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Design of an Adaptively Linearized Class-A RF Power Amplifier

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Abstract: Due to good characteristics, unconditional stability, wideband signal capability and high cancellation of distortions, compared with other techniques, feed forward linearization technique equipped with additional linearization loop is adopted in this study for linearizing a Class-A RF power amplifier having 5.8 GHz central frequency. In this study, the adaptation of feed forward technique is employed to improve the characteristics of a power amplifier for wireless application purposes. The nonlinear characteristics of commercial products are conditioned using AWR simulation technique to present linearized components for multicarrier transmission applications. In the linearized product, the third-order intermodulation is reduced to less than (-50 dBc) and the cancellation of inter modulation distortion approaches 24 dB. In addition for a carrier frequency of 5.8 GHz, an input signal of a bandwidth of about 125 MHz can be managed with maximum output power exceeding 32 dBm.

Key words: Feed forward technique, linearization, power amplifier, RF amplifier, inter modulation, bandwidth

INTRODUCTION

Power amplifiers play important roles in communication systems and their characteristics determine the best ways of their applications. In communication systems, the characteristics of power amplifiers like linearity, efficiency and bandwidth are considered as major parameters in the design requirements for each application. Power amplifies efficiently operate in saturation regions during the treatment of certain types of modulations like FM, FSK, GMSK and MFSK. These types of modulations have constant envelopes, thus, amplifiers operating in switching modes reveal high efficiency with disappearance of intermodulation distortion (Zhang *et al*., 2003). The disadvantage of constant envelope modulations is that they have low bit rate. For high bit rate applications, linear modulations such as QAM and QPSK should be adopted. Power amplifiers produce Intermodulation (IM) distortions when they are excited by spectrally efficient linear modulated signals due to the varying envelopes and phases of these signals. Power amplifiers excited by multicarrier configurations (such as OFDM and CDMA) also generate IM distortions (Zhang *et al*., 2003; Thandri and Silva-Martinez, 2003). These IM distortion products cause interference between adjacent channels (Yang *et al*., 2003). Therefore, linearization of power amplifiers become an important tool for better system performance. A linear power amplifiercan either be realized as an amplifier with added linearized circuits or another with back-off operation from its 1 dB compression point. Several linearization techniques are adopted to compensate for the nonlinearities of power amplifiers. These techniques are feedback technique, predistortion technique and feed forward technique. Feedback linearization technique is a simple one but it is associated with reduction in gain and stability in addition to its limited accuracy and bandwidth. The predistortion technique has unconditional stability with limited accuracy in analog technology implementations. Finally, the most technique used in wideband application is the feed forward linearization technique which is superior to other techniques and broadly used in modern digital and multicarrier communication systems (Jiang and Wilford, 2010; Gokceoglu *et al*., 2012; Taravati and Tayarani, 2013; Braithwaite and Khanifar, 2013; Kim *et al*., 2015; Gharaibeh and Al-Zayed, 2016). Disadvantages of feedforward technique are its sensitivity to drift due subtraction of nearly equal quantities and component tolerances. In addition, change in its output power occurs when the number of carriers changes.

In this study, the adaptive feed forward technique have been adopted to improve linearity of MMIC (MAAM26100-P1) power amplifier for 125 MHz wideband OFDM digital communication systems.

MATERIALS AND METHODS

The proposed adaptively linearized amplifier: The basic concept of feed forward technique is stated in Fig. 1. The output of the power amplifier is the amplified excitation

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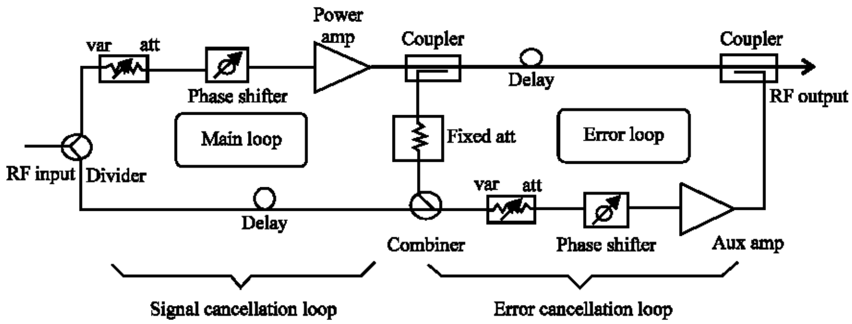

