elements have the smallest bandwidth, whereas the use of stubs and quarter-wave transformers have produced a larger bandwidth. When using physical microstrip lines, discontinuities from the transitions between loads, or quarter wave transformers, introduces reflections showing how calculations do not account for the physical manufacturing of the matched networks.

Keywords: (ADS, LineCalc, Impedance Matching, Smith Chart)

Contents

Chapter 1

Design Task 1

1.1 Design Requirements

For this design task, the goal was to match $31\,\Omega$ in series with a j$119.38\,\Omega$ to a source impedance of $50\,\Omega$ at $3.8\,\mathrm{GHz}$ using a network of matching elements of the group.

1.2 Implementation

Two methods were used to determine the values of the two components to match the load to the source impedance. It was important to first note that $31\,\Omega$ is less than $50\,\Omega$. Therefore, a component in series had to be placed before a component in parallel. The equations used for this task are:

$$B = \pm\frac{\sqrt{\frac{Z_0 - R_L}{R_L}}}{Z_0} \quad \text{and} \quad X = \pm\sqrt{R_L(Z_0 - R_L)} - X_L$$

where $R_L = 30$, $Z_0 = 50$, $X_L = 119.38$, B is the susceptance of the parallel component and X is the reactance of the series component. When entering the known variables and solving for the minus values of both equations, the values are $B = -0.0156\,\mathrm{S}$ and $X = -143.65\,\Omega$. We solve for the capacitance of X and the inductance of B at $3.8\,\mathrm{GHz}$. As can be seen in Figure 1.1, the capacitor value is $0.29\,\mathrm{pF}$ and the inductor value is $2.675\,\mathrm{nH}$.

1.3 Results

To determine a matched load, simulation was used. Using ADS, the magnitude of the reflection coefficient was plotted along $0.4\,\mathrm{GHz}$ to $14\,\mathrm{GHz}$ as can be seen in Figure 1.2. There is clearly a

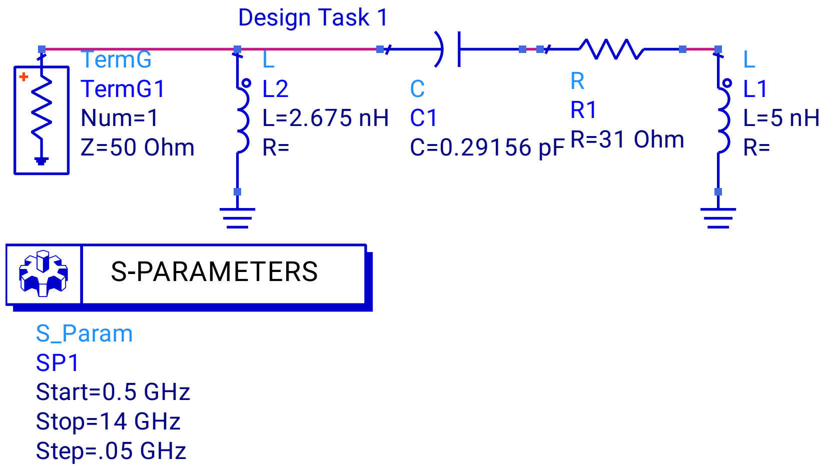


Figure 1.1: Schematic for Section Lumped Element Matching Network to Load.

minimum value, almost zero, at the desired frequency. Figure 1.3 shows the exact minium value at $3.8\,\mathrm{GHz}$ demonstrating a perfectly matched load the design frequency. Using the upper and lower frequencies where $|\Gamma| < 0.25$, the % bandwidth is:

$$\frac{f_{\text{upper}} - f_{\text{lower}}}{\frac{f_{\text{upper}} + f_{\text{lower}}}{2}} = 12.3\%$$

This is a limited bandwidth showing how the matched network can only work at the design frequency.

1.4 Smith Chart

A way to visualize this matching network is through the use of a Smith Chart as can be seen in Figure 1.4. Start out by plotting the normalized load. Then, adding a series reactive component until reaching the $r = 1$ circle. Since the input impedance is now on the $r = 1$ circle, all that is necessary is to add a parallel component. Therefore, getting the conjugate of the load, or $180°$ turn on the chart, will get us into admittance. After finding the susceptance necessary to get to a perfectly matched load at the center, the normalized series impedance value and the normalized parallel capacitance is know. The load can also be matched with a parallel element first and then a series. As can be seen in Figure 1.5, a capacitor in parallel and then a capacitor in series would also work. If the normalized load was inside the $g = 1$ circle, then it wouldn't be possible to add a reactive component in parallel in any way.

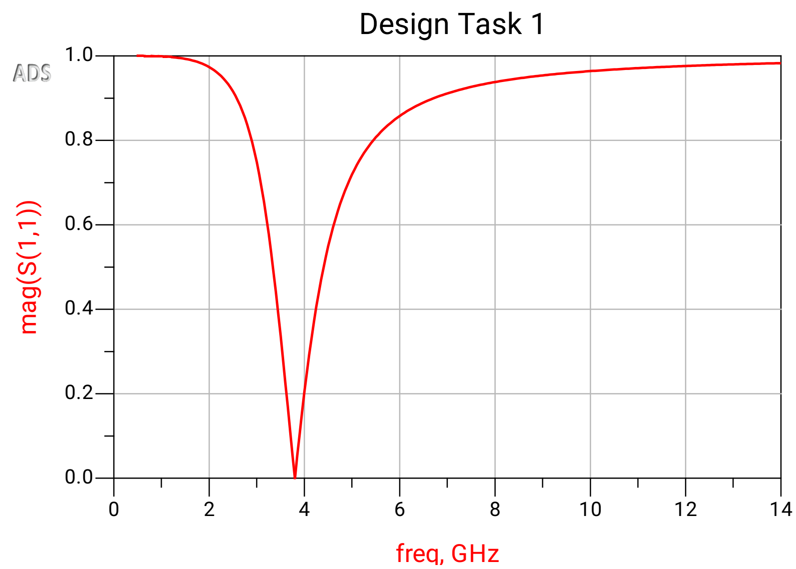


Figure 1.2: Magnitude of Reflection Coefficient $0.4\,\mathrm{GHz}$ to $14\,\mathrm{GHz}$.

