

# **X-band Power Amplifier using pHEMT GaAs Technology with Harmonic Tuning**

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**ABSTRACT:** This paper describes a new method to the design and measured performance of Monolithic Microwave Integrated Circuit (MMIC) power amplifier (PA) for application in communication circuit systems that increase efficiency, output power, gain, small return loss (input & output) and low cost in the circuit. The proposed method is based on a combination of a GaAs power amplifier along with power divider/combiner. The power amplifier (PA) is designed using 0.1 $\mu$ m GaAs power pHEMT technology. The combination and design of the proposed power amplifier ensure gain of over 21dB in the 8 to 12GHz (X-band) frequency bandwidth. With only 3.0 V of drain voltage (VDS) to driver and 4.0V of drain voltage to 2nd stage, the PA exhibits an output power at 1dB gain compression (P1dB) of 23.059dBm, and gain of 22.959 dB, respectively. The maximum current, I<sub>max</sub> of this packaged amplifier is 49mA and the power consumption for the device is 650mW. This method has desirable amplitude for the output signal in the fundamental and 2nd harmonics.

**KEYWORDS:** Monolithic microwave integrated circuit (MMIC), X-band, GaAs, pseudomorphic high electron mobility transistors (PHEMTs), power amplifier (PA), power divider/combiner.

## **I. INTRODUCTION**

In recent times, the market has grown significantly for wireless communication [1]. As a developing market, the communications industry has seen enormous advancements, which result in progressively and distinctive using this technology [2]. This consistent growth has transformed wireless communication into a noteworthy industrial development centre and stand out amongst one of the most competitive ones. To tackle the market needs, an effort has been made in order to improve the transceiver design, as well as to reduce implementation costs, using low cost technologies and solutions that allow a better operational reconciliation [3][4]. Power amplifier is one of the main parts of transceiver [5]. Power amplifier consumes more power as compared with other parts of transceiver. There are different technologies used for designing of power amplifier such as CMOS, GaAs pHEMT, HBT, GaN technology. As compared to CMOS technology GaAs technology has higher speed of operation. GaAs technology provides high output power and efficiency than CMOS technology. Development in high electron mobility transistors is called as pseudomorphic high electron mobility transistors (pHEMT). Pseudomorphic high electron mobility transistors are widely used in power amplifier, low noise amplifier and wireless communications in high frequency range as compared to other technology [6][7] GaAs Monolithic Microwave Integrated Circuit (MMIC) technology has matured over the years [8] It is used for both microwave and millimeter wave applications. The high power achievement at X-band frequencies is neither cheap nor easy to design [9][10] Design of input/output matching circuits and device stability used to be a critical issue but with advancements in semiconductor industry, amplifier designers today prefer to use MMIC devices. This has not only made circuit design simple and less time consuming but also a lot of miniaturization is being achieved.[11][12][13]

