200W Ku-Band Gan HEMT Power Amplifier For Satellite Communication

Vivek V. Ratnaparkhi, Anil S. Hiwale

Abstract: Design of 200W Ku band GaN HEMT power amplifier is presented. A balanced configuration using 20 mm bare die packaged GaN HEMT device is discussed. Branch line coupler is used to parallel cascade two single stage power amplifiers. Inductor based equivalent bondwire array model is used for this design. Simulated performance of power amplifier (PA) shows 200W output power with drain efficiency of 68% and power added efficiency (PAE) of 53% at design frequency of 11.10 GHz. Less than 0.5 dB variation in large signal gain is observed between 11.07-11.20 GHz band of frequency. Proposed GaN HEMT power amplifier can be used to replace conventional travelling wave tube amplifiers (TWTAs) used in Ku-band satellite communication.

Index Terms: GaN, Ku band, PAE, Satellite Communication, TWTA.

1 Introduction

TRAVELLING wave tube amplifiers (TWTAs) are used for high power amplification in satellites. For Ku-band satellite applications TWTAs are widely used due to its high output power and high efficiency compared with GaAs solid state power amplifiers (SSPAs) [1]. However, TWTAs need very high applied voltages and have limited lifetime. They also require large amount of time to start transmitting full output powers. These limitations are not convenient for broadcasting and news gathering systems using Ku-band satellite communications. On the other hand, SSPAs need lower applied voltages, have longer lifetime and require shorter preparation time than the TWTAs [3]. Hence, SSPAs are expected to replace conventional TWTAs used in satellite communications. Since last decade potential consideration is given to GaN HEMT based SSPAs for satellite as well as terrestrial communications. High operating voltage, higher power density, and higher thermal conductivity are major advantages which lead to extensive use of GaN devices in high power amplifiers [4]. There are various high power amplifiers presented in literature [5, 6, 7, 8] using GaN HEMTs. Discrete GaN HEMTs can work for extremely wide bandwidth from DC-26 GHz. In comparison to MMIC power amplifier, discrete GaN transistor PA can obtain higher output power in a specific band, and has a greater tuning flexibility and lower cost [9]. In this paper, parallel cascaded balanced configuration 200W high power amplifier is designed and simulated which produces 68% of drain efficiency and 53% of power added efficiency for Ku-band Indian satellite applications. To the best of authors' knowledge this is the highest output power and PAE reported at Ku band using balanced configuration. Qorvo's TGF2023-2-20 GaN HEMT device is used to design proposed power amplifier [10]. Due to its better thermal conductivity we have preferred alumina substrate for our design [11]. Alumina has dielectric constant of 9.8, thickness of 25 mil, and 0.0002 loss tangent is used for this design.

2 Circuit Design

A hybrid approach using bare-die transistor is preferred for considerable reduction in PA cost. There are two major challenges for hybrid PA design at microwave frequency. First, huge parasitic will be introduced by assembling and requirement of bondwires to connect device with microstrip substrate. Second, tolerances due to manufacturing constraints which may result into bandwidth limited matching networks [12]. Power amplifier design is started with obtaining accurate non-linear model from the device manufacturer. TGF 2023-2-20 is die packaged GaN HEMT device which requires bond wire arrays to connect it with microstrip. To model bond wire array we have used equivalent inductors in our design. The value of inductor is calculated theoretically as well as using EDA tool. At the beginning, DC analysis is carried out to fix proper bias point of amplifier. Class AB mode of operation is selected to achieve good compromise between efficiency and linearity. Device is biased at 28V VDS and 954mA of drain current. Since, device is unstable at lower frequencies stabilization network is used at input side. Parallel combination of resistor and capacitor in series with gate and series resistor in gate bias line is used for stability improvement. Load pull analysis is performed to find out value of load impedance which can produce maximum output power. Load impedance ZL= 2.33-j17.2 Ω and source impedance ZS=31.53-j97.019 Ω which are obtained after load pull need to be matched with 50 Ω impedance. Generally, higher order matching networks are used to improve bandwidth performance which can be achieved at the cost of higher insertion losses. To obtain reasonable bandwidth with minimum insertion losses a novel and simple matching networks are designed. Multiple transmission line sections with variable length and width are used to design matching networks. Fig.1 shows complete amplifier circuit which is ready for EM-Circuit cosimulation.

