Design of two stage low noise amplifier at 2.4 - 2.5 GHz frequency using microstrip line matching network method

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Abstract. This study aims to design a Low Noise Amplifier (LNA) with two-stage cascade configuration at frequency of 2.4 -2.5 GHz. The transistor that used in this study has characteristic of high gain and low noise. The design is using microstrip line matching network with single stub technique to minimize parasitic effects. Transistor is using cascade configuration to produce high gain and improve the stability. The simulation results show that the LNA has reached all of expected specification at frequency of 2.45 GHz where S21, NF, S11, S22 are 30.693 dB, 1.248 dB, -70.358 dB and -72.982 dB, respectively; Also other values VSWR input, VSWR output, stability (K), input impedance and output impedance at 50Ω are 1.001, 1.0004, 5.280, 50.010 + j0.029 and 49.991 + j0.02, respectively. The measurement results show that at frequency of 2.45 GHz, LNA obtained value of S21, S11, S22, VSWR input, VSWR output are 22.17 dB, -4.117 dB, -13.049 dB, 4.297 and 1.572, respectively. Whereas, the best measurement of S21 is 24.05 dB at frequency of 2.05 GHz, S11 is -5.700 dB at frequency of 2.0 GHz, S22 is -27.570 dB at frequency of 2.045 GHz, VSWR input is 3.07 at frequency of 2.0 GHz and VSWR output is 1.09 at frequency of 2.045 GHz.

1. Introduction
One of the developments of wireless networks is Wireless Local Area Network (WLAN). The use of WLAN that is in great demand makes the network grow rapidly. One of the developments is Wi-Fi technology. Wi-Fi is all WLAN products that work on the 2.4 GHz frequency. Development of serial 802.11n Wi-Fi is the latest technology developed from Wi-Fi b/g. Wi-Fi 802.11n offers high Wireless connectivity using MIMO technology and 40MHz channel width. Hence, the speed increases up to 600Mbps. Having high wireless connectivity, Wi-Fi is used for streaming, High Definition Video on TVs, Smart Phones, Tablets, home networking notebooks, mass data storage and printers which are implemented in 2.4 - 2.5 GHz. To meet the desired throughput requirements, its main performance is sensitivity, strong signal capability and resistance to interference. Wi-Fi networks can also be owned in every house, but the signal that must be received by the Wi-Fi router antenna from a device connected to it can be weakened. During the transmission process, the signal is often affected by noise. Noise is any unwanted interference that disrupts useful signals. Noise causes losses because the power emitted to the receiver is not optimal so that it will be weaker.
In order to receive signal stronger, the existence of Low Noise Amplifier (LNA) is one of the blocks needed on the receiver system [1]. LNA for the frequency of 2.45 GHz for example LNA-2450 produced by RF, Bay. Inc., with frequency range of 2400 - 2500 MHz, the gain generated is 16 dB and noise figure is 1.5 dB. The gain is considered not maximal considering the signal received by the antenna is very weak and the LNA must be able to strengthen the signal to reach a sufficient level to be processed by the receiving system. In meeting the required high gain, LNA can be designed using the cascade method (increasing the stage / level) of the transistor [2,3]. Based on the research that has been done, the design of LNA using the two-level cascade method can produce a gain of an average of 28.8 dB [4]. By using the cascade method, theoretically can produce high transistor stability [5]. In designing the LNA, an impedance adjustment circuit is also needed to maximize the transfer of power from the source to the load, but the use of LC components at high frequencies can cause parasitic effects. The advantages of microstrip channels compared to lump components are that they can minimize the parasitic effects that cause insulated amplifiers [6,7].

The Wi-Fi router functions as a gateway for wireless users (Wi-Fi devices) in an area to be able to enter the local network. The Wi-Fi router must receive relatively weak signals from devices using its network such as mobile phones. To be able to receive a weak signal, usually the Wi-Fi router is equipped with the right components, one of which is an antenna. Antennas are transitional / transition structures between free space and guided devices (waveguide) and vice versa [8,9]. With this method LNA can be developed, to get all the expected parameters, the choice of transistor type and LNA design must be correct [10-12].