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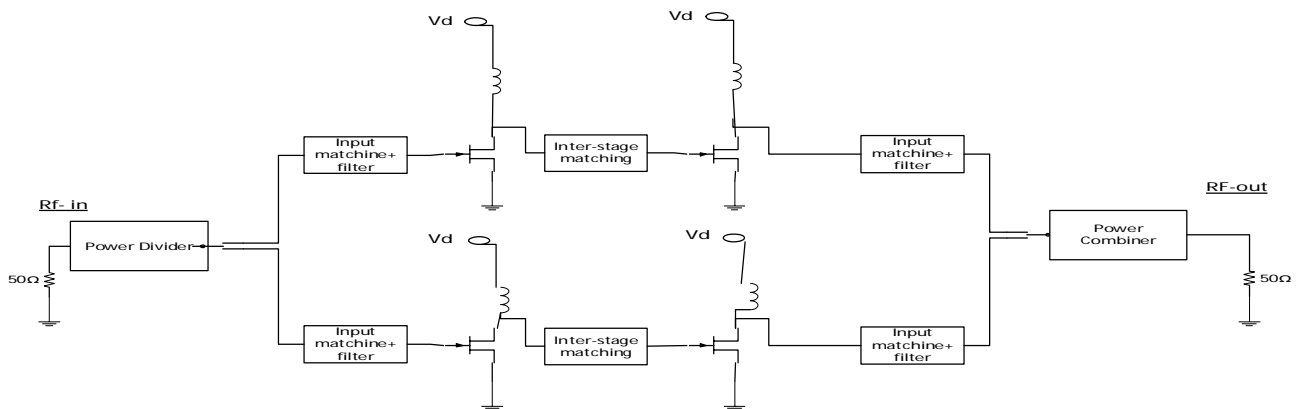
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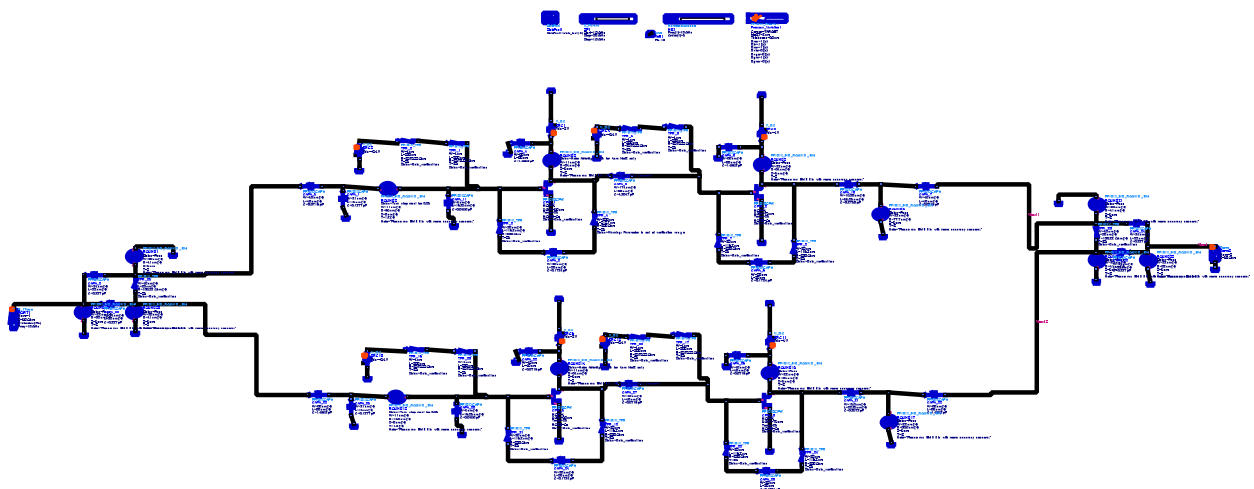
## II. CIRCUIT DESIGN

Power Amplifier design strongly depends on the operating frequency and applications, as well as on the available device technology in the market. This Power Amplifier circuit comprises of Power divider, 2 staged amplification using 4 FET and power combiner (Figure 1). The design of the power amplifier is based on GaAs pHEMT technology which has 4 no of fingers with a gate width of 100  $\mu\text{m}$ .



**Figure-1:** Block level diagram of a Power Amplifier

As depicted in the figure 2 the amplifier is based on a driver stage and a high power stage each stage having 2 FET. In power amplifier design, to achieve high accuracy and maximum power transmission, a matching network is required on the input and output to minimize the reflection problems. Input matching network and output matching network provides proper transformation of impedance between source (50 Ohm) and the PA as well as between PA and the load, in order to achieve maximum gain and output power.



