Published in AJSE, Vol: 24, Issue:1
Received on 20th October 2024
Revised on 21st April 2025
Published on 31th October 2025

AIUB JOURNAL OF SCIENCE AND ENGINEERING
ISSN: 1608 - 3679 (print) 2520 - 4890 (Online)
https://doi.org/10.53799/rg403m16

A Novel Linearization Technique for RF Power Amplifiers Combining Predistortion and Feedforward Linearizers

Protik P. Sheikh, Muhibul H. Bhuyan, Sadman S. Alam, M. Tanseer Ali, and Abu Shufian

***Abstract*—This paper presents a hybrid linearization technique for improving the performance of Class E radio frequency (RF) power amplifiers (PAs). The method combines feedforward and adaptive RF/digital predistortion to reduce nonlinear distortion without a significant reduction in power-added efficiency (PAE). The proposed approach achieves a reduction of 12.7% in harmonic distortion at 1.22 GHz. Simulation results, carried out using Agilent ADS, show improvements in third-order intermodulation distortion (IMD3), input third-order intercept point (IIP3), and output third-order intercept point (OIP3). Comparative analysis demonstrates that this technique provides superior linearity enhancement compared to conventional analog predistortion. While the results are simulation-based, this work highlights the trade-off between linearity and efficiency.**

***Index Terms*—Power Amplifier (PA), Class E, Distortion, Linearization, Feedforward, Power Added Efficiency (PAE), Predistortion.**

I. Introduction

Analog circuit designers have long been concerned with analyzing and predicting the nonlinear behavior of electronic circuits. The rise in popularity of portable electronics, such as cell phones and cordless phones, has emphasized the importance of addressing these issues. Today, there is a growing requirement to anticipate and enhance the distortion characteristics of various electronic circuit setups, like gigahertz-frequency power amplifiers (PAs), which are frequently influenced by nonlinear reactive factors [1]. Nevertheless, designers of radio frequency power amplifiers (RFPAs) for contemporary wireless communication systems encounter a challenging dilemma when dealing with these critical issues [2]. The dilemma revolves around the fact that even though wireless systems necessitate exceptionally linear PAs, introducing linearity comes at the cost of decreasing their power efficiency [3].

Efficiency is a sought-after quality in numerous wireless systems since it minimizes the energy lost as heat, resulting in cost savings and enhanced reliability. Improved efficiency in mobile devices has the potential to extend battery life. In most wireless devices, the RF power amplifier typically consumes a substantial portion of the overall power, making it worthwhile to focus on achieving high efficiency in this component [4].

In wireless systems, highly linear power amplifiers are required in the base station and repeaters [5]. The fundamental concept of linearity in a communication system revolves around its capacity to transmit data at the maximum achievable rate without undergoing distortion [2]. Among all the categories of power amplifiers, class E power amplifier operates with very high-power efficiency but has nonlinear characteristics [6].

Therefore, the aim of this research work is to study the high frequency power amplifiers and then device a novel technique to reduce the distortion levels by a big margin so that the class E PA can operate at a very high frequency with higher power output and higher efficiency.

The remaining part of the paper is prepared in sequence as, section II reviews literature papers on power amplifier design and its linearity issues, section III describes working methodology and simulation techniques, section IV presents simulation results and explains the outcomes of this research along with comparative study with the published data, and finally, the section V concludes the papers with final remarks and mentions future research directions.

II. Literature Review

The industry requirements for manufacturing radio frequency power amplifiers (RF PAs) are good linearity and higher power efficiency. It seems like a contradiction between these two requisites [7]. However, these can be achieved if an external circuit is employed with the power amplifier [8]. There are several types of power amplifiers. In the RF regime, several classes, like D, E, and F power amplifiers are used [2, 9]. The chief characteristics of a class E power amplifier are higher efficiency and larger distortions than the other amplifiers. Researchers have proved that at least theoretically high efficiency around 100 % may be achieved for class D, E, and F power amplifiers [10]. However, linearity has become a key issue in designing and characterizing an RF power amplifier. However, with the advancement of modulation techniques, the linearization of an amplifier is becoming easier [11].

