Single Supply, High Linearity, High Efficient PHEMT Power Devices and Amplifier for 2 GHz & 5 GHz WLAN Applications

Min Park, Hokyun Ahn, Dong Min Kang, Honggu Ji, Jaekyoung Mun, Haecheon Kim, and Kyoung Ik Cho

Microwave Device Team, Wireless Communication Devices Department, Basic Research Laboratory, Electronics and Telecommunications Research Institute, 161 Gajeong-dong, Yuseong-gu, Daejeon 305-350, Korea

Phone: +82-42-860-5795, Fax: +82-42-860-6183, E-mail: mpark@etri.re.kr

Abstract — **A single supply, high linearity, high efficient power devices and amplifier MMIC is implemented utilizing high performance of quasi-enhanced power PHEMT technology. The PHEMT power device features Vth= -0.65 V, Vbdg=26 V, Imax=144 mA/mm at Vgs=0.2 V, Gm=340 mS/mm. When matched on-wafer compromise between power and efficiency, the OIP3 at peak IP3 is 40.5 dBm for 2 GHz and 37.0 dBm for 5.8 GHz, respectively. The power amplifier achieves at 5.8 GHz Pout=27 dBm with associated PAE=45 % at 5 V under Vgs=0 V, G_L=14.5 dB, OIP3=37.5 dBm.**

I. INTRODUCTION

With the recent proliferation of wireless communication applications, there is an effort to develop low cost, low operating voltage, high efficiency and dual band operation. The wireless local area networks (WLAN) market estimates a strong shift from 2.4 GHz to 5 GHz. The 5 GHz band offers the advantages of higher data rate, for more available spectrum, and less sharing with other uses such as cordless phones and Bluetooth devices [1]. Some GaAs MMIC power amplifiers supply to meet the linearity requirement and improve the efficiency [2]-[3]. To illustrate the potential of this quasi-enhanced pseudomorphic high electron mobility transistors (PHEMT) technology, high linearity, single supply, high efficient power devices and amplifier are demonstrated for 2 GHz and 5 GHz applications. Quasi-enhanced mode PHEMT technology is gaining increased attention as a viable solution for single supply, low operating voltage, and no drain switch for GSM and DCS application [4].

II. DESCRIPTION OF FABRICATION

SEM photograph of 0.5 µm PHEMT power device with air-bridge metal interconnection are shown in Fig. 1.

This technology was used to realize a higher power density to minimize chip size, higher linearity, no negative gate bias and high efficiency. The quasi-enhanced mode PHEMT epi-structure and recess etch conditions were optimized to keep Idss at minimal levels, while maintaining Imax and transconductance (*gm)* at Vgs = 0 V high enough to achieve adequate RF performance. The process of fabrication feature 0.5 µm TiPtAu Schottky gates recess process [5] and the structure of the double-planar-doped AlGaAs/InGaAs/GaAs PHEMT epi-wafer were used for consideration of proper break-down voltage [6].

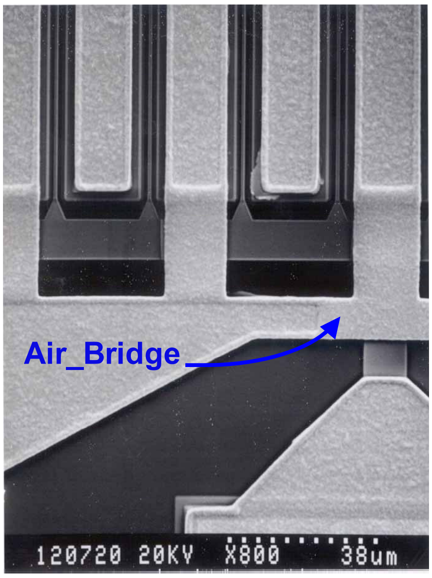


Fig. 1. SEM photograph of 0.5 µm PHEMT power device with air-bridge metal interconnection.

III. RESULTS AND DISCUSSION

Fig. 2 shows break-down characteristics for two kinds of total gate width. The total gate width of 1.5 mm PHEMT power device was made up 10 fingers with the gate size of 0.5 µm x 150 µm and the other device consisted of 2 fingers. The gate-to-drain break-down voltage (Vbdg) determined at a gate-to-drain current density of 1 µA/µm, was above 25 V as shown in Fig. 2. The value of Vbdg is in excess five times the operation voltage for PCS repeater and 5 GHz band of WLAN applications, which may be required under extreme output load conditions.

