



# **ANTENNA AMPLIFIER 88-108MHz**

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**Radio Project 2011**

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**Submitted**

**By**

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# **ANTENNA AMPLIFIER 88-108MHz**

## **Acknowledgements**

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### **Abstract**

The project describes the design work of a low noise amplifier with image rejection filter. The amplifier is designed to be used as an input stage of a superhetrodyne receiver for the FM radio (88-108 MHz).The report describes the approach and result from MATLAB and the practical measurements are presented and analyzed. The practical measurement such as Gain, Noise Figure and Image rejections from the analyzer are compared with the design specification of low noise amplifier and it was almost fulfilled with the design specifications.

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## 1. Introduction

The Low Noise Amplifier is the first building block in a FM receiver. The characteristics of amplifier are its low noise figure and high gain. A high gain and low noise minimizes the impact of noise in subsequent stages and therefore determines the total noise factor according to the Friss formula. It was designed to be an input stage for a superhetrodyne FM receiver and should be able to work within the specified frequency band 88-108 MHz. Except for the LNA itself it contains several filters to fulfill the specifications of pre-selection and image rejection. For the construction procedure the MATLAB deslib toolbox was used, the layout was created in a PCB tool Eagle and measurements was performed with the Network and Spectrum Analyzer.

## 2. Design Specification

- Operating frequency: 88-108MHz.
- Noise figure:  $F \leq F_{min} + 2\text{dB}$ .
- Gain:  $G \geq |S_{21}|^2$ .
- Source impedance:  $50\Omega$ .
- Load impedance:  $50\Omega$ .
- Image rejection  $\geq 20\text{ dB}$ .
- $VCC = 12\text{V}$ .

## 3.Theory

### 3.1 Image Rejection:

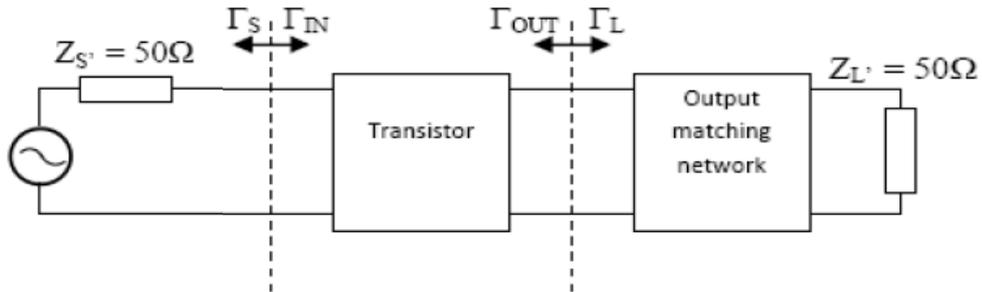
When the modulated signal shall be converted from the carrier frequency to the intermediate frequency the signal can be mixed with a signal from the Local Oscillator. The output frequency from the mixer consists of  $f_{mixer} = (f_{signal} + f_{LO})$  and  $(f_{signal} - f_{LO})$ . The last term is the down converted signal. The problem is that there is another frequency that also will be down transformed and will overlap with the wanted signal. This frequency is called image frequency and must be filtered out before the mixing stage. If high-side injection is used the image frequency is located at  $f_{signal} + 2(f_{LO} - f_{signal})$ . In the FM receiver this frequency is  $f_{signal} + 2 * 10.7\text{ MHz}$ .

### 3.2 Design Procedure:

The design of amplifiers with respect to gain using lossless matching networks to obtain the desired result. Typically, the source and the load that we want to connect to the two-port are fixed and if we are connecting directly to the two-port we will not get the desired gain and noise figure. So a matching network

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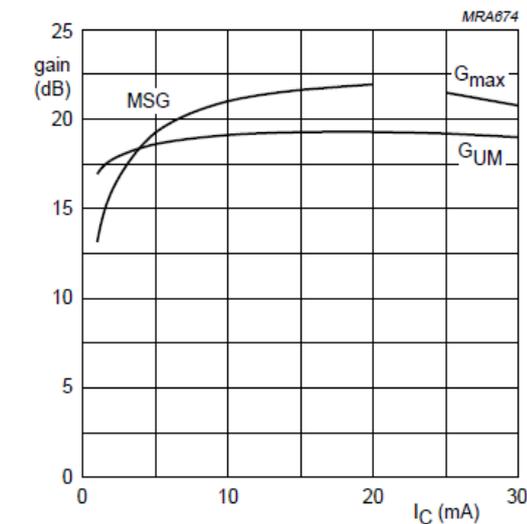
is connected between the source and the two-port and between the load and the two-port respectively. In our design there is no need for the input matching network. So the Low Noise Amplifier contain a transistor, output matching network between the transistor and the output for the next stage and a filter circuit for selecting the frequency band and removing the image frequency. **Figure 1** shows the block diagram of low noise amplifier.



