Predistortion Power Amplifier for Base-Station using a Feedforward Loop Linearizer

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Abstract— **A new LPA system using predistorter is described. A feedforward loop is employed in front of the main amplifier to generate the predistortion signal. For verification, the Error Generation Amplifier and the main amplifier are implemented by the same Doherty amplifiers using 90W PEP MRF5S21090 LD-MOSFETs at** $2.35\ GHz$**, and the Doherty amplifiers are four way power combined for the main amplifier. It has been monitored at** $47.8\ dBm$**, backed-off about** $10.8\ dB$ **from the 720W PEP. The two-tone and forward-link WCDMA 4FA signals have been used for testing. For the WCDMA signal, the efficiency of the amplifier is about** $12.7\ \%$**, higher than the general feedforward type LPA by about** $2\ \%$**. The adjacent channel leakage ratios at** $5\ MHz$ **and** $10\ MHz$ **offsets have been improved about** $7.1\ dB$ **and** $5.4\ dB$**, respectively, by the predistorter.**

I. Introduction

The LPA and HPA for the current and next-generation mobile communication systems require a high linearity as well as efficiency and the linearity enhancement techniques such as predistortion, feedback, feedforward etc. are heavily studied. Doherty power amplifier(DPA) becomes very popular for the main amplifier of the systems. In case of DPA, the linearization mechanism is a cancellation of intermodulation(IM) components between the carrier and peaking amplifiers [1],[2]. Accordingly, the DPA has a complex IM transfer curve according to the output power level and the transfer curve becomes more complicated by the memory effect [3], [4]. For the reason, the conventional analog predistortor with the quasi-cubic transfer curves of IM3, IM5 according to the average power level and the same upper and lower IM components can not deliver a good cancellation performance [5]. On the other hand, the feedforward amplifier has a good cancellation performance in the situation because the error components for cancellation of main amplifier's IM components are directly extracted from them [6]- [9]. For linear amplification of the error signal in the feedforward system, the peak envelope power(PEP) of the error amplifier should be high because the harmonics from the error amplifier reduce the cancellation level [10]. Besides, the delay compensation line and coupler losses are burdens of the amplifier in terms of an average output power and efficiency of the system. Due to the reasons, the feedforward amplifier has a low efficiency contrary to the high linearity performance.

Therefore, we have proposed a new topology which applies the feedforward loop for the predistortion signal generator. Since the feedforward loop is placed in front of the main amplifier, the PEP and gain of the error amplifier is reduced significantly compared to the conventional feedforward system. Also the delay line and coupler losses are not significant

factors affecting the amplifier performance. The main requirement of the new amplifier is the same IM amplitude and phase characteristics between the predistorter and main amplifier.

II. Main Amplifier Consideration

The DPA is very popular for the amplifier of the repeater system. The amplifier has a better linearity than the balanced or push-pull type class AB biased amplifier by the IM cancellation between the carrier and peaking amplifiers, a simple structure to implement, and a higher efficiency due to the class C biased peaking amplifier as described in many papers [1], [2], [10]. To further improve the linearity of the amplifier to the level of LPA, a linearization circuit is needed. Among them, the analog predistortor has been preferred not only for the DPA but also for the balanced or push-pull type class AB amplifier due to the simplicity. However, it is very difficult to implement a conventional predistorter with a good performance because of the complex IM characteristics of the DPA as illustrated previously. The measurement result of the DPA for two-tone signal tests with tone-spacings of 1, 5, 10, and $20\ MHz$, are shown in Fig. 1. The DPA has been implemented using 90W PEP MRF5S21090 LDMOSFETs. There is a sharp cancellation point at an output power of $46\ dBm$. The low point is about $15\ dB$ down from the maximum IM point. At one output power, the difference of the IM3 and IM5 along the tone-spacing is shown about $2\ dB$ as maximum value. Furthermore, there are unbalances between the upper and lower side of IM3 and IM5 and they become serious with the tone-spacing. The maximum difference is about $13.3\ dB$ at an average output power of $46\ dBm$ with $20\ MHz$ tone-spacing, which is the maximum value tested. The IM unbalances of the upper and lower sides due to the memory effect as a function of the tone-spacing and average output power level are summarized in Fig. 2 [3], [4].