Fig. 1: The basic feed forward linearization technique

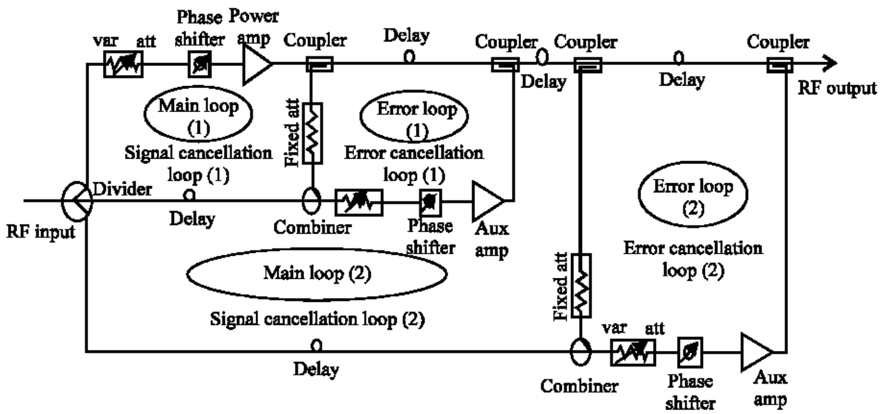

Fig. 2: The block diagram of the adaptive feed forward linearizer

signal associated with phase change and distortion. The basic function of the feed forward technique is the removal of the above distortion. In Fig. 1, there are two loops, the excitation signal cancellation loop (main loop) and the error cancellation loop. In the main loop, the excitation signal is cancelled in the combiner by adjusting the phase shifter, delay and fixed attenuator, thus, the output of the combiner is the attenuated distortion. The function of the error loop is the amplification of the attenuated distortion to the level than it can be cancelled in the output of the last coupler which represents the final RF output (Braithwaite and Khanifar, 2013).

Two sources of errors are existing in the output of the power amplifier. These errors are required to be cancelled. Hence, there are two cancellations which are the phase cancellation and the magnitude cancellation. These two cancellations are limited by the following expressions (Yang *et al*., 2003):

$$\text{Phase error cancellation (dB)} = 10\log_{10}\left[(\sin\theta_e)^2 + (1-\cos\theta_e)^2\right] \quad (1)$$

$$\text{Magnitude error cancellation (dB)} = 20\log_{10}\left(10^{\frac{E}{20}} - 1\right) \quad (2)$$

Where:

θe = The phase error and

E = The amplitude error in decibels

Cancellations in Eq. 1 and 2 correspond to narrowband results. In case of no error in amplitude, the phase error sufficient to produce 30 dBc cancellation is about 2°. In case of no error in phase, the magnitude error sufficient to produce 30 dBc cancellation is about 0.25 dB (Yang *et al*., 2003; Gharaibeh and Al-Zayed, 2015; Motavalli and Solbach, 2017).

In this research, an adaptive feed forward was proposed to linearize highly nonlinear power amplifiers and push them to research near nonlinear regions to produce high power. The block diagram of the proposed amplifier is shown in Fig. 2. It included two main signal cancellation loops and two error cancellation loops.

In the first error cancellation, the error signal might not be removed completely, thus, the second error cancellation loop is added to guarantee the complete removal of error or distortion.

The schematic design of the adaptive feed forward linearizer is similar to the basic feed forward amplifier except, it has two error cancelation loops to modify the linearity of the power amplifier. This means that the

