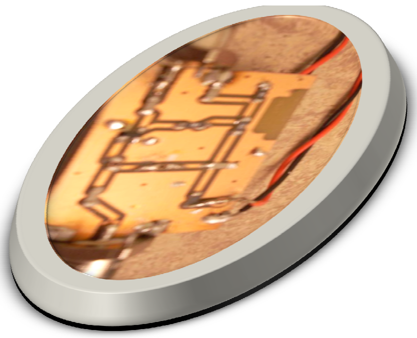
ACTIVE ANTENNA AMPLIFIER

KAJA NAJUMUDEEN & CHARLES

2009

RADIO PROJECT

ETI 041



Today's wireless communication world have many revolutionized organizations who are well advanced (& advancing) in design of full fledged compact high gain, low noise active antenna. This antenna revolution persuaded us to design an active antenna amplifier. This radio project course paved way for us. This project paper describes our design and verification of active antenna to the practical environment. We thank our supervisor, Professor Göran Jönsson and all others who guided us in this project.

Radio-Project

Supervisor: Göran Jönsson

LTH, Lund University, Sweden

CONTENTS

Prologue

In this project, we have developed an active antenna amplifier (LNA) which works in the range between 88-108 MHz. The transistor used here is BFG520/X. The whole system comprises of antenna section, biasing section and output matching network section. The input matching network is not considered in our project discussion as the impedance of the antenna is considered to be 50 ohms which is same as the chosen characteristic impedance of 50 ohms.

The main focus was given on the stability and the noise parameters of the amplifier in the chosen frequency range. The selected load reflection co-efficient and source reflection co-efficient were well under the stability region and hence provided a satisfactory performance as a low noise amplifier.

It's been a very good experience for both of us to learn more about the active antenna amplifier design through this project.

1. Introduction

In the modern RF world, low noise amplifier is one of the dominant players in any type of radio receiver circuits. It plays a very vital role as it determines the whole efficiency of the system by providing the required sensitivity for the respective circuit.

The RF amplifier which is at the input stage of the receiver is usually designed to give the best gain parameter and the least noise. It is done so for the reason that the noise and distortion parameters would get depressed in the later stages of the receiver system. The active antenna stage which is closely located to the amplifier would be responsible to capture the signals and the amplification of these weakest signals captured from the antenna is performed in the receiver.

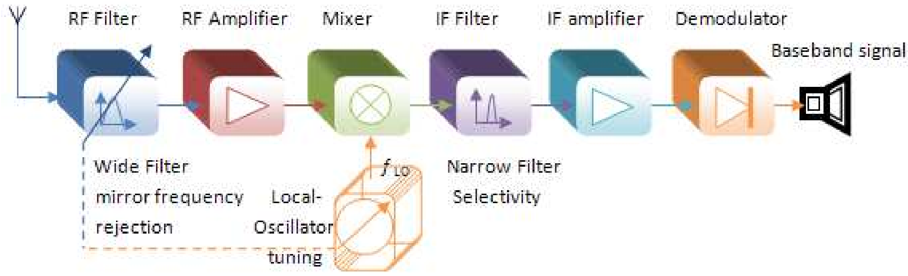


Fig 1: Basic block diagram of super heterodyne receiver

2. Antenna Section

The antenna section comprises the front end of the system. Antenna gain is essential for proper communication both at the transmitter as well as receiver. For simplicity we preferred wire antenna in our case. Moreover it is very easy to build a wire antenna. Range of frequency interest in our case is FM band frequency which is between 88-108 MHz and we designed antenna for a 100 MHz frequency. f_c= 100 MHz, $\lambda = \frac{c}{f}$, which is 3m and our interest, is quarter wave antenna and hence our quarter wave length is about 75 cm. But we can't have that much long wire antenna so we decided to take 1/5 th of the length and it is roughly around 20 cm. We measured and analyzed its impedance level with the help of Vector Network Analyzer.

The impedance of the antenna section is chosen to be 50 ohms because of the following reasons which are as follows:

- ✓ Since we use a wire antenna which has a very wavering nature of possessing random impedance, it is better to assume it to be of the common 50 ohms characteristic impedance.
- ✓ The wire antenna has a high sensitivity towards catching signals related to normal human movements around the ambience (in the laboratory in this case).
- ✓ There will not be any necessity to design the input matching network as the input side matching network is assumed to be 50 ohms.

3. Choice of Transistor

The transistor selected is BFG520/X. The general features of the transistor are high power gain, lower noise figure, high transition frequency and better reliability. The chosen operating point is V_{CE} = 6 volts and I_C = 20 mA.