Protik P. Sheikh is with the Department of EEE, American International University-Bangladesh, Dhaka. (e-mail: protik@aiub.edu).
Muhibul H. Bhuyan is with the Department of EEE, American International University-Bangladesh, Dhaka. (e-mail: muhibulhb@aiub.edu).
Sadman S. Alam is with the Department of EEE, American International University-Bangladesh, Dhaka. (e-mail: sadman.alam@aiub.edu).
M. Tanseer Ali is with the Department of EEE, American International University-Bangladesh, Dhaka. (e-mail: tanseer@aiub.edu).
Abu Shufian is with the Department of EEE, American International University-Bangladesh, Dhaka. (e-mail: shufian.eee@aiub.edu).

Many researchers have focused on creating more effective power amplifiers using several methods. They proved that the power efficiency of existing PAs may be upgraded at the expense of the linearity of the amplifiers, which is not accepted by industry people. As such, the current technique is to design a moderately linear PA by adding an extra technique so that the PA behaves linearly [12-14]. To boost efficiency, the power amplifier needs to be operated near the saturation region to have enhanced spectral efficiency in this region.

III. Methodology and Modeling

The general structure of an adaptive feedforward linearizer associated with an adaptive RF or digital predistorter is depicted in Fig. 1. This configuration integrates a complex memory polynomial-based adaptive RF or digital predistortion technique. The RF predistorter is positioned within the signal cancellation loop of the feedforward linearizer. It includes a gain adjuster, which is complex and manages both the amplitude and phase angle of the incoming signal. This predistorter relies on a functional approach that interpolates the inverse AM/AM and AM/PM nonlinearities of the PA. An envelope detector is utilized to extract the incoming amplitude modulation, which is then fed into the polynomial work function. The predistorter coefficients are adapted employing the error signal from the signal cancellation loop of the feedforward linearizer. Embedding the RF predistorter within the feedforward linearizer offers several benefits, including a reduction in the intermodulation distortion (IMD) requirements for the feedforward loop alone. This reduction decreases component sensitivities across the frequency range, ultimately leading to an enhancement in the overall efficiency of the PA.

