Analog Predistortion Linearizer for High-Power RF Amplifiers

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***Abstract*—We have developed an analog predistortion linearizer for a high-power amplifier of a code-division multiple-access (CDMA) base station. To effectively suppress the spectral regrowth in the adjacent channels, the odd-order intermodulation distortions (IMDs) should be cancelled. To accomplish this purpose, we employed a predistorter, which can cancel the third and fifth IMDs independently. The implemented predistorter linearized the RF amplifier with an average power of 45 dBm at 2.37–2.4-GHz band. A 9-dB suppression of spectral regrowth, from 33 to 42 dBc, was achieved for the CDMA signal with an 8.192-Mc/s chip rate over a 30-MHz bandwidth.**

***Index Terms*—Intermodulation distortion, linearization, predistortion, RF power amplifier.**

I. Introduction

AMONG THE various techniques for linearizing RF power amplifiers, a predistortion method is a low-cost solution for the moderate performance improvement [1]. It has additional advantages of low-power consumption and simple circuit configuration over feed-forward amplifiers [2]. In comparison with a feedback technique, the predistortion offers wider bandwidth because it is inherently an open-loop structure [3].

In general, the high-power RF amplifiers for base stations operate in class-AB mode for enhanced efficiency. As a result, in addition to the third-order intermodulation distortion (IMD), a significant amount of higher order distortions are generated. The linearization performance of the predistortion depends on how well the nonlinear characteristic of the predistorter follows that of the main amplifier. Therefore, we have developed a predistorter with a separate control of third- and fifth-order components for the efficient suppression of harmonics. Based on the predistortion method, we have demonstrated a high-quality linear power amplifier.

II. Nonlinearity of Main Amplifier

The amplifier module of code-division multiple-access (CDMA) base station uses large-size devices, which display a large memory effect. To predict the nonlinear behavior of the amplifier, the usual method of measuring AM/AM and AM/PM characteristics is not appropriate since the characterization is adequate only for memoryless systems [4]. For this reason, the two-tone transfer characteristics of the main amplifier are directly measured and the measured data is used for the predistorter design. The magnitude transfer functions of IMDs are easily measured on a spectrum analyzer. The method for measuring phase information was reported in [5]. We developed an improved method. In our approach, the phase offsets of the IMD components can be measured directly by finding the phase difference between the fundamental and intermodulation (IM) components. The measurement setup is shown in Fig. 1. The essence of the setup is the phase reference signal generator. The reference IM generator is operated at a very low frequency, i.e., 750 kHz, and at the low frequency, the phase of the harmonic terms are 0° or 180° without variation with the input power level [6]. The IMD terms of the main amplifier and IM generator are cancelled by adjusting the vector modulator. We can measure the relative phase variations of the fundamental and IMD terms as an input power level by monitoring the phase changes of the vector modulator.

We have employed a power amplifier with an average output power of 45 dBm and a peak power of 450 W. The amplifier consists of two parts: the driver and main amplifier. The driver is an LDMOS-based three-stage amplifier, and a 30-W LDMOS is used at the final stage to drive the main amplifier. The main amplifier is two stages. One stage is a 120-W LDMOS and the final stage is a four-way combined 120-W LDMOS, which can handle 450 W of peak power in a CDMA signal. The amplifier operates in class AB and the overall gain of the main amplifier is about 50 dB. Fig. 2 shows the power amplifier.

The measured fundamental, third intermodulation (IM3) and fifth intermodulation (IM5) relative phases of this main amplifier are shown in Fig. 3. As the amplifier saturates, the relative phases of IM3 and IM5 change rapidly. The relative phases of IM3 and IM5 differ significantly in most power levels, which implies that it is very difficult to compensate the IMDs of this amplifier with only one predistortion device.

III. Predistortion Circuit Configuration

A conventional configuration of predistortion circuit, shown in Fig. 4(a), uses one nonlinear device for the generation of predistortion signals [2], [7]. To compensate for nonlinearities, the IM components of predistortion circuits should have an equal magnitude and out of phase compared with those of the main amplifier. It is very difficult to match the nonlinear characteristics of the predistorter and main amplifier because they differ both in the size and number of stages. Therefore, the amount of cancellation of IMD is limited, especially with the IM5 and higher order distortions. To solve this problem, a modified configuration that can control the magnitude and phase of IM3 and IM5 independently is employed, as shown in Fig. 4(b). The error