BFG520/X Code: %ML	
1	collector
2	emitter
3	base
4	emitter

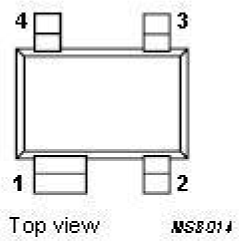


Fig 2: Transistor BFG520/X SOT143B

The reason for the selection of operating point is as follows:

- ✓ Our main focus is concentrating on high gain rather than considering obtaining less noise in the system.
- ✓ Though the noise has not been considered so strictly by taking higher current margins (20 mA in this case), we have got the acceptable noise margin level which is quite good.

These are well substantiated with the graph below from the datasheet from nxp.

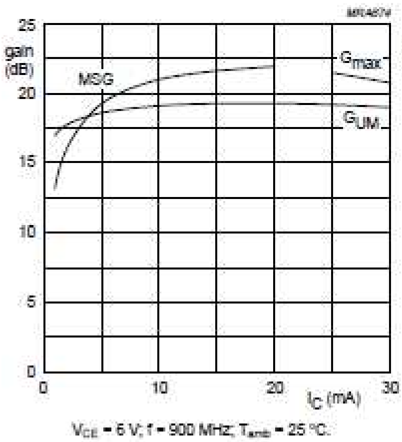


Fig 3: Gain as a function of Collector current

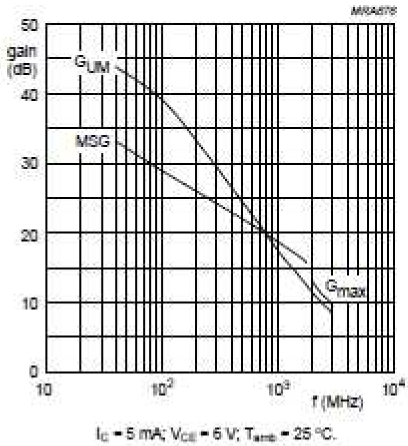


Fig 4: Gain as a function of frequency

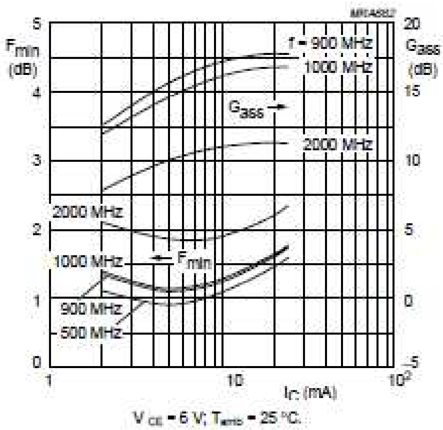


Fig 5: Minimum Noise Figure &Gain as a function of Collector Current

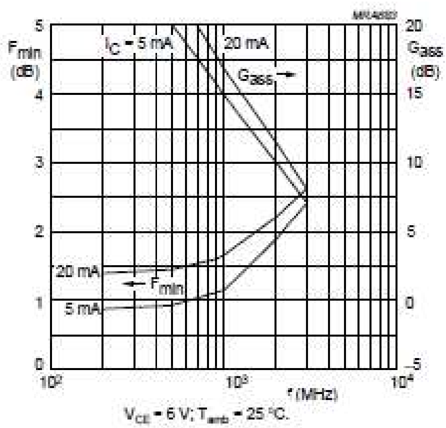


Fig 6: Minimum Noise Figure & Gain as a function of frequency

From these graphs we decided our operating point according to our desired gain and frequency of interest.

4. Transistor Biasing

The biasing configuration chosen for the LNA circuit is shown below. It shows a good stability property against temperature variations.

The circuit consists of bypassing capacitors, which creates the AC ground to maintain the drop to be fully reflected on the resistor. It also comprises decoupling capacitors which reduces the noise caused by the other circuit elements. The decoupling capacitors present at the input and the output side block the DC component from entering the signal stage.

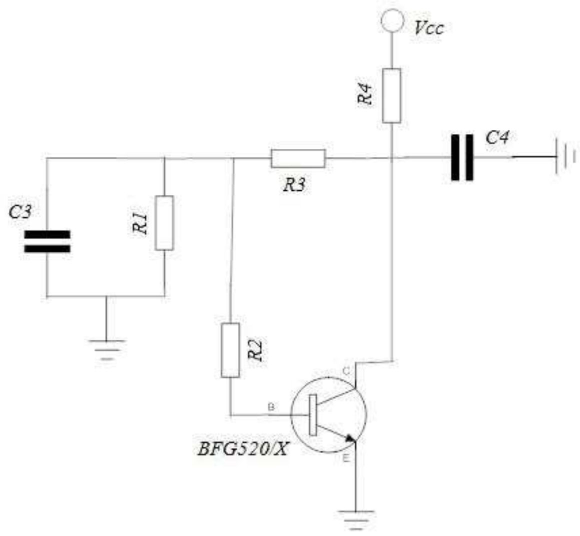


Fig 7: Biasing Circuit

CALCULATION:

V_{CC} = 12 volts; V_{CE} = 6 volts; I_C = 20 mA; β = 120

$I_B = I_C/\beta$ = 0.16 mA. $I_D = I_B/\beta^{\wedge 0.5}$ = 1.825 mA.

