Design a Broadband Low Noise Amplifier for Software Radio Receiver Application

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***Abstract*- This report describes the design of a broadband low noise amplifier (LNA) for the frequency range from 800MHz to 2GHz, using a microwave transistor. The passive components were implemented using microstrips. The complete circuit design through the use of a simulation software package of LNA has been achieved. Within the operational frequency band, the minimum achieved power gain is 10dB and the noise figure (NF) is within 0.5dB from the minimum NF of the transistor.**

I. INTRODUCTION

Software radio is the latest technology in radio communication. The word software comes from re-programmable function at the baseband processing such as digital signal processor (DSP). The software radio can support multiple modulation waveforms and multiple air interface standards. For example, it can serve a range of applications including analog cellular, digital cellular, personal communication services (PCS), advanced wideband, spread-spectrum military waveforms, and others [1].

Generally, in software radio receiver circuit can be divided into 2 main parts. First is the analog part and second is the digital part. In analog part, it has two stages which called radio frequency (RF) and intermediate frequency (IF) stages. RF stage includes analog components such as LNA, mixer, local oscillator and SAW filter. This paper focuses on the LNA design which can operates in frequency band between 800MHz and 2GHz.

II. LNA APPLICATIONS

Broadband LNAs find application in communication system and instrumentation equipment. A low noise amplifier is the first component in any RF part. There are 3 purposes of the LNA. First, is to provide the isolation between the local oscillator or mixer stages and the antenna. The isolation is needed because the mixer is not totally unilateral, therefore some oscillator signal can be allowed go through to the antenna from the mixer. Second, is to improve the image frequency rejection and lastly to provide some selectivity [2].

By using the LNA, we can increase the gain and thus better sensitivity. The LNA also can improve noise characteristics. Placing an LNA in the line between the mixer and the antenna limits the signal that is radiated to the atmosphere via the antenna.

LNA's in the 800MHz to 2GHz frequencies region are a design hybrid. Microstrip and lump elements work together. Because of circuit radiation, the microstrip techniques are used to transfer signals from one point to the other.

When designing a broadband LNA one can minimize the noise figure at every frequency point, or require that the noise figure is lower than some upper bound. The second approach allows the noise figure to be higher than the minimum at low frequencies and gives a wider band of [illegible]eration. Both types of wide-band LNAs find appli[illegible]on, but the first option was chosen for this design.

III. CHARACTERISTICS OF MICROWAVE TRANSISTOR

Most microwave bipolar junction transistor (BJT) are planar in form and made from silicon in the NPN type. Below 4GHz, silicon BJTs provide a reliable and low-cost solution to many electronic designs. The transistor dimensions are very small in order to permit operation at microwave frequencies.

The most frequently encountered transistor configuration is called *common-emitter* since the emitter is common or reference to both the input and output terminals. In this design, the MRF949T1 transistor, which is produced by Motorola Semiconductors has been used. It is designed for use in high gain, low noise small-signal amplifiers [3].

Figure 1 below shows the biasing circuit for MRF949T1 transistor. The transistor is operating with supply voltage of 10V and collector current of 5.07mA. This biasing circuit has been designed to achieve the collector-emitter voltage (Vce) equal to 6V and can operate within active region.

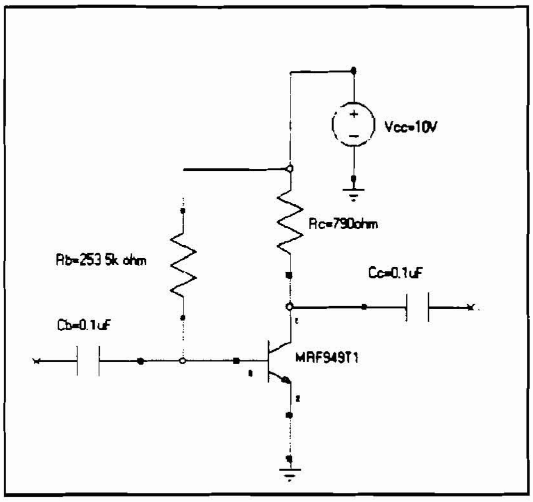


Figure 1 : Biasing circuit for MRF949T1 transistor

IV. STABILITY

The stability of an amplifier is a very important consideration in a design and can be determined from the S parameter, the matching networks, and the terminations. There are two possibilities either *Rollets Stability Factor, k* is smaller or greater than 1. If k is greater than 1, the device is unconditionally stable. There is no combination of passive source or load impedance that will cause the device to oscillate. If k is smaller than 1, the device is conditionally stable and potentially unstable. It can be induced into oscillation by certain passive source and load impedances [4].

