FINAL PROJECT REPORT

COMMUNICATION SYSTEM AND DEVICES

DESIGN A POWER TRANSISTOR AMPLIFIER AT FREQUENCY 3GHz USING GaN TRANSISTOR T1G600052

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A power amplifier is an electronic device that has a function to increase the power output of the system from the input signal to achieve a specific gain at the load network. There are some ideal condition of an amplifier

1. The gain is not to be affected by frequency
2. The gain remains constant for different inputs
3. The amount of output signal amplified is the same with each different frequency
4. It is not affected by noise
5. It is not affected by temperature change

A power transistor is an electronic device that handle the control of input signal to output signal that comes with large power.

This project is designed to create a power amplifier using power transitor T1G6000528 with matching input and ouput network lumped with L-C, T1G6000528 specifications such as:

- Frequency: 3.00 GHz.
- P3 dB=11
- G3 dB = 13.5
- Operating between 50-ohm terminals
- At 3 GHz, Zsp= 5+ j2.54, and Zlp = 21.38 + j3.85

1.2 PROJECT DESCRIPTION AND OBJECTIVE

In this project we need to create a schematic of a matching network input and output with lumped L-C elements. Find the stable input and output for network matching. Provide a simulation to show the gain is suitable for the network.

`

Fig. 1 flowchart of the project

First, we need to find the S parameter and find whether the system its stable and add a additional (shunt resistor) component to stabilize the system. After that we need to find GammaSP and GammaLP and use that to find Zl and Zs. Then we use Zl and Zs to find GammaA and GammaB and use it to find Ya, Yb, Za, Zb. Finally after we got Za and Zb we can then find Cin, Lin, Cout, and Lout. After that we verify whether the matching amplifier working or not.

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1.3 TOOLS AND EQUIPMENTS

- ADS 2016 (Advanced Design System)

  This program is used to make the schematic and have a simulation to the schematic to find the parameters and figures.

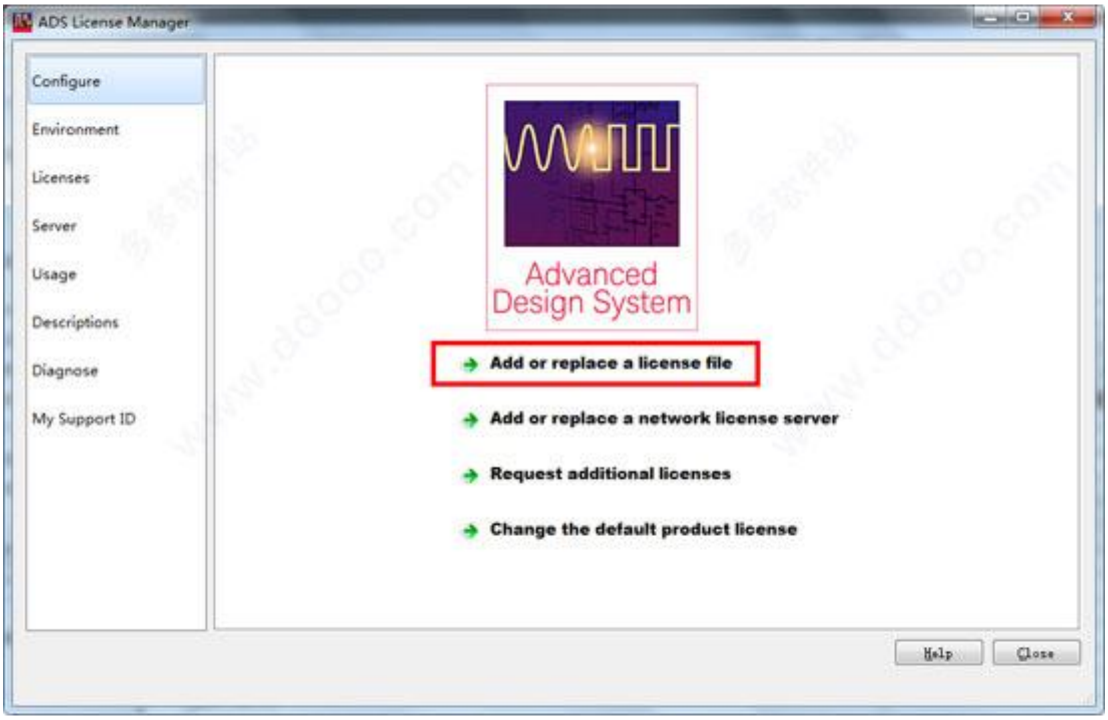


Fig.2 ADS

- Matlab

  This program has multiple function and tool to find the necessary parameters for matching network of amplifier. Also, it can be used to simulate and analyze the system or the device.

