Improvement of Memory Effects and ACPR of Power Amplifiers in CDMA Cellular Mobile and OFDM WLAN Transmitters

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Abstract: In this article, improvement of the memory effects and adjacent channel interference introduced by the nonlinearity of the power amplifier in the both Code division multiple access (CDMA) and Orthogonal frequency division multiplexing based (OFDM) transmitters is evaluated through Feedforward linearization method. For CDMA system, more than 17.27 dB increasing in OIP_3 is and at least 25 dB improvement in adjacent channel power ratio (ACPR) is obtained. For OFDM system, achieved improvement through Feedforward linearization method is at least 39.03 dB in third output intercept point (OIP_3), more than 26.6 dB in ACPR and 5.44 dB in peak-to-average ratio. It is observed that the designed Feedforward circuit can efficiently improve the nonlinearity caused by memory effects and saturation of the power amplifiers of CDMA cellular mobile telephony and OFDM wireless local area network (WLAN) transmitters.

Keywords: CDMA, Feedforward, Memory effect, OFDM, Power amplifier, WLAN

1. Introduction

CDMA and OFDM communication systems are the most frequently used systems in the recently years because of the significant advantages of these systems. In CDMA, all active links simultaneously use the entire allocated spectrum, but sophisticated codes are used that allow the signals to be separated in the receiver. OFDM has several desirable attributes,such as high immunity to inter-symbol interference, robustness with respect to multipath fading and the ability to transmit high data rates. However, one of the majorproblems posed by these systems is theirs high peak-to-average power ratio (PAPR), which considerably limits the power efficiency of the high-power amplifier (HPA) becausethe high PAPR causes a nonlinear distortion [1,2].Several methods for linearization of power amplifiers have been proposed [3-7]. In 1927, H.S. Black of Bell Telephone Laboratories presented the concept of negative feedback as a technique of linearizing power amplifiers [8]. The Feedforward linearization method is an efficient power amplifier linearization technique to decrease out-of band distortion that can approach wideband signals with high efficiency. The Feedforward structure includes two loops, where accurate adjustment between them is essential to guarantee proper distortion suppression. The Feedforward technique is unconditionally stable andthe distortion introduced by the main power amplifier should be properly subtracted. With the progression of the technology, the increasing demand for frequency and bandwidthrequirements, highlight the Feedback drawbacks andrecovering the Feedforward technique. In 1971 Seidel [9] linearized a travelling-wave tube amplifier, and then Bennett in 1974 [10], with theFeedforward technique. Feedforward became one of the linearizationmethids most developed and implemented incabletelevision, audio systems and radio frequency applications.The Feedforwardstructure consists of two cancellation loops.The goal of the first loop is to sample the distortion introduced bythe main power amplifier. It is well known as the “error loop” or the “signal cancellation loop”. The second cancellation loop uses thedistortion sample achieved from the error loop to subtract the distortioncomponents from t=he amplified main signal. It is well-known as the “distortion cancellation loop”.

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2. Cellular Phone Transmitter (CDMA System)

In the Feedforward structure, the adjustment technique consists in variations of the attenuator and phase shifter and delay line located in the second loop until the third order intermodulation products of the output signal will be minimum [11-16].

First, we consider to the One-Tone test of the linearized power amplifier with commercial software Advance Design System (ADS) [17]. The aim is to see how the designed circuit can overcome to the saturation of the power amplifier. The designed circuit must suppress the harmonic components of the main signal in a CDMA system which its frequency in 850 MHz. Figure 1 shows the schematic of the designed and simulated circuit.

The time domain spectrum of the output signals with and without the Feedforwardcircuit are shown in Figure 2, when the amplitude of the input signal of the circuit is swept.

