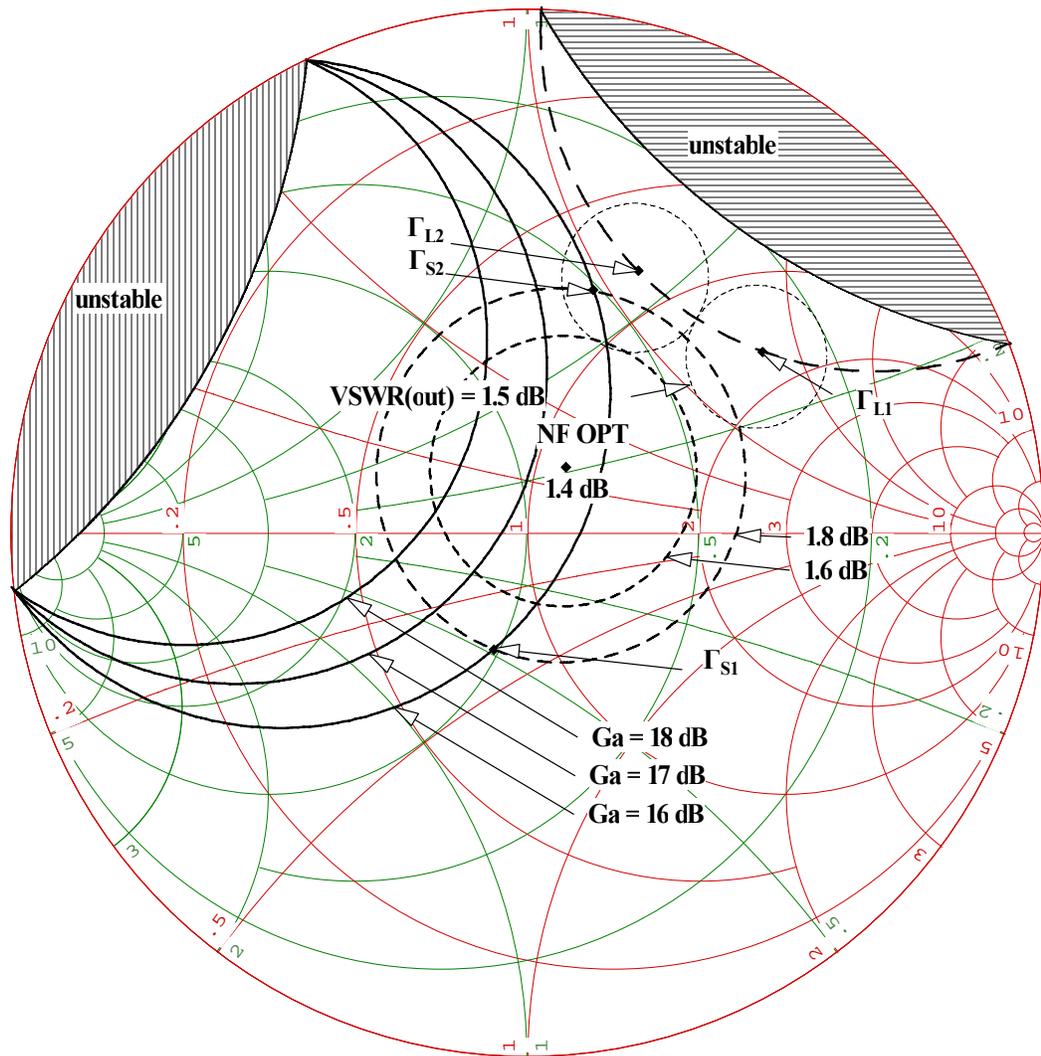

**Microwave Transistor Amplifier Design
Introduction and Reference Manual**



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Table of Contents

Chapter 1	5
Introduction.....	5
What This Module of <i>Slide-Rule</i> Does	5
 Chapter 2	 7
Design Interaction.....	7
Drawing Options	14
 Chapter 3	 17
Tutorial	17
A Simple Impedance Match.....	17
Small Transistor Design for MAG	20
Small Transistor Design for Specified Gain	23
Small Transistor Design for Minimum Noise.....	26
Small Transistor Design - Stability	29
Micro-strip Matching - A Simple Example	32
Micro-strip Matching - Different Characteristic Impedance's	35
A Single Stub Tuner	38
A Double Stub Tuner.....	39
Plotting of Performance Data	41
Handy notes for Impedance matching	43
 Chapter 4	 45
Equations Reference.....	45
VSWR Circle.....	45
Circuit Q Contour.....	46
Admittance Point	46
Conjugate Impedance Point.....	46
Impedance Match - Component Values.....	46
Small Transistor - Stability Circles	47
Small Transistor - Constant Gain Circles.....	48
Small Transistor - Constant VSWR Circles	50
Small Transistor - Noise Circles	50
Small Transistor Calculations	51
Source Reflection Coefficient Calculation	52
Load Reflection Coefficient Calculation	53
Small Transistor - Power Gain Equations.....	53
Y-Parameters to S-Parameters Conversion	53
Micro-strip Calculation	54
 Appendix A.....	 57
References.....	57

Chapter 1

Introduction

This module of *Slide-Rule* has been designed as a basic Graphical RF design package using the Smith Chart as the basic overlay. It has been designed for the popular PC platforms and running under Microsoft Windows. It allows the Engineer or Student of Microwave engineering a quick and fast method of designing simple RF circuits up to and including complex circuits such as a multistage wide-band amplifier. For complex designs, a CAD package is recommended for augmentation and checking of results. Because of the graphical nature of this design package, the Engineer can get an intuitive feel in the design stages because of the visual presentation of displayed data. All plotted data that can be visualized on one's monitor can also be output to a printer device as well. You can also write all plotted output as an extended metafile that can be imported into popular word processing programs such as Microsoft's *Word for Windows*. This feature makes for a powerful tool in itself when it comes time to publish an article. All the plots in this manual were prepared using this feature.

If you're new to Smith Chart techniques or need a refresher course, we recommend reference [2] as listed in appendix A. For a more comprehensive treatment, reference [1] covers more advanced topics. Reference [3] is also very good for an introduction to RF engineering. We recommend that you consult one or more of these references or similar references, and work some of the problems that pertain to the Smith Chart using this SOFTWARE package.

After you have installed this software, and have designed a few circuits, you should be pleasantly surprised at the power and versatility of this tool.

Enjoy!!

What This Module of *Slide-Rule* Does

This module is a basic graphical RF design function running under Slide-Rule that allows users to perform simple to complex RF designs by interacting with their mouse and keyboard to the visual plotted data that is presented on a Smith Chart overlay. The program allows the user to perform the following functions:

- Plot of basic Impedance Grid
- Plot of basic Impedance Grid plus Admittance Grid
- Input of Frequency for each grid
- Input of Characteristic Impedance for each plot
- Undo the last step or all steps.
- Record a given design session for latter play back.
- Output a given displayed window plot to the printer.
- Save a given displayed window plot as a Metafile for insertion into a document.
- Opening of multiple plot windows.

- Interactive text insertion anywhere on the plot by using the mouse and keyboard.
- Interactive plotting of arrows with text.
- Interactive plotting of straight lines.
- Interactive plotting of a particular VSWR circle by mouse positioning.
- Interactive plotting of a particular Circuit Q contour by mouse positioning.
- Interactive plotting of a particular Impedance Point by positioning of the mouse.
- Interactive plotting of an Admittance Point by positioning of the mouse on a particular Impedance Point.
- Interactive plotting of the Conjugate Impedance Point by positioning of the mouse on a particular Impedance Point.
- Interactive computation and plotted display of an Impedance Point along a lossless VSWR by mouse selection from the source or load impedance point along with length of travel and dielectric constant.
- Interactive impedance matching along a constant resistance or constant conductance line along with a visual display of the current component value.
- Interactive micro-strip matching along a constant resistance (shunt stubs) or constant VSWR circle (series strip) along with a visual display of the current computed value of .
- Plotting or locating an Impedance Point, an Admittance Point, or a Reflection coefficient, either in Cartesian or Polar coordinates.
- Plotting of a Radial line from the center of the chart out past the outer circle of the displayed Smith Chart and through the point of interest as selected by the position of the mouse cursor.
- The plotting of the Stability Circles for Small Transistor Design.
- The plotting of the Constant Gain Circles for Power Gain (G_p), Available Gain (G_p), S_{11} , or S_{22} .
- The plotting of Noise Circles for Small Transistor Design.
- The plotting of the Conjugate Match Circle ($1 + j$) as a rotation towards the Generator or Load as a fraction of Lambda.
- Small Transistor Calculations and display from S-parameters including the Rollett Stability Factor (K), (DEL), Maximum Available Gain (MAG), Source and Load reflection coefficients at MAG, G_s , G_o , G_l , and Maximum Transducer Gain both for the bilateral and unilateral cases.
- Source Reflection calculation from S-parameters and the Load Reflection coefficient.
- Load Reflection calculation from S-parameters and the Source Reflection coefficient.
- Plotting of Constant input or output VSWR circles.
- Calculation and storage of S-parameters from Y-parameters.
- Micro-strip calculation (quasi-TEM) of width, E_{ff} , and length from Characteristic Impedance, dielectric constant (E_r), substrate thickness, and fraction of wave-length.
- Micro-strip calculation (quasi-TEM) of Characteristic Impedance from dielectric constant, substrate thickness, and width of the micro-strip line.
- Transducer power gain G_T , operating power gain G_P , and available power gain G_A from S-parameters, and Source and Load Reflection coefficients (Γ_S & Γ_L).
- Calculation of Γ_{IN} and Γ_{OUT} from Γ_S and Γ_{OUT} .
- Plotting of empirical data either on a Smith overlay or a simple polar plot.

Chapter 2

Design Interaction

On the Smith Chart grid, once the drawing has been displayed on the monitor, we can interact with our mouse, and add functionally much as we did with text and arrow annotation as described in the **Annotation** section. To do this, we position the cross hair over the point of interest, then click the right most button on one's mouse, and while still holding down the right mouse button, select one of the functions as listed below:

- Text Insert...**
- Draw Arrow**
- Draw Line**
- VSWR**
- Circuit Q**
- Radial Line**
- Imped. point**
- Conjg. Imped point**
- 1/Imped. point**
- Load Reflection Calc...**
- Source Reflection Calc...**

In particular, a description of these functions are described as follows:

Text Insert...

Refer to *Slide-Rule* Manual.

Draw Arrow

Refer to *Slide-Rule* Manual.

Draw Line

Refer to *Slide-Rule* Manual.

VSWR

Draws a VSWR circle at the point the mouse cursor is positioned at when the right most mouse button is depressed.

Circuit Q

Draws a closed Circuit Q contour at the point the mouse cursor is positioned at. Note that Circuit Q is displayed in the upper right hand corner of the display when the mouse is positioned inside the Smith Chart.

Imped. point

Draws an upright triangle at the point the mouse cursor is positioned at.

Conjg. Imped. pt.

Draws an upright triangle at the conjugate impedance point from the impedance point as selected by the mouse cursor point when the right most mouse button is depressed.

1/Imped point

Draws an upside down triangle of the admittance point, which is located on a VSWR circle (and 180 degrees opposite) from the mouse selected impedance point when the right most mouse button is depressed.

Load Reflection Calc...

By positioning your mouse cursor over a point on an Available Power Gain circle, you can plot the point on the circle and at the same time plot the Load Reflection point. You can also select the Constant VSWR option and not only plot the Load Reflection point, but also constant VSWR circle around the Load Reflection point. You will be queried for the constant VSWR value.

Source Reflection Calc...

By positioning your mouse cursor over a point on an Operating Power Gain circle, you can plot the point on the circle and at the same time plot the Source Reflection point. You can also select the Constant VSWR option and not only plot the Source Reflection point, but also constant VSWR circle around the Source Reflection point. You will be queried for the constant VSWR value.

Please note that for Impedance matching, a permanent record of the element values are recorded on the left of the drawing and moving down. This allows one to keep track of the values during the impedance matching process.

There are additional interactive menu commands which can be selected under the Functions menu as displayed below.

- Add Smith Plot...**
- Smith Chart Grids...**
- Characteristic Impedance...**
- Frequency...**
- Stability Circles...**
- Constant Gain Circles...**
- Noise Circle...**
- Conj. Match Circle...**
- Parametric Data...**
- Small Transistor Calc...**
- Point type...**
- Impedance Match...**
- Microstrip Match...**
- Source Refl. Calc...**
- Load Refl. Calc...**
- Power Gain Calculations...**
- Y-param -> S-param...**
- Microstrip Calc...**

VSWR Calc...

In particular, a description of these functions are described as follows:

Add Smith Grid...

Presents a dialog menu whereby the user selects the title of the of the next basic Smith grid that is added to the shell script.

Smith Chart Grids...

By selecting one of these options, you can change the currently displayed grid on just refresh it.

Imped Grid

Imped Grid type II

Imped + Admit Grid

Imped + Admit reduced

Admit Grid

Admit Grid reduced

Refresh

Characteristic Impedance...

Presents a dialog menu whereby one can change the characteristic impedance.

Frequency...

Presents a dialog menu whereby one can change the frequency.

Stability Circles...

Presents a dialog menu whereby one can plot the stability circles for a given small signal transistor from the S-parameters (Refer to Functions reference - Chapter 4). You can plot both input and output stability circles. If they overlap, reverse the order if one completely overlaps the other.

Constant Gain Circles...

Presents a dialog menu whereby one can plot a constant gain circle for a given small signal transistor from the S-parameters (Refer to Functions reference - Chapter 4). The dialog procedure also allows the corresponding circle in the other plane to be plotted. As an example, if you're plotting an Available Power Gain circle on the input side, you can plot the corresponding circle of *matched* Load Reflection points.

Noise Circle...

Presents a dialog menu whereby one can plot a noise circle for a given small signal transistor from the S-parameters, the minimum noise figure in dB, the reflection value at the minimum, and the noise resistance in ohms (Refer to Functions reference - Chapter 4).

Conj Match Circle

Plots a Conjugate Match Circle (Refer to Functions reference - Chapter 4).

Parametric Data...

Plot Data...

A dialog box is presented to open and read the S-Parameters from a file in *Touchstone* format (Touchstone is a product of EESOF, Inc.). Another dialog box is then presented to allow the user to plot the S11, S21, S12, or S22 data. The S11 and S22 data are

plotted using a Bezier Curve fit on a reduced Smith grid overlay. The S21 and S12 data are plotted on a polar grid. If you are not familiar with Touchstone, the data (50j terminations) is tabulated with the first column being the frequency in GHz, second and third are the magnitude and angles in degrees of S11. Subsequent columns are magnitudes and angles of S21, S12 and S22. For the noise data, the columns are: frequency in GHz, optimum noise figure in dB, optimum reflection coefficient (bopt) in magnitude and angle and noise resistance normalized to 50 ohms.

List Data...

Opens the selected file (*.S2P format) using the Windows Notepad program for viewing.

Small Transistor Calc...

Manual...

Presents a dialog box for the inputting of S-parameters. When all parameters have been input, calculates the Rollett Stability Factor K and (DEL) and displays in a dialog box. If $K \geq 1.0$ and $(DEL) < 1.0$, the MAG (maximum available gain) of the transistor is displayed along with Load and Source reflection coefficients at maximum gain.

File...

Same function as in **Manual...**, except a dialog box is presented to open and read the S-Parameters from a file in *Touchstone* format. This function also reads in Noise parameters if they exist in the *.S2P file for selection. This parameters are then remembered when the Noise Circle dialog function is selected.

Important!! Note that some old (greater than 15 years) HP and Motorola libraries have been included. Don't design real world circuits using these libraries. Instead get the latest libraries from your selected vendor, and store them in a directory under the smith sub-directory.

Point type...

Plot...

Locate...

1/Imped...

Conjg Imped...

VSWR Circle...

Presents a dialog box, either to plot a given point, or to locate a given point with the cursor on the display, or to plot 1/Impedance point, or to plot the Conjugate impedance point, or finally, to plot the VSRW circle that intersects to input impedance point. The point can be either selected as an impedance point, as an admittance point, or as a reflection coefficient. The value may be either entered in Cartesian coordinates or in polar format.

Impedance Match...

Const Resistance - Load --> Source...

Const Conductance - Load --> Source...

Const Series resister - Load --> Source...

Const Shunt resister - Load --> Source...

Const Resistance - Source --> Load...

Const Conductance - Source --> Load...

Const Series resistor - Source --> Load...
Const Shunt resistor - Source --> Load...

Note that when performing interactive impedance matching, the last point is saved, such that when the user selects this command entry, the last point is automatically inserted into the dialog box. Note that if the last point is slightly off (by a fractional value), that you can correct the value in dialog box. Also, this method offers better accuracy, in that when selecting points with the mouse, one is limited to the pixel granularity of the monitor display. Refer to first example under tutorial section.