**Figure 1: Block diagram of LNA**

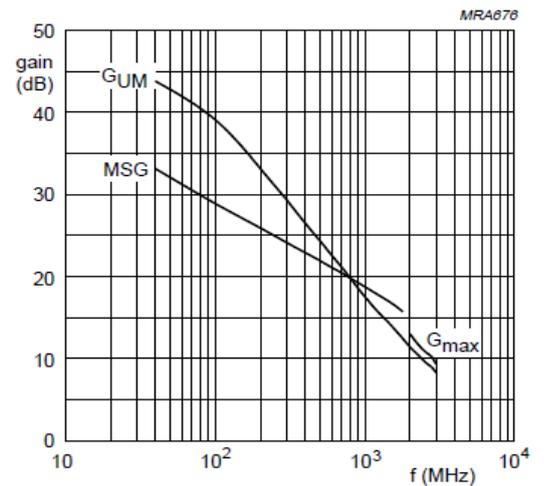
### 3.3 Choice of transistor:

The first step in the design is to choose a proper transistor. We selected BFG520X because of its high power gain, low noise figure, and high transition frequency and all the design specification of LNA are fulfilled with this transistor.



$V_{CE} = 6 \text{ V}; f = 900 \text{ MHz}; T_{amb} = 25 \text{ }^\circ\text{C}.$

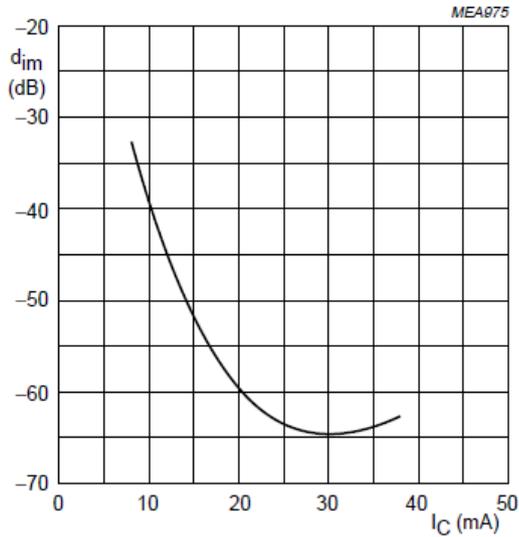
**Figure 2-Gain Vs Collector Current**



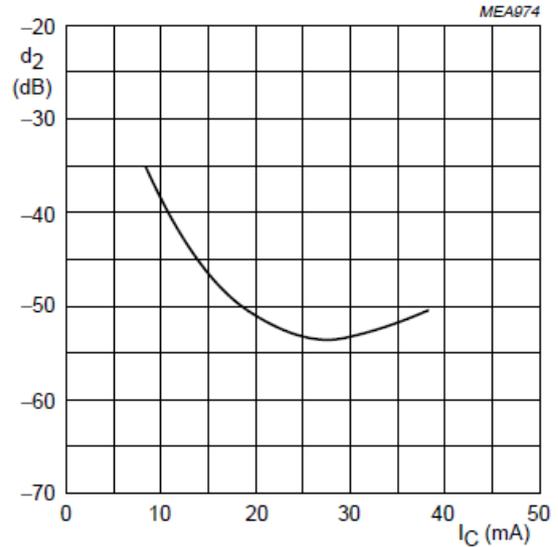
$I_C = 5 \text{ mA}; V_{CE} = 6 \text{ V}; T_{amb} = 25 \text{ }^\circ\text{C}.$