**Figure-2:** Schematics of a Power Amplifier in ADS

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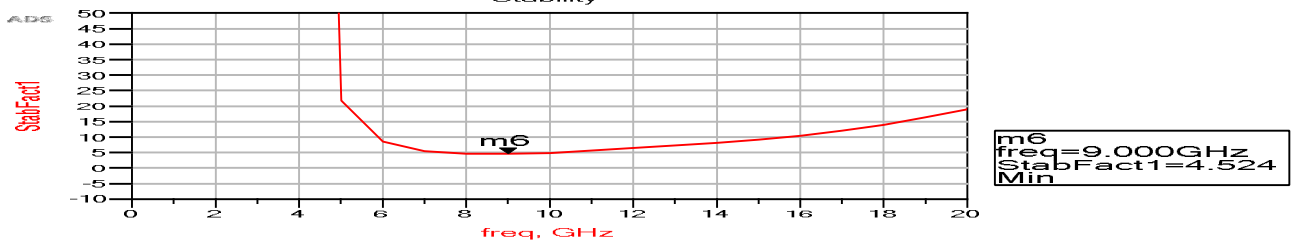
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### A. Stability analysis:

Stability is a very important element to consider when designing a power amplifier. Because of the high gain, oscillations are bound to happen if this is not considered. Our design is unconditionally stable if it passes K-Δ test Rollet's condition defined as [14]. Figure 3 shows the stability of the proposed design which has K always > 1 i.e. unconditionally stable for all frequency.

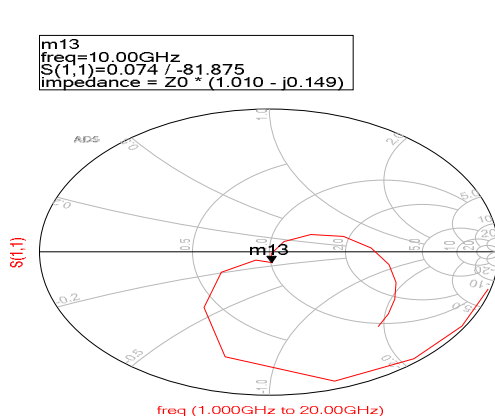
$$K = \frac{1 - |s_{11}|^2 - |s_{22}|^2 + |\Delta|^2}{2 \times |s_{12} \times s_{21}|} \dots\dots\dots (1)$$



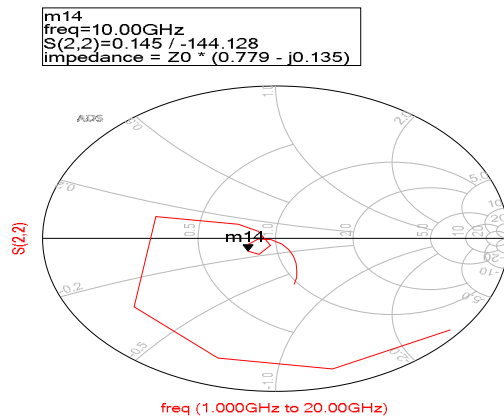
**Figure-3:**Stability factor measurement for X-band

### B. Impedance matching:

To have maximum power transfer is crucial to have good impedance matching at amplifier input. In this project the input matching network was designed with the help of Smith chart. Main aspect in a single stage amplifier is to design input and output matching circuits. But in case of multistage power amplifier, inter stage matching plays a vital role. The design of these networks are based on different matching function. The task becomes more significant and challenging in case of broadband power amplifier where a broader range of frequency is covered. The ultimate goal of matching network is to achieve maximum power transfer connecting two sections of network. In case of input it is focused on conjugate matching between complex impedance of power amplifier and signal source impedance. The input matching circuit is basically meant for resolving problems such as gain flatness, stability, input VSWR. As we all know, the input and output impedance of the RF power amplifier are both small, the input impedance is even smaller and slight change in frequency also cause a change in imaginary part, so the input matching is harder to design. The output matching is used to match output port and load. Its key function is to maximize output power transfer, improving output VSWR and suppress harmonic wave. The interstage network transforms the input impedance of the second-stage device to the optimal load impedance to present to the first-stage device.