Impedance Match Const Resistance - Load -->Source

A line is drawn along a constant resistance path from the selected impedance point as the user moves the cursor. The element value is displayed interactively in the upper left hand corner of the display, and the impedance (admittance) of the selected point along with the impedance (admittance) difference is displayed in the upper right hand corner of the monitor. This line is terminated when the user clicks the right most mouse button. Refer to first example in tutorial section.

Impedance Match Const Conductance - Load -->Source

A line is drawn along a constant conductance path from the selected impedance point as the user moves the cursor. The element value is displayed interactively in the upper left hand corner of the display, and the impedance (admittance) of the selected point along with the impedance (admittance) difference is displayed in the upper right hand corner of the monitor. This line is terminated when the user clicks the right most mouse button. Refer to first example in tutorial section.

Impedance Match Series resistor - Load -->Source

A line is drawn along a constant reactance path from the selected impedance point as the user moves the cursor. The element value is displayed interactively in the upper left hand corner of the display, and the impedance (admittance) of the selected point along with the impedance (admittance) difference is displayed in the upper right hand corner of the monitor. This line is terminated when the user clicks the right most mouse button

Impedance Match Shunt resistor - Load -->Source

A line is drawn along a constant-susceptance path from the selected impedance point as the user moves the cursor. The element value is displayed interactively in the upper left hand corner of the display, and the impedance (admittance) of the selected point along with the impedance (admittance) difference is displayed in the upper right hand corner of the monitor. This line is terminated when the user clicks the right most mouse button

Impedance Match Const Resistance - Source --> Load

Same as **Const Resistance -Load --> Source**, except load to source and the program calculates the correct element value as displayed in the upper left-hand corner of the monitor. This line is terminated when the user clicks the right most mouse button. Refer to first example in tutorial section. This line is terminated when the user clicks the right most mouse button.

Impedance Match Const Conductance - Source --> Load

Same as **Const Conductance -Load --> Source**, except load to source and the program calculates the correct element value as displayed in the upper left-hand corner of the monitor. This line is terminated when the user clicks the right most mouse button

Impedance Match Series resistor - Source --> Load

Same as **Const Series resistor -Load --> Source**, except load to source and the program calculates the correct element value as displayed in the upper left-hand corner of the monitor. This line is terminated when the user clicks the right most mouse button.

Impedance Match Shunt resistor - Source --> Load

Same as **Const Shunt resistor -Load --> Source**, except load to source and the program calculates the correct element value as displayed in the upper left-hand corner of the monitor. This line is terminated when the user clicks the right most mouse button.

Micro-strip Match...

Note!! All impedances must be converted to admittance points, and the Y Smith chart is MUST be used for stub circuits.

Series Line...

A line is drawn along a constant VSWR circle from the marked point as the user moves the cursor. The program calculates the fraction of wavelength, and displays in the upper left corner of the monitor.

Stub Open Circuit...

A line is drawn along a constant resistance contour from the marked point as the user moves the cursor while the program calculates the fraction of wavelength for an **open** circuit shunt stub, and displays it in the upper left corner of the monitor.

Stub Short Circuit...

A line is drawn along a constant resistance contour from the marked point as the user moves the cursor while the program calculates the fraction of wavelength for an **short** circuit shunt stub, and displays it in the upper left corner of the monitor.

Bal. Stub Open Circuit...

A line is drawn along a constant resistance contour from the marked point as the user moves the cursor while the program calculates the fraction of wavelength for an **open** circuit shunt stub, and displays it in the upper left corner of the monitor.

Bal. Stub Short Circuit...

A line is drawn along a constant resistance contour from the marked point as the user moves the cursor while the program calculates the fraction of wavelength for a **balanced short** circuit shunt stub(s), and displays it in the upper left corner of the monitor.

Series Open Circuit...

A line is drawn along a constant resistance contour from the marked point as the user moves the cursor while the program calculates the fraction of wavelength for a **open** circuit series stub, and displays it in the upper left corner of the monitor.

Series Closed Circuit...

A line is drawn along a constant resistance contour from the marked point as the user moves the cursor while the program calculates the fraction of wavelength for a **closed** circuit series stub, and displays it in the upper left corner of the monitor.

Quarter Wave Transformer – Z chart

A line is drawn along the horizontal axis from the center of the chart (Z0), while the program calculates the resistance value of a quarter wave transformer , and displays it in the upper left corner of the monitor.

Quarter Wave Transformer – Y chart

A line is drawn along the horizontal axis from the center of the chart (Z0), while the program calculates the resistance value of a quarter wave transformer , and displays it in the upper left corner of the monitor.

Source Refl. Calc...

Presents a dialog box for the inputting of S-parameters and the Load Reflection Coefficient. When all parameters have been input, calculates the Source Reflection Coefficient to properly terminate the transistor's input and displays in a dialog box. The equation for this is given by:

$$\Gamma_S = \left[S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - \Gamma_L S_{22}} \right]^*$$

You can also calculate the conjugate value by selecting the appropriate check box. The equation for this is given by:

$$\Gamma_{IN} = \left[S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - \Gamma_L S_{22}} \right]$$

Load Refl. Calc...

Presents a dialog box for the inputting of S-parameters and the Source Reflection Coefficient. When all parameters have been input, calculates the Load Reflection Coefficient to properly terminate the transistor's output and displays in a dialog box. The equation for this is given by:

$$\Gamma_L = \left[S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - \Gamma_S S_{11}} \right]^*$$

You can also calculate the conjugate value by selecting the appropriate check box. The equation for this is given by:

$$\Gamma_{OUT} = \left[S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - \Gamma_S S_{11}} \right]$$

Power Gain Calc...

Presents a dialog box for calculating the total transducer gain G_T , the operating power gain G_P , and the available power gain G_A of a Small Transistor from the S-parameters and the Source and Load reflection coefficients.

Y-param --> S-param...

Presents a dialog box for the inputting of Y-parameters. When all the Y-parameters have been input, the S-parameters are calculated and saved, and then are displayed under the Small Transistor Calc dialog box. They will be retrieved in any of the above procedures that require S-parameters as input. Note that each Y parameter must be multiplied by Z_0 .

Micro-strip Calc...

Presents a dialog box for:

1. Calculating the width and length of a micro-strip line from the Characteristic Impedance, Dielectric Constant, Substrate thickness, and fraction of wavelength (quasi-TEM).
2. Calculating the Characteristic Impedance of a micro-strip line from the Dielectric Constant, Substrate thickness, and width of the line (quasi-TEM).

VSWR Calc...

Calculates and displays VSWR(in) from Γ_S and Γ_{IN} , or VSWR(out) from Γ_L and Γ_{OUT} . Also, the Mismatch factor is calculated and displayed.

Drawing Options

Under the **Config** Tile on the Slide-Rule graphic, we can select drawing options as displayed below:

Line or Symbol Size...

VSWR Circle...
Circuit Q Contour...
Constant Gain Circle...
Stability Circles...
Conj Match Circle...
Radial Line...
Noise Circle...
Impedance Point...
Admittance Point...
Curve Fit Line...

These dialog functions allow one to adjust the line or symbol plotting size for their particular needs.

Line or Symbol Color...

VSWR Circle...
Circuit Q Contour...
Constant Gain Circle...
Stability Circles...
Conj Match Circle...
Radial Line...

Noise Circle...
Impedance Point...
Admittance Point...
Curve Fit Line...

These dialog functions allow one to adjust the line or symbol plotting color for their particular needs.

Curve Fit Tolerance...

This dialog function allow one to adjust the curve fitting tolerance for the Bezier curve fitting function for plotting of parametric data. Adjust up or down until you get to fit that you're satisfied with.

Impedance Match Data on Metafiles NO/YES

Allows the impedance data on the left of the monitor to be either included or not on metafile output.

Summary

This chapter has been a quick outline of the overall features of the **RF** design module. Chapter 3 will give more detailed design procedures along with actual design examples. Finally, Chapter 4 as a reference for the equations used in each design procedure.

Chapter 3

Tutorial

This chapter takes you through several design examples with step by step procedures along with a discussion of theory and equations where appropriate.

A Simple Impedance Match

Design an impedance network that matches a $15 - j15$ source to a $100 - j50$ ohm load at 100 MHz. The matching network must also act as a low-pass filter between the source and the load.

The requirement that the matching network act as a low-pass filter forces an L-configuration with a series-L, shunt-C configuration. Since the source impedance is a complex impedance, it wants to see the load impedance as its complex conjugate. Thus, we want to force the $100 - j50$ ohm load to look like an impedance of $15 + j15$ ohms.

Solution:

1. Under the **File** tile, select **New...->Smith Chart...**, and enter a file name. Then change the grid to *Imped+Admit reduced*. Then, under the Functions menu, select **Point type... Plot...** and fill in the dialog box with the conjugate source impedance of $15 + j15$ ohms in Cartesian coordinates. Repeat for the load impedance of $100 - j50$ ohms and note the two plotted points. Label these points as Z_s^* and Z_H using the text insert mode.
2. Under the **Functions** menu, select **Impedance Match... Const Conductance - Load -> Source**, and fill in the load impedance of $100 - j50$ ohms in Cartesian coordinates, and depress the enter key. Note the change in the cursor. Move the cursor down and note the line that is drawn along a constant conductance contour. At the same time note the component value that is being displayed in the upper left-hand corner of the monitor. When the drawn line along the constant conductance line intersects a constant resistance line that will pass through the conjugate source point, click the right most button on your mouse, and note that a solid line is drawn along with the component value of the shunt-C capacitor in the upper left corner of your monitor. You can monitor the impedance by observing the impedance on the third line in the upper right hand corner as you move your mouse. When this value is close to 15 ohms, click the right most button on your mouse. If you mess up, go to the edit tile, and click the undo tile to start over.
3. Again under the **Functions** menu, select **Impedance Match... Const Resistance - Load -> Source**. At this point a dialog box will be presented requesting that you enter the appropriate impedance point. However, the end impedance point of the series leg has been remembered, so just depress the enter key. Note that if the end impedance

point is slightly off, you can make a correctly in the dialog box. C Now, move the cursor up until the cursor window encloses the conjugate source impedance point, then click the right most mouse button.

At this point the design is complete. Note the Series-L inductor value as the second value listed in the upper left-hand corner. The design plot for the above example is shown in Figure 3.2a and the design circuit in figure 3.2b.

The equations used to determine the component values are as follows:

For a series-C component:

$$C = \frac{1}{\omega X Z_0}$$

For a series-L component:

$$L = \frac{X Z_0}{\omega}$$

For a shunt-C component:

$$C = \frac{B}{\omega Z_0}$$

For a shunt-L component:

$$L = \frac{Z_0}{\omega B}$$

where,

$$\omega = 2\pi f$$

X = the reactance from the chart

B = the susceptance from the chart

Z0 = the Characteristic Impedance value

$Z_0 = 50.0 \Omega$
 Freq. = 100.0 Mhz
 shunt-C=28.2pF
 series-L=88.30nH

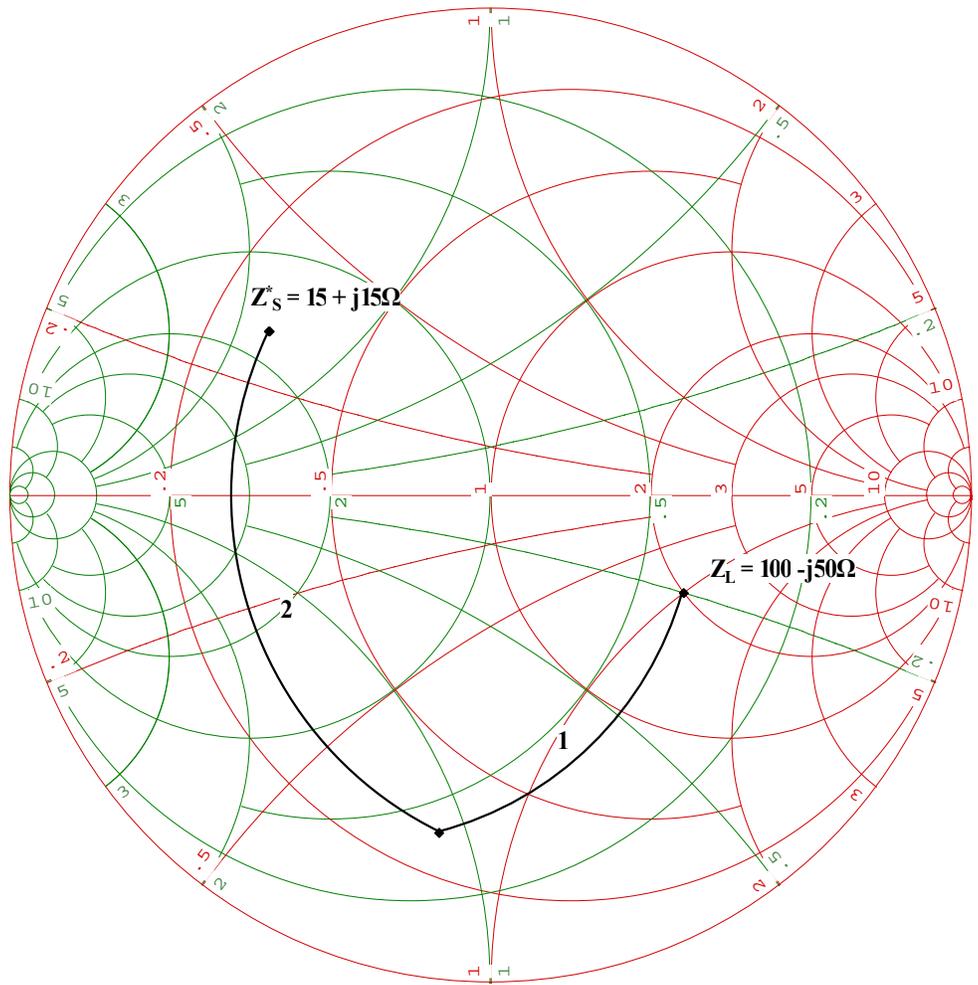


Figure 3.2a

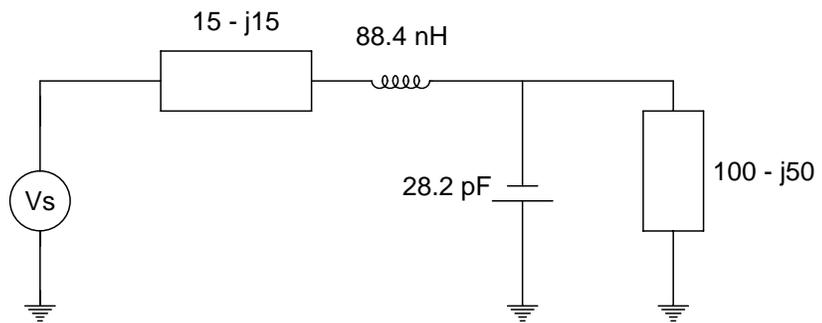


Figure 3.2b

Small Transistor Design for MAG

You're given a Motorola MPS571 High-Frequency Transistor. Design the input and output impedance matching network for Maximum Available Gain (MAG) using discrete components with 50 ohm Source and Load impedance's at 500 MHz with V_{ce} equal 5 volts and I_c equal 15 mA. The S-parameters for these conditions are as follows:

$$\begin{aligned}S_{11} &= 0.28 @ -175 \text{ deg.} \\S_{21} &= 5.62 @ 79 \text{ deg.} \\S_{12} &= 0.10 @ 65 \text{ deg.} \\S_{22} &= 0.18 @ -67 \text{ deg.}\end{aligned}$$

Solution:

1. Under the **File** tile, select **New...->Smith Chart...**, and enter a file name. Then modify the frequency to 500 MHz by selecting the Frequency Dialog box under the **Functions** Menu. Under the Grids tile, change the grid to *Imped+Admit reduced*.
2. We next select the **Small Transistor Calc... Manual...** under the **Functions** menu and input the S-parameters as listed above. This calculation is necessary to check the stability of the transistor at these operating conditions. From this calculation, we observe the following info box as follows:

$$\begin{aligned}\mathbf{K} &= \mathbf{1.029} \\ \mathbf{DEL} &= \mathbf{0.517} \\ \mathbf{MAG} &= \mathbf{16.45 \text{ dB}} \\ \mathbf{RefC(L)} &= \mathbf{0.657@54.3deg.} \\ \mathbf{RefC(S)} &= \mathbf{0.693@168.0deg.} \\ \mathbf{Gs} &= \mathbf{2.85 \text{ dB}} \\ \mathbf{Go} &= \mathbf{14.99 \text{ dB}} \\ \mathbf{G_I} &= \mathbf{-1.39 \text{ dB}} \\ \mathbf{G_{t,max}} &= \mathbf{16.45 \text{ dB}} \\ \mathbf{U} &= \mathbf{.03} \\ \mathbf{-0.27 < MaxErr(dB) < 0.28}\end{aligned}$$

From this info box, since $K \geq 1.0$, and (DEL) is ≤ 1.0 , we know that the transistor has stability under these conditions. We note the Source and Load Reflections for MAG, and proceed with the design. Note also, the unilateral figure of merit (U) and G_t/G_{tu} (MaxErr - dB).