**Figure 3- Gain Vs Frequency**

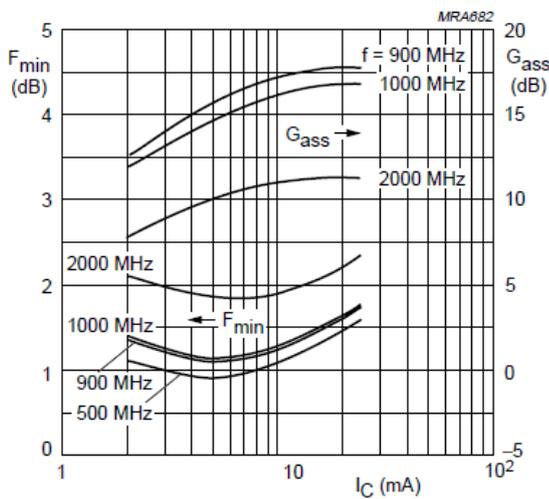
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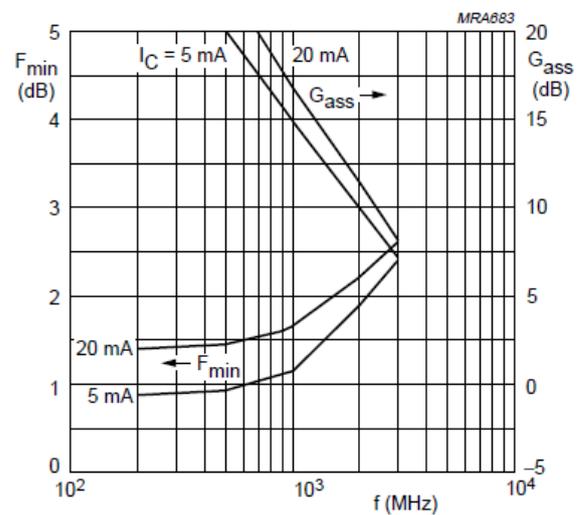
**Figure 4-Intermodulation distortion Vs collector current**



**Figure 5 - 2<sup>nd</sup> order Intermodulation distortion Vs collector current**



**Figure 6-Minimum Noise figure and gain as a function of collector current**



**Figure 7-Minimum Noise figure and gain as a function of Frequency**

The choice of bias point was made with help of the transistor data sheet. The bias point  $V_{CE} = 6V$  and  $I_C = 10mA$  was chosen. This was a good compromise between the added noise and the transistor gain. We selected to choose the

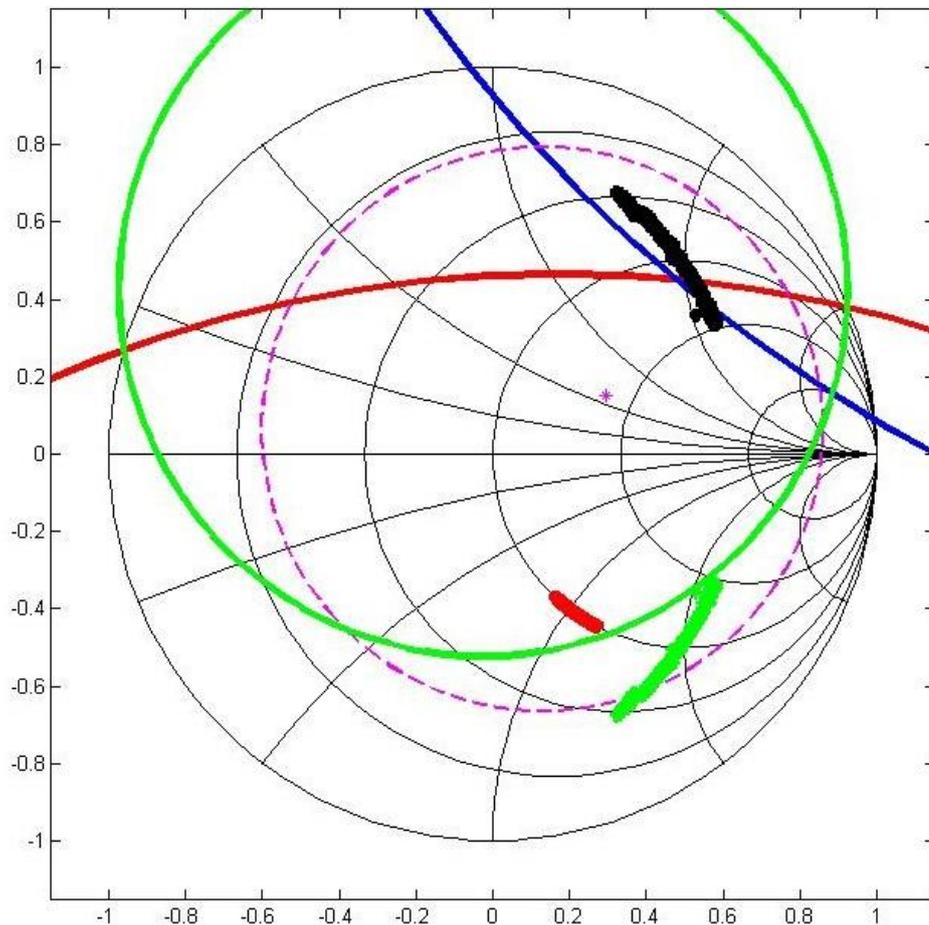
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transistor in Common Emitter (CE) configuration which gives gain in both current and voltage.

