High Speed Dynamic Bias Switching Power Amplifier for OFDM Applications

Jukyung Cha[*1], Youngsang Jun[**2], and Sangwook Nam[***3]

[*]*Samsung Thales, Giheung, Yong In, Korea*
[1]jk00.cha@samsung.com

[**]*Korean Intellectual Property Office(KIPO), Daejeon, Korea*
[2]ysjeon@chollian.net

[***]*School of Electrical Engineering and INMC, Seoul National University, Seoul, Korea*
[3]snam@snu.ac.kr

***Abstract* — An efficiency-enhanced power-amplifier system using dynamic bias switching method is presented. The presented system generates two different voltage sources from one source for drain bias of a RF power amplifier. The drain of the RF power amplifier is biased at low voltage level while the input RF signal is detected to be small. The drain bias is rapidly changed to high voltage level when the input RF signal reaches a certain threshold level. The measured drain bias at V_H state is 4.6V with the efficiency of the bias switching system, 49% and at V_L is 2.94V with 86%. The measured result shows that the overall efficiency of the proposed RF power amplifier is improved by 62% compared to that of the fixed bias amplifier, when OFDM signal with bandwidth 8.46MHz is applied.**

***Index Terms* — Power amplifier, dynamic bias, class E^2 rectifier, InGaP GaAs HBT**

I. Introduction

In portable wireless devices, the power amplifier consumes most of the power in the RF front-end. The overall RF front-end power consumption can be dramatically reduced by increasing the efficiency of the power amplifier. Systems applied to non-constant envelope modulation scheme need to have a linear power amplifier such as class A/AB. Those power amplifiers much have a capability to linearly amply the maximum power signal that takes place quite rarely in a high PAPR modulation scheme such as OFDM and CDMA. The overall efficiency of the system is very low since the bias is fixed for the maximum output power. To increase the efficiency of system, power amplifier linearization techniques are often used, so power amplifiers can operate more efficiently while achieving certain linearity. However, there is still limitation to improve the efficiency of system, for those amplifiers still need to operate at a significant back-off from the saturation point in order to maintain linearity performance.

Many techniques have been studied for improving the efficiency of linear power amplifiers[1]. A dynamic power supply power amplifier is one of the attractive ways to increase the efficiency of power amplifier [2]. Kahn's envelope elimination and restoration(EER) technique[3] is one of the dynamic power supply power amplifiers that

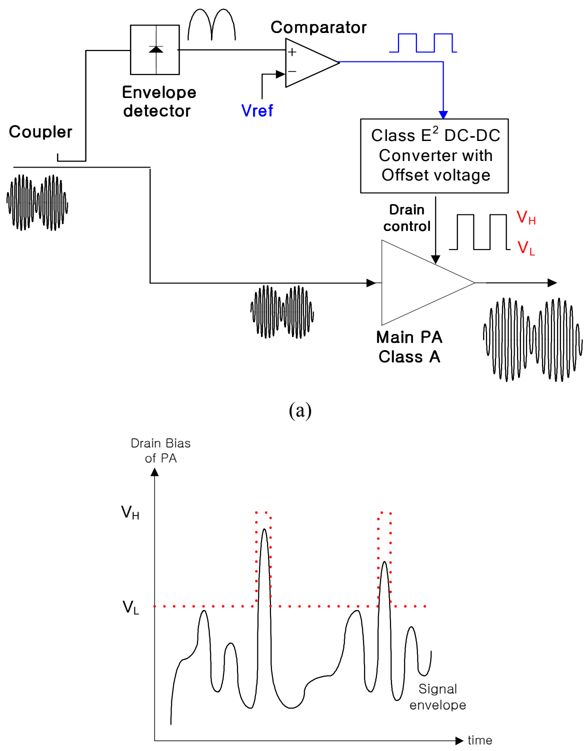


Figure 1. (a)Block diagram of dynamic bias switching PA (b)Drain bias waveform of RF power amplifier

