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A New Predistorter Using Low Frequency Intermodulation Signals Injection of a Harmonic Generator

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SUMMARY In this paper, a predistorter using low frequency intermodulation (IM) signals is proposed. The harmonic generator of the proposed predistorter that consists of a hybrid coupler and four diodes biased separately extracts a second order low frequency IM signal. And with multiplication of second order IM signals, fourth order IM signal is obtained. A vector modulator, modulate fundamental signal with low frequency IM signals, generates predistortion IM signals and controls amplitude/phase of them with modulation factors. As a result, this predistorter is suppressed individual order intermodulation distortion signals of power amplifier effectively. The suggested predistorter has been manufactured to operate in Korea PCS base-station transmitting band (1840–1870 MHz). The test results show that the third order IM is cancelled more than 20 dB and the fifth order IM is cancelled about 10 dB for CW two-tone signals. Also, it's improved the adjacent channel power ratio (ACPR) more than 10 dB for CDMA (IS-95) signals.

key words: *predistorter, linearizer, vector modulator, power amplifier, harmonic generator*

1. Introduction

At present, it may be inconvenient to live without mobile communication systems. In the past, the voice quality of communications was the only essential issue. However, it becomes that most people regard the transmission of a lot of data as an important thing in communication. Because of this circumstance, more complex modulation and demodulation methods, and broadband channel bandwidth are required for mobile communication systems. When signals are amplified in the power amplifier, unwanted harmonics and intermodulation distortion signals in addition to amplified signals are generated simultaneously. These generated IM signals increase bit error rate of data and interfere adjacent channel signals and decrease the efficiency of power amplifier [1]–[6].

In the third generation (3G) of mobile radio standards, very high linear transmitter that can support high crest factor signal is demanded than ever. So to power amplifier designer, high linearity and high efficiency are critical issue. In fact, as the power amplifier operates close to saturation region where both high efficiency and high output power emission are achieved, the degradation of linearity becomes significant. Compromise between power efficiency and linearity must be considered. Or linearization technique to recuperate nonlinearity of power amplifier is only solution. In this paper, a new predistorter that creates inverse transfer characteristics of power amplifier is proposed for linearization of an RF power amplifier. The proposed predistorter consisted of two part. First, the harmonic generator extracts low frequency IM signals with four diodes and then AM modulator is modulated original signal with extracted IM signals. Second, vector modulator is combined I and Q modulation signal. It's a generated IM signals. Then the generated modulation signals are controlled by individual order of IM so that drawbacks of a conventional predistorter, such as narrow bandwidth and low improvements of IMs, are overcome and guaranteed a wide dynamic range [1]. It simply involves the creation of individual order distortion that is precisely complementary to the distortion characteristic of the RF amplifier in order to ensure that the resulting system has little or no input-output distortion [2]–[6].

2. Operation of the Circuits

The harmonic generator of the proposed predistorter has a simple structure form. The harmonic generator consists of a hybrid coupler and four diodes with similar characteristics, which is operated on different operation points by biasing separately and generates low frequency intermodulation signals of input signal without any other devices.

Nonlinear transfer characteristic of harmonic generator is expressed as power series.

$$V_o = k_1 v_i + k_2 v_i^2 + k_3 v_i^3 + k_4 v_i^4 + \cdots \quad (1)$$

where v_i is input and v_o is output signal.

If input signals are two-tones, it is expressed as follow

$$V_i = A(\cos\omega_1 t + \cos\omega_2 t) \quad (2)$$

Unlike other predistorters, desired signals obtained from the harmonic generator are just the second order low frequency intermodulation signals. It's explained

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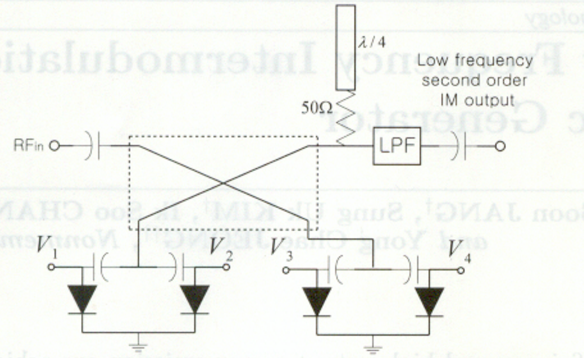

Fig. 1 A detailed circuit of the harmonic generator.