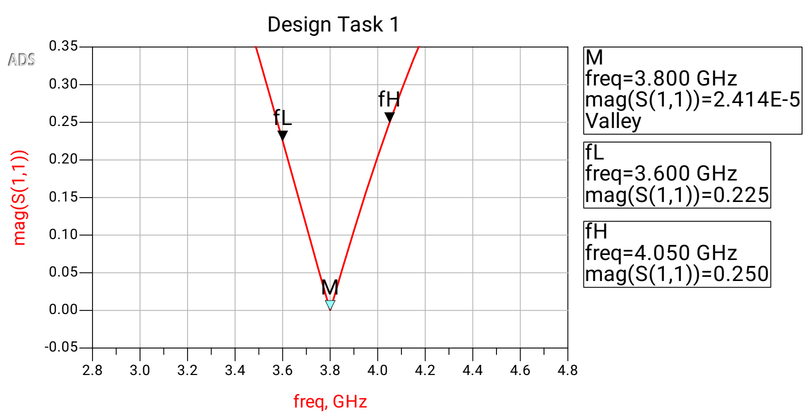


Figure 1.3: Zoomed In Graph of $|\Gamma|$ for Design Task 1

The Complete Smith Chart

Black Magic Design

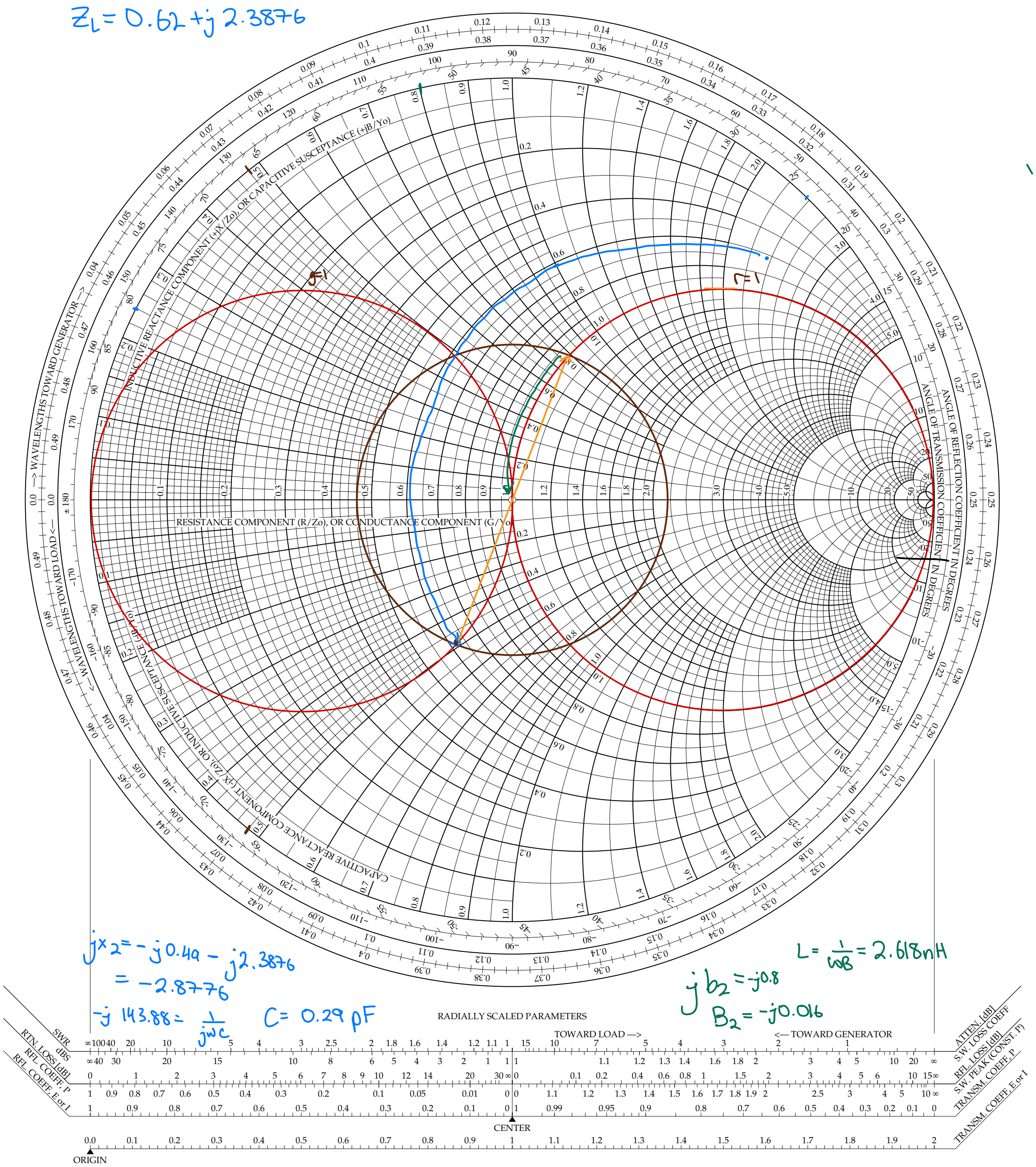


Figure 1.4: Smith Chart of Design Task 1

The Complete Smith Chart

Black Magic Design

$Z_L = 0.62 + j\,2.3876$

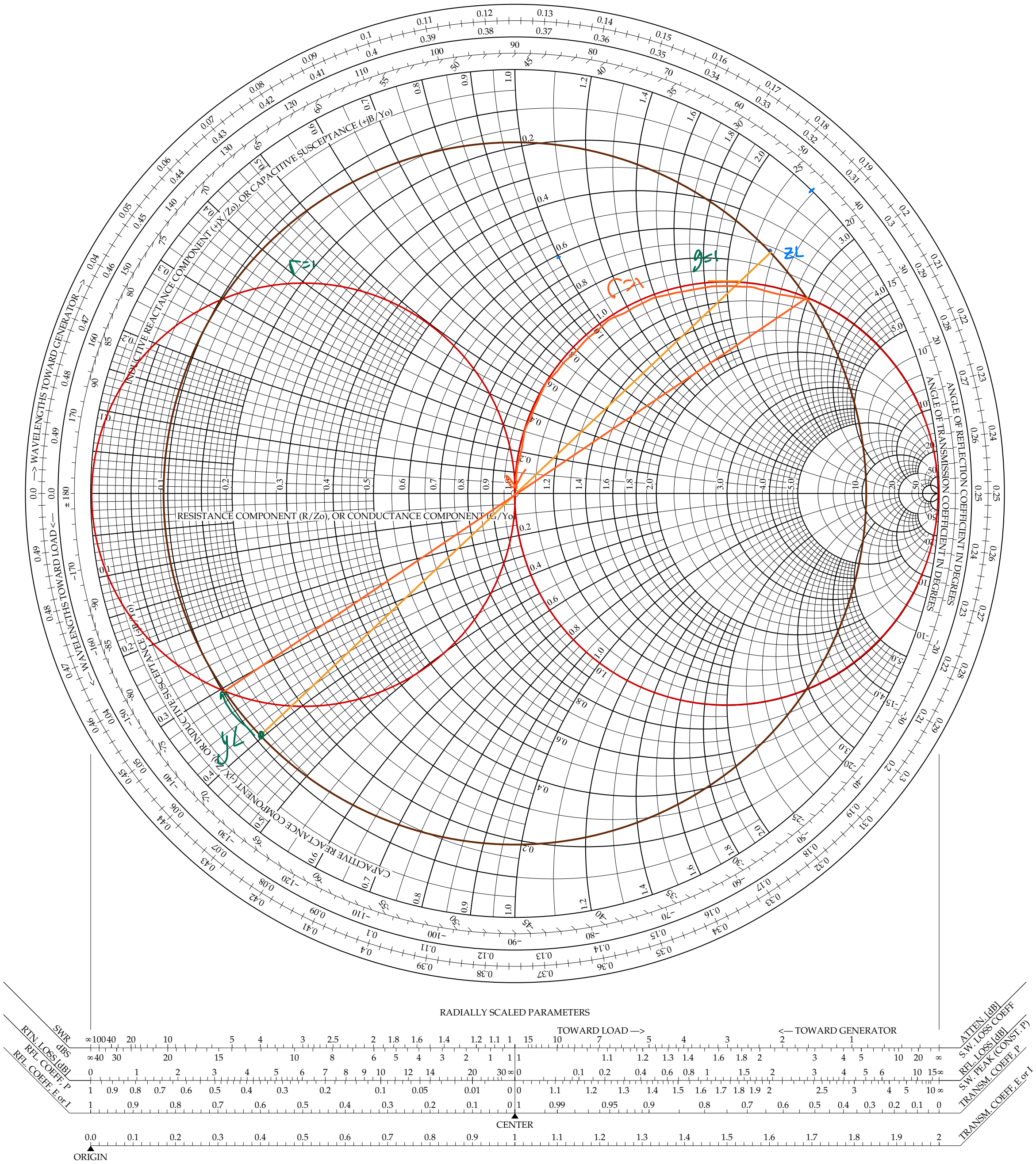


Figure 1.5: Smith Chart of Design Task 1 Alternative Order

Chapter 2

Design Task 2

2.1 Design Requirements

For this matching network the goal was to use a transmission line in series with a quarter-wave transformer to match the load to the $50\,\Omega$ source impedance. As an extra requirement, the quarter wave transformer had to be replaced by a 3-section binomial network.

2.2 Implementation

The main way to solve for the necessary length of the transmission line is to use a Smith Chart. After plotting the normalized load (reference the smith chart) and the constant gamma circle, measuring the amount of wavelengths it will take to rotate until a purely real load gives the length of the transmission line. There are two different points where the length of the transmission line can give a purely real load. As can be seen in Figure 2.2, the identified distances are $21.672°$ and $111.672°$. These two different angles also give two different input impedances seen. Figure 2.1 shows that one will give you about $550\,\Omega$, and the other $4.7\,\Omega$. The bandwidth according to Figure 2.14 is 3.16% for the latter impedance as a quarter wave transform, and 7.91% for the $550\,\Omega$.

To make this have a greater bandwidth, a three-section binomial transform was utilized. This was not fruitful because the transition sections are too large. Therefore, some sections act as an open circuit. Simulation could not handle these transitions. Figure 2.5 demonstrates the impedances of the quarter-wave transform from left to right going to the load. The purely theoretical binomial transform did show a slightly greater bandwidth, but these results are inconclusive.