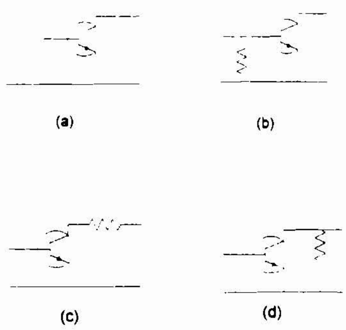
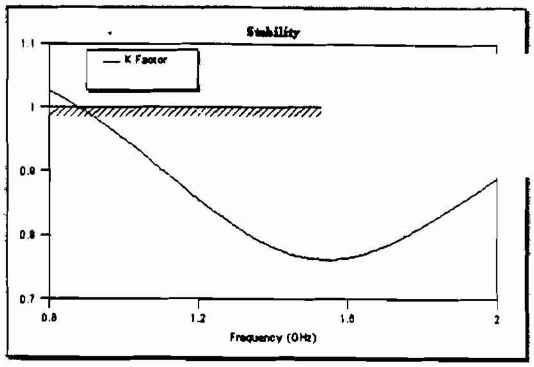


Figure 2: 4 types of resistive loading

There are 4 types of resistive loading to improve stability are shown in Figure 2. In this design, the second type has been chosen by loading a shunt resistor at the input. We can see in Figure 3 that the stability factor changed when a shunt resistor of 30 ohm loaded at the transistor input. The transistor was unstable at the frequencies between 0.87GHz and 2GHz before the resistive loading. After the resistive load added at the input terminal, it was found that a minimum value of 30Ω will satisfy $k > 1$ for a frequency range of 800MHz to 2GHz.



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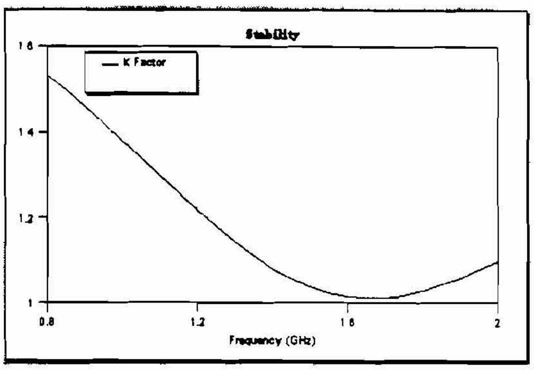


(b)

Figure 3 . Stability condition (a) before resistive loading (b) after resistive loading

Within such a stable condition, we design the minimum noise with optimum gain using S-Parameter concept. The target available gain is 10dB and the noise figure within 0.5dB from minimum noise.

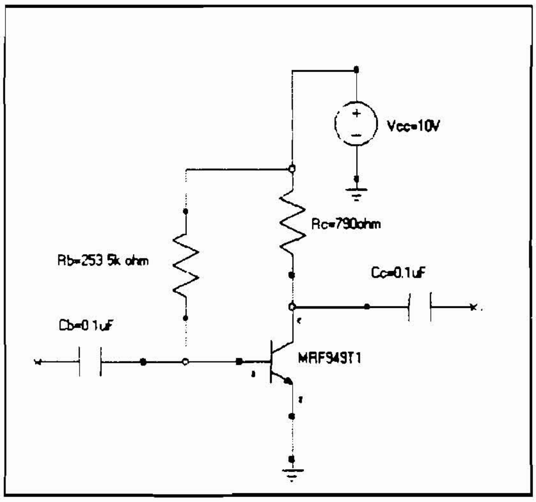
V. GAIN AND NOISE PERFORMANCE

There are several power gain equations are used in design of an amplifier. The transducer power gain G_T, the operating power gain G_P, and the available power gain G_A are defined as follows [5]:

G_T = (power delivered to the load)/(power available from the source)

G_P = (power delivered to the load)/(power input to the network)

