Radio Electronics ETI032

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1) Low Noise Amplifier (LNA) Design

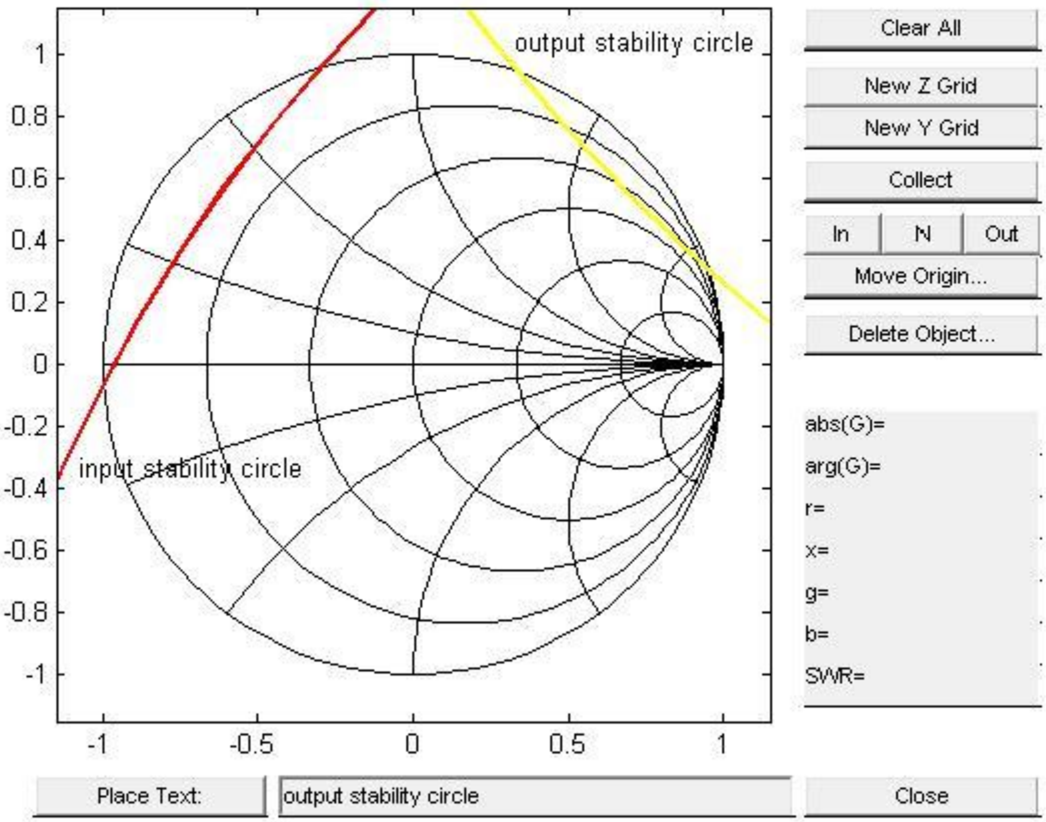
The design is based on Philips BFR520 transistor with S-parameters from lab2. The amplifier will work at 850 MHz. We'll use the specific gain design flow to finish design.

1.1) Unconditional Stability Analysis

The stability parameters are as follows:

delt =0.4154 K =0.8612

Since K<1, the transistor is only conditionally stable. And the stable circles are drawn as below:



Place Text: output stability circle

Since |S11|<1 &|S22|<1, the center of the Smith-chart is stable for the input and the output.