3. Under the Functions menu, select **Point type... Plot...** and fill in the dialog box with the source reflection coefficient of 0.693@168 degrees in Polar coordinates. Repeat for the load reflection coordinate of 0.657@54.3 degrees and notes the two plotted points. Label these points as GammaS and GammaL using the text insert mode as described in Chapter 2.
4. Now, under the **Functions** menu, select **Impedance Match... Const R - Source -> Load**, and fill in the source reflection coefficient of 0.693@168 deg. in Polar coordinates and depress the enter key. Note the change in the cursor. Move the cursor

down and note the line that is drawn along a constant resistance contour. At the same time note the component value that is being displayed in the upper left-hand corner of the monitor. When the drawn line along the constant resistance line intersects a constant conductance line that will pass through the 50 ohms source load, click the right most button on your mouse, and note that a solid line is drawn along with the component value of the series inductor in the upper left corner of your monitor. Note that you can monitor the admittance by observing the admittance on the forth line in the upper right hand corner as you move your mouse. When this value is close to 20 mmhos, click the right most-button on your mouse. If you mess up, go to the edit tile, and click the undo tile to start over.

5. Again under the **F**unctions menu, select **Impedance Match... Const G - Source -> Load**. At this point a dialog box will be presented requesting that you enter the appropriate impedance point. However, the end impedance point of the series leg has been remembered, so just depress the enter key. Now, move the cursor up until the cursor window encloses the source load of 50 ohms, then click the right most mouse button.
6. Again, under the **F**unctions menu, select **Impedance Match... Const G - Source -> Load**, and fill in the load reflection coefficient of $0.657 @ 54.3 \text{ deg.}$ in Polar coordinates. Move the cursor down and note the line that is drawn along a constant conductance contour. At the same time note the component value that is being displayed in the upper left-hand corner of the monitor. When the drawn line along the constant conductance line intersects a constant resistance line that will pass through the 50 ohm load, click the right most button on your mouse, and note that a solid line is drawn along with the component value of the shunt inductor in the upper left corner of your monitor. Note that you can monitor the impedance by observing the impedance on the third line in the upper right hand corner as you move your mouse. When this value is close to 50 ohms, click the right most button on your mouse. If you mess up, go to the edit tile, and click the undo tile, then repeat this step.
7. Again under the **F**unctions menu, select **Impedance Match... Const R - Source -> Load**. At this point a dialog box will be presented requesting that you enter the appropriate impedance point. However, the end impedance point of the shunt leg has been remembered, so just depress the enter key. Now, move the cursor up until the cursor window encloses the load of 50 ohms, then click the right most mouse button. At this point the design is complete. Note the Series-C component value as the fourth value listed in the upper left-hand corner.

The design plot is shown in figure 3.3a, and the design circuit from the above example is shown in Figure 3.3b.

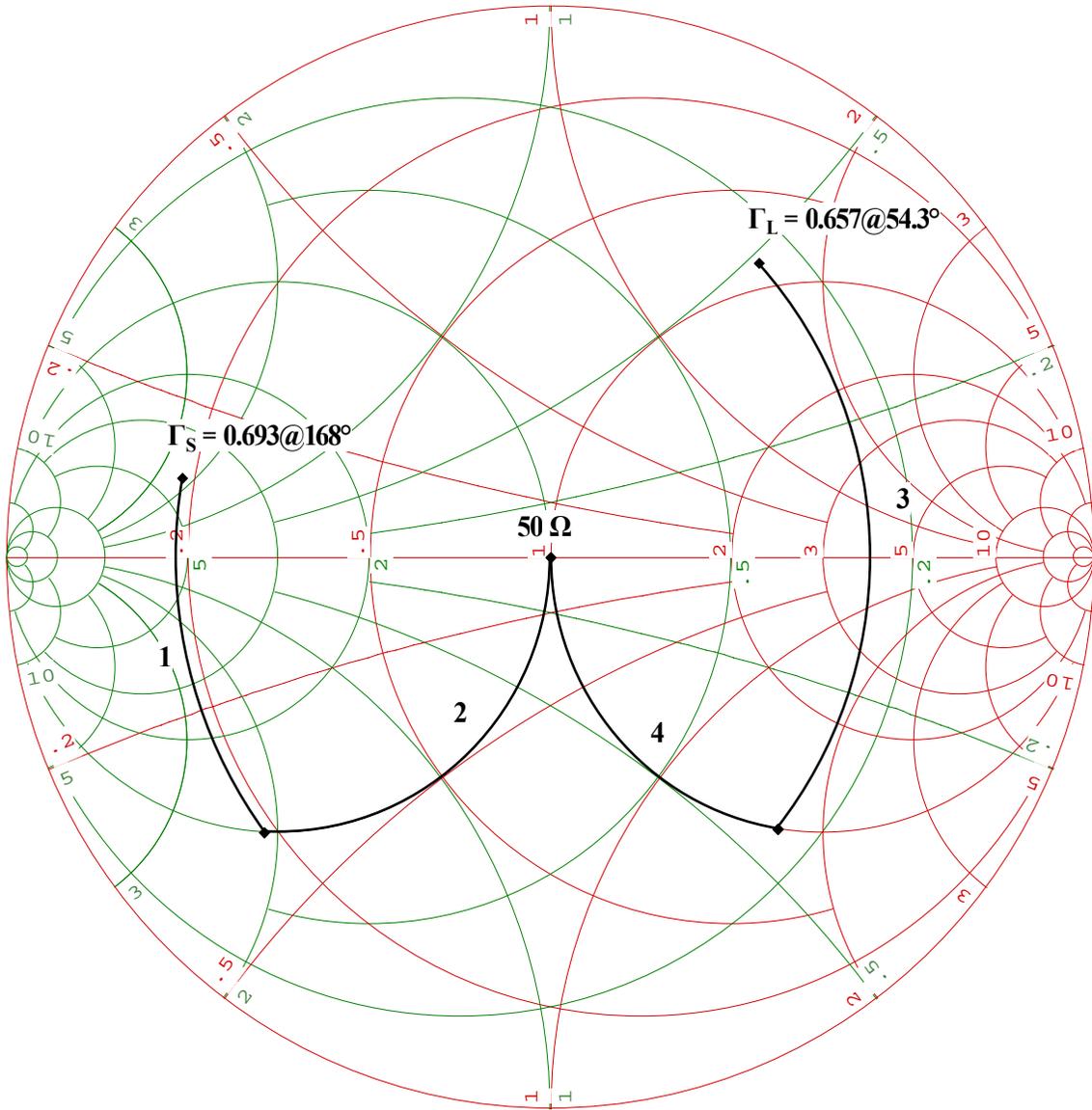


Figure 3.3a

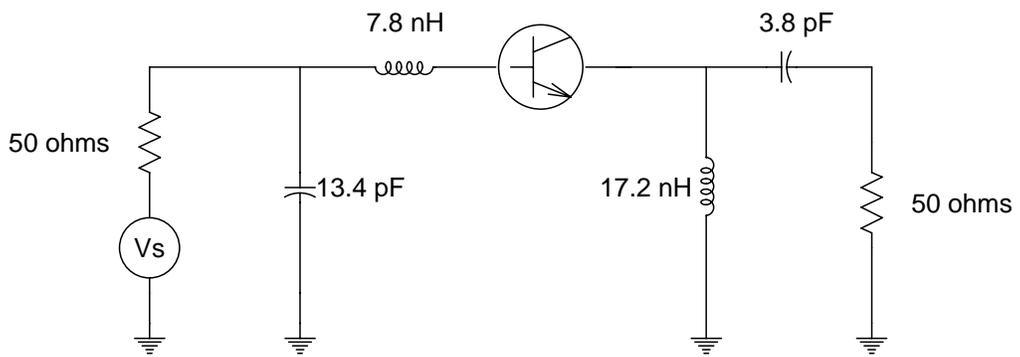


Figure 3.3b

Small Transistor Design for Specified Gain

You're given a Motorola LP1001A High-Frequency Transistor. Design the input and output impedance matching network for a gain of 8 dB using discrete components with 50 ohm Source and Load impedance's at 1000 MHz with Vce equal 10 volts and Ic equal 10 mA. The S-parameters for these conditions are as follows:

$$S_{11} = 0.05 @ 127 \text{ deg.}$$

$$S_{21} = 2.87 @ 58 \text{ deg.}$$

$$S_{12} = 0.16 @ 58 \text{ deg.}$$

$$S_{22} = 0.45 @ -41 \text{ deg.}$$

Solution:

1. Under the **File** tile, select **New...->Smith Chart...**, and enter a file name. Then modify the frequency to 1000 MHz by selecting the Frequency Dialog box under the **Functions** menu.
2. We next select the **Small Transistor Calc... Manual...** under the **Functions** menu and input the S-parameters as listed above. This calculation is necessary to check the stability of the transistor at these operating conditions. From this calculation, we observe the following info box as follows:

K = 1.076
DEL = 0.440
MAG = 10.85 dB
RefC(L) = 0.683@39.6 deg.
RefC(S) = 0.498@-152.3 deg.
Gs = 1.24 dB
Go = 9.16 dB
G1 = 0.46 dB
Gt,max = 10.85 dB
U = 0.01
-0.11 < MaxErr(dB) < 0.11

3. From this info box, since $K \geq 1.0$ and $(DEL) < 1.0$, we know that the transistor has stability under these conditions. Since we want only 8 dB of gain for this design, we go to the **Constant Gain...** dialog under the **Functions** menu to plot a constant gain circle of 8 dB. In this case will select the Operating Power Gain option (Gp), and then select a Load Reflection coefficient on this circle. Note that we also selected the corresponding locus of matched input reflection points in the opposite plane.
4. Once we select a Load Reflection coefficient, we can go to the **Source Refl. Calc...** under the **Functions** menu to calculate the Source Reflection coefficient or select the Load Reflection coefficient with the mouse crosshair and select the Source Reflection Calc with the right most button on the mouse. The plot for this procedure is shown in Figure 3.4a.

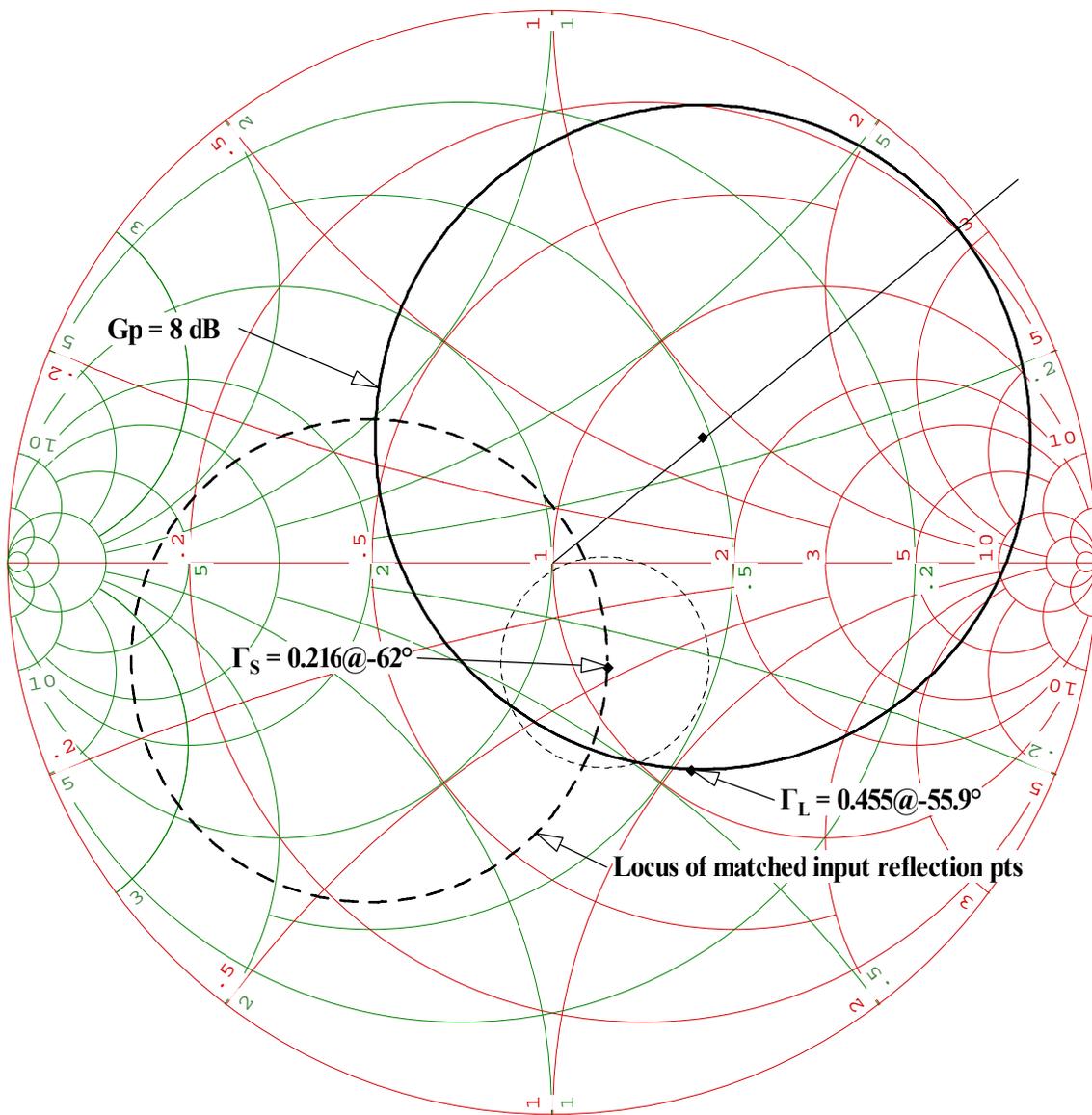


Figure 3.4a

5. From the above we select the Load Reflection coefficient as $.455 @ -55.9$ by positioning our cursor over this point and selecting the Source Reflection coefficient calculation with the right mouse button to calculate the input reflection coefficient as $.216 @ -62$ and proceed to the impedance match to match the source and load impedance values to 50 ohms. Note that we also plotted an input VSWR circle around the input reflection point of 1.5. The impedance matching plot is shown in figure 3.4c and the circuit for this design is shown in figure 3.4c.