As shown in Figs. 1 and 2, the Doherty amplifier has serious memory effect, and some techniques which can handle the effect such as feedforward amplifier, digital predistortor, etc. should be applied for the linearization of the amplifier. In spite of the advantage of the strong immunity to the memory effect, the feedforward amplifier has a poor efficiency. This is caused by the large error amplifier, delay line loss, and coupler loss after the main amplifier described previously [6], [8], [10]-[12]. Therefore, a solution for the efficiency limitation of the feedforward system has been suggested and experimented in this work.
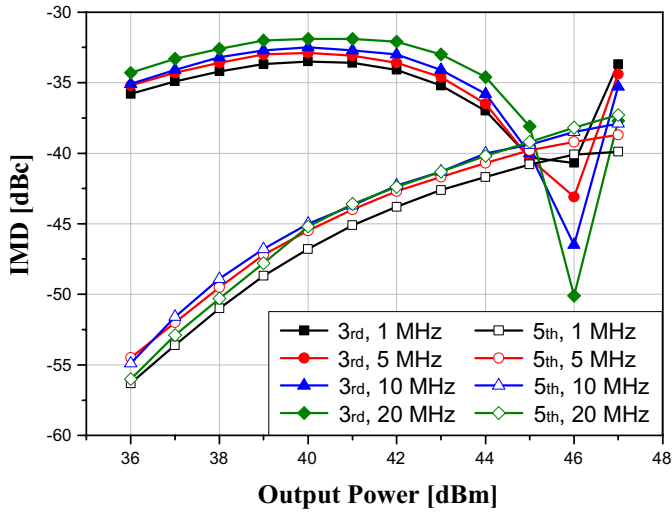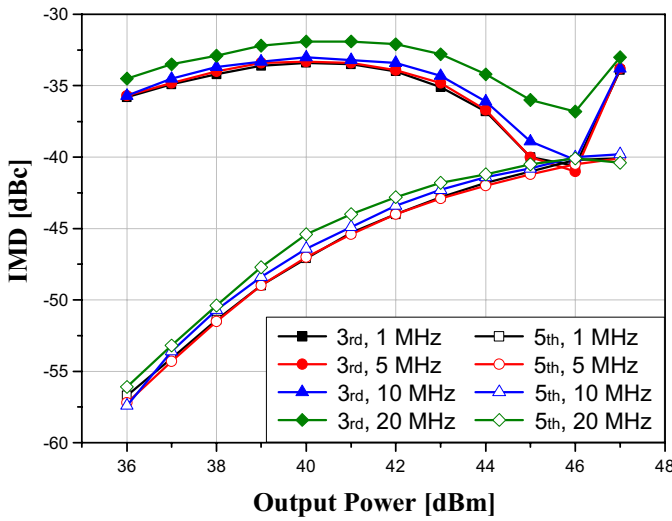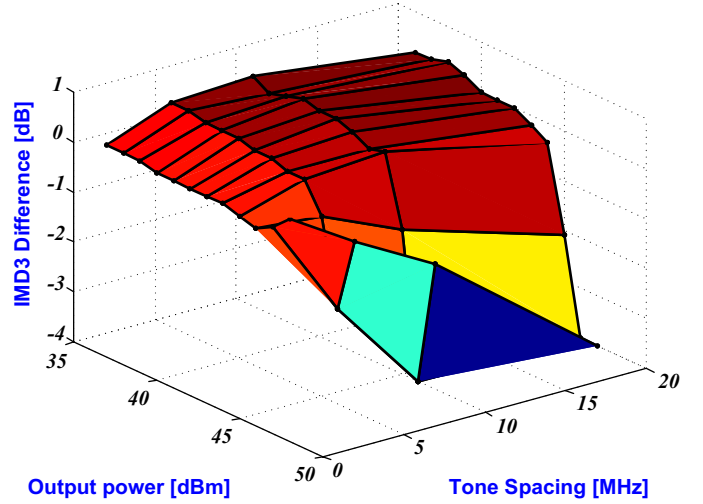
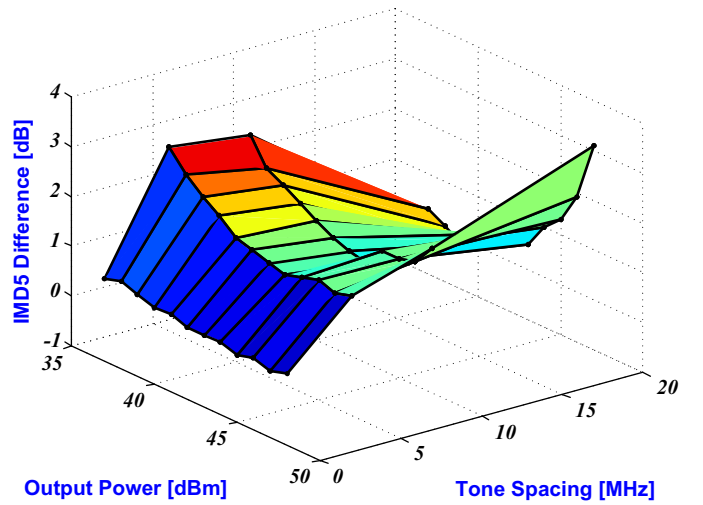Fig. 1. The IMD3 and IMD5 performances for two-tone signals with 1, 5, 10, and 20MHz tone-spacings. (a) Upper IMDs and (b) Lower IMDs.