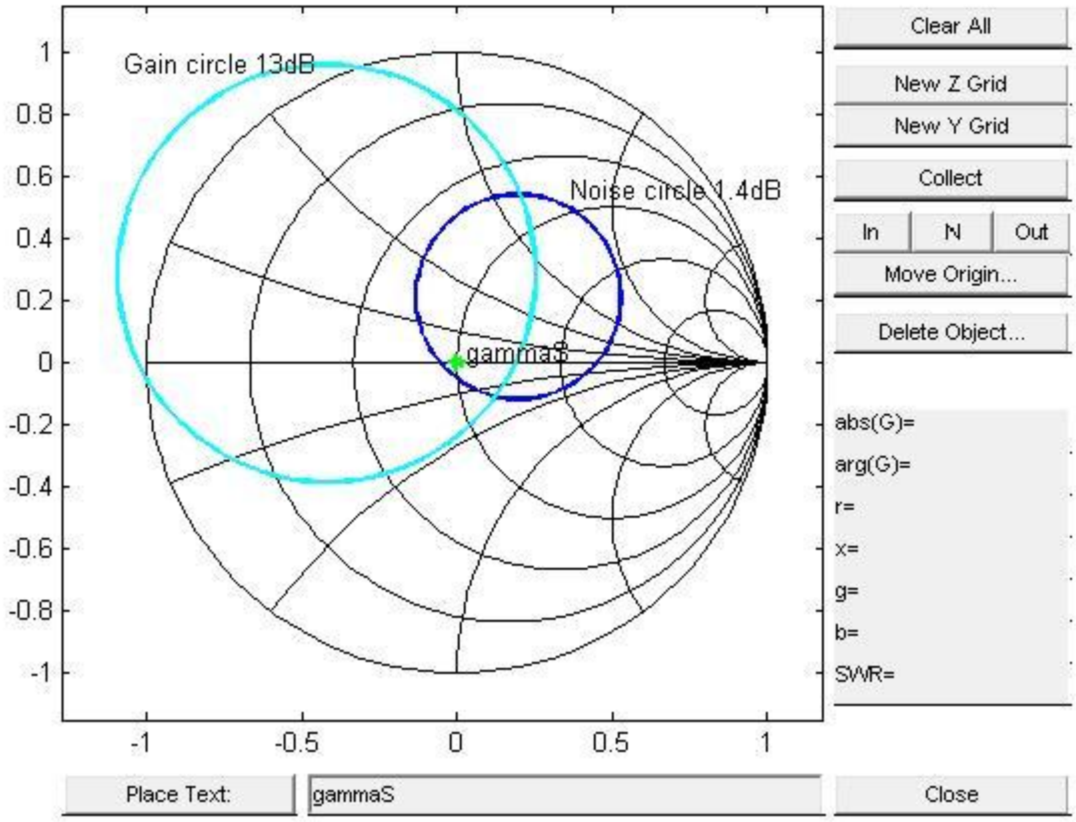
1.2) Conditional Stability Design

1.2.1) Design method for specific gain

The mismatch will be put at the input side of the transistor to generate the specific gain and a conjugate match will be used at the output side.

1.2.2) Required Gain and Noise circle

The circle of GT = GA = 13dB and Noise figure = 1.4dB are plotted as below:



From the Smith-chart, it can be seen that there is an intersection area of the gain circle and noise circle and any point (including the center point) in this area is suitable for the design. Since the source impedance (50Ω) is given, selecting the center point (also 50Ω of impedance) as gammaS will avoid using the input matching network.

