Advanced Engineering Technology and Application
An International Journal

http://dx.doi.org/10.12785/aeta/030302

Graphic User Interface for Memory Polynomial Based Digital Pre-Distortion of RF Power Amplifiers

Rajbir Kaur[1,*] *and Manjeet Singh Patterh*[2]

[1] Department of Electronics and Communication Engineering, Punjabi University, Patiala, Punjab, India
[2] Department of Electronics and Communication Engineering, Punjabi University, Patiala, Punjab, India

[*] Corresponding author e-mail: rajbir277@yahoo.co.in

Received: 3 Jun. 2014, Revised: 3 Aug. 2014, Accepted: 18 Aug. 2014

Abstract: The availability of fast and cost effective digital processing technology makes digital pre-distortion attractive for power amplifier linearization since it promises high power efficiency and flexibility. Digital pre-distortion task can be divided into three sub tasks: modeling of the power amplifier (PA), adaptive identification of the model parameters, and development of the pre-distorter. The memory polynomial model, which is reduced form of Volterra series, is most widely used by researchers. The accuracy of memory polynomial based digital pre-distortion depends on the memory depth and order of memory polynomial. In this work a generalized graphic user interface has been developed for modeling of power amplifier and digital pre-distorter. The memory depth and order of memory polynomial can be changed and experimentation can be done for different values of memory depth and order of memory polynomial.

Keywords: Graphic User Interface, Memory Polynomial, Power Amplifiers, Pre-Distortion, Wideband Code-Division Multiple Access.

1. Introduction

The first practical implementation of a gain based Digital Predistorter was proposed by James Cavers [1]. Prior to this method, the majority of the Digital Predistorters were based on the mapping principle, where each possible signal level was directly mapped to another output level. If the signal bandwidth is wide, such as in W-CDMA signals, Power Amplifier (PA) begin to exhibit memory effects. Many papers describe methods to measure memory effects in RF PAs [2]. These methods require the use of test equipment, and as a result are not practical in a Digital Predistorter implementation. Other papers and thesis [3] propose DPD models taking memory effects into account. Although they provide some insight into the causes of memory effects but are again not practical in a Digital Predistorter implementation. In recent years, some proposals have been made to measure and correct for memory effects in RF PAs. Not all major memory effects are considered, and only two of these papers show experimental results with actual memory effects correction.

The problem of linearization using DPD was also tried to be analysed by [4] but the solution was not applicable to wideband communication system. Stapleton [5] discussed the complex gain Predistorter but it was only an overview paper. Hammi *et al.* [6] presented simulative investigations on Digital Predistorter using sub-band technique. Earlier filters were also used to compensate for temperature changes, but no technique was proposed to compensate memory effects of PA. Ding *et al.* [7] proposed Digital Predistorter with Memory Polynomial but it has high implementation complexity. Varahman *et.al.* [8] proposed wideband adaptive DPD technique using the concept of combination of Memory Polynomial Predistorter and slope-dependent method. But the proposed method is complex to implement. Raithwaite and Santa [9] proposed adaptive DPD using reduced order memory correction. Eigen value decompositions were used to reduce the order of the memory coefficient estimation. But the proposed technique was tested for 20MHz signal only. Jiang and Wilford [10] proposed adaptive DPD using separable functions. But the proposed technique is complex to implement and PA modelling was not proposed.Rawat *et al.* Adaptive DPD using neural networks has also been proposed by [11], but only 20 dB improvement was obtained using the proposed technique. Although different researchers have worked on DPD technique using different approaches yet there is a need to develop a general framework where experimentation can be performed with different PAs. For this a GUI was developed by Altera Corporation, but it can be used for memory less DPD modelling. Sappal *et al.* [12] has proposed complex memory polynomial based DPD technique and were able to achieve an improvement of about 40 dB for third order IMD products. Although

Dennis R. *et al.* [13] has proposed a generalized memory polynomial model, but the model is not interactive for experimentation with variation of order and degree of polynomial. So this paper proposes a generalized GUI, which can be used for any wideband PA data. In this paper for modelling PA and DPD, the degree and order of memory polynomial can be varied to obtain the optimum result. The paper is organised as follows: section I provides introduction, polynomial for nonlinear curve fitting of data are presented in section II, nonlinear model identification is given in section III, proposed GUI is explained in section IV, results and discussions are provided in section V and section VI concludes the paper.

2. Memory Polynomial for Nonlinear Curve Fitting of Data

The memory Polynomial model [13] consists of several delay taps and non-linear static functions. This model is a reduced form of the general Volterra series and only consists of the diagonal terms in the Volterra series. Thus, the number of parameters has significantly been reduced as compared to general form of Volterra series. The Memory Polynomial model can be described as [13]

$$y(n) = \sum_{q=0}^{Q}\sum_{k=1}^{K} c_{2k-1,q}\,|x(n-q)|^{2(k-1)}\,x(n-q) \qquad (1)$$

Where, $x(n)$ is the input complex base band signal, $y(n)$ is the output complex base band signal, $c_{k,q}$ are complex valued parameters, Q is the memory depth and K is the order of the polynomial.

