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60 GHz power amplifier with 57.9% peak PAE in 0.15 µm PHEMT technology

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Abstract

In this paper, a 60 GHz high efficiency power amplifier (PA) with integrated input and output matching is presented. The designed PA uses a 0.15 µm gate length AsGa PHEMT (Pseudomorphic High Electron Mobility Transistor) process. The power amplifier achieves a peak power gain of 17.8 dB and a maximum single-ended output power of 14.34 dBm with 57.95% of power-added efficiency (PAE) at 60 GHz. These results are the best combination of output power and efficiency reported for an MMIC (Monolithic Microwave Integrated Circuit) AsGa device at V-band. The designed power amplifier has a 3-dB bandwidth of 7 GHz.

Keywords: *Power Amplifier, V-band, MMIC technology, HPA, amplifier, Millimeter wave band, 60 GHz, Pseudomorphic High Electron Mobility Transistor (PHEMT).*

1. Introduction

Recently, wireless telecommunication technology is being quickly developed with an increasing demand of higher transmission rates. As data transfer rate increases, the battery life of the signal transmission devices decreases.

For this, several solutions are being considered including the increase in frequency to millimeter wave spectrum.

Operating on the millimeter wave frequencies become attractive because of the availability of large free frequency bands. The band around 60 GHz is free to use and offers the possibility of data communication within short distance at speeds of several gigabits per second. [1]

This band is used for Wireless Personal Area Network (WPAN) which is governed by the standard IEEE 802.15.3c for multi-gigabit multimedia applications. [2]-[3]

These applications are possible due to the development in transistors performance. The progress in physics of semiconductors have been the origin of a new generation of components, called heterojunction transistors such as HEMT (High Electron Mobility Transistors). Another family of HEMTs, named "pseudomorphic" offers better noise performance. [4]-[5]

The high mobility of electrons in these transistors [4] allows operation at high frequencies (over 60 GHz).

Power amplifiers consume a relatively large amount of power in the RF transmitter (Tx) system. Therefore, improving the PAE of power amplifiers is very important. The PA represents the last block of the transmitter front-end system, and its function is to amplify without introducing an excessive level of distortion the RF signal and deliver it to the load (or the antenna).

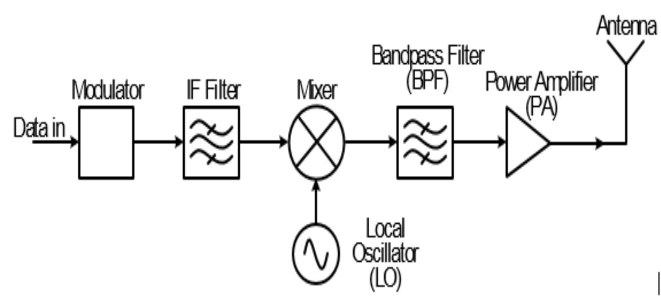

Fig.1 Block diagram of a basic RF transmitter (Tx)

Fig.1 shows the architecture of the transmitter at 60 GHz. It consists of a modulator, band-pass filters, a mixer, a patch antenna network, a frequency multiplier and a power amplifier. The LO signal is provided by an external source that is not integrated in the module.

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In this paper, we present the design of a high efficiency amplifier that will be used as a part of a WPAN transmitter block working in the millimeter-wave band at 60 GHz.
Reported PAs for 60 GHz applications achieve good gain values around 16 dB [6]-[8] but have a very low PAE.
A high PAE Power amplifiers are very desirable since they consume lower DC power.
The presented PA is designed using PPH15 process from UMS foundry.

2. The PPH15 process characteristics

2.1 Process choice

In order to choose the adequate PHEMT transistor topology, we are going to simulate the MaxGain while changing the number of fingers (N) and the gate width (W) of this transistor as shown in Table 1 and Fig.2 The MaxGain is the maximal gain possible if the input and the output are matched for maximum gain.

Table 1: Peak Maxgain according to the number of fingers (N)

Number of fingers (N)	2	4	6	8	10
Peak gain	9.42 dB	9.31 dB	8.60 dB	8.37 dB	8.25 dB

From the Table 1 we can conclude that the MaxGain increases by reducing the number of fingers (N) of the transistor.

