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Design of Class-A RF Power Amplifier For S-Band

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ABSTRACT

Military communication equipment is build to encode, decode transmissions and carry on rough treatment in unfriendly climates. They use various bands of frequency to send and receive signals to other radios and satellites. The unmanned aerial vehicle contains digital QPSK transmitter which successes the power amplifier. The telemetry takes place in S-band frequency (2.2-2.3GHZ) and Class-A PA is to be design to operate such high frequency. In this paper a RF power amplifier of Class-A is designed to work in the frequency range of 2.2GHz to 2.3GHz with GaN HEMT. Designed single stage PA provides optimized performance, over desired band with 17 dB signal gain and 1W output power with 21.18% power added efficiency .The proposed RF power amplifier operates with 28 V drain bias voltage and has been implemented with Gerber PCB design software. The proposed power amplifier design is simulated by using software tool Advanced design system (ADS). The simulation results show that RF power amplifier is implemented for S-band with high power ability in the practical frequency range.

Keywords— Power amplifier(PA), Class-A, RF, Gallium Nitride device (GaN)

I. INTRODUCTION

RF PA is a circuit that converts the RF power to the load by amplifying the input power. The power amplifier design involves several critical parameters such as output power, efficiency and linearity. A GaN HEMT was preferred because of low parasitic capacitances value with high power density and voltage operation values. [10, 11].

An AlGaN/GaN HEMT has superior performance with high voltage operation because of very good properties of material. There is advanced requirement for high output power devices for S-band applications like Marine, Meteorological and military RADARs. Several papers have reported AlGaN/GaN HEMTs with high output power characteristics is selected for various bands [3], [4].

In this paper, we report design of a RF S-band PA with AlGaN/GaN HEMT. The result indicates the S-band AlGaN/GaN HEMT developed in the practical frequency range for S-band applications.

Class-A power Amplifier

Transistor power amplifiers can handle large signals. So they are usually classified as per their mode of operation, amount of transistor bias and input signal amplitude. The power amplifier is classified based on the conduction cycle of device. They are classified as class A, class B, class AB, class C and class D power amplifier.

Class A PAs are inherently linear circuits where the transistor are biased to conduct over the full cycle of input signal. The maximum theoretical efficiency of Class-A PAs is 50 % that means half of the supplied DC power is dissipated in the active device. So Class A amplifiers are characterized by a high output fidelity output and also small A output power per transistor. The maximum achievable efficiency is 25% with resistive load. Class-A power amplifier are used in applications that require low output power levels and where power dissipation and efficiency are less important.

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II. ANALYTICAL DESIGN OF POWER AMPLIFIER

The power amplifier design involves a set of trade-offs such as linearity, output power, efficiency, power gain etc. The structure of the power amplifier, Selection of biasing point, class of operation and technology of the active device are determined by the designer.

A. Transistor selection

Transistor selection is the initial step in power amplifier design. In this paper, Cree's GaN HEMT transistor CGH40006P is selected for class A PA design of 1W output in S-band. This transistor is selected based on its advantages and the data given in its data sheet. GaN HEMT was chosen because the parasitic capacitances of GaN HEMTs are low as compared to GaAs MESFETs with high power density and voltage operation. As per the requirements, this transistor was used as an active device in proposed design, which gives superior performance.

B. DC Biasing

Biasing: making the circuit to determine the specified DC voltages and currents for the operation of the electronic equipment.

- Biasing by fixing VGS and finding the input power with the drain current.

$$\text{Drain current} = \frac{\text{DC Power}}{\text{Drain to source Voltage}} = \frac{P_{DC}}{V_{DS}} \quad \ldots\ldots\ldots\ldots\ldots\text{(1)}$$

$$\text{Input power (Pin)} = \text{output power (Pout)} = \text{Gain (G in dB)}$$

C. S-parameter analysis

S-parameter describes the electrical behavior of linear electrical signals. S-parameters can de defined by using the wave functions in two-port network is as shown in the Fig.1

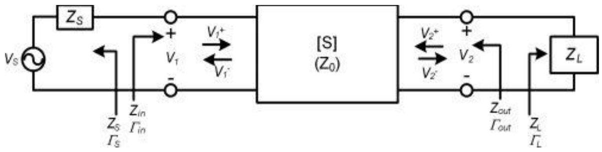

Fig1: Two Port Network with General Source and Load Impedance

The connection is made between the mirrored and incident power waves; therefore the S-parameter matrix is given by:

$$\begin{bmatrix} b1 \\ b2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

Voltage standing wave ratio: The voltage standing wave ration (VSWR) at a port is represented by "s", is the ratio of the standing wave maximum voltage to the standing wave minimum voltage.

