Microwave amplifier design using high mobility electron transistor

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Abstract. Microwave amplifier is a radio frequency device used for many applications in telecommunication technology such as C Band weather radar application. The microwave amplifier usually exists in transmitter section to amplify weak signal that will be delivered to antenna. This paper discusses design and fabrication of a microwave amplifier using High Mobility Electron Transistor (HMET) CGH40006P. The reason using such kind of transistor is due to its high gain and linearity. In order to achieve maximum power transfer at frequency of 5.6 GHz. The amplifier is constructed in cascade architecture using the same type of transistors. Open ended single stub matching impedance networks are applied in this design as well. Based on measurement result, power gain of 21 dB is obtained for +20 dBm input power with Voltage Standing Wave Ratio (VSWR) of 1.1 and 13 dB noise figure.

1. Introduction

Microwave amplifier is radio frequency device used to amplify weak signal especially in weather radar application or in many others applications in general. In this paper, a microwave amplifier design is discussed. This amplifier operates at frequency of 5.6 GHz in order to conduct gap analysis among related journals the followings are reviews of several journals related to this topic. The journals describe such as the design and measured results of a single stage S-Band high-efficiency power amplifier that uses state-of-the-art GaN-HEMT [1]. Large signal modelling approach of GaN on Si device for RF amplifier application has also been improved to account for parasitic buffer loading [2]. ATF-551M4 is also already implemented at frequency of 3 GHz resulting 22 dB gain. This amplifier is designed for coastal surveillance radar [3]. This RF amplifier is designed using single transistor that is MGF4230A operating for frequency of 9.3 GHz and this amplifier can produce gain of 5 dB with SWR of 3 for the input and SWR4.3 and SWR of 2.02 for the output. Monolithic integrated C-band low noise amplifier using AlGaN/graded-AlGaN/GaN HEMTs GHz is designed with single stub matching and result gain of 10 dB. [4]. Using transistor 1x100µm CGHMET at frequency of 6 GHz produce gain of 10dB with 2.7 dB noise Figure. Design and Development of C-Band Microwave Amplifier for Wireless Applications [5]. Transistor ATF-34143 is also used for this amplifier design and operates at frequency of 5.8 GHz. With this transistor gain of 12.4dB is obtained. In development of a Single Stage C-Band Pulsed Power Amplifier for Radar Transmitter, in this design transistor FPD6836P70 is used. The amplifier works very well at frequency of 7.23 GHz and result gain of 10.31 dB [5]. Another design and realization of high gain power amplifier is done by Alqadami and result gain of 10.73 dB [6]. The design and measured performance of X-band power amplifier. This design for drain modulated applications, A
X-band GaN monolithic microwave integrated circuits (MMIC) High Power Amplifier is designed for future generation Synthetic Aperture Radar systems [7]. The HPA delivers 14 W of output power [8]. Based on the above journal reviews, summary is made to find the gap. In general, most of design using single transistor therefore the gain of the amplifiers is about 10 dB at average. Input and output matching circuits are also implemented using some techniques. To obtain high gain power amplifier. This amplifier is constructed in cascade or two stages using the same type transistor, we expect to get almost double gain of a single stage amplifier.

2. Method
In designing microwave amplifier, specifications have to be defined first. Transistor stability has to be evaluated in order to make sure that the transistors are in absolute stable condition to use. Input matching circuit and output matching circuit have to be applied in order to achieve matched transistor impedance seen to the source and the load. Biasing circuit also has to be considered for the design in order the amplifier will work properly at its operating point.

2.1. Specification
The amplifier is designed according to specification as given in table 1.

| Table 1. Design specification. |
|-------------------------------|
| Gain | >20 dB |
| Operating frequency | 5.6 GHz |
| Input impedance | 50 Ω |
| Output impedance | 50 Ω |
| Input VSWR | <1.5 |
| Output VSWR | >1.5 |
| Bandwidth | 20 MHz |

2.2. Biasing circuit
Given $V_{DS} = 28$ volt and $I_D = 0.1$ A. By simulation it shows that $V_{GS}$ is about -2.8 volt in which the value is close to the calculated ones. Therefore, power consumed of the amplifier can be calculated as $V_{DS}$ multiplied by $I_D$ yield 2.8 watt. Circuit simulation is shown in figure 1.