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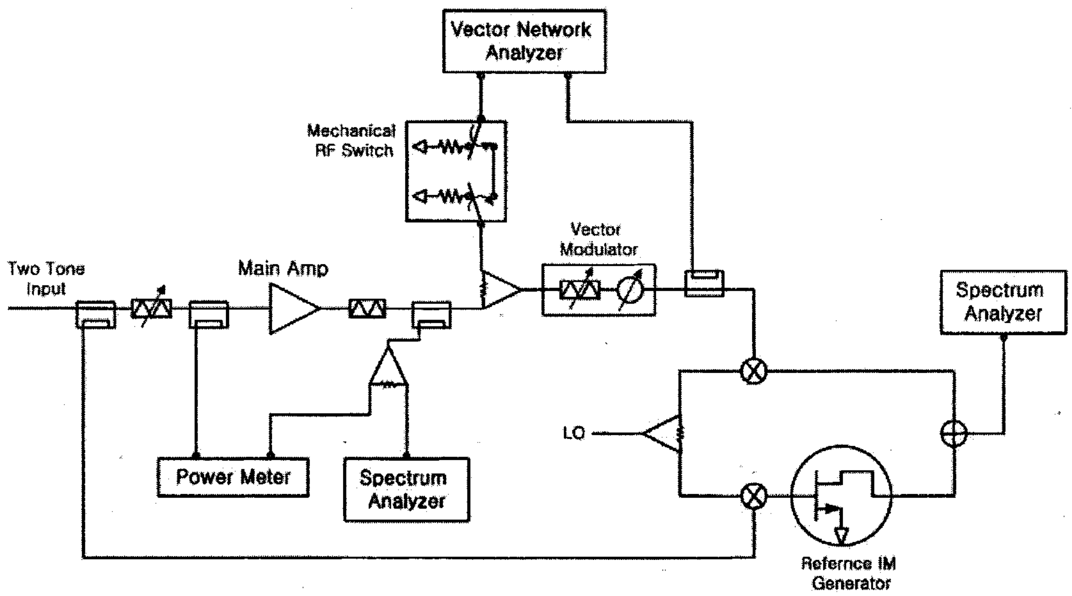

Fig. 1. Measurement setup for two-tone transfer characteristics.

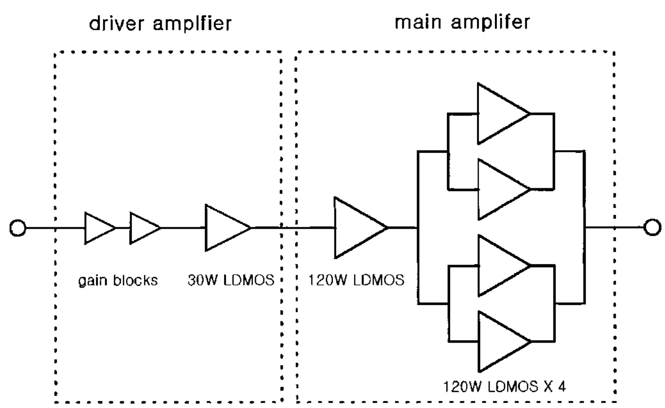

Fig. 2. Power-amplifier module used for the experiment.

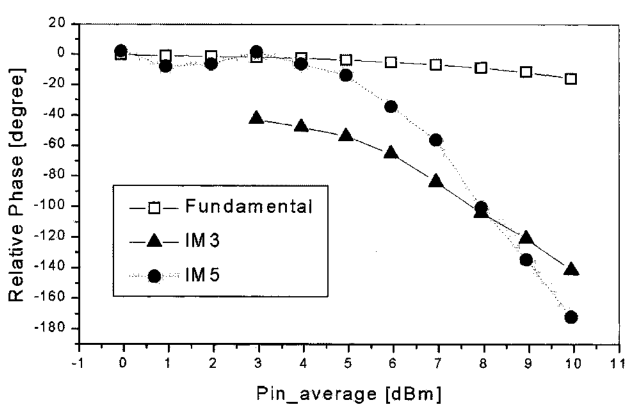

Fig. 3. Input power dependence of the relative phases of fundamental IM3 and IM5.

generating amplifier for IM3 is quite linear and only IM3 harmonic is significant. To generate IM5, another error generating amplifier with higher nonlinearity is employed. In general, the IM3 is greater than the IM5 level and IM3 is cancelled out using the IM3 component of an IM3 generating amplifier. We can have significant IM5 and can control the magnitude and phase of IM5 independently by a vector modulator.