$V_D = 0.5 * V_{CE}$ = 3 volts.

$R_1 = V_D/I_D$ = 1.643 KΩ

$R_2 = V_D/I_B$ = 18.75 KΩ

$R_3 = (V_{CE} - V_D)/(I_D + I_B)$ = 1.511 KΩ

$R_4 = (V_{CC} - V_{CE})/(I_D + I_D + I_B)$ = 1.511 KΩ

$C_1 = C_2 = C_3$ = 31.84 pF

The reactive impedance is assumed to be of the characteristic impedance 50 ohms for the calculation.

5. S-Parameter Measurement

The S-Parameter was measured to check the stability of the transistor in operating conditions. The setup followed in the measurement of the S-Parameter was shown below in the figure as follows

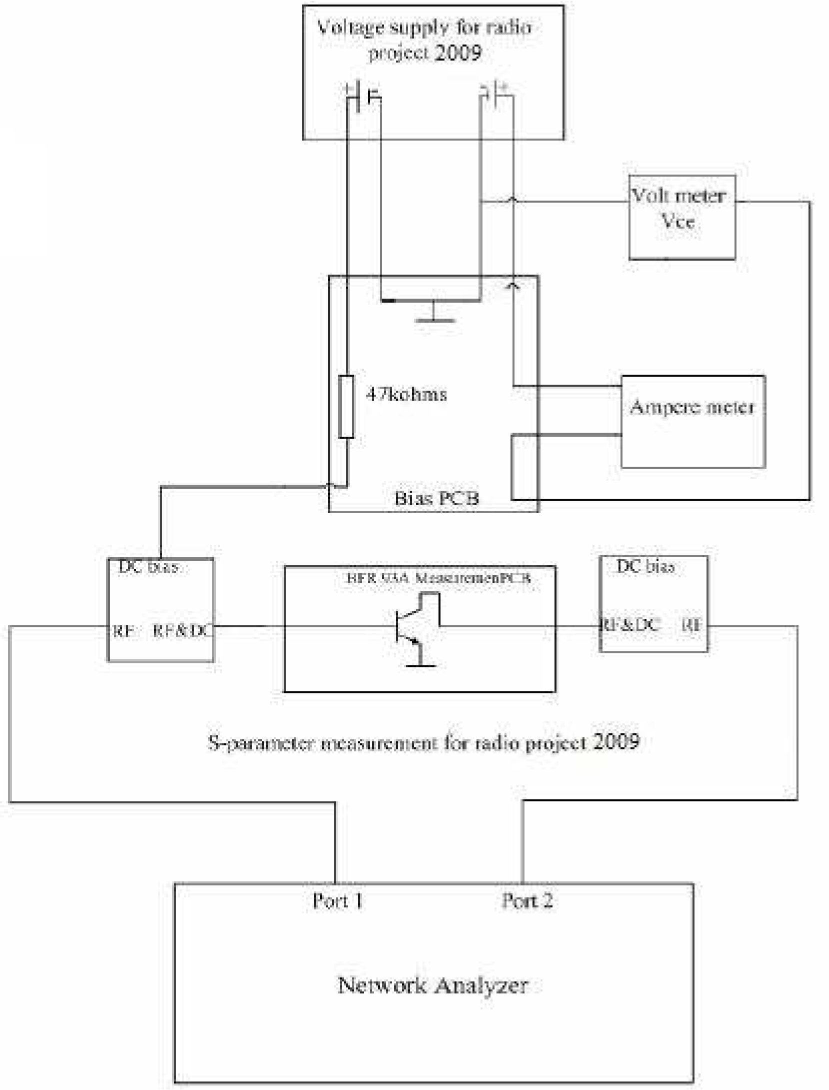


Fig 8: Setup for S-Parameter Measurement [4]

As per the setup we measured the S-Parameter for our frequency of interest (88-108 MHz). From the values we tested the transistors stability through Matlab simulation.

6. Matlab Simulation

From the S-Parameter values for frequency f_c= 100 MHz, we get values for delta and stability factor (K) to be as $\Delta = 0.5209$ and K=0.2647.

From these values it is clear that the transistor is conditionally stable. Then input and output Stability circles are drawn with the help deslib library. Then gain circles and noise circles are drawn to know our stability area.

Then we chose our Γ_s satisfying both gain and noise requirements and further proceeded in the designing of matching network. The Matlab code is attached at the end for reference. The figures for stability analysis of the transistor are shown here.

