Optimum Design of Doherty RFPA for Mobile WiMAX Base Stations

Abubakar Sadiq Hussaini[1], Tahereh Sadeghpour[2], Raed A. Abd-Alhameed[2], Mark B. Child[2], Nazar T. Ali[3], and Jonathan Rodriguez[1]

[1] Instituto de Telecomunicações – Aveiro, Portugal
[2] Mobile & Satellite Communications Research Centre, University of Bradford, Bradford, United Kingdom, BD7 1DP
[3] Khalifa University, Sharjah, PO Box 573, United Arab Emirates
{ash,jonathan}@av.it.pt,
{tsadeghp,r.a.a.abd,m.b.child}@bradford.ac.uk,
ntali@kustar.ac.ae

Abstract. RF power amplifiers in mobile WiMAX transceivers operate in an inherently nonlinear manner. It is possible to amplify the signal in the linear region, and avoid distortion, using output power back-off; however, this approach may suffer significant reduction in efficiency and power output. This paper investigates the use of Doherty techniques instead of back-off, to simultaneously achieve good efficiency and acceptable linearity. A 3.5 GHz Doherty RFPA has been designed and optimized using a large signal model simulation of the active device, and performance analysis under different drive levels. However, the Doherty EVM is generally poor for mobile WiMAX. Linearity may be improved by further digital pre-distortion, and a simple pre-distortion method using forward and reverse AM-AM and AM-PM modeling. Measurements on the realized amplifier show that this approach satisfies the EVM requirements for WiMAX base stations. It exhibits a PAE over 60%, and increases the maximum linear output power to 43 dB_m, whilst improving the EVM.

Keywords: Doherty, RFPA, linearity, digital pre-distortion, OFDM.

1 Introduction

A linear power amplifier (PA) with a high efficiency across a wide range of output power is very important for mobile WiMAX, and general mobile applications that utilize power control. The PA should also have acceptable linearity with respect to a non-constant envelope signal. This is due to the fact that when amplifying such a signal, a nonlinear PA might cause and generate distortion, dramatically affecting the dynamic range of the system dominated by the maximum signal levels [1]. The resulting output signal might be combined by the intermodulation distortion (IMD). This would be undesirable since it falls in-band, and typically in adjacent channels.

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Mobile WiMAX adopts Orthogonal Frequency Division Multiplexing (OFDM), with modulations from QPSK to 64-QAM, and has crest factor around 9dB-12dB. This wideband digital modulation scheme offers high data rates and has resilience to multipath effects. However, the scheme is critically dependent on linearity in the hardware system due to its inherently high crest factor [2]. Mobile WiMAX strives to reach a 100Mbps data rate. To support the proposed data services, the base station and the user terminal itself must be able to handle higher data rates. Achieving high efficiency and good linearity simultaneously in power amplifier design are the most challenging task. The error vector magnitude (EVM) is critical for a given rated output power. This indicates which PA is capable of meeting the system requirements. Mobile WiMAX power amplifiers must not exceed 5% EVM for 16-QAM and 2.5% for 64QAM OFDM modulation. There are ten frequency bands defined in the WiMAX standard, the 3.5 GHz band being the most common in Europe, this band has a range of frequency from 3.4GHz to 3.6GHz (Uplink: 3400MHz – 3500MHz, Downlink: 3500MHz – 3600MHz).

In this paper, the performance of a Doherty amplifier is investigated and discussed in terms the coupling factor of the input splitter, the gate bias voltage, and the adjustment of output matching of the peaking amplifier. This adjustment was introduced by using an extra quarter wavelength section of transmission line. The gate bias and the output matching of the peaking amplifier are optimized. The peaking amplifier allows the Doherty amplifier to respond to the high input levels of short duration, by amplifying the signal peaks, and to dynamically change the load impedance of the main amplifier. For linearity a baseband digital pre-distorter has been applied. Results in terms of efficiency and linearity have been achieved.

