Design of a Predistortion HPA Using a Frequency Up-conversion Mixing Operation

In this article, a new predistortion linearizing method using the frequency up-conversion operation of a microwave mixer is proposed. This linearizing method does not require any additional signal source in spite of the frequency up-conversion mixing operation. It extracts the low second-order frequency intermodulation distortion signal from the input signals and uses it as the mixing signal source. To validate the proposed predistortion method, a Korean Personal Communication Service (K-PCS) power amplifier was fabricated. With the two-tone signals amplification process, the carrier-to-interference (C/I) ratio of the amplifier is improved by 26 dB (for P_o = 22 dBm/tone), where the two tones are 1.8544 and 1.8556 GHz. The C/I ratio is improved by more than 20 dB for a 17 dB output signal dynamic range. For an IS-95A CDMA 1FA signal amplification, the improvements in the adjacent channel power ratio (ACPR) are 10.8 dB and 6.4 dB at ±885 kHz and ±1.25 MHz offset points, respectively.

Mobile communication systems currently use linear modulation schemes for effective usage of the frequency spectrum resource. Signals that use linear modulation schemes, however, such as QPSK, and 16- and 64-QAM, have a high peak-to-average power ratio and the signal envelope is changed severely. Therefore, modern mobile communication systems require very linear power amplifiers. To a power amplifier designer, high linearity and high efficiency are critical design issues. In fact, as the power amplifier operates close to the saturation region where both high efficiency and high output power are achieved, the degradation in linearity becomes significant. A compromise between power efficiency and linearity must be considered. Otherwise, a linearization technique to reduce the nonlinearity of the power amplifier is the only solution. Various linearization methods, including feedforward, feedback, predistortion, LINC (linear amplifi-

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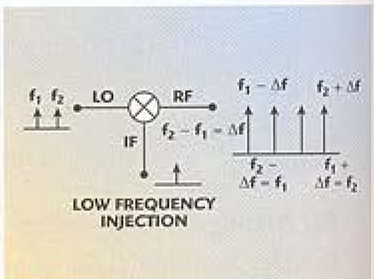
cation with nonlinear components), CALLUM (combined analog locked loop universal modulator), EER (envelope elimination and restoration) and so forth are reported.[1,2] However, the operating bandwidth, efficiency, circuit size and implementation costs are different, according to the linearization technique used.

Predistortion is conceptually the simplest form among linearization methods for an RF power amplifier, although the amount of reduction is not as great as for a feedforward configuration method. A predistortor can correct for both AM/AM and AM/PM distortion, is not restricted in bandwidth and can be implemented in compact size. Therefore, the predistortion method is proper to be used in a medium power amplifier or when a relatively modest reduction in distortion is acceptable. In general, in the predistortion method, it is difficult to generate the predistortion signals and control their magnitude and phase.[3]

In this article, a new predistortion scheme is proposed that generates the predistortion signals using a frequency up-conversion mixing operation and reduces the nonlinear components of the power amplifier by controlling the predistortion signals. The proposed predistortion method does not require any additional signal sources even though it is using a mixing operation. This method is simple to generate the predistortion signals and control them.[4]

FREQUENCY UP-CONVERSION MIXING OPERATION

Mixers perform frequency up- or down-conversion operations by using the nonlinearity of a diode or transistor when injecting a local oscillator (LO) signal. Either the intermediate frequency (IF) or the RF signal is mixed with the LO signal, resulting in the frequency up- or down-conversion operation. For the up-conversion case, the RF port frequency components are the sum and difference between the LO and IF signal frequency component. If the LO signals consist of two, equal-amplitude signals at frequencies f_1 and f_2 ($f_1 < f_2$), and the IF signal frequency is $\Delta f = f_2 - f_1$, then the frequency components at the RF port are $f_1 - \Delta f$, $f_2 - \Delta f$ ($= f_1$), $f_1 + \Delta f$ ($= f_2$) and $f_2 + \Delta f$. These $f_1 - \Delta f$ and $f_2 + \Delta f$ frequency components are the third-order intermodulation distortion products that can be produced in the amplifier. ***Figure 1*** shows the spectrum of the frequency up-conversion mixing operation.[5]



▲ Fig. 1 The frequency spectrum resulting from an up-conversion mixing operation.