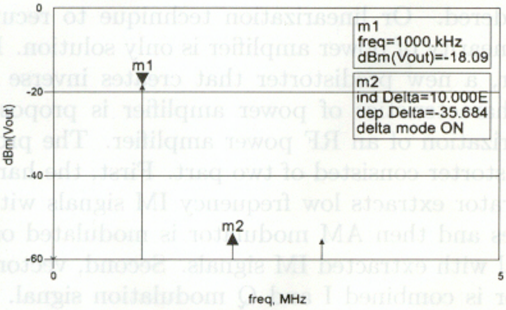

Fig. 2 A simulation result of harmonic generator after diode bias voltage controlling.

below an expression.

$$\begin{aligned} H_2 &= k_2 v_i^2 \\ &= k_2 A^2 + \frac{1}{2} k_2 A^2 [\cos 2\omega_1 t + \cos 2\omega_2 t \\ &\quad + 2\cos(\omega_1+\omega_2)t + 2\cos(\omega_2-\omega_1)t] \end{aligned} \tag{3}$$

The desired signal $(\omega_2-\omega_1)$ is one element of second order harmonics (H_2) as shown Eqs. (1), (2) and (3). Figure 1 shows a detailed circuit of harmonic generator proposed in this paper. The harmonic generator has four bias voltage controllers (V_1, V_2, V_3, V_4) that are random controlled to bias diodes and four diodes that are biased separately to generate only desired second order IM term.

Also, harmonic generator output port is matched with 50 ohm resistor terminated quarter-wavelength open stub, so that the main signal is null and only low frequency second order intermodulation signal is passed.

A simulation of harmonic generator has been performed with ADS2001 software of Agilent Technologies. Figure 2 shows the simulation result of a harmonic generator after diode bias for two-tone signals. And Fig. 3 shows low frequency second order intermodulation signal measurement results in case of CW two-tone, CDMA 1FA, and CDMA 2FA. At Fig. 2, Fig. 3 the simulation and measured conditions are followed that harmonic generator input power is 0 dBm, two-tone frequencies are 1854.5 MHz, 1855.5 MHz, and four