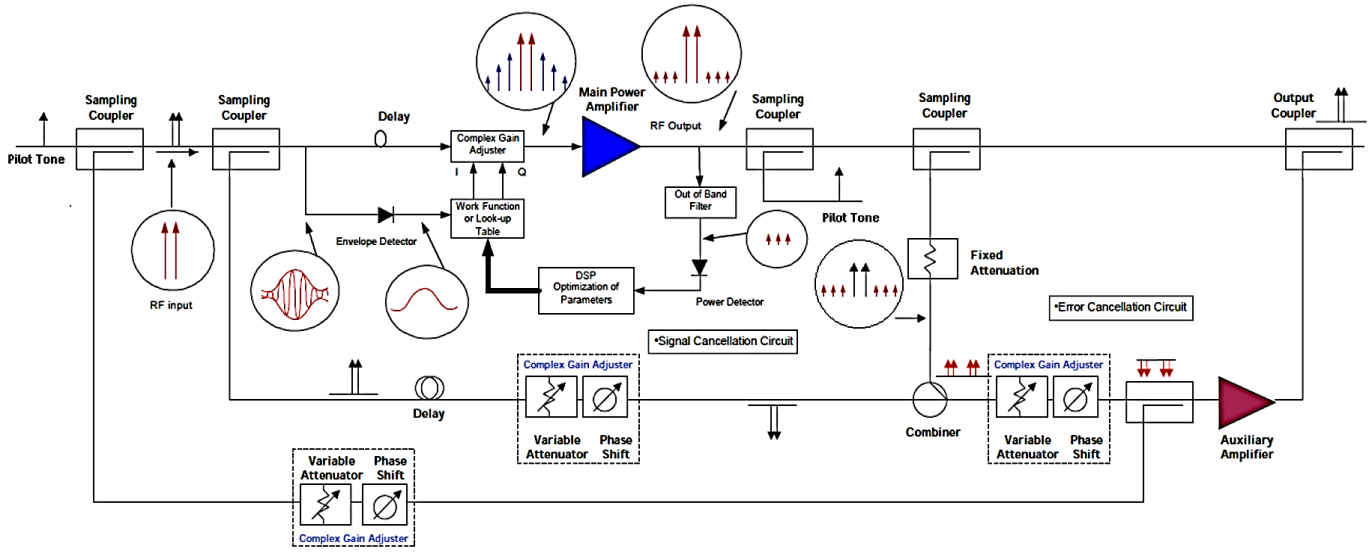


Fig. 1. General architecture of feedforward linearizer combined with adaptive RF/digital predistorter.

A. Operations

Two-tone signals are used as input, and pilot tones are utilized to fine-tune the coefficients in both loops of the system. A pilot tone is inserted at the beginning of the feedforward linearizer and monitored at the output of the signal cancellation loop. The primary intention of the main pilot tone is to ensure efficient minimization of the fundamental component in the signal. As a result, the remaining signal mainly contains distortion caused by the power amplifier (PA). Additionally, a second pilot tone is introduced into the upper branch of the initial loop and observed at the output of the feedforward linearizer. This second pilot tone is intended to optimize the reduction of distortion produced by the PA through the error cancellation loop. An effective strategy for optimizing the coefficients is to reduce the adjacent channel power at the error port [15].

When we expose the input to a two-tone signal, we examine how the spectral response behaves at different points within the RF predistorter integrated into the signal cancellation circuit, as illustrated in Fig. 1. In this configuration, the lower section incorporates an envelope detector to capture the amplitude modulation of the RF signal input. At the same time, the upper section includes a delay element that compensates for the time required for the work function. Once finely tuned, the complex gain adjuster generates a pre-distorted signal to counteract the nonlinear characteristics of the power amplifier. Ideally, the intermodulation products should have the same amplitude, but opposite phases compared to those generated as the two tones traverse the power amplifier. Furthermore, a filter located in the branch at the power amplifier's output monitors the interference power in adjacent channels (ACPI), measures its level, and transmits this data to the digital signal processor (DSP). Subsequently, the DSP adjusts the work function parameters to minimize ACPI [16-17].

The output of the RF predistorter is coupled, and the fundamental two tones are attenuated to the level of the input signal and combined with the output of the lower branch, where the input signal is inverted by a phase angle of 180^0, leaving only the error signal. The error signal generated by the signal cancellation circuit of feedforward linearizer is then fed to the error cancellation circuit of the feedforward linearizer where first the error signal is inverted again by a phase angle of 180^0 by using complex gain adjuster and then amplifying it with an

auxiliary amplifier to amplify the error signal to the similar state of the error generated by the PA and finally combining this signal with the RF predistortion output to remove the IMD products as shown in Fig. 1.

B. Parameterization of Components and Simulation Controls

In this sub-section, the parameter defined for the components and the parameter sweep and optimization declaration of certain parameters are shown. In Fig. 2, it is shown that the values of the variables are defined in a variable box available in the Advanced Design System (ADS) software. We used two variable boxes to define our variables. The first variable box named VAR1 is used to define definite variables, and the second variable box named VAR3 is used to define variables that will undergo iteration for optimization.

Variables	Values	Variables	Values
RFfreq	1.22 GHz	Alpha_5th	-0.0
Delta	100 MHz	Beta_5th	-0.0
Delta_Pilot1	350 MHz	Alpha_I	0:597
Delta_Pilot2	-350 MHz	Alpha_Q	0.141
Pavs	13 dBm	Beta_I	0.639
P_Pilot1	-50 dBm	Beta_Q	0.0000213
P_Pilot2	-50 dBm	Gamma_I	0.250
Group Delay_Env	0.1	Gamma_Q	0.069
Alpha_3rd	-0.0	Group_Delay_Loop	0.3415e-9
Beta_3rd	0.0		

Fig. 2. Variables defined for the feedforward combined with RF/digital predistortion linearization technique.

