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Design of Ku Band Power Amplifier for Satellite Communication

[1*]Ms. B. N.Ganthade, [2]Prof. S. R. Gagare
[1]*Student, Dept. of E&TC, Amrutvahini College of Engineering, Sangamner*
[2] *Dept. of E&TC, Amrutvahini College of Engineering, Sangamner*

Abstract: *Wireless communication system have proliferated our lifestyle. These wireless applications have different requirements which depend upon frequency of operation and type of input signal. While most the wireless communication systems have a minimum of RF- modulator, filter, mixer, power amplifier (PA) and an antenna at the transmitter side. Designing of all these components is critical in almost all the wireless communication systems. Out of which design of power amplifier is very critical as the output power of the wireless system depends upon the ability of PA to amplify the low- power RF signal to the required level. In this paper, we have presented design simulation and analysis of single stage Ku band power amplifier based on 0.25µm GaN-HEMT technology. The ADS schematic of proposed PA consists of gain stage provides 10.9dBm for input power of 24 dBm at 15 GHz.*

Keywords: *GaN-HEMT technology, power amplifier, Ads, gain, output power, input power.*

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I. Introduction

The future wireless communication system demands integration of various technologies in order to make the wireless systems as compact as possible and consume less power. Technologies such as VLSI (Very Large Scale Integration), SoC (System on Chip) and MEMS (Micro-electromechanical systems) have been now integrated on same board to meet the specifications of need of wireless systems. Different wireless systems have different requirements depending upon operational frequency. While a typical wireless communication has several components as shown in Fig.1, design of Power Amplifiers (PA) is one the most crucial component in wireless systems. Hence, design of PA for different wireless applications will vary. For each specific wireless application, PA is expected to deliver specific output power, gain and efficiency under specific linearity conditions. For example, mobile communication system demands high efficiency and linearity while radar systems demand high output power[1-5].

MMIC (Monolithic Microwave Integrated Circuits) and HIC (Hybrid Integrated Circuits) for mobile and satellite communication applications based on GaAs (Gallium Arsenide) technology have been in use for a long time.However, due to low operational voltage, GaAs technology has limited output power for high input power. Alternatively, GaN (Gallium Nitride)-HEMT (High Electron Mobility Transistor) offers high output power due to high breakdown voltage. Hence, a GaAs device can be used as a driver stage for GaN-HEMT, while GaN-HEMT can be used in the power stage. However, this method of design can be used in HIC only as MMIC does not allow integration of different semiconductor technologies on the same board[6-10].

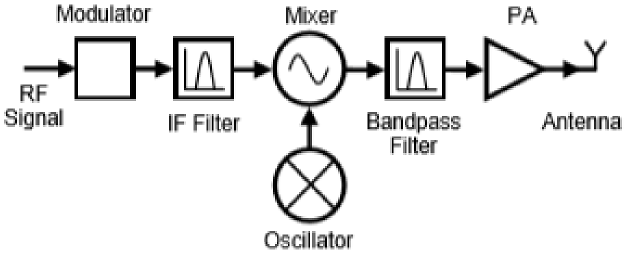


Fig. 1 Typical block diagram of wireless transmitter system

In this paper, we have designed a single stage power amplifier based on 0.25µm GaN-HEMT technology that operates at Ku band. The proposed PA consists of gain stage which is designed to full match for 50Ω input and output impedance matching. The design simulation and analysis is carried out using ADS simulation software. The proposed PA design achieves considerable gain, high output power and high PAE (Power Added Efficiency).

II. Design Methoodology

The aim of the project is to design a HIC-PA using GaN technology. The PA must meet the following design specifications as presented in Table I.

TABLE I: Design specifications of Ku band PA

Parameter	**Specification**
Frequency	Ku band (12 to 18 GHz)
Output power	> 40dBm
Gain	> 10dBm
PAE	> 10%

a) Bias Point selection:

Based on the design specifications listed in Table I, the power amplifier must provide gain of about 10dBm and PAE of 10%. This allows us to choose bias point from a wide variety of choices. As we know that, a PA can operate in Class A, B and AB (Table II). Class AB is chosen so that it can get both the advantages of Class A and Class B.