3 Simulation Results

In this section, simulation results of proposed power amplifier are presented and discussed. According to the design specifications, the power amplifier should provide at least 7 dB gain and PAE more than 45 %. The output power should be more than 150 W.

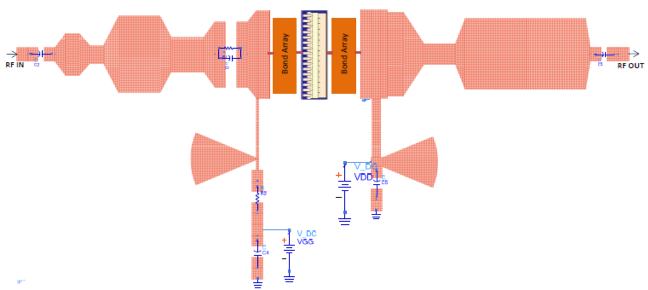

Fig.1. Single stage Ku band GaN SSPA

The complete amplifier is designed and simulated using Keysight's Advanced Design System (ADS) software. Different characteristic parameters of designed SSPA are simulated and shown in this section. Fig.2 shows output power and large signal gain of proposed high power amplifier. It is seen that, output power is more than 90W and large signal gain is higher than 7 dB. Fig.3 shows drain efficiency is more than 60%, power added efficiency is greater than 50% in the range of 11.025-11.170 GHz. At design frequency of 11.10 GHz output power is found to be 105.11W, PAE found to be 59.18% and large signal gain is 7.5dB. Drain efficiency at design frequency is 70.63%. Power amplifier performance with input power sweep is shown in Fig.4, which shows the PAE and drain efficiency performance of designed PA with input power sweep. Generally GaN based PAs are designed and operate at 2-3 dB compression level to get maximum output power. To obtain 105W of output power we have driven our PA at 3 dB compression. The obtained results of TGF 2023-2-20 die packaged GaN HEMT device are very much closer to the performance specified in device datasheet. The stability of amplifier is also checked and it is found that designed PA is stable from DC-15 GHz. Fig.5 shows return loss performance of single stage Ku-band SSPA. Return loss performance is just acceptable and can be further improved by using balanced configuration. Ideally, this results in the same gain and twice the output power as the input signal.