2 Mobile WiMAX: Linearity and Output Power Requirements

The envelope variation of an OFDM signal clearly requires a linear RFPA. It should be noted that the IEEE 802.16e/Mobile WiMAX standard doesn't specify the minimal required intermodulation distortion (IMD) of the user terminal PA, but it uses system level requirement to describe the maximal allowable distortion. These system level requirements are: Spectral Mask (SM) and Error Vector Magnitude (EVM) [3], [4]. The spectral mask is specified at the PA output, and ensures that the user terminal transmitter does not corrupt or block the spectrum from adjacent channels. The error vector (E(s)) is the difference between the actual transmitted (A(s)) and ideal (H(s)) constellation point. EVM is specified after reception and demodulation by an ideal receiver and ensures a correct transmission within the channel. The EVM of a symbol S is defined as,

$$\mathrm{EVM} = \sqrt{\frac{|\mathrm{E(s)}|^2}{\frac{1}{\mathrm{N}}\sum_{\mathrm{S}}|\mathrm{H(s)}|^2}}$$

To obtain EVM as a percentage, the RMS value is used, this is a useful systems level figure of merit for the accuracy of the OFDM signal,

$$\mathrm{EVM}(\%) = \sqrt{\frac{P_{error}}{P_{ref}}} \cdot 100\%$$

where P_{error} is the RMS power of the error vector, and P_{ref} is the power of the outermost point in the reference constellation. The spectral mask and EVM targets for mobile WiMAX comparatively rigorous among existing standards.

3 Doherty RF PA Design for Mobile WiMAX

This section explored the Doherty configurations. In 1936 W.H Doherty, from Bell Telephone Laboratories Inc, proposed the high efficiency power Amplifier called Doherty Amplifier [5]. The concept of the Doherty power amplifier configuration, have narrated in our previous paper [6], involves the use of two or more power amplifiers and the quarter wave transmission line coupler or impedance inverting network. The resultant linear power amplifier achieves a higher efficiency at the outputs below peak output power (PEP) than conventional class B linear power amplifier [7], [8]. The basic block diagram of this kind of amplifier can be seen in Fig.1.

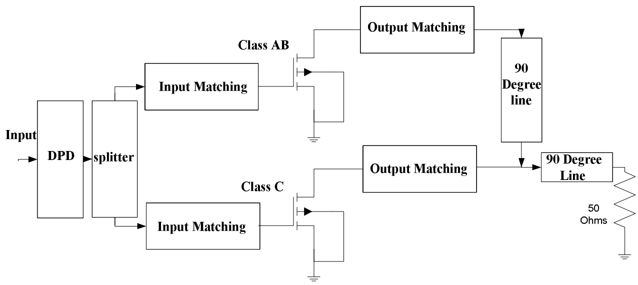

Fig. 1. Block diagram of a mobile WiMAX Doherty power amplifier

The Doherty PA configuration was introduced at Bell Labs in 1936 [5], and has received fresh attention in modern radio design. The Doherty approach uses two or more PA and a quarter wave transmission line coupler, or impedance inverter, as shown in Fig. 1. The resulting sub-system is capable of achieving a higher efficiency at the outputs below the peak output power than a conventional Class B PA [6].

The Doherty PA in this study uses the load modulation technique, and the linearity was enforced by further digital pre-distortion. The Freescale N-channel Enhancement-Mode Lateral MOSFET MRF7S38010HR3 was used throughout. The dynamic load adaptation is provided by a 50Ω transmission line impedance inverter, the passive sub-system also includes a 90° hybrid splitter. The design also includes the optimized bias and class of operation for the carrier and peaking amplifiers, this was obtained from a large signal harmonic balance analysis. The bias condition for the Class AB carrier amplifier are V_{gs} = 3.0V (I_{ds} =300 mA), and for the Class C peaking amplifier, V_{gs} = 2.4V (I_{ds} = 1 mA). Both of the amplifiers use the same drain voltage (30V). The performance of this design is strongly influenced by the coupling factor of the hybrid splitter, and the Class AB and Class C biasing. Furthermore, the turn–on of the class C amplifier was dependent on the gate bias voltage, and the input signal, which in turn fixes the low efficiency and peak values of the configuration.