TABLE II: Classes of operation

Class of operation	Advantages and Disadvantages
Class A (Output current is always available)	Highest linearity and gain but has lowest efficiency (of about 50%)
Class B (Output current is available during half input signal cycle)	Higher efficiency (of about 78.5%) as compared to class A but low gain
Class AB (biased between cut off point and Class A)	Has high linearity and efficiency

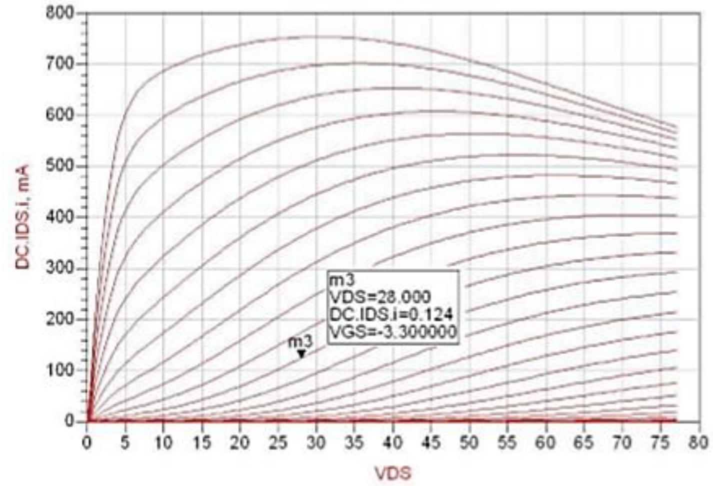


Fig. 2 IV characteristics of GaN device

Fig. 2 shows the IV characteristics of the GaN device which gives information of how the drain current can be controlled by controlling gate and drain bias voltages. For class AB operation, the bias point has to be selected between cut-off and class A, the drain to source voltage V_{DS} is selected as 28V and gate to source voltage is selected as $V_{GS} = -3.3V$.

b) Stability network:

To avoid oscillations, an amplifier should satisfy stability conditions i.e., Stability factor $K > 1$(close to 1) and stability measure $|\Delta| > 0$. If an amplifier does not satisfy these conditions, the amplifier is said to be unstable. Hence, a stability network has to be designed to ensure that the PA is unconditionally stable.

Here, we have used a capacitor (C6 = 0.33 pF) in parallel with a series resistance (R5 = 22Ω) and a series resistance at the gate bias network (100Ω) for designing the stability network which is an equivalent of high pass filter (As shown in Fig. 3). Ideally, this stability network should attenuate lower frequencies and pass higher frequencies. However, use of stability network can result in slight decrease in gain due to tolerances of the components used in designing of PA. The series resistance (R5 = 22Ω) at the gate bias network has provided overall gain flatness. All the resistances used are standard film resistances. To attach the single layer capacitor to the distributed network we have to use golden bonding wires. To compensate the effect of golden bonding wires a rough estimated inductor has been introduced in series with the capacitor.

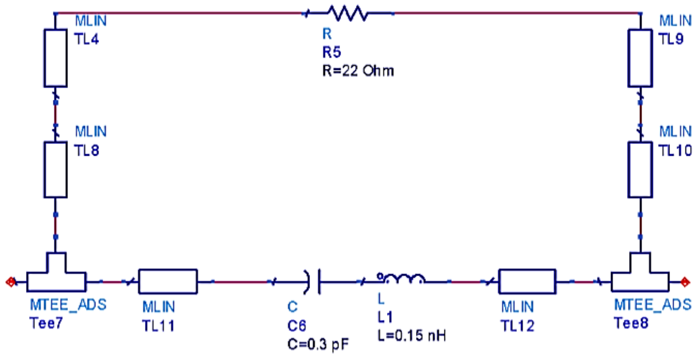


Fig. 3 Schematics of stability network

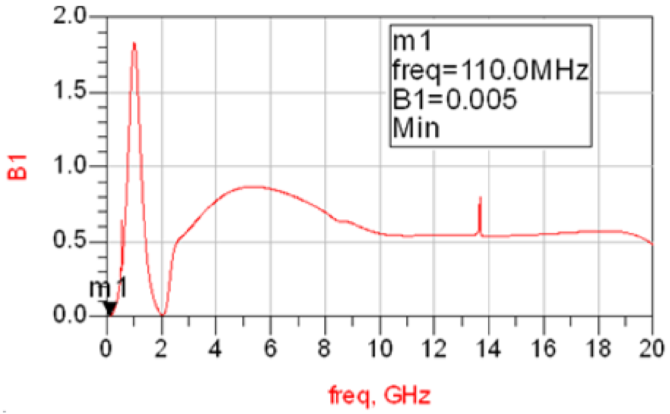


Fig. 4 Stability measure (|Δ|)