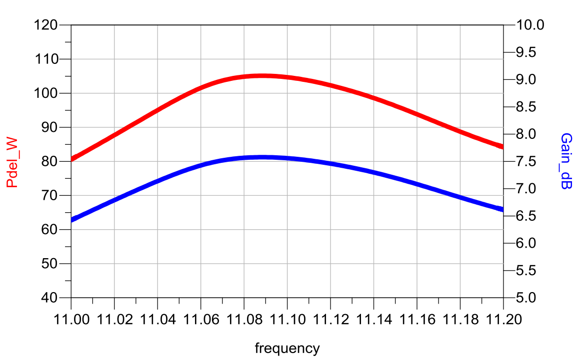

Fig.2. Output power and gain of single stage PA

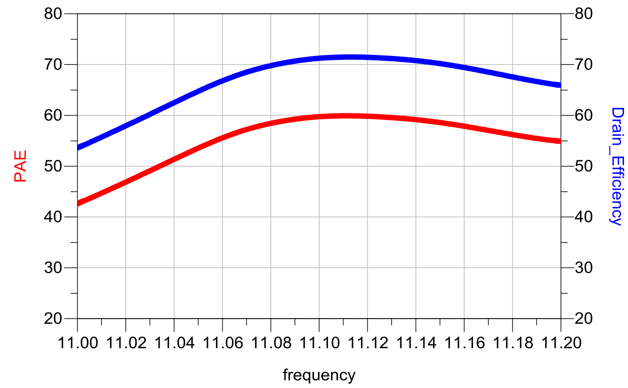

Fig.3. PAE and drain efficiency of single stage PA

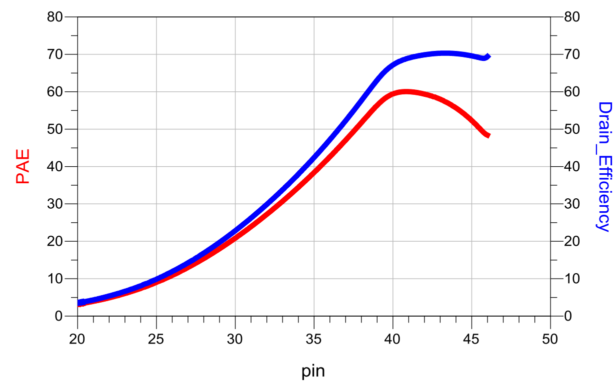

Fig.4. Efficiency over input power sweep of single stage PA

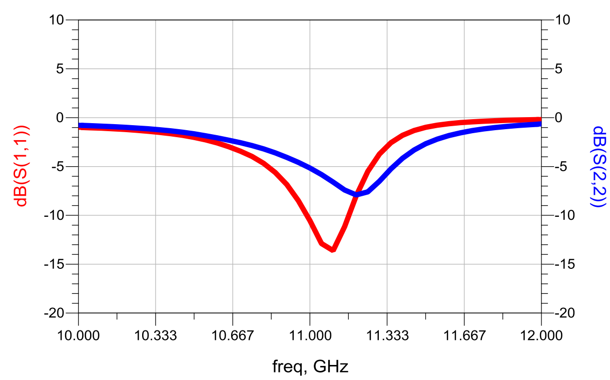

Fig.5. Return loss of single stage PA

Two single stage amplifiers are parallel cascaded to improve output performance. It is necessary to maintain amplifier efficiency and bandwidth while improving output power performance. Balanced configuration as shown in Fig.6 is used to combine two single stage amplifiers [9]. It consists of 3 dB quadrature hybrid coupler used to split the input signal into two components with a 90^0 phase difference between them. The signals are then fed to two paired amplifiers and then combined together by another 3 dB quadrature hybrid coupler at the output of the PAs. Branch line couplers are used in balanced configuration. Since, fourth port is terminated with 50 Ω this will always result into better VSWR performance.

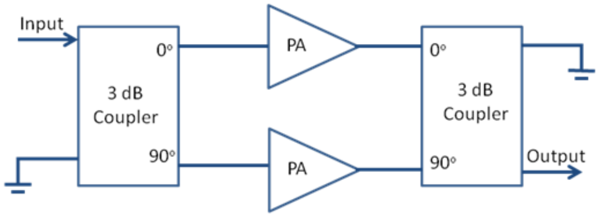

Fig.6. Typical balanced configuration

Length and width of this branch coupler is calculated and optimized to some extent for better response using Keysight's ADS. The amplitude and return loss response of branch line coupler is shown in Fig.7.

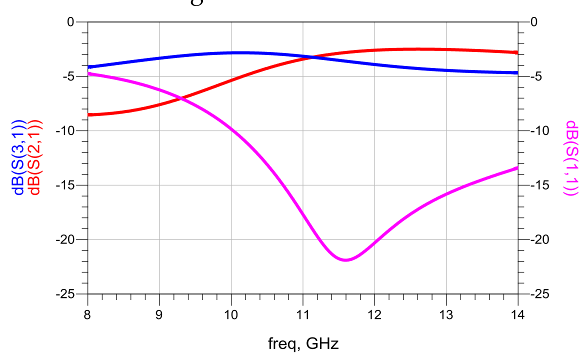

Fig.7. BL coupler response

Two single stage PA as shown in Fig.1 are parallel cascaded by using above discussed branch line couplers. Branch line couplers are designed and optimized in such a way that, they should offer minimum insertion loss. It can be seen from Fig.7, BL coupler offer 0.25 dB of insertion loss. Amplitude and phase imbalance of BL coupler is also maintained over desired frequency range. Frequency response of parallel cascaded balanced PA is plotted in Fig. 8 which shows output power and gain response over the frequency sweep. It is observed that, almost 200W of output power is obtained at design frequency of 11.10 GHz. Large signal gain is also more than 7 dB at design frequency. The PAE and drain efficiency is plotted in Fig.9, and it is found that PAE is more than 53% and drain efficiency is about 70%. Two stage power amplifier performance with input power sweep is shown in Fig.10. The Most importantly, the return loss improvement can be seen in Fig.11, which is due to use of branch line coupler.