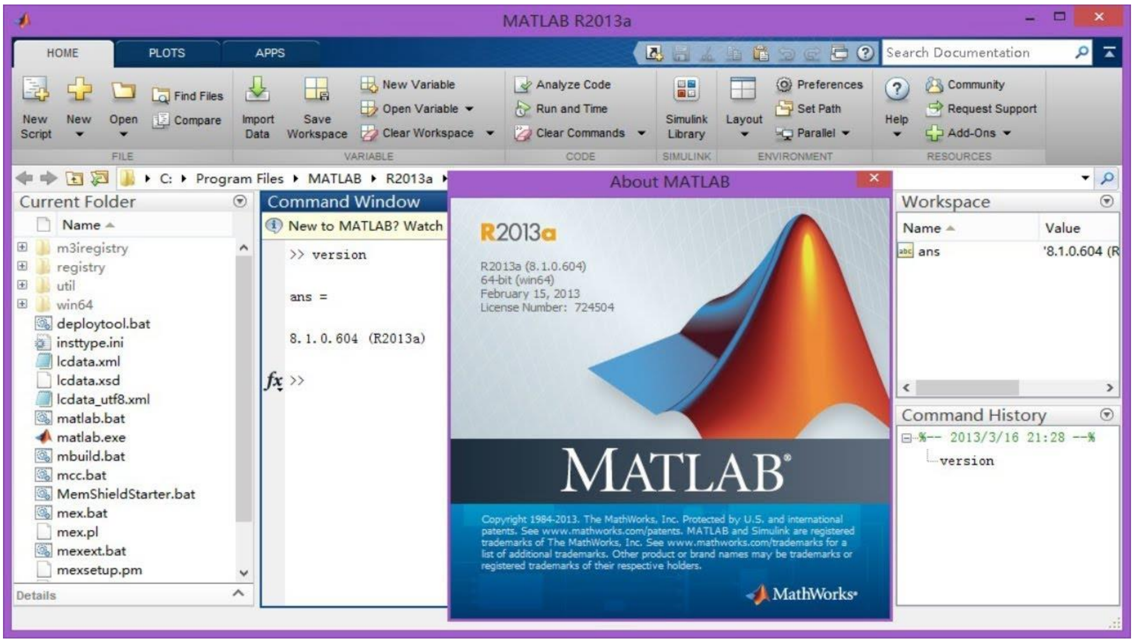


Fig. 3 Matlab

CHAPTER 2

CALCULATION

2.1 PROJECT DESIGN

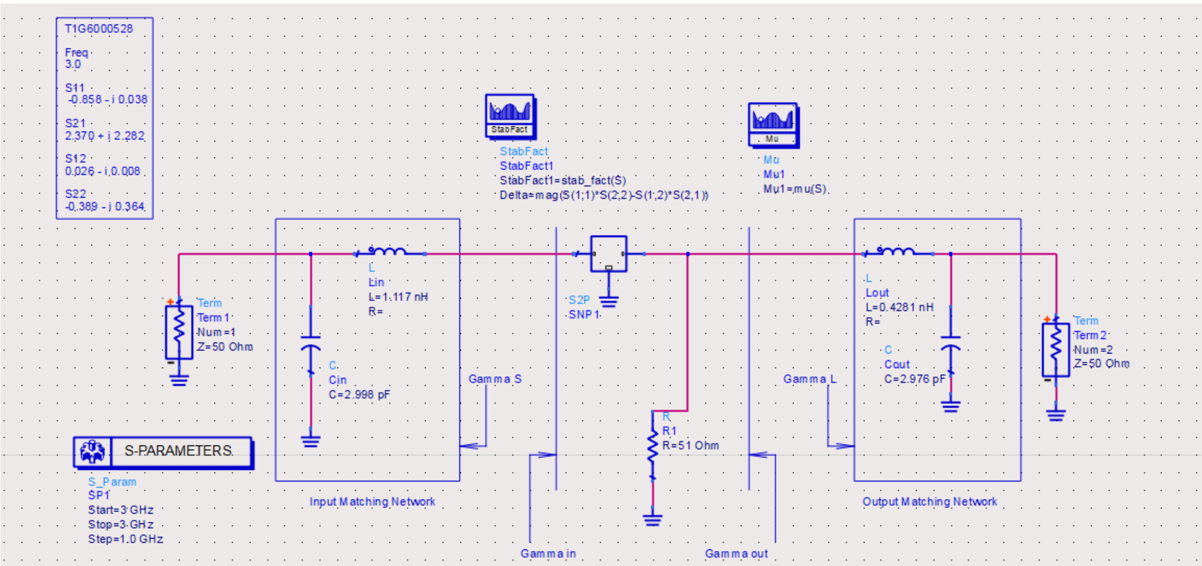


Fig.4 Design with input and output matching network with lumped L-C

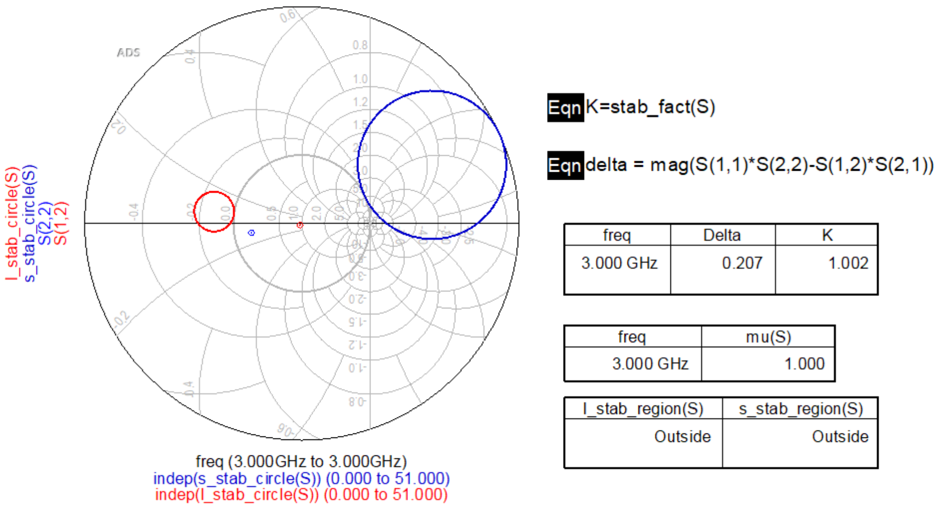


Fig.5 the stability of matched amplifier

- The S-Parameter controller

is used to define the signal-wave response of an n-port electrical element at a given frequency. It is a type of small-signal AC simulation that is most commonly used to characterize a passive RF component and establish the small signal characteristics of a device at a specific bias and temperature.

- StabFact
- Mu

2.2 <u>MATLAB CODE</u>

- inserting the amplifier object with the parameter

unmatched_amp = read(rfckt.amplifier, 'T1G6000528.s2p')

T1G6000528.s2p file :

“FET T1G6000528

FREQ GHz S RI R 50

! Freq reS11 imS11 reS21 imS21 reS12 imS12 reS22 imS22

`

2.0   -0.818 -0.289 2.006 3.515 0.030 -0.005 -0.249 -0.446

2.5   -0.849 -0.166 1.895 2.899 0.025 -0.007 -0.339 -0.402

3.0   -0.858 -0.038 2.370 2.282 0.026 -0.008 -0.389 -0.364

3.5   -0.839 0.132 3.097 1.371   0.030 -0.009 -0.433 -0.339

4.0   -0.800 0.278 3.145 0.555   0.029 -0.007 -0.481 -0.290

"

- creating the plot for operating gain gain available, and Transducer Gain

figure

plot(unmatched_amp,'Gp','Ga','Gt','dB')

- Creating variable 3GHz

fc = 3e9;

- Creating Smithplot for satability of unmatched amplifier

hsm = smithplot;

circle(unmatched_amp,fc,'Stab','In','Stab','Out','Ga',10:2:20,hsm);

legend('Location','SouthEast');

- Function to find minimum R1 for shunt resistor to stabilize the amplifier

lna_match_stabilization_helper.m :

"function mu_minus_1 = lna_match_stabilization_helper(propval, fc, ckt, element, propname)

%LNA_MATCH_STABILIZATION_HELPER Return Stability MU-1.

`

```
% MU_MINUS_1 = LNA_MATCH_STABILIZATION_HELPER(PROPVALUE, FC, CKT,
% ELEMENT, PROPNAME) returns stability parameter MU-1 of a circuit, CKT