3. Non Linear Model Identification

There are many different types of models for system identification of non-linear systems. A non-linear function of the parameter vector can be searched by using non-linear optimization techniques. Due its ease of implementation and unique feature of finding nearly accurate global minima, the LSE technique [14] is widely used to find the coefficients of the memory polynomial. In general, to identify the coefficients of say matrices $\mathbf{Y}$ and $\mathbf{H}$ which are first defined as [14]

$$\mathbf{Y} = [y(n) \quad y(n+1) \quad \ldots \quad y(n+N-1)]^T \qquad (2)$$

$$\mathbf{H} = [H_0 \ldots H_q \ldots H_Q] \qquad (3)$$

where $y(n)$ represents the output data samples and N represents the number of output samples. Let

$$\mathbf{H_q} = \begin{bmatrix} h_{1,q}(n) & h_{3,q}(n) & \cdots & h_{2k-1,q}(n) \\ h_{1,q}(n+1) & h_{3,q}(n+1) & \cdots & h_{2k-1,q}(n+1) \\ \vdots & \vdots & \ddots & \vdots \\ h_{1,q}(n+N-1) & h_{3,q}(n+N-1) & \cdots & h_{2k-1,q}(n+N-1) \end{bmatrix} \qquad (4)$$

Hence,

$$h_{2k-1,q}(n) = |x(n-q)|^{2(k-1)}\,x(n-q) \qquad (5)$$

Now if,

$$\mathbf{c} = \begin{bmatrix} \mathbf{c_0} & \ldots & \mathbf{c_q} & \ldots & \mathbf{c_Q} \end{bmatrix} \qquad (6)$$

Where

$$\mathbf{c_q} = \begin{bmatrix} \mathbf{c_{1,q}} & \mathbf{c_{3,q}} & \ldots & \mathbf{c_{2k-1,q}} \end{bmatrix} \qquad (7)$$

Then the following matrix equation holds [14]

$$\mathbf{Y = Hc} \qquad (8)$$

If $\mathbf{\hat{a}}$ is the estimated parameter matrix then minimum root mean square (RMS) error between the measured and simulated output $\mathbf{\hat{a}}$ can be calculated as follows [14]:

$$\mathbf{(HH^*)(H^*H) = I} \qquad (9)$$

$\mathbf{H^*}$ is the conjugate transpose of $\mathbf{H}$, also known as the Hermitian transpose or the adjoint matrix. Then equation 8 can be rewritten as

$$\mathbf{(HH^*)(H^*H)^{-1}\,Y = Hc} \qquad (10)$$

Hence using least square criterion,. $\mathbf{\hat{a}}$. can be calculated as

$$\mathbf{\hat{a} = H^*(H^*H)^{-1}\,Y} \qquad (11)$$

Where $\mathbf{\hat{a}} = \begin{bmatrix} \mathbf{\hat{a}_0} & \ldots & \mathbf{\hat{a}_q} & \ldots & \mathbf{\hat{a}_Q} \end{bmatrix}^{\mathbf{T}}$, and,

$$\mathbf{H^+ = H^*(H^*H)^{-1}} \qquad (12)$$

If $\mathbf{H^+}$ is the pseudo inverse matrix of $\mathbf{H}$, then

$$\mathbf{\hat{a} = H^+Y} \qquad (13)$$

The simulated output can be calculated from the input and estimated parameters as [14]

$$\begin{aligned} \mathbf{\hat{Y}} &= \begin{bmatrix} \hat{y}(n) & \hat{y}(n+1) & \ldots & \hat{y}(n+N-1) \end{bmatrix}^T \\ &= \mathbf{H\hat{a}} = \sum_{q=0}^{Q} \mathbf{H_q \hat{a}_q} \end{aligned} \qquad (14)$$

Then the error between simulated and measured can be defined as [14]

$$\mathbf{E} = \mathbf{Y} - \mathbf{\hat{Y}} = \begin{bmatrix} e(n) & e(n+1) & \ldots & e(n+N-1 \end{bmatrix}^T \qquad (15)$$

4. Graphic User Interface

A GUI is an interactive environment, which helps the user perform tasks through buttons and sliders. GUI tools enable us to perform tasks such as creating & customizing plots and analyzing & filtering signals. The developed GUI shown in Fig 1, consists of four major sections named Load and Analyze PA Data, Memory Polynomial Modeling of PA, Memory Polynomial Modeling of DPD and Display Results.

Load and Analyze PA Data section is used to calculate PA parameters like ACLR, EVM, AM-AM characteristics, efficiency and Linear Limit of PA. Memory Polynomial Modeling of PA section can be used to vary the memory length and degree for achieving minimum error in PA modeling. For PA modeling, memory polynomial and non-linear curve fitting tool has been used. This section can also be used to calculate and compare various characteristics of actual (measured) PA and Modeled (Estimated) PA. The Memory polynomial model of DPD section is used to model the DPD module. Similar to PA modeling, the DPD module is designed by varying memory length and degree of the memory polynomial. This section can be used to display and calculate the various parameters of DPD. Display Result section can be used to plot various results of the combination of PA and DPD module. AM-AM, AM-PM characteristics of the combination of PA and DPD module, the spectrum of input signal, PA output signal and output signal of the combination of PA and DPD module can also be plotted by using this section.