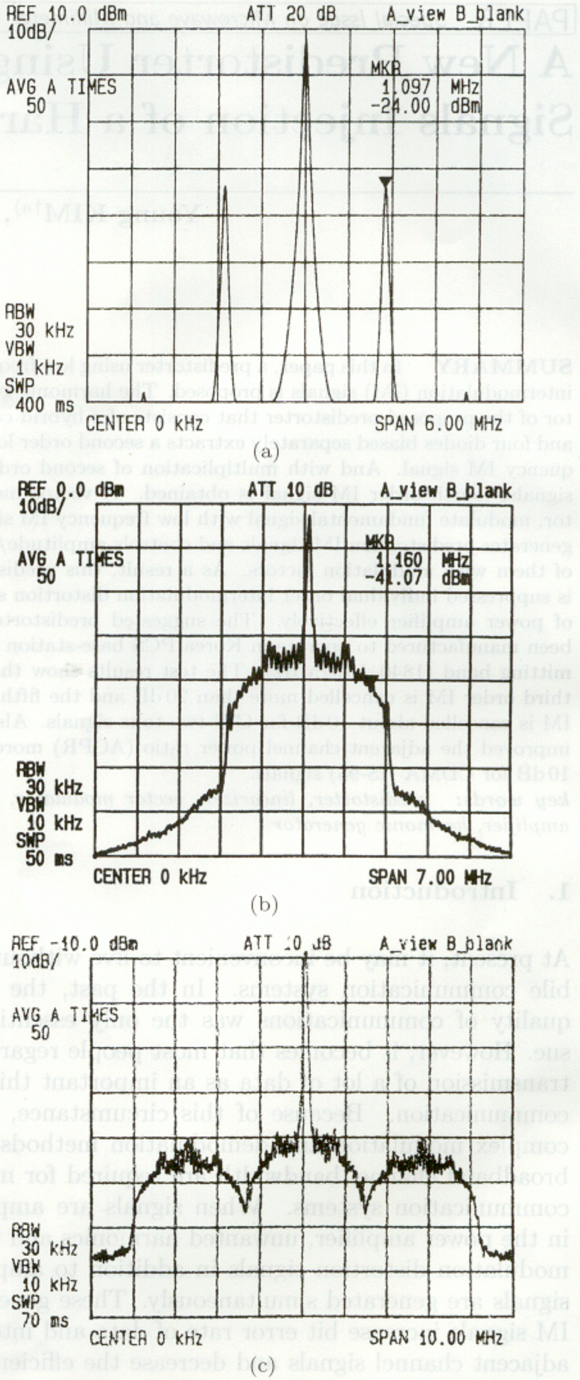

Fig. 3 (a) Low frequency intermodulation signal at two-tone signals. (b) Low frequency intermodulation signal at CDMA 1FA signal. (c) Low frequency intermodulation signal at CDMA 2FA signal.

bias voltages are almost similar to simulation condition. Also, diode model is used to provide ADS2001 software. Consequently at two-tones condition, measured results are almost similar to simulation condition. These are expressed validity of the above harmonic generator.

The level of low frequency intermodulation signal $(\omega_2-\omega_1)$ generated from the harmonic generator is big

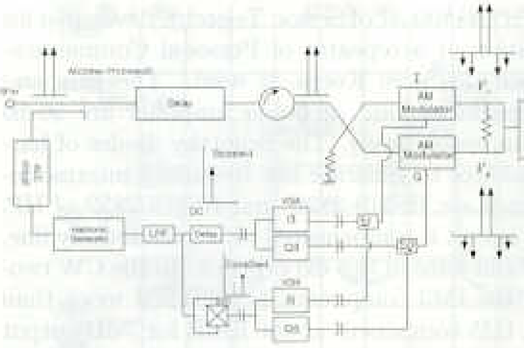

Fig. 4 A schematic of the proposed linearization power amplifier.

enough to modulate with fundamental signal in the AM modulator and the variable gain amplifiers (VGAs) that control modulation factor are used in order to cancel the third order intermodulation of power amplifier.

Figure 4 shows a schematic of the proposed predistortion power amplifier. The IM generator uses the structure of vector modulator composed of in-phase and quadrature-components. The VGAs are controlled in-phase and quadrature low frequency IM signal. Finally the structure of vector modulator is generated predistorted signals. This predistorter controls the amplitude and phase of intermodulaton distortion components at the same time. It provides faster adjustment of phase and amplitude than that provided with conventional controllers consisting of variable phase shifter and variable attenuator. The automatic level control (ALC) circuit at the input port stabilizes the device making constant IM signal in spite of sensitivity of incoming power level. The fourth order intermodulation signal $(2\omega_2 - 2\omega_1)$ also can be generated by multiplication the low frequency second order intermodulation signal obtained from the harmonic generator. This signal is added with second order IM signal $(\omega_2 - \omega_1)$ and modulation factor is also controlled to cancel the fifth order intemodulation of power amplifier using in-phase and quadrature structure. The signal $(\omega_2 - \omega_1)$, generated from the harmonic generator under proper bias conditions, and multiplied signal $(2\omega_2 - 2\omega_1)$ are modulated with a main signal in the AM modulator and the vector modulator output is generated the predistorted IM signals and then the four VGAs are used to control the predistorted third and fifth IM signals individually. The I and Q components in vector modulator are expressed as follow.

In-Phase Signal

$$\begin{aligned} V_i &= A(1 + B\cos\omega_m t + C\cos 2\omega_m t) \\ &\quad \cdot (\cos\omega_{c1}t + \cos\omega_{c2}t) \\ &= A\cos\omega_{c1}t + \frac{AB}{2}\cos(\omega_{c1}+\omega_m)t \\ &\quad + \frac{AB}{2}\cos(\omega_{c1}-\omega_m)t + A\cos\omega_{c2}t \\ &\quad + \frac{AB}{2}\cos(\omega_{c2}+\omega_m)t + \frac{AB}{2}\cos(\omega_{c2}-\omega_m)t \\ &\quad + \frac{AC}{2}\cos(\omega_{c1}+2\omega_m)t + \frac{AC}{2}\cos(\omega_{c1}-2\omega_m)t \\ &\quad + \frac{AC}{2}\cos(\omega_{c2}+2\omega_m)t + \frac{AC}{2}\cos(\omega_{c2}-2\omega_m)t \end{aligned} \tag{4}$$