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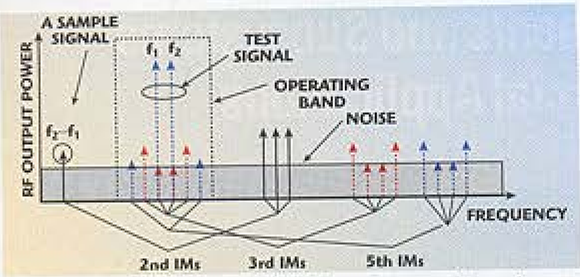
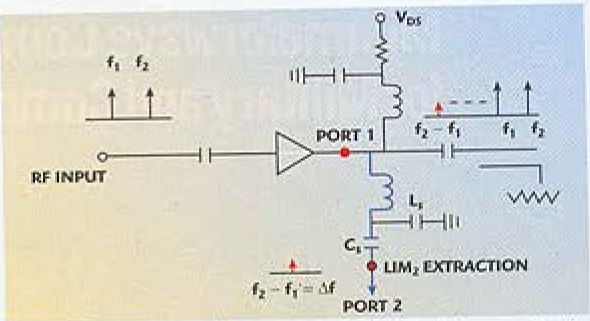


▲ *Fig. 2 The frequency spectrum at the output port of a nonlinear amplifier.*



▲ *Fig. 3 Block diagram of the second-order low frequency intermodulation distortion signal generator.*

SECOND-ORDER LOW FREQUENCY INTERMODULATION SIGNAL GENERATION

The transfer function of a weakly nonlinear amplifier can be expressed in a Taylor series form as

$$V_{out} = G_1V_{in} + G_2V_{in}^2 + G_3V_{in}^3 + \ldots \quad (1)$$

The coefficients G_i ($i = 1, \ldots, n$) are determined by the exact shape of the input/output characteristic. If the input signal consists of two, equal-amplitude signals as

$$V_{in} = A[\cos(\omega_1 t) + \cos(\omega_2 t)] \quad (2)$$

then DC, intermodulation distortion components ($\omega_1 \pm \omega_2$, $2\omega_1 - \omega_2$, $2\omega_2 - \omega_1$, ...) and harmonic components ($2\omega_1$, $2\omega_2$, $3\omega_1$, $3\omega_2$, ...) besides the amplified input signals appear at the output. ***Figure 2*** shows the output signal spectrum for a nonlinear amplifier. For the frequency up-conversion mixing operation, the second-order, low frequency, intermodulation signal ($\omega_1 - \omega_2$) is required.

In this article, a second-order low frequency intermodulation signal (LIM_2) generator is proposed and shown in ***Figure 3***. The generator circuit consists of a small signal amplifier, a directional coupler, an inductor (L_s) and capacitors. The input signals are amplified and several nonlinear components are generated at the small signal amplifier output port. When the coupled and through ports of the coupler are open circuited, the coupler operates as a bandpass filter. The in-band signals, among the amplifier output signals, are terminated in a load resistor. The LIM_2, however, is reflected by the coupler and is extracted through an inductor. The ca-

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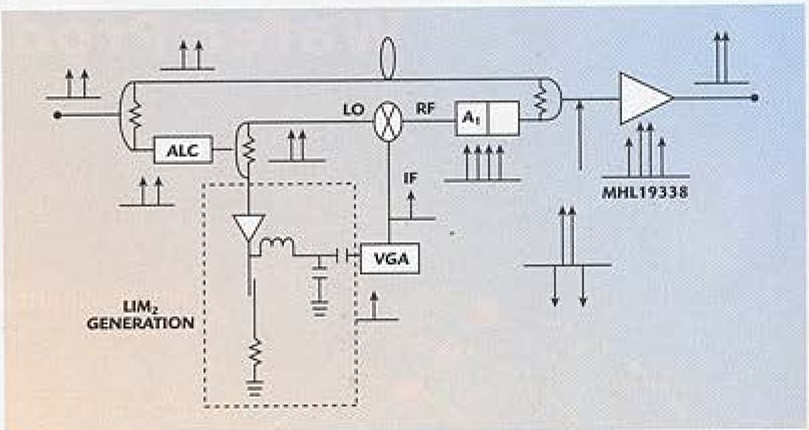
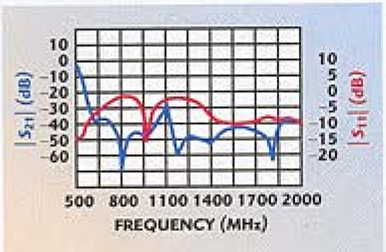


▲ *Fig. 4 Block diagram of the proposed predistorted HPA.*



▲ *Fig. 5 S-parameters of the second low frequency intermodulation distortion signal generator.*

pacitor, C_5, is properly chosen to isolate the DC current and transmit LIM_2.