IV. Experimental Results

The predistortion circuit of Fig. 4(b) is used to linearize the high-power RF amplifier described in Section II. The error generating amplifier is made by a GaAs FET monolithic-microwave integrated-circuit (MMIC) amplifier with an output $P1$ dB of 21 dBm. Fig. 5 shows the two-tone power spectra at several points in the predistorter circuit. The IM3 level of the IM3 generating amplifier is 25 dB higher than the IM5 level and the IM5 component of IM3 generation part does not affect the IM5 component of the IM5 generating amplifier. In the IM5 generation part, the power levels of higher than IM5 components are much lower than IM5 and they are negligible. The carrier signal is cancelled by about 30–35 dB and IM3 component in the IM5 generation part is cancelled by 20 dB. The vector modulator consists of a variable attenuator and a phase shifter. They are reflection types using a 3-dB hybrid coupler, as shown in Fig. 6(a). To achieve a 30-dB cancellation level, the variations of attenuation and phase shift of the vector modulator is less than ± 0.2 dB and 2°, respectively [2]. The measured attenuation and phase shift over a 30-MHz frequency range are shown in Fig. 6(b). As shown in this figure, the variations are within ± 0.1 dB and 2°, and the vector modulator satisfies the accuracy requirement.

Fig. 7 illustrates the results of the CDMA test with the main amplifier and predistortion linearizer. The test CDMA signal is 8.192-MHz bandwidth with a center frequency of 2.385 GHz and has about 11-dB peak-to-average ratio. The spectral regrowth of the main amplifier at the average output power of 45 dBm is suppressed by about 9 dB at 5-MHz offset from the center frequency. Fig. 6(a) and (b) shows the spectra before and after linearization, respectively. Fig. 6(c) shows the measured spectral regrowth of the main amplifier at the center frequencies of 2.375, 2.385, and 2.395 when the output power is lowered from the average output power of 45 dBm. The lineariza-

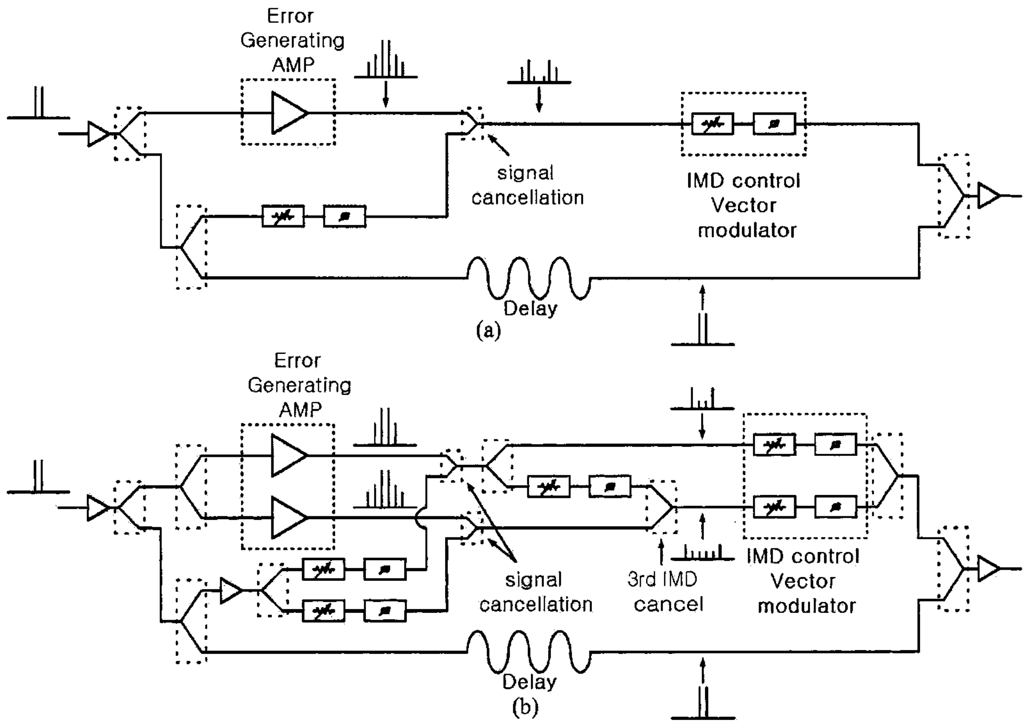

Fig. 4. (a) Conventional and (b) modified predistortion circuit configurations.

