A Linear Power Amplifier Design Using an Analog Feedforward Method

Ung Hee Park and Haeng Sook Noh

ABSTRACT—We propose and describe the fabrication of a linear power amplifier (LPA) using a new analog feedforward method for the IMT-2000 frequency band (2,110–2,170 MHz). The proposed analog feedforward circuit, which operates without a pilot tone or a microprocessor, is a small and simple structure. When the output power of the fabricated LPA is about 44 dBm for a two-tone input signal in the IMT-2000 frequency band, the magnitude of the intermodulation signals is below –60 dBc and the power efficiency is about 7%. In comparison to the fabricated main amplifier, the magnitude of the third intermodulation signal decreases over 24 dB in the IMT-2000 frequency band.

Keywords—Amplifiers, feedforward, linearization, high power amplifier, linear power amplifier.

I. Introduction

To obtain the maximum efficiency in a high-power amplifier (HPA), the operation point of the high-power transistor must be located near the saturation region where a highly nonlinear characteristic is inevitable. When multiple carriers are injected into a nonlinear high-power transistor simultaneously, an intermodulation (IM) signal occurs in the output of the HPA. Since an IM signal in a communication system is noise, the IM signal in an HPA must be reduced to improve the communication capacity. To decrease the IM signal, it is generally necessary to add a circuit to realise the linearization method.

A block diagram of the linear power amplifier (LPA) using the general feedforward method is shown in Fig. 1. A feedforward LPA can be divided into a dual block, comprising an error sensor loop and an error injection loop. The error sensor loop amplifies the input signal at the HPA and extracts the IM signal of the HPA at the output of the error sensor loop. The error injection loop amplifies the IM signal from the error sensor loop and removes the IM signal at the output of the LPA. The LPA extracts the IM signals at the combiner in the error sensor loop and removes the IM signals at the coupler in the error injection loop [1], [2] .

This paper proposes an analog feedforward method which operates without a pilot tone or microprocessor. The suggested method uses only a simple comparison circuit and operates stably in real time.

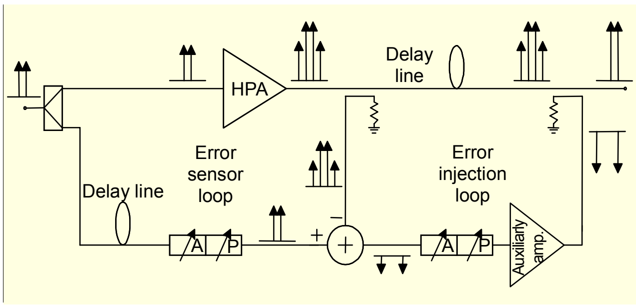

Fig. 1. Block diagram of linear power amplifier using basic feedforward method.

II. The Proposed Analog Feedforward Method

A block diagram of the proposed analog feedforward method is shown in Fig. 2. The feedforward circuit can be divided using an error sensor loop and error injection loop. In the proposed analog feedforward circuit, the main characteristic of the error sensor loop is the IM signal extraction method which directly compares the RF signal at the combiner. The operation mechanism of the error sensor loop in

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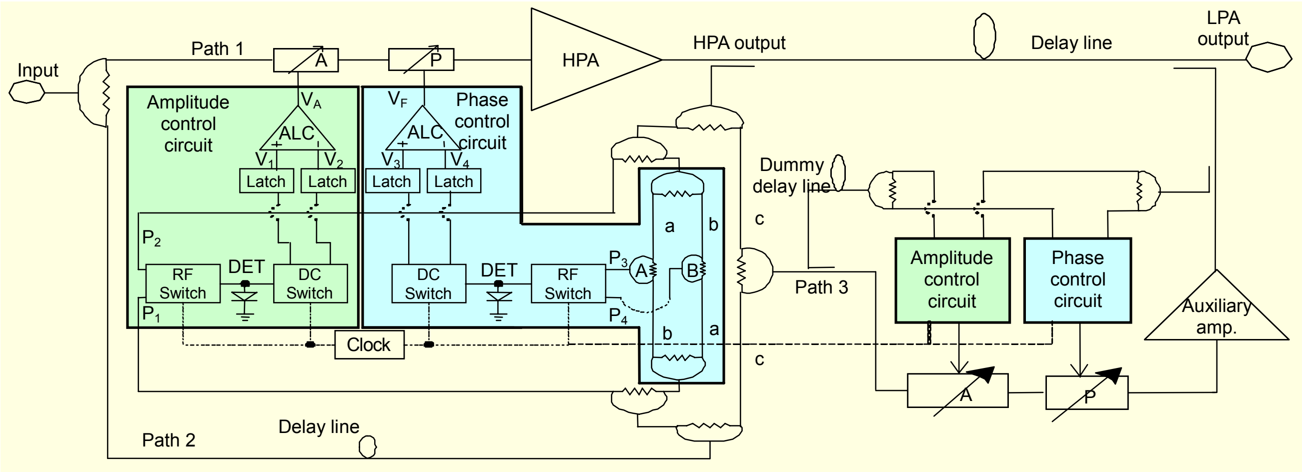

Fig. 2. Block diagram of the proposed LPA.