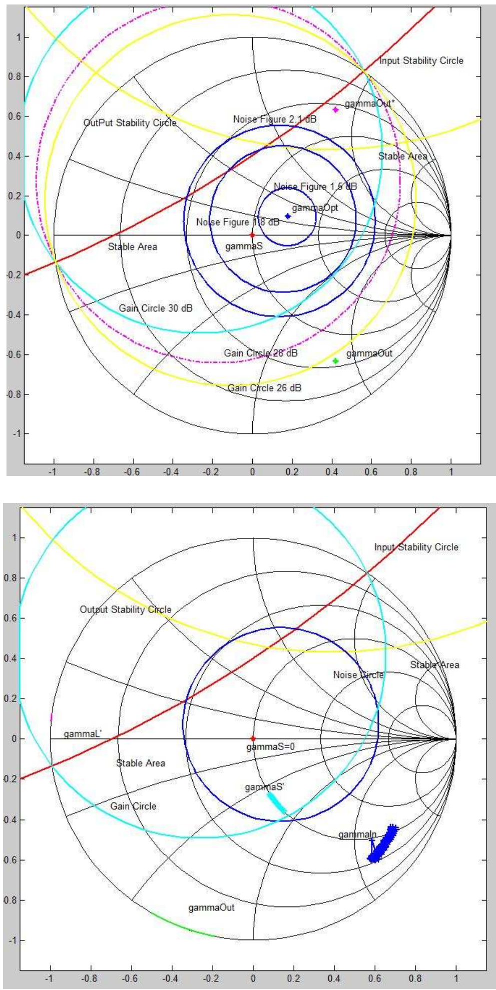


Fig 9: Stability analysis of the transistor

Input Matching Network

From the above figure we come to conclusion that noise figure of 2.1 dB is quite suitable for our requirements of gain ≥ $|S_{21}|^2$ dB and stable area from the input stability circle. Since Γ_s =0 (gammas=0) satisfies both the gain and noise circle and also the stability area it makes unnecessary of input matching network and also minimum noise figure for Γ_s =0 is well below.

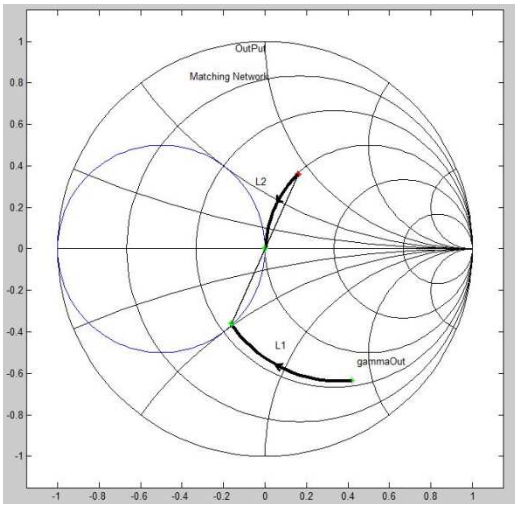
Output Matching Network

The output matching network is designed using simulation tool as well as smith chart manually. The output matching network consists of two inductors, one in parallel and the other in series. The theoretical calculated values of the inductors are

L_3 = 1.925 nH and L_4 = 1.872 nH

The values obtained for inductors are rounded to near values. The actual value of the inductors chosen for our case was 2.2 nH for both inductors due to the possible availability of components in the laboratory.

The output matching network designed using the simulation tool is shown here.



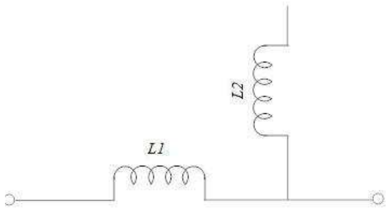


Fig 10: Output matching network

The transducer gain as per our requirement was $\geq |S_{21}|^2$ dB and the graph depicting the gain as a function of frequencies of FM band can be shown below as

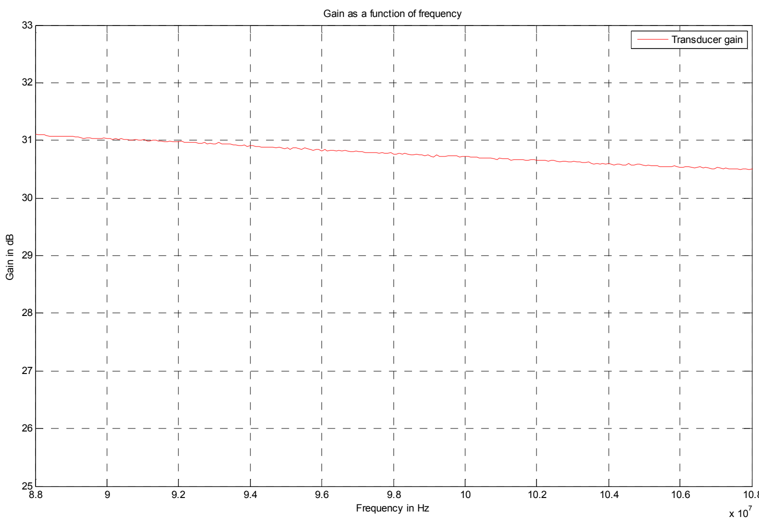


Fig 11: Gain as a function of frequency

7. PCB Process

After analysis in Simulation we designed our circuit for PCB fabrication using Eagle Software and the schematic diagram of our Circuit can be shown as follows