Fig. 3 shows drain-source current density as a function of drain-to-source voltage (Vds) for the 0.5 µm GaAs PHEMT devices with total gate width of 1.5 mm. A maximum output current density of 210 mA/mm at Vgs =0.4 V was measured. The gate-to-drain break-down voltage is about 26 V. As shown in Fig. 2, the devices exhibit a good pinch-off characteristic at a drain voltage of 5.0 V.

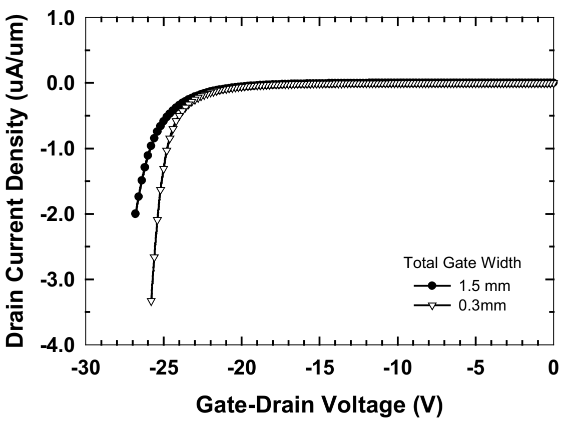


Fig. 2. Drain current density versus gate-drain voltage of AlGaAs/InGaAs PHEMT device with two kinds of total gate width.

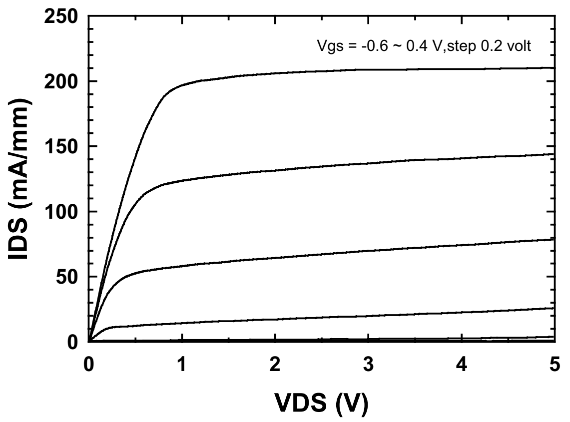


Fig. 3. Drain-source Current density *Ids* versus drain-source voltage *Vds* of AlGaAs/InGaAs PHEMT with total gate width of 1.5 mm.

The dependence of extrinsic transconductance (*gm*) and drain current density (Ids) on gate bias voltage at Vds = 3 V are shown in Fig. 4. The device of short total gate width (dotted line) shows an extrinsic peak *gm* of 340 mS/mm and a much broader *gm* profile (better gain linearity) than the total gate width of 1.5 mm. The *gm* profile has a shoulder near the pinch off point, which is due to the parallel conduction in the lower supply and buffer layers. The threshold voltage (Vth) was –0.65 V

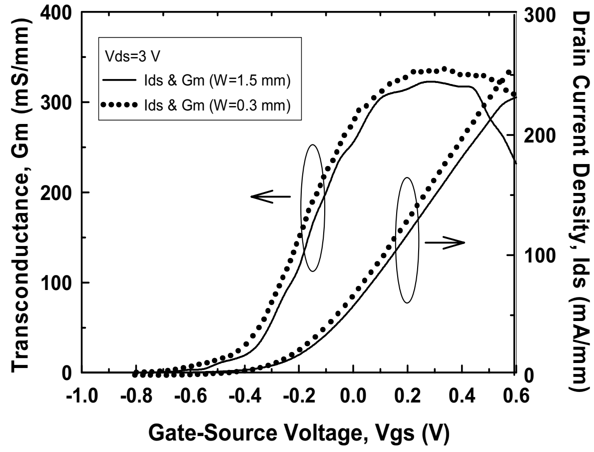


Fig. 4. Transconductance *gm* and drain-source current density *Ids* versus gate bias *Vgs* with two kinds of total gate width.