At the input port, S_{in} is given by

$$\mathbf{s_{in}} = \frac{1+|s_{11}|}{1-|s_{11}|} \quad \ldots\ldots\ldots\text{(2)}$$

At the output port, S_{out} is given by

$$\mathbf{s}_{out} = \frac{1+|s_{22}|}{1-|s_{22}|} \quad \ldots\ldots\ldots\text{(3)}$$

D. STABILITY FACTOR ANALYSIS

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For any design of an amplifier, the stability of the device is very important by time inspection; otherwise the amplifier may turns into an oscillator. The most important way of finding the stability of the device by calculating the Rollett's stability factor (K).K is calculated by means of set of S-parameters at the operated frequency.

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} \qquad \text{………. (4)}$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| \qquad \text{………. (5)}$$

The parameters must satisfy K>1 and |Δ|<1 for a transistor to be unconditionally stable. Once the K is calculated and find the device must satisfy above condition, then Maximum Available Gain (MAG) can be calculated.

$G_{MAX} = \frac{|S_{21}|}{|S_{12}|}$ *(K-_K2-1) (maximum available gain) ……..… (6)

Where K must be within unity, the equation(6) becomes :

$$G_{MSG} = \frac{S_{21}}{S_{12}} \qquad \text{…………….. (7)}$$

where MAG is also known as Maximum stable gain (MSG)

E. Gain

Using S-parameters, the overall transducer gain can be calculated. There are three parts in the transducer gain such as Source gain, load gain and the output gain. Overall transducer gain = $10\log_{10}$ (Go, Gs, Gl).

$$G_S = \frac{(1 - |\Gamma_S|2)}{(\ |1 - S11\Gamma_S|2)} \qquad \text{.....…..… (8)}$$

$$G_L = \frac{(1 - \ |\Gamma_L|2)}{(\ |1 - S_{22}\Gamma_S|2)} \qquad \text{.....…..… (9)}$$

G_O=|S21|2

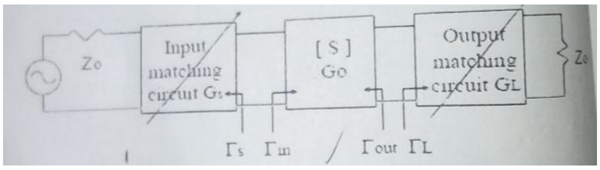

Fig2: Blocks of input and output matching

III. IMPLEMENTATION OF CLASS A RF POWER AMPLIFIER

The proposed design is implemented by using software tool ADS. This tool is widely for Radio Frequency, Microwave and high speed digital applications. Class A power amplifier is designed to operate in the frequency range by using ADS in an integrated platform.

- **Frequency range : 2.2 GHz to 2.3 GHz**
- **Centre frequency : 2.25 GHz**

The design steps are:

STEP 1: Open new schematic window. Use FET Curve Tracer to plot the I-V characteristics. Load lines are plotted and bias point is selected for the desired class of amplifier used.

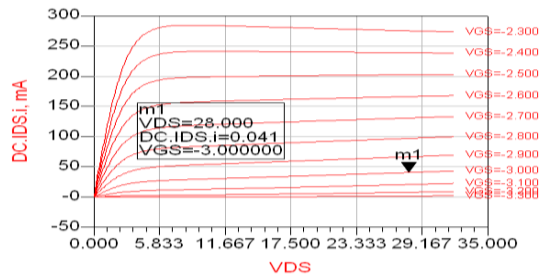

Fig3: I-V Characteristics Curve

STEP 2: Design bias network and determine the resistor value to get bias between gate and drain. Perform by using DC simulation. Use DC feed for RFC.