**Figure-4(a):**Input impedance matching



**Figure-4(b):**Output impedance matching

### C. Power divider/combiner:

Power dividers have served a prominent role for years in RF and microwave community. The main function comprises of splitting/combining of given input signal into two or more signals or vice versa. The novel Wilkinson power divider with harmonic suppression for 2nd and 3rd harmonics suppression is proposed. It is a three-port network that is lossless when the output ports are matched; where only reflected power is dissipated. The proposed solution for Wilkinson power divider, is to insert a resistor among the 2 outputs. This resistor absorbs energy if there is a match among the outputs. Additionally, It helps unreflected the 2 outputs once the circuit function as an influence combiner (Figure 5). Following equation helps to find the components value for particular frequency [15]

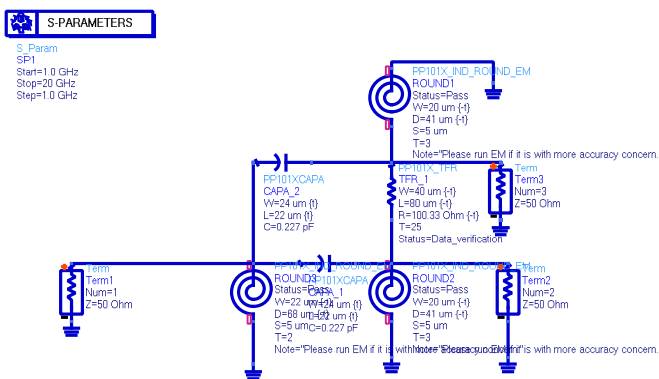
$$C_1 = C_2 = \frac{1}{\left(\sqrt{2R_a \cdot \sqrt{R_b R_c}} \cdot \omega^2\right)} \dots\dots (2)$$

$$L_3 = L_2 = \sqrt{\frac{2R_a \cdot \sqrt{R_b R_c}}{\omega^2}} \dots\dots (3)$$

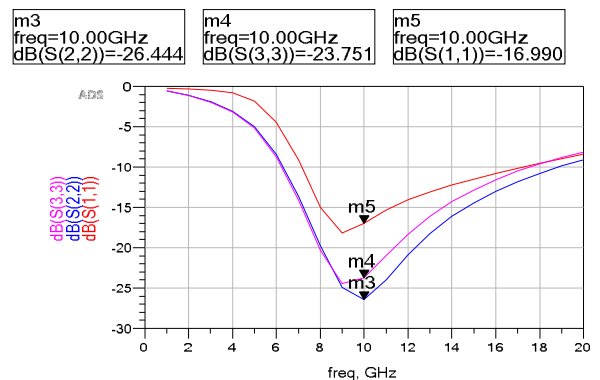
$$L_1 = \sqrt{\frac{R_a \cdot \sqrt{R_b R_c}}{2\omega^2}} \dots\dots (4)$$

$$R = 2\sqrt{R_b R_c} \dots\dots (4)$$

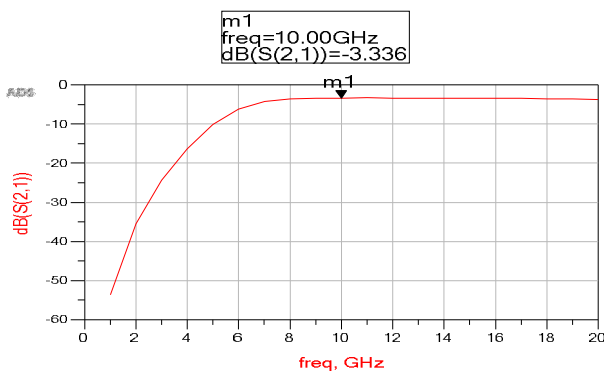
Where, for any arbitrary impedance  $Z_0 = R_a = R_b = R_c = 50$  ohms and  $\omega$  is the angular frequency.