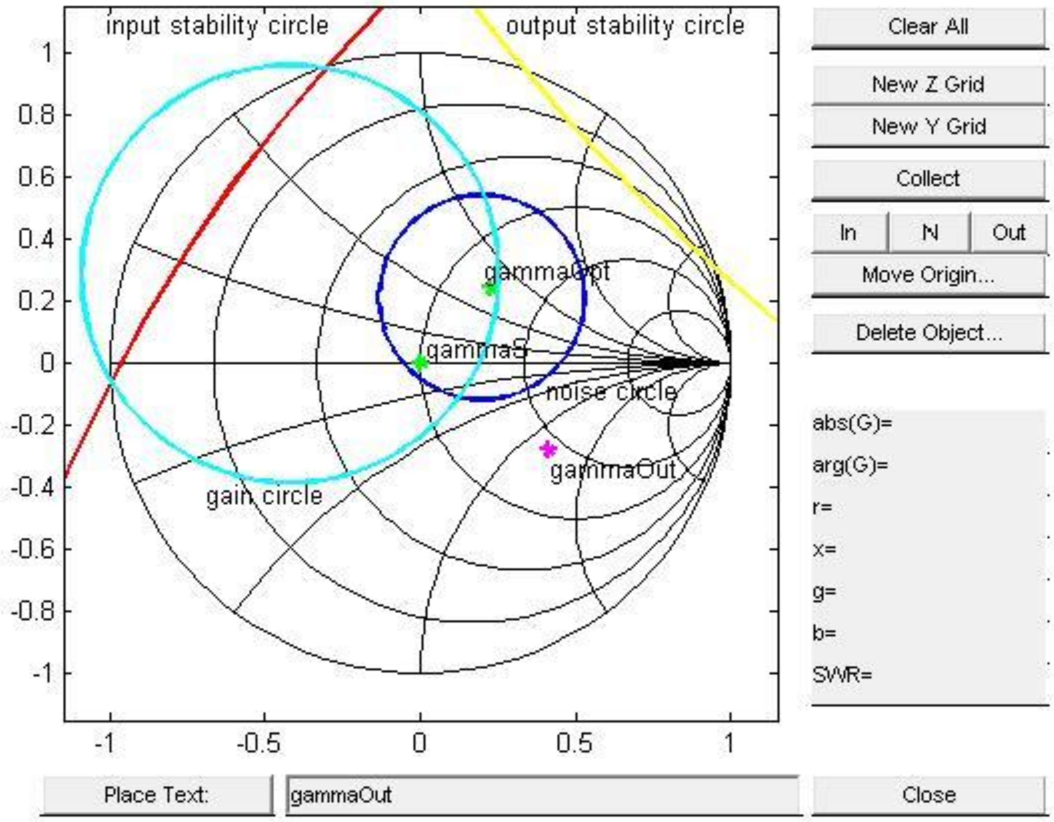
1.2.3) gammaOut and Stability Check

Since gammaS has been selected, we can calculate gammaOut. Then, check the stability of gammaS and gammaOut.

From the following Smith-chart, we got the gammaOut and found both gammaS and gammaOut are in stable area.

Result: gammaS = 0∠0° or zs=1+0j

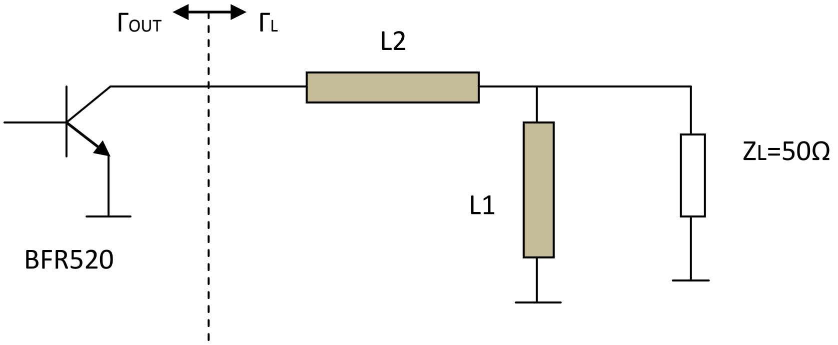
gammaOut = 0.5∠-33.9° or zout= 1.7858-1.3280j