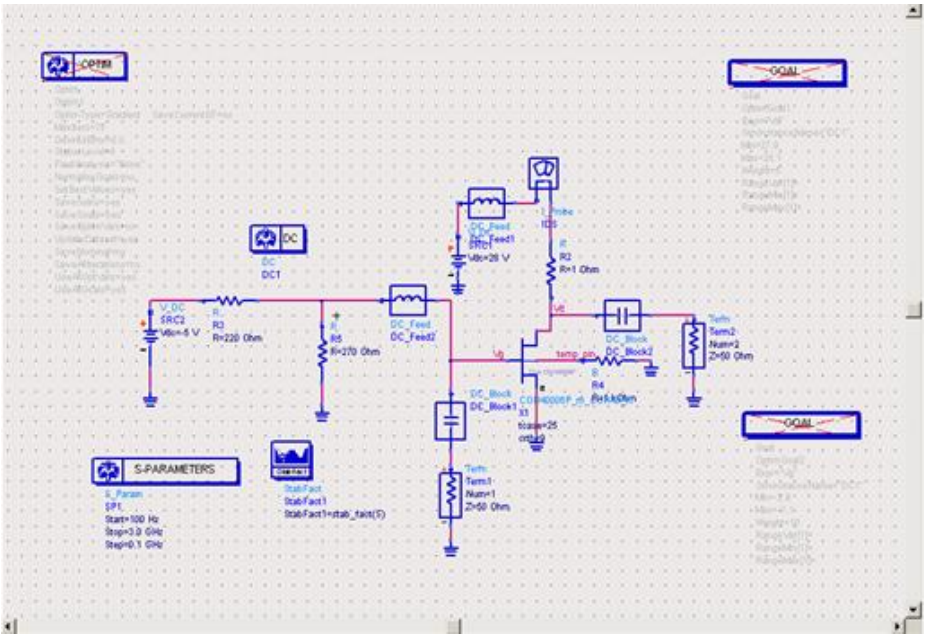

Fig4: DC Bias Network

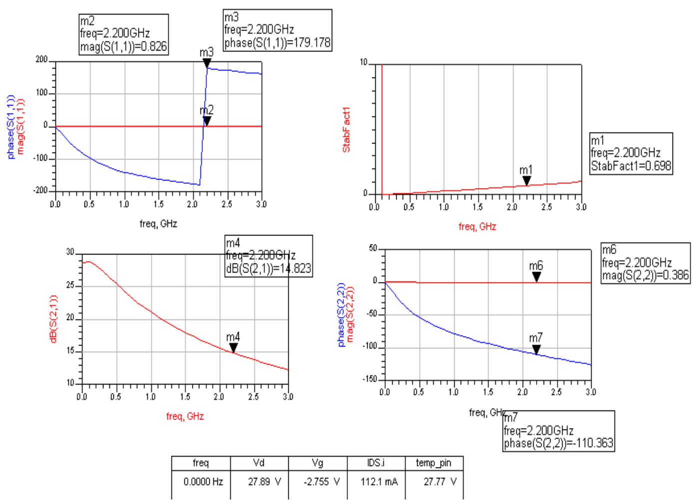

Fig5: DC Bias Circuit Simulation Result

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STEP 3: Run S-parameter simulation to check input and output stability. It is found from simulation results that stability factor, K=0.698<1 and hence the device is inherently unstable at the desired frequency range.