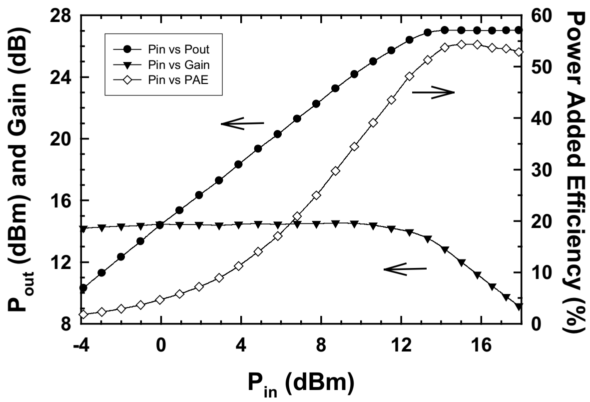


Fig. 5. Output power, PAE, and power gain as a function of input power at 5.8 GHz 1 tone for a total gate width of 1.5 mm PHEMT device under 5.0-V operation. (Vgs = 0 V)

and the *gm* at Vgs = 0 V was 256 mS/mm with Ids = 55.3 mA/mm.

Fig. 5 shows the output power, PAE, and power gain as a function of input power at 5.8 GHz 1 tone for a total gate width of 1.5 mm PHEMT device under 5.0-V operation with the Vgs of zero volt. The power measurements were performed on a load-pull system with computer controlled mechanical tuners to measure the optimum load impedance for maximum output power tuning. At 5.8 GHz and Vds = 5.0 V (Vgs = 0 V), with the device tuned for maximum output power (Pout), a peak power-added efficiency (PAE) of 55 % was obtained, as shown in Fig. 5. Under the same conditions, a linear power gain G_L = 14.5 dB and a saturated output power Psat = 26 dBm (power density = 267 mW/mm) were achieved.

The two-tone test is a very useful signal for test and measurement purposes since the amplifier is driven through the whole range of its transfer characteristic (from zero to the signal envelope maximum). Fig. 6 shows the dependence of carrier power and third-order

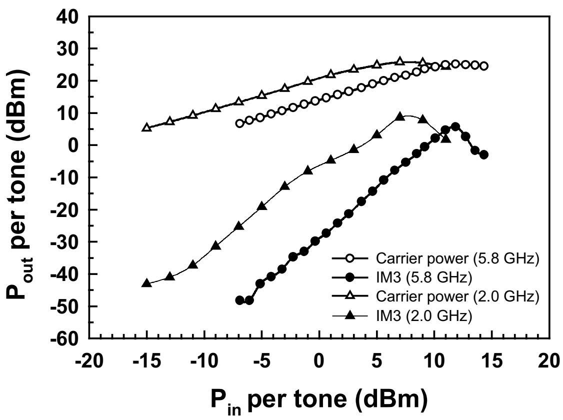


Fig. 6. Carrier Power and third-order intermodulation (IM3) as a function of input power at 2.0 GHz and 5.8 GHz for a total gate width of 1.5 mm PHEMT device under 110 mA of *Ids* and 5.0-V operation. (Vgs = 0 V)

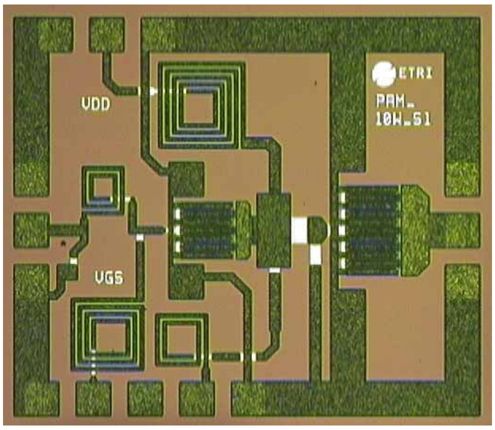


Fig. 7. Microphotograph of 2-stage power amplifier MMIC for 5 GHz wireless applications with the size of 1.3 mm x 1.1 mm.

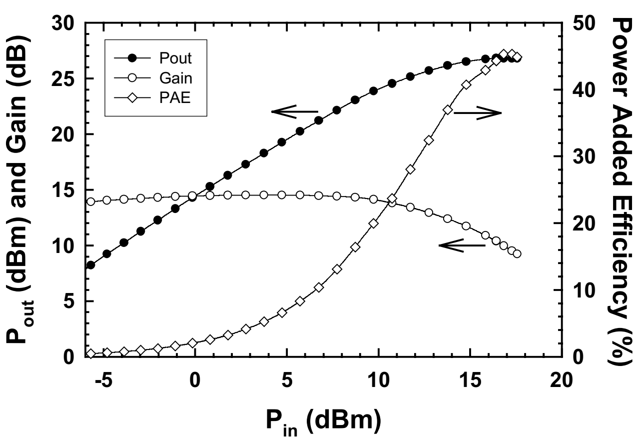
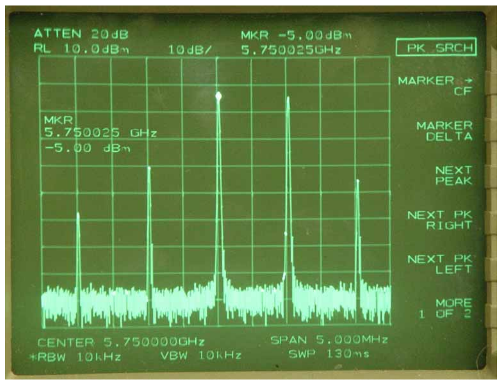


