Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 658-659

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Balanced-type Peak Power Injection Amplifier for Simultaneous High Efficiency and Large Saturation Power

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1. Introduction

In recent years, for the purpose of efficient use of frequency resources, multi-carrier signals such as WCDMA and OFDM have been applied to RF communication systems. Devices with high saturation power, high efficiency and low distortion have been developed for such systems. On the other hand, to amplify the signals with large peak to average ratio, the amplifiers should operate in large back-off state to improve distortions, where the amplifiers have very low efficiencies in back-off operation in general. Therefore, circuit technologies that provide high efficiency in back-off operation and large saturation power need to be developed. For example, Doherty amplifier is one of the technologies for improvement of efficiency in back-off operation[1].

So far, the authors have proposed "Peak Power Injection Amplifier" (PPIA) and demonstrated its effectiveness, whose purpose is improvement of efficiency in back-off operation. PPIA realizes high efficiency and large saturation power simultaneously, by changing effective load impedance of the main-amplifier with injected RF power from the sub-amplifier through a circulator[2].

In this work, we propose new type of PPIA that uses 90-degree hybrid circuits instead of the circulator.

2. Operation Principles

Fig. 1 shows the schematic diagram of new PPIA. It is composed of a coupler, a phase shifter, an attenuator, a main-amplifier of balanced-type that uses 90-degree hybrid circuits and a sub-amplifier (Class-C).

Input signal is divided into two signals by the coupler: one is simply amplified by the main-amplifier and the other is amplified by the sub-amplifier when input instantaneous power level of the sub-amplifier is large enough for the Class-C sub-amplifier to operate. The amplified signal from the sub-amplifier is injected to the output side of the balanced-type main-amplifier through the isolation terminal of 90-degree hybrid circuit (HYB2). The injected signal's phase and amplitude can be adjusted by the phase shifter and the attenuator.

When signal is not injected into the isolation terminal, the output circuits of the main-amplifier's FETs are tuned to optimum efficiency matching. When the instantaneous power is large, output load impedance Z_L of the main-amplifier's FET is changed by the injected signal from the sub-amplifier effectively. The impedance Z_L (tuned to power added efficiency match) can be changed to power match when the instantaneous power is large, by adjusting the phase shifter and the attenuator. This mechanism makes it possible to realize high efficiency in back-off operation, and large saturation output power.

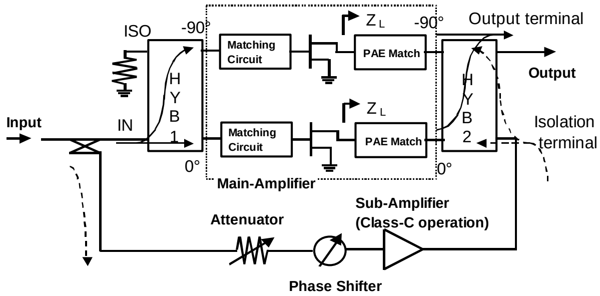

Fig. 1 Schematic diagram of PPIA

3. Design

We performed a Harmonic balance simulation in 5 GHz using simulator from AWR (Microwave Office 2002). We used a large signal equivalent circuit model of GaAs PHEMT in this simulation, whose model parameters are from catalog data[3], and its saturated power is about 0.6 W.

Fig. 2 shows results of the load-pull simulations of FET used for the main-amplifier. (FET Bias: Vds=8V, Ids=0.125Idss) Thin circles show load-pull contours of Power Added Efficiency (PAE) at input power of 6dBm and thick circles show load-pull contours of output power at input power of 16dBm respectively. Max PAE is calculated to be 16% at optimum efficiency-matching impedance when input power is 6dBm (input signal power is small). Saturated power is 28dBm at optimum power-matching impedance when input power is 16dBm (input signal power is large). By changing Z_L in the direction of the arrow shown in Fig. 2 as the input power becomes large, the saturated output power is expected to become larger.

Next, we designed the balanced-type power added efficiency match main-amplifier, and constituted PPIA shown in Fig. 1, and adjusted the phase shifter and the attenuator appropriately. Fig. 3 shows the calculated effective Z_L of the main-amplifier with respect to the change of the input power to PPIA. Effective Z_L changes as increasing the input power level, and is approaching to the optimum power-matching impedance.