DESIGN OF THE PREDISTORTION HPA USING A FREQUENCY UP-CONVERSION MIXING OPERATION

A predistortion high power amplifier (HPA) was designed using a frequency up-conversion mixing operation, as shown in **Figure 4**. The predistortion circuit consists of a power divider, an automatic level controller (ALC), the LIM_2, a mixer, a variable attenuator and a variable phase shifter. The input two-tone signals are divided into the power amplifier path and ALC path through the power divider.

The ALC generates a constant signal level for a dynamic input power range. Then this signal is divided between the LO port of the mixer and the LIM_2 generator. The voltage gain amplifier (VGA) controls the magnitude of the LIM_2. Finally, the LO port signal is mixed with the amplified LIM_2 and the predistortion signals are generated. The magnitude and phase of these predistortion signals are controlled to match those of the intermodulation distortion signals generated by the HPA with the variable attenuator and variable phase shifter.

EXPERIMENTAL RESULTS

To validate the proposed linearizing method, the proposed predistortor and HPA were fabricated. The operating frequency is the K-PCS base station transmitting band (1840 to 1870 MHz). The Motorola MHL19338 device is used as the HPA, for which the gain and P1dB are 30 dB and 35 dBm, respectively. For the LIM_2 generation, the Mini-Circuits ERA-4SM amplifier is used. The VGA and mixer are the Analog Devices AD602 and Mini-Circuits LRMS-30J, respectively. The variable attenuator and variable phase shifter are realized as reflection-types in order to obtain good reflection characteristic. The Sony 1T362 varactor diode is used for the variable phase shifter and the HP PIN diode HSMP-4810 is used for the variable attenuator.

Figure 5 shows the transfer and reflection characteristics between the output port of the small signal amplifier and the LIM_2 output port of the fabricated LIM_2 generator (between ports 1 and 2). Good transfer characteristics are obtained in the low frequency range, but poor transfer characteristics are obtained in the frequency band of the input signals. Thus, the LIM_2 components are effectively extracted from the small sig-

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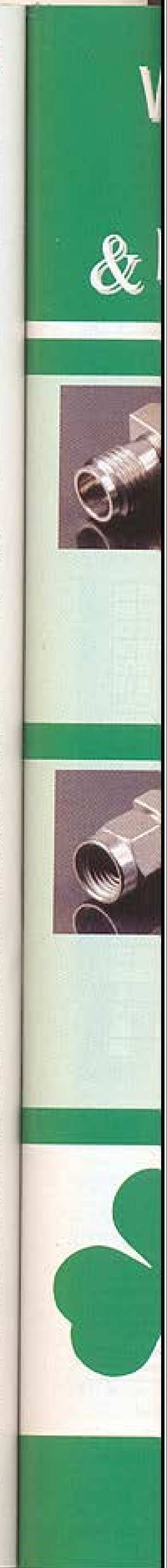

nal amplifier output port. ***Figure 6*** shows the output spectrum of the LIM_2 generator, where the input frequencies are 1.8544 and 1.8556 GHz, respectively. ***Figure 7*** shows the output spectrum of the frequency up-conversion mixing operation between the input signals and the extracted LIM_2 signal. In the mixing operation, the signal level of the LO is properly controlled so that intermodulation signals are not made from the LO signals themselves. Therefore, only the predistortion IM_3 can be obtained in the case of small IF signal levels. The IF signal level can be also controlled to match higher nonlinear components besides IM_3 of the HPA.