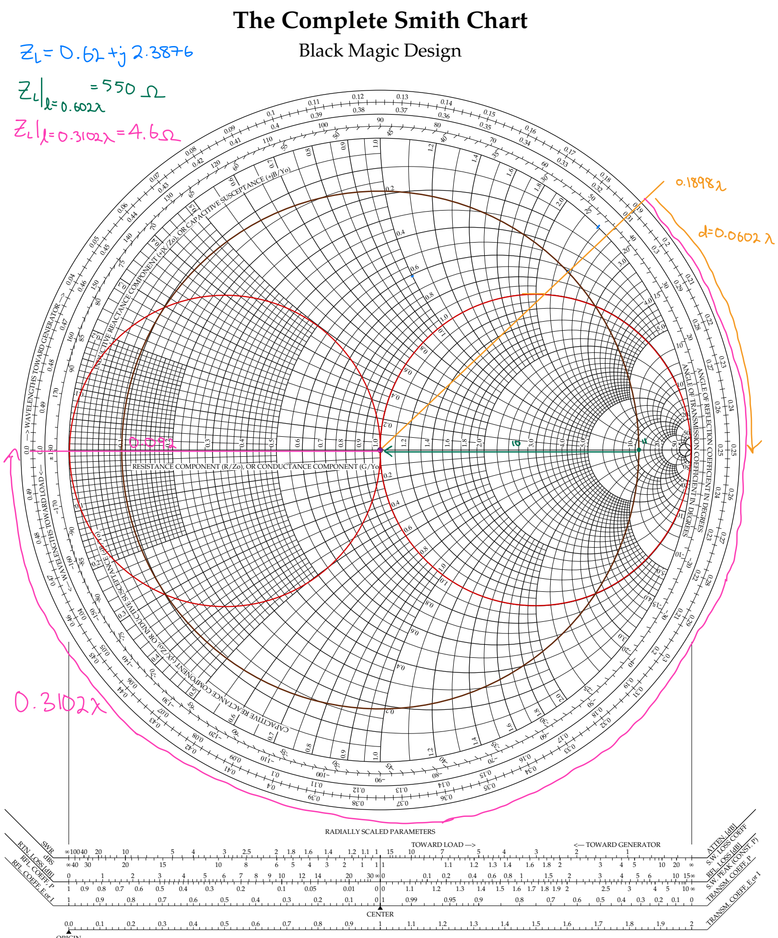


Figure 2.1: Smith Chart of Design Task 2

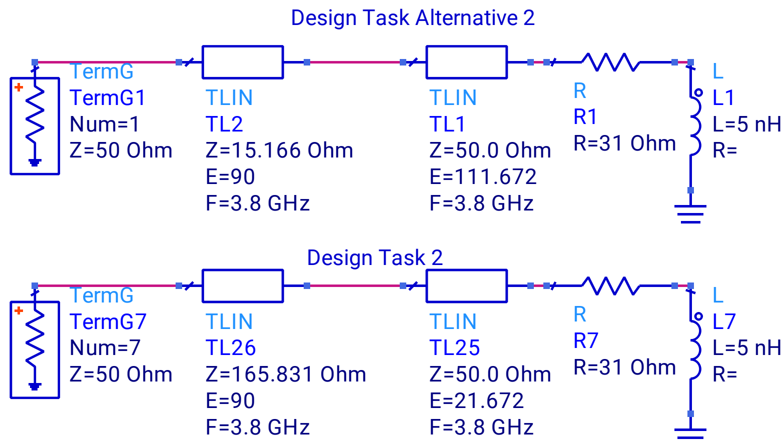


Figure 2.2: Sch

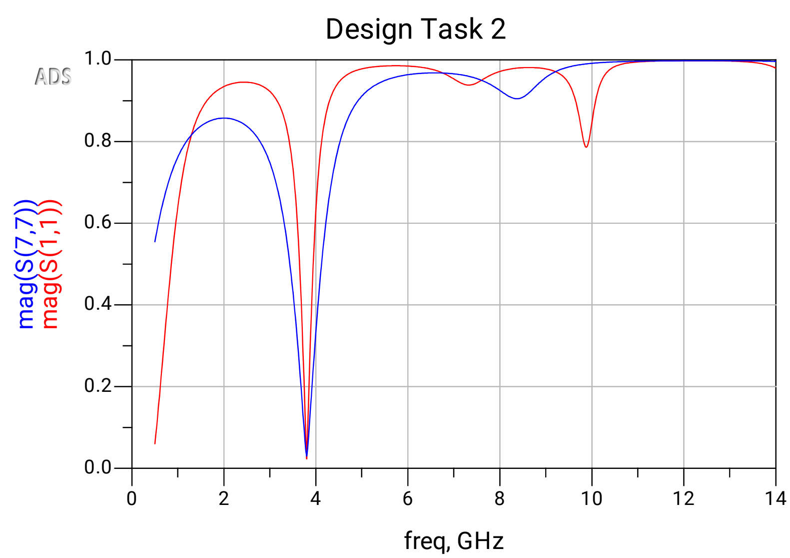
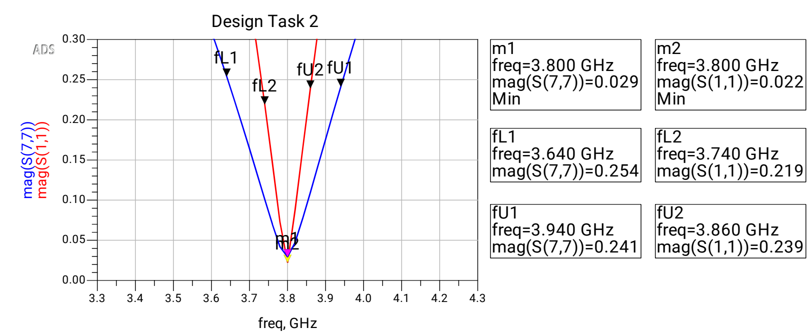


Figure 2.3: Zoomed In Graph of $|\Gamma|$ for Design Task 2



Design Task 2
ADS
mag(S(7,7))
mag(S(1,1))
freq, GHz
fL1
fL2
fU2
fU1
m1
m2
m1
freq=3.800 GHz
mag(S(7,7))=0.029
Min
m2
freq=3.800 GHz
mag(S(1,1))=0.022
Min
fL1
freq=3.640 GHz
mag(S(7,7))=0.254
fL2
freq=3.740 GHz
mag(S(1,1))=0.219
fU1
freq=3.940 GHz
mag(S(7,7))=0.241
fU2
freq=3.860 GHz
mag(S(1,1))=0.239

Figure 2.4

```
LineCalc (*) 620.shp Mar  6 2025

Fri Jun 13 16:18:50 2025

Element type: MLIN
Element ID: TL29

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 1.09914 mm
    L = 9.79877 mm
    Wall1 = 2.5000000000000002e+28 mm
    Wall2 = 2.5000000000000002e+28 mm

Electrical Parameters
    Z0 = 67.475 Ohm
    E_Eff = 90 deg

Result Parameters
    K_Eff = 4.05145
    A_DB = 0.00988425
    SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Fri Jun 13 16:19:46 2025

Element type: MLIN
Element ID: TL28

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 0.036965 mm
    L = 10.6462 mm
    Wall1 = 2.5000000000000002e+28 mm
    Wall2 = 2.5000000000000002e+28 mm

Electrical Parameters
    Z0 = 165.831 Ohm
    E_Eff = 90 deg

Result Parameters
    K_Eff = 3.43215
    A_DB = 0.108296
    SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Fri Jun 13 16:20:34 2025

Element type: MLIN
Element ID: TL27

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 8.1e-05 mm
    L = 11.0035 mm
    Wall1 = 1e+30 mil
    Wall2 = 1e+30 mil

Electrical Parameters
    Z0 = 407.557 Ohm
    E_Eff = 90 deg

Result Parameters
    K_Eff = 3.21284
    A_DB = 18.5572
    SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Fri Jun 13 16:40:34 2025

Element type: MLIN
Element ID: TL23

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 1.99232 mm
    L = 11.8233 mm
    Wall1 = 1e+30 mil
    Wall2 = 1e+30 mil

Electrical Parameters
    Z0 = 50.0001 Ohm
    E_Eff = 111.672 deg

Result Parameters
    K_Eff = 4.28427
    A_DB = 0.00891268
    SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Wed Jun 11 16:15:14 2025

Element type: MLIN
Element ID: TL20

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 10.8775 mm
    L = 8.67715 mm
    Wall1 = 2.5000000000000002e+28 mm
    Wall2 = 2.5000000000000002e+28 mm

Electrical Parameters
    Z0 = 15.1659 Ohm
    E_Eff = 90 deg

Result Parameters
    K_Eff = 5.16655
    A_DB = 0.0039649
    SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Wed Jun 11 16:14:08 2025

Element type: MLIN
Element ID: TL19

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 3.26438 mm
    L = 9.27471 mm
    Wall1 = 2.5000000000000002e+28 mm
    Wall2 = 2.5000000000000002e+28 mm

Electrical Parameters
    Z0 = 37.106 Ohm
    E_Eff = 90.0001 deg

Result Parameters
    K_Eff = 4.52225
    A_DB = 0.00576026
    SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Wed Jun 11 16:15:56 2025

Element type: MLIN
Element ID: TL18

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 30.6582 mm
    L = 8.3581 mm
    Wall1 = 1e+30 mil
    Wall2 = 1e+30 mil

Electrical Parameters
    Z0 = 6.19801 Ohm
    E_Eff = 90 deg

Result Parameters
    K_Eff = 5.56851
    A_DB = 0.00331744
    SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Fri Jun 13 16:39:52 2025

Element type: MLIN
Element ID: TL4

Units
    Freq = GHz
    Length = mil
    Res = Ohm
    Angle = deg

Frequency = 3.8

Shared Parameters:
    Substrate: MSUB = MSub1
        H = 1.3 mm
        Er = 5.8
        Mur = 1
        Cond = 41000000
        Hu = 3.9e+34 miil
        T = 17 um
        TanD = 0
        Rough = 0 mm
        DielectricLossModel = 1
        FreqForEpsrTanD = 1 GHz
        LowFreqForTanD = 1 kHz
        HighFreqForTanD = 1 THz
        RoughnessModel = 2

Physical Parameters
    W = 1.99232 mm
    L = 2.29454 mm
    Wall1 = 1e+30 mil
    Wall2 = 1e+30 mil

Electrical Parameters
    Z0 = 50.0001 Ohm
    E_Eff = 21.672 deg

Result Parameters
    K_Eff = 4.28427
    A_DB = 0.00172968
    SkinDepth = 0.0502 mil
```