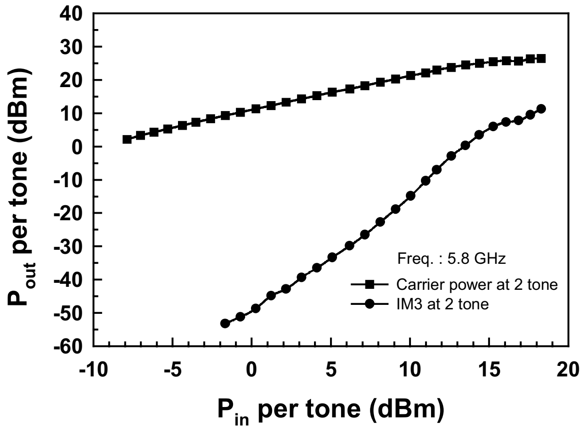
Fig. 8. Output power, PAE, and power gain as a function of input power at 5.8 GHz for 2-stage power amplifier MMIC. Psat=27 dBm, PAE=45%.

intermodulation (IM3) on input power at 2.0 GHz and 5.8 GHz for a total gate width of 1.5 mm PHEMT device under 110 mA of Ids and 5 V operation. For nonlinear output, the signal no longer follows the true envelope shape. There is asymmetrical signal clipping resulting in distortion. The third-order intercept point (IP3) which characterize the third-order distortion of an amplifier is then defined as the theoretical level at which the intermodulation products are equal to the fundamental tone. In Fig. 6, each of the OIP3 at peak IP3 is 40.5 dBm for 2 GHz and 37.0 dBm for 5.8 GHz under condition of 1MHz tone spacing, respectively. The linear power gain at 2 GHz and 5.8 GHz were 20 dB and 14.5 dB, respectively.

Fig. 7 shows the microphotograph of simple 2-stage power amplifier MMIC for 5 GHz wireless applications. When the amplifier was tested at 5.8 GHz and tuned for maximum output power (Z_L=18.83-j3.74 Ω) biased at Vds = 5 V and Vgs = 0 V, the maximum output power was 27 dBm with a peak PAE of 45 % and G_L of 14.5 dB, as shown in Fig. 8.



(a)



(b)

Fig. 9. The measured results of 5.8 GHz 2-stage power amplifier: (a) Spectrum analysis of inter modulation output carrier power. (b) Carrier Power, and third-order intermodulation (IM3) as a function of input power with 1MHz offset, OIP3=37.5 dBm.

The output power and PAE at 1-dB compression point were as high as 25 dBm and 36 %, respectively. The response of the amplifier at any point is determined solely by the value of the input signal at that moment and not by any previous input and output signal value.

The spectrum representation of this distorted frequency-domain waveform is shown in Fig. 9 (a) and in addition to harmonic distortion, other frequency components or intermodulation (IM) products are also present. Fig. 9 (b) shows the dependence of carrier power and IM3 on input power at 5.8 GHz for 2-stage power amplifier MMIC under 5 V operation with Vgs of 0 V. The third order intermodulation distortion (IMD3) is larger than 30 dBc at P1dB compression point. In Fig. 9 (b), the OIP3 at peak IP3 is about 37.5 dBm for 5.8 GHz under condition of 1MHz tone spacing.

IV. CONCLUSION

A high performance power devices and amplifier utilizing the quasi-enhanced mode PHEMT technology were demonstrated achieving single supply voltage, high break-down voltage of 26 V, high linearity of 37.5 dBm and PAE of 45 % for 5 GHz band wireless LAN of notebook personal computer (PC), which become valuable information for 2 GHz & 5 GHz WLAN applications.

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