1.2.4) Matching Network

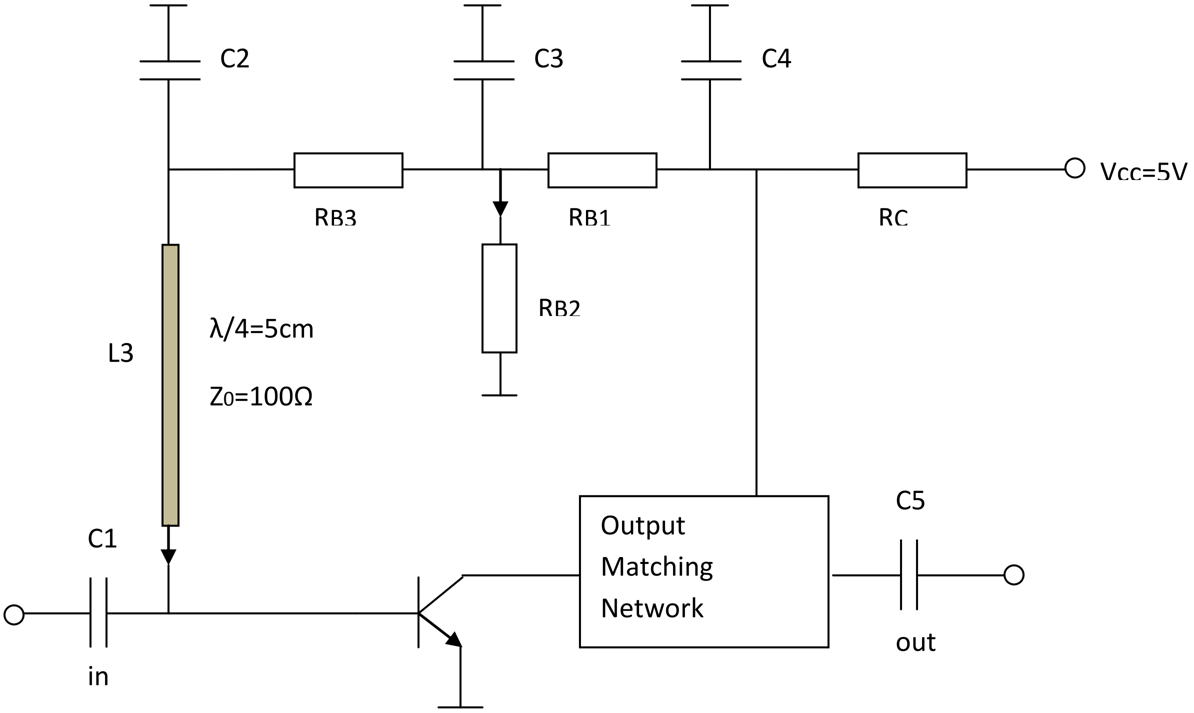
A matching network is needless at input and a conjugate matching network will be used at output side.

Since gammaOut = 0.5∠-33.9° or zout= 1.7858-1.3280j, for a conjugate match, we can get gammaL = 0.5∠33.9° or zL= 1.7858+1.3280j (which is still in the table area for gammaL). We used a 50Ω series transition line and a short-circuit 50Ω stub to build this matching network.



From the following smith chart, we can see that the length for the 50Ω short-circuit stub(L1) is 0.114λ and the length for the series transmission line(L2) is 0.1192λ.

2) Bias Circuit design



2.1) Calculation of Components

We have already known that $\beta_0 = 120, V_{CC} = 5V$ and the goals are $I_C = 5mA, V_{CE} = 3V$.

A current driven biasing circuit as above is choosen.

For the resistors, if we assume $I_C = I_D\sqrt{\beta_0}$ and $I_D = I_B\sqrt{\beta_0}$, we'll get $I_C = 5mA, I_D = 0.456mA, I_B = 0.04167mA$.

So, $R_C = \frac{V_{CC}-V_{CE}}{I_C+I_D+I_B} = \frac{5V-3V}{5mA+0.456mA+0.04167mA} \approx 364\Omega$

Then, if we assume $V_D = 2V_B = 1.4V$, we'll get

$$R_{B1} = \frac{V_C - V_D}{I_D + I_B} = \frac{3V - 1.4V}{0.456mA + 0.04167mA} \approx 3.125k\Omega$$

$$R_{B2} = \frac{V_D}{I_D} = \frac{1.4V}{0.456mA} \approx 3.07k\Omega$$

$$R_{B3} = \frac{V_D - V_B}{I_B} = \frac{1.4V - 0.7V}{0.04167mA} \approx 16.79k\Omega$$

2.1.1) Motivtion to Choose Biasing Network:

This biasing have high loop gain

$$\text{Loop Gain} = \frac{\beta R_c}{R_{B3}} \times \frac{R_{B2}}{R_{B1}+R_{B2}} \approx 1.3$$

It helps to sudden changes of I_C current due to temperature. So the "Thermal Runaway effect" can be avoided.