Figure 2.5: LineCalc For Binomail Section With Larger Impedance on Top and Lower on Bottom

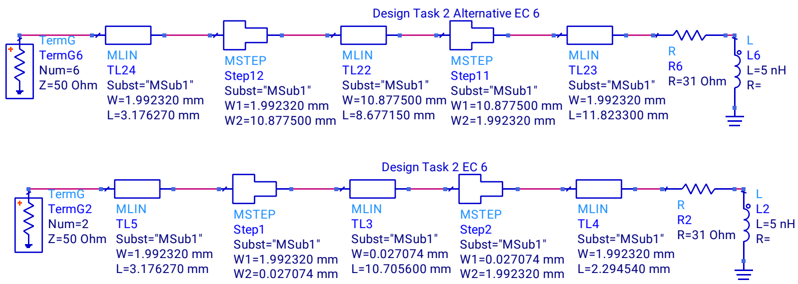


Figure 2.6

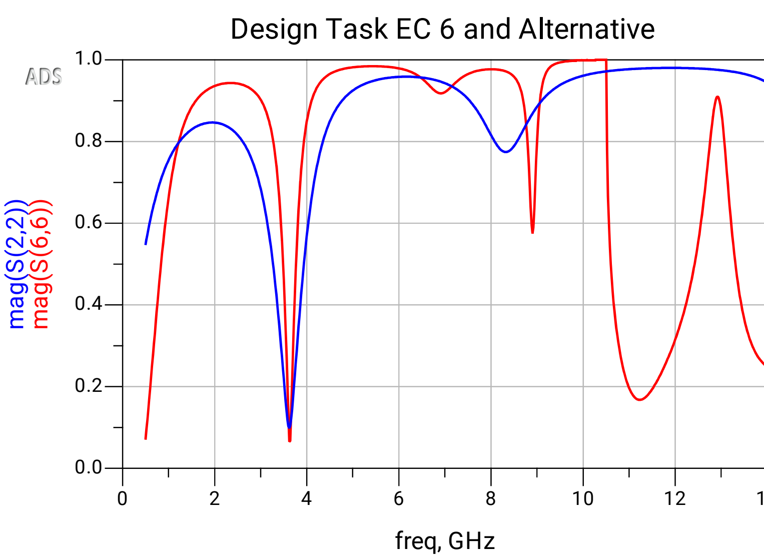


Figure 2.7: Zoomed In Graph of $|\Gamma|$ for Design Task 2 with Step Components in Microstrip Lines