G_A = (power available from the network) /(power available from the source)



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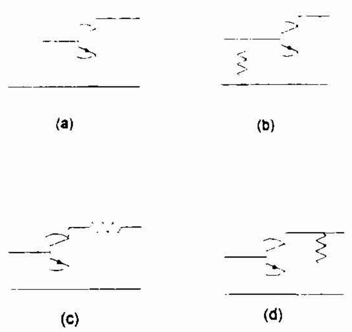

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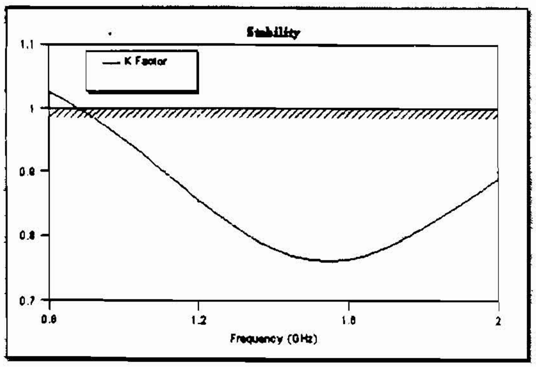

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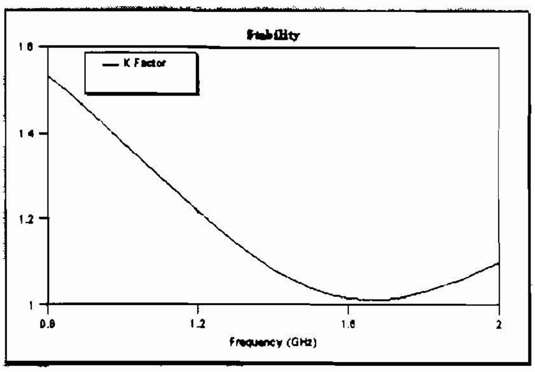

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The maximum gain available (MAG) and maximum stable gain (MSG) can be calculated by using S-Parameter and k as expressed in equation 5.1 below [3]:

$$MAG = \left| \frac{S_{21}}{S_{12}} \left(k \pm \sqrt{k^2 - 1} \right) \right| \quad \text{.................}(5.1)$$

Therefore, with k equal to 1.10, the value of MAG at frequency of 2GHz is 12.4dB. The detail graphs, which include G_T, G_P, and G_A, are shown in Figure 4.

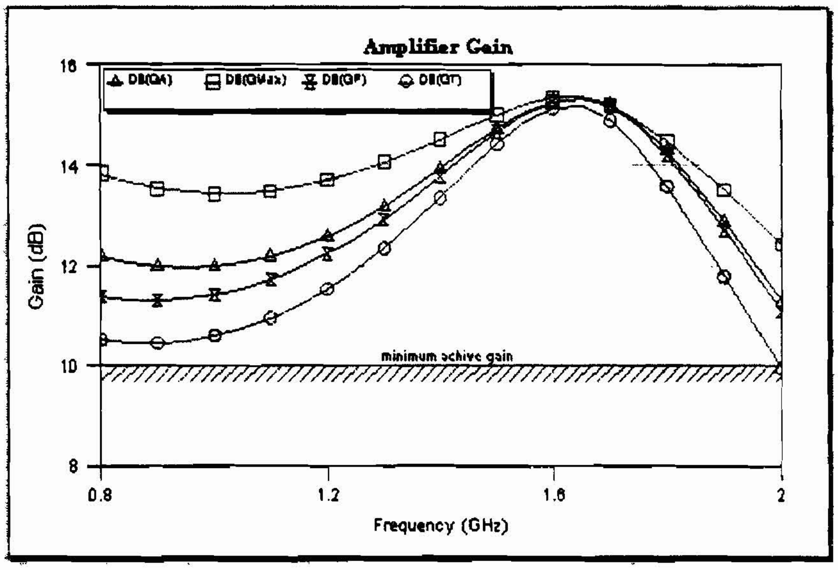


Figure 4: Gains of the amplifier

Within frequency range of 800MHz to 2GHz, all of the gains are above the minimum achieve of 10dB. The maximum gain can reach until 15.3dB at 1.6GHz and the minimum gain of 12.4dB at 2GHz. The graph shows the gains are stable due to the value of k factor is greater than one at each operating frequency.