If we use the resistor at emitter to avoid thermal effects, it'll lead to problems at high frequencies when parasitic capacitance and inductance become dominate.

2.2) AC Decoupling

We use microstrip transmission lines to isolate the bias circuit and small signal circuit. The transmission line's type is epoxy fibreglass, its height is 0.8mm and $\varepsilon_r = 4.55$.

Note: It's assumed that the capacitors are large enough.

2.2.1) Matlab Code for Calculating Physical Lengths of Micro Strips

```
% Microstrip on 0.8 mm epoxy-fiberglas (epsilonr = 4.55)
% f=850 MHz, Z0 = 50 ohms for output matching network and Z0 = 100 ohms for
input matching network required
% calculation of W/h for Z0 = 50 ohms
wh=(1.6:0.02:2.2)';
x=[msz0(4.55,wh),wh]
% calculation of W/h for Z0 = 100 ohms
wh=(0.4:0.001:0.7)';
x=[msz0(4.55,wh),wh]
% Z0 = 50 for W/h = 1.85
% the width of the microstip line is W/h*0.8 mm
W_50_ohms  = 1.8662*0.8*1e-3;
W_100_ohms = 0.4230*0.8*1e-3;
% Calculation of the wavelength lambda at 850 MHz
f0=850e6;
epsiloneff_50_ohms  = mseffeps(4.55,1.8662 )
epsiloneff_100_ohms = mseffeps(4.55,0.4230 )
lambda_eff_50_ohms  = 3e8/sqrt(epsiloneff_50_ohms)/f0
lambda_eff_100_ohms = 3e8/sqrt(epsiloneff_100_ohms)/f0
% physical length of the microstrip line
% physical length = electrical length * lemda-eff
short_stub_len   = 0.114*lambda_eff_50_ohms
ser_line_len     = 0.1192*lambda_eff_50_ohms
base_supply_len  = 0.25*lambda_eff_100_ohms
```

Through the above matlab code, we get the length of short stub(L1) is 21.7mm, the length of serial line(L2) is 22.7mm, and the length of base supply(L3) is 50mm.