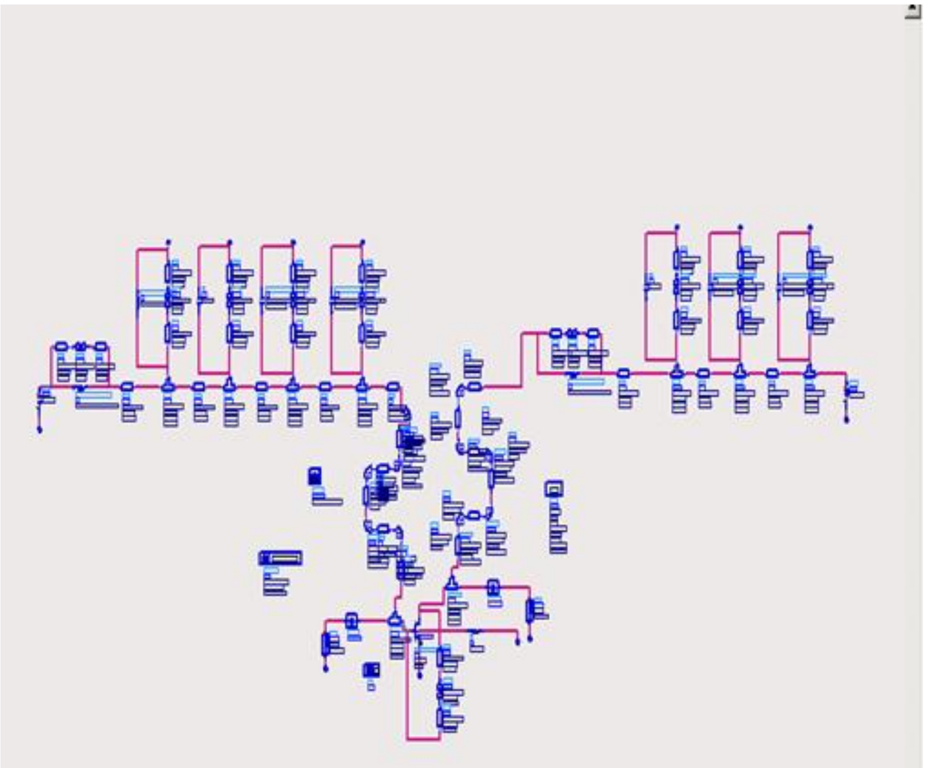
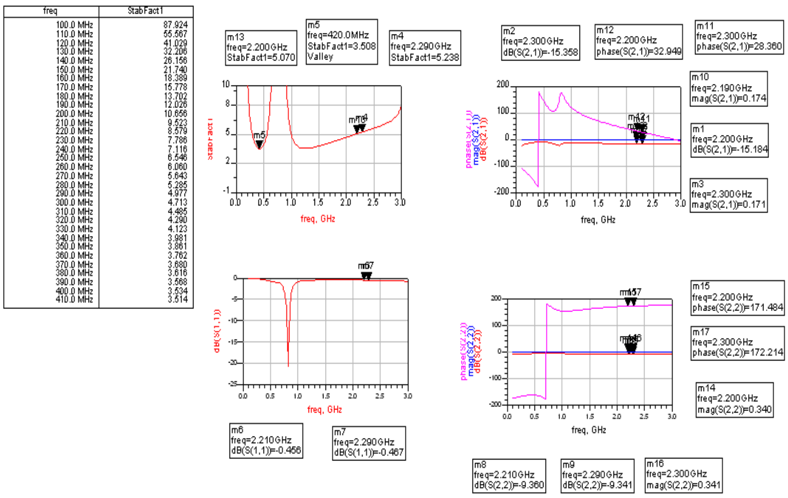


Fig6: Addition of Surface Mount Devices



freq	StabFact1
100.0 MHz	87.924
110.0 MHz	55.567
120.0 MHz	41.029
130.0 MHz	32.206
140.0 MHz	26.156
150.0 MHz	21.740
160.0 MHz	18.389
170.0 MHz	15.778
180.0 MHz	13.702
190.0 MHz	12.026
200.0 MHz	10.656
210.0 MHz	9.523
220.0 MHz	8.579
230.0 MHz	7.786
240.0 MHz	7.116
250.0 MHz	6.546
260.0 MHz	6.060
270.0 MHz	5.643
280.0 MHz	5.285
290.0 MHz	4.977
300.0 MHz	4.713
310.0 MHz	4.485
320.0 MHz	4.290
330.0 MHz	4.123
340.0 MHz	3.981
350.0 MHz	3.861
360.0 MHz	3.762
370.0 MHz	3.680
380.0 MHz	3.616
390.0 MHz	3.568
400.0 MHz	3.534
410.0 MHz	3.514

Fig7: Simulation results for SMD Pad Device

- So design a stability network with RLC components at either input ,output or feedback.
- Now SMD pads in parallel are added to lumped components of the stability network and simulate and optimize.
- Ideal ground of the transistor is replaced by via (if the transistor needs to be grounded through via) and checks for stability and gain.

STEP 4: Perform input matching and then output matching

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- Place SMD pads and gaps for all the lumped components in parallel to it and optimize gain stability.
- Input and Output matching