5. Results and Discussions

We have taken PA data from Xilinx website. The AM/AM characteristics in Fig 2 shows the existence of dispersion in the relationships between input and output signals due to the dependence of output signal on current and past input signals.

The variation of the efficiency of PA with input power has been shown in Fig 3 and linear limit of PA has been shown in Fig 4.

The mathematical model for PA has been developed by using memory polynomial with degree 7 and memory length 3. The AM-AM characteristics of modeled PA and variation of its efficiency with input power are shown in Fig 5 and Fig 6 respectively.

The ACLR and EVM values of actual and modelled PA are shown in Table1 and error in PA design comes out to be 0.3741 only.

In the simulations of DPD module, the memory polynomial is used to with degree 6 and memory length 4. This gives very small error of 0.1730 in DPD modelling. The coefficients of DPD are shown in Table II.

The EVM and ACLR of Modelled PA and Linearized PA are shown in Table 3. Results show that EVM has been decreased from 64.6447 dB to 54.8204 dB whereas upper channel ACLR1

been decreased from -46.6461dB to-62.2606 dB, lower channel ACLR1 been decreased from -75.3282 dB to -74.9568 dB, upper channel ACLR2 been decreased from -77.0577 dB to -74.3350 dB and lower channel ACLR2 been decreased from -47.1175 dB to -62.1608 dB. Fig 7 shows the accuracy of the modelled DPD in comparison with the AM-AM characteristics of actual DPD.

The combined AM-AM response of PA and DPD is shown on Fig 8. Curve reveals that the proposed DPD is able to achieve high order of linearity. From combined AM-PM response shown in Fig 9, it can be concluded that the proposed DPD has also mitigated the effect of input power variation on the phase of the output signal, which was having quite significant effect on the phase of output signal (without DPD) as shown in Fig 3.

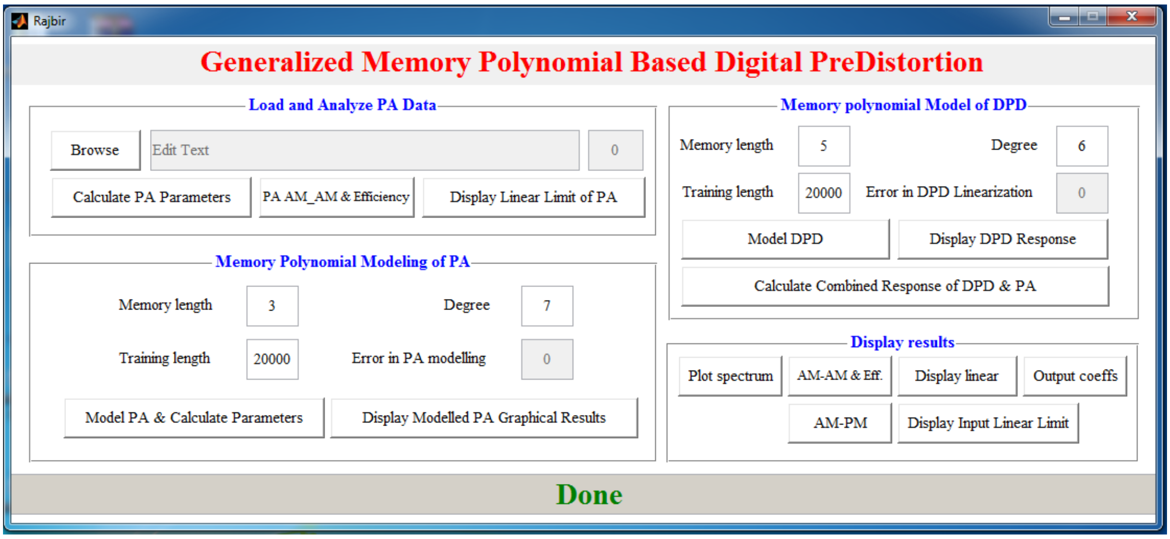
Fig 10 shows the spectrum of input signal, PA output signal without DPD and PA output signal with DPD.

Results show that the proposed DPD has resulted in reduction of the in band and out band IMD components significantly. The maximum reduction in ACLR has been noticed as 28.2783 dB.

6. Conclusion

Due to its flexibility and moderate implementation complexity with high linearization capability, DPD is becoming popular among engineers to tackle with the problem of high PAPR and hence the problem of PA non-linearity. Different DPD techniques are available in literature and due to ease of implementation; DPD using memory polynomial is quite popular. In this paper a general and intractable DPD solution has been provided using Matlab GUI feature. Any wideband PA data of the systems like WCDMA or WiMAX can be applied to the GUI and PA can be modeled accurately by varying the value of memory length and degree. Also depending upon the PA non-linearity, DPD can be modeled by varying memory length and degree. The actual characteristics of PA and DPD can also be compared with their modeled versions. The combined response of DPD can be visualized in terms of its AM-AM, AM-PM and spectral characteristics. The developed GUI will be quite useful for the researchers who want to work in the field of DPD based PA linearization.

