Power Amplifier Module with Digital Adaptive Predistortion for Cellular Phone.

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Abstract— **This paper describes a new type of PA-module which contains a predistortion function and the application to N-CDMA handset terminals. The predistortion technology is based on look-up-table method using the input and output signal envelopes and can operate independent from the base-band block. By omitting the adaptative predistortion for AM/PM, and integrating main controlling functions on CMOS IC chip, the predistortion technique has been realized in a PA-module. The PA-module has been achieved the power added efficiency (PAE) of 48% at the output power of 27.5dBm. This PAE is extremely high in comparison with the conventional PA-module for N-CDMA.**

I. Introduction

Cellular phones are going to be playing not only conventional wireless phones but also portable data terminals. Consequently, a power amplifier (PA) used in cellular phone is required higher power added efficiency (PAE).

Distortion compensation technologies are useful to improve the PAE. Generally, the PA for handset terminals is often used as configuration of MMIC or PA-module. However, conventional predistortion or feed-forward techniques, which are powerful to reduce the distortion, become very large in terms of the scale of its relevant circuit. RF-linearizer is often used in the MMIC but the effectiveness of distortion compensation is not sufficient to improve the PAE[1]. Consequently, it is desired to realize the predistortion-PA-module (PDPA) which represents very high PAE.

The authors are focusing on the predistortion technology using look-up-table (LUT)[2]. This technology is good to operate independent from the Base-Band block and to follow the power-control operation. However, as the technology needs a quadratic demodulator and two A/D-convertors for the adaptive predistortion, these circuits are still large size. And that, the controlling time delay due to accessing time to the LUT will degrade the effectiveness of predistortion. Thus, the conventional LUT method has to be modified by developing some new technologies.

This paper describes a new predistortion technology using LUTs and prototype of a PA-module build-in the predistortion function for N-CDMA (900MHz band) handset terminals. The PA-module has been achieved the PAE of 48% at the output power of 27.5dBm. This PAE is extremely high in comparison with the conventional PAs for N-CDMA.

II. Predistortion Power Amplifier

A. The investigation of PAE improvement by applying predistortion.

For PA operation with higher PAE, the saturated output power (Psat) of the PA should be near to the specified output power. On the other hand, when part of signal envelope exceeds the Psat, its clipping-distortion will appear. Consequently, even when the predistortion is applied, there still exists trade-off between PAE and distortion. The difference between the specified output power and the Psat (=back-off) depends on the peak to average ratio of the modulated input signal and specified adjacent channel power ratio (ACPR)[3]. The required back-off for PDPA can be acquired from simulation by using ACPR1 (= 900kHz offset) and ACPR2 (1.98MHz offset) as criteria.

As the presented PA is for N-CDMA, the modulated input signal is OQPSK (1.2288Mcps) and the peak to average ratio is set to 5dB. When the ACPR1 and ACPR2 are set to 5dB lower than the specified values in IS-95B, the required back-off was about 1.8dB. In the case of conventional PA for N-CDMA, as the back-off is about 3.5dB~4dB, the PAE will be improved extremely by the predistortion.

B. Architecture.

Fig.1 shows a block diagram of the proposed PA module. It includes a PA block for which the distortion compensation is performed, a gain-controlling block, a

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phase-controlling block, two signal envelope detecting blocks and CMOS IC which controls them and all of them are packaged in one module (built-in PDPA module).

Part of the RF input signal is detected, and then, its variable-envelope is sampled, detected and digitized by the A/D converter and accesses LUTs. Data from LUTs are converted to analog signals and drive the gain and phase controlling blocks.

The output voltage of PA is represented by

$$Vo(vi)=g(vi)\cdot exp\{j\cdot \theta(vi)\} \qquad (1)$$

where *vi* is the input signal envelope voltage, $Vo(vi)$ is the complex output voltage, $g(vi)$ and $\theta(vi)$ represent AM/AM and AM/PM nonlinearities respectively. Here, the PA is assumed to be memory-less.

Assuming predistortion functions for AM/AM and AM/PM as $f(vi)$ and $\phi(vi)$ respectively, the linearized output, $Vo\_lin(vi)$, is represented by

$$Vo\_lin(vi)=g\{f(vi)\}\cdot exp[j\cdot\{\theta(f(vi))-\phi(f(vi))\}] \\ =g0\cdot vi\cdot exp(j\cdot\theta_0) \qquad (2)$$

where $g0$ is the linearized gain and θ_0 is the phase offset caused by temperature etc. Defining $g(vi)$ and $\theta(vi)$ by cubic spline-function from measured data, $f(vi)$ and $\phi(vi)$ are determined by solving equation (2).