% when the property called PROPNAME of an element, ELEMENT is set to
% PROPVAL.
%
% LNA_MATCH_STABILIZATION_HELPER is a helper function of RF
% Toolbox demo: Designing Matching Networks (Part 1: Networks with an LNA
% and Lumped Elements).
% Copyright 2007-2008 The MathWorks, Inc.
set(element, propname, propval)
analyze(ckt, fc);
mu_minus_1 = stabilitymu(ckt.AnalyzedResult.S_Parameters) - 1;”
```

- applying the function to find the R1, in this case the minimum shunt resistor that can use to stabilize

```
stab_amp = rfckt.cascade('ckts', {unmatched_amp, rfckt.shuntrlc});
R1 = fzero(@(R1) lna_match_stabilization_helper(R1,fc,stab_amp,stab_amp.Ckts{2},'R'),[1 1e5])
```

- putting the shunt resistor

```
shunt_r = rfckt.shuntrlc('R',51);
stab_amp = rfckt.cascade('ckts',{unmatched_amp,shunt_r});
```

`

- finding the GammaL, GammaS, Zs, and Zl on the operating power 13.5 dB

```
figure

hsm = smithplot;

circle(stab_amp,fc,'Gp',13.5,'Ga',13:17,hsm)

legend('Location','SouthEast')

Zl = 0.114 - 0.155i

GammaL = 0.9827*exp(1j*168.9*pi/180)

GammaS = 0.8061*exp(1j*167.9*pi/180)

Zs=gamma2z(GammaS,1)
```

- plotting a constant conductance circle that cross the center of smith chart to find GammaB

```
figure

hsm = smithplot;

circle(stab_amp,fc,'G',1,'R',real(Zs),hsm);

hsm.GridType = 'YZ';

hold all

plot(GammaS,'k.','MarkerSize',16)

text(real(GammaS)+0.05,imag(GammaS)-0.05,'\Gamma_{S}','FontSize', 12, ...

   'FontUnits','normalized')

plot(0,0,'k.','MarkerSize',16)
```

`

```
hold off
```

- plotting a constant conductance circle that cross the center of smith chart to find GammaB

```
hsm = smithplot;

circle(stab_amp,fc,'G',1,'R',real(Zl),hsm);

hsm.GridType = 'YZ';

hold all

plot(GammaL,'k.','MarkerSize',16)

text(real(GammaL)+0.05,imag(GammaL)-0.05,'\Gamma_{S}','FontSize', 12, ...

    'FontUnits','normalized')

plot(0,0,'k.','MarkerSize',16)

hold off
```