Figures



Edit Text 0

Memory length 3 Degree 7

Training length 20000 Error in PA modelling 0

Memory length 5 Degree 6

Training length 20000 Error in DPD Linearization 0

Figure 1: *Snapshot of the Main GUI*

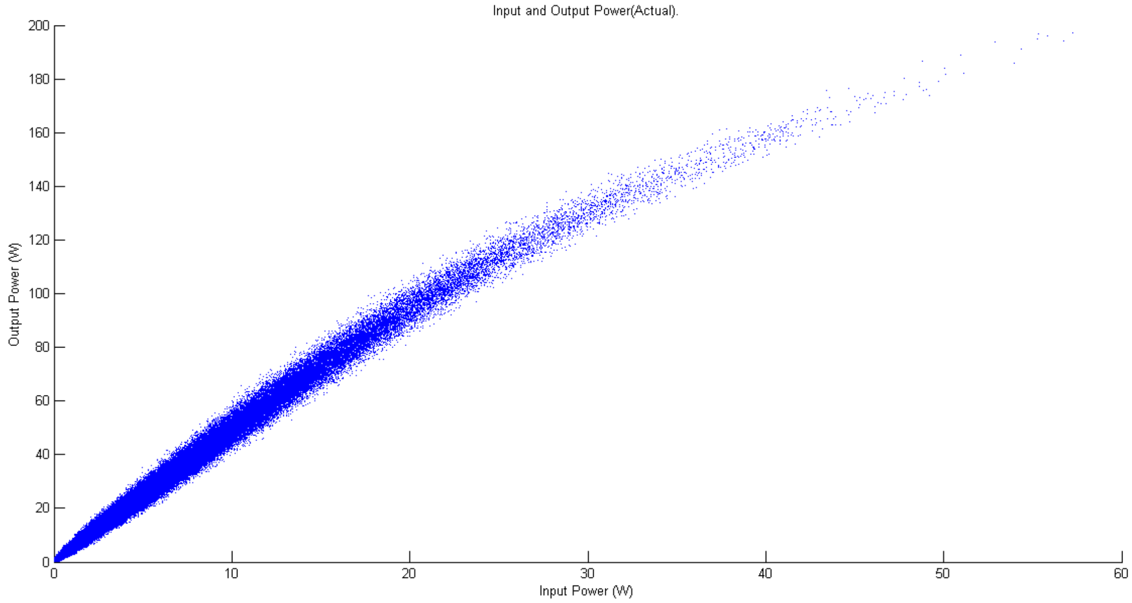


Figure 2: *PA input vs. output characteristics.*

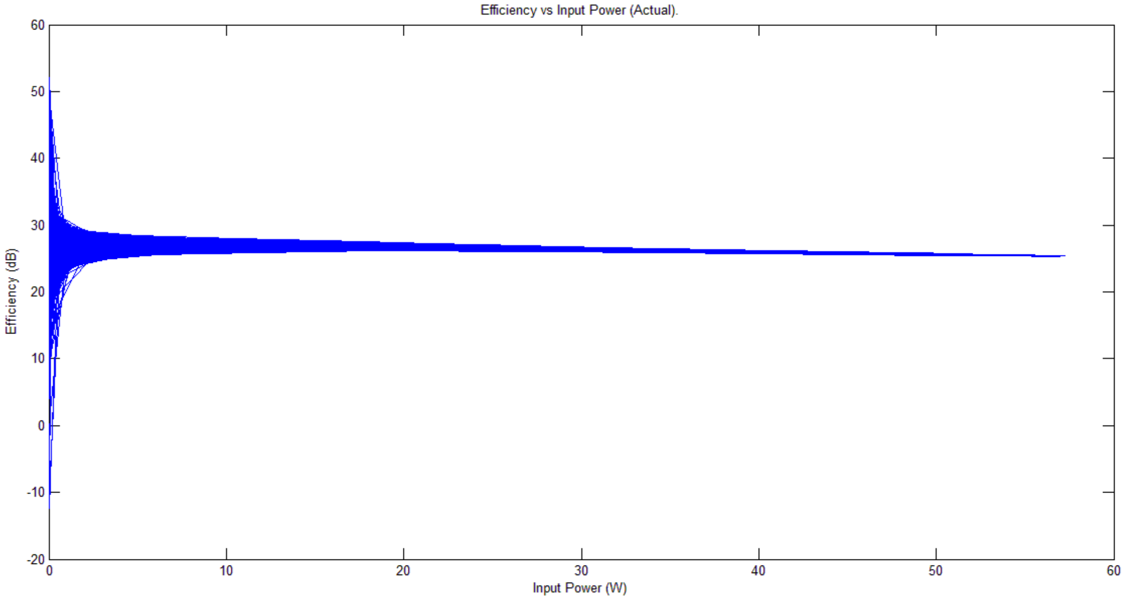