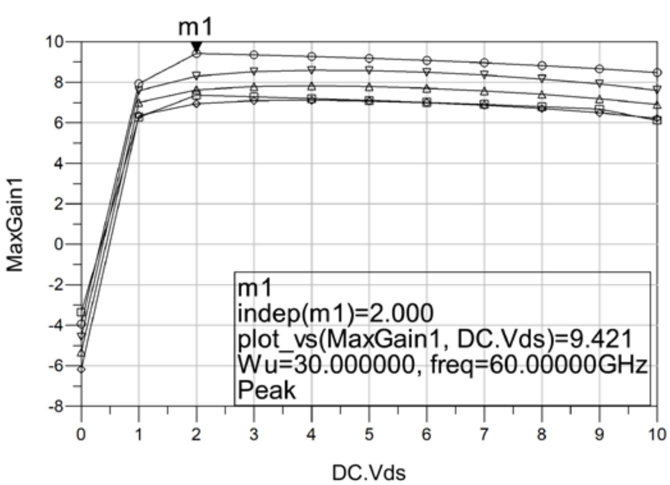

Fig.2 MaxGain as a function of Vds and Wu (Wu= 10 µm (□); Wu= 30 µm (O); Wu= 50 µm (▼); Wu= 70 µm (∆); Wu= 90 µm (◊)).

During this work, we choose to use a PPH15x transistor with a gate width of 30 µm and a number of fingers equal to 2. This topology exhibits better performances.

2.2 Bias point selection

Classes A and AB power amplifier are suitable in this design. They both have sufficient gain to avoid severe P1db compression from previsions stages. class AB is preferred as its efficiency is higher than that of class A. Then, transistors used in our two first stages of the designed circuit are biased according to the operation points m2 (Vds = 2V, Vgs = 0V) in order to have a good gain. While transistors used in the final stage of the designed circuit are biased according to the operation points m3 (Vds = 2V, Vgs = -0.5V) to high PAE performance. (Fig.3 and Fig.4)

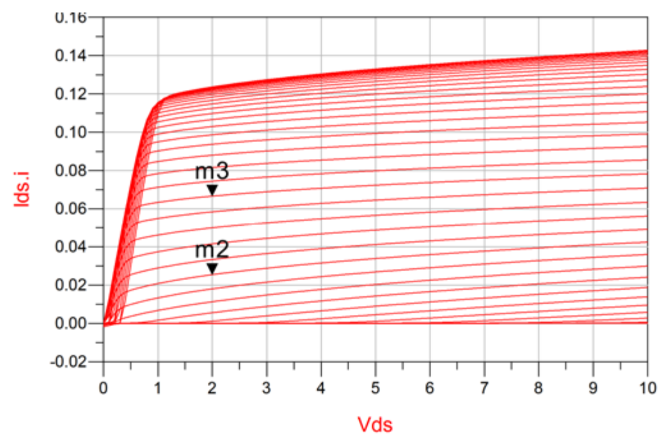

Fig.3 static characteristic Ids according to Vds for different Vgs values.

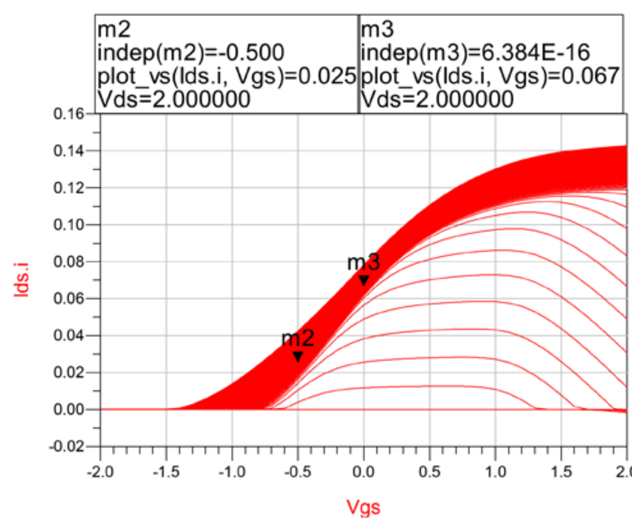

Fig.4 Ids according to Vgs for different Vds values.