- fiding the value of GammaA from the intersection point of conductance circle and Zs contant load

```
GammaA = 0.8205*exp(1j*(-144.5)*pi/180);

#finding the value of Za and Ya

Za = gamma2z(GammaA,1);

Ya = 1/Za;
```

- finding the value of GammaB from the intersection point of conductance circle and Zl constant load

`

GammaB = 0.8146*exp(1j*(-144.5)*pi/180);

- finding the value of Zb and Yb

Zb = gamma2z(GammaB,1);

Yb = 1/Zb;

- calculate the value of Cout & Lout

Cout = imag(Yb)/50/2/pi/fc

Lout = (imag(Zl) - imag(Zb))*50/2/pi/fc

- finding the input Capacitor and Output Capacitor

$$2\pi f_c C_{in} = \mathrm{Im}\left(\frac{Y_a}{50}\right)$$

Cin = imag(Ya)/50/2/pi/fc

$$2\pi f_c L_{in} = 50(\mathrm{Im}(Z_s) - \mathrm{Im}(Z_a))$$

Lin = (imag(Zs) - imag(Za))*50/2/pi/fc

- Find the the values of Cout and Lout.

Cout = imag(Yb)/50/2/pi/fc

Lout = (imag(Zl) - imag(Zb))*50/2/pi/fc

- Verify the design, creating the input and output matching networks.

input_match = rfckt.cascade('Ckts', ...

{rfckt.shuntrlc('C',Cin),rfckt.seriesrlc('L',Lin)});

`

```
output_match = rfckt.cascade('Ckts', ...

    {rfckt.seriesrlc('L',Lout),rfckt.shuntrlc('C',Cout)});
```

- then cascade the input and output matching network, the amplifier and shunt resistor to define power amplifier

```
LNA = rfckt.cascade('ckts', ...

    {input_match,unmatched_amp,shunt_r,output_match});
```

- plot the result of power amplifier

```
analyze(LNA,2e9:10e6:4e9);

plot(LNA,'Gp','Ga','Gt','dB');
```

2.3 THEORY AND EQUATION

Conjugate Match - Bilateral Case

A sufficient stability factor to two port network to be unconditionally stable are K > 1 and |Delta| < 1.

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

K = 0.659 (before installing shunt resistor)

$$\text{with } \Delta = S_{11}S_{22} - S_{12}S_{21}$$

Delta = 0.240+0.286i

`

$$P_{\mathrm{OUT}}(\mathrm{dBm}) = G_p(\mathrm{dB}) + P_{\mathrm{IN}}(\mathrm{dBm})$$

we can write the output power at the 1-dB gain compression point, called $P_{1\,\mathrm{dB}}$, as

$$P_{1\,\mathrm{dB}}(\mathrm{dBm}) = G_{1\,\mathrm{dB}}(\mathrm{dB}) + P_{\mathrm{IN}}(\mathrm{dBm}) \tag{4.7.2}$$

In this equation we assume that if, G_{1dB}(dB) = G_p(dB) at 1-dB gain compression point, so as G_{3dB}(dB) = G_p(dB) at 3-dB gain compression point.

$$\boxed{\begin{aligned}\Gamma_S &= \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1}\\ \Gamma_L &= \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2}\end{aligned}} \quad \boxed{\begin{aligned}B_1 &= 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2\\ B_2 &= 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2\\ C_1 &= S_{11} - \Delta S_{22}^*\\ C_2 &= S_{22} - \Delta S_{11}^*\end{aligned}}$$

B_1 = 1.314

B_2 = 0.406

C_1 = -0.660 - 0.014i

C_2 = -0.172 - 0.127i

GammaS = -0.997 - 0.076i

GammaL= -0.950 + 0.311i

The coefficion reflection of load and source

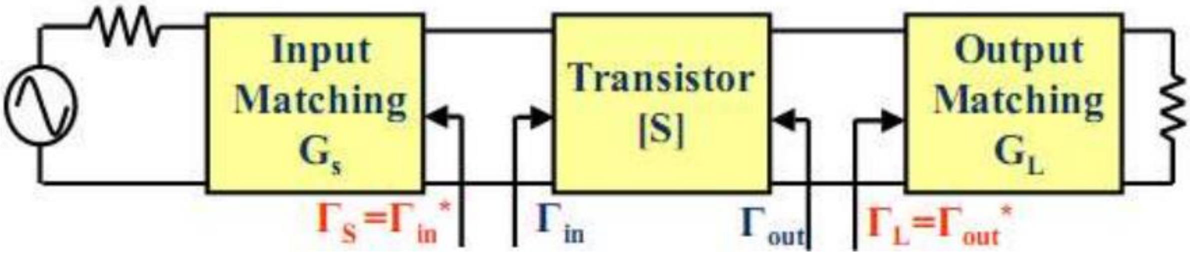
$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12}\Gamma_L S_{21}}{1 - \Gamma_L S_{22}} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

$$\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12}\Gamma_S S_{21}}{1 - \Gamma_S S_{11}}$$