Fig. 2. The IMD difference between the upper and lower sides according to the tone-spacing and output power level. (a) IMD3 and (b) IMD5.

III. IMPLEMENTATION AND EXPERIMENTAL RESULTS

Fig. 3 shows the proposed amplifier diagram. Five identical Doherty amplifiers, one for the error generation amplifier(EGA) and four for the main amplifier, are built using 90W PEP MRF5S21090 LDMOSFETs. The matched source and load impedances for the amplifiers are Z_S = 2.038 - j*1.531, Z_L =0.612 - j*2.315, respectively, and the optimum length of offset line is $0.175\ \lambda$ [2]. The optimum quiescent bias points of carrier and peaking amplifiers are 3.8 V(0.75 A) of Class AB and 3.3 V of class C, respectively. Therefore, the main amplifier can handle a 720W PEP and has been tested at an average output power of $47.8\ dBm$, $10.8\ dB$ backed-off from the peak power. The drive amplifier for the EGA is consisted of AH102, FLL177 GaAs FET, and 100W PEP PRF6S23100 LDMOSFET for a high linearity. The 3W PEP MHL21336 LDMOSFET is used for the fundamental gain amplifier in the first loop, and AH1, ERA5SM, and MHL21336 are used for the error amplifier stage with the gain of $51\ dB$ in the second loop. The vector modulator for the amplitude and phase controls is fabricated with the series connection of a reflection type attenuator and phase shifter using $3\ dB$ hybrid couplers,

PIN diodes and varactor diodes [5]. Both the first and second loop delays have been compensated using coaxial cables of $9.9\ ns$ and $16\ ns$, respectively.