3) Matlab Code for Verifying

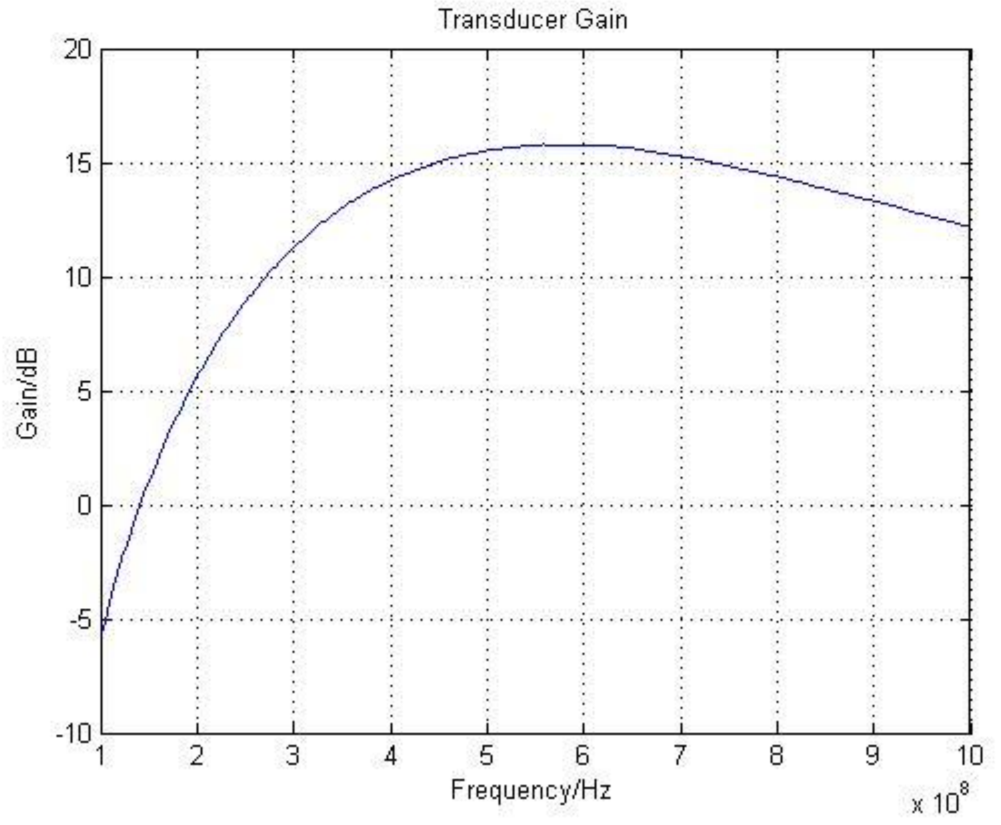
Matlab codes for the calculation of gammaIn, gammaOut and transducer gain are as follows:

```matlab
Rs=50;           % Source Resistance
Rl=50;           % Load Resistance
Z0=50;           % Characteristic Impedance
op_freq = 850e6; %frequency for which design the LNA
L1=0.114;        %short-circuit stub at output matching network
L2=0.1192;       %series transmission line at output matching network
L3=0.25;         %short-circuit stub at base
% Read S-parameters from given file
s=readspar('SPAR08.S2P');
f=s(:,5); % selection of frequency column
% short-circuit as the ground
gam_Short = [zeros(size(f,1),1)-1,f];
% reflection coefficient for the short-circuit stub at input side of transistor, which has a length of L3
gam_L3P=serline(gam_Short,L3,op_freq);
% reflection coefficient for the short-circuit stub at output side of transistor, which has a length of L1
gam_L1P=serline(gam_Short,L1,op_freq);
%%%%%%%%%%%%%%%%%%%%%%%%%%Calculate gammaIn%%%%%%%%%%%%%%%%%%%%%%%%%%%
% reflection coefficient at the load resistor
gam_Rl=serr(gam_Short,Rl,Z0);
% use parg function to calculate the reflection coefficient with parallel short-circuit stub L1
gam_L1=parg(gam_Rl,gam_L1P);
% reflection coefficient at the transmission line L2
gam_L2=serline(gam_L1,L2,op_freq);
gam_l=gam_L2(:,1); %gam_l should not contain frequency component
% gammaIn for the transistor
gammaIn_tran=sgamin(s,gam_l);
% renormal gammaIn of the transistor
gammaIn_tran_R=renorm(gammaIn_tran,50,100);
% use parg funtion to calculate the reflection coefficient with parallel short-circuit stub L3
gam_L3In_R=parg(gammaIn_tran,gam_L3P);
% renormal gammaL3In back to 50 oM
gam_L3In=renorm(gam_L3In_R,100,50);
% the system gammaIn now calculated
gammaIn=gam_L3In;
%%%%%%%%%%%%%%%%%%%%%%%%Calculate gammaOut%%%%%%%%%%%%%%%%%%%%%%%%%%%
%reflection coefficient at the source resistor
gam_Rs=serr(gam_Short,Rs,Z0);
% renormalize gamma of the source resistor
gam_Rs_R=renorm(gam_Rs,50,100);
% use parg funtion to calculate the reflection coefficient with parallel short-circuit stub L3
gam_L3_R=parg(gam_L3P,gam_Rs_R);
% renormalize gammaL3 back to 50 ohms
gam_L3=renorm(gam_L3_R,100,50);
gam_s=gam_L3(:,1); %gam_s should not contain any frequency component
% gammaOut for the transistor
gammaOut_tran=sgamout(s,gam_s);
% reflection coefficient at the transmission line L2
gam_L2Out=serline(gammaOut_tran,L2,op_freq);
```

```
% use parg function to calculate the reflection coefficient with parallel
short-circuit stub L1
gam_L1Out=parg(gam_L2Out,gam_L1P);
% the system gammaOut now calculated
gammaOut=gam_L1Out;
%GainT=((1-abs(gam_s).^2)./(abs(1-
gammaIn(:,1).*gam_s).^2)).*(abs(s(:,2)).^2).*((1-abs(gam_l).^2)./(abs(1-
s(:,4).*gam_l).^2));
GainT=sgt(s,gam_s,gam_l);
%Plot absolute value of gammaIn and gammaOut to check the stability
characteristic
figure
plot(gammaIn(:,2),abs(gammaIn(:,1)),'r--
',gammaOut(:,2),abs(gammaOut(:,1)),'b:');
title('Stability Test');
xlabel('Frequency/Hz')
ylabel('|Gamma|')
legend('|GammaIn|','|Gammaout|')
%plot the transducer gain in db
figure
plot(f,10.*log10(GainT));
title('Transducer Gain')
ylabel('Gain/dB')
xlabel('Frequency/Hz')
grid;
```