In a design requiring low noise figure, the source (Γ_S) and load (Γ_L) reflection coefficient are selected as follows:

$$\Gamma_S = \Gamma_{opt} \quad \text{and} \quad \Gamma_L = \Gamma^*_{out}$$

where Γ_{opt} is the optimum noise source reflection coefficient and Γ^*_{out} is the conjugate of output reflection coefficient. The noise figure (F) of two-port amplifier is given by [5] :

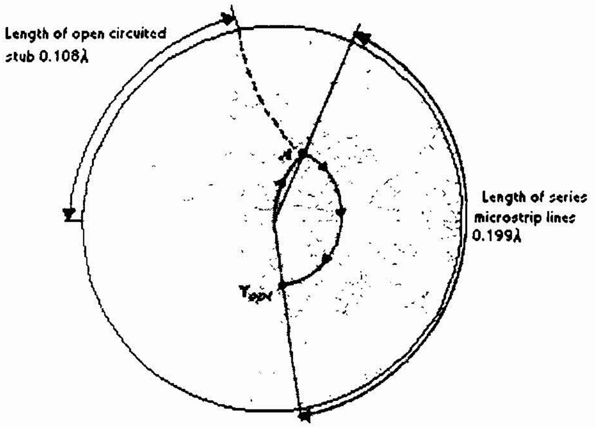
$$F = F_{min} + \frac{4r_n \left| \Gamma_s - \Gamma_{opt} \right|^2}{\left(1 - \left| \Gamma_s \right|^2 \right) \left| 1 + \Gamma_{opt} \right|^2} \quad \text{.............}(5.2)$$

where r_n is a noise resistance. Equation 5.4 above depends on F_{min}, r_n and Γ_{opt}. These parameters are given by the manufacturer of the transistor (*i.e.* Motorola Semiconductor) and known as the noise parameters.

VI. MATCHING NETWORK.

Input and output matching networks can be implemented by microstip elements. Both values of Γ_{opt} and Γ_L are required to design the matching networks. In broadband designing, we cannot consider all of reflection coefficients at every frequency points between 800MHz and 2GHz. Therefore, the parameters such as reflection coefficient, noise resistance, noise figure and s-parameters should be measured at one frequency point. In this case, the maximum operating frequency val of 2Gz has been chosen. At 2GHz, Γ_{opt} is 0.3 $\angle$103°. Therefore, from the optimal reflection coefficient value, we obtained 0.644$\angle$97.29° for the Γ_L.

Figure 5 below shows the Γ_{opt} and Γ_L on the smith chart. The input matching network can be designed with an open shunt stub of length 0.108λ and a series transmission line of length 0.199λ. The output-matching network is designed with an open shunt stub of length 0.161λ and a series transmission line of length 0.186λ.



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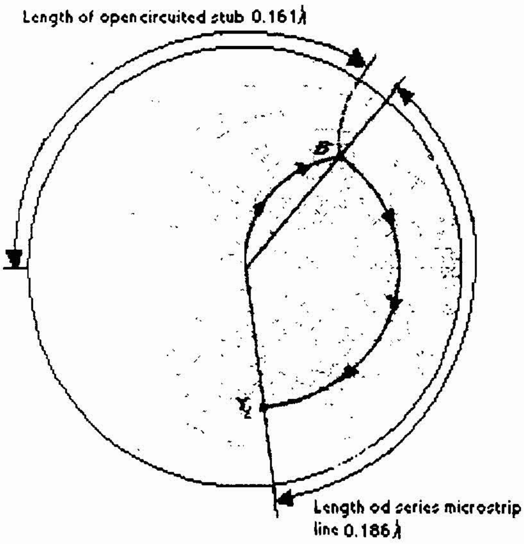

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Figure 5: (a)The input matching network design (b)The output matching network design

By using microstrip (*RT/Duroid® 6010*) with relative permittivity, ε_r=10.8, thickness of dielectric (h)=0.254mm, foil cladding thickness (T)=0.017mm, width of line (w)=0.21mm, and characteristic impedance=50Ω, we find that effective relative permittivity, ε_{ff}=6.822 and the wavelength, λ=57.3909mm. All of the expressions above were calculated using Microwave Design Computations software, provided by Rogers Corporation. Since the value of λ = 57.3909mm, the open shunt stub and series transmission line were determined:

0.108λ = 6.1982mm
0.199λ = 11.4208mm
0.161λ = 9.2399mm
0.186λ = 10.6747mm

At 2GHz, the F_{min} value is 1.86dB. When the matching network was carried out with the microstrip elements as above, the noise figure increased to 2dB. This value is still within 0.5dB from the minimum noise figure. But, at frequencies between 0.8GHz and 1.6GHz, the noise figures are out of the enclosed area.