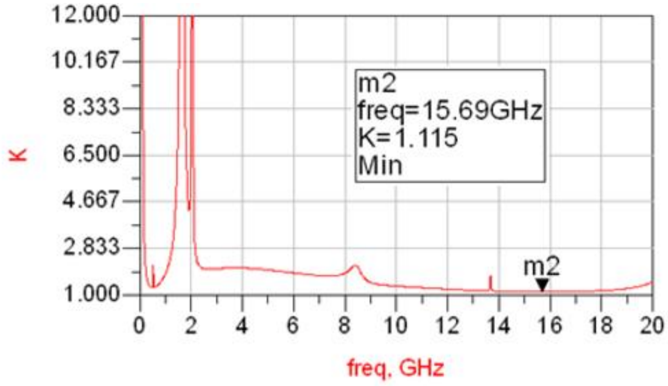


Fig. 5 Stability Factor (K)

As stated earlier, the stability factor (K) > 2 and stability measure (|Δ|) > 0 for a PA to be unconditionally stable. Fig. 4 shows that the stability measure is greater than 0 for the entire operational Ku band while the stability factor shown in Fig. 5 is close to 1 over the entire Ku band frequencies.

c) Bias network:

The bias network blocks the unwanted DC and RF signals while rests of the signals are passed un-attenuated. This can be achieved by designing a bias network which operates as open circuit at the operational frequencies. However, special attention has to be paid while considering the blocking frequency of the bias network. Here, we have designed an open circuit by using an open radial stub together with a quarter wave transmission line. To electromagnetically define an open radial stub, a short transmission line between open radial stub and tee is used. This is because the open radial stub is transformed into short circuit at a tee junction while a 90^{O} transmission line transforms a short circuit to open circuit at the gate of the device. Fig. 6 shows schematics of the bias network.

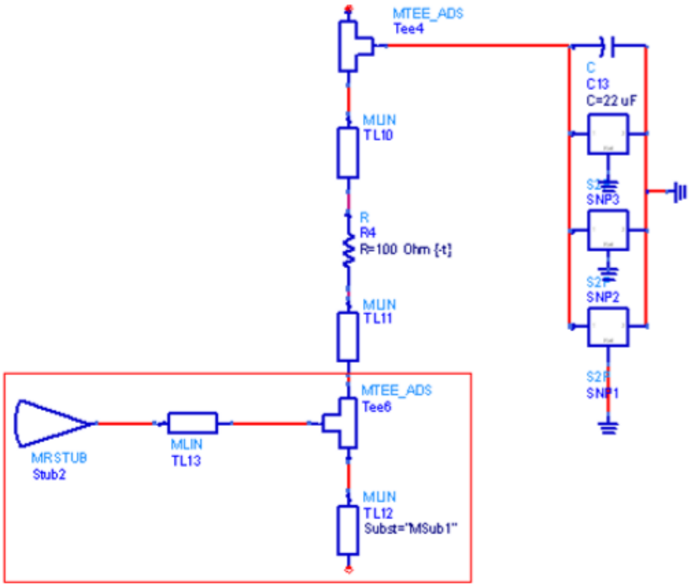
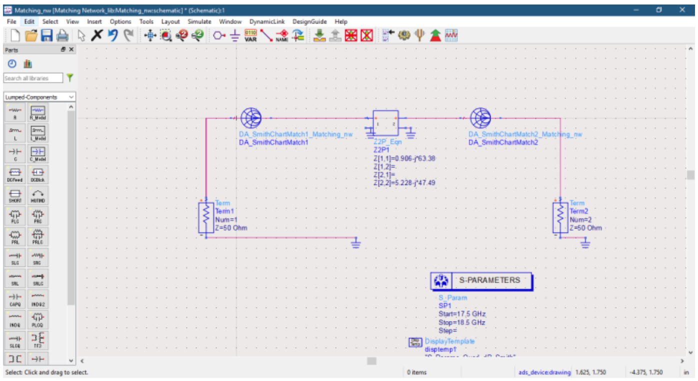


Fig. 6 Bias network schematics

d) Matching network:

The maximum power transfer theorem states that maximum power can be transferred from source to load if source and load impedances are perfectly matched. The matching network works on the principle of maximum power transfer theorem by providing transformations from Z_{source} (source impedance) and Z_{load} (load impedance) to standard 50Ω termination. Matching source and load impedances to standard 50Ω termination ensures that desired maximum power, gain or PAE is achieved. Hence it is important to find the optimum values of source and load impedances through proper simulation. With ADS auto tuning feature, finding these optimum values is relatively very easy.