amplifies RF signals with theoretical efficiency up to 100%. In the Kahn technique, an envelope and a phase modulated signal are extracted from an RF input. The phase modulated carrier is amplified by a class E amplifier. A dc-dc converter enables the supply voltage of the class E drain bias to change continuously, according to the envelope of the RF input. To improve the linearity performance, a class A power amplifier can be used instead of a class E power amplifier. This technique is known as Envelope Tracking(ET). In spite of the benefit of dynamic power supply schemes, there is the problem that it is difficult to control the drain bias at high speed due to the narrow bandwidth of the dc-dc converter[4]. Dynamic bias switching is an attractive way to overcome bandwidth problem. The drain bias is changed discretely[5][6]. However, there are some problems that more than two voltage sources are required and it is difficult to design power supplies which enable the current to change abruptly.

A novel structure of dynamic bias switching method is proposed[7] in order to solve those problems mentioned above. The novel dynamic bias switching system generates two different levels of bias voltage using only one voltage source. Furthermore, the bandwidth of the system is up to 1.23MHz.

In this paper, the novel dynamic bias switching system is fabricated using InGaP GaAs HBT technology. In additional, the system bandwidth, 8.46MHz, is achieved.

II. ARCHITECTURE

Figure 1 shows the block diagram of dynamic bias switching PA system, which consists of two parts, a bias switching system and a main RF power amplifier. The bias switching system is what this paper mainly deals with. As shown in Figure 1, an envelope detector, a comparator, and an oscillator play the roll of controller of the system and class E^2 rectifier having an additional offset voltage generates a certain level of voltage to the drain bias of main RF power amplifier.

Figure 2 shows the modified class E^2 rectifier. For the generation of two types of voltage source, the high speed bias switching circuit is composed of a typical class E^2 rectifier and one voltage source attached to the diode in rectifier circuit. Unlike the envelope tracking system, there are two dc bias states, high voltage state(V_H) and low voltage state(V_L). The output voltage of the converter is V_H only when the input signal forms peak. Except for the peak time, the output voltage of the converter stays V_L. This system is quite beneficial to the application using high PAPR signal. The possibility that the signal peaks occur in high PAPR system is very low and the efficiency of V_L state is theoretically 100%, so the overall efficiency of the PA using the bias switching technique is improved. One bit control signal determines either the bias switching circuit operates or not. When the control signal in Figure 2 is high, the Class E amplifier starts to operate and the output of it is rectified. In this case, the voltage of the load reaches to V_H. While the control signal is low, the class E amplifier is turned off and the dc source(V_{DD}) keeps connected to the load through the diode. Since the voltage drop at the diode is critical for efficiency of the bias switching circuit, the schottky diode is used. Therefore, load voltage(V_L) of system is lower than V_{DD} by about 0.4V. The switching frequency of the Class E amplifier is selected about 200MHz considering the necessary bias switching speed and the efficiency of V_H state.