### 3.4 Stability, Gain and Noise Behavior:

To see if the specifications of the LNA are fulfilled, we have plotted the output stability circle, input stability circle, gain circle and noise circle for a chosen bias point with measured S-parameters and the transistor was conditionally stable and could be stable if  $\Gamma_S$  and  $\Gamma_{OUT}$  are chosen in the stable regions. Different input reflection coefficients was tested and  $\Gamma_S$  ( $Z_S=50-j50\Omega$ ) which give  $\Gamma_L=\Gamma_{OUT}^*$  ( $Z_L=\dots$ ) was finally chosen.  $\Gamma_{OUT}^*$  was located close to the output stability circle. **Figure 8** shows the plot.

Red-Input Stability Circle, Blue-Output Stability Circle, Magenta-Noise Circle, Green-Gain Circle



### 3.5 Image Rejection Filter

The image rejection filter was used at the output of the amplifier to filter out the image signals. The constructed filter consists of three components. One capacitor and two inductors. During the signal frequency the parallel circuits has maximum impedance and consist of  $L_2$  and  $C_2$ . At the image frequency the series circuit consisting of  $L_1$  and  $C_2$  has minimum impedance and forces the

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frequency directly to ground. The designing of inductors and capacitors as follows.

$$F_{01} = \frac{1}{2\pi\sqrt{L_2 C_2}} = 98\text{MHz} \quad C_2 = 10\text{pF}, L_2 = \mathbf{263\text{nF}}$$

$$F_{02} = \frac{1}{2\pi\sqrt{L_1 C_2}} = f_{\text{signal}} + 2 * f_{\text{IF}} = 119.4\text{MHz} \quad C_2 = 10\text{pF} \text{ and } L_1 = \mathbf{177.5\text{nF}}.$$

The capacitor C2 used will be a variable capacitor and the value of the capacitor is adjusted in such a way that the output will have maximum gain.

### 3.6 Transistor Biasing:

The biasing circuitry forces a device into a desired operating point in terms of DC terminal voltages and currents. Once the parameter set has been chosen matching networks can be designed to obtain the desired gain and noise figure etc and after that the biasing circuitry is designed to obtain the desired voltages and currents associated with the parameter set chosen. The biasing circuitry must be designed in such a way that it does not change gain, noise figure and stability of the design.

Let  $V_{CC} = 12\text{V}$  and  $V_{CE} = 6\text{V}$  and  $I_C = 10\text{mA}$  from the data sheet.

$\beta_0 = 120$  for BFG520X

$V_{BE} = 0.7\text{V}$ ;

$I_D = I_C / \sqrt{\beta_0}$ ; where  $I_D$  is the current through  $R_{B2}$  and  $V_D$  is the voltage across  $R_{B2}$ .

$I_B = I_D / \sqrt{\beta_0}$ ;

$R_C = (V_{CC} - V_{CE}) / (I_C + I_D + I_B)$ ;

**$R_C = 560\Omega$**

$V_D = 2 * V_{BE}$ ; Two times voltage drop across the pn junction

$R_{B1} = (V_{CE} - V_D) / (I_D + I_B)$ ;

**$R_{B1} = 4.7\text{K}$**

$R_{B3} = (V_D - V_{BE}) / I_B$ ;

**$R_{B3} = 8.2\text{K}$**

$R_{B2} = V_D / I_D$ ;

**$R_{B2} = 1.5\text{K}$**

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## 4. Circuit Diagram:

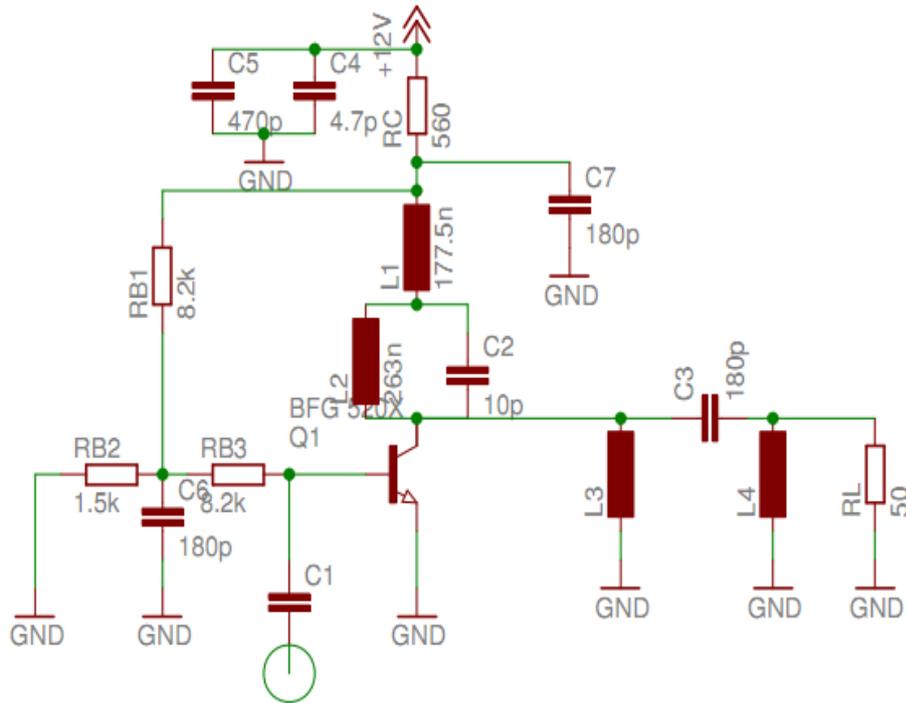


Figure 9-Antenna Amplifier

## 5. PCB Layout:

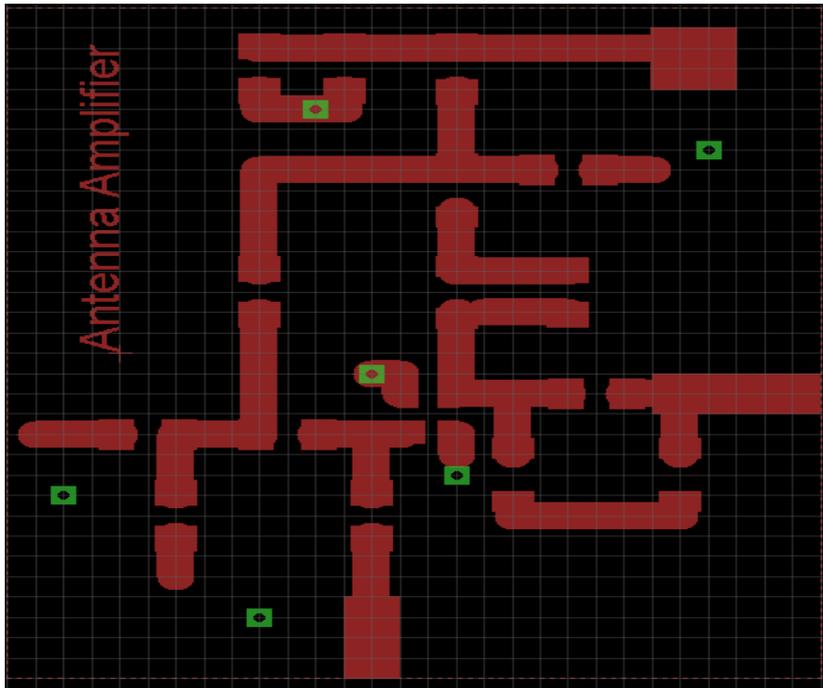


Figure 10-Layout of Antenna Amplifier

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### 6. Measurement and Results:

The S-parameters are used for the calculations of stability of the transistor in the operating condition, using these S-parameters measured for the frequency 100MHz with the help of MATLAB on the Smith chart stability, gain and noise circles are calculated. The setup for the measurement of S-parameters is shown in figure 11[4].