Figure 3: *Efficiency of actual PA*

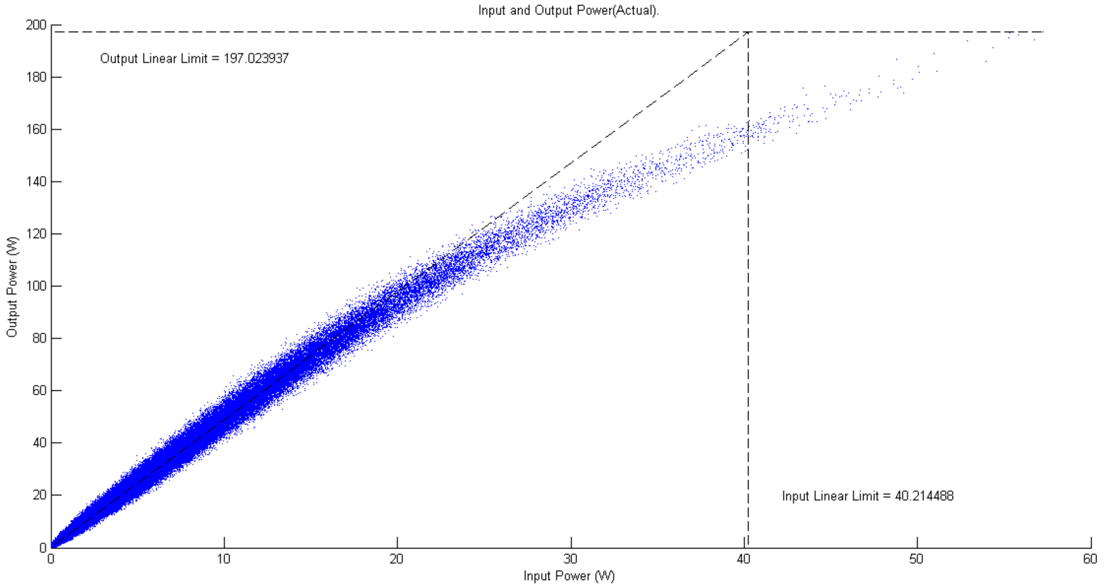


Figure 4: *Calculation of linear limit of PA characteristics.*

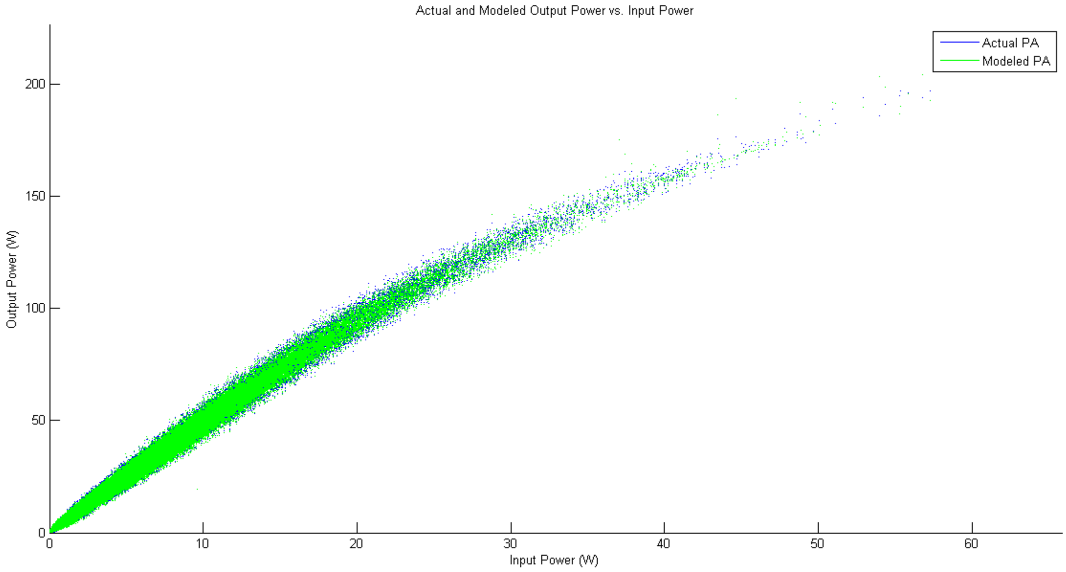


Figure 5: *Characteristics of Actual PA and Modeled PA*

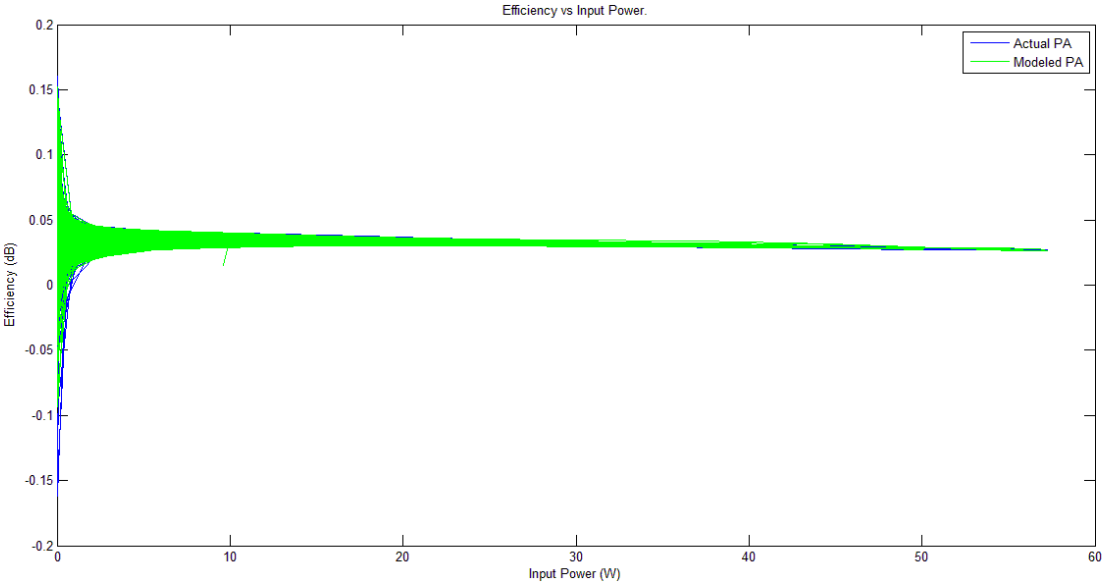


Figure 6: *Efficiency of Actual PA and Modeled PA*