Fig. 7 shows input and output impedance matching optimization using ADS simulation software. The input matching network for the gain stage is designed to transform 50Ω transmission line impedance to the source impedance of 0.906-j*63.38 (as shown in Fig. 8) while the output matching network is designed to transform the load impedance of 5.228-j*47.49 to 50Ω transmission line impedance (as shown in Fig. 9) (Refer Table III for Z_{source} and Z_{load} values)



Z[1,1]=0.906-j*63.38
Z[1,2]=
Z[2,1]=
Z[2,2]=5.228-j*47.49

Num=1
Z=50 Ohm

Num=2
Z=50 Ohm

Start=17.5 GHz
Stop=18.5 GHz
Step=

Fig. 7 Input and output matching n/w optimization using ADS

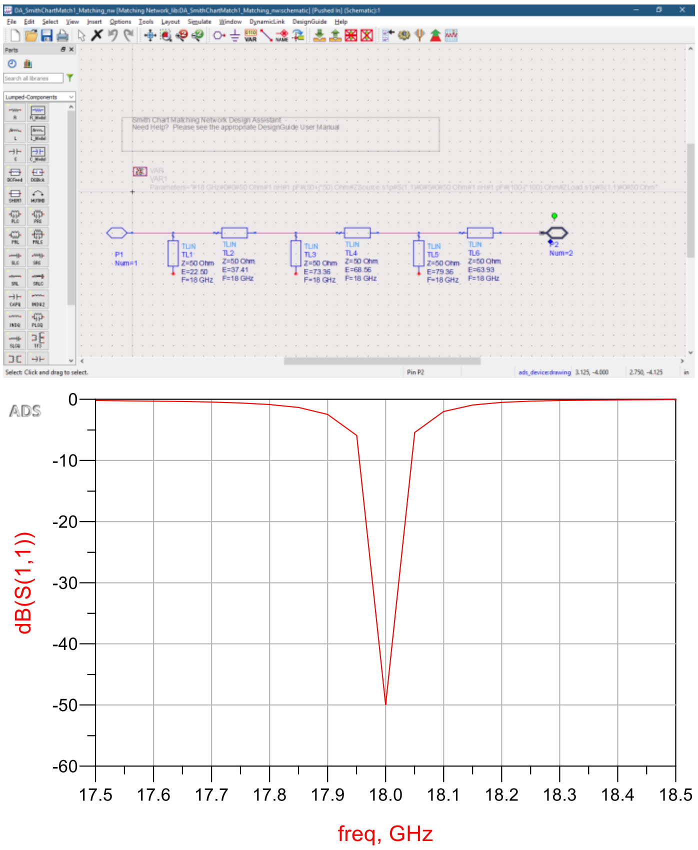


Fig. 8 Input matching network schematics and corresponding S_{11}

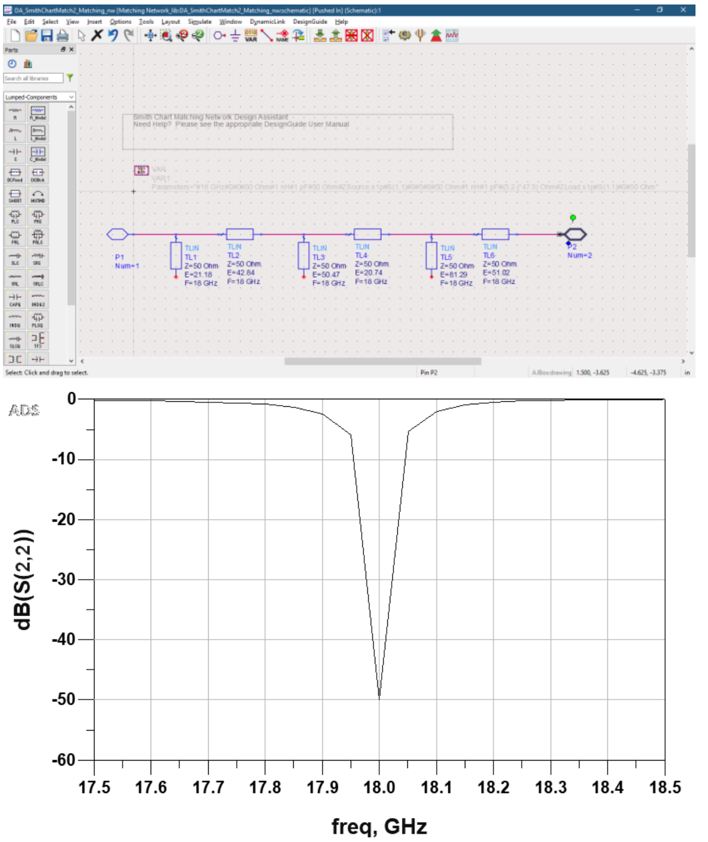


Fig. 9 Output matching network schematics and corresponding S_{22}

e) Gain stage amplifier design

As stated earlier, the gain stage of the PA is designed to drive the power stage of the PA. As the name suggests, the gain stage is designed to provide most of the overall gain of the PA. Hence, source-pull and load-pull simulations for high gain are carried out and matching network based on these impedances is designed. Table III shows the gain, PAE, source and load impedances of gain stage of proposed PA.

Table III: Input and Output impedances of gain stage

Pin	Pout	Gain	PAE (%)	Z_{source}	Z_{load}
21	32.94	11.94	21.45	0.906-j*63.38	5.228-j*47.49
22	34.00	12.00	24.32	0.906-j*63.38	5.228-j*47.49
23	35.04	12.04	27.46	0.906-j*63.38	5.228-j*47.49