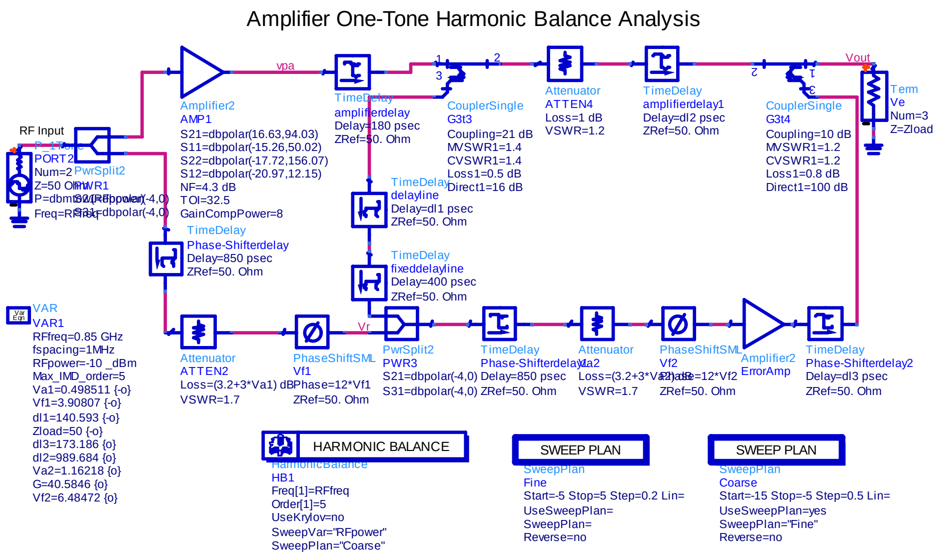

Figure 1. Schematic of the Feedforward power amplifier working in 850 MHz.

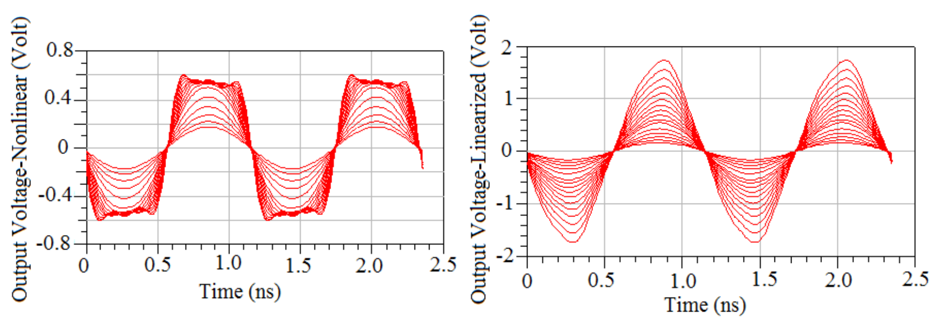

Figure 2. Comparison of the output waveform of the (a) Nonlinear and (b) Linearized Power Amplifier.

In the next step, we consider improvement in intermodulation distortion suppression of the poweramplifier with the designed structure. The central frequency coincides with the channel in the cellular mobile standard. Two tones are generated 2 MHz separated, so the third order intermodulation products are located into the adjacent channels.

$$f_1 = 850MH_Z - \frac{2MH_Z}{2} = 849MH_Z \tag{1}$$

$$f_2 = 850MHz + \frac{2MHz}{2} = 851MHz \tag{2}$$

$$IP_{3|1} = 2f_2 - f_1 = 853MHz \tag{3}$$

$$IP_{3|2} = 2f_1 - f_2 = 847MHz \tag{4}$$

As can be seen from Figure 3, the distance between third order intermodulation with the main signal (DS) is calculated as, DS = P(main) – P(IM)= 30.537 dB and then OIP3 = P(main) +(DS/2) = 17.493 dBm for the nonlinear power amplifier and the DS = 70.343 dB and then OIP_3 = 34.765 dBm for linearized power amplifier.

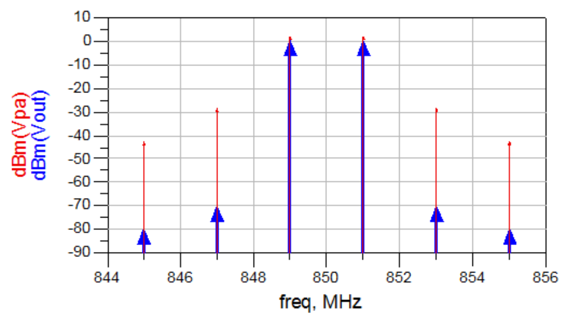

Figure 3.Comparison of the intermodulation distortion suppression, where Vpa (red-line) is for the main power amplifier and Vout (blue-line) is for the linearized power amplifier.