2. Theoretical foundations

2.1. Scattering parameter
To calculate a relation between the wave voltage comes with the reflected wave voltage that is [6,13]:

\[
\begin{bmatrix}
b_1 \\
b_2 
\end{bmatrix} =
\begin{bmatrix}
S_{11} & S_{12} \\
S_{21} & S_{22}
\end{bmatrix}
\begin{bmatrix}
a_1 \\
a_2 
\end{bmatrix}
\]  

(1)

Where \(a_n\) represents the normalization of the voltage coming into the two-port circuit, while \(b_n\) is the normalization of the reflected voltage of the two-port circuit, each given by the equation:

\[
a_1 = \frac{E_{i1}}{\sqrt{Z_0}}
\]  

(2)

\[
a_2 = \frac{E_{i2}}{\sqrt{Z_0}}
\]  

(3)

\[
b_1 = \frac{E_{r1}}{\sqrt{Z_0}}
\]  

(4)

\[
b_2 = \frac{E_{r2}}{\sqrt{Z_0}}
\]  

(5)

\(S_{11}\) = Input reflection coefficient, \(S_{22}\) = Output reflection coefficient, \(S_{12}\) = Reverse transmission gain dan \(S_{21}\) = Forward transmission gain.

2.2. Parameter low noise amplifier
To calculate the stability value (K) is as follows [3,14]:

\[
K = \frac{1 - |S_{11}|^2 - |S_{12}|^2 + |\Delta|^2}{2|S_{12}|S_{21}^*}
\]  

(6)
Unconditionally stable if $K > 1$ and $|\Delta| < 1$:

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

(7)

Then calculate the Transducer Power Gain ($G_T$) as follows:

$$G_T = \frac{|S_{21}|^2(1 - |\Gamma_S|^2)(1 - |\Gamma_L|^2)}{|1 - \Gamma_S\Gamma_L|^2|1 - S_{22}\Gamma_L|^2}$$

(8)

where:

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

(9)

Calculate Operating Power Gain / ($G_P$) as follows:

$$G_P = \frac{|S_{21}|^2(1 - |\Gamma_L|^2)}{(1 - |\Gamma_{in}|^2)|1 - S_{22}\Gamma_L|^2} = \frac{S_{21}}{S_{12}} \left[k - \sqrt{k - 1}\right]$$

(10)

Calculate the Available Power Gain / ($G_A$) as follows:

$$G_A = \frac{|S_{21}|^2(1 - |\Gamma_S|^2)}{(1 - |\Gamma_{out}|^2)|1 - S_{11}\Gamma_S|^2}$$

(11)

where:

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

(12)

Then calculate the VSWR or the ratio between the voltages reflected in the way:

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

(13)

Where $\Gamma$, $V_0^+$, $V_0^-$, $Z_L$, $Z_0$ are a reflection coefficient, transmission voltage, reflected voltage, load impedance and lossless transmission line impedance respectively. So, the VSWR equation is as follows:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

(14)

The next step is to calculate the return loss output and Input in the following way:

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

(15)

$S_{11}$ (input) in decibel (dB) is represented by:

$$S_{11}(dB) = 20 \log_{10} |\Gamma_{in}|$$

(16)

whereas the reflection coefficient on port 2 (output) is written as follows:

$$\Gamma_{out} = \frac{Z_{out} - Z_0}{Z_{out} + Z_0}$$

(17)

$S_{22}$ (output return loss) in decibel (dB) is represented by:

$$S_{22}(dB) = 20 \log_{10} |\Gamma_{out}|$$

(18)

Then calculate the contribution of noise from a system symbolized by noise factor ($F$) which is represented as follows:

$$F = \frac{N_{in} + N_{added}}{N_{in}}$$

(19)

The equation describing $NF$ is indicated by:
\[ NF = 10 \log_{10} \left( \frac{S_{in}/N_{in}}{S_{out}/N_{out}} \right) \]  

(20)

where \( S \) is the signal power and \( N \) is noise power.

3. Method of low noise amplifier design

Low Noise Amplifier is designed using Advance Design System (ADS) software in 2011. The LNA Cascade 2 level design will be designed. Antenna design validation is needed in simulations to determine the optimal performance of LNA. The tuning process in ADS is shown in figure 1.