In VAR1, we have defined the values of RFfreq, Delta, Pavs, Delta_Pilot1, Delta_Pilot2, P_Pilot1, P_Pilot2, and Group_Delay_Env. The fundamental center frequency is defined as a variable called RFfreq, which has a value of 1.22 GHz. Next, the spacing between the two fundamental tones and the fundamental center frequency used in the two-tone test is defined as a variable called Delta, which has a value of 100 MHz. The spacing between the center frequency and the pilot tones is defined as a variable called Delta_Pilot1 and Delta_Pilot2, which have a value of +350 MHz and 350 MHz, respectively. The average power of the fundamental tone, pilot tone 1, and pilot tone 2, are defined as variables called Pavs, P_Pilot1, and P_Pilot2 that have values of 13 dBm, –50 dBm, and –50 dBm, respectively. The group delay of the envelope is defined as a variable named Group_Delay_Env, which has a value of 0.1 ns.

In VAR3, the values of Alpha_3rd, Alpha_5th, Betay_3rd, Beta_5th, Apha_I, Beta_I, Gamma_I, Gamma_Q, and Group_Delay_Loop are defined. In the RF predistortion linearization circuit, we have used four complex gain adjusters that are X2, X3, X4, and X5 as their instance names. The values of Alpha_I and Alpha_Q are the DC inputs of the complex gain adjuster (X3) that need to be optimized so that the complex gain adjuster (X3) can align the input signal in terms of both magnitude and phase with the reference signal. The values of Beta_I and Beta_Q are the DC inputs of the complex gain adjuster (X4), and the magnitudes of Gamma_I and Gamma_Q are the inputs of the complex gain adjuster (X5). The values of Beta_3rd and Beta_5th are the inputs for the coefficients of the non-linear voltage-controlled voltage source (VCVS) with an instance name of VSRC4 in the polynomial work function section of the RF predistortion linearization circuit. The values of Alpha_3rd and Alpha_5th are the inputs for the coefficients of the non-linear voltage-controlled voltage source (VCVS) with an instance name of VSRC6 in the polynomial work function of the RF predistortion linearization circuit. Thus, besides setting the starting values of Alpha_I and Alpha_Q, a range of values is defined in which the ADS simulator will iterate to get more accurate values for them.

In Fig. 3, the optimization is configured using harmonic balance and optimization instances. In the harmonic balance (HB1) setup, parameters for the fundamental frequency and pilot tones are defined. The maximum IMD product or the maximum generated harmonics to be swept are defined up to the 5th harmonic for the IMD product and the 1st harmonic for the pilot tones.

HARMONIC-BALANCE		OPTIM	
Variables	Values	Variables	Values
Freq[1]	RFfreq - Delta	Optim_Type	Gradient
Freq[2]	RFfreq + Delta	ErrctForm	L2
Freq[3]	RFfreq + Delta_Pilot1	Maxters	10
Freq[4]	RFfreq + Delta_Pilot2	FinalAnalysis	"None"
Order[1]	5	NormalizeGoals	no
Order[2]	5	UpcateDataset	yes
Order[3]	1	SaveNominal	yes
Order[4]	1	SaveAlliterations	yes
		UseAllOptVars	yes
		UseAllGoals	yes
		SaveCurrentE F	no

Fig. 3. Optimization parameters and goals of the feedforward combined with RF/digital predistortion linearization technique simulator.