Gammain = -0.6104 + 0.1468i

Gammaout= -0.9126 + 0.1439i

The circuit will be:



Chapter 3

DESIGN AND ANALYSIS

3.1 SMITH CHART & GRAPHIC

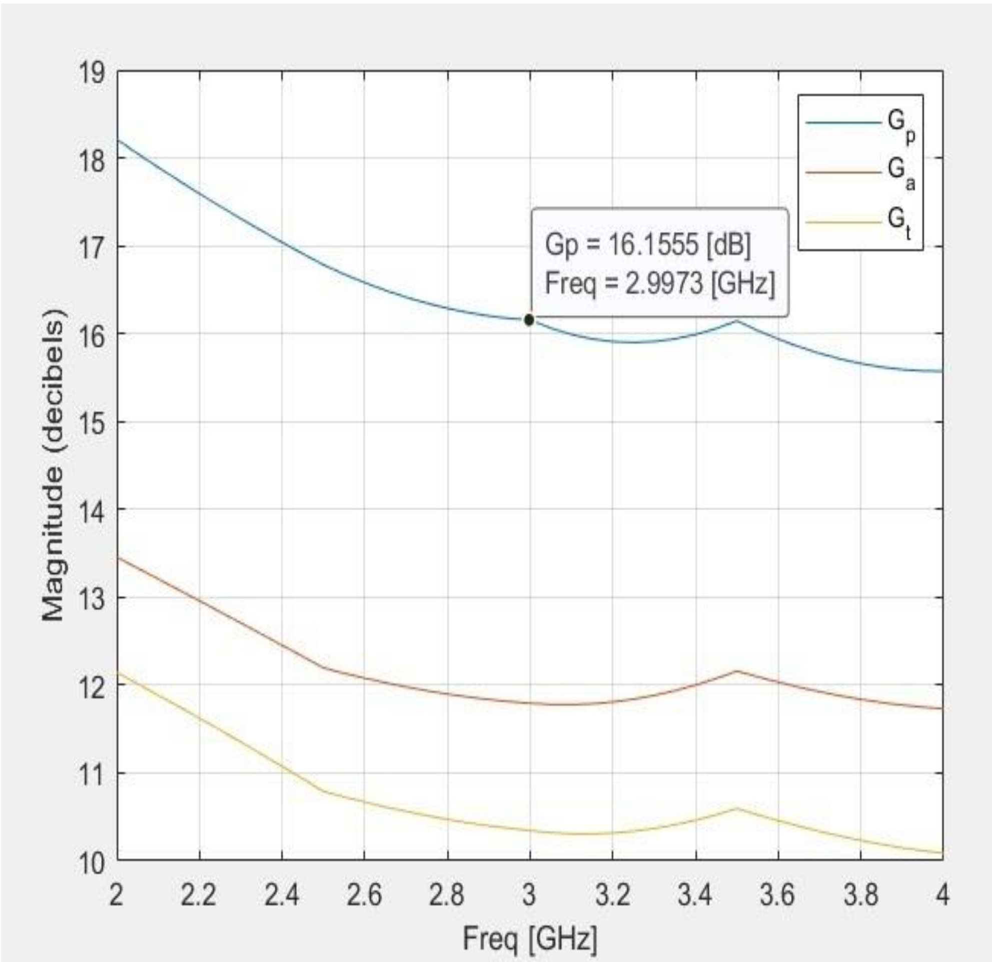


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Fig.6 unmatched amplifier T1G6000528 from 2 GHz to 4 GHz