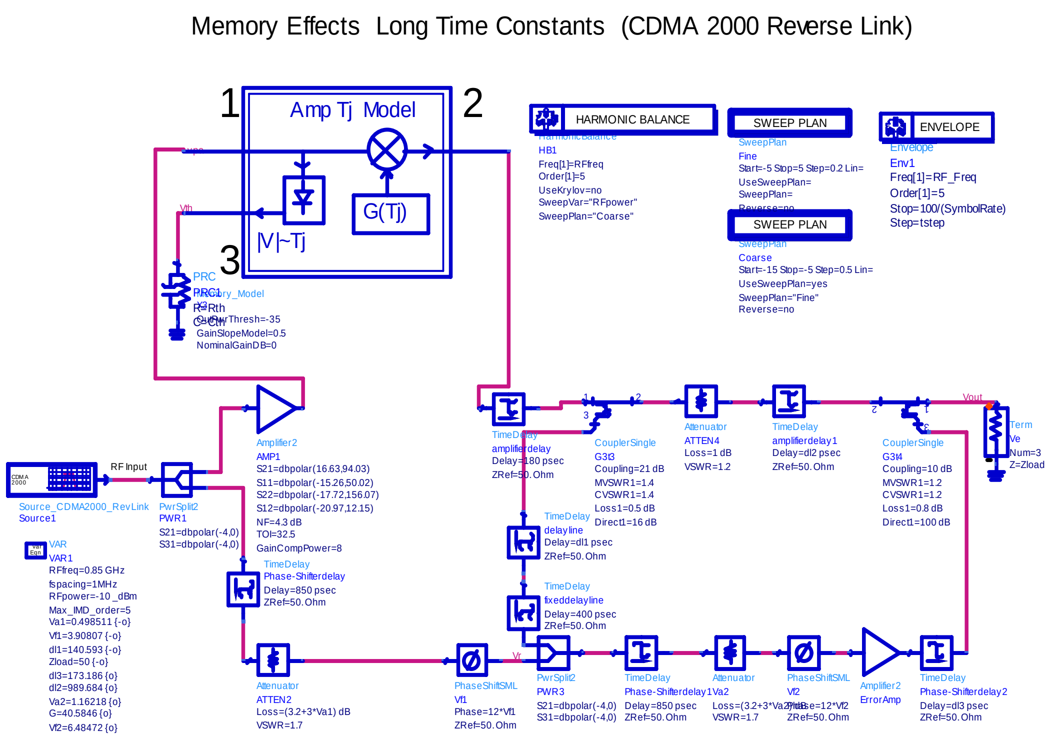

Figure 4. Schematic of the Feedforward amplifier with consideration of the memory effects of the main power amplifier in a CDMA transmitter.

Hence, more than 17.27 dB improvement in OIP_3 is achieved via Feedforward linearization.

In the next case, we consider the memory effects cancelation of the linearized amplifier. Thermal power feedback causes memory effects at low modulation frequencies. Increasing the power dissipation of the amplifier causes increasing the temperature of the power amplifier device's junction which in turn alters the power amplifier's gain. These memory effects are observed as the envelope varies over time. Modeling of these long time constant effects needs a form of thermal power feedback. Figure 4 shows the schematic of the simulation set up. The gain is finally decreased by 0.5dB for every 1.0dB increasing of the output power from -5.0dBm. The excess power that the amplifier is putting out over the threshold is turned into a thermal current that "charges up" a heat-sink. The bleeder resistor is the ability of the heatsink to transfer heat to the environment. The voltage at the Vth node becomes the analogy of junction temperature and modulates the linear gain. Ramp(x)=0 for x<0, x for x>0. This means that if the input power is below (-35-0) =-5 dBm, thermal effects are neglected. Figure 5 shows the equivalent circuit of the amplifier T-junction model.