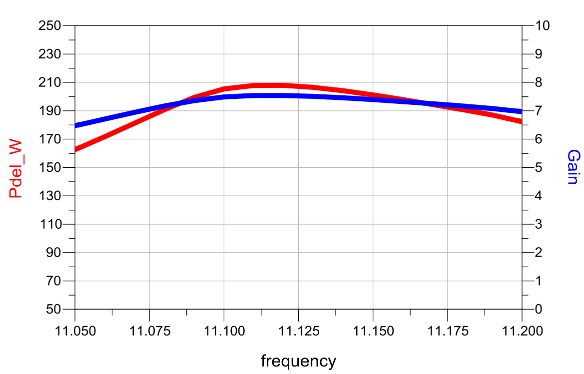

Fig. 8. Output power and gain of two stage PA

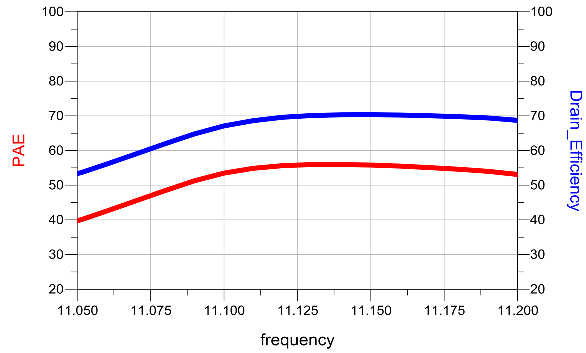

Fig. 9. PAE and drain efficiency of two stage PA

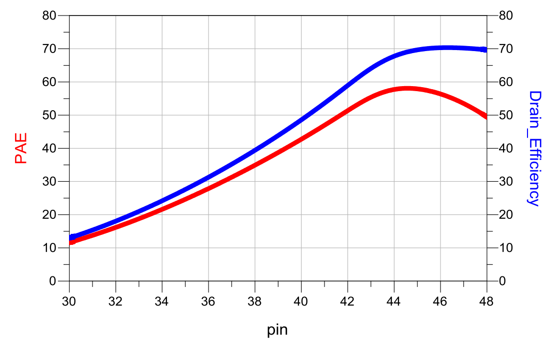

Fig. 10. Efficiency over input power sweep of of two stage PA

The reasonable improvement in return loss bandwidth is obtained by using BL couplers. The input and output return losses S11 and S22 are well below -15 dB during 11-12 GHz. However, the complete response of two stage parallel cascaded PA is slight shifted towards higher frequency.

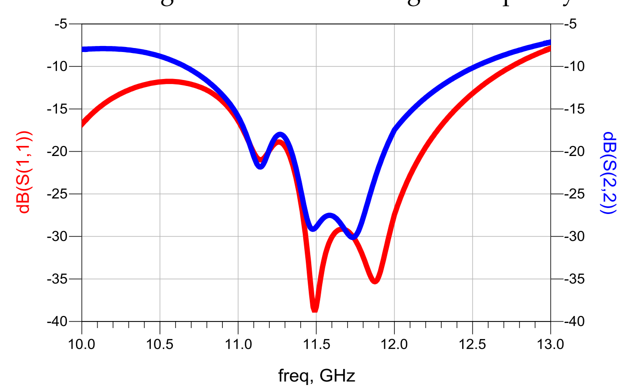

Fig.11 Input and Output return losses of two stage PA

Table 1 compares state-of –the art Ku band PAs, and it is seen that proposed PA produce highest output power and efficiency reported ever.

Table 1*Comparison of State-of-the art Ku band Pas*

Reference	Bandwidth (GHz)	Pout (W)	Gain (dB)	PAE (%)
2011[2]	14.75-15.25	62	8.9	45
2009[3]	14-14.5	120	27	9
2014[9]	13.3-13.7	33.8	7.3	30
2016[12]	13.75-14.5	12	6	23
2014[13]	13.75-14.5	80	--	22
This Paper	**11.05-11.20**	**200**	**7.5**	**53**

4 Conclusion

In this paper 200W high power amplifier with 53% power added efficiency for Ku band Indian satellite applications is presented. TGF2023-2-20 bare die GaN HEMT is used for this design. Novel matching network topologies have designed to achieve optimum bandwidth with minimum insertion loss. Table I shows comparison of state-of-the-art Ku band power amplifiers. Proposed power amplifier has highest output power and efficiency reported by the time for Ku-band applications.

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