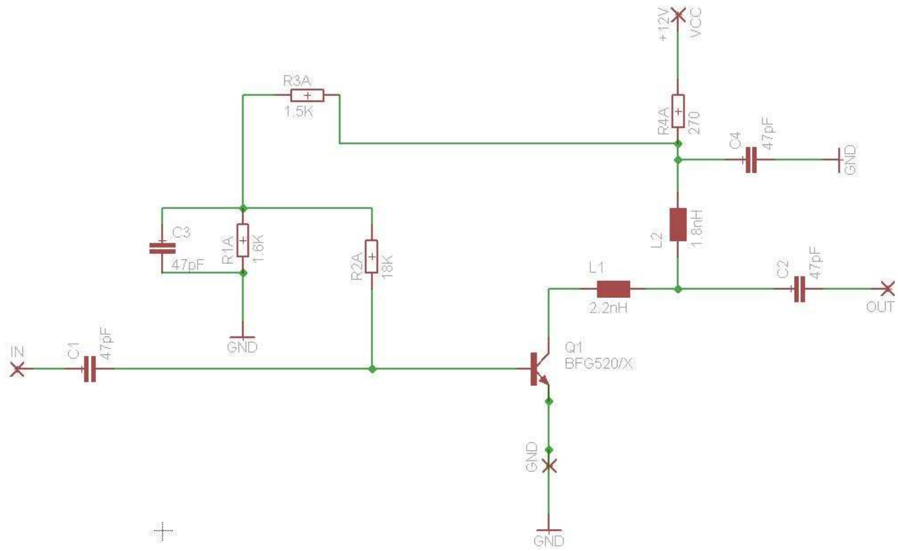
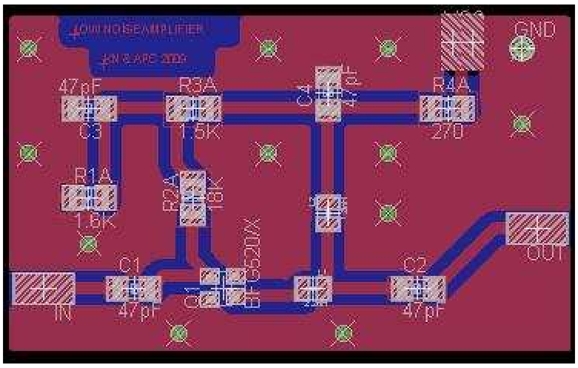
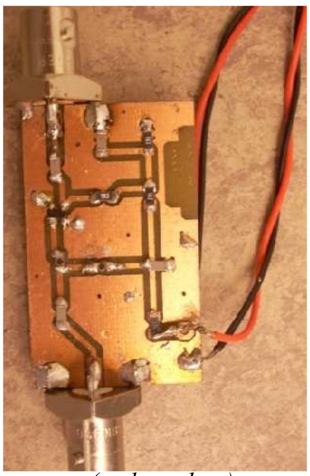


Fig 12: Schematic Diagram of the Active Antenna Amplifier circuit

Then the PCB layout was drawn using Eagle and layouts are shown here

After that PCB was fabricated from our laboratory and we analyzed our designed active antenna amplifier using vector network analyzer





(end product)

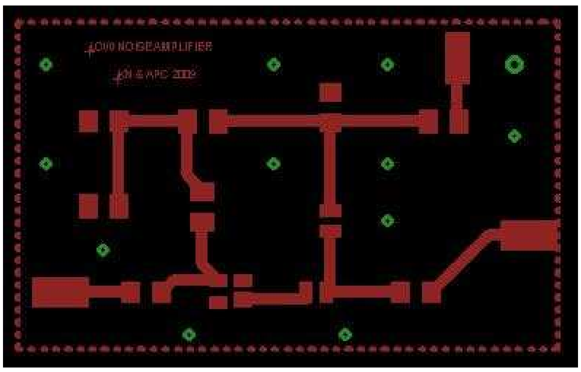


Fig 13: PCB layout of the Active Antenna Amplifier circuit

8. Experiment and Analysis

We performed the experiment with our designed active antenna amplifier by measuring its gain and its impedance level. The experiment was first performed without antenna to analyze whether the designed amplifier works well in the operating region and we found it was quite good in its operating point. The picture representing our analysis measurement from vector network analyzer can be shown below as