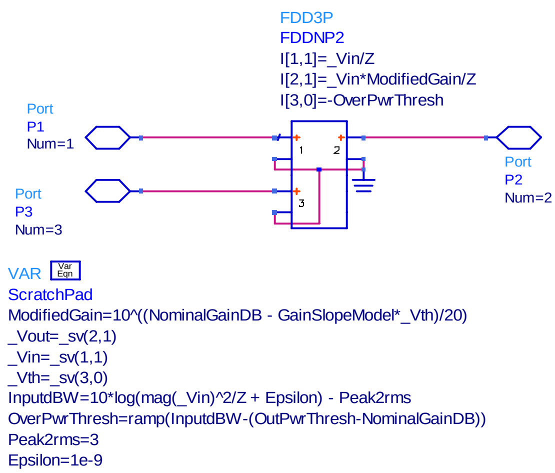

Figure 5. Amplifier T-junction model.

Figure 6 shows the comparison between the ACPR of the lower/upper channels for nonlinear and Linearized Power Amplifier. It can be seen using Feedforward method at least 25 dB improvement in ACPR is obtained. The output specrum of the transmitter with and without Feedforward circuit are shown in Figure 7. It can be seen from Figure 7 that ACPRs of the system are decreased more than 25 dB through Feedforward linearization technique.

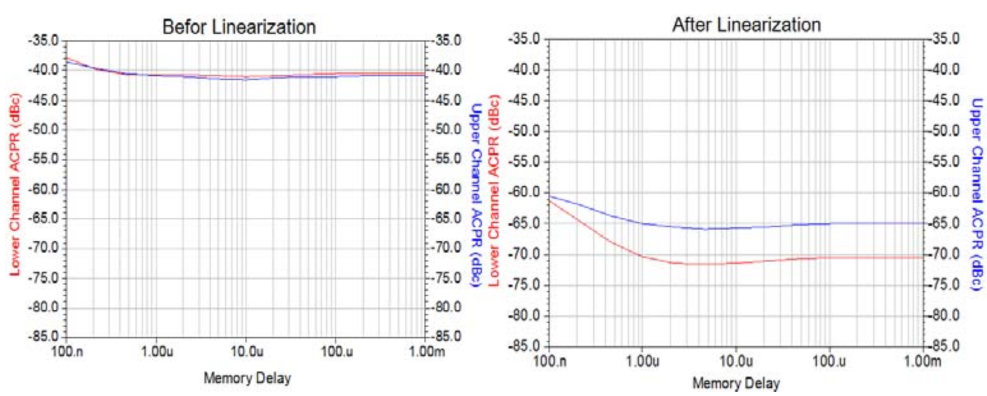

Figure 6.Comparison of the ACPR of the lower and upper channels, (a) Nonlinear and (b) Linearized Power Amplifier.

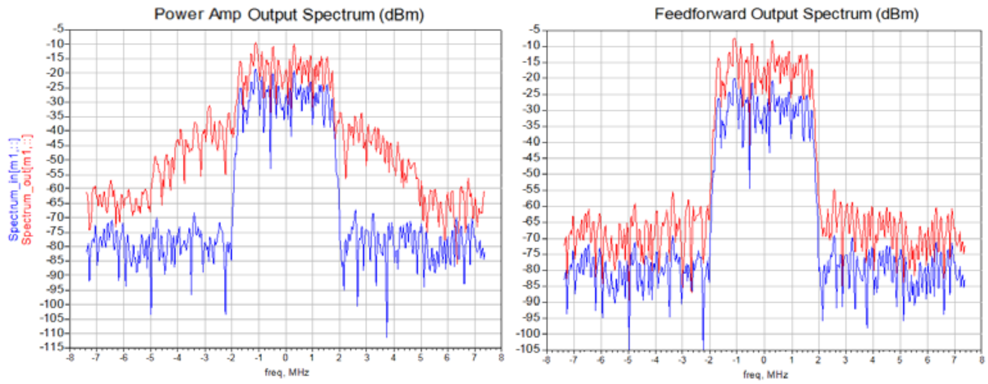

Figure 7. Comparison of the output spectrum of the CDMA transmitter with, a) Nonlinear and b) Linearized power amplifier