Nominal optimization, often referred to as performance optimization, employs iterative simulations to attain user-defined objectives by automatically adjusting certain simulation design parameters within specified user-defined ranges. The general optimization parameters, such as the type of optimization that is GRADIENT in our case, and the other parameters, such as the maximum number of iterations, which is set to 10, is also defined in the OPTIM instance named Optim1. Under these general optimization parameters, there are three different optimization goals. The three optimization goals are OptimGoal4, OptimGoal5, OptimGoal6, OptimGoal7, and OptimGoal8. Another control parameter is called the Pfc, which is used to measure the rms power of one frequency component of a harmonic balance waveform. The five Pfcs used are Pfc1, Pfc2, Pfc3, Pfc4, and Pfc5, as shown in Fig. 2, and are used to find the rms power of Pilot1, Pilot2, Pilot3, 5th harmonic, and 3rd harmonic, respectively.

IV. Simulation and Results

The schematic diagram of the feedforward linearizer merged adaptive RF/digital predistortion technique, implemented in Advanced Design System (ADS) software, is shown in Fig. 4. This design was derived from the general architecture of Fig. 1.

For the simulation of adaptive feedforward linearization, there are a few simulation software. In our work, we have used ADS to show the simulation outcomes of the Class E power amplifier by implementing the adaptive feedforward linearization techniques. ADS is an electronic design automation software from Agilent. It gives an integrated design environment (IDE) to design RF electronic circuits and systems, such as mobile phones, pagers, wireless network devices, satellite communications, radar systems, and high-speed data links.

Using Agilent ADS, a circuit designer can draw schematic captures, layouts, frequency-domain and time-domain circuit simulations, and electromagnetic field simulations. It allows the engineers to design, characterize, simulate, and optimize an RF circuit or system without modifying design software [18].

Since we aim to analyze the non-linear characteristics of the class E PA and then optimize its harmonic distortion components by using this new approach of linearization, a basic class E PA was inserted into the hierarchy of the power amplifier symbol labeled as “Class E Power Amplifier” in Fig. 4. The value of the frequency spacing between the two fundamental frequencies was set to 200 MHz. Two pilot tones, one at 350 MHz and another at –350 MHz, were also included in this simulation.