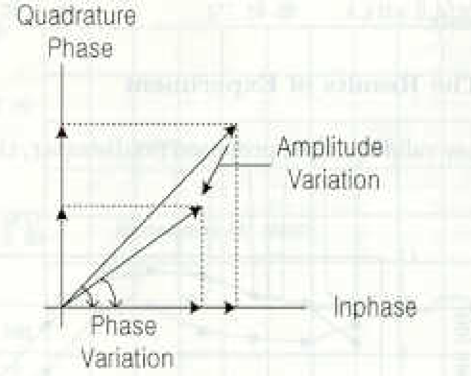

Fig. 5 Amplitude and phase variation of modulated signal.

Quadrature Phase Signal

$$\begin{aligned} V_q &= A(1 + B\cos\omega_m t + C\cos 2\omega_m t) \\ &\quad \cdot (\sin\omega_{c1}t + \sin\omega_{c2}t) \\ &= A\sin\omega_{c1}t + \frac{AB}{2}\sin(\omega_{c1}+\omega_m)t \\ &\quad + \frac{AB}{2}\sin(\omega_{c1}-\omega_m)t + A\sin\omega_{c2}t \\ &\quad + \frac{AB}{2}\sin(\omega_{c2}+\omega_m)t + \frac{AB}{2}\sin(\omega_{c2}-\omega_m)t \\ &\quad + \frac{AC}{2}\sin(\omega_{c1}+2\omega_m)t + \frac{AC}{2}\sin(\omega_{c1}-2\omega_m)t \\ &\quad + \frac{AC}{2}\sin(\omega_{c2}+2\omega_m)t + \frac{AC}{2}\sin(\omega_{c2}-2\omega_m)t \end{aligned} \tag{5}$$

where $A, \omega_{c1}, \omega_{c2}$ are amplitude and frequencies of CW two-tones

B, ω_m are amplitude and frequency of low frequency second order IM signal.

C is amplitude of low frequency fourth order IM signal.

The low frequency IM signals generated in proposed harmonic generator are frequency-transferred to predistortion IM3 and IM5 signals of power amplifier. The predistorted signals are consisted of I and Q components. So, when we are only changed amplitude of low frequency IM signal, the I and Q components are changed amplitude and phase simultaneously. The modulation factors adjustment of low frequency IM signals controls the phase and amplitude of the predistorted IM3 and IM5 components. Figure 5 shows that when the low frequency second order IM signal is changed amplitude with modulation factor, the predistorted signals are changed amplitude and phase simultaneously.

3. The Results of Experiment

To show validity of the proposed predistorter, the power amplifier (STA1800-37 of Sewon Teletch), developed for a base station or a repeater of Personal Communication Service (PCS) in Korea, is used. The gain and 1-dB compression point of power amplifier are 50 dB and 37 dBm, respectively. The Schottky diodes of harmonic generator to generate low frequency intermodulation signals are HSMS-282C and HSMS-2852 of HP. The delay circuit is compensated by a coaxial delay line, which is about 14ns in this experiment. In the CW two-tone test, the IM3 component is cancelled more than 20 dB and IM5 component about 10 dB for 7 dB output power variation. Additionally the cancellation of the IM components is improved in the broad bandwidth and the wide dynamic range of the power amplifier. In the CDMA test, the spectral regrowth is improved more than 10 dB at the 1FA and multi-FA signals. The proposed predistorter linearizer is limiting to improve IM3 and IM5 components only. Figure 6 shows the ACPR improvements for power variation in case of the CDMA 1FA. Figure 7 shows the CW two-tone results. The test frequencies are 1854.5 MHz, 1855.5 MHz with frequency spacing is 1 MHz and output power is 37.17 dBm. Figure 8 shows the CDMA one-tone results.

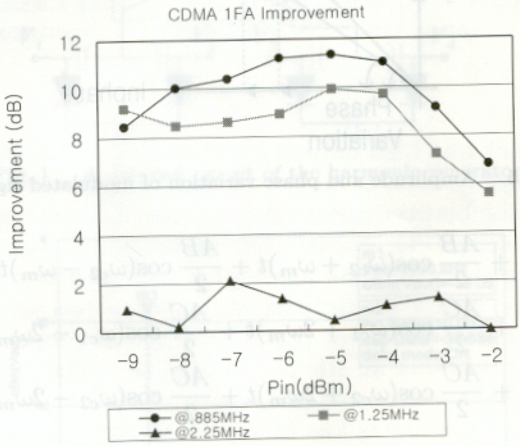

Fig. 6 ACPR improvements for power variation in case of CDMA 1FA.