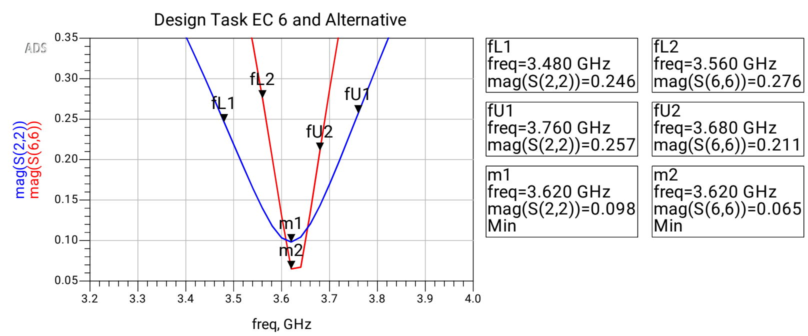


Figure 2.8

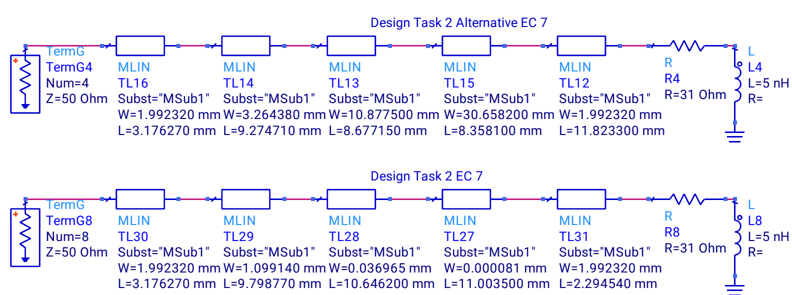


Figure 2.9

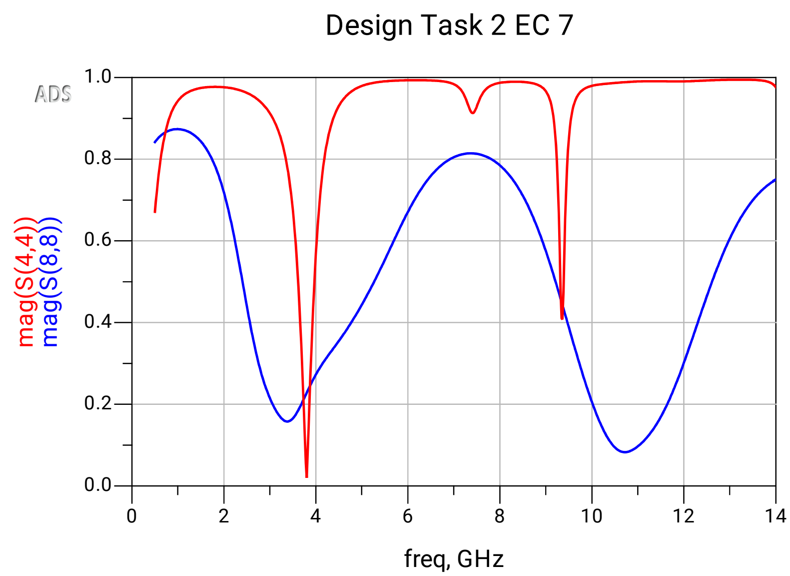


Figure 2.10

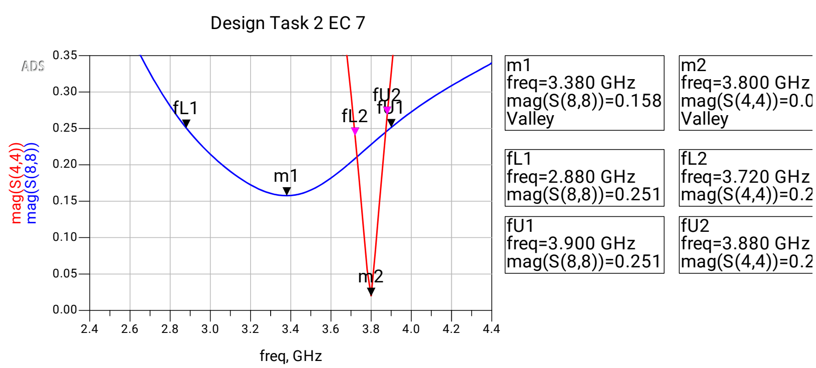


Figure 2.11

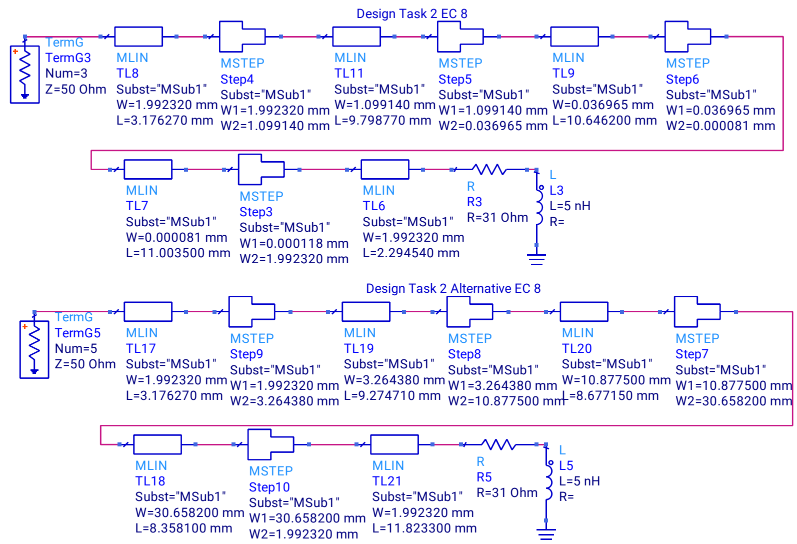


Figure 2.12

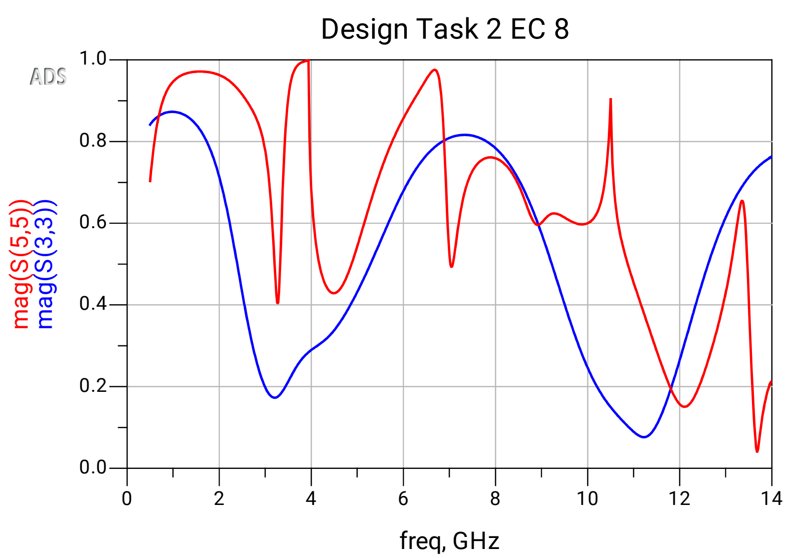


Figure 2.13

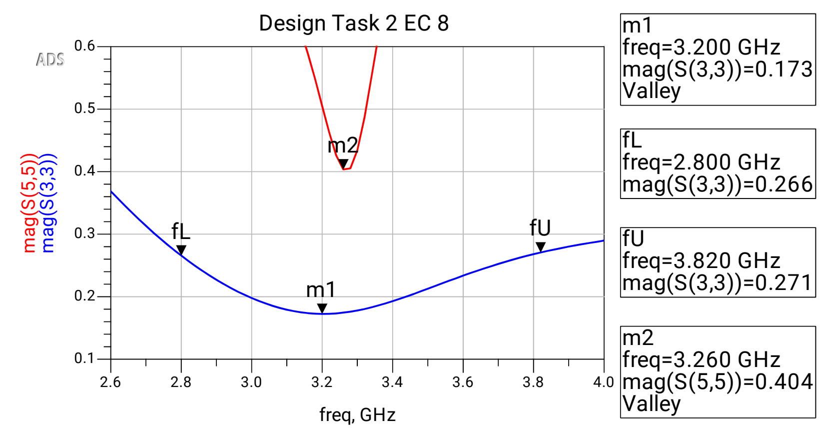

Design Task 2 EC 8
ADS
0.6
0.5
0.4
0.3
0.2
0.1
mag(S(5,5))
mag(S(3,3))
m2
fL
fU
m1
2.6
2.8
3.0
3.2
3.4
3.6
3.8
4.0
freq, GHz
m1
freq=3.200 GHz
mag(S(3,3))=0.173
Valley
fL
freq=2.800 GHz
mag(S(3,3))=0.266
fU
freq=3.820 GHz
mag(S(3,3))=0.271
m2
freq=3.260 GHz
mag(S(5,5))=0.404
Valley

Figure 2.14

Chapter 3

Design Task 3

3.1 Design Requirements

For this matching network, a series transmission line and a parallel shunt element were used to match the load impedance. The series element was used to match the real part of the load and shunt to match to the reactive part of the load.

3.2 Implementation

The primary method to solve this problem was to use a Smith Chart as seen in Figure 3.4. Using the normalized load and constant gamma circle, the length of the series transmission line was found to get the real part of admittance equal to zero. Then to solve for the shunt element, the Smith Chart had to be flipped to admittance and finding the susceptance required to completely match the load. Then, using the short-circuit point on the admittance chart, the length of the shunt element was found. As can be seen in Figure 4.1, the electrical lengths of the series elements are match the Smith Chart and are for the specific design frequency. Figure 3.2 shows a very well-matched network at the design frequency with a very low $|\Gamma|$. Figure 3.3 shows a bandwidth of 4.21% which is very small compared to many of the other networks used thus far.

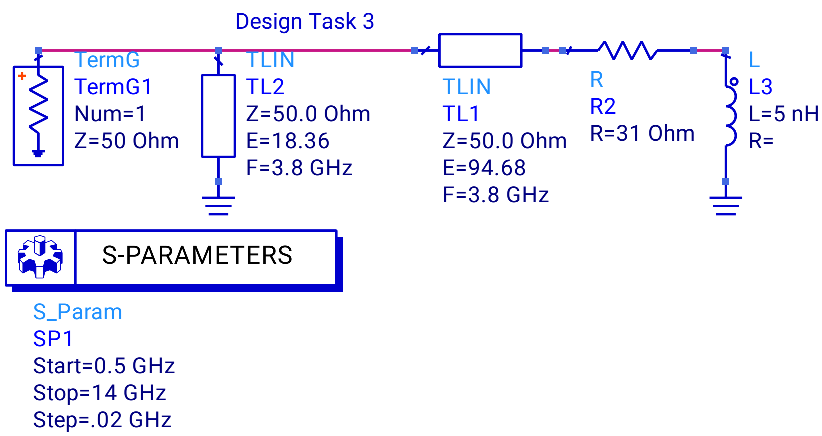


Figure 3.1: Schematic for Section Lumped Element Matching Network to Load.