![Figure 1. DC biasing and first stage amplifier circuit simulation.](image-url)
2.3. Stability consideration
In RF and microwave amplifier design transistor stability has to be considered. Based on transistor HEMT CGH40006P data sheet, the stability of the transistor is evaluated using given set of scattering parameters as follows,

\[
S_{11} = 0.884 < 170.99^0 \\
S_{12} = 0.028 < -18.568^0 \\
S_{21} = 0.927 < 12.225^0 \\
S_{22} = 0.612 < -157.675^0
\]

Therefore, the stability can be obtained as follows;

\[
|\Delta| = |S_{11}S_{22} - S_{12}S_{21}|
\]

\[
|\Delta| = |(0.884 < 170.99 X 0.612 < -157.675) - (0.028 < -18.568 X 0.927 < 12.225)|
\]

\[
|\Delta| = 0.516
\]

\[
K = \left| \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2 |S_{12}S_{21}|} \right|
\]

\[
K = \frac{1 - |0.884<170.99|^2 - |0.503<-167.265|^2 + |0.414|^2}{2 |0.028<-73.533 X 2.143<5.277|}
\]

\[
K = 0.78 < 1
\]

Transistor stability for first stage amplifier, K <1 therefore the transistor in conditional stable at frequency of 5.6 GHz. In order to increase the stability value more than 1 additional resistive components have to be connected in pararel in transistor input section. With resistor of 470Ω it is obtained that stability value become,

\[
|\Delta| = |S_{11}S_{22} - S_{12}S_{21}|
\]

\[
|\Delta| = |(0.885 < 138.087 X 0.504 < -167.607) - (0.027 < -73.370 X 2.105 < 3.441)|
\]

\[
|\Delta| = 0.405
\]

\[
K = \left| \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2 |S_{12}S_{21}|} \right|
\]

\[
K = \frac{1 - |0.885<138.087|^2 - |0.504<-167.607|^2 + |0.405|^2}{2 |0.027<-73.370 X 2.105<3.441|}
\]

\[
K = 1.121 > 1
\]

By adding resistive component the stability value become >1 therefore the transistor in absolute stable condition.

2.4. Maximum available gain
After stability values are obtained that is K > 1 so value of maximum available gain of the first stage of amplifier can be obtained using these equations;

\[
G_{MAX} = 10\log\left|\frac{S_{21}}{S_{12}}\right| + 10\log|K + \sqrt{K^2 - 1}|
\]

\[
G_{MAX} = 10\log\left|\frac{2.105<3.441}{0.027<-73.370}\right| + 10\log|1.121 - \sqrt{1.121^2 - 1}| = 16.8 \text{ dB}
\]

2.5. Input matching network
Source Reflection coefficient,

\[
C_S = S_{11} - \Delta S \ast S_{22}
\]

\[
C_S = 0.885 < 138.087^0 - 0.405 x 0.504 < 167.607^0
\]

\[
C_S = 0.6681 < 136.462^0
\]

\[
B_S = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2
\]

\[
B_S = 1 + |0.885 < 138.087|^2 - |0.504 < -167.607|^2 - |0.405|^2
\]

\[
B_S = 1.364
\]
Using smith chart utility in ADS software application, source reflection \( \Gamma_{SM} = 0.948 < -136.462^\circ \) is typed in gamma dialogue of smith chart utility window to find input matching network like shown in Figure 1, value of \( Z_L \) is obtained 0.03095 < 0.399010.

\[ \begin{align*}
C_S &= S_{11} - \Delta S_{22} \\
C_S &= 0.885 < -138.087^\circ - (-0.405) \times 0.504 < -167.607^\circ \\
C_S &= 0.681 < -136.462^\circ \\
\Gamma_{SM} &= C_S \left[ \frac{B_S \pm \sqrt{B_S^2 - 4|C_S|^2}}{2|C_S|^2} \right] \\
\Gamma_{SM} &= 0.681 < 136.462 \left[ \frac{1.364 \pm \sqrt{1.364^2 - 4 \times 0.6681 < 136.462^2}}{2 \times 0.6681 < 136.462^2} \right] \\
\Gamma_{SM} &= 0.948 < -136.462^\circ
\end{align*} \]

2.6. Output matching network

Load Reflection coefficient,
\[ \begin{align*}
C_L &= S_{22} - \Delta S_{11} \\
C_L &= 0.504 < -167.607 - 0.405 \times 0.885 < -138.087^\circ \\
C_L &= 0.15 < 179.346 \\
B_L &= 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \\
B_L &= 1 + |0.504 < -167.607|^2 - |0.885 < 138.087|^2 - |0.405|^2 \\
B_L &= 0.306 \\
C_L &= S_{22} - \Delta S_{11} \\
C_L &= 0.504 < 167.607^\circ - (-0.405) \times 0.885 < 138.087^\circ \\
C_L &= 0.15 < -179.346 \\
\Gamma_{LM} &= C_L \left[ \frac{B_L \pm \sqrt{B_L^2 - 4|C_L|^2}}{2|C_L|^2} \right] \\
\Gamma_{LM} &= 0.15 < -179.346 \left[ \frac{0.306 \pm \sqrt{0.306^2 - 4 \times 0.15 < 179.346^2}}{2 \times 0.15 < 179.346^2} \right] \\
\Gamma_{LM} &= 0.826 < -179.346
\end{align*} \]