3. OFDM WLAN Transmitter

In the WLAN transmitter, we use ATR3515 power amplifier which is designed for 5-GHz IEEE 802.11a OFDM WLAN. Its frequency range is from 4.9 GHz to 5.9 GHz and its P_{1dB} is 25.5 dBm.A two-tone signal with central frequency of 5.223527 GHz is applied to the input of the circuit with 16 MHz frequency difference between tones such that their intermodulation components lie in their adjacent channels:

$$f_1 = 5223.527MH_Z - \frac{16MH_Z}{2} = 5215.527MH_Z \quad (5)$$

$$f_2 = 5223.527MHz + \frac{16MHz}{2} = 5231.527MHz \quad (6)$$

$$IP_{3|1} = 2f_2 - f_1 = 5247.784MHz \quad (7)$$

$$IP_{3|2} = 2f_1 - f_2 = 5199.527MHz \quad (8)$$

The output spectrums of both nonlinear and linearized power amplifiers are show in Figure 8. The DS and then OIP3 are calculated.

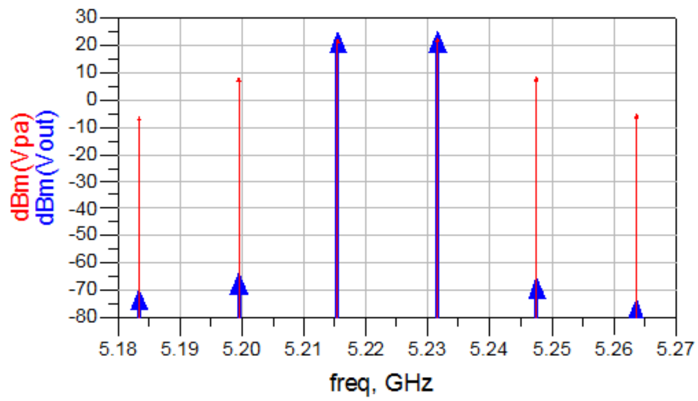

Figure 8. Comparison of the intermodulation distortion suppression, whereVpa (red-lines) are for the main power amplifier and Vout (blue-lines) are for the linearized power amplifier.

As can be seen from Figure 8,DS = 14.235 dB and OIP_3 = 29.3485 dBm for the nonlinear power amplifier. Also, DS = 89.124 dB and then OIP_3 = 68.379 dBmfor the linearized power amplifier. Hence, 39.03 dB improvement in OIP_3 is achieved via Feedforward linearization.

In the next case we consider to the evaluation of the ACPR improvement of the WLAN transmitter. Figure 9 shows the schematic of theintermediate frequency(IF) and radio frequency (RF) stages WLAN transmitter. In this circuit, we use linearized power amplifier in the circuit of the WLAN (OFDM system) transmitter and apply circuit and RF co-simulation.