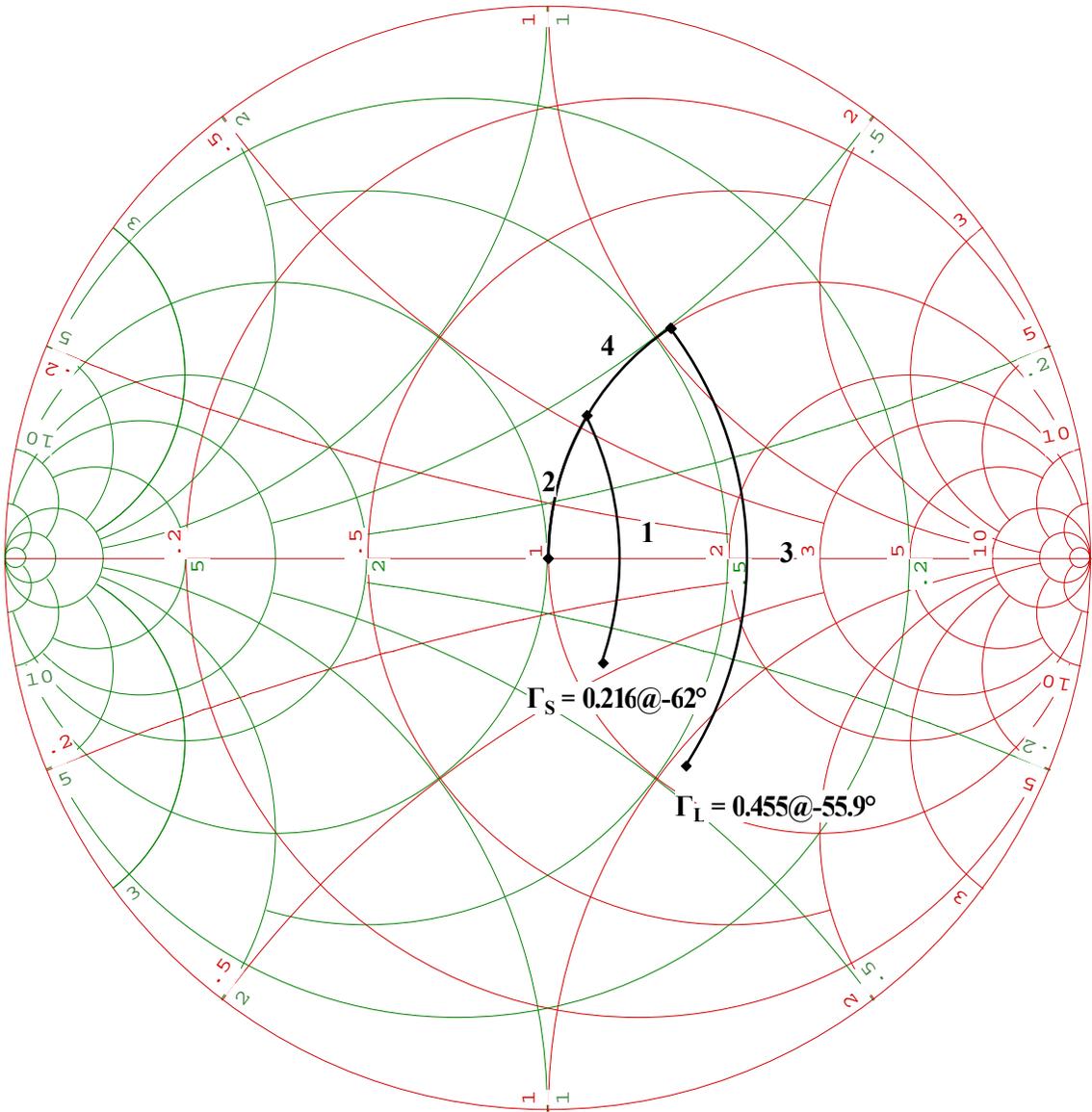


Figure 3.4c

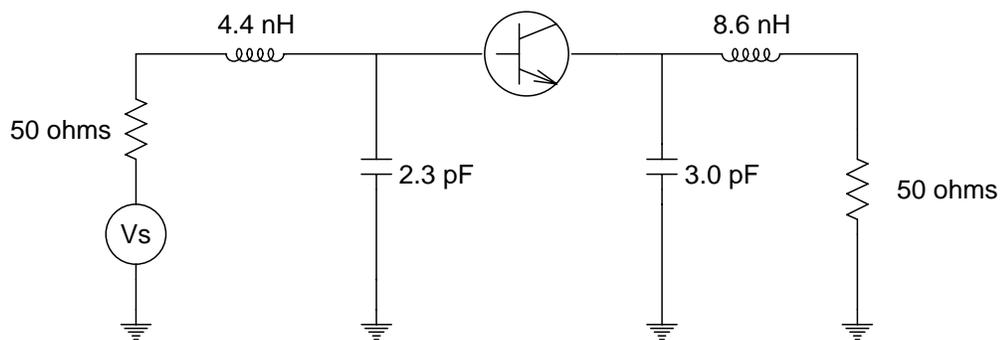


Figure 3.4c

Small Transistor Design for Minimum Noise

You're given a Motorola MRF571 High-Frequency Transistor. Design the input and output impedance matching network for a front end amplifier using discrete components with $Z_s = 35 - j60$ ohms and $Z_l = 50 - j50$ ohms at 1000 MHz with V_{ce} equal 6 volts and I_c equal 5 mA. The gain is specified at 10 dB with a minimum noise figure of 2 dB. The noise parameters for these conditions are $N_f = 1.5$ dB, equivalent noise resistance (R_n) = 7.5 ohms, and $\Gamma_{OPT} = 0.48 @ 134^\circ$. The S-parameters for these conditions are as follows:

$$S_{11} = 0.61 @ 178 \text{ deg.}$$

$$S_{21} = 3.0 @ 78 \text{ deg.}$$

$$S_{12} = 0.09 @ 37 \text{ deg.}$$

$$S_{22} = 0.28 @ -69 \text{ deg.}$$

Solution:

1. Under the **File** tile, select **New...->Smith Chart...**, and enter a file name. We then modify the frequency to 1000 MHz by selecting the Frequency Dialog box under the **Functions** menu.
2. We next select the **Small Transistor Calc...** under the **Functions** menu and input the S-parameters as listed above. From this calculation, we observe the following info box as follows:
$$\begin{aligned} K &= 1.037 \\ DEL &= 0.102 \\ MAG &= 14.05 \text{ dB} \\ RefC(L) &= 0.806 @ 66.1 \text{ deg.} \\ RefC(S) &= 0.891 @ -178.7 \text{ deg.} \\ G_s &= 6.85 \text{ dB} \\ G_o &= 9.54 \text{ dB} \\ G_l &= -2.24 \text{ dB} \\ G_{t,max} &= 14.05 \text{ dB} \\ U &= -10.99 \text{ dB} \\ -0.67 &< MaxErr(dB) < 0.72 \end{aligned}$$
3. From this info box, since $K \geq 1.0$ and $(DEL) \leq 1.0$, we know that the transistor has stability under these conditions.
4. Since we want the minimum noise figure to be less than 2 dB, we process to the **Noise Circle...** dialog under the **Functions** menu to plot some noise circles.
5. We next proceed to the **Constant Gain...** dialog menu under the **Functions** menu in order to plot a constant gain circle of 10 dB. In this case we opted to plot the Gain Available circles (Ga). From this, an input Reflection Coefficient of $0.235 @ 109.3^\circ$ was selected.
6. The Load Reflection coefficient of $0.304 @ 81^\circ$ is calculated by using the **Load Refl. Calc...** under the **Functions** menu. The plot for this procedure is shown in Figure 3.5a.

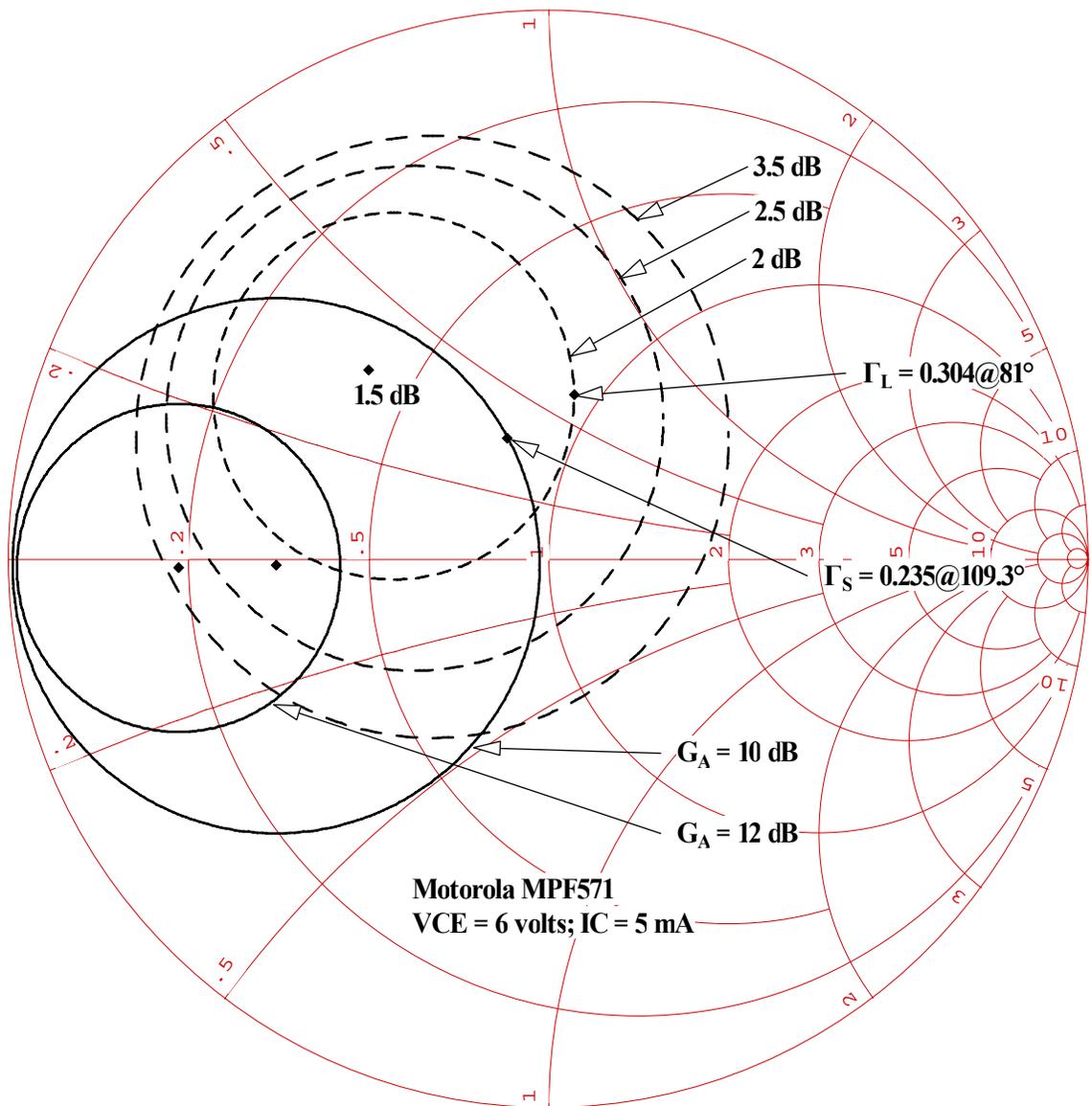


Figure 3.5a

- Using the above reflection coefficients, the impedance matching plot is shown in Figure 3.5b and the circuit is shown in Figure 3.5c

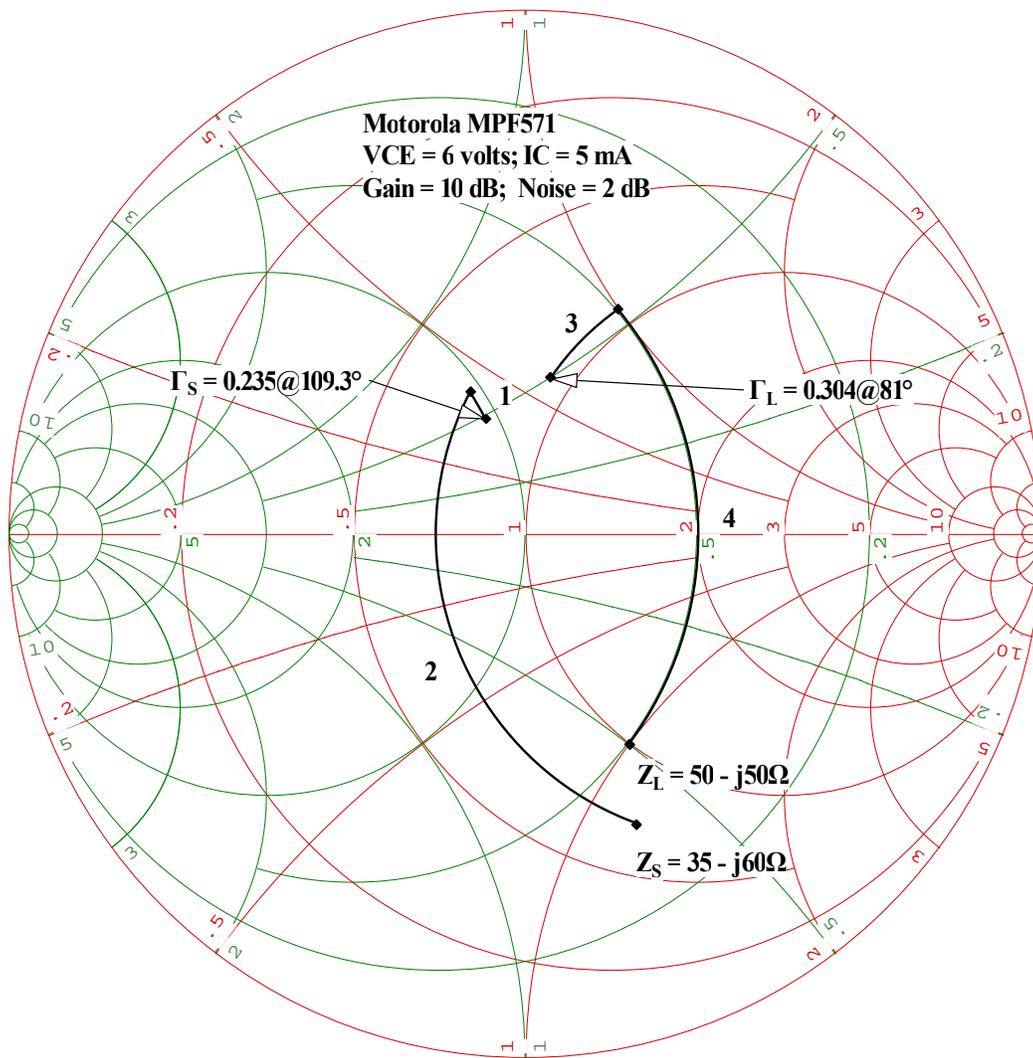


Figure 3.5b

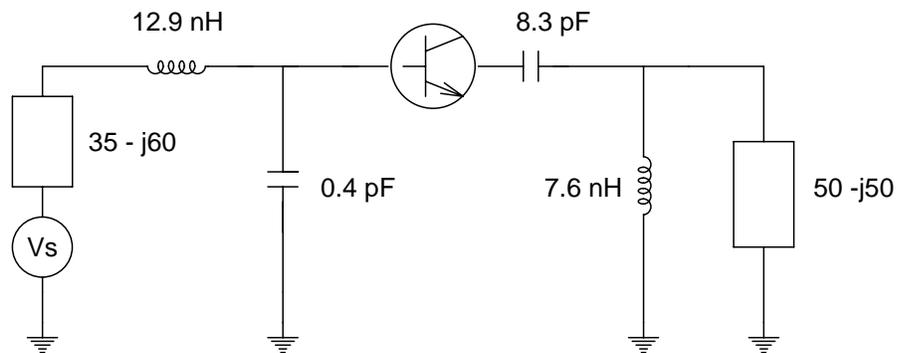


Figure 3.5c

Small Transistor Design - Stability

You're given a Motorola MRF5711LT1 High-Frequency Transistor. Design the input and output impedance matching network using discrete components with $Z_s = 35 + j50$ ohms and $Z_l = 50 - j50$ ohms at 500 MHz with V_{ce} equal 6 volts and I_c equal 10 mA. The gain is specified at 16 dB with a minimum noise figure of 1.6 dB. The noise parameters for these conditions are $N_f = 1.2$ dB, equivalent noise resistance (R_n) = 7 ohms, and $\Gamma_{OPT} = 0.36 @ 104^\circ$. The S-parameters for these conditions are as follows:

$$S_{11} = 0.69 @ -160 \text{ deg.}$$

$$S_{21} = 6.9 @ 92 \text{ deg.}$$

$$S_{12} = 0.06 @ 34 \text{ deg.}$$

$$S_{22} = 0.30 @ -92 \text{ deg.}$$

Solution:

1. Under the **File** tile, select **New...->Smith Chart...**, and enter a file name. We then modify the frequency to 500 MHz by selecting the Frequency Dialog box under the **Functions** menu.
2. We next select the **Small Transistor Calc...** under the **Functions** menu and input the S-parameters as listed above. From this calculation, we observe the following info box as follows:

$$K = 0.59$$

Proceed to Stability

Circle calculation

3. We next plot the stability circles by selecting the **Stability Circles...** dialog under the **Functions** menu. The S-parameters will be remembered from the **Small Transistor Calc...** dialog procedure, so just depress the enter key.
4. We then proceed to the **Constant Gain...** dialog procedure under the **Functions** menu in order to plot the constant gain circle of 16 dB. In this case we opted to plot the Gain Available circles (G_a). From this an input Reflection Coefficient of $0.167 @ -12.8^\circ$ is selected.
5. The Load Reflection coefficient of $0.245 @ 98^\circ$ is then calculated by using the **Load Refl. Calc...** dialog procedure under the **Functions** menu. The plot for this procedure is shown in Figure 3.5a.