24	36.04	12.04	30.90	0.906-j*63.38	5.228-j*47.49
25	36.98	11.98	34.52	0.906-j*63.38	5.228-j*47.49
26	37.82	11.82	38.05	0.906-j*63.38	5.228-j*47.49
27	38.44	11.44	40.52	0.906-j*63.38	5.228-j*47.49

III. Results And Discussions

The proposed single stage PA (the gain stage) provides a gain of 10.340 dBm (as shown in Fig. 10) while an output power of 8.929 dBm(as shown in Fig. 11) for applied input of 24.00 dBm. The output of the gain stage will be then applied to the power amplifier. As stated earlier, the gain stage provides most of the overall gain of PA while power stage provides most of the overall power of PA. Hence, a small noticeable change in the gain can be observed after designing of the second stage (the power stage) of the PA. The final gain, efficiency and PAE delivered by the PA will be calculated after the design of power stage.

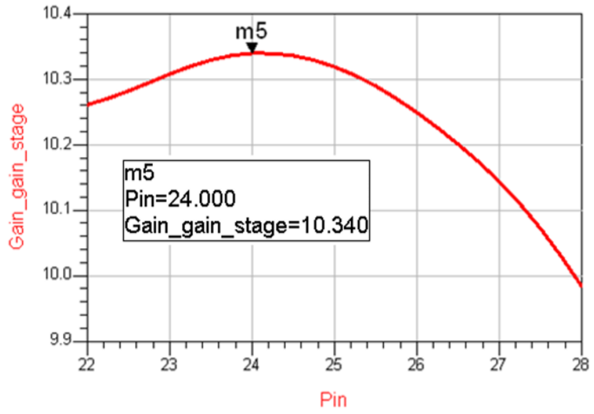


Fig. 10 Gain of the gain stage of PA

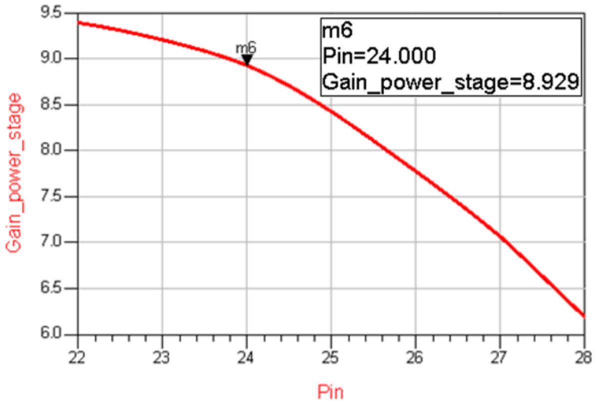


Fig.11 Output power delivered by gain stage of PA

IV. Conclusion And Future Scope

In this paper, a 0.25µm GaN-HEMT technology based Ku band (12-18 GHz) amplifier is designed using ADS Keysight simulation software. The proposed single stage amplifier consists of gain stage that provides a high gain of 10.34dBm (>10 dBm as per technical specifications mentioned in Table I) while low output power of 8.929 dBm. Thus in the later design part we need to design a power stage amplifier that will meet the technical specifications of high output power and high PAE.

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