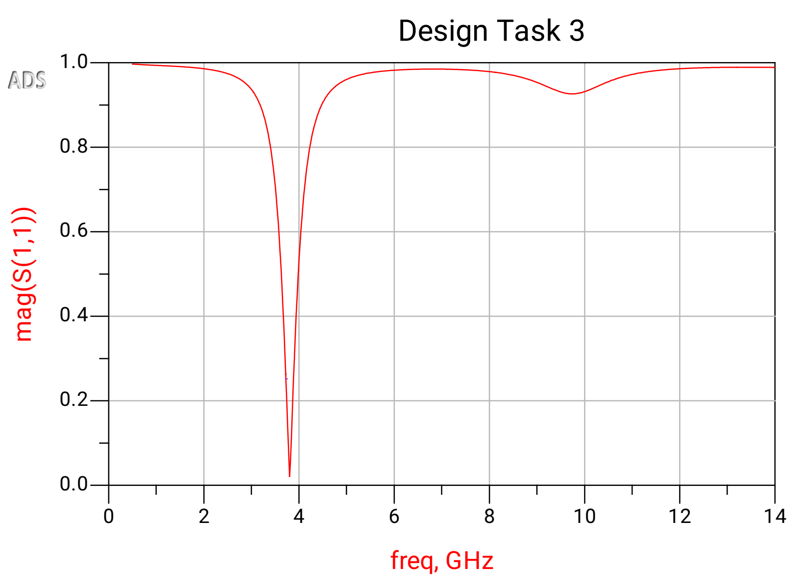


Figure 3.2: Graph of $|\Gamma|$ for Design Task 3

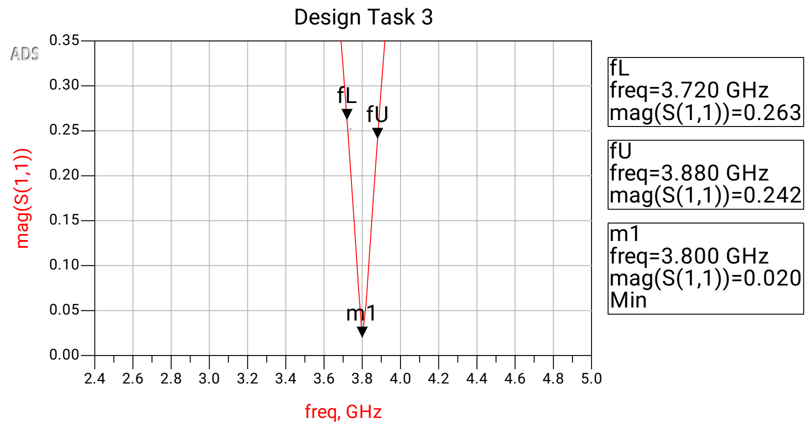


Figure 3.3: Zoomed in Graph of $|\Gamma|$ for Design Task 3

The Complete Smith Chart

Black Magic Design

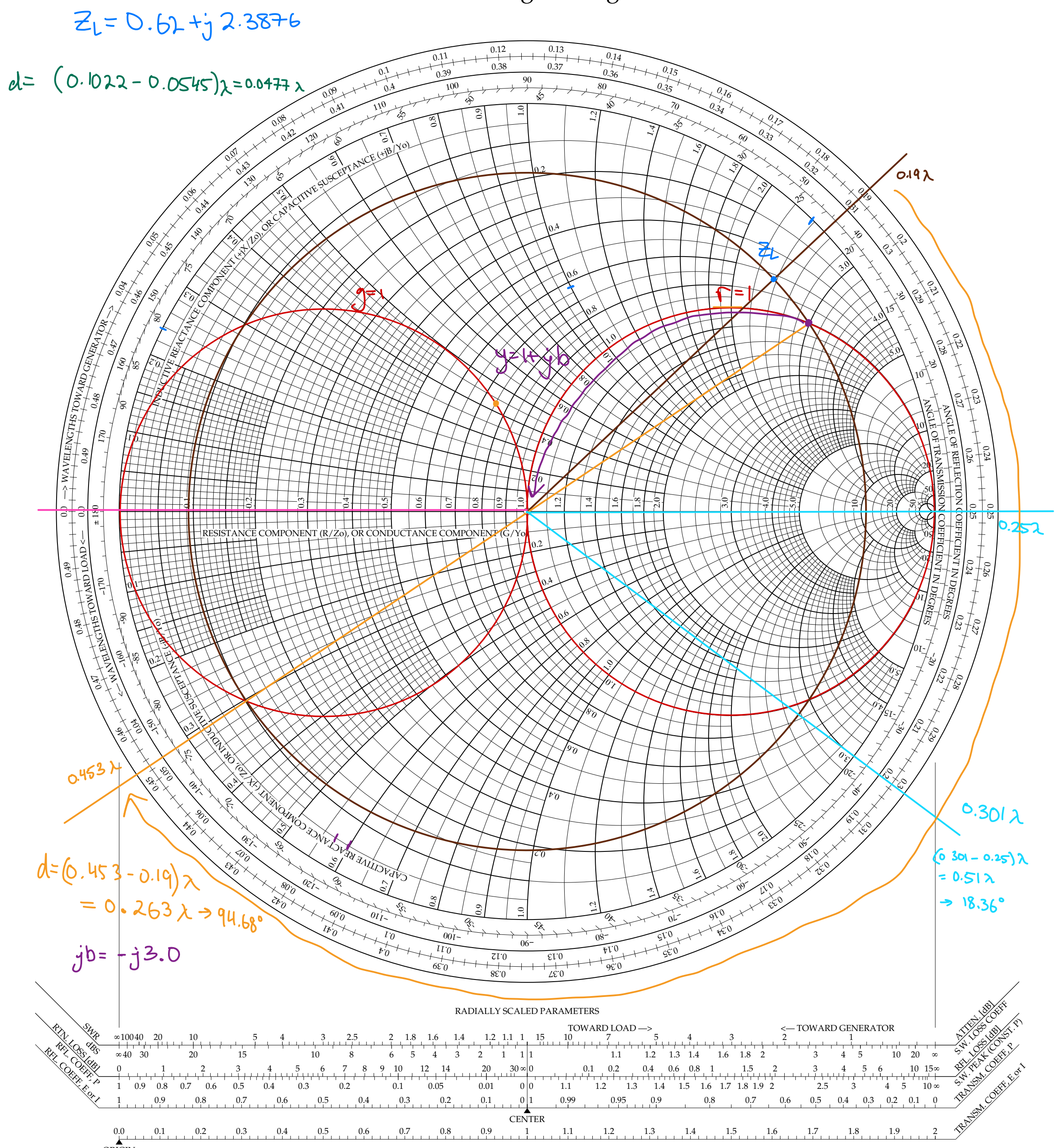


Figure 3.4: Smith Chart of Design Task 3

3.3 Extra Implementation

To make simulation results more applicable to the real world, microstrip lines are used. LineCalc was used to determine the dimensions of the lines as can be seen in Figure 3.8. The tee-junction adds the discontinuities seen at $90°$ angles that happens with a shunt element due to current crowding and other angle related physics. Therefore, the "MTEE" component in Figure 3.5 makes the simulation more realistic. Figure 3.6 shows how the reflection coefficient with the tee-junction and microstrip lines is slightly different than the ideal schematic in Figure 3.1. The bandwidth with microstrip lines significantly decreases with about 2.2% as can be seen in Figure 3.7. The matched frequency also decreases, and doesn't reach a small magnitude compared to ideal conditions.

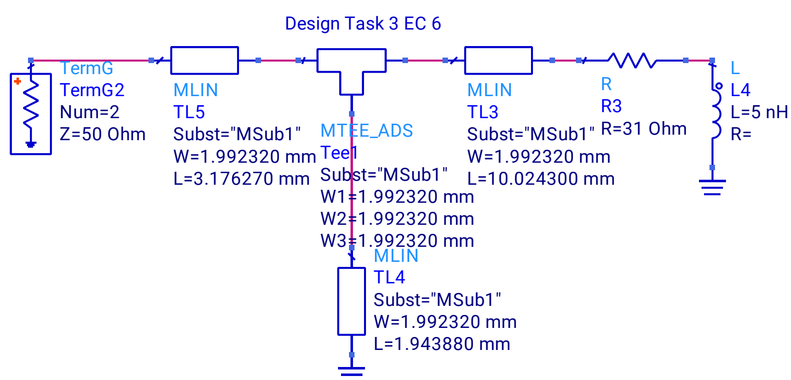


Figure 3.5: Schematic for Section Lumped Element Matching Network to Load With Tee-Junction

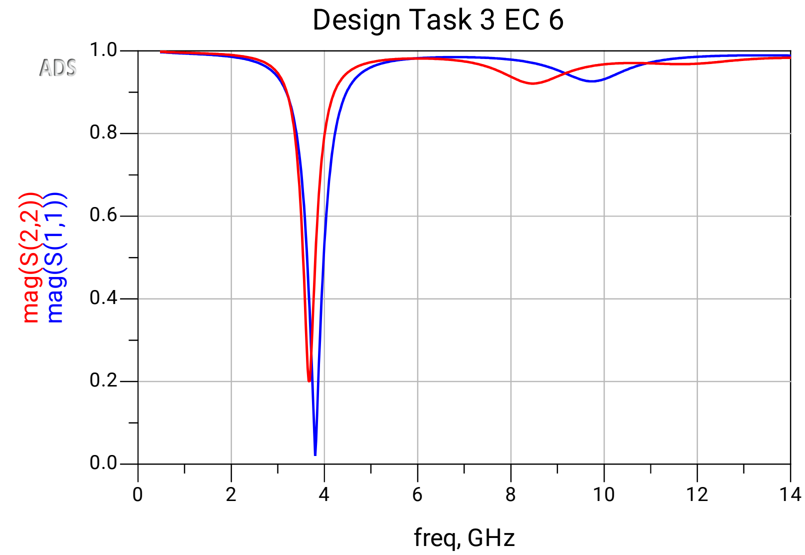


Figure 3.6: Graph of $|\Gamma|$ for Design Task 3 With Tee-Junction

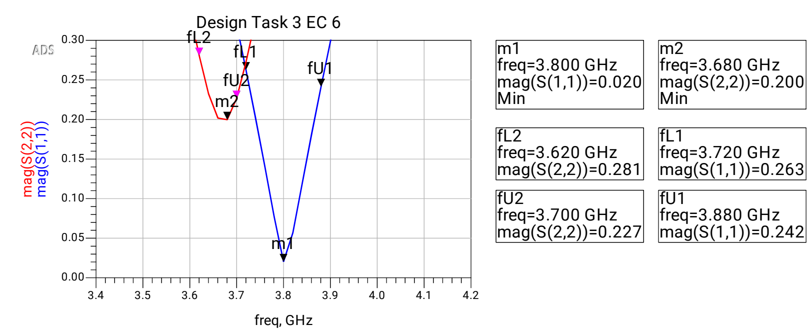


Figure 3.7: Zoomed in Graph of $|\Gamma|$ for Design Task 3 With Tee-Junction

```
LineCalc (*) 620.shp Mar  6 2025

Fri Jun 13 13:06:11 2025

Element type: MLIN
Element ID: TL4

Units
   Freq = GHz
   Length = mil
   Res = Ohm
   Angle = deg

Frequency = 3.8

Shared Parameters:
   Substrate: MSUB = MSub1
      H = 1.3 mm
      Er = 5.8
      Mur = 1
      Cond = 41000000
      Hu = 3.9e+34 miil
      T = 17 um
      TanD = 0
      Rough = 0 mm
      DielectricLossModel = 1
      FreqForEpsrTanD = 1 GHz
      LowFreqForTanD = 1 kHz
      HighFreqForTanD = 1 THz
      RoughnessModel = 2

Physical Parameters
   W = 1.99232 mm
   L = 1.94388 mm
   Wall1 = 2.5000000000000002e+28 mm
   Wall2 = 2.5000000000000002e+28 mm

Electrical Parameters
   Z0 = 50 Ohm
   E_Eff = 18.36 deg

Result Parameters
   K_Eff = 4.28427
   A_DB = 0.00146534
   SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Fri Jun 13 13:05:35 2025

Element type: MLIN
Element ID: TL3

Units
   Freq = GHz
   Length = mil
   Res = Ohm
   Angle = deg

Frequency = 3.8

Shared Parameters:
   Substrate: MSUB = MSub1
      H = 1.3 mm
      Er = 5.8
      Mur = 1
      Cond = 41000000
      Hu = 3.9e+34 miil
      T = 17 um
      TanD = 0
      Rough = 0 mm
      DielectricLossModel = 1
      FreqForEpsrTanD = 1 GHz
      LowFreqForTanD = 1 kHz
      HighFreqForTanD = 1 THz
      RoughnessModel = 2

Physical Parameters
   W = 1.99232 mm
   L = 10.0243 mm
   Wall1 = 2.5000000000000002e+28 mm
   Wall2 = 2.5000000000000002e+28 mm

Electrical Parameters
   Z0 = 50 Ohm
   E_Eff = 94.68 deg

Result Parameters
   K_Eff = 4.28427
   A_DB = 0.00755655
   SkinDepth = 0.0502 mil
```

```
LineCalc (*) 620.shp Mar  6 2025

Wed Jun 11 13:22:58 2025

Element type: MLIN
Element ID: TL8

Units
   Freq = GHz
   Length = mil
   Res = Ohm
   Angle = deg

Frequency = 3.8

Shared Parameters:
   Substrate: MSUB = MSub1
      H = 1.3 mm
      Er = 5.8
      Mur = 1
      Cond = 41000000
      Hu = 3.9e+34 miil
      T = 17 um
      TanD = 0
      Rough = 0 mm
      DielectricLossModel = 1
      FreqForEpsrTanD = 1 GHz
      LowFreqForTanD = 1 kHz
      HighFreqForTanD = 1 THz
      RoughnessModel = 2

Physical Parameters
   W = 1.99232 mm
   L = 3.17627 mm
   Wall1 = 2.5000000000000002e+28 mm
   Wall2 = 2.5000000000000002e+28 mm

Electrical Parameters
   Z0 = 50 Ohm
   E_Eff = 30 deg

Result Parameters
   K_Eff = 4.28427
   A_DB = 0.00239434
   SkinDepth = 0.0502 mil
```