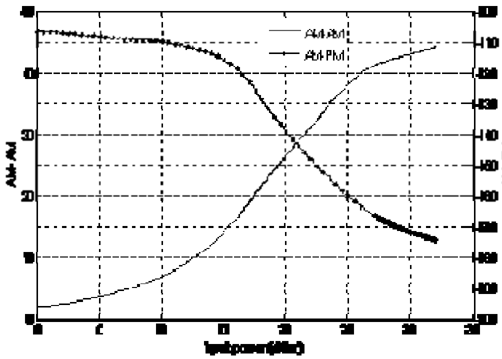

Fig. 2. AM/AM and AM/PM characteristics

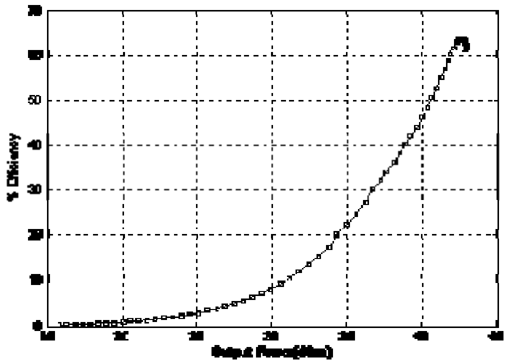

Fig. 3. % Efficiency of Doherty PA

The amplifier has been tested with one tone test characterizing the AM-AM and AM-PM responses (Fig. 2), two tone test, and 802.16e signal (10MHz bandwidth 16-QAM OFDM modulation signal and crest factor of 10dB). Comparing with a conventional Class AB design, there is an improvement from 20% to 25% efficiency; and the design is capable of delivering 15 W of RF power with a 60% workable efficiency. The IMR[1] value is -22.5 dB for IMD3 and -40 dB for IMD5 (for the 1 dB compression point), the input and output IP3 values are 26 dBm and 46 dBm, respectively.

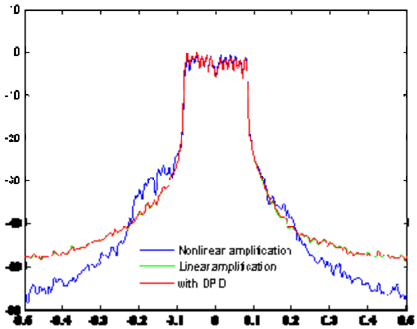

Fig. 4. Nonlinear amplification of OFDM signal

The nonlinear amplification of OFDM signal is given in Figure 4. Spectral re-growth is observed as the result of nonlinearity. The improvement of the linearity has been achieved by means of baseband digital pre-distortion, where the multicarrier input signal is pre-distorted in such a manner that the overall system becomes approximately linear. Figure 4 shows the measurement performance of amplification of an 802.16e signal in an OFDM power amplifier applying the pre-distortion. For two-tone excitation, the Doherty amplifier showed both better ACPR and PAE at the same time than the conventional class AB type amplifier. An ACPR performance of -40dBc was achieved using this pre-distortion method. This results show that the Doherty power amplifier and digital pre-distortion method can be a promising combination to enhance the efficiency and linearity for 4G communication systems.

4 Conclusions

The results show that the implementation of a Doherty configuration can provide efficient RF power transmission. It demonstrates a significant improvement in power added efficiency (PAE) in the low power region, compared to a traditional design. It has exhibited a PAE of 60% for 15 W output power, and by applying a digital pre-distorter, the maximum output power EVM has improved. The operation of this design was strongly influenced by the coupling factor of the splitter, and biasing of the Class AB/C amplifiers. In addition, the turn–on of the class C amplifier depends on the gate bias voltage and the input signal. The self-managing characteristic of the Doherty amplifier has made its implementation more attractive.

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[1] The difference between the fundamental power (dBm) and the IMD power (dBm).

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