Therefore, using the Microwave Office Design tool, the design was fine tuned again using the optimizer. The performance of the amplifier implemented with microstrips at 2GHz compared with the design that has been tuned is shown in Figure 6 below. We can see that the noise figure is within 0.5dB from the F_{min} after tuned.

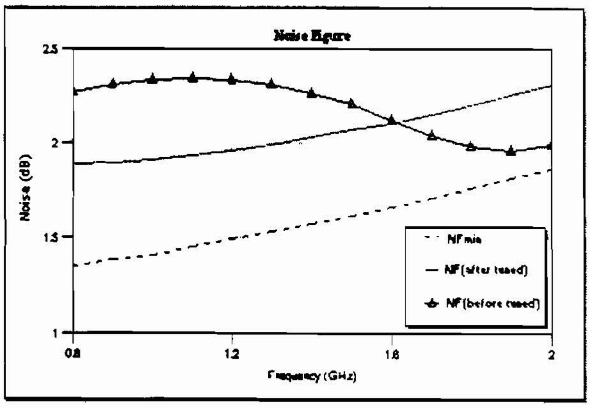

Figure 6: Noise Figure versus frequency

After the amplifier implemented by microstip elements, the available gain is still above 10dB. Figure 7 below shows the available and maximum gains of the amplifier. As described before, the amplifier cannot achieve maximum gain due to the target of minimum noise. However, the differences between the maximum and available gains are not too far. The design was further fine tuned using the optimizer of the Microwave Office Design tool, and the components value can be read from the schematic of Figure 8.

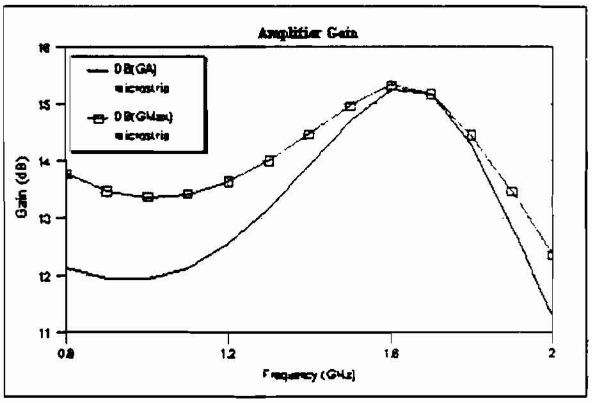

Figure 7: Maximum and Available gain versus frequency

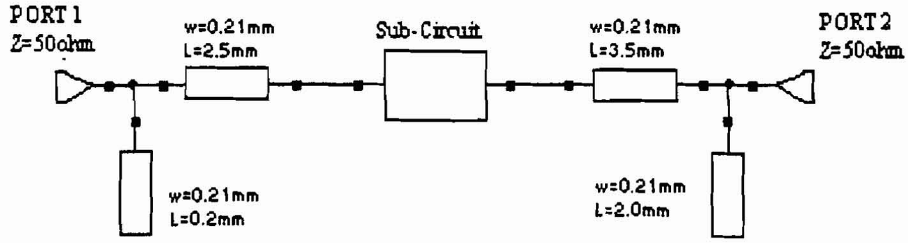

Figure 8: The LNA design implemented with microstrips

VII. CONCLUSION

In this project, a broadband LNA has been designed and implemented in microstrip technology with a minimum gain value of 10dB and the noise figure within 0.5dB from minimum noise figure. LNA is one of the components in RF front-end part of a software radio receiver. The other components are mixer, local oscillator, and bandpass filter. Since the frequencies are between 800MHz and 2GHz, the design should be implemented with microstrips to reduce higher noise and distortion.

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