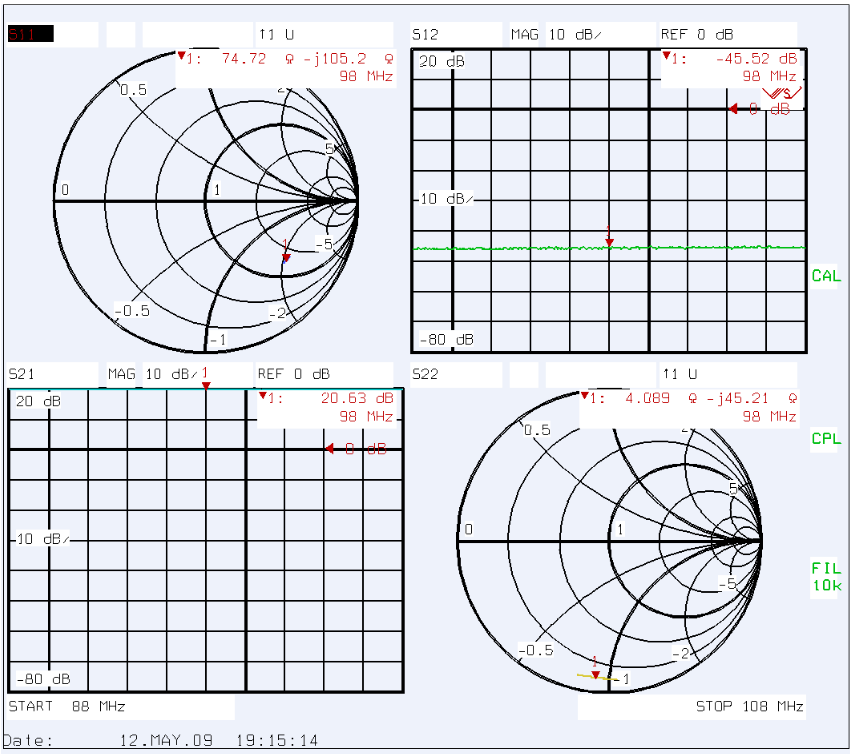


Fig 14: Measurement in Vector Network Analyzer

Then we measured 1dB compression point measurement with the help of spectrum analyzer for frequency of interest at 100 MHz and it is in acceptable range. 1dB compression point graph is plotted and it is shown below.

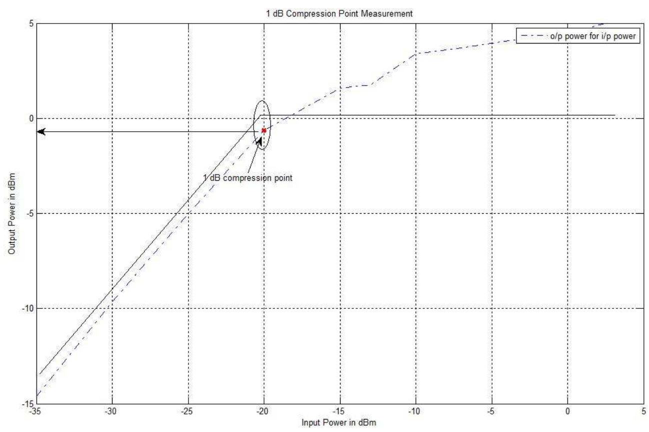


Fig 15: 1 dB compression point measurement

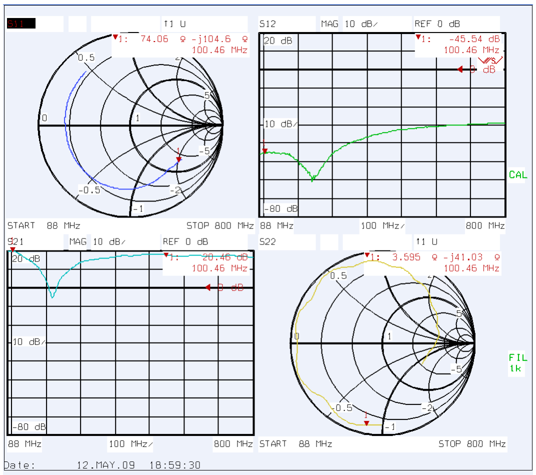


Fig 16: S-Parameter Measurement for large span

Then we tested our active antenna amplifier stability to noise with spectrum analyzer (with noise source) and we found that our amplifier worked satisfactorily well and the measurement graph can be shown as