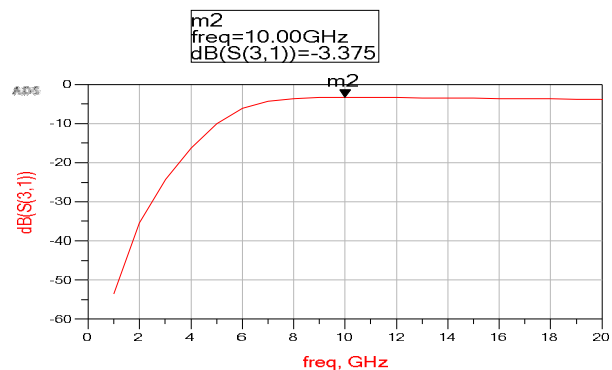
**Figure-5:** Schematic for Wilkinson Power divider on ADS coefficients



**Figure-6(a):** S-parameter analysis for reflection-coefficients



**Figure-6(b):** Gain at output 1



**Figure-6(c):** Gain at output 2

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## D.Feedback:

The complete schematic designed of x band PA is shown in Figure 7. Resistor TFR\_3 and TFR\_4 forms the feedback and capacitor CAPA\_3 is added to allow for independent biasing of the gate and source of the transistor. CAPA\_3 can normally be chosen so that it is large enough to be a short circuit over the frequency of interest. In addition, the effect of feedback is to make the input and the output impedances more convenient for matching.

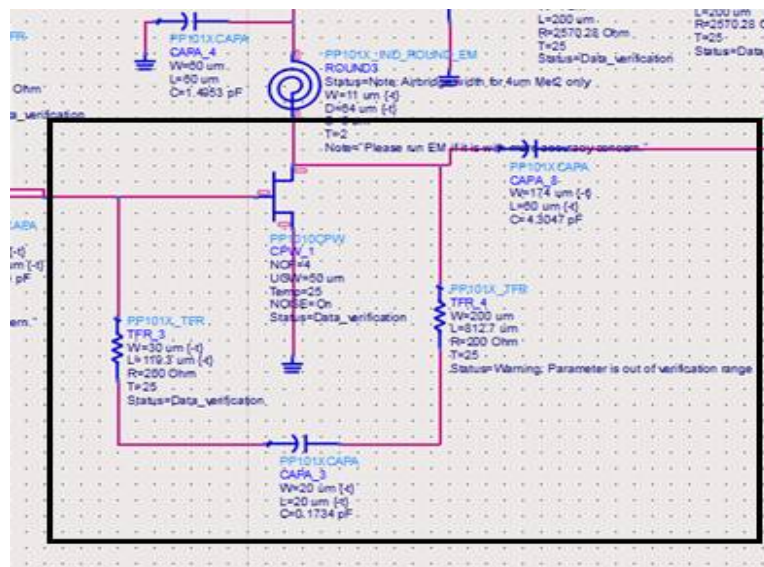


Figure-7:Feedback circuit schematic

## III. RESULTS AND SIMULATIONS

### A. Amplifier Output:

The proposed amplifier gives output power of 23.059 dBm for an input power of 0.100 dBm. The simulation results are shown in Figure 8. This graph shows that at a given input of -5 to -0.100 dBm, corresponding output is around 20.00 - 23.059 dBm which is our desired goal in this design.

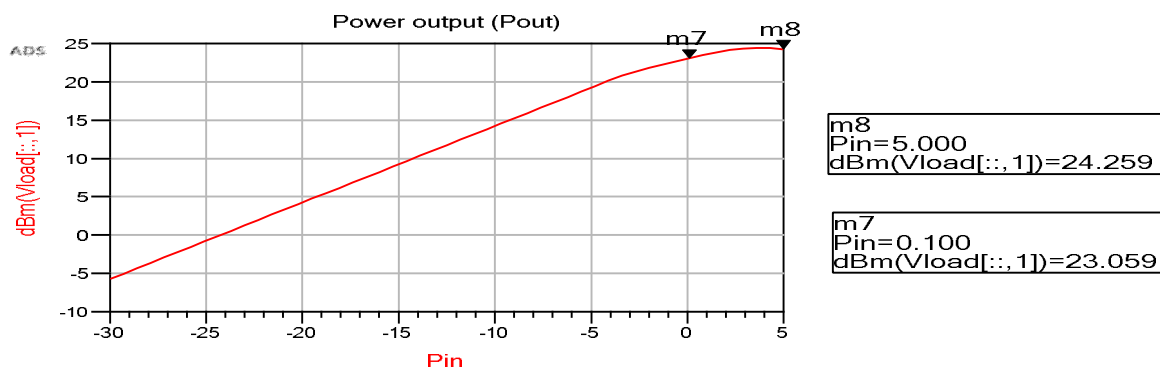


Figure-8: Output and input power at the 1dB gain compression point for the proposed PA