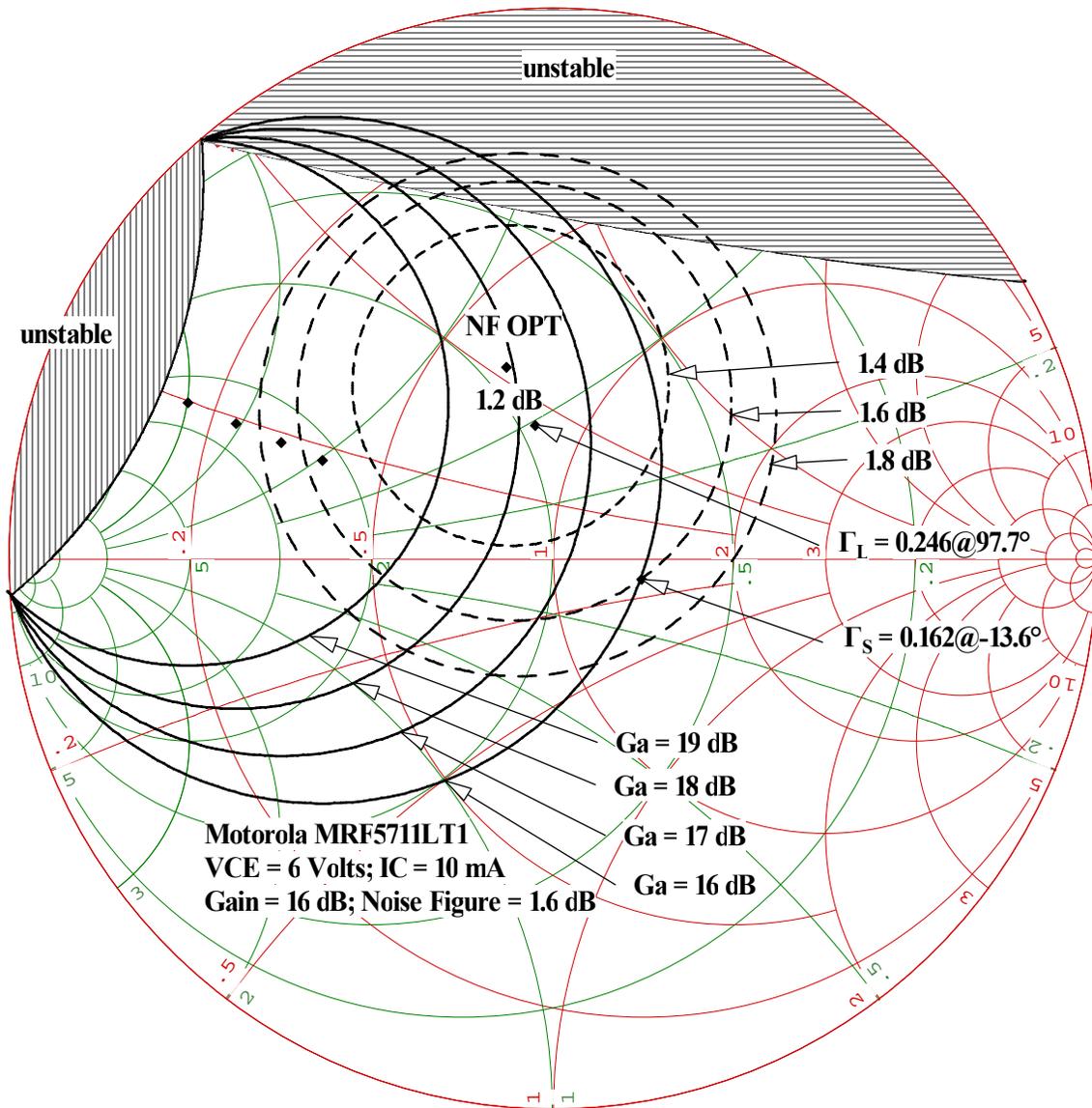


Figure 3.6a

- Using the above reflection coefficients, the impedance matching plot is shown in Figure 3.6b and the circuit is shown in Figure 3.6c.

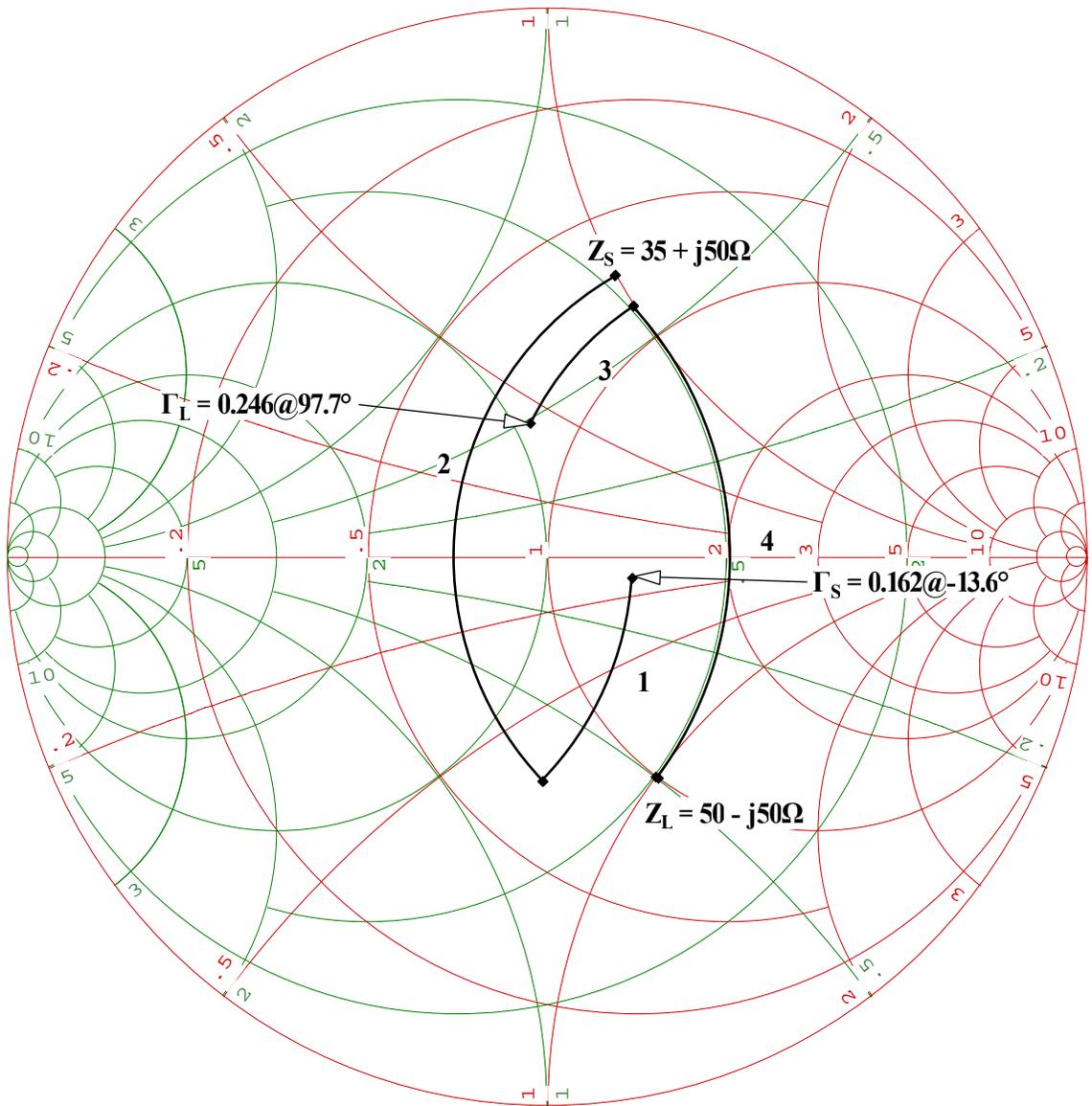


Figure 3.6c

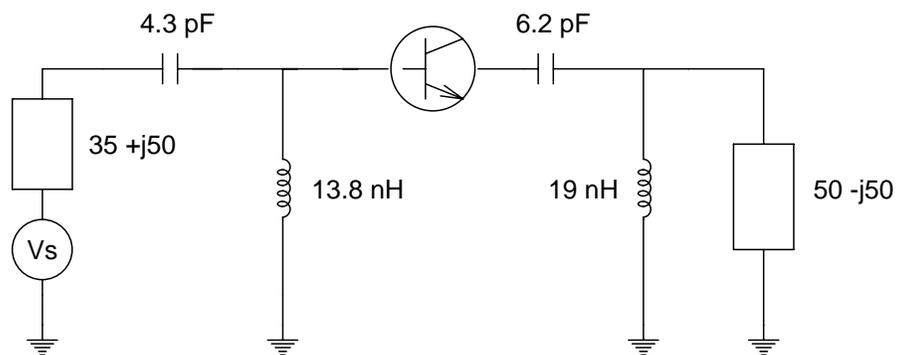


Figure 3.6b

Micro-strip Matching - A Simple Example

The amplifier block diagram shown in figure 3.7a shows the input and output reflection coefficients Γ_S and Γ_L . Design the input and output matching networks in a 50 ohm system with a frequency of 2.4 GHz. The substrate material is Duriod.

$$\epsilon_r = 2.23, h = 0.75mm$$

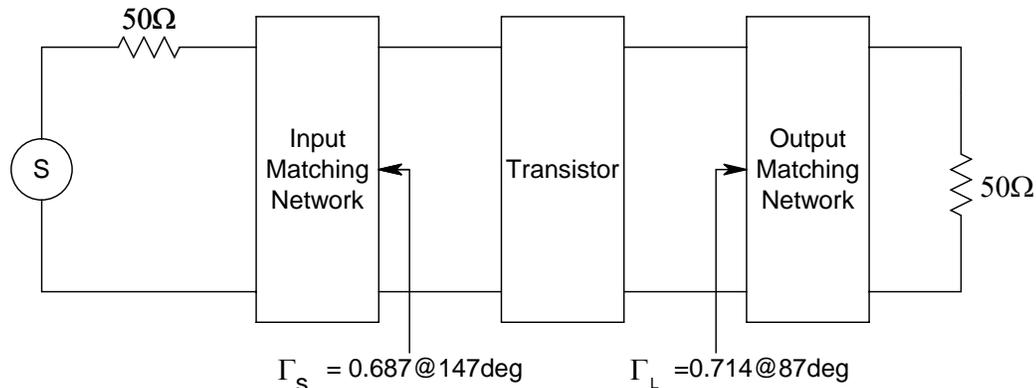


Figure 3.7a

1. We start with an Impedance grid with Freq. = 2400MHz.
2. Starting with the Input Matching Network, we first plot Γ_S by plotting this point using the **Point type... Plot...** dialog procedure under the **Functions** menu.
3. We next plot Y_s by using the **Point type... 1/Imped. point** dialog menu under the **Functions** menu. Refer to reference [2] as to why using the Y Smith is convenient when designing micro-strip impedance matching networks.
4. We next plot the VSWR circle by using the **Point type... VSWR Circle...** dialog procedure under the **Functions** menu.
5. Label these points using the text annotation feature.
6. Now, under the **Functions** menu, select **Micro-strip Match... Stub Open Circuit...**, and input a value of 50 and also click the *Direction* radio button to select **Towards Generator** and depress the enter key. Note the line drawn along a constant resistance line as you push the cursor up and to the right. Click the right most mouse button when the small cursor intersects the VSWR circle, and note the *open-Stub=0.172* statement displayed in the upper left hand corner.
7. Next select the **Micro-strip Match... Series Line...**, and click the *Direction* radio button to select **Towards Generator** and just depress the enter key since the endpoint of the last match is remembered and is the starting point of the next match. Now pull the mouse down and note the line that is drawn along the constant VSWR circle. Click the right most mouse

button when the small cursor is over the Admittance point Y_S . Note the *series-Line* = 0.111 as displayed in the upper left of your monitor. At this point, the input network has been designed except for the calculation of the actual micro-strip dimensions. The design plot for the Input Matching Network is shown in Figure 3.7b.

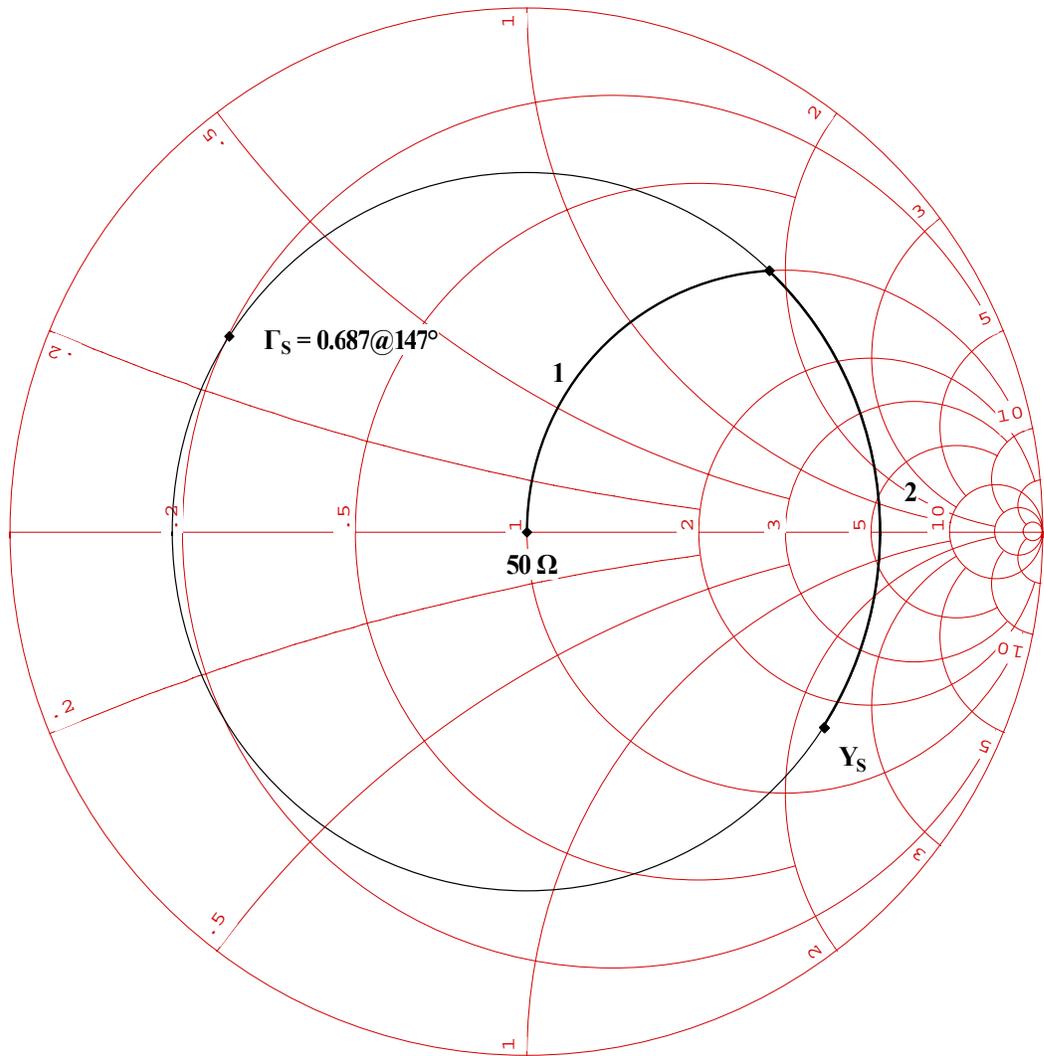


Figure 3.7b

8. Repeating the above procedure for the Output Matching Network except we use a short circuit stub, we get a *short-Stub* = 0.073, and a *series-Line* = 0.067 for the micro-strip parameters. The design plot for the Output Matching Network is shown in Figure 3.7c.
9. Using the Micro-strip Calc... dialog under the Functions menu, the line lengths including a quarter wave transformer ($\lambda/4$) to supply the V_{BB} input voltage are as follows:
 - 0.173 = 1.571 mm
 - 0.111 = 1.008 mm
 - 0.073 = 0.663 mm
 - 0.067 = 0.608 mm
 - 0.250 = 2.270 mm

The circuit diagram including bypass and coupling capacitors for the above example is shown in figure 3.7d. The above design could have used balanced shunt stubs which minimize the transition between the shunt stubs and the series transmission line. In this case, each side of the balanced stub must equal half of the total admittance. For the input matching network, the open circuit balanced stubs are 0.121, and for the output network, the short circuit balanced stubs are 0.123 (at 50 ohms).