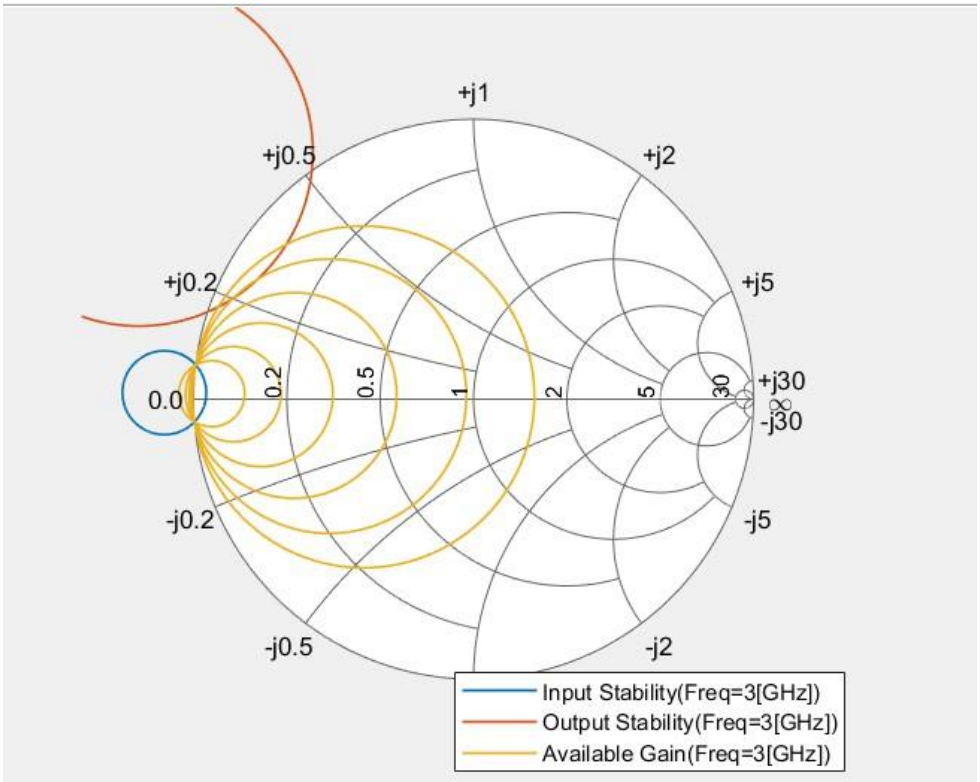


Fig.7 Smith Chart of stability of unmatched amplifier T1G6000528

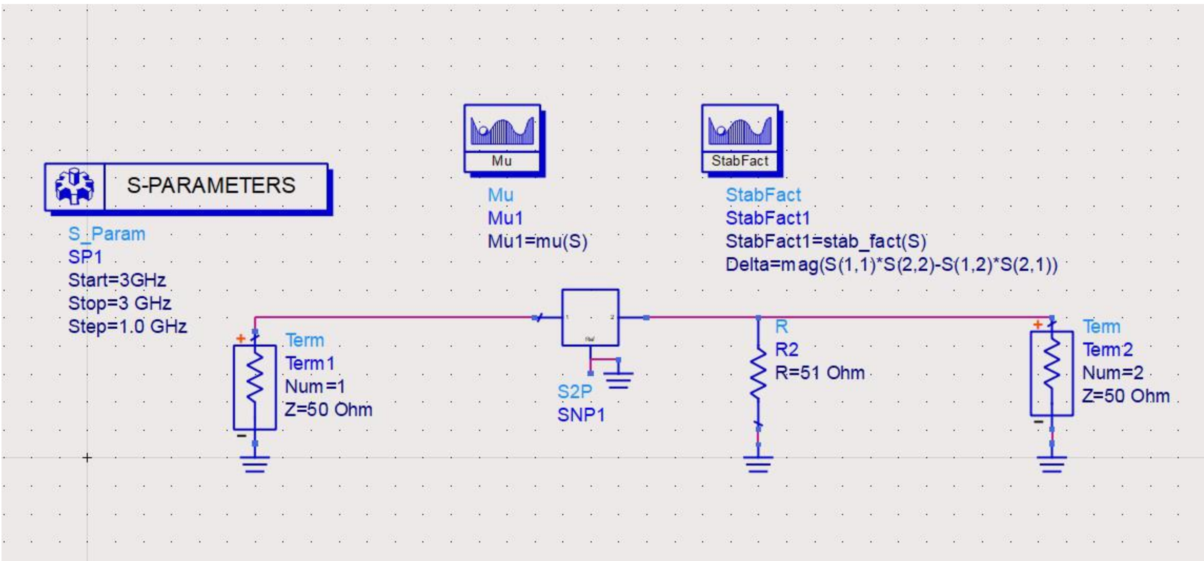
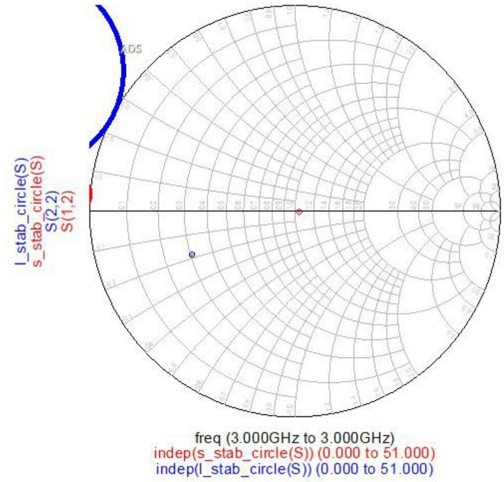


Fig.8 Schematic after inserting R shunt



Eqn delta = mag(S(1,1)*S(2,2)-S(1,2)*S(2,1))

Eqn K=stab_fact(S)