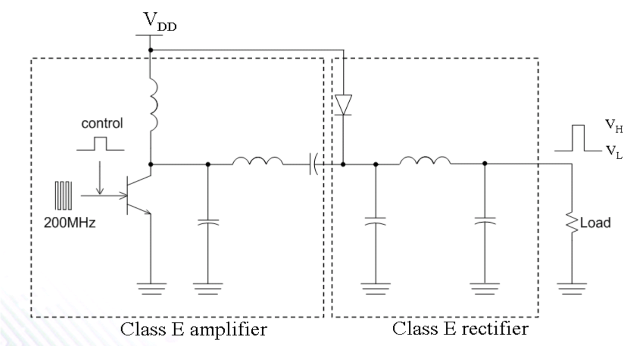


Figure 2. Schematic of the modified class E^2 rectifier

The operation of class E amplifier in class E^2 rectifier boosts up the output to be high at the load in Figure 2. An oscillator is placed in the previous stage of class E^2 rectifier to drive the class E amplifier. Figure 3 shows the relaxation oscillator used in the system. The transistor in class E amplifier is used as a switch. Therefore, to efficiently drive this switch, a driving signal shaped like rectangular waveform is preferred to sinusoidal waveform. The relaxation oscillator in Figure 3 outputs the signal resembling rectangular waveform, so this type of oscillator is adopted in the system. The oscillation frequency is determined by the value of R-C time constant. While the oscillator operates, the power loss occurs at the resistors in oscillator. Therefore, when the oscillator is designed, the value of resistors should be as large as possible, which means the value of capacitor must be as small as possible. The minimum value of capacitor is determined by fabrication technology.

A switch component is necessary to turn on and off the oscillator. The components playing the roll of the switch at the relaxation oscillator are NPN type transistors. The efficiency when the oscillator does not operate is especially critical. The reason is that the overall system operates at low bias state for most of the time, when high PAPR signal is applied. The measured power dissipation at the bias of V_L is less than 6mW.

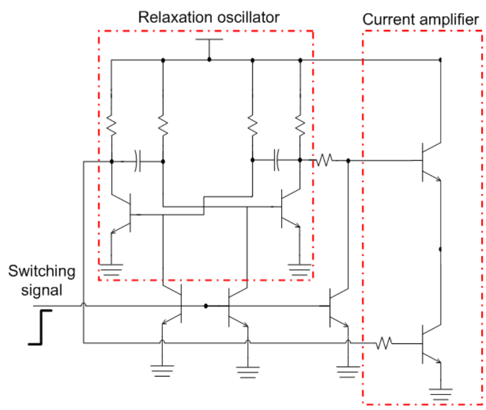


Figure 3. Schematic of the relaxation oscillator and current amplifier

In the schematic of Figure 3, a current amplifier is placed between the relaxation oscillator and the class E amplifier. The current amplifier converts the voltage output signal of the oscillator into the power signal which drives the class E amplifier without distortion.

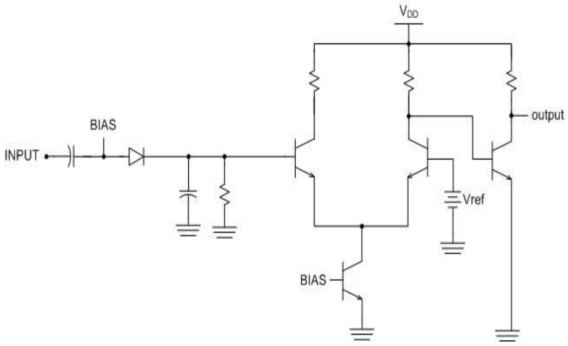


Figure 4. Schematic of the envelope detector and comparator

The Figure 4 shows an envelope detector and a comparator which gives the on/off switching signal to the oscillator in the next stage. The simple envelope detector consists of a diode, a capacitor, and a resistor. A bias circuit is connected to the input of diode to minimize the effect of voltage drop at the diode. The comparator has two stages, which make the transition period steeper. The threshold voltage which determines the moment when the output is high or low can be adjusted by V_{ref} in Figure 4.

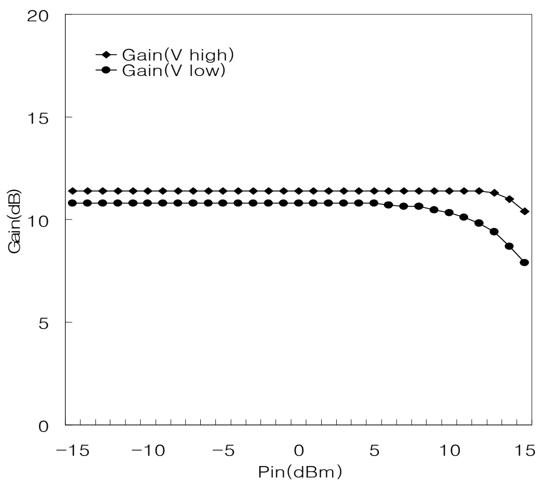


Figure 5. The gain curve of the class A power amplifier at high(4.6V) and low(2.9V) drain bias

The main class A power amplifier was designed using a transistor EFA240C. In Figure 5, the gain of power amplifier is represented for the each operation mode. The difference of the gain between V_H state and V_L state is about 0.6dB. this difference brings the result of non-linearity of the output signal. Therefore, the RF PA with very small difference of its gain is necessary to improve the linearity performance.