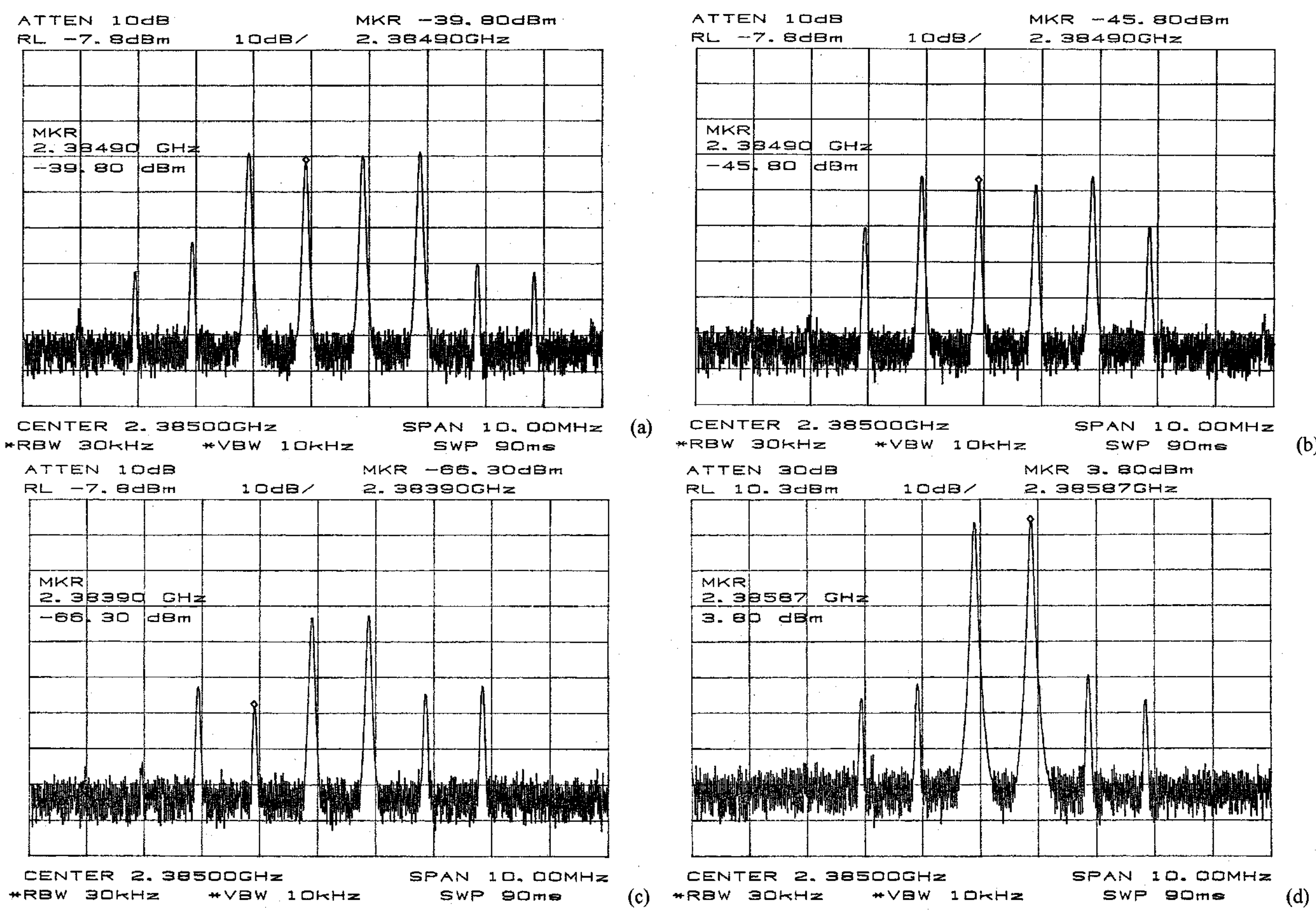

Fig. 5. Two-tone power spectra at the several points of the predistortion circuit. (a) After carrier cancellation at IM3 generation path. (b) After carrier cancellation at IM5 generation path. (c) After IM3 cancellation at IM5 generation path. (d) Final output of predistorter.