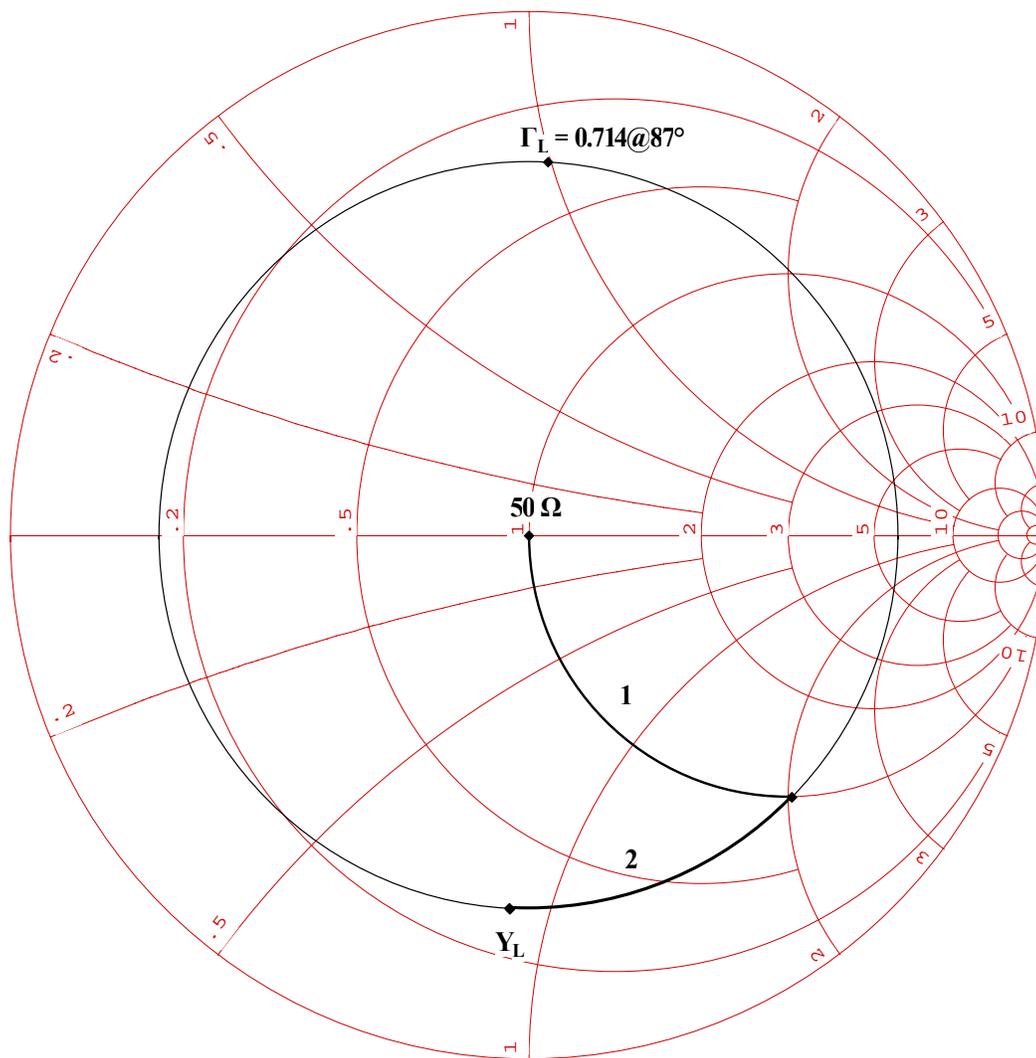


Figure 3.7c

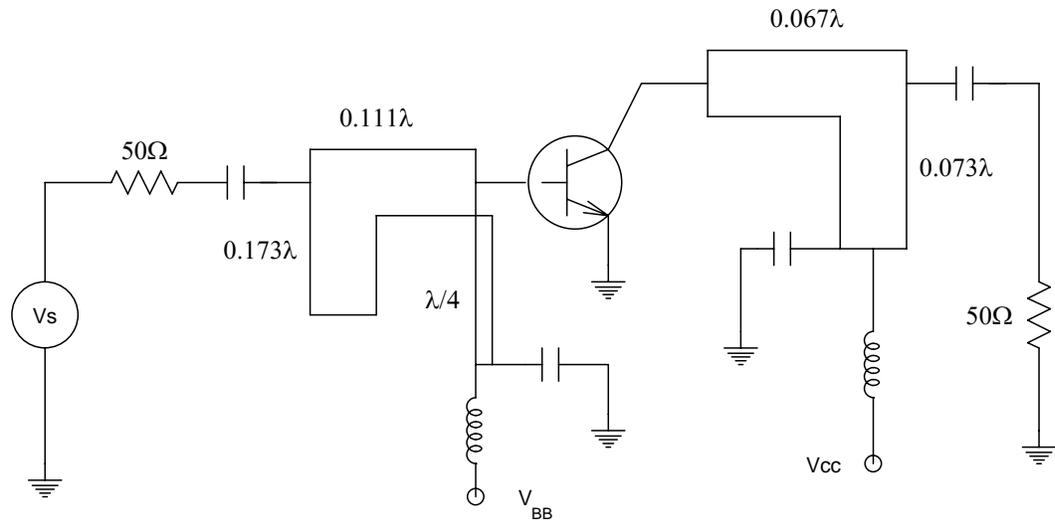


Figure 3.7d

Micro-strip Matching - Different Characteristic Impedance's

We repeat the input network design of the last example, except will use micro-strip lines with different characteristic impedance's.

Solution 1:

1. Repeat the first 5 steps in the previous example.
2. Move your cursor over the Z_S plotted point, and read off the value of $Y_S = 33 - j46.8$ millimhos in the upper right hand corner of your display. Lets use a quarter wave transformer to transform the source impedance of 50 to a resistance of $1/0.033 = 30.2$ ohms. The resistance of this micro-strip line is given by $Z_0 = \sqrt{50(30.2)} = 38.8\Omega$
3. Under the **Functions** menu, select **Micro-strip Matching using a Quarter Wave Transformer – Y-Chart**. Move the cursor **right** until the resistance value in the upper left hand corner reads ~ 38.8 ohms, then right click on your mouse.
4. We can now use an open circuit shunt stub of 0.375 or a short circuit stub of 0.125 to transform the susceptance of $-j46.79$ milli-mhos. The resistance of this line is $1/0.04679 = 21.372$.
5. Select the **Micro-strip Match... Stub Open Circuit...** dialog procedure, and change the resistance value of the strip to 21.372 ohms. The direction is **Towards -> Generator** (Source) and the *from* point is the admittance point of the 30.13 impedance point as remembered from step 4. Move the cursor down until the cursor is over Y_S and note the *open-Stub=0.375* statement displayed in the upper left-hand corner of the monitor (as expected). The design plot for the Input Matching Network is shown in Figure 3.7e, and the input network circuit for the above design is shown in figure 3.7f.

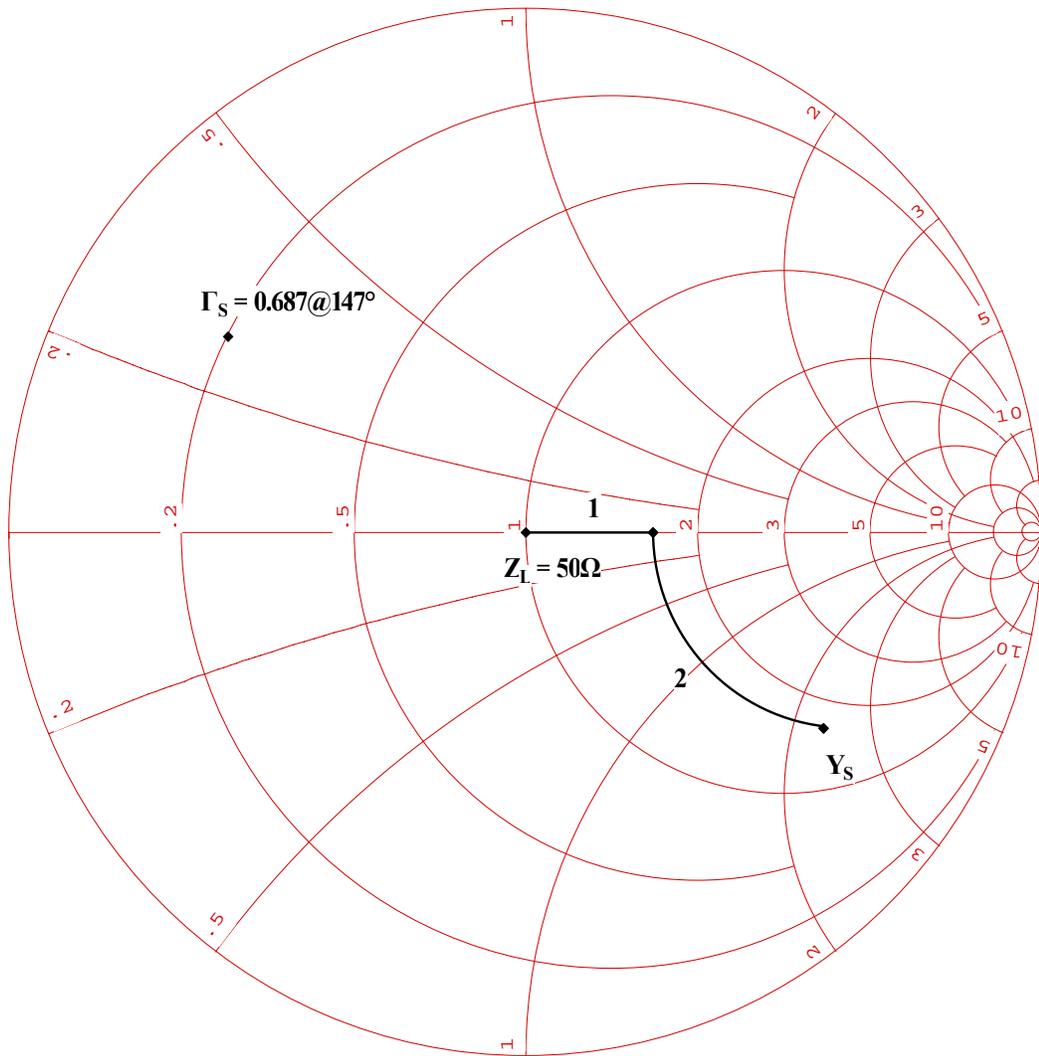


Figure 3.7e

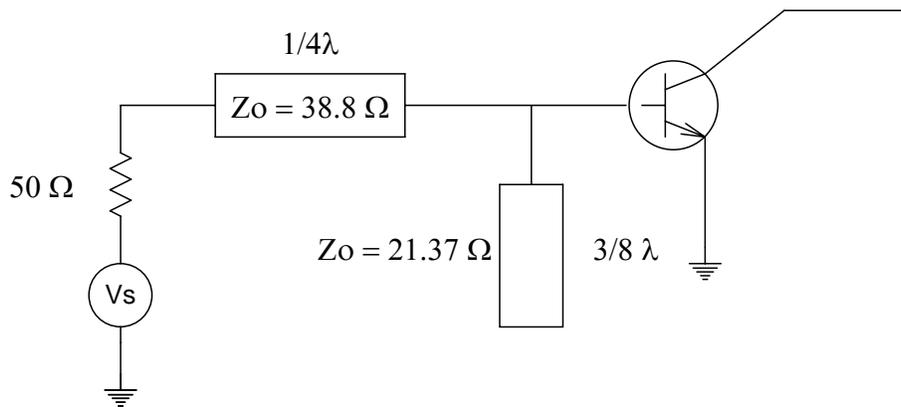


Figure 3.7f

Solution 2:

1. Plot the Z_S point using the **Point type... Plot...** dialog as found under the **Functions** menu.
2. Under the **Functions** menu, select **Point type... VSWR**, to plot a VSWR circle through Z_S .
3. Now select **Micro-strip Matching using a Quarter Wave Transformer – Z Chart**, and move the cursor **left** until the cursor intersects the VSWR circle, then right click on your mouse.
4. Select the **Micro-strip Match... Series Line...** from under the **Functions** menu with direction Towards ->Generator, and move the cursor up until the cursor is over the Z_S point, then right click on your mouse. The length of this line is 0.046 and the resistance at this point is 9.28 ohms

The design plot for the Input Matching Network is shown in Figure 3.7g, and the input network circuit for the above design is shown in figure 3.7fh

$Z_0 = 50.0 \Omega$
Freq. = 1000.0 Mhz
 $\lambda/4, Z_0 = 21.6 \Omega$
series-Line=0.046 $\lambda, Z_0 = 50 \Omega$

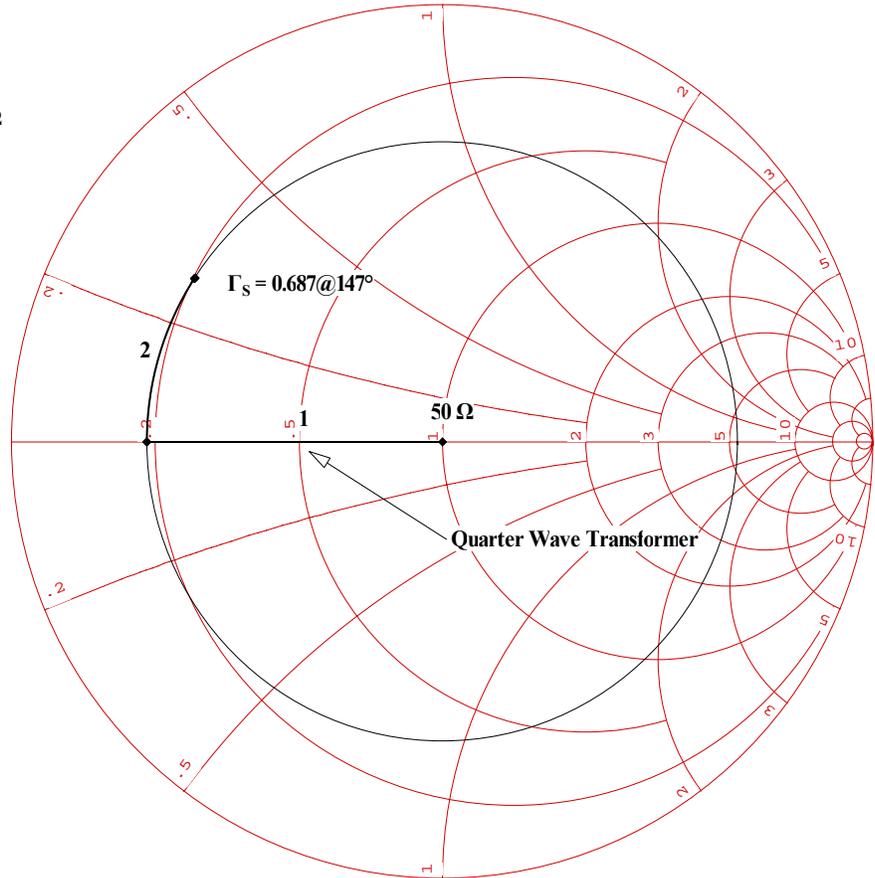


Figure 3.7g

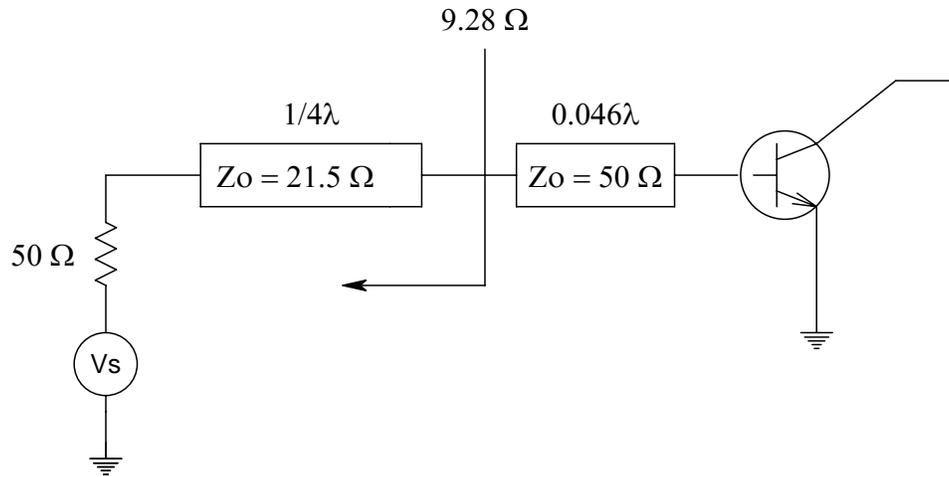


Figure 3.7h

A Single Stub Tuner

You're given a 50 ohm transmission line with a load of $125 -j150$ ohms at a frequency of 100MHz. The transmission line has an effective relative dielectric constant ϵ_{ff} of 2.56.

Determine how far back from the load (d) you need to go to insert an open circuit stub of the same transmission medium and the length (l) of the stub such that you create a match to the 50 ohm line.

Solution:

1. The first step is to plot the impedance point of the load by using the **Point type... Plot...** dialog menu under the **Functions** menu.
2. We next plot the conjugate match circle with $\lambda = 0$, and then plot the admittance point of the load by using the **Point type... 1/Imped...** dialog selection under the **Functions** menu.
3. Next, select **Micro-strip strip... Match Series Line...** under the Functions menu, and depress the enter key. Move the small cursor up along the VSWR circle towards the conjugate match circle. When the small cursor intersect this point, click the right mouse button to determine the fraction of wave length traveled.
4. Next select the **Micro-strip Match... Open Circuit Stub...** under the **Functions** menu, and depress the enter key. Move the cursor down and to the left until the small cursor intersects the center point on the chart. Then click the right most-button on your mouse to determine the fraction of wave length traveled for an open circuit stub. From this we have the series-line as 0.158, and the open circuit line as 0.320. The equation for the actual distances traveled is

$$d = x\lambda = \frac{xv_p}{f} = \frac{xc}{f\sqrt{\epsilon_{ff}}}$$

From the above equation,

$$d = \frac{0.158(3 \times 10^{10} \text{ cm})}{10^8 \sqrt{2.56}} = 29.625 \text{ cm}$$

$$l = \frac{0.320(3 \times 10^{10} \text{ cm})}{10^8 \sqrt{2.56}} = 60 \text{ cm}$$

The plot of the above solution is shown in figure 3.8.