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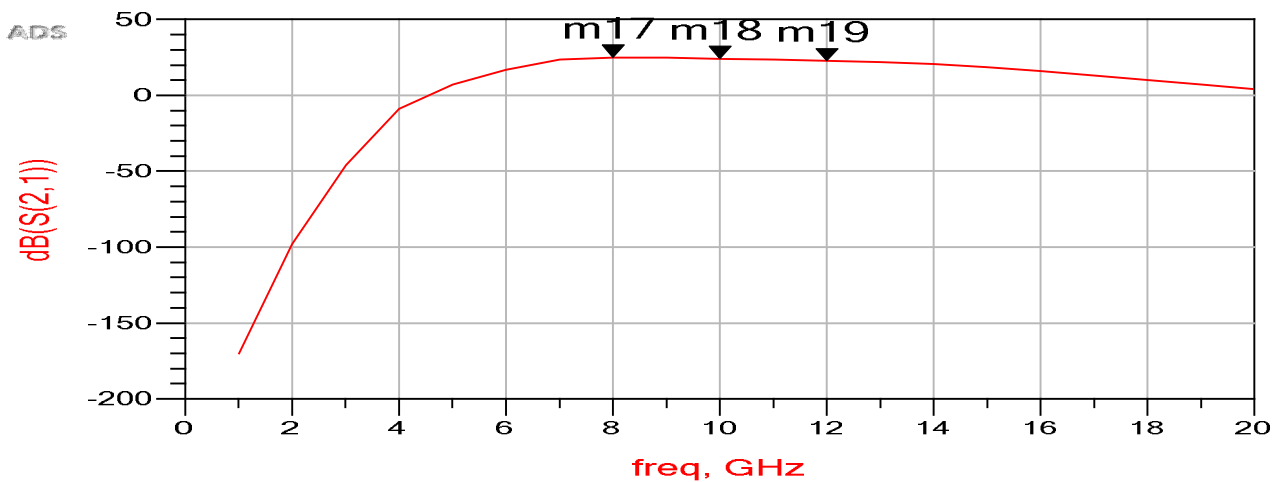
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### B. S-Parameters analysis:

The S-Parameters at the designed frequency show a flat gain of approximately 24.241 dB as shown in Figure 9. This gain is kept as flat as possible to meet the specific requirement of application in which it is to be used.

<b>m17</b> freq=8.000GHz dB(S(2,1))=25.104	<b>m18</b> freq=10.00GHz dB(S(2,1))=24.241	<b>m19</b> freq=12.00GHz dB(S(2,1))=22.665
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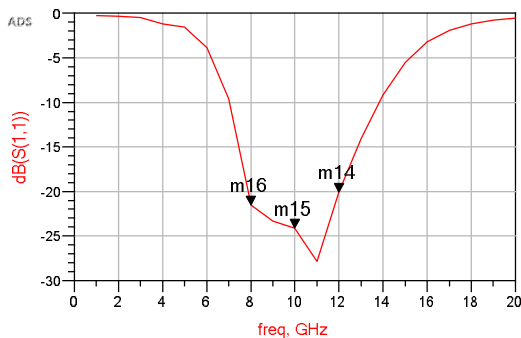


**Figure-9:** Gain at the frequency band between 8-12 GHz.

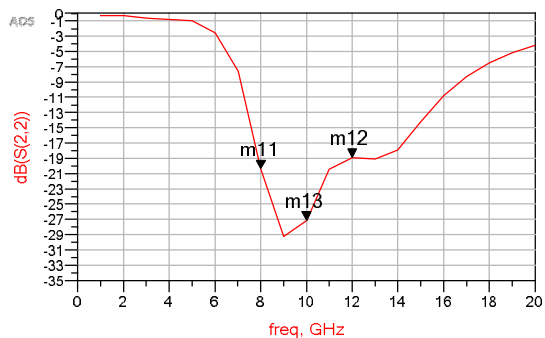
### C. Input and output reflection co-efficient:

The input/output reflection coefficient at the two ports of the cascade is shown in Figure 10. These plots show that due to good matching at both the ports, reflections have been minimized.

