# Improved Performance of An Ultra Wideband Amplifier 3.1 to 10.6 GHz Using High Electron Mobility Transistor

Aayush Aneja
*University college of Engineering, RTU, Kota*

Mithilesh Kumar
*University College of Engineering, RTU, Kota*

## Abstract

*An ultra wideband amplifier is designed to amplify radio signals received in UWB band i.e. 3.1 to 10.6 GHz with liner and flat gain, low noise figure and low reflection loss from either ports. For improved performance the load is matched to the source using step impedance matching technique. The paper presents a single stage amplifier which is designed using a High electron mobility transistor or HEMT that is biased using potential divider bias. The results display a high gain with minimised losses from both ports in the UWB band. The amplifier requires low voltage for operation and demonstrates good results in the entire frequency range.*

**Keywords**— *Ultra Wide Band, High Electron Mobility Transistor, Two Port Network.*

## 1. Introduction

It is a low-power technology firstly approved in USA for indoor wireless communication in the 3.1-10.6 GHz frequency band with a limited isotropically-radiated power (EIRP) of -41.3 dBm/MHz. UWB was intended from the beginning for short-range operation in Wireless Personal Area Networks. Combining a lower power and broader spectrum, it improves the speed and has the potential to avoid interference with other wireless systems. UWB communication systems can coexist with other narrow band systems without interfering with one another. Another advantage is that it has large channel capacity with low signal to noise ratio, or large data rate transfer speeds. The design of broadband amplifiers introduces new difficulties, which require careful considerations. Basically, the design of constant gain amplifier over the UWB frequency range requires proper matching networks both at source and load, in order to compensate gain variations with frequency.

The paper describes a new approach to design the Ultra wideband amplifier. This approach makes it possible to realize the amplifier without techniques such as cascading and current reuse. Amplification is one of the most basic and prevalent microwave circuit functions in modern RF and Microwave systems. Early microwave amplifiers relied on tubes, such as klystrons and travelling-wave tubes. Now due to dramatic improvements and innovations in solid-state technology, most RF and microwave amplifiers today used transistor devices such as Si, SiGe BJTs, GaAs HBTs, GaAs or InP FETs, GaAs HEMTs.

The UWB amplifier, both at the transmitter and receiver side is an important and inseparable part of a UWB transreceiver system. The amplifier has to fulfill certain requirements such as linearity, gain, low noise figure etc. Therefore many designs and solutions were proposed for an efficient UWB amplifier.

Moez and Elmarsy, University of Waterloo, presented a methodology for design of low noise Ultra wideband amplifiers for UWB applications. They used a triple resonance circuit as the drain impedance to achieve a gain of 8dB using CMOS technology. Their results were satisfactory but the design was complex and expensive [1].

Mehrjoo and Yavari , Amirkabir University, Tehran proposed an Ultra wideband Low Noise amplifier using an active positive feedback to reduce noise figure. The simulation is done in a 0.13μm RF CMOS technology. The amplifier was proposed to achieve a good gain and worked at low power [2]. The letter proposed by Vancl, Sokol, Cerny and Skvor described the general principle of Ultra Wideband amplifier in a planar structure using commonly available monolithic amplifier. A roll off stage was used for the compensation of declining gain and biasing of the amplifier. The structure was simple and achieved gain of the order of 7dB in UWB range[3].

In this paper, an Ultra Wideband Amplifier is proposed having a simple structure that has single HEMT as active device that can be fabricated using the commonly available MMIC technique for fabrication. The Amplifier operates in the frequency band of 3.1 to 10.6 GHz, accepts the input signal from a UWB pulse generator, amplifies the signal and sends it to a UWB antenna through which the amplified UWB signal can be transmitted. The UWB signal is generated by employs one FET, One diode which can be optional and few passive components which can be implemented in MIC or MMIC or extended form of BiCMOS. The signal is transmitted using a UWB antenna. Planar monopole antenna have been found to be excellent candidates to operate in UWB systems, since they present a low cost, very compact structure[4].

The amplifier can be thought of as a booster that can boost the signal power high enough such that it can propagate the required distance over the wireless medium. The high frequency and short wavelength of microwave energy make for difficulties in analysis and design of microwave components and systems. Matching of the input and output of the transistor must be considered and designed around. For a UWB amplifier, the bandwidth is more as compared to conventional microwave and other RF amplifiers. Therefore, The Speed of transmission is very high and thus maintaining linearity across the whole of bandwidth is a challenge.