Fig. 2 is as follows. Path 1 in Fig. 2, the main path, consists of an HPA, a variable attenuator, and a phase shifter located in front of the HPA to compensate for the magnitude and phase errors. Path 2 serves as the reference for the magnitude control and phase control in the main path. The amplitude control circuit controls the variable attenuator in path 1. Here, when the same powers P_1 and P_2 are applied to the detector, the same voltages V_1 and V_2 are generated. The ALC circuit adjusts V_2 to equal V_1 by increasing or decreasing the output voltage, V_A, which controls the variable attenuator. The phase control circuit, which controls the phase shifter in path 1, is similar to the amplitude control circuit. The difference between the two circuits is the signal condition at the input port of the RF switch. The RF switch in the phase control circuit has two input signals (P_3 and P_4). For signal cancellation at the combiner, the phase difference between the two input signals must be 180°. If the electrical lengths of paths a and b differ by α degrees, the output phase of combiner A is 180 + α degrees, and the output phase of combiner B is 180 – α degrees. Since combiners A and B are the same difference phase (α) from 180°, the output powers P_3 and P_4 have the same value. If the phase control circuit causes the phase shifter to have the same phase difference at combiners A and B, the phase difference of the combiner in path 3 becomes 180°. If the magnitudes and phases of paths 1 and 2 are equal and 180° apart, the Wilkinson combiner at the beginning of path 3 is used only to obtain the IM signals [3]. To decrease the IM signal of the HPA, the IM signal in the error injection loop must be amplified without distorting the magnitude and phase. However, the auxiliary amplifier, which is a nonlinear circuit, distorts the IM signal. The variable attenuator and phase shifter in the error injection loop can offset the magnitude and phase variation of the auxiliary amplifier. The reference signal for the amplitude and phase control circuits in the error sensor loop is the output signal of the Wilkinson combiner at the start of path 3, and the comparative signal is the output signal of the auxiliary signal. The amplitude control circuit and phase control circuit in the error injection loop and the amplitude circuit and phase control circuit in the error sensor loop are the same circuit and the same operating method. Nevertheless, the reference path in the error injection loop needs a dummy delay line to compensate for the time difference between the reference and comparative signals in the error injection loop.

The block diagram of the HPA in the proposed LPA for the IMT-2000 frequency band is shown in Fig. 3.

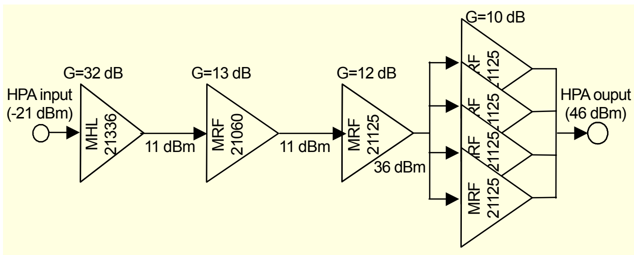

Fig. 3. Block diagram of the HPA.

III. Results

An LPA using the analog feedforward method is shown in Fig. 4. The fabricated LPA can operate within any 30 MHz frequency range of the IMT-2000 band (2,110 to 2,170 MHz). This limitation of the frequency band arises from the characteristics of the auxiliary amplifier, which operates at a 120-MHz band from 2,080 to 2,200 MHz. The maximum average output power of the fabricated LPA is 44.4 dBm and the power efficiency is 7%. Here, we consider a 10 dB peak-to-average ratio of the communication signal. The gain and the gain flatness of the fabricated amplifier were about 54 dB and

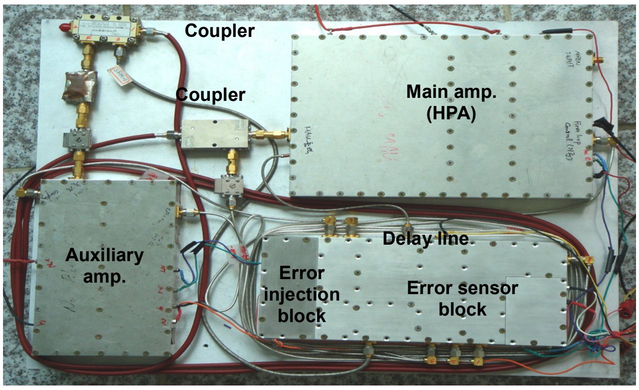

Fig. 4. Photograph of the fabricated LPA.