Figure 3.8: LineCalc For Stub and $50\,\Omega$ Transmission Line

Another way of modeling the shunt element is with a radial stub. The issues with a radial stub instead of a rectangular stub is that it acts like an antenna. Outside noise can be picked up by the matching network which will affect the reflection coefficient. Parasite capacitance is also produced because a radial stub is a metal plate on top of a substrate. So, any metal layers underneath can create capacitance. The schematic for this design can be seen in Figure 3.9. The reflection coefficient can be seen in Figure 3.10 With a resonant frequency and a very small reflection coefficient initially. The bandwidth is about 1.6% which is almost half of the rectangular stub. As can be seen, the results are pretty similar, except for the bandwidth being smaller. The primary way the dimensions for the radial stub were obtained was using a starting width that matched the $50\,\Omega$ transmission lines and then a length that is 90%. The angle was chosen as it provides the smallest reflection coefficient magnitude.

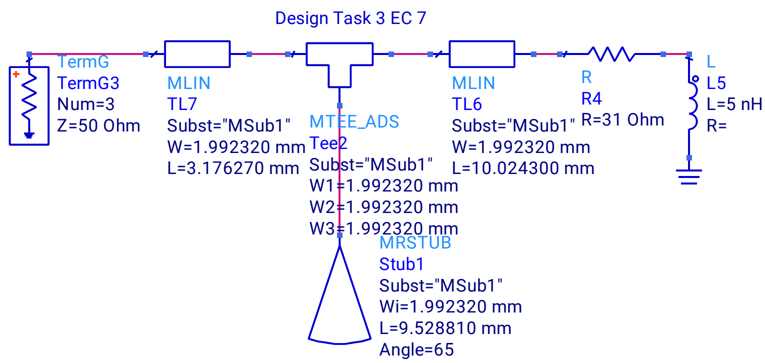


Figure 3.9: Schematic for Section Lumped Element Matching Network to Load With Radial Stub

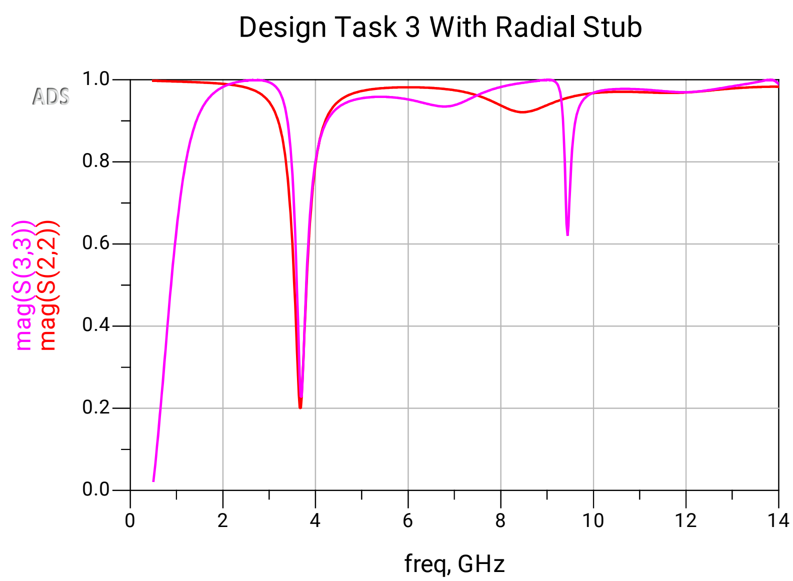


Figure 3.10: Graph of $|\Gamma|$ for Design Task 3 With Radial Stub

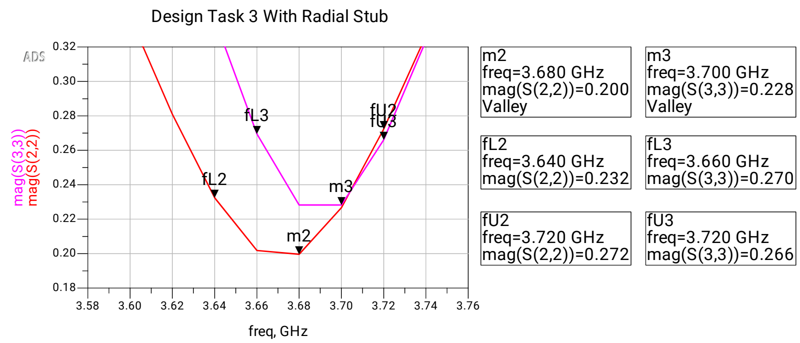


Figure 3.11: Zoomed in Graph of $|\Gamma|$ for Design Task 3 With Radial Stub

An example of a better magnitude of reflection coefficient, but a slightly off frequency is Figures 3.12, 3.13, and 3.14. The matched frequency is the furthest away from the design frequency, but the bandwidth is 4%.

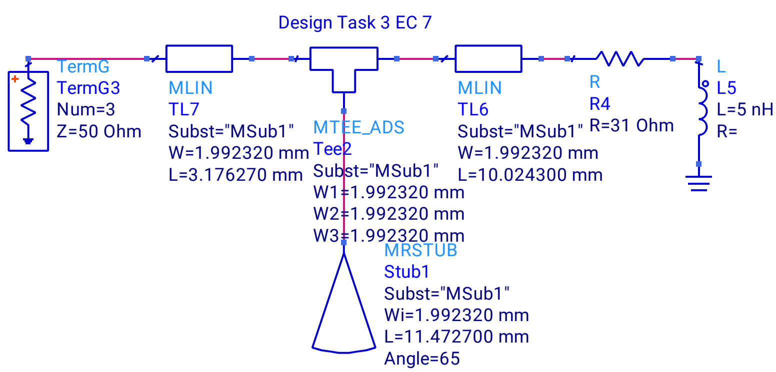


Figure 3.12: Schematic for Section Lumped Element Matching Network to Load With Radial Stub With Smallest $|\Gamma|$

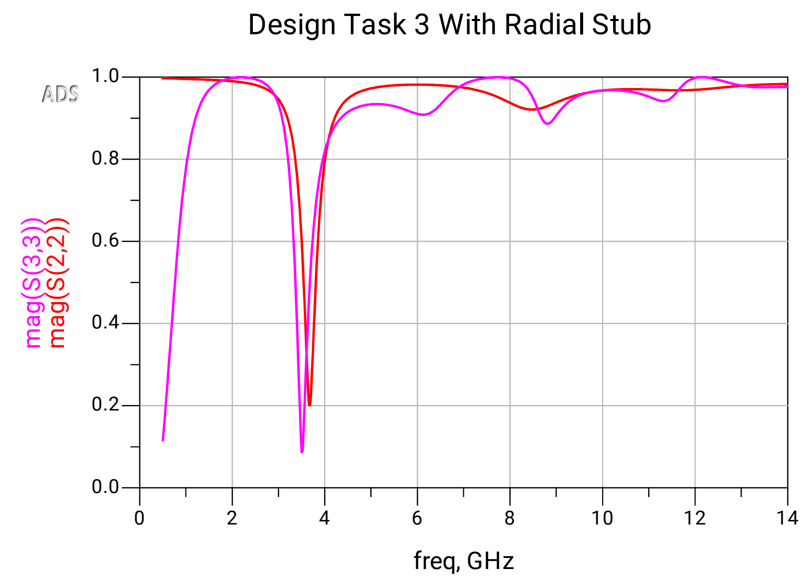


Figure 3.13: Graph of $|\Gamma|$ for Design Task 3 With Radial Stub With Smallest $|\Gamma|$

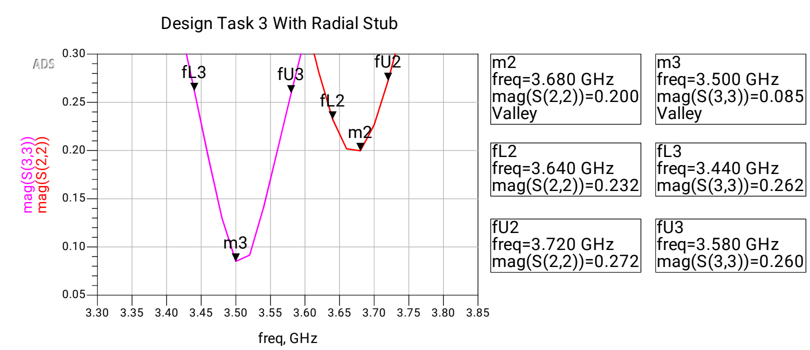


Figure 3.14: Zoomed in Graph of $|\Gamma|$ for Design Task 3 With Radial Stub With Smallest $|\Gamma|$

Chapter 4

Design Task 4

4.1 Design Requirements

For this matching network, the goal was to use two series components to match the load to the source impedance. A series component was first used to convert the real part of the load to $50\,\Omega$, and then a series reactance to cancel the imaginary part of the converted impedance. Figure 4.4 shows how the normalized load was plotted, then brought to the r=1 circle 0.013λ, and then a capacitive component was added to match the load. Figure 4.1 shows the capacitor and length of the transmission line to match the load. Figure 4.2 and 4.3 show a bandwidth of 13.1% which is the largest out of the matched networks.