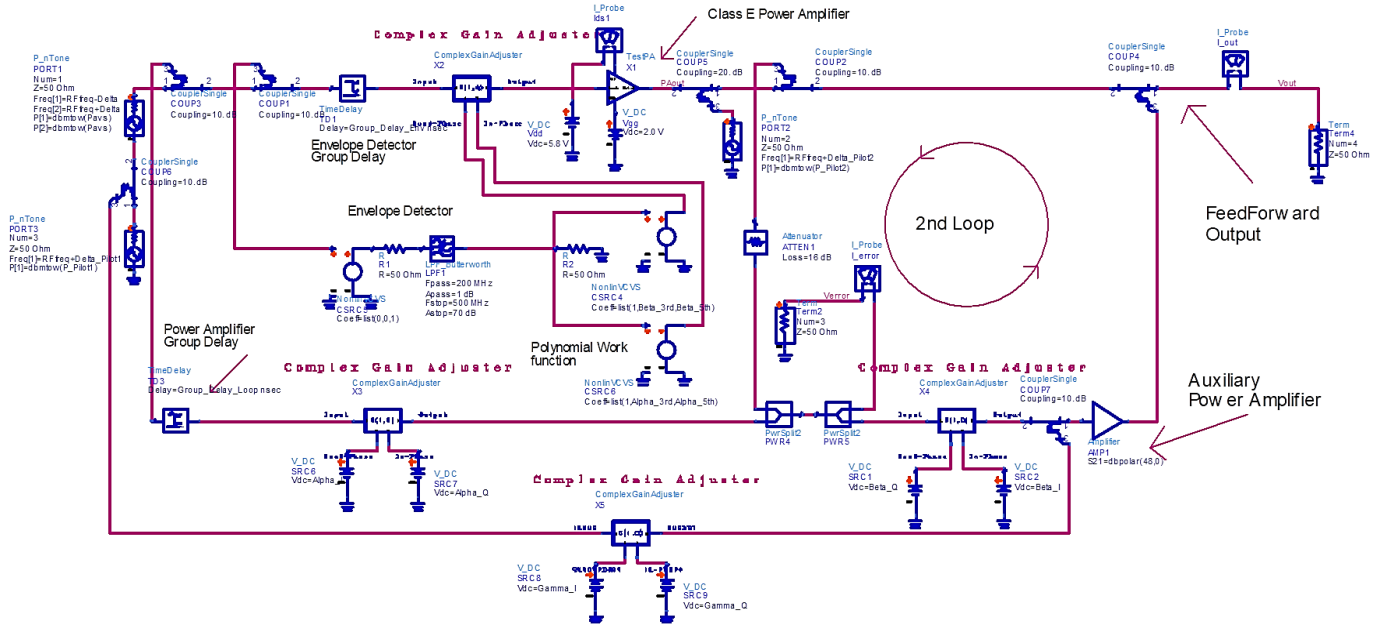
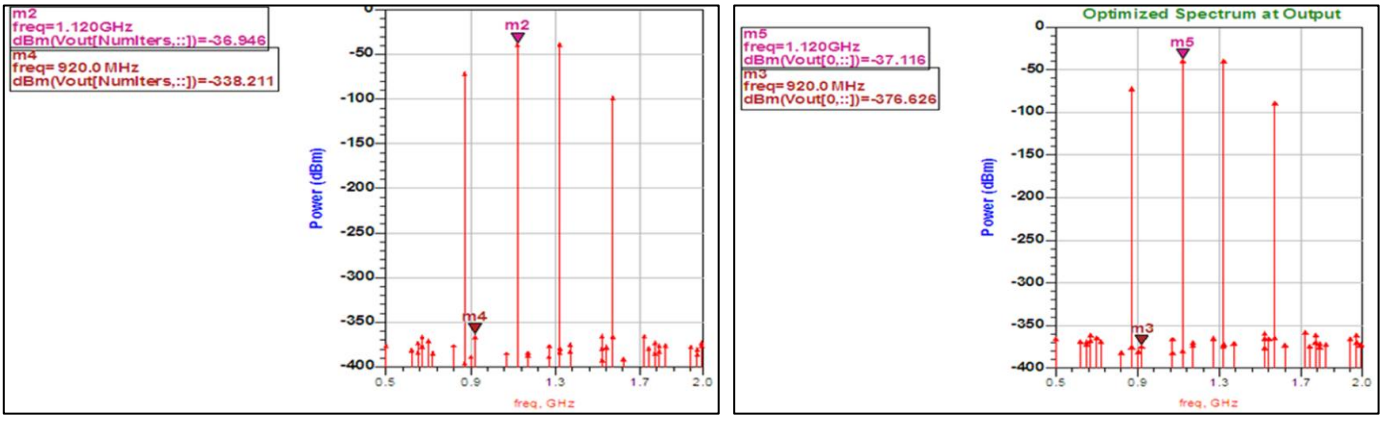


Fig. 4. Feedforward linearizer combined with adaptive RF/digital predistorter schematic as seen in ADS.

A. *Spectral Analysis*

The spectrum of Fig. 5 (a) shows the output of class E PA. The difference between m2 and m4, which is known as IMD3, is calculated as 301.265 dBm. The spectrum of Fig. 5 (b) shows the output of the class E PA after feedforward combined with adaptive RF predistortion linearization. The difference between m5 and m3 (IMD3) is calculated as 339.51 dBm. The IMD3 has increased by 38.245 dBm, which indicates that linearization has been achieved.



(a) Initial spectrum at output, (b) Optimized spectrum at output

Fig. 5. Spectral analysis before and after feedforward combined with adaptive RF predistortion linearization of the class E PA.