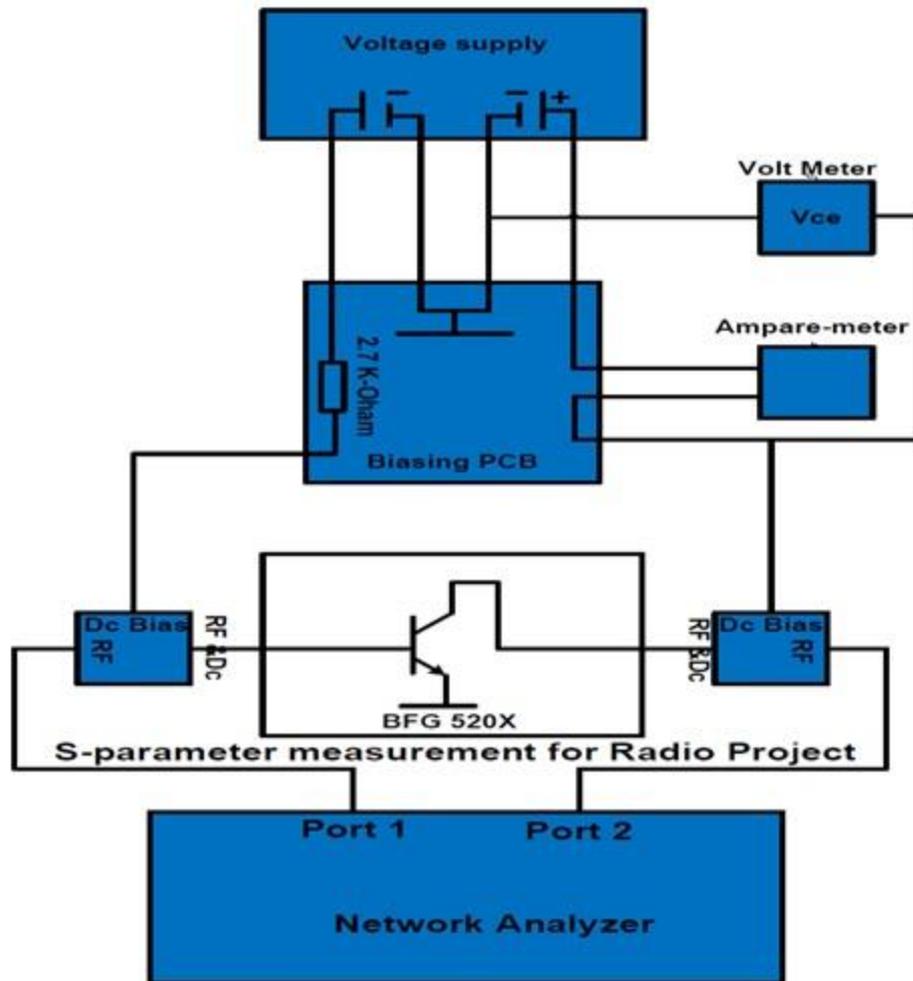


Figure 11-Setup for measuring S-Parameter

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## 6.1. S-parameter measurement:

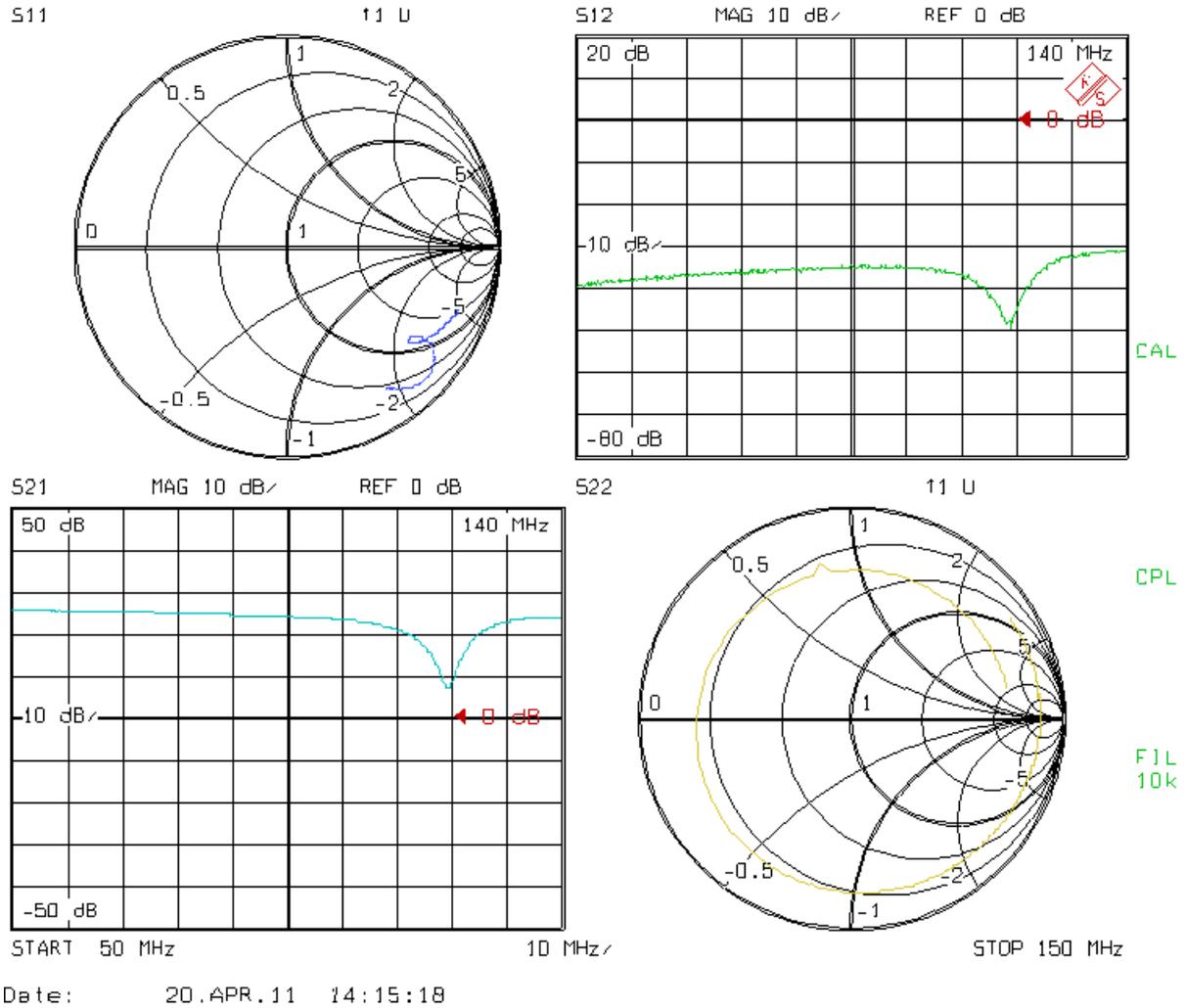


Figure 12

From the S21 measurement the gain of the amplifier is found as 23.8dB.

## 6.2 Compression point measurement:

The compression point shows the amplifier to have high performance and a wide dynamic range. 1 dB compression point of the amplifier is measured by applying the signal at 103MHz and by varying the RF input power,CP1 was measured as -23dBm.OIP3 of the amplifier is measured by applying a two tone at 102MHz and 103MHz.The third order intermodulation tones were observed at 101MHz and 104MHz.OIP3 was found as -9dBm.

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### 6.3 Noise figure measurement:

The noise figure was measured to be 1.6dB. It is almost constant for the entire frequency range. Figure 13 shows a Peak in Noise figure at 107.5MHz due to the interference from the broadcasting station. So the noise measurements was performed in the shielded room and the results obtained is shown in figure 14