In the gain-controlling block, a dual-gate FET is used. The dual-gate FET is easy to vary the gain by controlling its 2nd gate voltage, *vc*. However, at the same time, also the transmission phase (=phase of S21) varies[4]. Here, *vca*, and *vcp* are defined as data for AM/AM and AM/PM predistortion. Representing AM/AM and AM/PM of the dual-gate FET as $h(vi,vca)$ and $\theta g(vi,vcp)$ respectively, when the predistortion is performed, *vca* and *vcp* can be decided from following relations, equation (3) and (4),

$$f(vi,)=h(vi,vca) \qquad (3)$$

$$\phi\{f(vi)\}=-[\theta\{f(vi)\}+\theta\{f(vi),vcp\}]\,. \qquad (4)$$

As *vca* and *vcp* depend only on *vi*, it can operate mostly independent from the base-band block except for downloading *vca* and *vcp* to LUTs.

C. Adaptive predistortion.

In well known adaptive predistortion technologies, a demodulator circuit is used to detect the distortion caused by AM/PM nonlinearity. However, as the demodulator circuit occupies large space, it is not acceptable for PDPA module in terms of size as usual.

There is the case that the AM/PM, represented by $\theta(vi)$, is almost same except for θ_0 when the temperature has changed[5][6]. Particularly, this is remarkable when the drain current is regulated by controlling the gate bias voltage. The authors measured AM/PM characteristic with the AM/PM predistortion by varying temperature from -30 degrees to +80 degrees, and the $|max\ \theta(vi)-min\ \theta(vi)|<2$ degrees was obtained. From this result and simulation, the degradation of ACPR was about less than 1dB. Consequently, the adaptive predistortion for AM/PM could be omitted.

The AM/AM adaptive predistortion is performed by detecting the sign of difference between input and output signal envelopes using a comparator and modifies LUT for AM/AM.

By omitting the adaptive predistortion for AM/PM, the configuration is simplified and it makes possible to realize the build-in PA-module with the adaptive predistortion.

D. Delay time sensitivity.

In the presented technology, the performance of distortion compensation is sensitive to the time delay of CMOS IC. From simulation, allowable delay time, τ_{da} was determined

$$\tau_{da}<40\,/\,fmax \qquad (5)$$

where *fmax* is the maximum frequency of signal envelope and *fmax* is 614.4kHz(=1.2288MHz/2) for N-CDMA. Then, from equation (5), $\tau_{da}<50ns$. To minimize the time delay, the flush type A/D converter and 0.25μm process are used in CMOS IC. It takes 25ns from A/D start to D/A output. Furthermore, part of RF-signal is detected before RF-SAW band pass filter (BPF) in Fig.1. As the group delay of the SAW BPF was about 30ns, the delay of CMOS IC is mostly canceled.

E. Design of Gain, Phase-Controlling Blocks and PA block.

As mentioned above, a dual-gate FET was used in the gain-controlling block, its variable gain range was 10dB. From simulation, the required variable gain range was about 4.5dB. In the phase-controlling block, a variable-capacitance-diode was used, its phase controlling range was more than 10 degrees.

The keys of designing the PA block appropriate for the predistortion are the Psat and the PAE at the specified output power. The required Psat was more than 30dBm. The PAE should be designed as high as possible at the specified output power. The PAE of the PA block was 51% at the output power of 27.5dBm.

III. PERFORMANCE

Fig.2 shows ACPR and PAE performances of presented PDPA module. Fig.3 shows the output spectrum of the module. The RF signal is for N-CDMA in Japan. From Fig.2, ACPR1 (900kHz-offset) = -49dBc, 7dB improvement and ACPR2(1.98MHz-offset)= -59dBc, 4dB improvement were achieved at the output power of 27.5dBm. The PAE was 48% including the current consumption of the CMOS IC. CMOS IC consumed about 15mA. As the PAE of the conventional PA for N-CDMA is about 40% at most, 48% of the PAE is extremely high. As an example, if F-class technology is applied to it, the PAE will be improved more.

This module size is 11mm × 10mm × 2.0mm by mounting power-FET chip on back-side of the module. Such order of size is sufficient small to utilize in the cellular phones. The size will be smaller by using the MMIC-PA chip integrating with the dual-gate FET.

Simulated results of ACPR1 and ACPR2 with the predistortion case are also shown in Fig.2. The agreement is so good. In Fig.2, the ACPR1 and ACPR2 increase rapidly when the output power (Pout) is more than Pout=26dBm or 26.5dBm. This is result from the signal envelope clipping by Psat.

Fig.4 shows results of the adaptive predistortion measurement using the amplitude-modulated signal with the bias current variation, the bias current often varies on temperature. In Fig.4, in the case of the PA with adaptive predistortion, the signal power is constant, i.e. the recovery of the signal envelope is performed. The improvement of the distortion is maintained less than 10dB comparing with the PA without adaptive predistortion. This means that the distortion compensation except for AM/PM adaptatative predistortion operates effectively even when the bias current changed.

IV. CONCLUSION

A new type of the predistortion-power-amplifier-module for handset terminals has been impremented. The predistortion technology is based on look-up-table method using the input and output signal envelopes and can operate independent from the base-band block. The main controlling functions are integrated on CMOS IC chip. The adaptive predistortion for AM/AM is performed by detecting sign of difference between the input and output signal envelopes. The adaptive predistortion for AM/PM is omitted. The PAE of the presented PDPA is achieved 48% at the output power of 27.5dBm. This PAE is extremely high in comparison with the conventional PAs for N-CDMA.