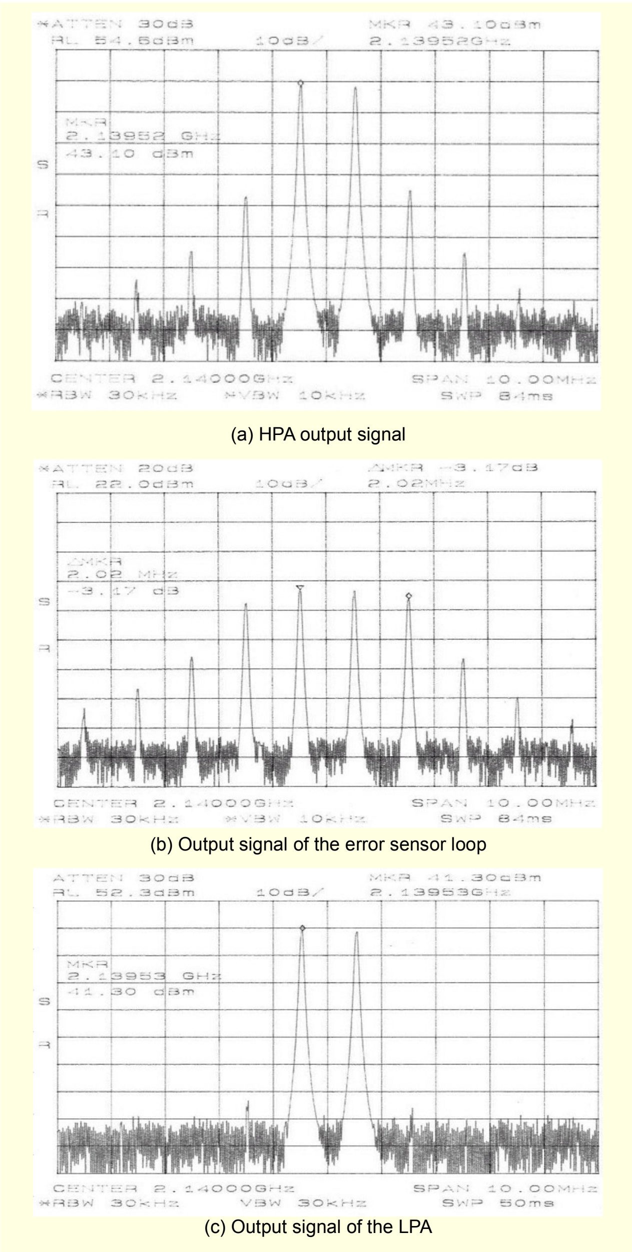

Fig. 5. Output signal of the fabricated LPA.

were within ±0.2 dB in the IMT-2000 band. When the HPA outputs about 46 dBm, the supply power of the HPA is 338 W (V=26 V, I=13 A) and the power efficiency is 12%.

When the input signal is two tones and the average output power is about 44 dBm, the IM signal level of the fabricated LPA is below –60 dBc over the entire IMT-2000 frequency range. When the input signal is f_1=2,139.5 MHz and f_2=2,140.5 MHz, the signal output at each point is as shown in Fig. 5. In the figure, (a) is the output signal of the fabricated HPA, an output power of 46.4 dBm, and (b) is the output signal of the error sensor loop. Figure 5(c) shows the output signal of the fabricated LPA. The gain of the fabricated LPA is about 49 dB and the gain flatness is within ±0.4 dB from 2,110 to 2,170 MHz.

IV. Conclusion

We proposed an analog control circuit which can easily be adapted to the error sensor loop and error injection loop of a feedforward linearizer. The control circuit consisting of analog components without a microprocessor can operate in real time. This analog feedforward method is characterised by a direct comparison method for the RF signal in the error sensor loop and a compensation function for the delay line in the error injection loop.

Using the analog feedforward circuit, we fabricated an LPA with a maximum output power of 44.4 dBm which operates over the IMT-2000 frequency band. The gain of the fabricated LPA was about 49 dB, and the gain flatness was within ±0.4 dB. When the average output power of the LPA was from 35 to 44 dBm, the measured IM signal of the fabricated LPA was below –60 dBc. The measured data for the fabricated LPA confirms that the proposed analog feedforward method can operate stably and perform well.

References

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