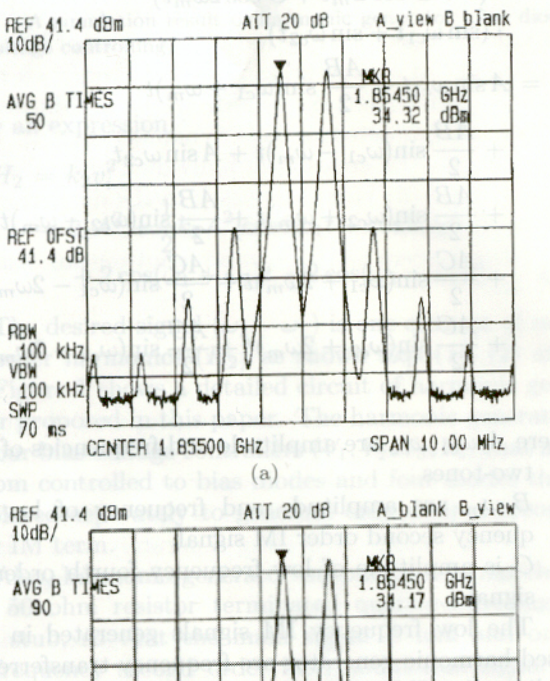

Fig. 7 (a) Two tone output (PA) @Po=37.32 dBm. (b) Two tone output (LPA) @Po=37.17 dBm.

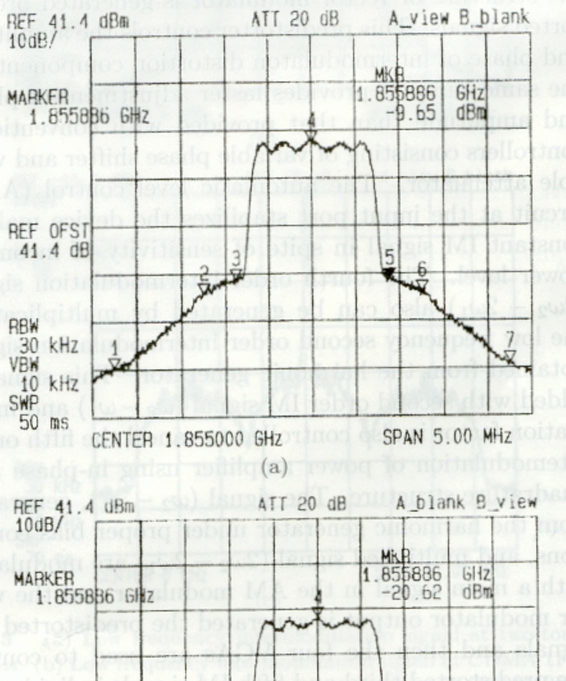

Fig. 8 (a) CDMA 1FA output (PA) @Po=35.13 dBm. (b) CDMA 1FA output (LPA) @Po=35.13 dBm.