Figure 8 compares the results of the HPA nonlinear characteristics with and without the predistortor using a frequency up-conversion mixing operation. At the output power of P_o = 22.09 dBm/tone, C/I_{3rd} is 39.97 dBc in the case without the predistortor and is 65.97 dBc with the predistortor. Hence, the C/I is improved by approximately 26 dB. In addition, ***Figure 9*** shows the improvements in

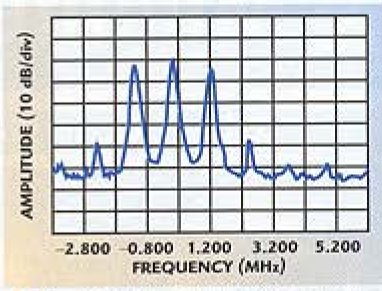

Fig. 6 Output spectrum of the second low frequency intermodulation distortion signal generator (the negative frequencies left of center are meaningless).

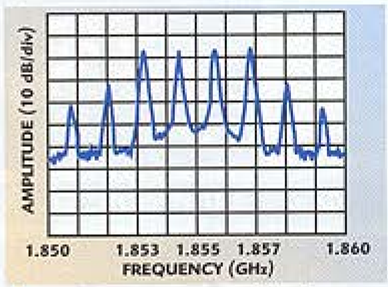

Fig. 7 Output spectrum of the frequency up-conversion mixer.

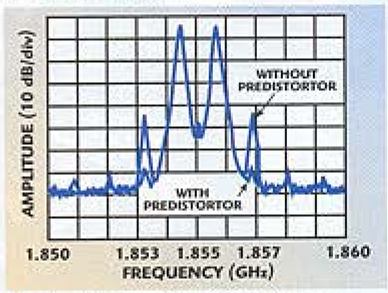

Fig. 8 Comparison of the nonlinear characteristics of the HPA with and without the predistortor.

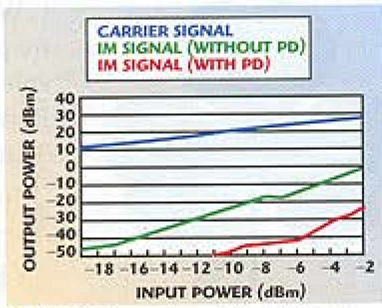

Fig. 9 Comparison of the nonlinear characteristics of the HPA as a function of power output.

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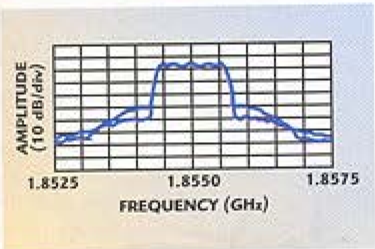
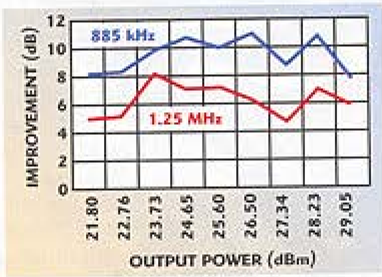


▲ *Fig. 10 HPA nonlinear characteristics with and without the predistortor for a CDMA 1FA signal.*



▲ *Fig. 11 HPA ACPR improvement as a function of output power for a CDMA signal.*

the nonlinear characteristics for an output power range of 11 to 28 dBm/tone. Improvements of at least 20 dB are possible in the entire range.

Figure 10 compares the results of the HPA nonlinear characteristics with and without the predistortor in the case of an IS-95 CDMA 1FA signal. The improvements in adjacent channel power ratio (ACPR) are 10.8 and 6.4 dB at $f_0 \pm 0.885$ MHz and $f_0 \pm 1.25$ MHz, respectively, with an output power of 26.5 dBm. ***Figure 11*** shows the ACPR improvements of the PA for an output power range of 21.8 to 29.05 dBm/FA.

CONCLUSION

In this article, a predistortion HPA scheme using a frequency up-conversion operation was proposed and the proposed predistortor was validated. The proposed predistortion method does not require any additional signal source even though it uses a frequency up-conversion mixing operation. This method makes it very easy to generate predistortion signals and control them. Also, a new second-order low frequency signal generation method is proposed. Although the nonlinear characteristics of power amplifiers are different according to the devices used, their operating voltage and environmental conditions, the proposed predistortor is very useful because the predistortion signals can be controlled by simply changing the mixing condition. ■

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