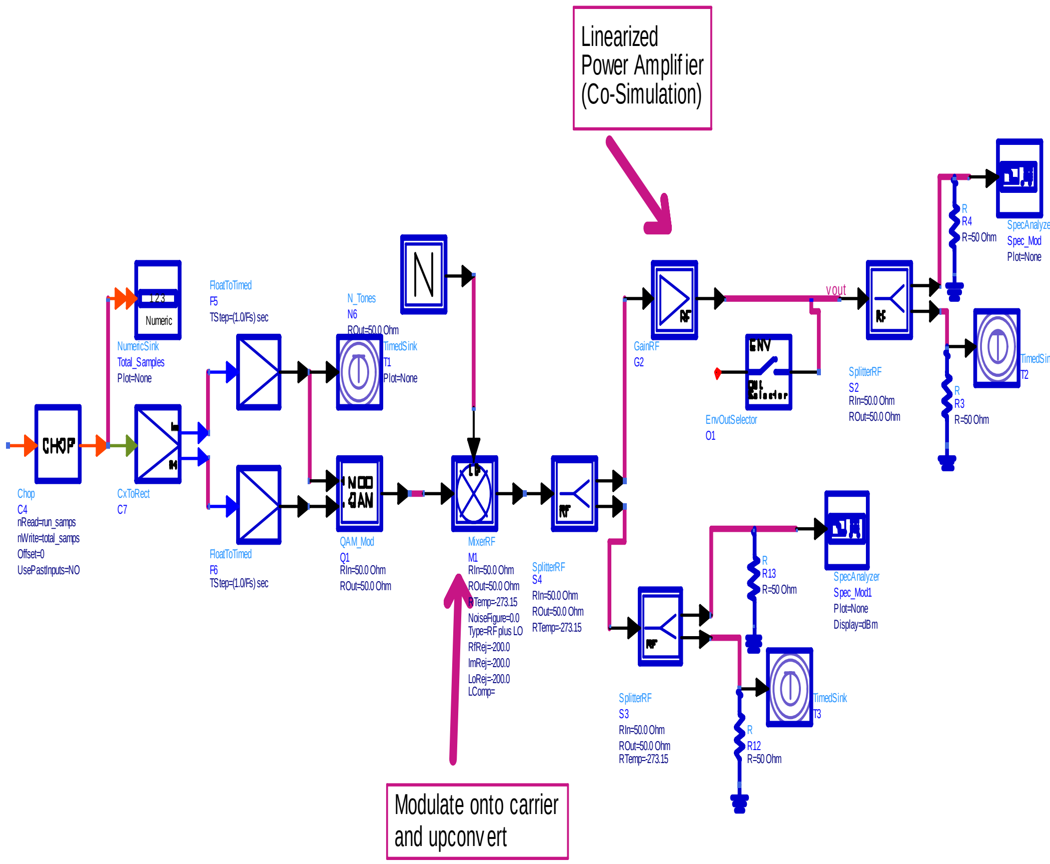

Figure 9. Schematic of the IF and RF stages of the OFDM WLAN transmitter with Feed forward linearized power amplifier.

Figure 10 shows the spectrums of the input and output of the OFDM WLAN transmitter when the used power amplifier is nonlinear or Feedforward linearized.

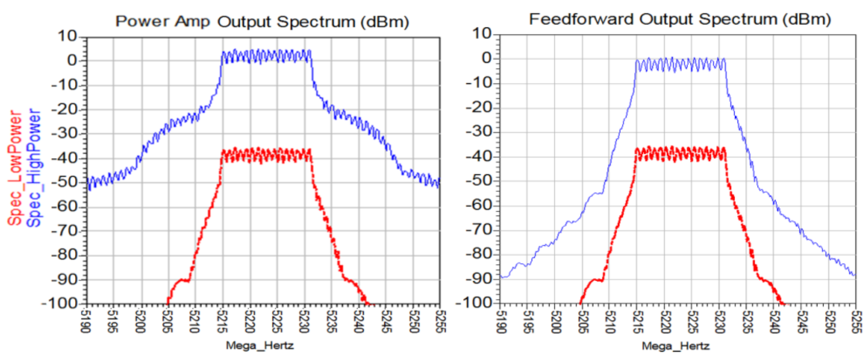

Figure 10. Output spectrum of the OFDM transmitter with (a) Nonlinear power amplifier and (b) Linearized power amplifier

As can be seen from Figure 10, for the nonlinear power amplifier, the lower and upper channels ACPRs are-27.40 dBc and -28.78 dBc, respectively. Peak-to-average ratio is 5.42 (7.34 dB). For the Feedforward linearized power amplifier, the lower and upper channels ACPRs are -54.08 dBc and -56.16 dBc, respectively.The peak-to-average ratio is 18.96 (12.78 dB). Hence, more than 26.6 dB improvement in ACPR and 5.44 dB improvement in peak-to-Ave ratio is achieved through Feedforward linearization method.

4. Conclusion

In this paper, efficiency of Feedforward linearization technique in two recently most developed communication systems, CDMA cellular mobile telephony and OFDM WLAN is considered. In the CDMA system, more than 17.27 dB increasing in OIP_3 is and at least 25 dB improvement in ACPR is obtained. For OFDM system, the achieved improvement through Feedforward method is at least 39.03 dB in OIP_3 , more than 26.6 dB in ACPR and 5.44 dB improvement in peak-to-Ave ratio. It is observed that the designed Feedforward circuit can significantly improve the nonlinearity caused from memory effects and saturation of the power amplifiers of CDMA cellular mobile telephony and OFDM WLAN transmitters.

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