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3. The 60 Ghz power amplifier MMIC design

Fig.5 shows an electrical schematic of the three-stage V-band PA MMIC circuit. The input and the output ports were designed to have a good matching with 50Ω load impedance to maintain sufficient load power in the high-frequency region around 60 GHz.

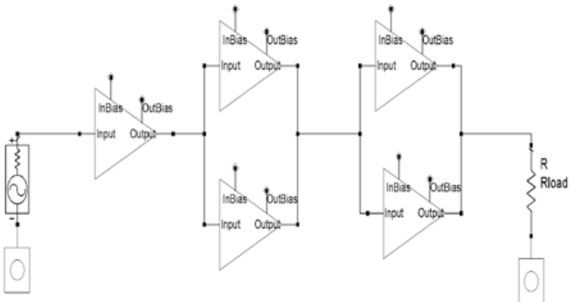

Fig.5 Used PA topology.

Fig.6 shows the output gain of the proposed LNA. The 3-dB bandwidth is from 56 to 62 Ghz.

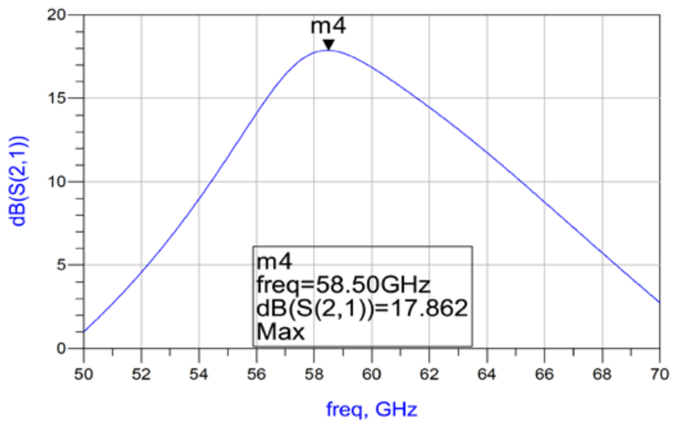

Fig.6 Output Gain.

This PA exhibits a high direct gain (S21) of 17.8 dB (m4) at 58.5 GHz.
Fig.7 shows the S-parameters simulation results of the proposed PA.

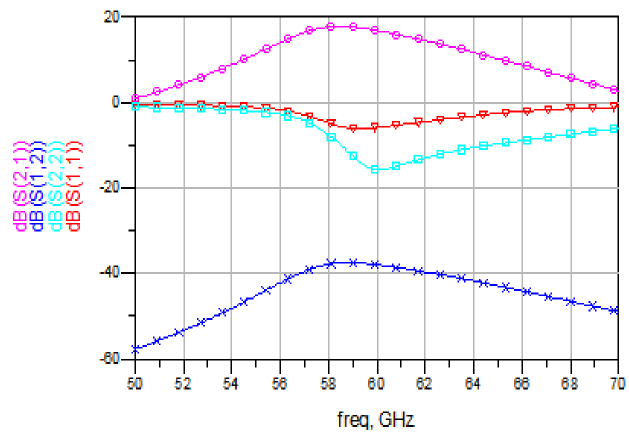

Fig.7 S-parameters of the proposed LNA: S21(O) ; S11(Δ) ; S22(□); S12(x).

Low reverse gain (S12) is desired to provide sufficient isolation and to simplify input and output matching. From Fig.7 we observe that S12 is lower than -30 dB. We can also see an input return loss (S11) of -8 dB and an output return loss (S22) of -18 dB at 60 GHz.
Fig.8 shows the gain and the output power of the designed PA.