## 2. Amplifier Design

In RF and microwave (MW) circuit design, it is useful to represent circuit blocks by two port networks. Two-port networks have the ability to reduce most complex active and passive circuit devices to simple input-output relations. Input and output port parameters can be experimentally determined without the need to know the internal structure of the system.

At low frequencies, the two-port network shown in Figure 1 can be represented in several ways. The most common representations are the impedance matrix (z parameters), the admittance matrix (y parameters), the hybrid matrix (h parameters) and the chain or ABCD matrix. However, at high frequencies all the above parameters are extremely difficult to measure. Therefore, a new representation for a two port network is required: the scattering or S-parameter matrix. The S parameters are basically power wave descriptors that enable the input output relations of a network be defined in terms of incident and reflected power waves. With reference to Figure 1, the incident normalized power wave $a_n$ and the reflected normalized power wave $b_n$ are defined as follows:

$$a_n = \frac{1}{2\sqrt{z0}}(v_n + z_0 i_n) \tag{1}$$

$$b_n = \frac{1}{2\sqrt{z0}}(v_n - z_0 i_n) \tag{2}$$

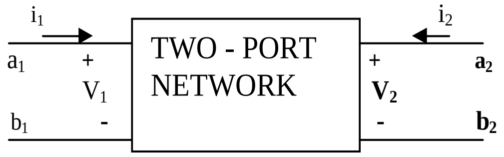


**Figure 1**: S-parameters representation of a two port network.

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{3}$$

The design procedure is strictly on small signal S-parameters. Each S parameter represents a one of the important parameter of an amplifier. The two most commonly used reflection coefficients are those at the load and at the source defined as follows:

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \tag{4}$$

$$\Gamma_s = \frac{Z_s - Z_0}{Z_s + Z_0} \tag{5}$$

In addition, the input and output reflection coefficients $\Gamma_{IN}$ and $\Gamma_{OUT}$ can be shown to be equal to:

$$|\Gamma_{in}| = \left|S_{11} + \frac{S_{12}S_{21}\Gamma_L}{(1 - S_{22}\Gamma_L)}\right| \tag{6}$$

$$|\Gamma_{out}| = \left|S_{22} + \frac{S_{12}S_{21}\Gamma_s}{(1 - S_{22}\Gamma_s)}\right| \tag{7}$$

For maximum power transfer (optimum power match) we require $\Gamma_s = \Gamma_{in}^*$ and $\Gamma_L = \Gamma_{out}^*$ . If the device is unilateral (i.e. $Sn$ =0) then equation (6) and (7) become $\Gamma_{in} = S_{11}$ and $\Gamma_{out}$ = S22, thus for maximum power transfer in the unilateral case $\Gamma s = S_{11}^*$ and $\Gamma_L = S_{22}^*$ [5].

But, to deliver maximum power to the load the amplifiers must be properly terminated at both the input and the output port. Matching networks are targeted to deliver maximum power to a load. The most basic type of network is that which uses discrete components, mainly capacitors and inductors. These networks are easy to analyze but can be used only up to frequencies in the low GHz range. There are methods for matching of high frequency amplifiers like single stub matching or strip lines. However for our amplifier working in such broadband range, source is matched to the load using step impedance stub matching technique. A load may be matched to any desired impedance by selecting the correct lengths of transmission lines and stubs.[6] In our case, this allows a source impedance to be transformed to 50 ohm. When designing output matching networks, impedance matching using microstrip lines and step impedance stub matching is used and the same procedure is followed.

The High electron mobility transistor (HEMT) is used as an active device for designing the amplifier working in UWB range. In this, the hetro-junction created by different band-gap materials forms a quantum well in the conduction band where the electrons can move quickly without colliding with any impurities, and from which they cannot escape. The effect of this is to create a very thin layer of highly mobile conducting electrons with very high concentration, giving the channel very low resistivity or to put it another way, "high electron mobility".[7] The HEMT used is NEC's NE3210S01 which is a pseudomorphic Hetro-junction FET, that uses the junction between Si-doped AIGaAs and undoped InGaAs to create very high mobility electrons

The device has a low gate length $L_G < 20\mu m$. and gate width = 160µm. . Considering the typical test conditions , i.e. $V_D$ = 2V and $I_D$= 5mA., the S parameters of the NE3210S01 is as shown in Table-1.