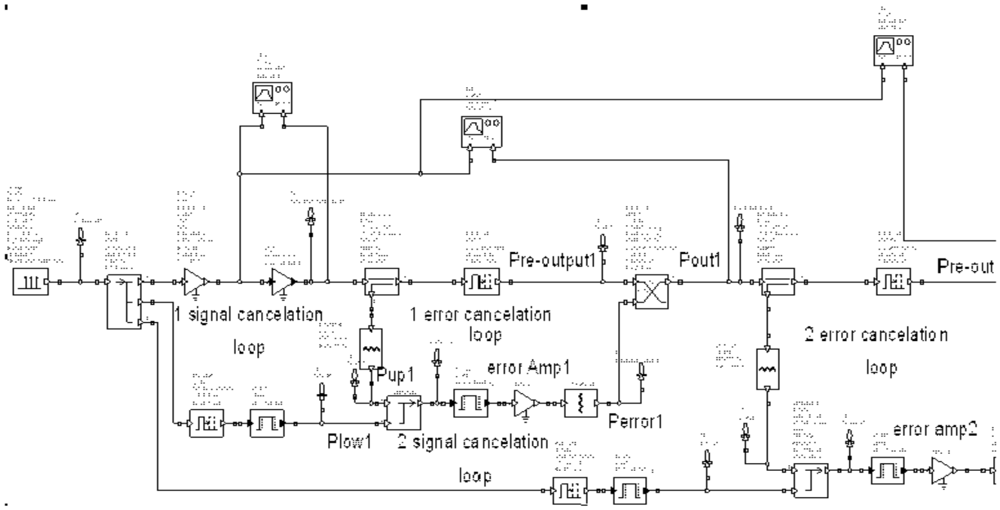

Fig. 3: AWR® design of the adaptive feed forward linearizer

Table 1: Main amplifier characteristics

Variables	Values
Gain	18 dB
OutputPower	34 dBm (2.5 W)
Linearity	First adjacent channel: ACLR1≤_-50 dBc
	Second adjacent channel: ACLR2≤_-60 dBc
Efficiency	>30% including DC/DC converter
Bandwidth	Any 125 MHz band within
	2-7 GHz, field adjustable

adaptive linearizer has two error amplifiers and additional couplers, attenuators and phase shifters. The circuit diagram of the adaptive feed forward amplifier is shown in Fig. 3. It is designed on AWR Design Environment ®.

The typical specifications of the power amplifier used in the AWR implementation of the linearized power amplifier with the adaptive feed forward technique are shown in Table 1. This amplifier is capable of supporting four carriers but in this design, two carrier frequencies are used. These carriers are 5.8 and 5.85 GHz. Optimization variables were adjusted to achieve minimizing the IMD in the adjacent channels to have power levels close to -50 dBm and phase difference of 180°. The optimization variables used in accessing results are the time delays in the adaptive feed forward linearizer.

RESULTS AND DISCUSSION

The main amplifier (MMIC MAAM26100-P1) was tested on AWR environment to measure its AM-AM characteristics or its linearization capability. Figure 4 shows the results of this test.

The adaptive feedforward linearization circuit was analyzed and optimized for minimum IMD output. The results of the AM-AM characteristics of this test is shown in Fig. 5. A simple comparison between the AM-AM characteristics in Fig. 4 and 5, demonstrates that a linearization of more 25% has taken place.

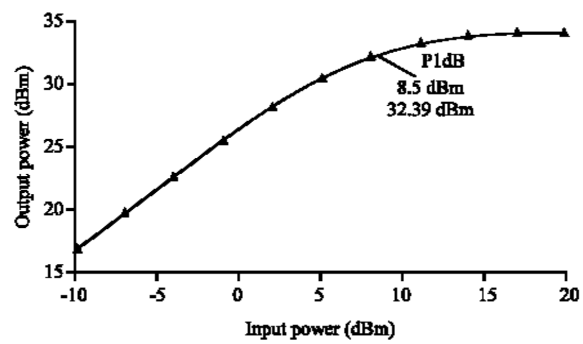

Fig. 4: The AM-AM performance of the main amplifier before linearization

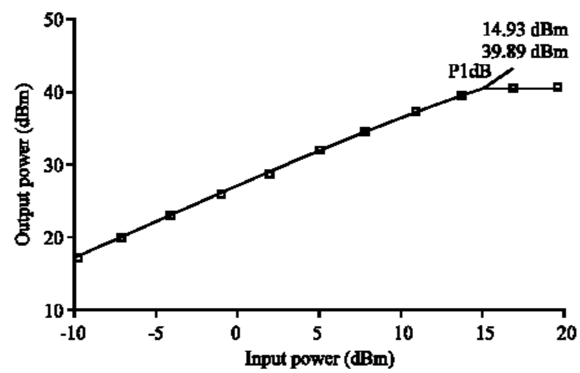

Fig. 5: The AM-AM performance of the main amplifier after linearization

Figure 6 shows the power levels in the signal cancellation loop corresponding to an input signal having