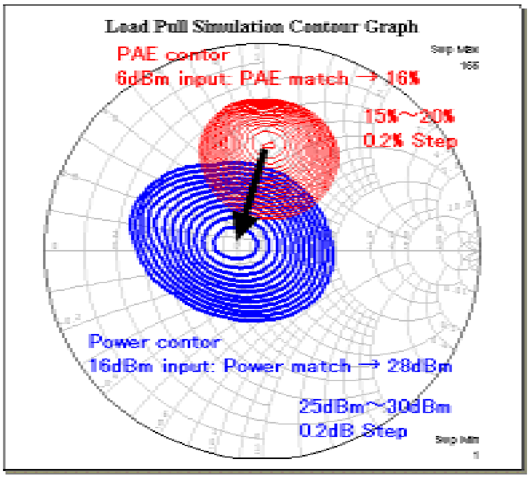

Fig. 2 Loadpull simulation (Vds=8V, Ids=0.125Idss)

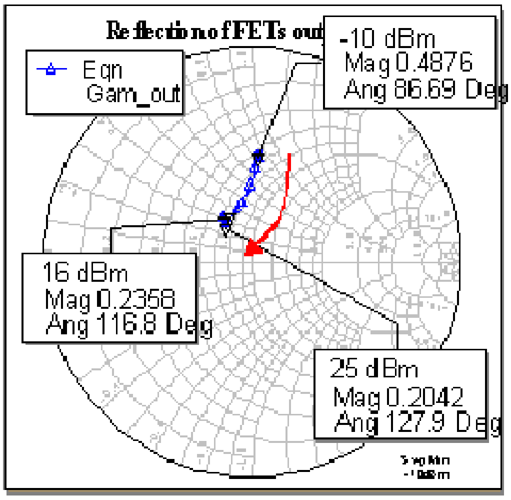

Fig. 3 Z_L characteristics versus input power to PPIA

4. Simulation Results

In Fig. 4, the simulation results of three kinds of amplifiers are shown; (a) the balanced-type amplifier that is tuned to power match, (b) the balanced-type amplifier that is tuned to PAE match, (c) PPIA (PAE of PPIA includes consumption power of the sub-amplifier.). Saturated power of PPIA has almost same power as the power-matched balanced-type amplifier, while PAE of PPIA has almost same PAE as the PAE-matched balanced-type amplifier when the input power is small [see Fig. 4].

Fig. 5 shows the calculated IM_3s of the three type amplifiers. The separation of input two-tone CW signals (Δf) is 10MHz. When the output power is small (when the input power is small), the IM_3 characteristic of PPIA is similar to that of efficiency-match. When the output power becomes large (when the input power becomes large), the IM_3 characteristic of PPIA approaches to the IM_3 characteristic of the power-match. PPIA has good IM_3 over wide dynamic range.

New PPIA turned out to have high efficiency in back-off state, large saturation power, and good IM_3 with rather simple configuration.

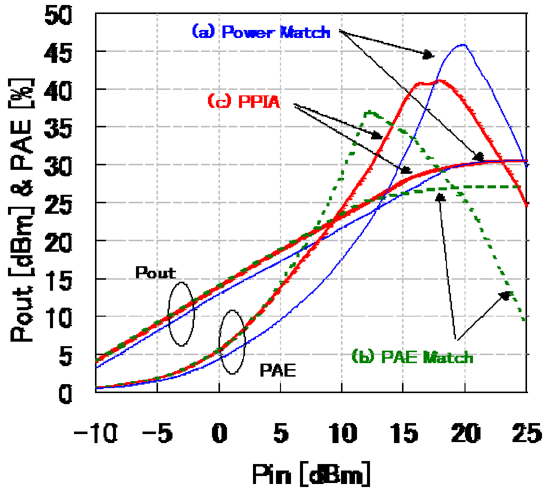

Fig. 4 Calculation results of AM-AM and PAE.
(Freq.=5GHz, Vds=8V, Ids=0.125Idss,
Att=0dB, Phase shift=95°)

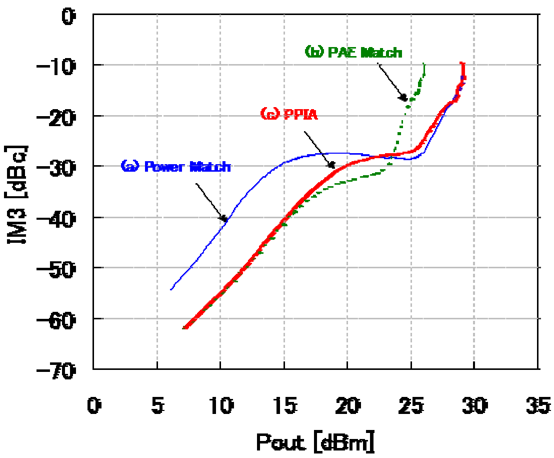

Fig.5 Simulated IM_3 performance
(Freq.=5GHz, CW, Δ=10MHz)
(a) Power match, (b) PAE Match, (c) PPIA

5. Conclusion

New PPIA using a balanced-type amplifier is proposed. We report an operation principle of the PPIA and calculate the PPIA characteristics (AM-AM, PAE and IM_3 and so on.).

References

[1] R.J.McMorrow, D.M.Upton, and P.R. Maloney, IEEE MTT-S Digest, pp 1653-1656. 1994.
[2] M. Nakayama, K. Horiguchi and Y. Ikeda, Technical Report of IEICE, MW2001-112, pp.5-11, Nov, 2002. (In Japanese)
[3] URL: http://www.filss.com/semiconductor/index.html