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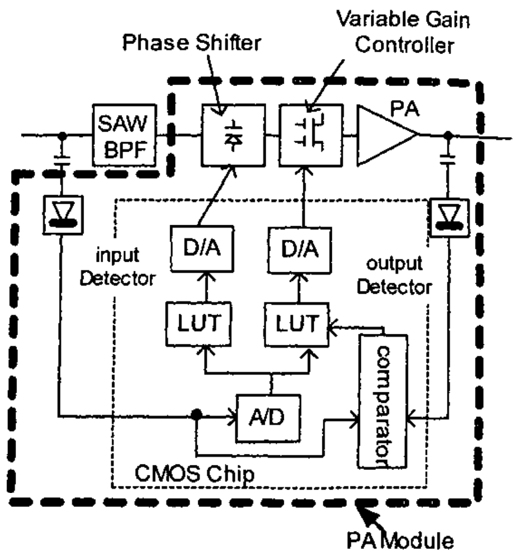

Fig. 1. The Block Diagram of presented PDPA module

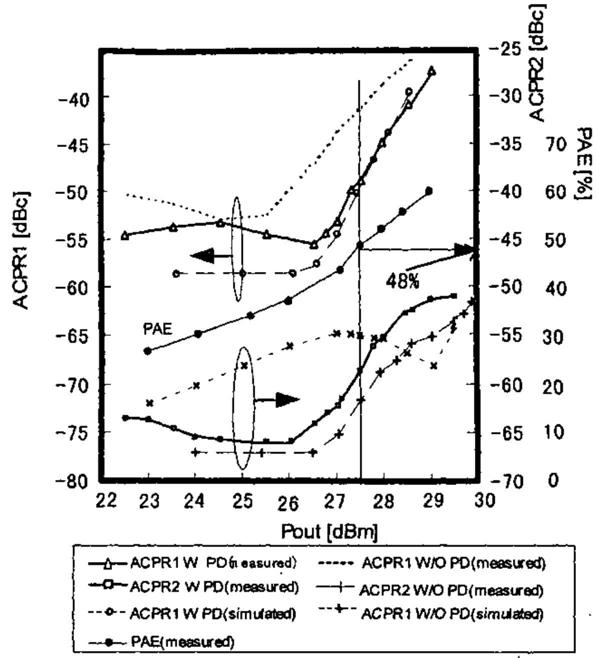

Fig.2. ACPR and PAE performance of presented PDPA

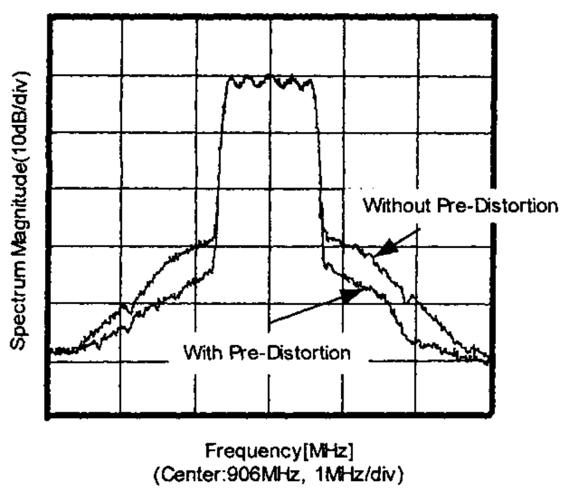

Fig.3. Output spectrum of the presented PDPA module with and without pre-distortion.

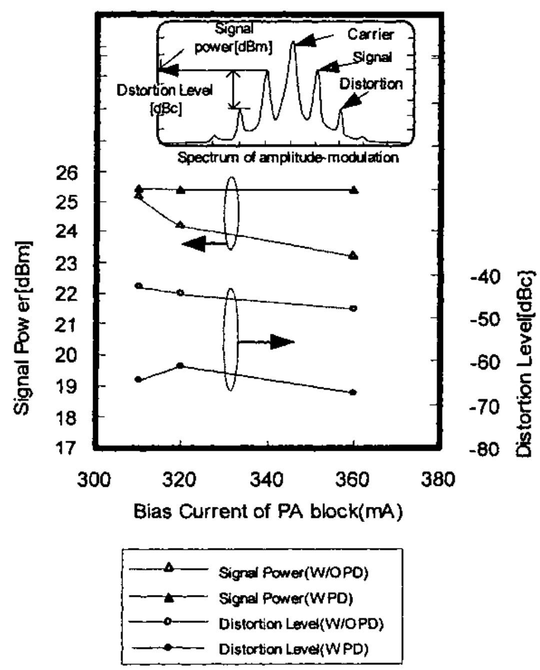

Fig.4. Results of adaptive predistortion measurement using amplitude-modulated signal with bias current variation.