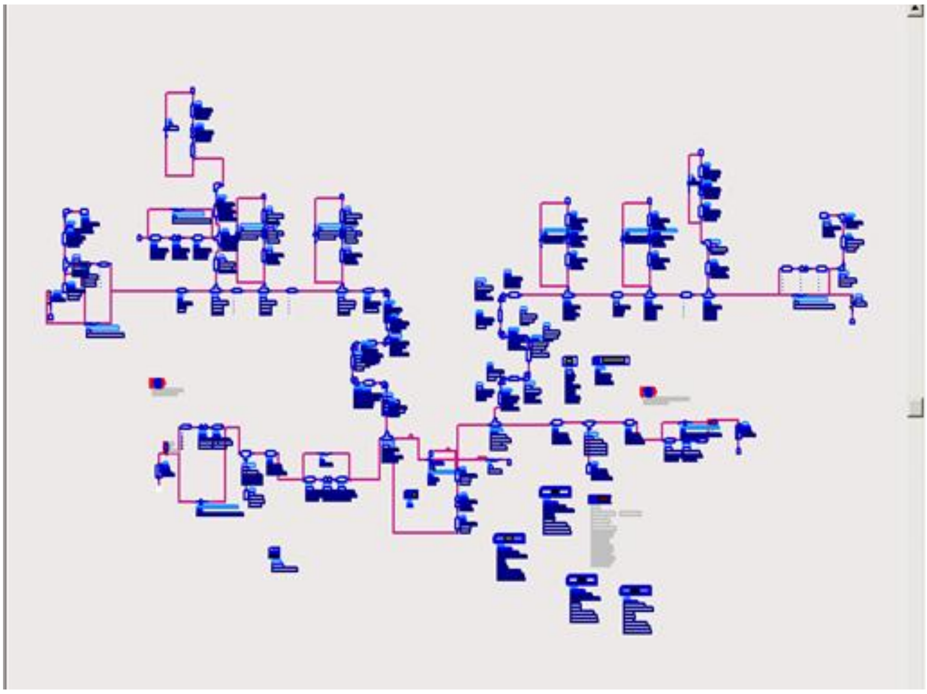

Fig8: Matched Circuit

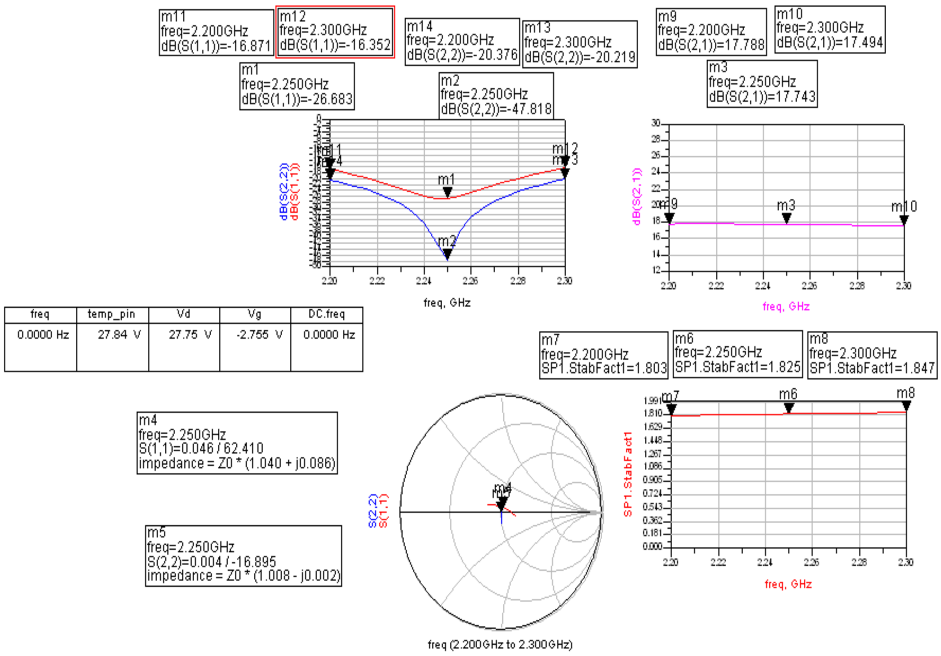

Fig9: Simulation Results of Matched Circuit

STEP 5: Disable all the lumped components and generate the layout.

STEP 6:

- Do S-parameter simulation and check the design response is desired.
- This is also called as Circuit-Electromagnetic-co-Simulation.

- ➢ Optimize lumped components if required.