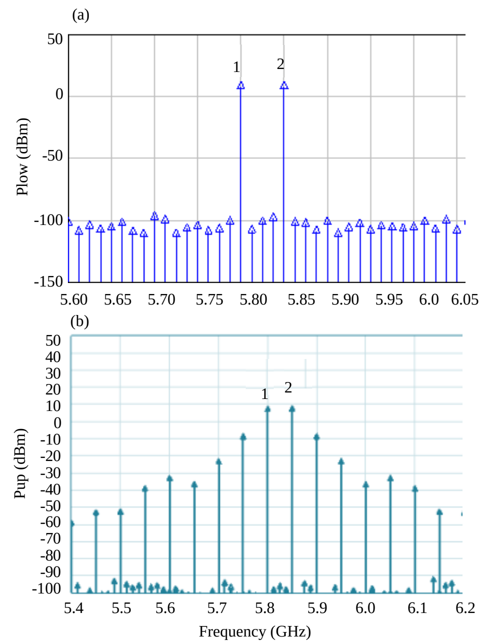

Fig. 6: Signals along the first signal cancellation loop: a) Plow 1 signal and b) Pup 1 signal

two carrier frequencies 5.8 and 5.85 GHz with 8 dBm for each carrier. Pup 1 signal is the signal travelling through the upper branch and coupled from the first coupler. It represents the first input of the combiner in the first signal cancellation loop as shown in Fig. 6b. Figure 6a shows the signal travelling through the lower branch which is called Plow 1 signal and it represents the second input of the combiner in the first signal cancellation loop.

At the output of the cancellation loop, the input carrier signals to some extent cancel each other. In Fig. 7, the IMD amplitudes are marked by 1 and 2 at 5.75 and 5.9 GHz, respectively. The signal "Pre-output 1" represents the output of the main amplifier in the first error cancellation loop while the signal "Perror 1" represents the output of the first error amplifier. Figure 7 are presents Pre-output 1 signal while Fig. 7b represents Perror 1 signal.

The RF output of the first feed forward loop is shown in Fig. 8. It is obvious that IMD levels at 5.75(point 3) and 5.9 GHz (point 4) are decreased compared to their values in Fig. 7a. It is also, observed in Fig. 8, that the main carriers at 5.8 (point 1) and 5.85 GHz (point 2) remain at their original values in Fig. 7a (32 dBm).

In the same manner done in the first feed forward loop, the IMD at 5.75 (marked by 3) and 5.9 GHz (marked by 4) are greatly decreased at the output of the second feed forward loop as shown in Fig. 9. It is observed that a decrease in IMD levels at the frequencies of 5.75 (point 3) and 5.9 GHz (point 4) has taken place with powers of

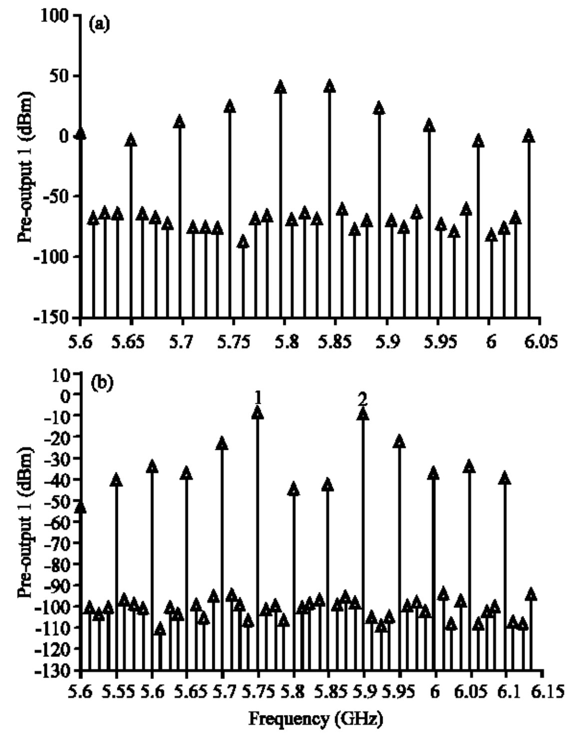

Fig. 7: Signals before the output coupler of first error loop: a) Pre-output 1 signal and b) Perror 1signal