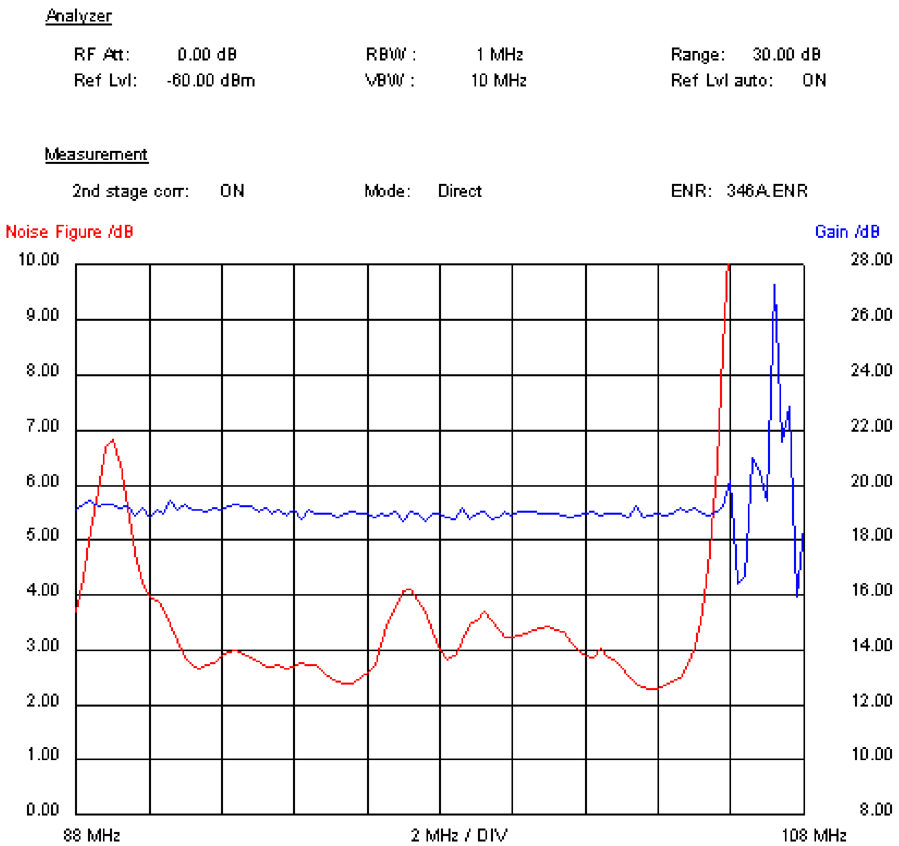


Fig 17: Noise Figure Measurement

The result of peaks in the noise figure graph was due to the disturbances from the base station at particular frequencies. This measurement was carried out in the open space meaning our amplifier was not shielded and hence we could experience the disturbances from the other base station and thus noise figure is large in those frequency base stations.

Another fact in this measurement was gain factor. The gain factor was not disturbed for major frequencies but it was quite pathetic at 107 MHz and it was quite large due to high reception signal from the near FM base station operating in that frequency.

9. Conclusion

- ✓ The proof of the obtained high gain is shown in a graph below, from the Spectrum analyzer measurements. In the figure, the blue plot below represents "antenna connected directly to the port of the Spectrum analyzer" and the other represents "antenna connected through the input port of the amplifier to the Spectrum analyzer". It clearly shows the gain of about 20 dB with the amplifier connected.

- ✓ One interesting but sad fact to be noted is that the gain noted in the data sheet of the transistor is about 30 dB. But we could manage to get only around 20.46 dB because of the practical issues incorporated with the retrieval of the maximum gain from the amplifier circuit.