$Z_0 = 50.0 \Omega$
 Freq. = 100.0 Mhz
 series-Line=0.158 λ , $Z_0 = 50\Omega$
 open-Stub=0.320 λ , $Z_0 = 50\Omega$

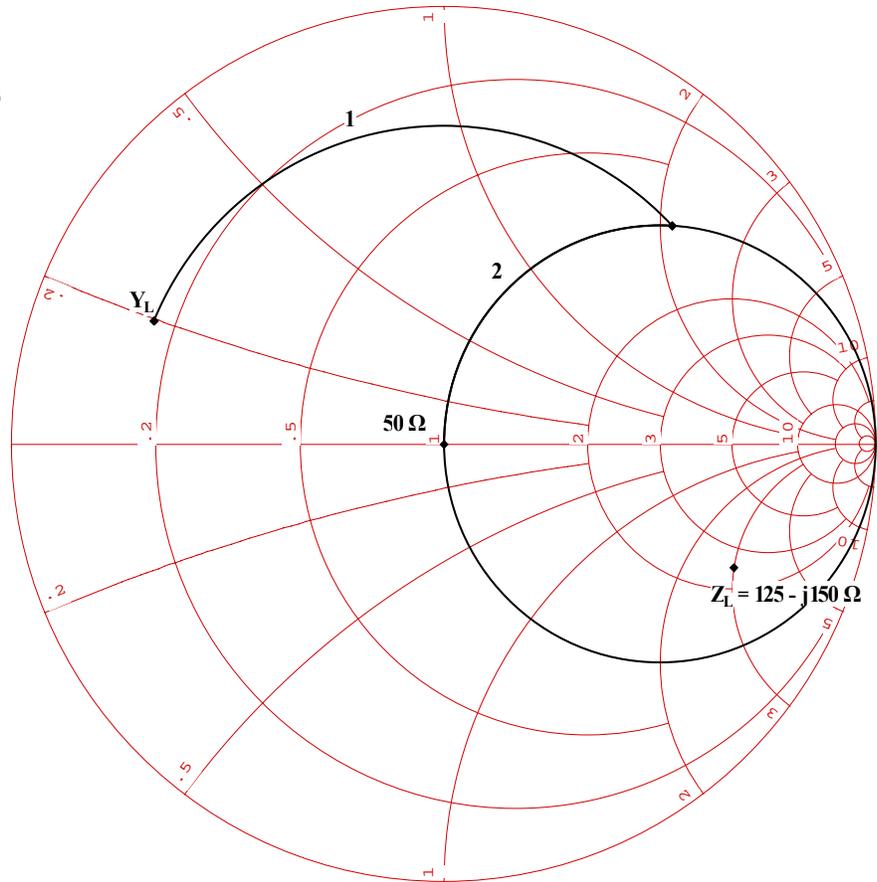


Figure 3.8

A Double Stub Tuner

We repeat the **Single Stub Tuner** example as given above, but add the requirement that two short open circuit stubs be used, with the first one a distance of 0.30 from the load, while the second stub is 3/8 from the first. All other conditions remain the same. Find the distances d_1 and d_2 that each stub is from the load, and the length of each stub (l_1 and l_2).

1. The first step is to plot the impedance point and admittance point of the load. First select the **Point type... Plot...** dialog from under the **Functions** menu, and enter the impedance value of 125 - j150 ohms.
2. Repeat the above, but select the **1/Imped...** selection to plot the admittance point.
3. Next, select **Micro-strip Match... Series Line...** under the Functions menu, and depress the enter key. Move the small cursor to the right along the VSWR circle until the read out in the upper left hand corner reads *series-Line=0.300*. This is shown as point 1 in figure 3.9a.

4. Next, select the **Conj Match Circle...** from the **Functions** menu and enter a value of **zero** to plot the $1 + j$ conjugate match circle.
5. Repeat the above, but enter 0.375 to plot the $1 + j$ conjugate match circle as rotated towards the generator by $3/8$.
6. Next, select **Micro-strip Match... Open Circuit Stub...** under the **Functions** menu, and depress the enter key. Push the small cursor down until the small cursor intersects the rotated $1 + j$ conjugate match circle, then click the right most button on your mouse. The read out in the upper left of your monitor should read *open-Stub=0.157*.
7. Again, select **Micro-strip Match... Series Line...** under the **Functions** menu, and depress the enter key. Push the small cursor around (clockwise) until the small cursor intersects the $1 + j$ conjugate match circle, then click the right most button on your mouse. The read out in the upper left of your monitor should read *series-Line=0.375*.
8. Now, select the **Micro-strip Match... Open Circuit Stub...** under the **Functions** menu, and depress the enter key. Move the cursor down and to the right until the small cursor intersects the impedance value of 50 ohms as displayed in the upper right hand corner of your monitor. Then click the right most button on your mouse to determine the fraction of wave length traveled for an open circuit stub. From this we have the open circuit stub as 0.077. The equation for the actual distances traveled is

$$d = x\lambda = \frac{xv_p}{f} = \frac{xc}{f\sqrt{\epsilon_{ff}}}$$

From the above,

$$d_1 = \frac{0.300(3 \times 10^{10} \text{ cm})}{10^8 \sqrt{2.56}} = 56.25 \text{ cm}$$

$$l_1 = \frac{0.158(3 \times 10^{10} \text{ cm})}{10^8 \sqrt{2.56}} = 29.6255 \text{ cm}$$

$$d_2 = d_1 + \frac{0.375(3 \times 10^{10} \text{ cm})}{10^8 \sqrt{2.56}} = 126.56 \text{ cm}$$

$$l_2 = \frac{0.076(3 \times 10^{10} \text{ cm})}{10^8 \sqrt{2.56}} = 14.25 \text{ cm}$$

$Z_0 = 50.0 \Omega$
 Freq. = 100.0 Mhz
 series-Line=0.300 λ , $Z_0 = 50\Omega$
 open-Stub=0.158 λ , $Z_0 = 50\Omega$
 series-Line=0.375 λ , $Z_0 = 50\Omega$
 open-Stub=0.076 λ , $Z_0 = 50\Omega$

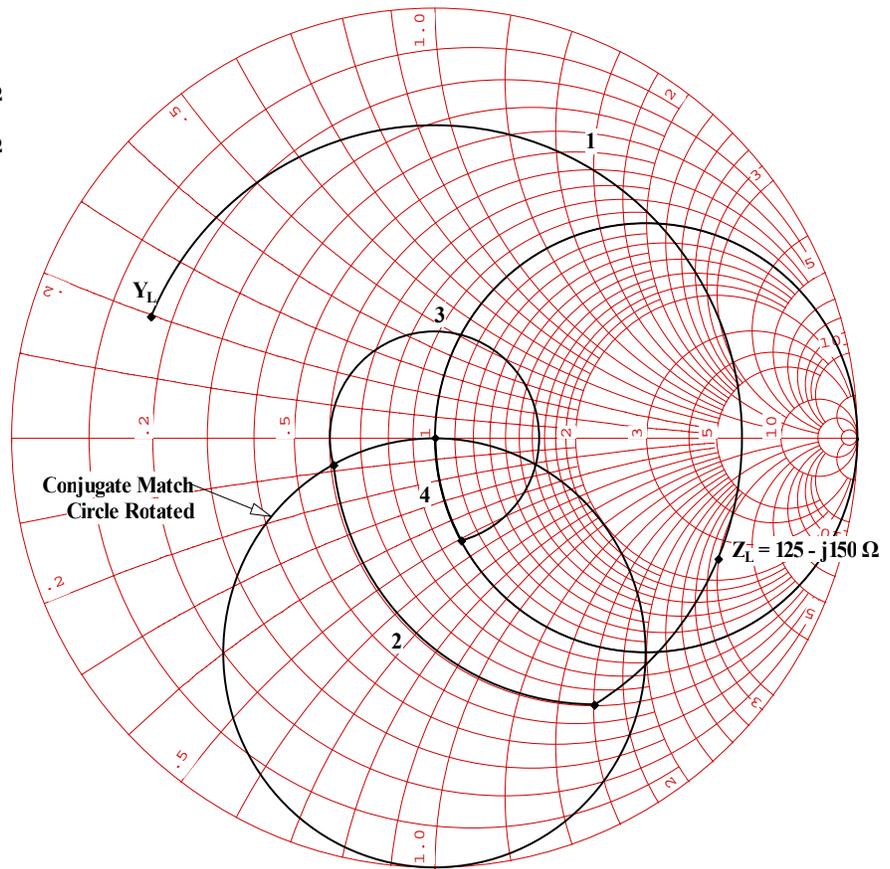


Figure 3.9a

Plotting of Performance Data

We were given a Motorola MPS571 NPN Silicon High-Frequency Transistor. Plot the S-Parameter data for $V_{CE} = 5$ Volts and $I_C = 5$ mA as given under directory MOTOROLA\MPS\MPS571a.S2P.

1. We first start with an Impedance only grid with a characteristic impedance of 50 ohms and at any frequency to plot the S_{11} and S_{22} data.
2. We list this file by selecting under the **Functions** menu, **Parametric Data... List...**, and select the file to open under the path MOTOROLA\MPS\MPS571a.S2P. The format of this data will look as follows. Refer to **Parametric Data** in chapter 2 of this manual for a description.

```

! MPS571A.S2P
! MPS571
! VCE=5V; IC=5mA
# GHZ S MA R 50
! S-PARAMETER
0.2 0.62 -80 8.22 122 0.07 56 0.63 -44
0.5 0.40 -148 4.52 87 0.11 50 0.36 -58
1 0.39 155 2.51 54 0.16 48 0.23 -78
1.5 0.46 122 1.86 32 0.23 42 0.15 -114
  
```

3. Under the **F**unctions menu, select **Parametric Data... Plot...** , and select the file to open. When the next dialog box appears, select S11 and S22, then reflection data.
4. Open up a new plotting window by selecting **F**ile **N**ew... under the **F**ile menu selection. Repeat the above for S21 and S12, and reflection data.

The plots of the above can be found in figures 3.10a & 3.10b. The annotation was added interactively by using the text annotation function. Note! Plot types of S21 and S12 are of polar type and can't be mixed with S11 and S22, which are plotted on a Reduced Smith Chart overlay. By using a network analyzer and recording S-parameter data as a file in Touchstone format, one can make similar plots as shown below. Note that these plots were created, then a metafile was generated as described in Chapter 2, and inserted into this manual by using the insert picture function in Microsoft Word for Windows.

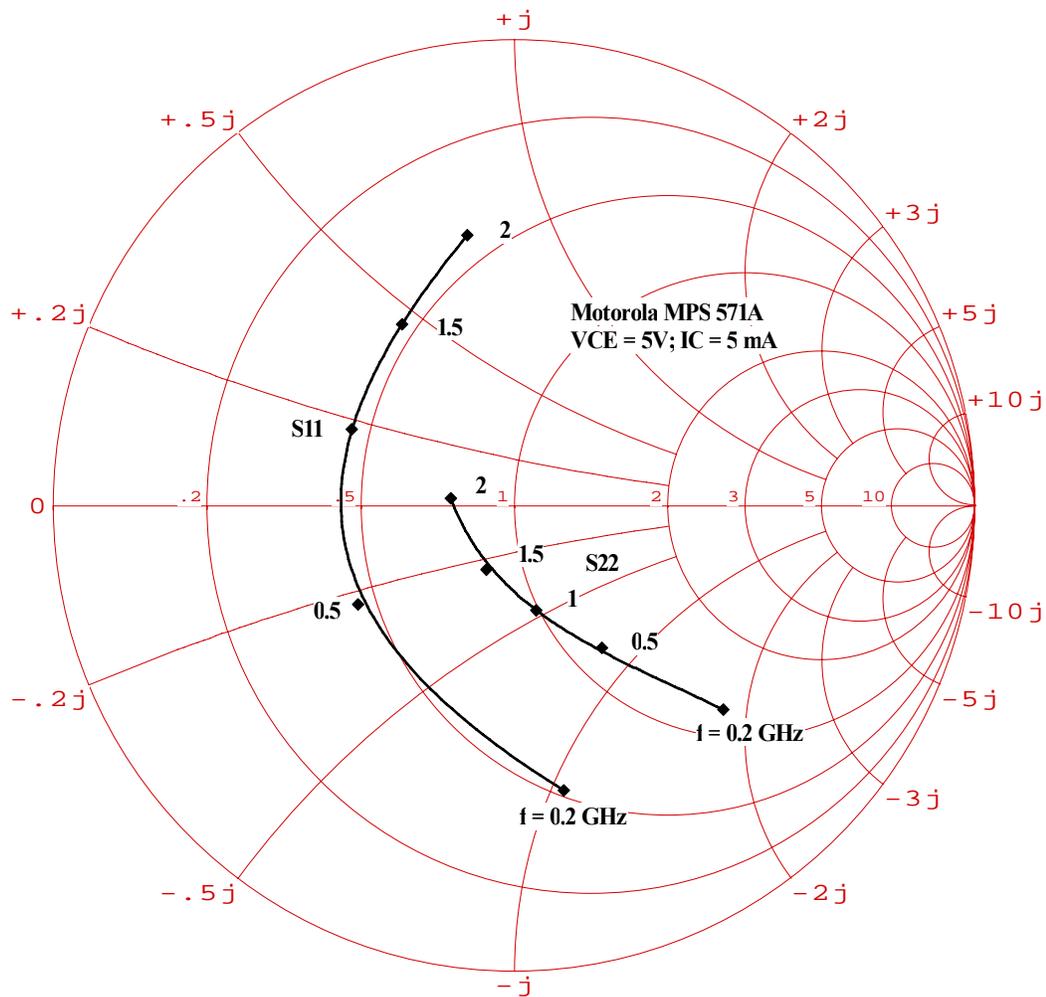


Figure 3.10a

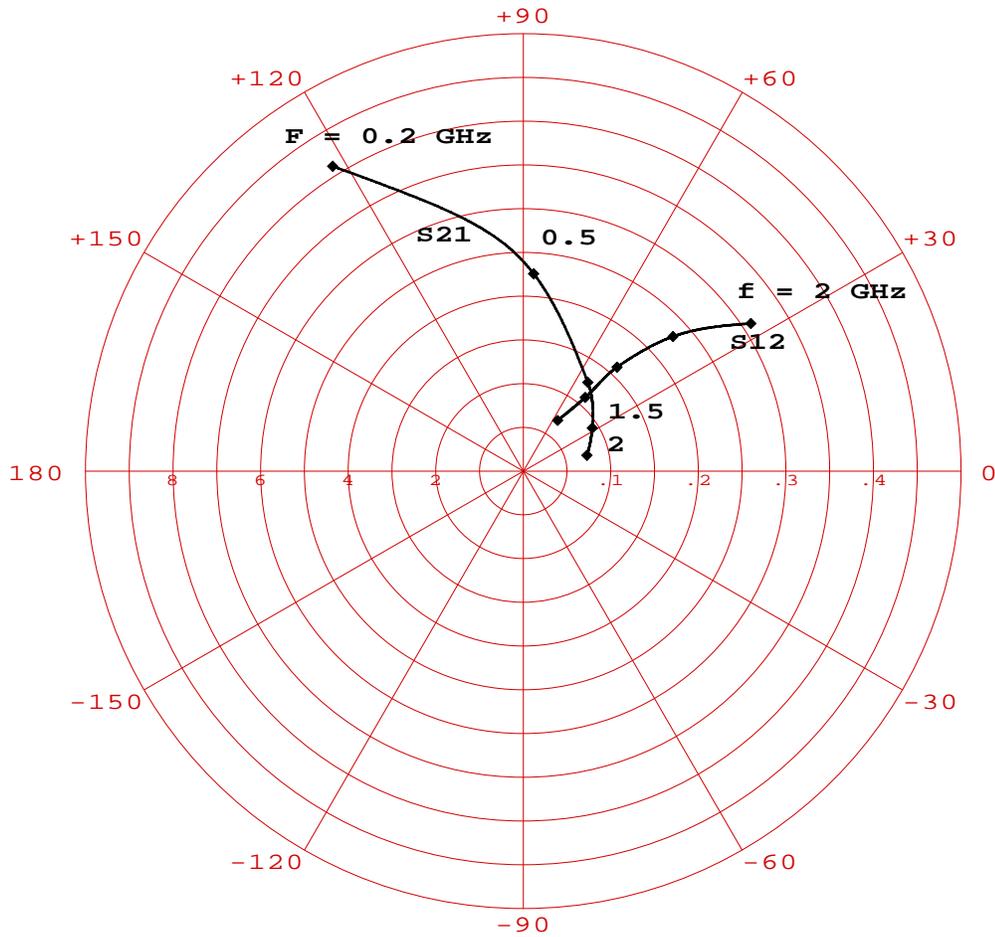


Figure 3.10b

Handy notes for Impedance matching

In the process of performing an impedance match, we need a few rules to keep in mind so that we come up with the right answer

1. For a simple impedance match as illustrated in the first example of this chapter, take the conjugate of the source impedance, and then either:
 - Start at the Conjugate Source Impedance and proceed to the Load such that the direction is **Source->Load**.
 - Start at the Load Impedance and proceed to the Conjugate Source Impedance such that the direction is **Load->Source**.
2. For impedance matching the input or output of a transistor, the reflection coefficients Γ_S and Γ_L are considered the Source points.