After the validation process before the LNA is fabricated, then the step that must be done is to layout the LNA series in the help of the Altium 2013 software. The final LNA design is shown in figure 2.

4. Results and discussion

The results of this study are designing a two-stage Low Noise Amplifier (LNA) at the 2.45 GHz frequency using the microstrip channel impedance adjustment method with the Advance Design System (ADS) software. The following is the comparison of the results of the comparison between LNA simulations and LNA measurement results.
Table 1. Comparison between LNA simulation and measurement.

| Parameter       | Initial/Target Specifications | Simulation Result | Measurement Result | Explanation                                      | Best Measurement     |
|-----------------|-------------------------------|-------------------|--------------------|-------------------------------------------------|---------------------|
| Center Frequency| 2.45 GHz                      | 2.45 GHz          | 2.45 GHz           | -                                               | -                   |
| $S_{11}$        | $<-10$ dB                     | $-70.358$ dB      | $-4.117$ dB        | A frequency response shift occurs                | $-5.700$ dB at 2.0 GHz |
| $S_{22}$        | $<-10$ dB                     | $-72.982$ dB      | $-13.049$ dB       | In accordance with the initial specifications    | $-27.570$ dB at 2.045 GHz |
| VSWR Input      | $<2$                          | 1.001             | 4.297              | A frequency response shift occurs                | 3.07 at 2.0 GHz      |
| VSWR Output     | $<2$                          | 1.0004            | 1.572              | In accordance with the initial specifications    | 1.09 at 2.045 GHz    |
| $S_{21}$        | $>16$ dB                      | 30.693 dB         | 22.17 dB           | In accordance with the initial specifications    | 24.05 dB at 2.05 GHz |
| Noise Figure    | $<-1.5$ dB                    | 1.248             | 7.548 dB           | A frequency response shift occurs                | 3.018 dB at 2.425 GHz |

Table 1 shows the comparison between simulation result and measurement result. For input return loss at 2.45 GHz, the value for simulation result and measurement result are $-70.358$ dB and $-4.117$ dB, respectively. The value for simulation result meets the target specification but for measurement result, there is a shifting in frequency response. For output return loss at 2.45 GHz, the value for simulation result and measurement result are $-72.982$ dB and $-13.049$ dB, respectively. These values meet the target specification.

For input VSWR at 2.45 GHz, the value for simulation result and measurement result are 1.001 and 4.297, respectively. The value for simulation result meets the target specification but for measurement result, there is a shifting in frequency response. For output VSWR at 2.45 GHz, the value for simulation result and measurement result are 1.0004 and 1.572, respectively. These values meet the target specification. For gain value at 2.45 GHz, the value for simulation result and measurement result are 30.693 dB and 22.17 dB, respectively. These values meet the target specification. For noise figure at 2.45 GHz, the value for simulation result and measurement result are 1.248 dB and 7.548 dB, respectively. The value for simulation result meets the target specification but for measurement result, there is a shifting in frequency response.

From simulation, we also get the value of stability (K), input impedance and output impedance at 50Ω are 5.280, 50.010 + j0.029 and 49.991 + j0.02, respectively. The best measurement of $S_{21}$ is 24.05 dB at frequency of 2.05 GHz, $S_{11}$ is $-5.700$ dB at frequency of 2.0 GHz, $S_{22}$ is $-27.570$ dB at frequency of 2.045 GHz, VSWR input is 3.07 at frequency of 2.0 GHz and VSWR output is 1.09 at frequency of 2.045 GHz.

5. Conclusion

In measurements using Spectrum Analyser, Signal Generator, Vector Network Analyser, there are differences between simulation and measurement results. This is due to the value of the passive component which has a tolerance value (not ideal in the simulation), the value of the active component that is not as dynamic as the datasheet and is ESD (Electro Static Discharge), microstrip strip erosion that is too deep during fabrication, high internal noise and there is a loss on the cable connection between.
the Spectrum Analyser, the LNA Circuit, and the Vector Signal Generator, as well as the cable connection on the VNA port to the LNA circuit.

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