Using smith chart utility in ADS software application, source reflection \( \Gamma_{LM} = 0.826 < -179.346^\circ \) is typed in gamma dialogue of smith chart utility window to find input matching network like shown in Figure 3, value of \( Z_L \) is obtained 0.09600 < 0.06000.

\[ \begin{align*}
\text{Figure 2. Input matching network.} \\
\text{Figure 3. Output matching network.}
\end{align*} \]
2.7. Cascading the amplifiers
As already stated earlier that this amplifier design is constructed in cascading architecture. That means two amplifiers with two identical transistors are connected in tandem. In order the two amplifiers can do maximum power transfer they have to be coupled properly with inter stage matching network between the first stage and the second stage amplifier. Figure 4 illustrate inter stage matching network which is capacitive coupling network using 1/λ micro strip line.

![Figure 4. Inter stage matching network.](image)

2.8. Micro strip line
To calculate dimension of micro strip line we can make use of linecalc tool (calculator for calculating strip line) in ADS software application. It is necessary to input specification of Rogers Duroid Printed Circuit Board (PCB) like $\varepsilon_r = 2.2$, $h = 1.575 \text{ mm}$, and $T = 0.350 \text{µm}$. And the followings are calculated dimension of micro strip lines such as width (W) = 4.9 mm, and length (L) of TL1 $L_{\text{shunt}}$ = 8.6427 mm, TL2 $L_{\text{series}}$ = 17.99 mm, TL3 inter stage $L_{\text{series}}$ = 3.88477. Finally for load section $L_{\text{series}}$ = 1.81081 mm and $L_{\text{shunt}}$ = 7.65139 mm. Figure 5 shows final amplifier circuit with micro strip line.

![Figure 5. Final amplifier circuit with micro strip line.](image)

2.9. Design simulation of final amplifier
Figure 5 is final amplifier design and we need to know its performance such as gain, VSWR, and stability factor of the amplifier them self. The following Figures are simulation results of the amplifier. Figure 6 show the overall gain of the amplifier while Figure 7 is input VSWR and Figure 8 is output VSWR.

![Figure 6. Overall gain of the amplifier.](image)  
![Figure 7. Input VSWR.](image)  
![Figure 8. Output VSWR.](image)
2.10. PCB Layout fabrication

After design and simulation steps are done PCB and component layout has to be realized. Figure 9 shows the PCB layout is drawn using Altium 8.3 software application and PCB used is Rogers Duroid. And Figure 10 shows component assembly layout of the amplifier.

![Figure 9. PCB layout fabrication.](image)

![Figure 10. Component assembly layout.](image)

3. Measurement results and discussions

3.1. Gain measurement

Gain measurement set up is shown in Figure 11, by applying +20 dBm input power and swept frequency from 5 up to 6 GHz. The measurement result is illustrated in figure 11.

![Figure 11. Gain measurement set up.](image)

Figure 11 shows the gain versus frequency where the frequency is swept from 5 GHz to 6 GHz is peaking at frequency of 5.6 GHz. This is maximum gain of the amplifier which is about 21 dB.

![Figure 12. Gain vs frequency.](image)

![Figure 13. Output power vs input power.](image)
Figure 12 illustrate the relationship between input power and output power. By applying input power range from -30 dBm up to -17 dBm. It shows that output power is proportional to input power. It means the amplifier is linear within the input power range.

3.2. Input and output VSWR measurements

VSWR (Voltage Standing Wave Ratio) measurement is conducted to know how matched source to load impedance of the amplifier. This is swept frequency measurement where ones can measure ratio of reflected power to incident power using VSWR bridge or directional coupler. The results are shown in Figure 14 and 15 respectively.

![Figure 14. Input VSWR versus frequency.](image1)

![Figure 15. Output VSWR versus frequency.](image2)

Input VSWR of 1.1 and output VSWR of 1.5 show in Figure 14 and 15 respectively show that input impedance of the amplifier is matching to the source impedance and so the output one is also matching to the load impedance. Based on above VSWR measurements show that the results have met specification.

4. Conclusion

Based on the discussion it can conclude that the research has been successfully carried out. Some indicators may support the statement likes microwave amplifier designs using single non-high mobility electron type transistor exhibit commonly 10 dB up to 12 dB gain in one hand and on the other hand using single high mobility electron type transistor as for this research it exhibits more less 16 dB gain for one stage of amplifier. By cascading two stage of amplifiers with two identical high mobility electron transistors in tandem one can increase the gain of the amplifier become 21 dB which is more less double gain.

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