**Table 1**: S-parameters of NE3210S01

| Frequency (GHZ) | $S_{11}$ (dB) | $S_{21}$ (dB) | $S_{12}$ (dB) | $S_{22}$ (dB) |
|---|---|---|---|---|
| 3.0 | 0.954 | 3.338 | 0.041 | 0.698 |
| 4.0 | 0.920 | 3.381 | 0.053 | 0.670 |
| 5.0 | 0.879 | 3.378 | 0.062 | 0.638 |
| 6.0 | 0.835 | 3.428 | 0.070 | 0.604 |
| 7.0 | 0.778 | 3.525 | 0.081 | 0.553 |
| 8.0 | 0.680 | 3.539 | 0.086 | 0.469 |
| 9.0 | 0.589 | 3.527 | 0.091 | 0.398 |
| 10.0 | 0.505 | 3.432 | 0.089 | 0.335 |
| 11.0 | 0.481 | 3.490 | 0.096 | 0.302 |

Where,
Input Return Loss= $S_{11}$ (dB)
Gain(Power Gain)= $S_{21}$ (dB)
Reverse Isolation= $S_{12}$(dB)
Output Return Loss= $S_{22}$(dB)

The ultra wideband amplifier is designed by selecting a proper HEMT with low noise and less power dissipation. For this purpose, we have selected NE3210S01 as active device. The HEMT is biased using potential divider bias. Finally input and output matching circuits are designed based on the frequency range of the amplifier. However Wideband matching is difficult to implement as compared to impedance matching of other microwave amplifiers. The matching is done using step impedance matching or which is equivalent to radial stub matching. The amplifier chosen is made to work in the desired frequency range, 3.1 to 10.6 GHz. At microwave frequencies 50Ω transmission lines and 50Ω termination are commonly used to measure the S parameters of a two port network. The design of UWB amplifier using a single HEMT is shown in Figure 2.

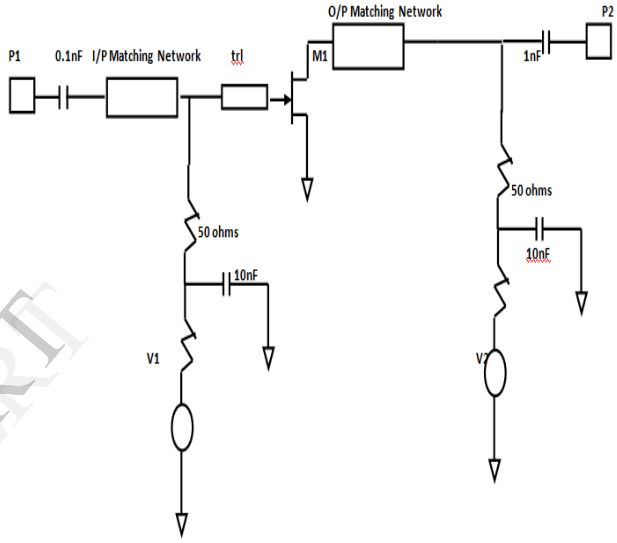


**Figure 2**: Ultra wideband amplifier using HEMT.

The gain , linearity and stability of an amplifier are the key parameters that define the proper working of an amplifier. The gain of an amplifier is derived in terms of transducer power gain.

$$G_T = \frac{1-|\Gamma_s|^2}{|1-\Gamma_{in}\Gamma_s|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (8)$$

$$G_T = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-\Gamma_{out}\Gamma_L|^2} \quad (9)$$

$$G_p = \frac{1}{1-|\Gamma_{in}|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (10)$$

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

Where, $G_T$ is transducer power gain, $G_p$ is operating power gain, $G_A$is available power gain.
It is beneficial if the two-port network or amplifier is unconditionally stable because any load could be connected without affecting the system's stability.

Also, no input and output stability circles would be required. For unconditional stability, the two equations must hold:

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} > 1 \qquad (12)$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \qquad (13)$$

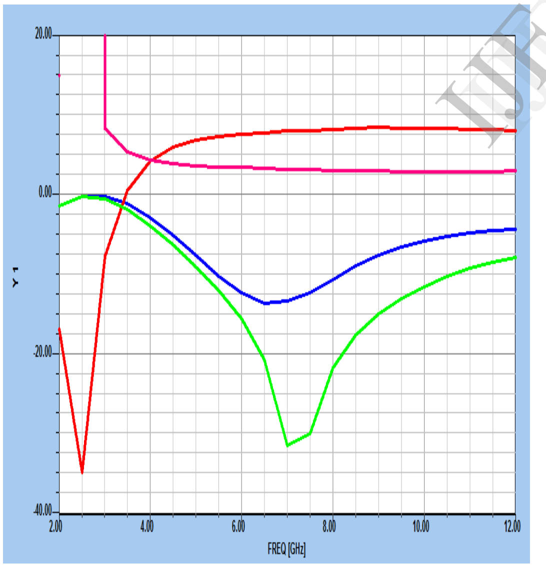
The noise in an amplifier is determined by the noise figure, 'F' which is obtained as :