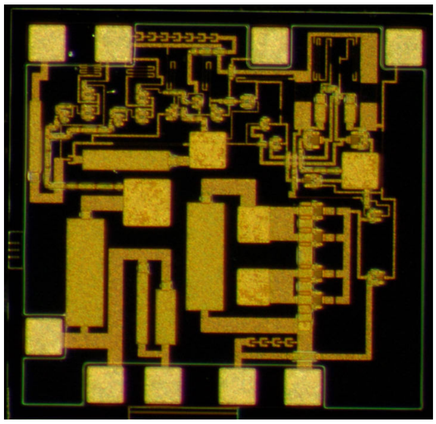


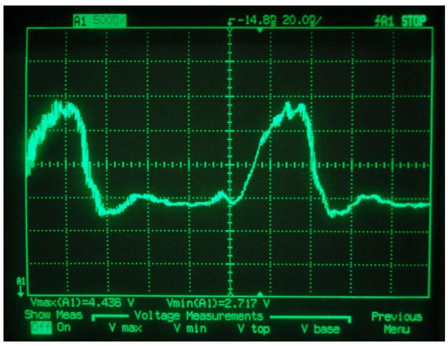
Figure 6. The die photo of bias switching system

The components depicted in Figure 2, 3, and 4 were implemented using InGaP GaAs HBT technology provided from Knowledge*on except for inductors, a schottky diode, and a capacitor in low pass filter. Figure 6 represents the fabricated die photo, whose size is 1.1mm x 1.1mm.

III. MEASUREMENT RESULTS

This session deals with what is mentioned below;

(1) The two tone measurement of Integrated circuit
(2) The high PAPR signal measurement of the overall system



(a)

	Controller	Class E^2 rectifier	V_{out}
V_L	4mA	82mA	2.94V
V_H	53mA	313mA	4.6V

(b)

Figure 7. (a) Time-domain waveform at the load when two tones are applied to the system(f_1=2.3955GHz, f_2=2.4045GHz) (b) Measured current from power supply at the each case

In the two tone experiment, the two-tone spaced 9MHz apart with center frequency 2.4GHz is applied to the input of bias switching system. The load of IC is connected to a resistor, 36Ohm, which is input impedance of drain of class A power amplifier. Figure 7 represents the output of the bias switching system and the measured current from power supply at the each case, V_L and V_H. The closer the tone spacing of input signal is, the sharper the transition between two states is. V_{DD} is 3.3V, so the efficiencies of V_L and V_H are 86% and 49%, respectively.

The overall system measurement is performed by combining the bias switching system, class A power amplifier, coupler, and a delay line. An orthogonal frequency-division multiplexing(OFDM) signal is applied to the input of the system. The OFDM whose bandwidth is approximately 8.46MHz similar with that of WiBro is 802.11g with a different sampling rate. Figure 8 shows the output spectrum masks at each drain bias conditions including V_H, V_L, and the proposed operation. In Figure 8, in case of V_L operation, the adjacent channel re-growth occurs about 2.5dB compared to that of V_L mode. In case of using the bias switching system, however, the adjacent channel level becomes lower as same as that of V_H operation. It must be noticed that there is a spectral re-growth