For the verification, the experiments have been conducted using a forward-link WCDMA 4-carrier signal at $2.35\ GHz$. At first, the main amplifier with single DPA has been experimented to exhibit the cancellation performance of the proposed system. The measurement results are shown in Fig. 4. Fig. 4(a) shows the ACLRs versus average output power before and after the cancellation at $5\ MHz$ and $10\ MHz$ offsets, and Fig. 4(b) shows the power spectral density at an average output power of $42\ dBm$. The ACLRs at the power are $-48.9\ dBc$ and $-49.8\ dBc$ at $5\ MHz$ and $10\ MHz$ offsets, enhanced by $9.2\ dB$ and $8.4\ dB$, by the cancellation. At $38\ dBm$, the maximum cancellation levels of about $14.6\ dB$ and $12.5\ dB$ have been achieved with ACLRs of $-51.6\ dBc$ and $-52.6\ dBc$, respectively, verifying the very good linearization performance. These results explain that the proposed configuration has a strong immunity for the memory effect and complex harmonic characteristics of the main amplifier. The ACLRs of upper and lower sides have the same amplitude supporting the advantages.
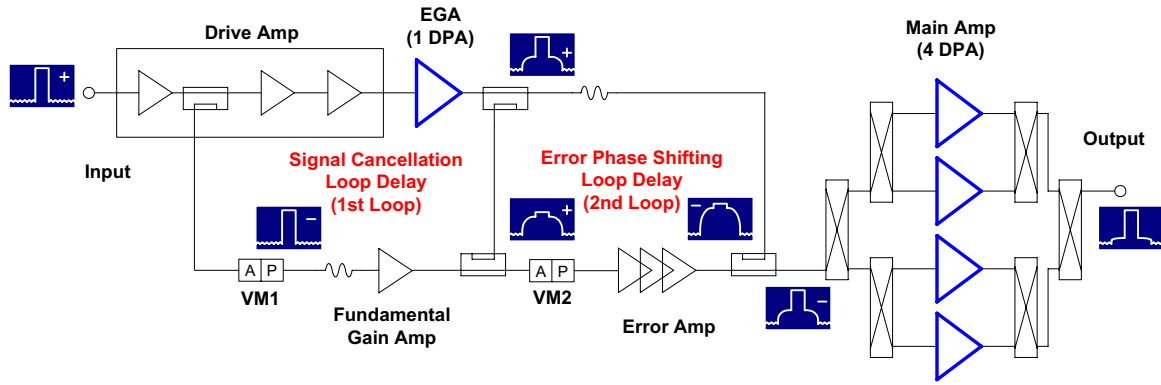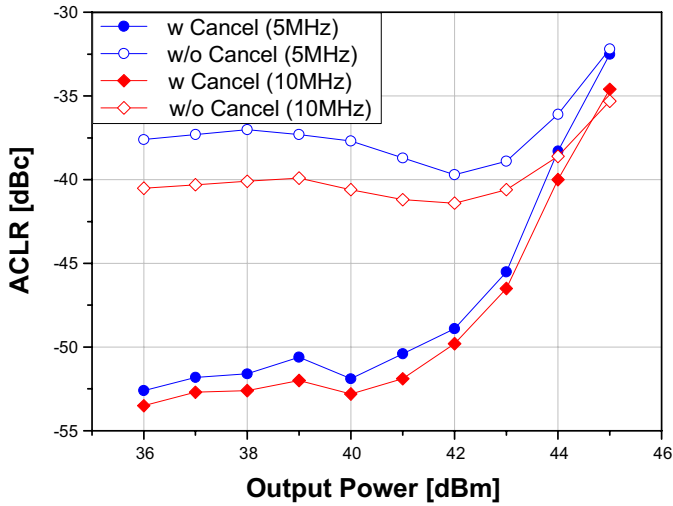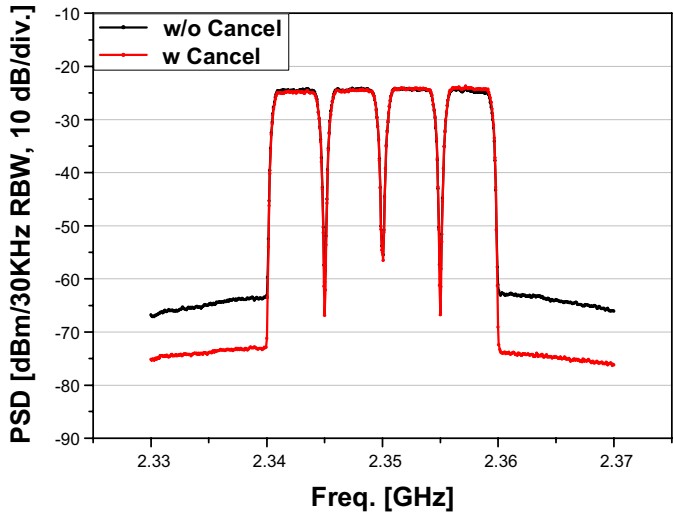
Fig. 3. The proposed linearization circuit using feedforward predistortion(FFP).


(a)

(b)

Fig. 4. The ACLRs of the amplifier with single Doherty main amplifier for the forward-link WCDMA 4FA signal versus average output power, and (b) it's power spectral density at an average output power of $42\ dBm$.

Based on the excellent result, the cancellation experiment for the main amplifier with four DPAs has been carried out. Fig. 5(a) and (b) show the power spectral density of the output at an average output power of $47.8\ dBm$ with the spans of $40\ MHz$ and $100\ MHz$. The ACLRs at $5\ MHz$ and $10\ MHz$ offsets are $-46.3\ dBc$ and $-48.7\ dBc$, respectively, enhanced by about $7.1\ dB$ and $5.4\ dB$, respectively, by the cancellation. This cancellation is a little lower than that of the single DPA case due to the nonuniform DPAs, power divider and combiner, which can be solved in the well controlled manufacturing environment. As shown in Fig. 5(b), the power spectral density of the canceled output has a symmetrical shape, illustrating the strong immunity to the serious memory effect.