freq	delta	K
3.000 GHz	0.433	1.002

freq	mu(S)
3.000 GHz	1.001

l_stab_region(S)	s_stab_region(S)
Outside	Outside

Fig. 9 Smith chart on stable unmatched amplifier

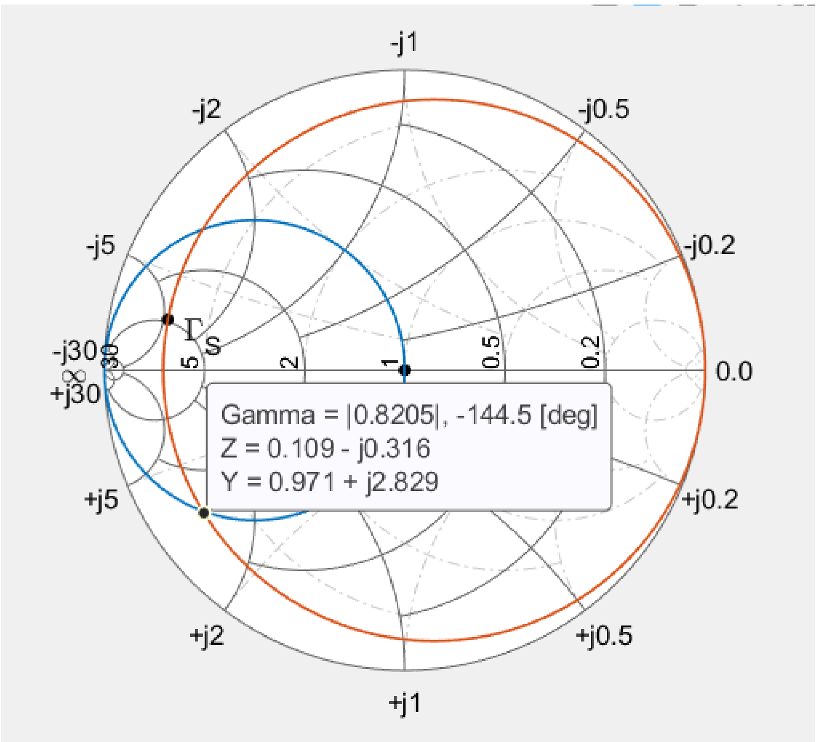


Fig. 10 Smith Chart for constant conductance circle and Zs circle

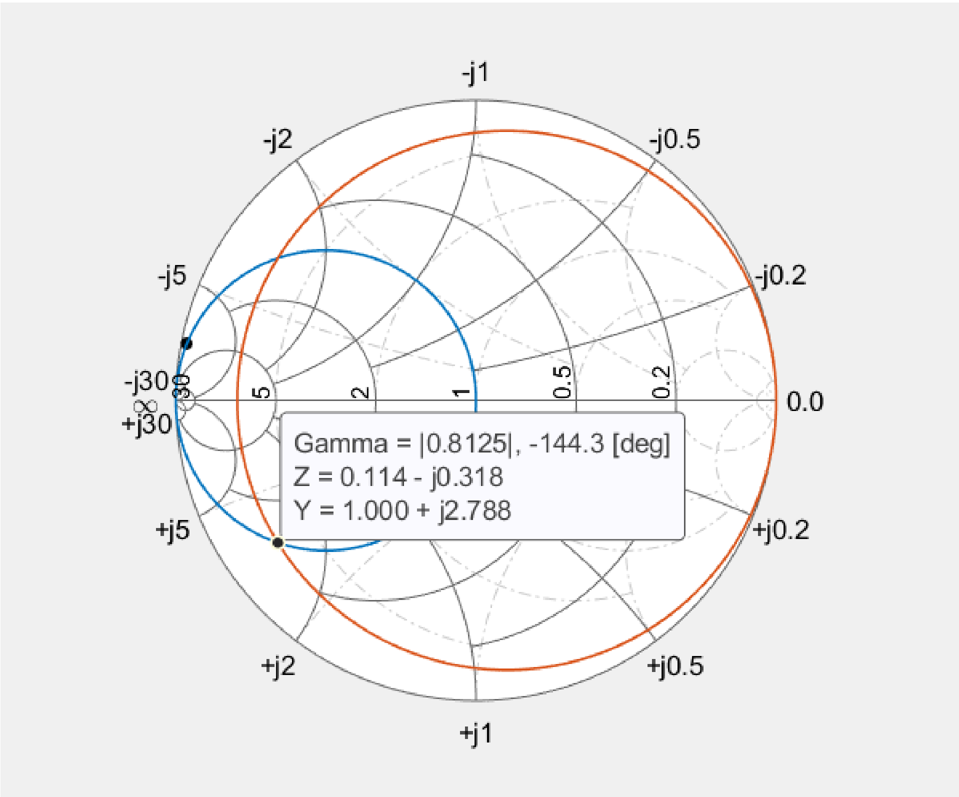


Fig.11 Smith Chart for constant conductance circle and Zs circle

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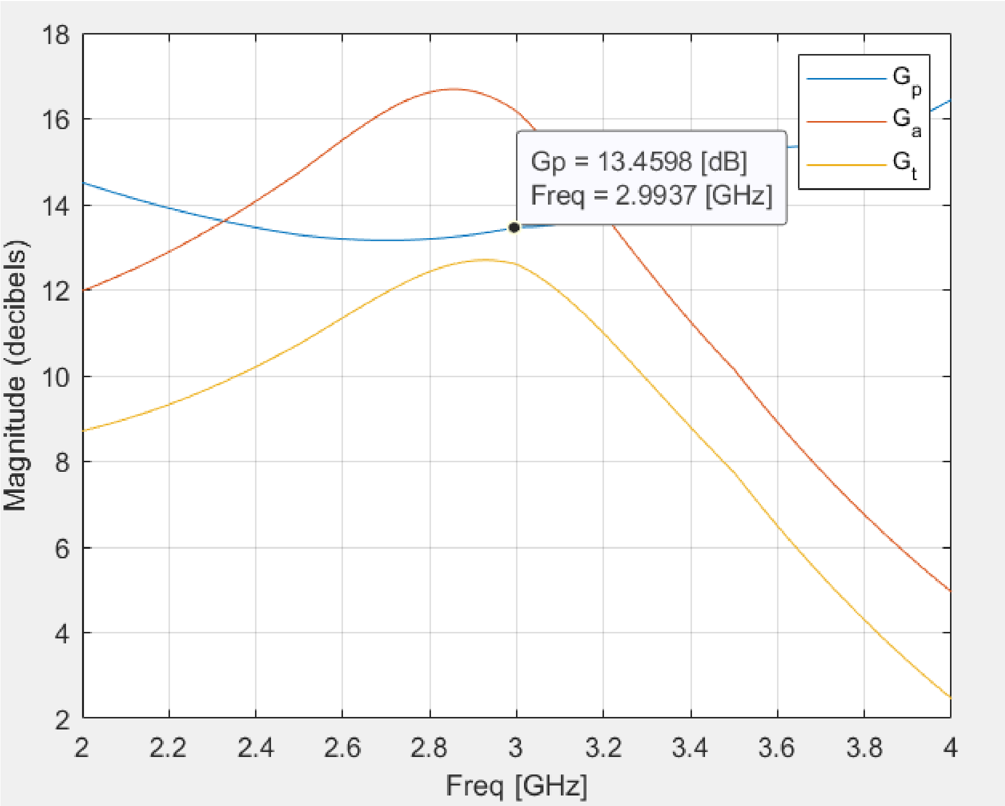