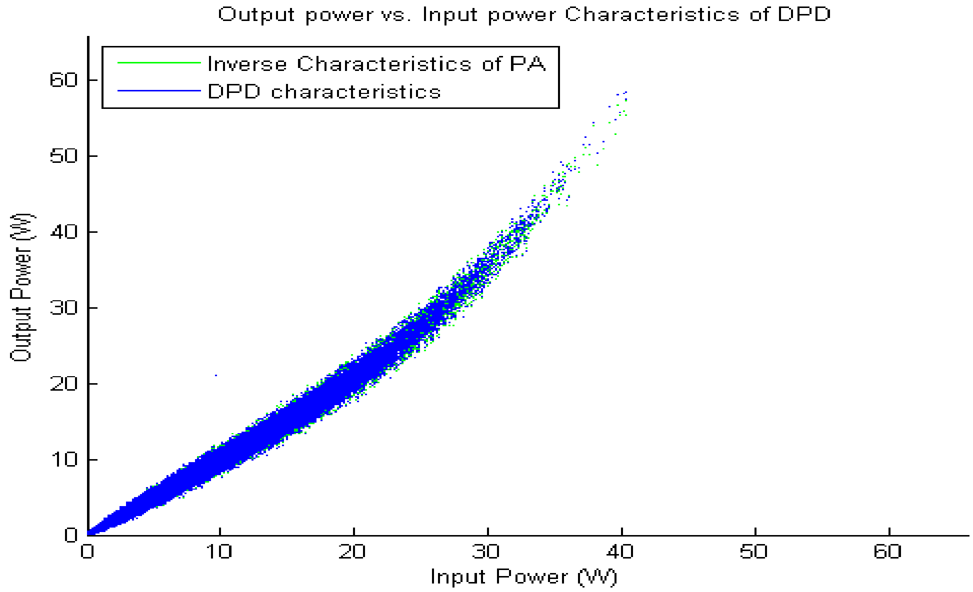


Figure 7: *Characteristics of Actual DPD and Modeled DPD*

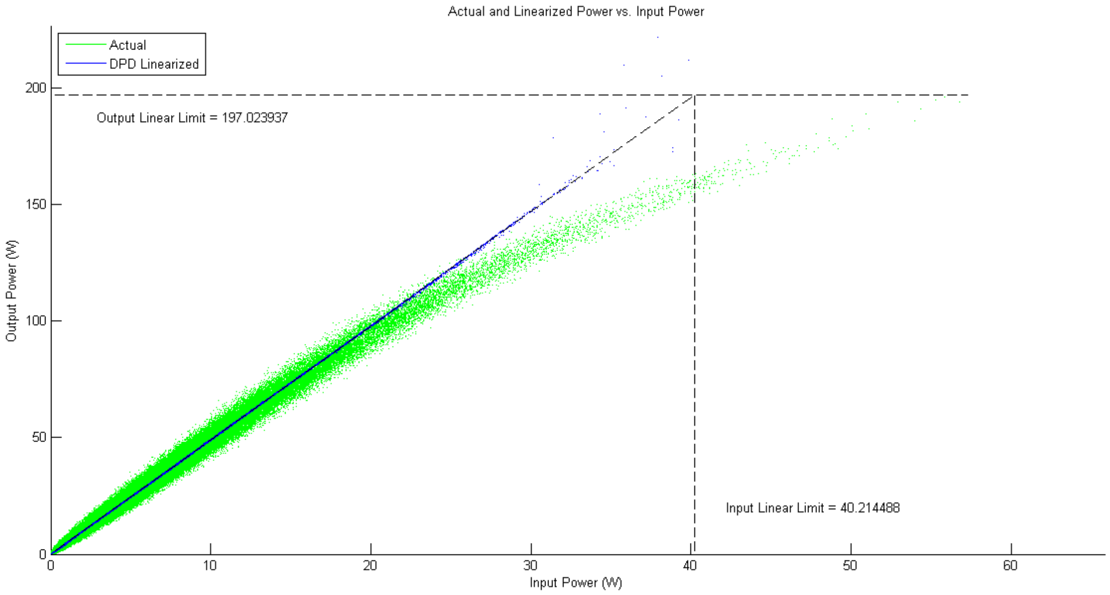


Figure 8: *Combined AM-AM response*

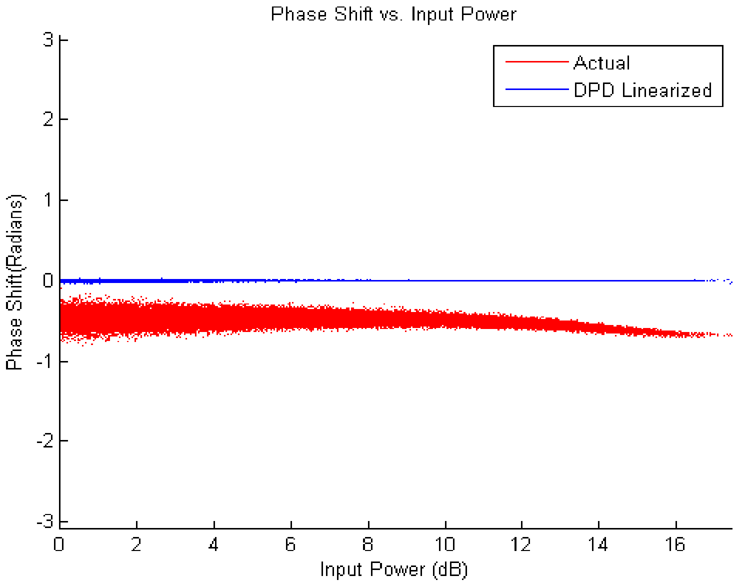


Figure 9: *Combined AM-PM response*

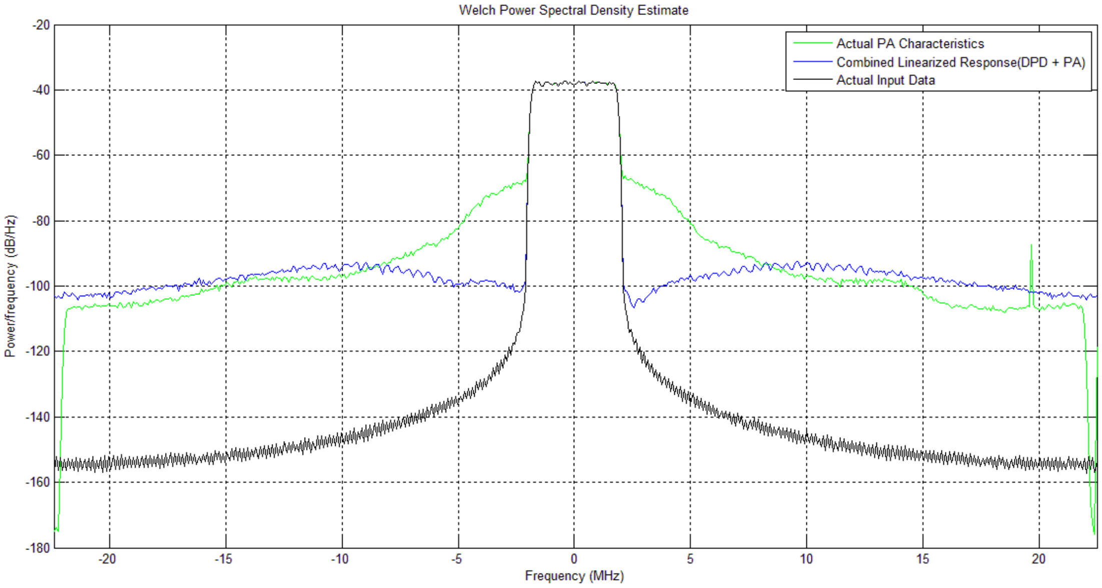


Figure 10: *Spectrum of Input Signal, PA Output Signal and Linearized Signal*

Table 1. EVM and ACLR of Actual and Modelled PA

Parameter	Actual Power Amplifier	Modelled Power Amplifier
EVM (RMS Value)	64.3685 dB	64.6447 dB
ACLR1 (Upper Channel)	-46.5342 dB	-46.6461 dB
ACLR2 (Upper Channel)	-60.7407 dB	-77.0577 dB
ACLR1 (Lower Channel)	-47.0499 dB	-75.3282 dB
ACLR2 (Lower Channel)	-59.4759 dB	-47.1175 dB