<b>m16</b> freq=8.000GHz dB(S(1,1))=-21.508	<b>m15</b> freq=10.00GHz dB(S(1,1))=-24.143	<b>m14</b> freq=12.00GHz dB(S(1,1))=-20.089	<b>m11</b> freq=8.000GHz dB(S(2,2))=-20.372	<b>m13</b> freq=10.00GHz dB(S(2,2))=-27.120	<b>m12</b> freq=12.00GHz dB(S(2,2))=-18.923
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**Figure-10(a):** Return loss at input port



**Figure-10(b):** Return loss at output port

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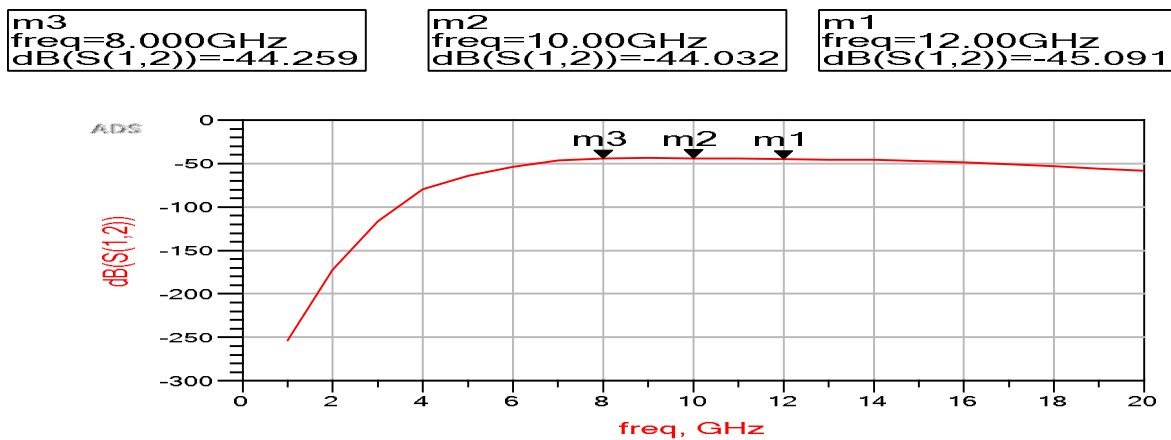
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### D. Reverse isolation:

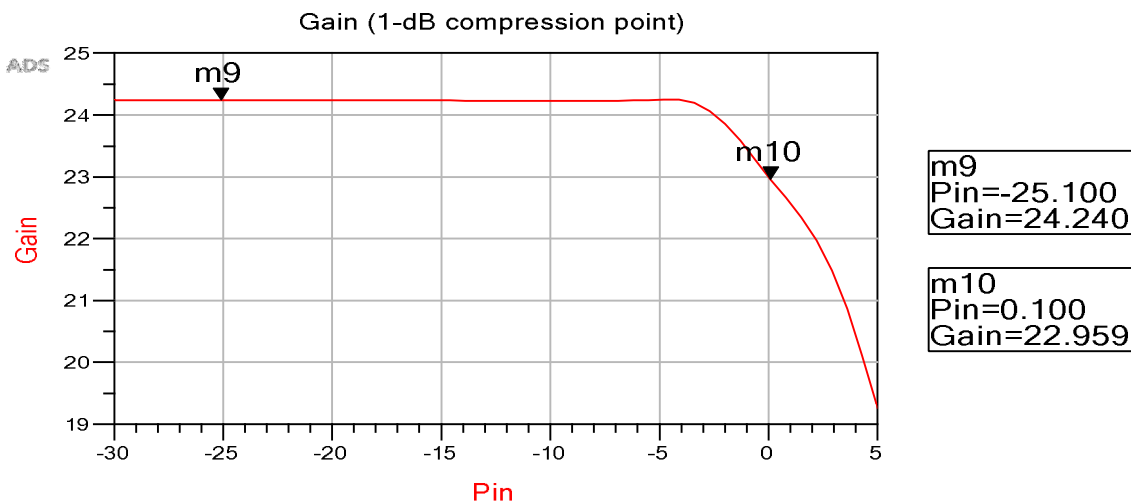
The proposed power amplifier not only provides the high gain needed to produce high power signals, but also offers inherently good isolation of -44.032 dBm for wide range. A good rule of thumb is that roughly 40 dB of isolation is required to measure up to IP3 numbers above +25 dBm [16].