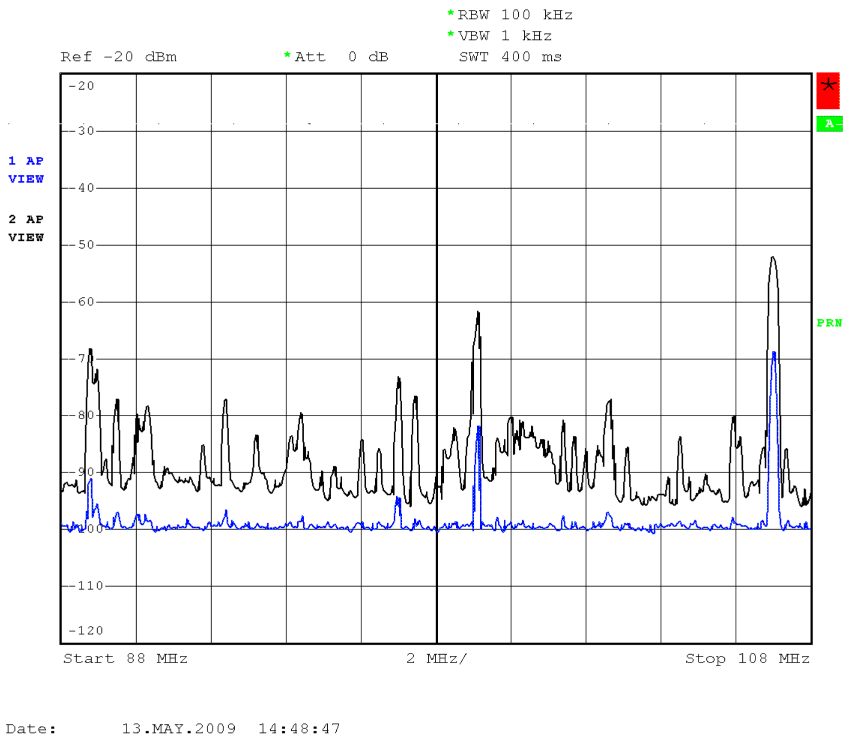


Fig 18: Reception of signal with and without Amplifier

10. Acknowledgment

We would like to thank our lecturer Göran Jönsson for his valuable support which he had given to us throughout the whole term of the project. His advices were very helpful in designing an optimized LNA by using some intelligent choices of biasing components. We would also like to extend our thanks to Lars Hedenstjerna, who provided us the PCB layout.

11. References

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11. http://www.dxzone.com/catalog/Antennas/Wire/

12. Appendix

```
% Define colours
red=[1,0,0];
green=[0,1,0];
yellow=[1,1,0];
blue=[0,0,1];
cyan=[0,1,1];
magenta=[1,0,1];
black=[0,0,0];

Rs=50; Rl=50; Z0=50; f0 = 100e6; %desired frequency for
which the LNA is designed
C1=47e-12;C2=47e-12;
L1=2.2e-9; %series inductor at output matching network
L2=2.2e-9; %short-circuit inductor at output matching
network

smtool;
% Read S-parameters
s=readspar('6V20MA.S2P');
type 6V20MA.S2P;
s1=s(251,:);
f=s(:,5);
% Check the stability at 100 MHz
delta =abs(sdelta(s1))
K = sk(s1)
% The transistor is conditionally stable at 100 MHz
% draw the input (red) and output (yellow) stability
circle
drawci(sinstci(s1),2,'-',red);
drawci(soutstci(s1),2,'-',yellow);

% Read the noise parameters at 100 MHz
nfmin=idbp(1.45);
gammaopt=p2c(0.204,28.0);
rn=0.250;
% plot gammaopt and noise circle
plotc(gammaopt,2,'*',blue);
drawci(noisecig(idbp(1.5),nfmin,rn,gammaopt),2,'-
',blue,1);
drawci(noisecig(idbp(1.8),nfmin,rn,gammaopt),2,'-
',blue,1);
drawci(noisecig(idbp(2.1),nfmin,rn,gammaopt),2,'-
',blue,1);

% Calculate the noise figure for gammaS=0
gammaS=0;
plotc(gammaS,2,'*',red);
F=nfg(nfmin,rn,gammaopt,gammaS)
FdB=dbp(F)
% Available gain circles for Ga >= S21.^2 dB (in gammaS
smithchart)
% The available gain circle is calculated using the
parameter ga derived
% from: Available gain = abs(s21)^2*ga
ga1=idbp(30-dbp(abs(s1(1,2))^2));
```

```
drawci(singcib(s1,ga1),2,'-',cyan,1);
ga2=idbp(28-dbp(abs(s1(1,2))^2));

drawci(singcib(s1,ga2),2,'-.',magenta,1);
ga3=idbp(26-dbp(abs(s1(1,2))^2));
drawci(singcib(s1,ga3),2,'-+',yellow,1);
s11=abs(s1(1));
s22=abs(s1(4));
% Calculation of the maximum gain in dB at 100 MHz
maxstablegain=dbp(sgmsg(s1))
% Calculation of the maximum stable transducer gain in
dB at 100 MHz
gtmax=dbp(sgtmax(s1))
% Available gain in dB, for Zs = 50 (gammaS = 0)
gammaS=0;%p2c(0.871,-167.609);
Ga = dbp(sga(s1,gammaS));
plotc(gammaS,2,'*',red);
%Output Matching Network
%Calculation of gammaOut from gammaS
gammaOut=sgamout(s1,gammaS)
plotc(gammaOut,2,'*',green);
%Calculation of gammaL=conj(gammaOut)
gammaL=gammaOut'
plotc(gammaL,2,'*',magenta);

smtool;
plotc(gammaOut,1,'*',green);
drawgci(1,1,'-',blue);
drawrarc(real(g2nz(gammaOut(1))),imag(0.573-
0.488i),imag(g2nz(gammaOut(1))),3,'-',black,3);
y=-nz2g(0.573-0.488i);
plotc(-y,2,'*',green);
plotc(y,2,'*',red);
gammaLdash=0;
drawrarc(real(g2nz(y(1))),imag(g2nz(y(1))),gammaLdash,3,
'-',black,3);
plotc(gammaLdash,2,'*',green);
drawrad(0,-y,y,2,'-',black);
```