- For component values, if you start at these impedance values, then the direction is **Source->Load**, else if you start with the Load point and move to the Source point (Γ_S or Γ_L), then the direction is **Load->Source**.
 - For micro-strip matching using shunt (series) stubs, first plot the impedance point of Γ_S or Γ_L , then (for shunt stubs only) its corresponding admittance point. Then the direction (for stubs only) is **Towards->Load** from Γ_S or Γ_L , else **Towards->Generator** from the load. For series line, take the shortest path, where **Towards->Generator** is clockwise and **Towards->Load** is counter-clockwise.
3. For micro-strip matching a load to a transmission line using shunt (series) stubs, first plot the impedance point of the Load, then (for shunt stubs only) its corresponding admittance point. Then in all cases (shunt stubs, series stubs, or series line):
- Start at the admittance (impedance) point of the Load and move to the impedance of the line where the **direction** is **Towards Generator**.
 - Start at the impedance of the line and move towards the admittance (impedance) point of the Load where the **direction** is **Towards Load**.

Chapter 4

Equations Reference

This chapter presents the basic equations used throughout the program on a per topic basis.

VSWR Circle

The standing wave ratio of an impedance point is given by,

$$S = \frac{1 + \rho}{1 - \rho},$$

where ρ is equal to the reflection coefficient at the impedance point. The value ρ is given by,

$$\rho = \frac{Z - Z_0}{Z + Z_0},$$

where Z_0 is the Characteristic Impedance. The complex Characteristic Impedance is given by,

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

or to simplify

$$Z_0 = \sqrt{\frac{L}{C}}$$

Then the locus of all impedance points with the same VSWR is thus a circle centered at the normalized impedance point of 1.0 with a constant radius equal to,

$$r = \sqrt{R_0^2 + X_0^2}$$

where

R_0 equals the normalized impedance resistance

X_0 equals the normalized impedance reactance

Circuit Q Contour

The Circuit Q contour is all those impedance points whose ratio of absolute reactance to absolute resistance is a constant. In equation form this is given by,

$$Q_c = \frac{|X|}{|R|}$$

where an impedance value is given by,

$$Z = R + jX$$

Admittance Point

The equation for an Admittance point from a given Impedance point is given by,

$$Y = \frac{1}{Z}$$

Conjugate Impedance Point

Given an impedance point by the equation,

$$Z = R + jX$$

The conjugate impedance point is given by,

$$Z^* = R - jX$$

Impedance Match - Component Values

When performing an impedance match along constant resistance lines or constant conductance lines, the equations to determine the component values are as follows:

For a series-C component:

$$C = \frac{1}{\omega X Z_0}$$

For a series-L component:

$$L = \frac{X Z_0}{\omega}$$

For a shunt-C component:

$$C = \frac{B}{\omega Z_0}$$

For a shunt-L component:

$$L = \frac{Z_0}{\omega B}$$

where,

$$\omega = 2\pi f$$

X = the reactance from the chart

B = the susceptance from the chart

Z_0 = the Characteristic Impedance value

Small Transistor - Stability Circles

A stability circle on a Smith Chart represents the boundary between values of source or load impedance values that can cause instability. The boundary of the circle represents the locus of points that causes the Rowlett Stability Factor (K) to equal 1. The center locations and the radii of the input and output stability circles are calculated as follows:

1. Calculate D_s as follows: (Eq. 4-1)

$$D_s = S_{11}S_{22} - S_{12}S_{21}$$

2. Calculate C_1 (Eq. 4-2)

$$C_1 = S_{11} - D_s S_{22}^*$$

3. Calculate C_2 (Eq. 4-3)

$$C_2 = S_{22} - D_s S_{11}^*$$

4. Calculate the center of the input stability circle (Eq.4-4)

$$c_s = \frac{C_1^*}{|S_{11}|^2 - |D_s|^2}$$

5. Calculate the radius of the input stability circle (Eq. 4-5)

$$r_s = \left| \frac{S_{12}S_{21}}{|S_{11}|^2 - |D_s|^2} \right|$$

6. Calculate the center of the output stability circle (Eq. 4-6)

$$c_o = \frac{C_2^*}{|S_{22}|^2 - |D_s|^2}$$

7. Calculate the radius of the output stability circle (Eq. 4-7)

$$r_o = \left| \frac{S_{12}S_{21}}{|S_{22}|^2 - |D_s|^2} \right|$$

Small Transistor - Constant Gain Circles

Operating Power Gain - G_p

The operating power gain is independent of the source impedance. The center location and the radius of the circle for a given gain is calculated as follows:

1. Calculate D_2 .

$$D_2 = |S_{22}|^2 - |\Delta|^2$$

2. Calculate C_2 using equation 4-3.

3. Calculate desired gain (Eq. 4-8)

$$g_p = \frac{\text{DesiredGain(absolute)}}{|S_{21}|^2}$$

4. Calculate the center location of the gain circle (Eq. 4-9)

$$c_p = \frac{g_p C_2^*}{1 + D_2 g_p}$$

5. Calculate the radius of the gain circle (Eq. 4-10)

$$r_p = \frac{\sqrt{1 - 2K|S_{12}S_{21}|g_p + |S_{12}S_{21}|^2 g_p^2}}{1 + D_2 g_p}$$

Available Power Gain - G_A

The center location and the radius of the circle for a given gain is calculated as follows:

1. Calculate D_2 .

$$D_2 = |S_{11}|^2 - |\Delta|^2$$

2. Calculate C_1 using equation 4-2.

3. Calculate desired gain (Eq. 4-11)

$$g_A = \frac{\text{DesiredGain(absolute)}}{|S_{21}|^2}$$

4. Calculate the center location of the gain circle (Eq. 4-12)

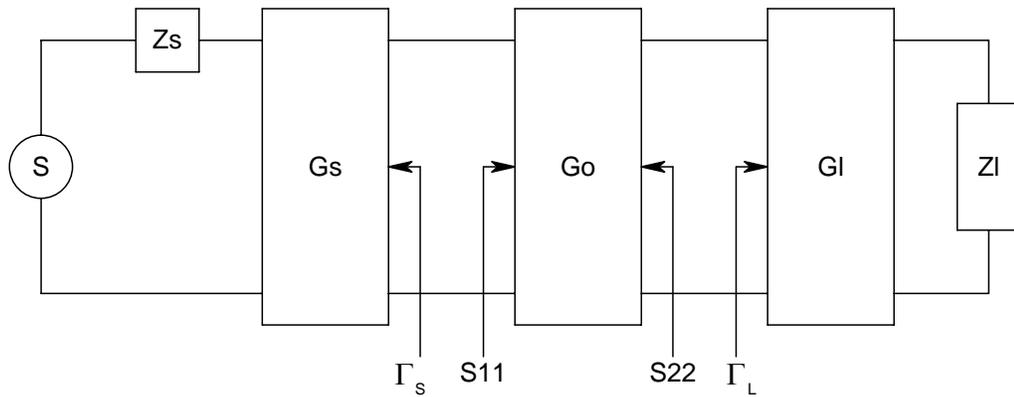
$$c_A = \frac{g_A C_1^*}{1 + D_2 g_A}$$

5. Calculate the radius of the gain circle (Eq. 4-13)

$$r_A = \frac{\sqrt{1 - 2K|S_{12}S_{21}|g_A + |S_{12}S_{21}|^2 g_A^2}}{1 + D_2 g_A}$$

Unilateral Cases - S12 equals zero

When S12 is small, we can represent the transducer power gain of the transistor by the following block diagram.



The equation for the unilateral transducer gain is then given by, (Eq. 4-14)

$$G_{Tu} = G_S G_O G_L$$

The equations for each block are given by,

$$G_S = \frac{1 - |\Gamma_S|^2}{|1 - S_{11}\Gamma_S|^2}$$

$$G_O = |S_{21}|^2$$

$$G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

Small Transistor – Constant VSWR Circles

The input VSWR of a microwave amplifier is given by:

$$\text{VSWR}_{\text{IN}} = \frac{1 + |\Gamma_a|}{1 - |\Gamma_a|}, \text{ where } |\Gamma_a| = \left| \frac{\Gamma_{\text{IN}} - \Gamma_S^*}{1 - \Gamma_{\text{IN}}\Gamma_S} \right|$$

Γ_a can also be computed by

$$\Gamma_a = \sqrt{1 - M_S}, \text{ where } M_S \text{ is the Source Mismatch Factor given by}$$

$$M_S = \frac{(1 - |\Gamma_S|^2)(1 - |\Gamma_{\text{IN}}|^2)}{|1 - \Gamma_S\Gamma_{\text{IN}}|^2}$$

The output VSWR of a microwave amplifier is given by:

$$\text{VSWR}_{\text{OUT}} = \frac{1 + |\Gamma_b|}{1 - |\Gamma_b|}, \text{ where } |\Gamma_b| = \left| \frac{\Gamma_{\text{OUT}} - \Gamma_L^*}{1 - \Gamma_{\text{OUT}}\Gamma_L} \right|$$

Γ_b can also be computed by

$$\Gamma_b = \sqrt{1 - M_L}, \text{ where } M_L \text{ is the Load Mismatch Factor given by}$$

$$M_L = \frac{(1 - |\Gamma_L|^2)(1 - |\Gamma_{\text{OUT}}|^2)}{|1 - \Gamma_L\Gamma_{\text{OUT}}|^2}$$

Small Transistor - Noise Circles

The center location and radius of a given noise circle for a two-port amplifier is calculated as follows:

1. Calculate a noise parameter N_p (Eq. 4-18)

$$N_p = \frac{F_p - F_{\text{min}}}{4 R_N / Z_0} |1 + \Gamma_0|^2$$

where,

F_p is the desired noise circle contour in dB

F_{min} is the minimum noise figure (from the manufacture)

Z_0 is the characteristic impedance

Γ_0 is the reflection coefficient at the input port for minimum noise

R_N is the effective noise resistance (from the manufacture)

2. Calculate the center of the noise circle (Eq. 4-19)

$$c_n = \frac{\Gamma_0}{1 + N_p}$$

3. Calculate the radius of the noise circle (Eq. 4-20)

$$r_n = \frac{1}{1 + N_p} \sqrt{N_p^2 + N_p(1 - |\Gamma_0|^2)}$$

Small Transistor Calculations

The Rowlett Stability Factor - K

The Rowlett Stability factor is calculated as follows.

1. Calculate D_s from equation 4-1.
2. Calculate K as (Eq. 4-21)

$$K = \frac{1 + |D_s|^2 - |S_{11}|^2 - |S_{22}|^2}{2|S_{21}||S_{12}|}$$

The Maximum Available Gain - MAG

The Maximum Available Gain is only defined when K is ≥ 1 .

1. First calculate B (Eq. 4-22)

$$B = 1 + |S_{11}|^2 - |S_{22}|^2 - |D_s|^2$$

2. Then MAG is calculated as follows.

if $B \geq 0$

$$MAG = 10 \log \frac{|S_{21}|}{|S_{12}|} + 10 \log \left| K - \sqrt{K^2 - 1} \right|$$

if $B < 0$ Potential Unstable

$$MAG = 10 \log \frac{|S_{21}|}{|S_{12}|} + 10 \log \left| K + \sqrt{K^2 - 1} \right|$$

The Load Reflection Coefficient at MAG

1. First calculate B_L (Eq. 4-23)

$$B_L = 1 + |S_{22}|^2 - |S_{11}|^2 - |D_s|^2$$

2. Next calculate C_L (Eq. 4-24)

$$C_L = S_{22} - D_s S_{11}^*$$

3. Then $|\Gamma_L|$ is calculated as follows.

if $B_L \geq 0$

$$|\Gamma_L| = \frac{B_L - \sqrt{B_L^2 - 4|C_L|^2}}{2|C_L|}$$

if $B_L < 0$

$$|\Gamma_L| = \frac{B_L + \sqrt{B_L^2 - 4|C_L|^2}}{2|C_L|}$$

$$\text{ARG}(\Gamma_L) = -\text{ARG}(C_L)$$

The Source Reflection Coefficient at MAG (Eq. 4-27)

$$\Gamma_S = \left[S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - \Gamma_L S_{22}} \right]^*$$

Source Reflection Coefficient Calculation

The Source Reflection Coefficient is calculated from a given Load Reflection Coefficient by the following equation.

$$\Gamma_S = \left[S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - \Gamma_L S_{22}} \right]^*$$

The input reflection coefficient is given by:

$$\Gamma_{IN} = \left[S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - \Gamma_L S_{22}} \right]$$

Load Reflection Coefficient Calculation

The Load Reflection Coefficient is calculated from a given Source Reflection Coefficient by the following equation.

$$\Gamma_L = \left[S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - \Gamma_S S_{11}} \right]^* \quad (\text{Eq. 4-28})$$

The output reflection coefficient is given by:

$$\Gamma_{\text{OUT}} = \left[S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - \Gamma_S S_{11}} \right]$$

Small Transistor - Power Gain Equations

The Transducer Gain is the gain of the amplifier stage plus the gains from the effects of input and output matching networks. From the S-parameters defined at a given operating state and for a given set of source and load reflection coefficients, the Transducer Gain is given by,

$$G_T = \frac{1 - |\Gamma_S|^2}{|1 - \Gamma_{IN}\Gamma_S|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

The Operating Power gain given by:

$$G_P = \frac{1}{1 - |\Gamma_{IN}|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2}$$

The Available Power gain given by:

$$G_A = \frac{1 - |\Gamma_S|^2}{|1 - S_{11}\Gamma_S|^2} |S_{21}|^2 \frac{1}{1 - |\Gamma_{\text{OUT}}|^2}$$

Y-Parameters to S-Parameters Conversion

The **Y-param -> S-param...** dialog menu under the **Functions** menu is given to convert Y-parameters to S-parameters. The parameters once converted to S-parameters are saved internally and the S-parameters for other dialog procedures are initialized from these saved values. Note that if you must first multiply each individual Y parameter by Z_0 before enter the value in the dialog box. The equations for these conversions are as follows:

$$S_{11} = \frac{(1 - y_i)(1 + y_0) + y_r y_f}{(1 + y_i)(1 + y_0) - y_r y_f}$$

$$S_{12} = \frac{-2y_r}{(1 + y_i)(1 + y_0) - y_r y_f}$$

$$S_{21} = \frac{-2y_f}{(1 + y_i)(1 + y_0) - y_r y_f}$$

$$S_{22} = \frac{(1 + y_i)(1 - y_0) + y_r y_f}{(1 + y_i)(1 + y_0) - y_r y_f}$$

Micro-strip Calculation

The **Micro-strip Calc...** dialog menu under the **Functions** menu is given to calculate either the width and length of a micro-strip line or its characteristic impedance. It is based on the quasi-TEM assumption and negligible thickness of the strip conductor.

For the Width and Length calculation the inputs are as follows:

1. The Characteristic impedance of the line.
2. The thickness of the substrate.
3. The dielectric constant of the substrate material ϵ_r .
4. The fractional wavelength of the micro-strip (λ)
5. The operating frequency.

The calculations are performed as follows: (Reference[1], pp 143-152)

1. First calculate parameters A and B as follows:

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left(0.23 + \frac{0.11}{\epsilon_r} \right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

2. Next calculate W, where W is the width of the line, and h is the thickness of the substrate.

for $W/h < 2$

$$W = \frac{8e^A h}{e^{2A} - 2}$$

for $W/h \geq 2$

$$W = \frac{2}{\pi} \left\{ B - 1 - \ln(B - 1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left[\ln(B - 1) + 0.39 - \frac{0.61}{\epsilon_r} \right] \right\}$$

3. Calculate λ

for $W/h \geq 0.6$

$$\lambda = \frac{\lambda_0}{\sqrt{\epsilon_r}} \left[\frac{\epsilon_r}{1 + 0.63(\epsilon_r - 1)(W/h)^{0.1255}} \right]^{1/2}$$

for $W/h < 0.6$

$$\lambda = \frac{\lambda_0}{\sqrt{\epsilon_r}} \left[\frac{\epsilon_r}{1 + 0.6(\epsilon_r - 1)(W/h)^{0.0297}} \right]^{1/2}$$

4. Calculate ϵ_{ff}

$$\epsilon_{ff} = \left(\frac{1}{\lambda} \right)^2$$

5. Calculate the length of the micro-strip.

$$l = \frac{\lambda}{k_0 \sqrt{\epsilon_{ff}}}$$

where

$$k_0 = \frac{2\pi f}{c}$$

For the Characteristic Impedance calculation the inputs are as follows:

1. The thickness of the substrate (h).
2. The dielectric constant of the substrate material.
3. The width of the micro-strip in millimeters (W).

The calculations are performed as follows:

1. First calculate the effective dielectric constant.

For $W/h \geq 1$

$$\epsilon_{ff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12 \frac{h}{W} \right)^{-1/2}$$

For $W/h < 1$

$$\epsilon_{ff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\left(1 + 12 \frac{h}{W} \right)^{-1/2} + 0.04 \left(1 - \frac{W}{h} \right)^2 \right]$$

2. Next, calculate Z_0

For $W/h \geq 1$

$$Z_0 = \frac{120\pi\sqrt{\epsilon_{ff}}}{W/h + 1.393 + 0.667 \ln(W/h + 1.444)}$$

For $W/h < 1$

$$Z_0 = \frac{60}{\sqrt{\epsilon_{ff}}} \ln\left(8 \frac{h}{W} + 0.25 \frac{W}{h}\right)$$

Appendix A

References

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