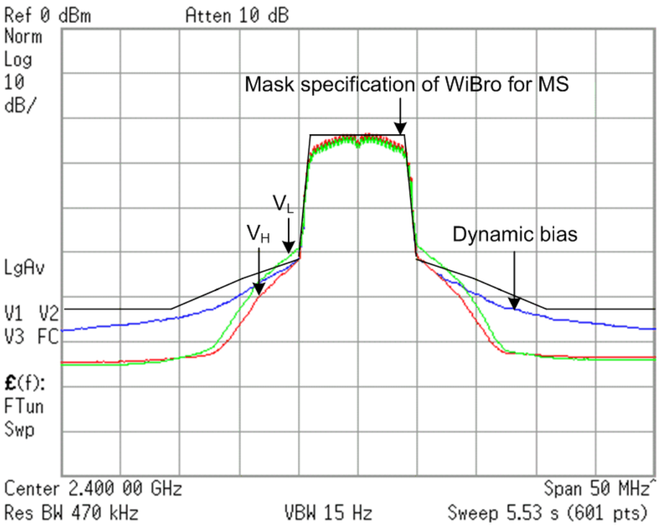


Figure 8. Output spectrum masks at each drain bias conditions(V_H, V_L, and bias switching operation)

when the proposed system is used. This non-linearity is thought to be due to the gain and the delay mismatch. Although this re-growth exists, there is still the benefit that the system can be used in some cases such as WiBro whose mask specification of spectrum is more strict in adjacent channel rather than outside the channel. The overall efficiency in a constant V_H(4.6V) mode is 6% and efficiency in the introduced system mode with V_{DD}(3.3V) is 9.8%. Consequently, the calculated efficiency improvement is 62%.

IV. Conclusion

The high speed bias switching power amplifier is introduced. It is also introduced that the controller components and the modified class E^2 rectifier, both of which are designed for fast bias switching. The system including the controller and the class E^2 rectifier is fabricated using InGaP GaAs HBT technology, which shows the possibility of using it for mobile application. The remarkable feature of the fabricated bias switching system is that it has very high efficiency when it is V_L mode. Therefore, it is expected that there is a large efficiency enhancement in high PAPR system. The experiment using OFDM signal shows a good efficiency enhancement and satisfactory linearity performance.

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References

[1] F. H. Rabb, P. Asbeck, S. Cripps, P. B. Kenington, Z. B. Popović, N. Pothecary, J. F. Sevic, and N. O. Sokal, "Power Amplifiers and Transmitters for RF and Microwave," *IEEE Trans. Microwave Theory & Tech.,* vol. 50, no. 3, pp. 814-826, March 2002.

[2] G. Hanington, P. F. Chen, P. M. Asbeck, L. E. Larson, "High-Efficiecny Power Amplifier Using Dynamic Power-Supply Voltage for CDMA Applications," *IEEE Trans. Microwave Theory & Tech.,* vol. 47, no. 8, pp. 1471-1476, August 1999.

[3] L.R. Kahn, "Single-sideband transmission by envelope elimination and restoration,*" Proc. IRE*, pp. 803-806, July 1952.

[4] H. Raab, "Intermodulation Distortion in Kahn-Technique Transmitters," *IEEE Trans. Microwave Theory & Tech.,* vol. 44, no. 12, pp. 2273-2278, December 1996.

[5] C. Buoli, A. Abbiati, D. Riccardi, "Microwave power amplifier with envelope controlled drain power supply," in *Proc. of 25th European Microwave Conference*, September 1995, pp. 31-35.

[6] Khanifar, N. Maslennikov, R. Modina, and M. Gurvichm, "Enhancement of Power Amplifier Efficiency Through Dynamic Bias Switching" *in IEEE MTT-S Int. Microwave Symp. Dig.,* 2004, pp. 2047-2050.

[7] Young-Sang Jeon, Jukyung Cha, and Sangwook Nam, "High-Efficiency Power Amplifier Using Novel Dynamic Bias Switching," *IEEE Trans. Microwave Theory & Tech.,* vol. 55, no. 4, pp690-696, April 2007.