$$F = 1 + \frac{P_n}{P_{N\ in}G_A} \qquad (14)$$

Where, $P_n$ is internal noise of the amplifier, $P_{N\ in}$ is the noise power from noisy resistor and $G_A$ is available power gain.

## 3.Results And Discussions

The UWB amplifier designed is simulated in Serenade SV and as shown in Fig. 2. The transistor is biased using a potential divider bias and the input output matching circuit is designed using a step impedance stub matching technique. The variation of S-parameters of the amplifier with respect to frequency simulated are shown in Figure.3.



🟩 $S_{22}$ 🟥 $S_{21}$ 🟦 $S_{11}$ 🟪
$S_{12}$

**Figure 3**: Variation of S-parameters of the amplifier with frequency.

The amplifier generally have exceeded noise figure, However The effect of noise in the simulated amplifier is controlled considerably to large extent. The variation Noise Figure with frequency is depicted in Figure 4.

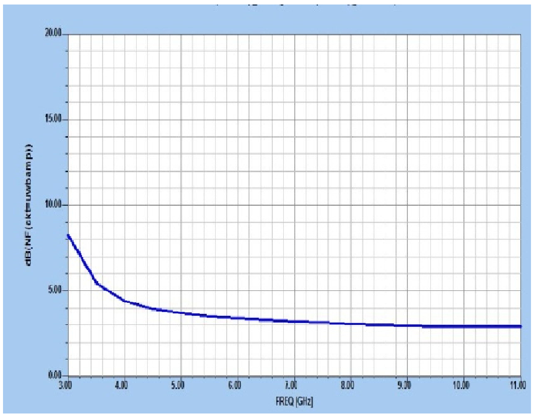


**Figure 4**: Variation of Noise figure with frequency

## 4. Conclusion

The design methodology of an ultra wideband amplifier is described in the paper. The Ultra Wideband amplifier working in the frequency range of 3.1 to 10.6GHz is designed and simulated using Serenade SV simulation tool and the results have been characterized. The amplifier attains a flat and high gain with single HEMT which is around 8dB in the whole of bandwidth. The reflections from either ports is also minimised. The Reflection coefficients S11 and S22 are less than 10 dB across the UWB range. Low noise figure does not ascertain the optimum functioning of an ultra wideband amplifier . However, the circuit response shows a low noise figure in the frequency range where the circuit accounts for maximum gain.

## 5. References

[1] Kambiz K. Moiz, Mohamed I. Elmarsy, " A 3-10 GHz Low Noise amplifier for Ultra-Wideband Applications",IEEE North-East Workshop on Circuit and Systems, 2006, pp. 9-12, 18-21 July 2006.

[2] Mohammad Sadeh Meharjoo and Mohammad Yavari, "A Low power UWB Very Low Noise Amplifier Using An Imporved Noise Reduction Technique", IEEE International Symposium on Circuit and System ISCAS, pp. 227-280, 2011.

[3] Jan Vancal, Vratislav Solol, Petr Cerny,Zbynek Skvor " The UWB Amplifier 3.1 to 10.6 GHz.", IEEE 14th International Conference on Microwave Techniques, COMITE 2008, pp. 1-4, April 2008.

[4] M.Kumar , A. Basu and S.K. Koul " Circuits And Active Antennas For Ultra Wide Band Pulse Generation And Transmission", Progresss in Electromagnetics Research B , Vol. 23 , pp. 251 – 272 , 2010.

[5] Guillermo Gonzalez, “Microwave Transistor Amplifier Analysis and Design”. , TMH,20 Aug, 1996, 2nd edition , ISBN-10 : **0132543354.**

[6] A. Aneja, M. Kumar “Design of Ultra Wideband Amplifier Using Single Hetro-Junction Bipolar Transistor For Wireless Applications, IEEE 5th International Conference on Computational Intelligence and Communication Networks, pp. 442-445, September 2008.

[7] Liao Samuel Y. , “Microwave Devices and Circuits”., Pearson Education India, 3rd Edition, ISBN-10 : **817758353.**