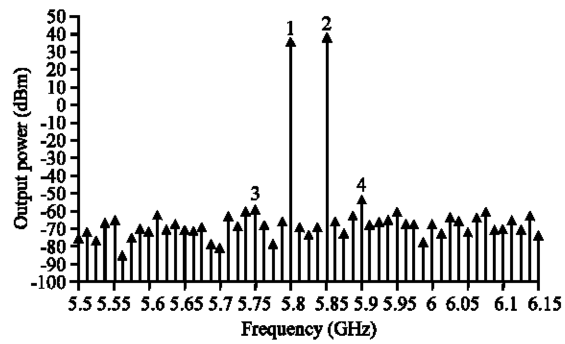

Fig. 8: RF output spectrum from the first feed forward loop

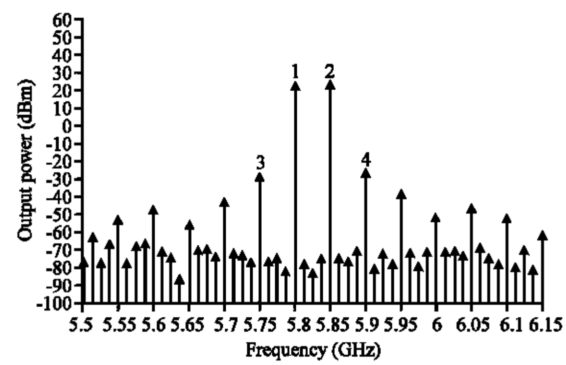

Fig. 9: RF output spectrum from the adaptive feed forward linearizer

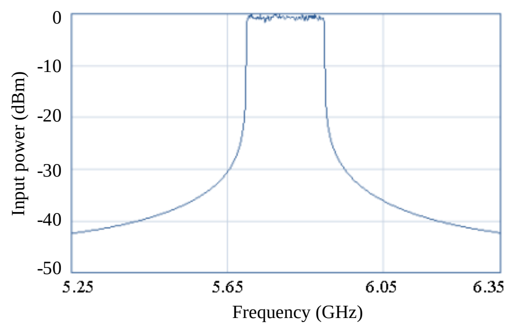

Fig. 10: The OFDM input signal spectrum

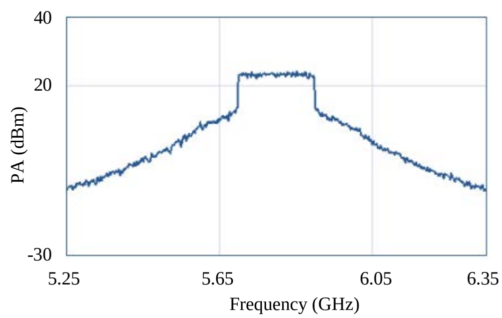

Fig. 11: The output spectrum of the main power amplifier

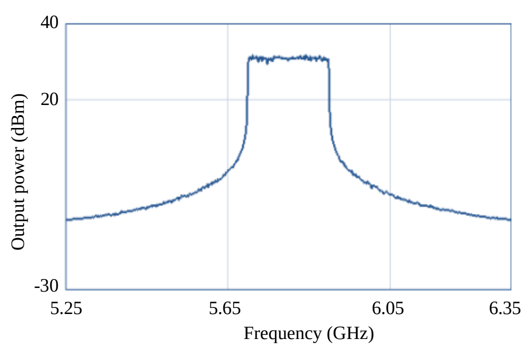

Fig. 12: The output spectrum of the adaptive feed forward power amplifier

-60.85 and -55.03 dBm, respectively. It is also, observed that the main carriers at 5.8 (point 1) and 5.85 GHz (point 2) remain at about 32 dBm and both IMD levels a 5.75 (point 3) and 5.9 Ghz (point 4) decrease to about -60 dBm.

Another source signal was used to excite the adaptive feed forward of Fig. 3. The new excitation was an OFDM signal, similar to the DVB-T standard signal (Taravati and Tayarani, 2013; Gharaibeh and Al-Zayed, 2015) with the following parameters: subcarrier: 128 active subcarriers, subcarrier spacing: 0.003125 GHz, guard interval: 1/8 and constellation: 64 QAM. The 64-QAM modulated OFDM input signal was applied to the adaptive feed forward amplifier. The power spectrums of input signal is shown in Fig. 10. Figure 11 shows output spectrum of the main amplifier while Fig. 12 shows the output spectrum of whole feed forward amplifier. It is clear that the output of the main power amplifier (Fig. 11) is distorted compared to the adaptive linearized output (Fig. 12).

CONCLUSION

The simulation results of the adaptive feed forward amplifier demonstrates the possibility of reducing distortion associating power amplifiers and increasing their bandwidth. In addition, this technique has great impact in reduction of in termodulation distortions, thus, it offers the feasibility of being used in multicarrier wireless communication systems.

LIMITATIONS

The disadvantages of this technique are its decreased efficiency because of double error amplifiers, sensitivity to electronic circuit tolerances and the variation in power levels during changing the number of excitation carriers.

RECOMMENDATIONS

These disadvantages can be compensated by using assisting techniques like vector modulators as good replacements of attenuators and DSP for monitoring changes in circuit parameters and then adjusting the magnitudes and phases of signals by varying the settings of attenuators and phase shifters.

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