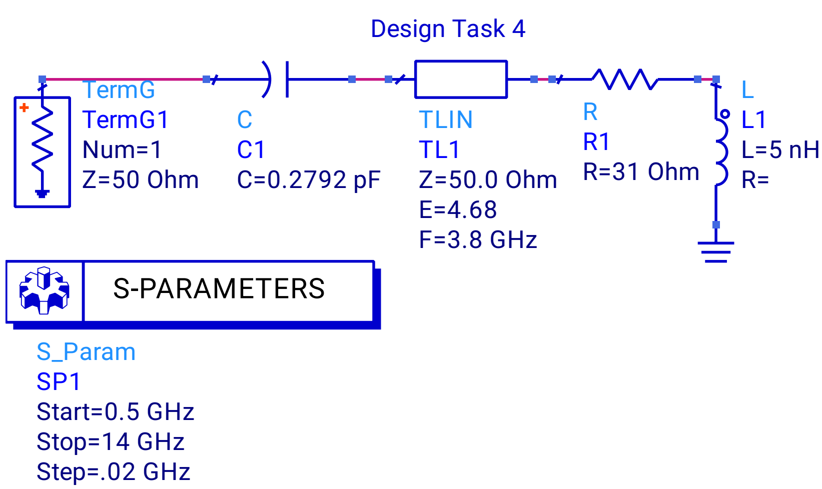


Figure 4.1: Schematic for Section Lumped Element Matching Network to Load.

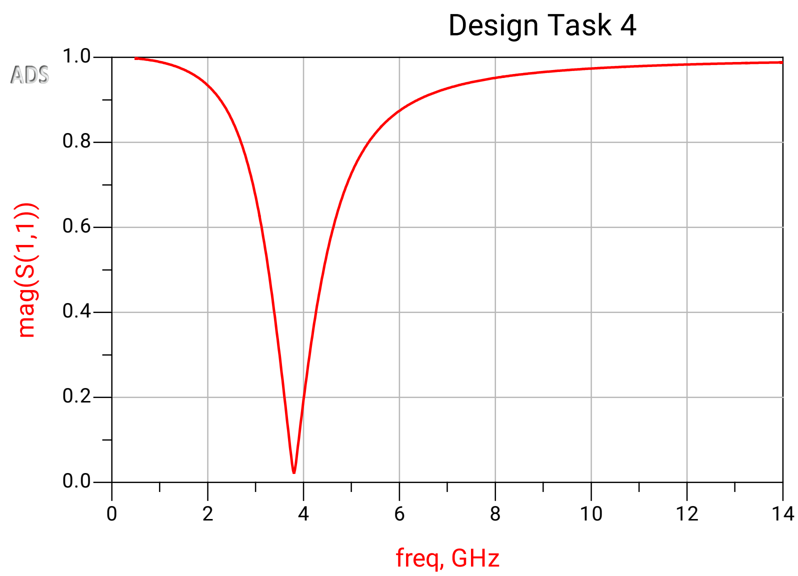


Figure 4.2: Schematic for Section Lumped Element Matching Network to Load.

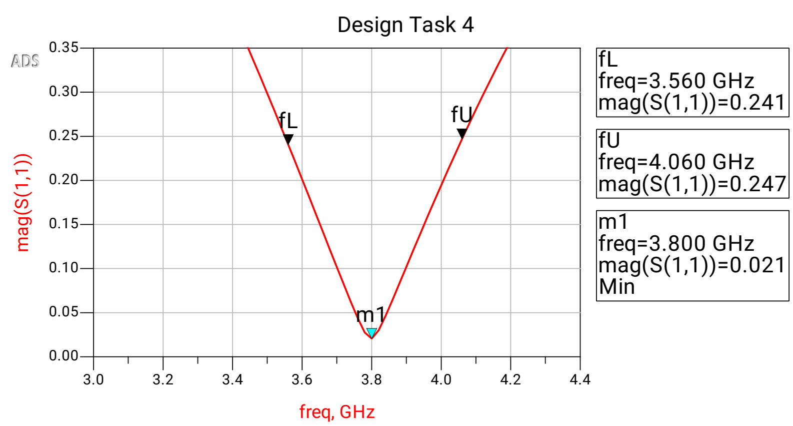


Figure 4.3: Schematic for Section Lumped Element Matching Network to Load.

The Complete Smith Chart

Black Magic Design

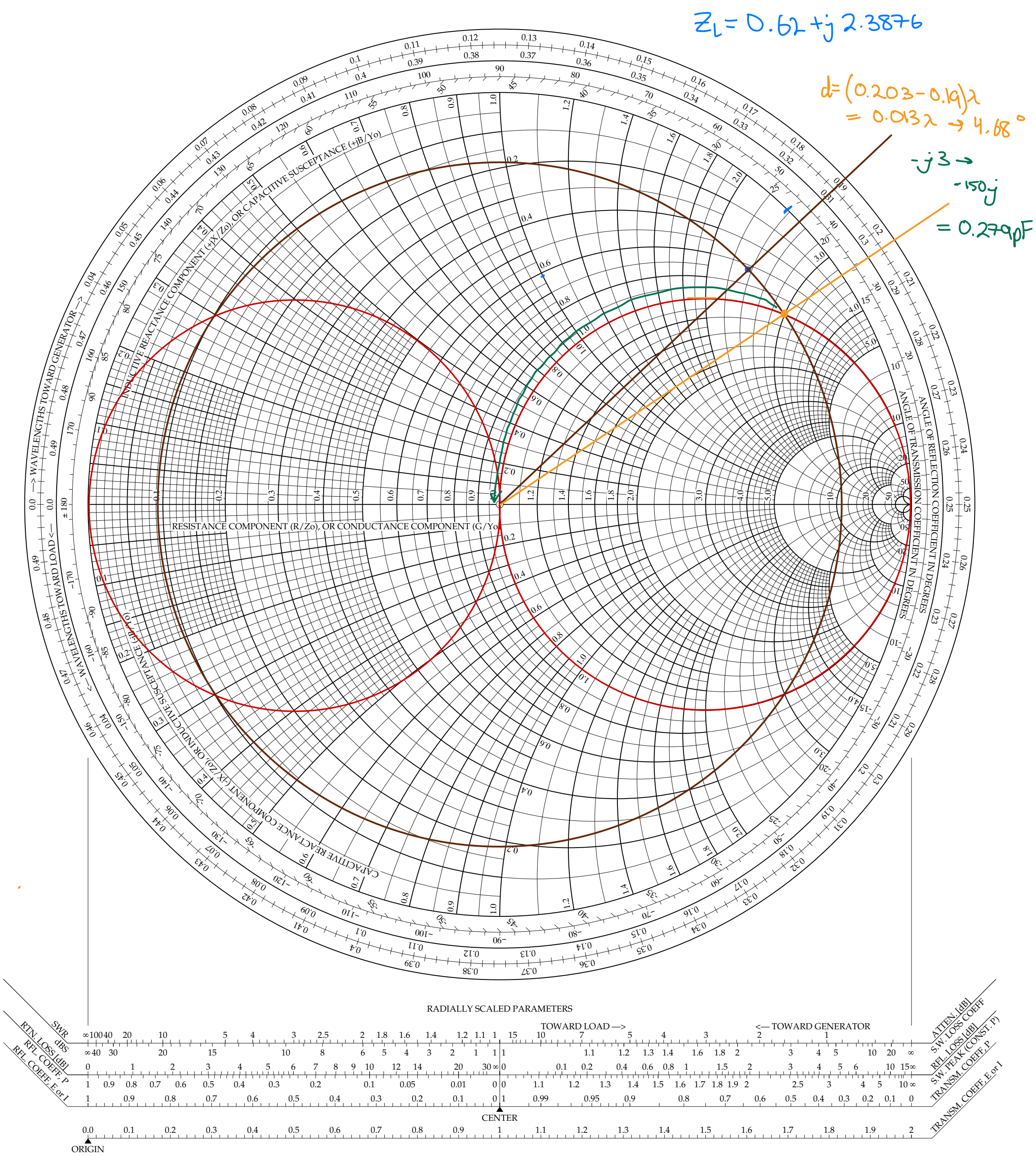


Figure 4.4: Smith Chart of Design Task 4