The total efficiency of the amplifier with the proposed topology is about $12.7\ \%$, which is enhanced siginifcantly compared to the general feedforward type LPA for base-station. Furthermore, this predistortion amplifier has a good thermal stability because the error characteristics of the EGA and main amplifier are changed dynamically at the same manner. Therefore, it is expected that the new amplifier with be very useful for the LPA system requiring high linearity and efficiency.

IV. CONCLUSIONS

For the high efficiency as well as high linearity of an LPA system for the base-station, a new predistorter based on the feedforward loop has been investigated. By implementing the feedforward loop in front of the main amplifier, the PEP and gain of the error amplifier could be reduced, and the delay line and coupler losses of the main amplifier also could be eliminated. Due to these advantages, the total efficiency of the amplifier has been enhanced significantly compared to the general feedforward type LPA system. For the verification, the amplifier has been implemented using DPAs based on 90W PEP LDMOSFETs, and the forward-link WCDMA 4FA signal at $2.35\ GHz$ has been used as a test signal. At the cancellation test of the amplifier with single Doherty main amplifier for an average output power of $42\ dBm$, the ACLRs are $-48.9\ dBc$ and $-49.8\ dBc$ at $5\ MHz$ and $10\ MHz$ offsets, respectively, enhanced by $9.2\ dB$ and $8.4\ dB$, respectively, by the cancellation. For the main amplifier with 4 DPAs, the ACLRs are enhanced by about $7.1\ dB$ and $5.1\ dB$ at $5\ MHz$ and $10\ MHz$ offsets, respectively, and the total efficiency is about $12.7\ \%$ at an average output power of $47.8\ dBm$, backed-off $10.8\ dB$ from the total 720
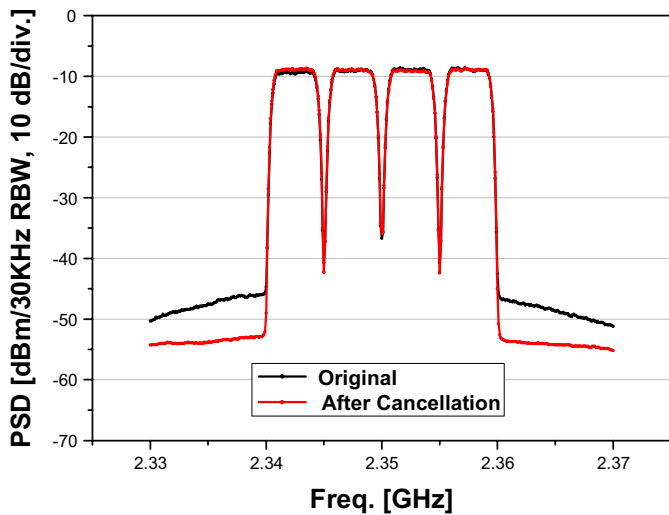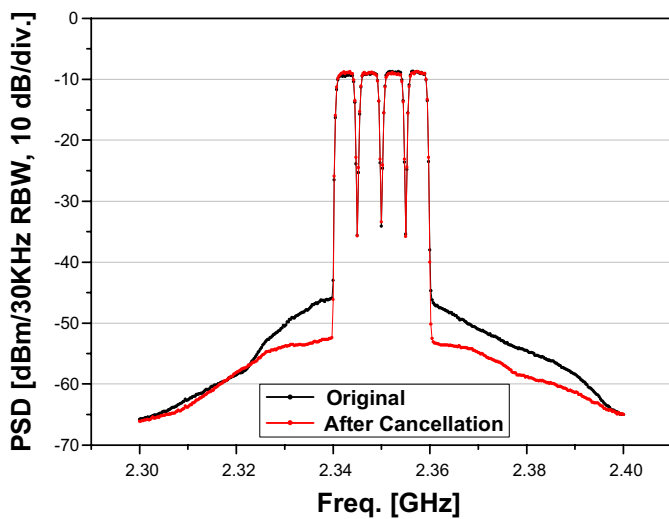
Fig. 5. The power spectral density of the amplifier with four Doherty main amplifier at average output power of 47.8 dBm, (a) 40 MHz span and (b) 100 MHz span.

W peak power. The linearity performance is degraded by the nonuniform IM characteristics of the EGA and main amplifier. Because the problem of nonuniformity can be overcame easily in the industrial production environment, even better linearity can be achieved, comparable to the feedforward type LPA system. The proposed feedforward predistortion amplifier is expected to be very attractive for LPA system that requires a high efficiency as well as high linearity.

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