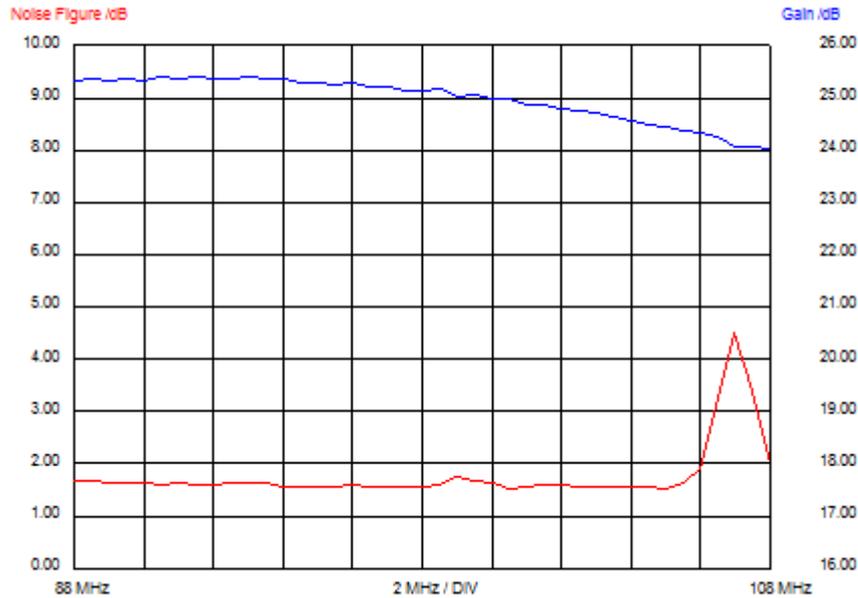


Figure 13

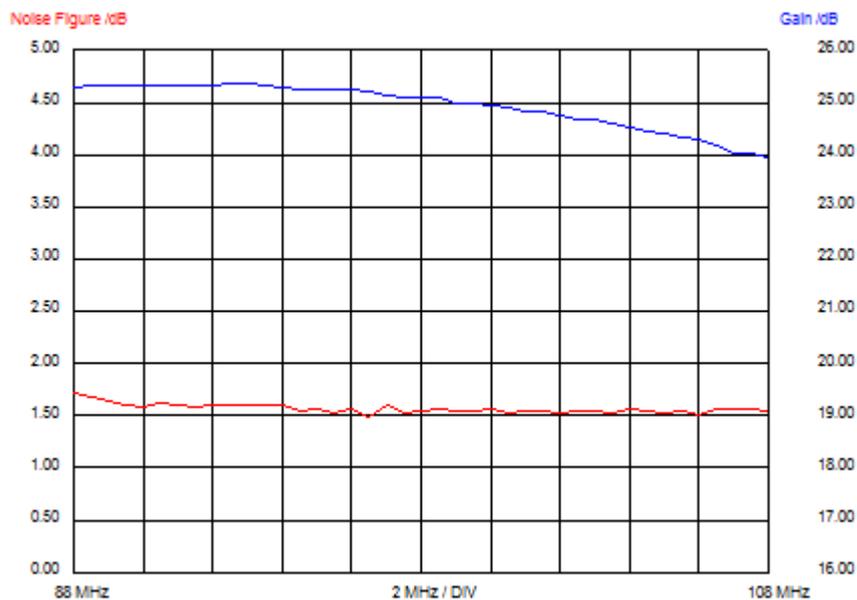
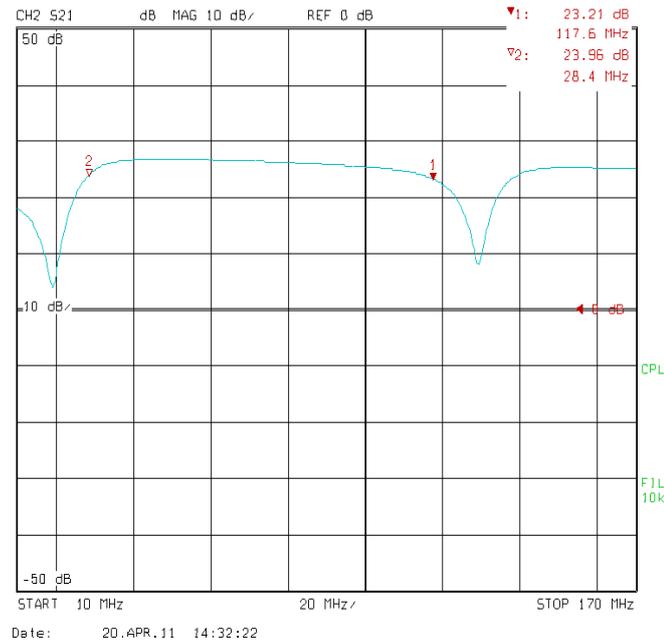


Figure 14-Noise figure measured in shielded room

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## 6.4 Bandwidth:

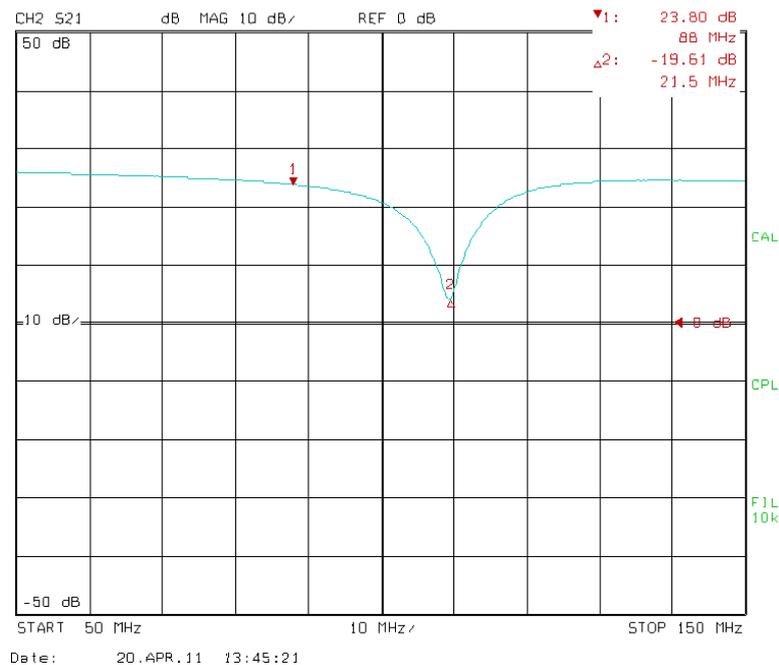


**Figure 16-Bandwidth of the Amplifier**

We observed that amplifier provides wide bandwidth; it may cause problems for the out of band signals. But we have a good image rejection filter; it will filter out the image signals.

## 6.5 Image Rejection:

Image rejection capability of the amplifier is measured as 19.61dB. For the input RF signal at 88MHz, Image signal is observed at 109.5MHz. Measured result is shown in figure 17.



**Figure 17-Image Rejection**

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### 7. Conclusion:

The designed circuit fulfilled the design specification but there are some improvements for the output matching circuit should be performed. The choice of bias point should be selected more carefully to avoid problems with stability. The image rejection filter is designed for rejecting the image frequency, which fulfilled the design requirement of 20dB.

### 8. References:

1. L. Sundström, G. Jönsson and H. Börjeson, "Radio Electronics".
2. <http://www.nxp.com>
3. Youtube lectures about Eagle Software
4. <http://www.eit.lth.se/fileadmin/eit/courses/eti041/VT2010/01a.pdf>