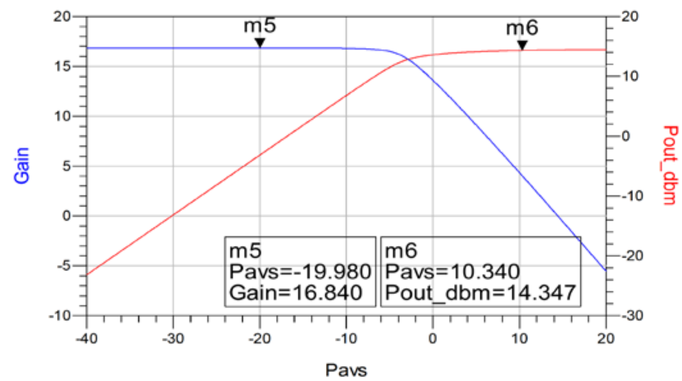

Fig.8 Plot of simulated Measured PA power gain and output power curves at 60 GHz.

The amplifier delivers a linear gain of 16.840 dB with a saturated output power of 14.347 dBm at 60 GHz.

Fig.9 shows the third Intercept point (IP3) of the designed PA.

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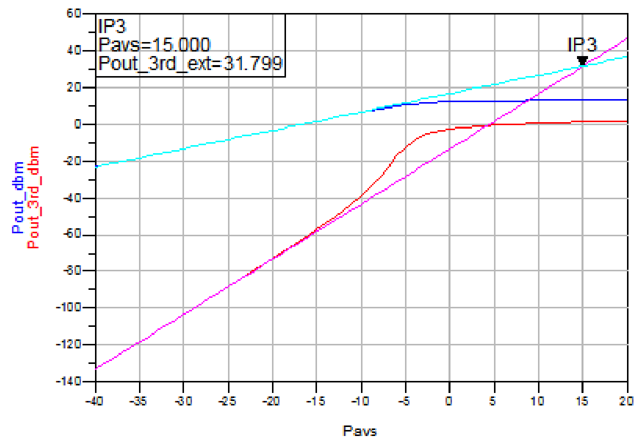

Fig.9 Order 3 Intercept Point.

From Fig.9 we observe that the designed PA have a -15 dBm 3rd Order Intput Intercept Point (IIP3).
Another important factor in a power amplifier is Power Added efficiency (PAE). [9] (Fig.10)

$$PAE=\frac{Pout-Pin}{Pdc} \quad (1)$$

Where Pout Pin are respectively the output and the input power of the amplifier and Pdc is the DC power consumption of the amplifier.

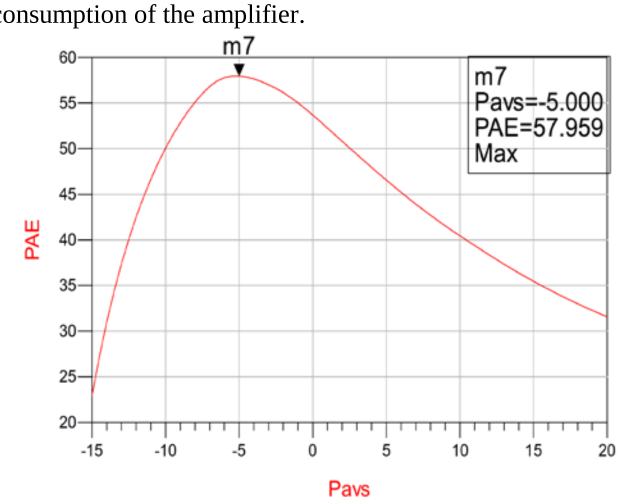

Fig.10 Simulated power added efficiency (PAE %) of the 60GHz power amplifier.

From Fig.10 we can observe that the designed PA achieves a maximal PAE= 57.9%.
By improving the PAE of the power amplifier we can reduce its DC power consumption. (Fig.11)

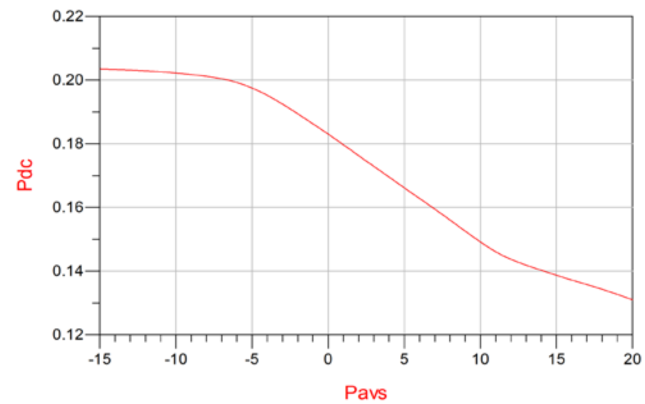

Fig.11 Simulated DC power consumption (Pdc) of the 60GHz power amplifier.