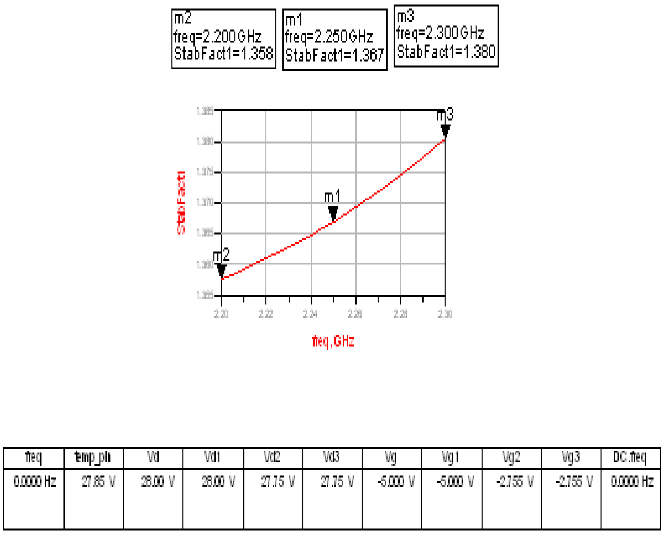

Fig10: S-Parameter simulation results

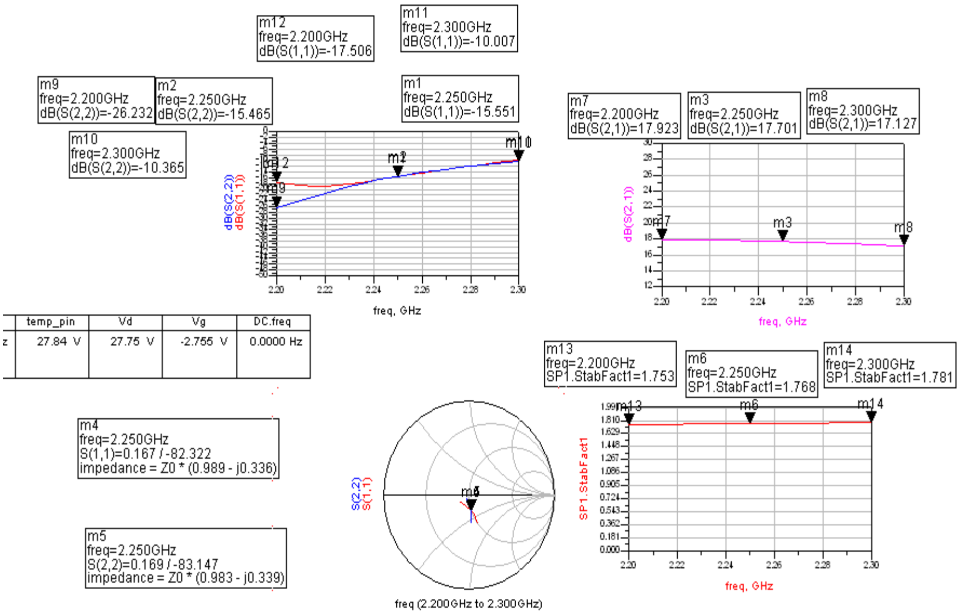

Fig11: Output of the Final Design

Fig.11 has the output results of the final power amplifier circuit with the table representing the DC values V_D, V_G. The smith chart gives the input and output return losses with the impedances. There is a stability factor vs frequency graph and a gain in db vs frequency graph. Finally there is a input and output return losses in db vs frequency which shows the losses in terms of db for different frequencies.

Simulation results:

In this paper proposed RF S-band Power Amplifier is designed using Agilent ADS software tool. The designed PA works in Class-A to get suitable parameters such as PAE and linearity. After implementation simulation results achieved are P load=1W, PAE=21.18%, Zin=0.989+j0.336 Ohm, Zout=0.989+j0.336 Ohm , K-Factor = 1.768 and Gain = 17.701db.

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IV CONCLUSIONS

Class A power amplifier is designed to operate in the frequency range of 2.2GHz to 2.3GHz. The transistor used in the design of power amplifier is CGH40006P. It is a 6Watt GaN HEMT. Initially its load lines are plotted and biased then it is found that the device is unstable, after the design of stability network it becomes stable and provides a stability of 1.768 over the entire band of frequency of operations. The PA provides a gain of approximately 17dB over the desired frequency band. The gate and drain voltages were designed to be -3V and 28V respectively. The final gate and drain voltages are -2.75V and 27.75V respectively.

The design is simulated on ADS in UAV flight conditions mode where the altitude is 2000-5000 meters, pressure is 60 Kpa and temperature of -15 to -40 degree Celsius. The initial S-parameter simulation of the dc biased circuit gives input return loss of magnitude of 0.826 and phase 179.181 and output return loss of magnitude of 0.386 and phase of -110.341.These losses are reduced after Surface Mount Padding, tuning and optimization is performed. Input return loss of magnitude 0.167 and phase -82.322 and output return loss of magnitude 0.169 and phase -83.147 is obtained. Even though much of these losses are reduced with the help of tuning and optimization, the existing losses contribute to the power added efficiency. Single stage PA is designed that providing optimized performance, over desired band with 17 dB small signal gain and 1W output power with 21.18% PAE. This simulation result obtained let us to use this power amplifier with QPSK modulations.

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