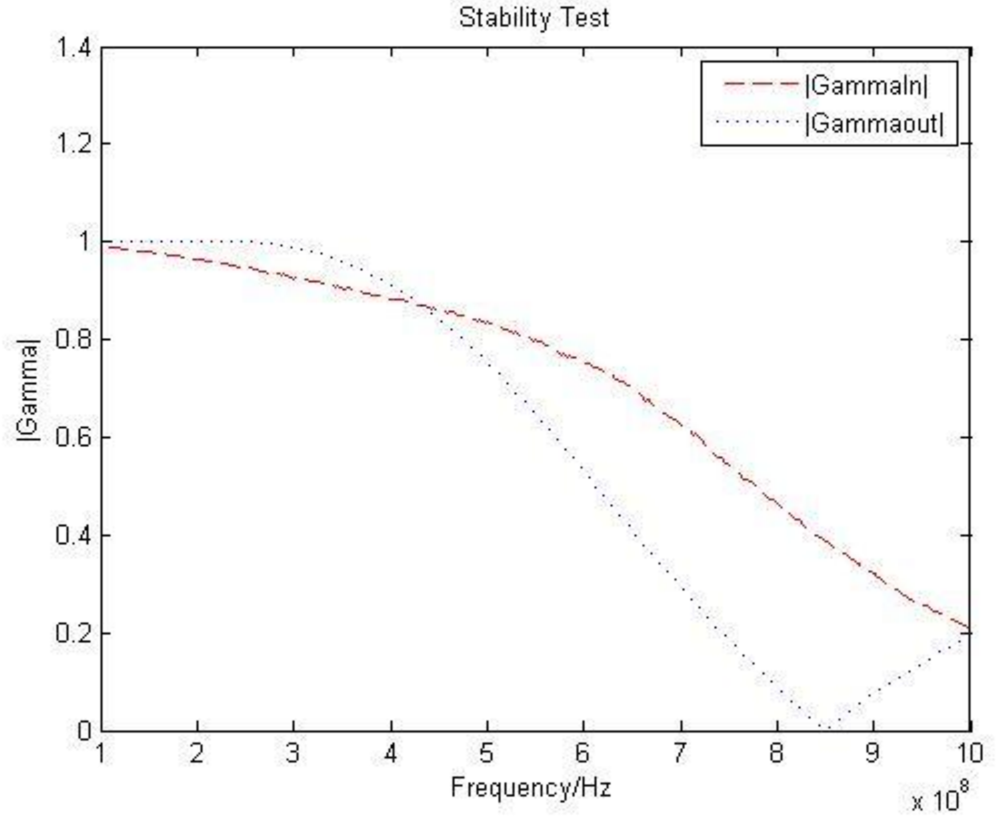
4) Verifying Results

4.1)Transducer Gain



From the above figure, we can see that at 850MHz the transducer gain is about 14dB, which fulfill the requirement.

4.2) Stability Check



We can see that during most of the frequency range, the system is stable. At 850 MHz, the gammaOut parameter is almost near to zero, which means good output matching at that frequency.