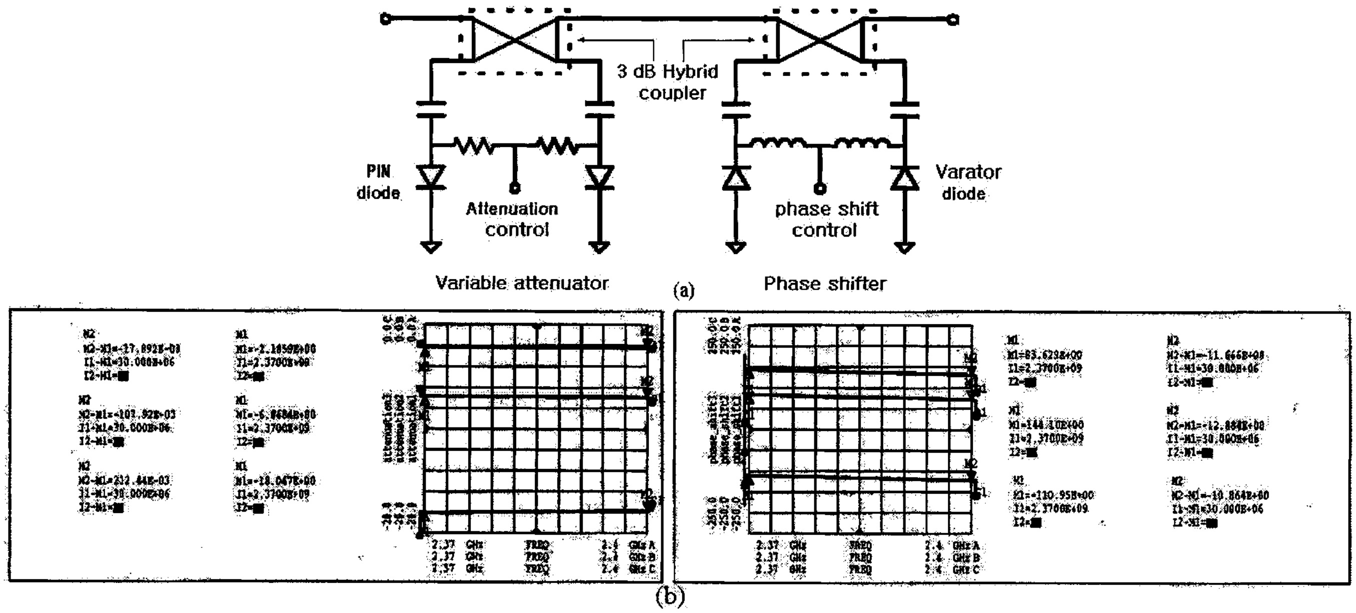

Fig. 6. Refection-type vector modulator: schematic and measured result. (a) Schematic of vector modulator. (b) Measured result.