The simulated DC power remains lower than 0.22 Watts.

Table 2 shows a comparison of this work to some pervious power amplifiers in literature.

Table 2: Comparison of present work and previously reported works.

Ref.	***[6]***	***[7]***	***[8]***	***This work***
Technology	0.12µm PHEMT	0.15µm PHEMT	130nm mHEMT	0.15µm PHEMT
3-dB bandwidth (GHz)	56~ 62	58~62	49~64	56~ 62
S21	16.5~17.2	12~13	16	17.86
S11	< –9	< –5	< –3	< –7
S22	< –4	< –5	< –6	< –18
Pout (dBm)	13	10	20	14.34
PAE %	N/A	N/A	19	57.9

As we can see this work demonstrate a high efficiency power amplifier with a high Gain that reaches 17.8dB.

Table 3 shows a performances summary of the designed PA

Table 3: PA performances summary

Performance parameter	Performance
Output Power Pout (dBm)	14.340
Gain (dB)	16.840
PAE max (%)	57.9
Pdc (Watts)	< 0.22
Linearity (IIP3) (dBm)	15

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From Table 3 we can observe that the designed PA presents good performances at 60 GHz, it reaches a good gain which is about 16.8 dB, a high efficiency and high linearity. This amplifier exhibits a very low DC power consumption which is very important in order to extend the battery life of millimeter wave devices.

4. Conclusions

The better your paper looks, We have demonstrated a V-band high efficiency amplifier based on a 0.15 µm gate-length AsGa PHEMT process. The amplifier exhibits small-signal gain of 17.8 dB at 60 GHz with 14.3 dBm saturated output power.

References

[1] N.Almajid, S.Mazer, M.Bekkali, C.Algani, “Design of a V-band MMIC LNA for WPAN Applications around 60 GHz” 14th Mediterranean Microwave Symposium (MMS2014).

[2] J. Hansen, “A novel stochastic millimeter-wave indoor radio channel model,” IEEE J. on Selected Areas in Comm., vol. 20, no. 6, pp.1240-1246, Aug. 2002.

[3] Wireless Medium Access Control (MAC) and Physical Layer (PHY), Specifications for High RateWireless Personal Area Netwoks (WPANs), IEEE 802.15.3c, Oct. 2009, Version 1.0a.

[4] Del Alamo, Jesus A. "The High-Electron Mobility Transistor at 30:Impressive Accomplishments and Exciting Prospects." 2011 International Conference on Compound Semiconductor Manufacturing Technology, May 16-19, 2011, Indian Wells, California.

[5] Sheng S. Li, “Semiconductor Physical Electronics”, Second Edition.

[6] Woojin Chang, Seung-Hyeub Oh, and Haechoen Kim, “A 60 GHz Medium Power Amplifier for Radio-over-Fiber System,” ETRI Journal, Volume 29, Number 5, October 2007.

[7] Min Han et al, “V-Band CPW Balanced Medium Power Amplifier for 60 GHz Wireless LAN Application,” Proc. APMC, 2005.

[8] Youngmin Kim, Yumin Koh, Jihoon Kim, Seokchul Lee, Jinho Jeong, Kwangseok Seo, and Youngwoo Kwon,“A 60 GHz Broadband Stacked FET Power Amplifier Using 130 nm Metamorphic HEMTs”, IEEE Microwave and Wireless Components Letters, VOL. 21, NO. 6, JUNE 2011.

[9] S. C. Cripps, “RF Power Amplifiers for Wireless Communications.” Artech House, second ed., 2006.

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