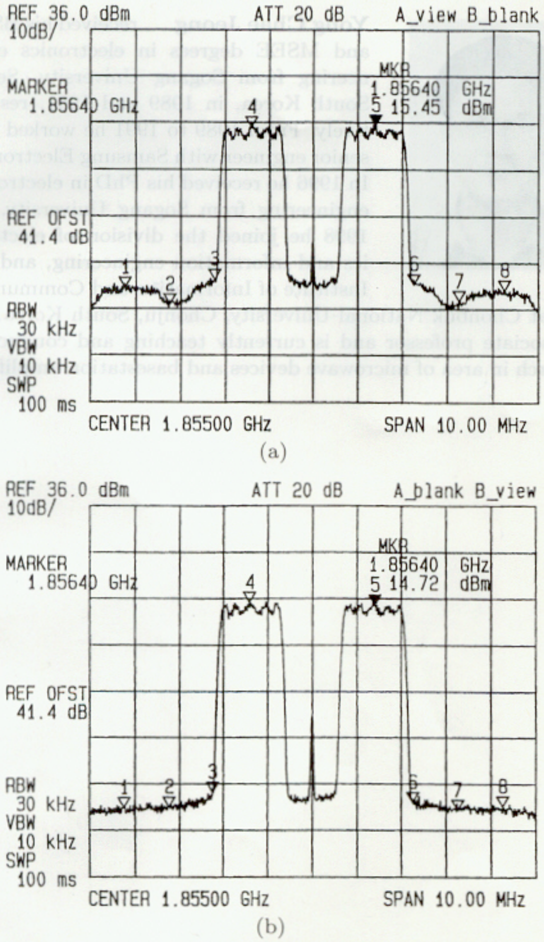

Fig. 9 (a) CDMA 2FA output (PA) @Po=34.33 dBm. (b) CDMA 2FA output (LPA) @Po=33.83 dBm.

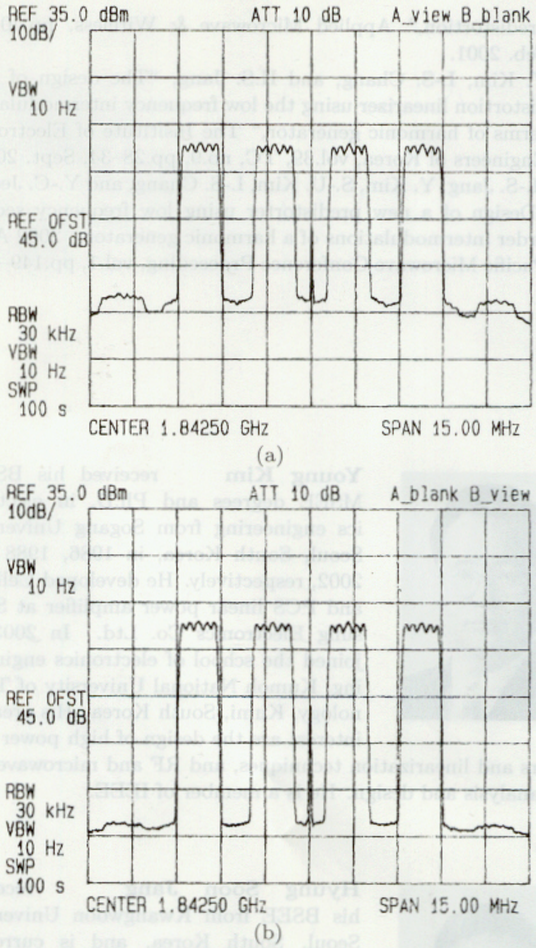

Fig. 10 (a) CDMA 4FA output (PA) @ Po=34.32 dBm. (b) CDMA 4FA output (LPA) @ Po=33.82 dBm.

The output power is 35.13 dBm and test frequency is 1855 MHz. Figure 9 shows the CDMA 2FA results. The test frequencies are 1853.77 MHz, 1856.23 MHz and frequency bandwidth is 3.69 MHz. Figure 10 shows the CDMA 4FA results. The test frequencies are 1838.81 MHz, 1841.27 MHz, 1843.73 MHz, 1846.19 MHz and frequency bandwidth is 8.61 MHz. The test signal generator is ESG4433B of Agilent Technologies. This equipment was observed at center frequency something like the carrier leakage.

4. Conclusions

In this paper, a new predistortor using simple and efficient harmonic generator is suggested. The harmonic generator extracts the second low frequency intermodulation signals and modulates input signal with the extracted IM signals in AM modulator. Hence, the amplitude and phase of the IM components are easily controlled simultaneously because the vector modulator consists of in-phase and quadrature phase components, and its performance reduce the effort of retuning the attenuators and the phase shifters.

In the experiments, good IM cancellation characteristics are obtained for a wide dynamic range and many kind of signals. If we attached adaptive controller in the proposed predistortor, it is expected that the proposed predistortion method may be applied to many kind of power amplifiers. Because the low frequency IM signals are easily obtained for multi-carrier signal, the proposed linearizer is used to implement multi-carrier linearizer. Also, when RFIC or MMIC design technologies are used, the compact size of the predistorter are possible to implement.

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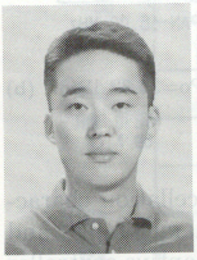

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