**Figure-11:** Simulated measured Reverse isolation

### E. 1-dB Compression points:

The X band PA achieved an output power, Pout of 23.059dBm at 1dB gain compression (P1dB) with the input power, Pin of 0.100 dBm. From -30 dBm to 3 dBm, this packaged amplifier showed the linear Pin-Pout characteristic and no gain compression until input power reached 0.100 dBm and the output power will saturate started from 10 dBm of input power. The power gain of 22.959 dB was obtained at 0.100dBm of input power.



**Figure-12:** The gain compression curve



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## F. Output Spectrum:

Figure 13 shows that analysis of the first and third harmonics indicate very desirable output power at the X band. The first harmonic of the output spectrum at the fundamental frequency was 24.097 dBm and the third harmonic was -0.796 dBm. The more negative the numerical value of the harmonics becomes, the better the performance of the circuit. The downtrend of the output spectrum from the fundamental harmonic to the third harmonic indicates suitable matching in the input and output of the proposed circuit.

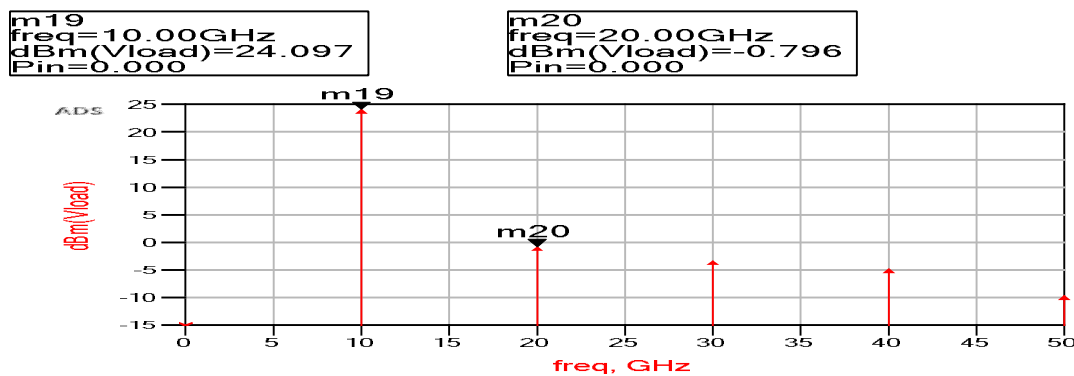


Figure-13: Output Spectrum at the fundamental and second harmonic frequencies

## IV. CONCLUSION

In this paper GaAs MMIC's based, 2 staged X-band power amplifier has been designed and measured performance of power amplifier at X band employing 0.10 $\mu$ m GaAs pHEMT technology has been demonstrated. PA achieved a gain of 23.059 dB, a P1dB of 22.959 dBm, linear gain of around 25.104 dB and desirable amplitude for the output signal in the fundamental and 2nd harmonics. The maximum current,  $I_{max}$  is 49 mA and the power consumption of the device is 650 mW. The amplifier in this work outperforms previously reported power amplifiers in the literature; especially in terms of P1dB. This novel method was implemented using the Wilkinson power divider/combiner and 2 stage GaAs FET to achieve better performance than previous works.

## V. ACKNOWLEDGEMENT

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