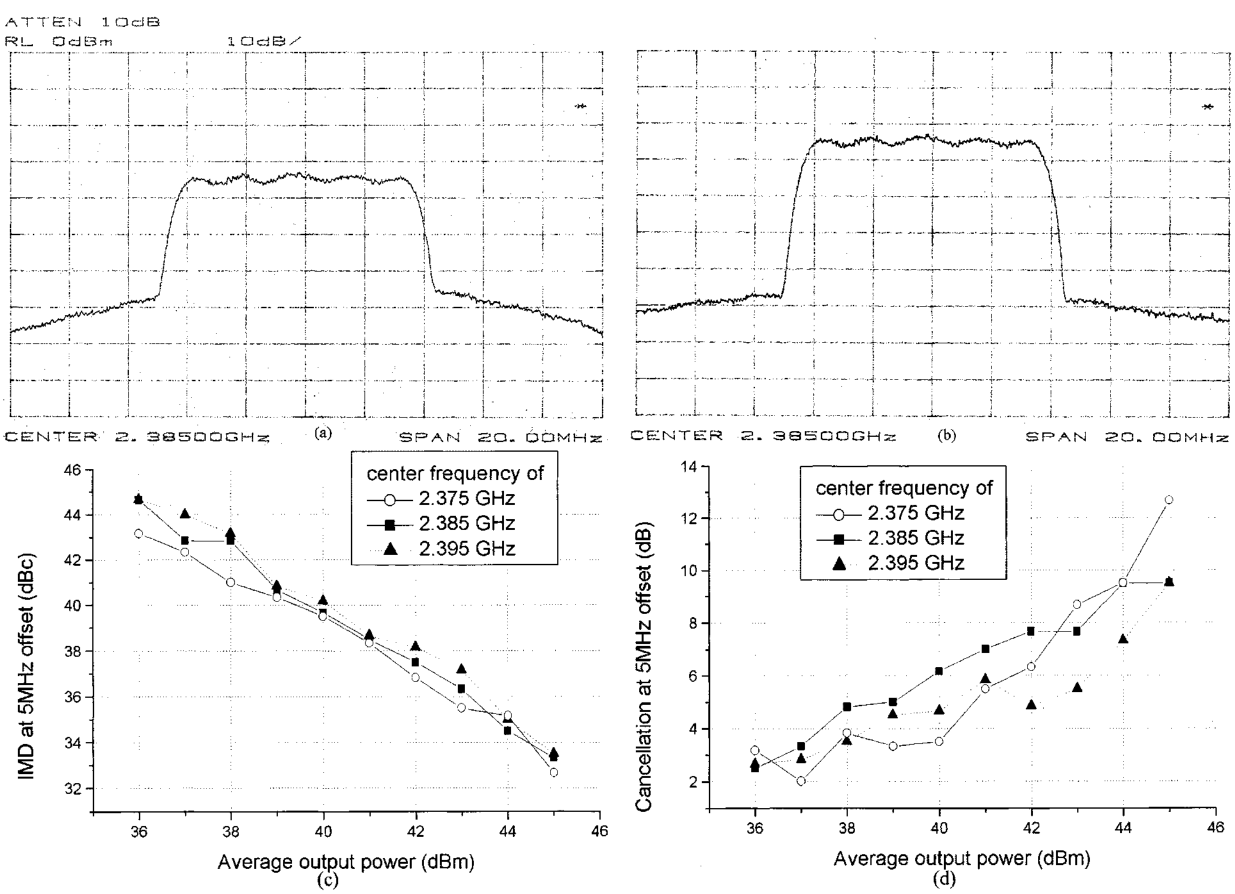

Fig. 7. Spectral regrowth. (a) Before linearization. (b) After linearization. (c) Spectral regrowth of the main amplifier. (d) Suppression of spectral regrowth for different power levels. (a) Before linearization (at average output power of 45 dBm). (b) After linearization (at average output power of 45 dBm). (c) Spectral regrowth versus output power for the main amplifier at 5-MHz offset from several center frequencies (measured IMD is the difference of the spectral power at the center and offset frequencies). (d) Suppression of spectral regrowth for different power levels.

tion result of Fig. 6(d) shows that the spectral regrowth is suppressed for the broad power range. The spectral regrowth of the linearized amplifier is below 42 dBc for the 30-MHz bandwidth, which is quite usable for many real systems. The improvement is smaller for the lower power, but the amplifier is more linear at that power, and this amplifier satisfies the linearity characteristics for all power levels.

V. Conclusions

In this paper, we have developed a predistortion linearizer that can control the IM3 and IM5 separately and applied it to the linearization of a high-power RF amplifier with an average output level of 45 dBm. The phase variations of the IM terms are accurately measured using the new method and the data is employed for the predistorter design. About 9-dB improvement of adjacent channel leakage ratio (ACLR) was achieved at 5-MHz offset from the center frequency of a CDMA signal with an 8.192-MHz signal bandwidth. This amplifier covers a 2.37–2.4-GHz bandwidth.

References

[1] J. S. Kenney and A. Leke, "Design considerations for multicarrier CDMA base station power amplifiers," *Microwave J.*, vol. 42, no. 2, pp. 76–83, 1999.

[2] T. Nojima and T. Konno, "Cuber predistortion linearizer for relay equipment in 800 MHz band land mobile telephone system," *IEEE Trans. Veh. Technol.*, vol. VT-34, pp. 169–177, Nov. 1985.

[3] C. G. Rey, "Predistorter linearizes CDMA power amplifiers," *Microwaves RF*, pp. 114–123, Oct. 1998.

[4] W. Bosch and G. Gatti, "Measurement and simulation of memory effects in predistortion linearizers," *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 1885–1890, Dec. 1989.

[5] N. Suematsu, Y. Iyama, and O. Ishida, "Transfer characteristic of IM3 relative phase for a GaAs FET amplifier," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 1885–1890, Dec. 1997.

[6] Y. Yang, Y. Kim, J. Yi, B. Kim, and M. Park, "Modeling and measurement of two tone transfer characteristics of high power amplifiers," in 2000 European Microwaves Conf., submitted for publication.

[7] R. C. Tupynamba and E. Camargo, "MESFET nonlinearities applied to predistortion linearizer design," in *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, 1992, pp. 955–958.

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