Table 2. DPD Coefficients

Memory Polynomial Coefficients of DPD
0.134558084087843 + j0.108564831471696
-0.275201081052892 - j0.165784742472512
0.207523384503554 + j0.0338530094985604
-0.408773169621611 - j0.167115098406856
1.14648137668389 + j0.664830821433609
0.00140201203125858 - j0.000749731126392750
-0.00218830802524235 + j0.000653893183728635
0.000473993357048716 - j0.000932244045857288
8.04356648786980e-05 + j0.00132290577531854
0.00860177127269095 - j0.00593706631926316
-7.08933758645659e-05 + j7.21218746752250e-05
0.000125776365110175 - j8.06281346773247e-05
-6.09756003354214e-05 + j0.000117727271087019
-0.000105560566741262 - j0.000203969549122160
-0.000256388608828436 + j0.000593079472852533
2.32677535597474e-06 - j3.56180814321591e-06
-4.16948049428619e-06 + j4.65163481821385e-06
2.68014417877694e-06 - j5.89012129008320e-06
3.82924522493438e-06 + j1.06995596960390e-05
5.25470583815855e-06 - j2.74691066039030e-05
-5.33769453293540e-08 + j7.94386173581121e-08
1.00069260848886e-07 - j1.25605851455427e-07
-7.50931164186514e-08 + j1.59147511936071e-07
-2.53042638801533e-08 - j2.76583941637853e-07
-1.34691547955575e-07 + j6.22711702810184e-07
4.38960136929868e-10 – j5.43836309106885e-10
-8.66801107079493e-10 + j9.43246775917326e-10
7.42863191336277e-10 - j1.37737933061344e-09
-2.77316024272450e-10 + j2.33281843424163e-09
1.52318554551504e-09 - j4.58501370341012e-09

Table 3. EVM and ACLR of Modelled and Linearized PA

Parameter	**Modelled Power Amplifier**	**Linearized Power Amplifier**
EVM (RMS Value)	64.6447 dB	54.8204 dB
ACLR1 (Upper Channel)	-46.6461 dB	-62.2606 dB
ACLR2 (Upper Channel)	-77.0577 dB	-74.3350 dB
ACLR1 (Lower Channel)	-75.3282 dB	-74.9568 dB
ACLR2 (Lower Channel)	-47.1175 dB	-62.1608 dB

References

[1] J. Cavers: Amplifier linearization using a digital predistorter with fast adaptation and low memory requirements. IEEE Transactions on Vehicular Technology.39, 374-382, (1990)

[2] H. Ku and J. Kenney: Behavioral modeling of nonlinear RF power amplifiers considering memory effects. IEEE Transactions Microwave Theory and Techniques. 51, 2495-2504, (2003)

[3] L. Ding: Digital predistortion of power amplifiers for wireless applications. Georgia Institute of Technology, 2004.

[4] M. Faulkner, T. Mattsson and W. Yates: Automatic adjustment of quadrature modulators. IEEE Electronics Letters. 27, 214, (1991)

[5] Stapleton, S. (2001) Amplifier Linearization Using Adaptive Digital Predistortion. Applied Microwave & Wireless.13, 72-77.

[6] O. Hammi, S. Boumaiza, M. Jaidane and F. Ghannouchi: Baseband digital predistortion using subband filtering technique. IEEE MTT-S International Microwave Symposium Digest, (2003)

[7] L. Ding, G. Zhou, D. Morgan, Z. Ma, J. Kenney, J. Kim and C. Giardina: A Robust Digital Baseband Predistorter Constructed Using Memory Polynomials. IEEE Transactions on Communications.52, 159-165, (2004)

[8] P. Varahram, Z. Atlasbaf and N. Heydarian: Adaptive Digital Predistortion for Power Amplifiers Used in CDMA Applications. 2005 Asia-Pacific Conference on Applied Electromagnetics.

[9] R. N. Braithwaite: Wide bandwidth adaptive digital predistortion of power amplifiers using reduced order memory correction. 2008 IEEE MTT-S International Microwave Symposium Digest.

[10] H. Jiang and P. A. Wilford: Digital predistortion for power amplifiers using separable functions. IEEE Transactions on Signal Processing 58, 4121-4130, (2010)

[11] M. Rawat, K. Rawat and F. Ghannouchi: Adaptive Digital Predistortion of Wireless Power Amplifiers/Transmitters Using Dynamic Real-Valued Focused Time-Delay Line Neural Networks. IEEE Transactions on Microwave Theory and Techniques 58, 95-104.

[12] A. S. Sappal, M. S. Patterh and S. Sharma: Fast complex memory polynomial-based adaptive digital predistorter. International Journal of Electronics.98, 923-931, (2011)

[13] D. Morgan, Z. Ma, J. Kim, M. Zierdt and J. Pastalan: A Generalized Memory Polynomial Model for Digital Predistortion of RF Power Amplifiers. IEEE Transactions on Signal Processing 54, 3852-3860.

[14] K. Hyunchul and J.S. Kenney: Behavioral Modeling of Nonlinear RF Power Amplifiers Considering Memory Effects. IEEE Transactions on Microwave Theory and Techniques, 51(2013).