Fig. 12 Gains after matching L-C circuit with amplifier

3.2 ANALYSIS

As you can see in figure 5, the Gain available and gain transducer is below the Gain compression of 3dB but the output gain is higher than which is 13.5 dB at 3 GHz. So, we need to increase it and find the matched input and output of the network.

According the system this system is not stable as if |s11| < 1, then to be unconditionally stable its need to have K>1 and |Delta|<1 (see figure 7). In this case the Delta is already fulfill the conditions, but the K is not. So, to increase the stability we have to add additional shunt resistor.

We find the minimum shunt resistor resistance using matlab and then install it into the schematic (see figure 8) and as we can see that the system now has K>1 and Mu>1 which means it is unconditionally stable (see figure 9)

After we got its stability, we plot the operating gain to find the GammaS (-0.7882 + 0.1690i),

`

GammaL (-0.9643 + 0.1892i), Zs (0.1140 - 0.1550i), & Zl (0.1125 - 0.3164i)

And then we plot the constant conductance circle that crosses the center of the Smith chart and the constant resistance circle that crosses Zs and find the intersection to find GammaA (-0.6680 - 0.4765i) (see figure 10) and the constant conductance circle that crosses the center of the Smith chart and the constant resistance circle that crosses Zl and find the intersection to find GammaB (-0.6632 - 0.4730i) (see figure 11).

GammaA and GammaB is used to find Ya (0.9689+ 2.8255i),Yb (0.9977 + 2.8056i), Za (0.9977 + 2.8056i), Zb (0.1125 - 0.3164i). after we got the parameters we can find Cin(2.9980e-12 F), Lin (2.9768e-12 F), Cout (1.1179e-09), and Lout(4.2819e-10).

And then we input the L-C elements to the system and analyze the Gain available and Transducer Gain is close to each other and well above 13.5 dB and operating gain is 13.4598 dB. We can see that the Gp or operating gain become closer G_{3dB} or close to the target of 13.5 dB (see figure 12).

3.3 ERROR

From a couple of try we stabilize the system, we need to find the GammaSP and GammaSL with conjugating the Gammain and Gammaout which we have from manually calculating the s parameter in the above formula to find Zs (0.0398 + 0.0782i) and Zl (0.2317 + 0.1123i). We use the Zs and Zl to find the GammaA and GammaB by Plotting the constant conductance circle that crosses the center of the Smith chart and the constant resistance circle that crosses Zs. We use the point where the constant conductance meets with Zs circle or Zl circle, in this point we always choose the minus degree of GammaA (-0.8574 - 0.3499i) to get a positive Lin & Cin and GammaB (-0.4531 - 0.4980i) for positive Lout & Cout. Using Matlab code above we can find Ya (0.9970 + 4.9021i), Yb (0.9993 + 1.8206i), Za (0.0398 - 0.1959i), and Zb (0.2317 - 0.4221i) to find Lin (7.2714e-7) , Cin (5.2013e-14), Lout (1.4175e-08), and Cout (1.9318e-13). In this process the result of the magnitude become minus (-) decibels. Because of the error somewhere on the equations we made manually.

another problem arises when we don't use the lower half intersection of the Smith chart when finding the GammaA and GammaB. The Result will make the Cin and Cout will be minus and will make an error on the program.

Chapter 4

CONCLUSION

4.1 CONCLUSION

From this project we can analyze the stability and gain using application like Matlab and ADS. Also we can design a power amplifier using S-parameter and other specification to make a power amplifier that its stable by adding a shunt resistor and after installing the L-C elements, we have an operating gain of almost 13.5 dB and available gain and transducer gain have bigger magnitude. That means we can control the gain and stability by adding components to the system.

REFERENCES

• Gonzales,Guilemro. Microwave Transistor Amplifiers: analysis/design – 2nd ed.

• Pozar, David M.Microwave Engineering - 4th ed

• https://uk.mathworks.com/help/rf/examples/designing-matching-networks-part-1-networks-with-an-lna-and-lumped-elements.html