Design of High-Efficiency Co-Designed Load Modulation Power Amplifier Using Tunable Matching Network

Taeyeop Kwon and Jinho Jeong
Dept. of Electronic Engineering, Sogang University, Seoul, Korea
tykwon@sogang.ac.kr, jjeong@sogang.ac.kr

Abstract

In this paper, design procedure of load modulated power amplifier (PA) is presented to enhance power added efficiency (PAE) at back-off power regions. The designed amplifier is composed of high-efficiency harmonic-tuned PA and output tunable matching network (TMN). The impedance tunability is implemented using varactor diodes, of which the capacitance can be controlled by the envelope signal, so that TMN presents the optimum load impedance at all envelope amplitudes. The designed PA using commercial GaN HEMT operates at a frequency of 1.85 GHz with 6 W maximum output power. Experimental result shows that the designed TMN allows an efficiency enhancement of 14.5% at 4.5 dB back-off and more than 10% at both 7 dB and 10 dB back-off regions.

Keywords: Load modulation, high-efficiency power amplifier, tunable matching network

1. Introduction

Recently, many communication standards, such as LTE, WiMAX, etc., were developed, and they use modulation signals with high peak-to-average ratio for higher data rates. Consequently, efficiency of power amplifiers (PAs) at back-off power regions is as important as that at peak power. Accordingly, many architectures such as envelope tracking (ET), envelope elimination and restoration (EER), Doherty PA (DPA), load modulation PA, etc., were developed. Among these techniques, ET [1] and EER systems modulate output supply voltage to get high efficiency. But, these topologies consist of extra circuits like envelope detector or envelope amplifier, leading to high circuit complexity. DPA [2] also has some disadvantages such as narrow bandwidth owing to a quarter-wave transmission line and poor linearity due to peaking amplifier. In this paper, load modulation [3] technique is chosen for high efficiency PA with simple structure and easy implementation, compared with other methods to attain high efficiency.

2. Design methodology

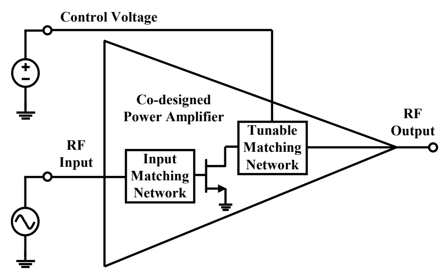

Fig. 1. Block diagram of load modulated PA

Fig. 1 shows an overall block diagram of designed load modulated PA. Output TMN is controlled by the envelope signal of RF input. It allows high efficiency operation even at low power regions. Design procedure of load modulated PA is presented below.

Firstly, high-efficiency harmonic-tuned class-AB PA was designed at 1.85 GHz using Cree CGH40006P GaN HEMT. To determine optimum source and load impedances of PA for high efficiency, multi-harmonic source-pull/load-pull simulations were performed at drain bias voltage of 28 V. We considered a fundamental impedance at the source side, because harmonic source impedances have little effect on the efficiency. On the other hand, impedances at fundamental, 2^{nd}, and 3^{rd} harmonic frequencies were considered at the drain side.

Table 1. Optimum source/load impedances

Frequency (GHz)	Optimum load impedances (Ω)	Optimum source impedances (Ω)
1.85 (f_0)	$Z_{L1,opt} = 22 + j27$	$Z_{S1,opt} = 16 + j57$
3.70 ($2f_0$)	$Z_{L2,opt} = j46$	-
5.55 ($3f_0$)	$Z_{L3,opt} = j76$	-

Table 1 shows the optimum source and load impedances obtained from multi-harmonic source-pull/load-pull simulations using Agilent ADS. The simulation showed a maximum PAE of 85% at the peak output power of 39 dBm.

Next, output TMN was designed using varactors of which the junction capacitance is controlled by the bias voltage. The varactors modeled by a variable capacitor with a minimum capacitance (C_{min}) of 4.7 pF and a capacitance ratio (C_{max}/C_{min}) of 8. This varactor has a high breakdown voltage about 60 V, hence it is suited for high power applications.

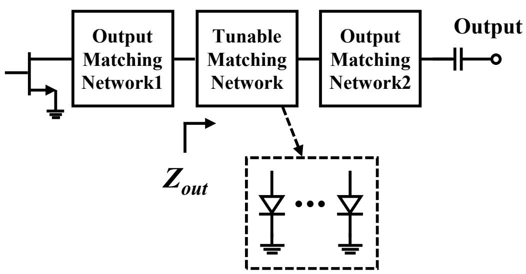

Fig. 2. Output tunable matching network of load modulated PA

Fig. 2 shows a schematic of designed output TMN. It is used as a part of output matching networks. .

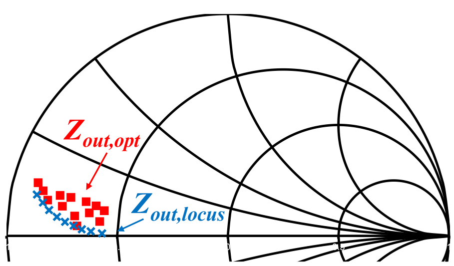

Fig. 3. Optimum impedance variation depending on output power.

Fig. 3 shows impedance variation according to output power. Z_{out} is load impedance looking into TMN as shown in Fig. 2. $Z_{out,opt}$ is optimum Z_{out} found from the load-pull simulation, and $Z_{out,locus}$ is input impedance of the designed TMN. This figure shows that the designed TMN can provide the optimum impedances for high efficiency over a wide range of output powers.

3. Measurement results

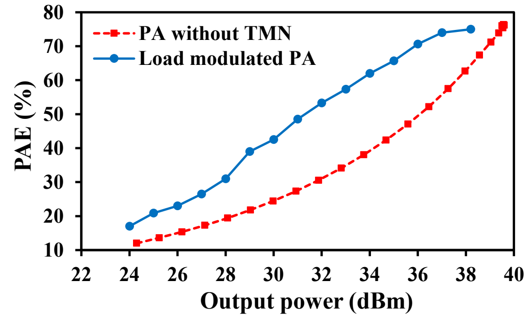

Fig. 4. PAE versus output power of PA without TMN and load modulated PA

Fig. 4 shows measured PAEs of two PAs, PA without TMN and load modulated PA. It is shown that load modulated PA achieves higher efficiency than the PA without TMN. Load modulated PA shows the maximum output power of 37.7 dBm with a PAE of 75.5%. Load modulated PA improves the PAE by 14.5% at 4.5 dB back-off power, compared with the PA without TMN. It also shows more than 10% improvement at both 7 dB and 10 dB back-off regions.

4. Conclusion

In this paper, a design procedure of load modulated PA was presented. The achieved result shows that PAE increased 14.5 % maximally at 4.5 dB back-off region.

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