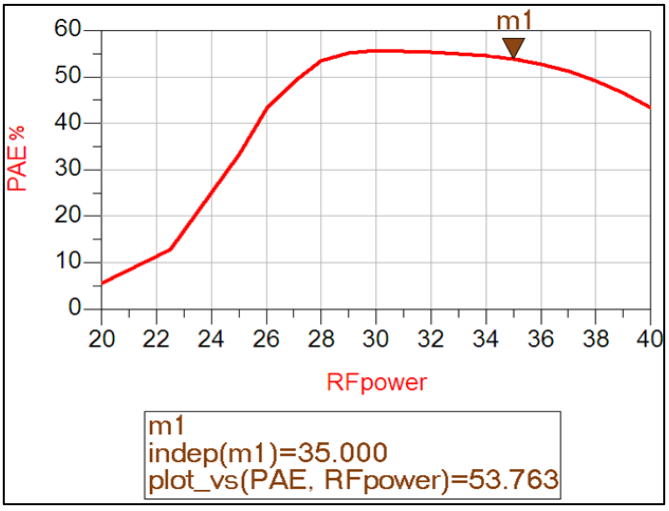
B. *Power Added Efficiency*

The ADS software uses Eq. 1 to calculate the power-added efficiency (PAE) of the class E power amplifier before and after the feedforward, combined with the adaptive RF/digital predistortion linearization technique.

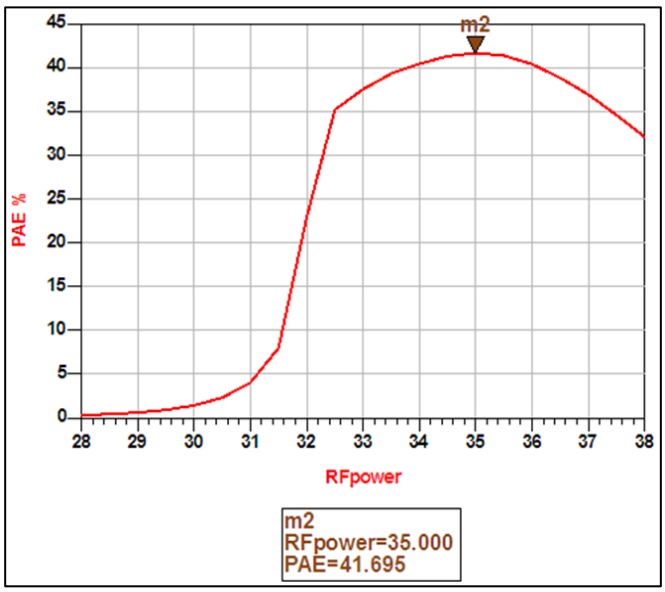
$$PAE = \frac{P_{RFout} - P_{RFin}}{P_{DCtotal}} \quad (1)$$

The power-added efficiency curve of the class E PA before it was linearized by the feedforward, combined with the adaptive RF/digital predistortion method, is shown in Fig. 6 (a). At an operating frequency of 1.22 GHz, we get a maximum efficiency of about 55% for an input power of 30 dBm. Since class E PA is the most efficient among all the other classes of power amplifiers, theoretically, the power-added efficiency should have been much higher. We would expect a very high efficiency (about 70%), but we are limited by the transistor's characteristics, which gives us a maximum efficiency of 55% where input power is 30 dBm in class E operation. The marker m1 in Fig. 6 (a) denotes the point at which the PAE of class E PA is 53.763% at an input power (RF power) of 35 dBm.

The power-added efficiency curve of the class E PA after it was linearized by the feedforward, combined with the adaptive RF/digital predistortion linearization method, is shown in Fig. 6 (b). At our operating frequency of 1.22 GHz, we get a maximum efficiency of 41.695% for an input power of 35 dBm, as indicated by the marker m2. It is seen that the PAE of the class E PA decreased from 53.763% to 41.695% after linearization at an input power of 35 dBm. A decrease in PAE by 22.45% indicates that there is a trade-off between linearization and efficiency. If we want to improve the spectral efficiency of a power amplifier by suppressing its intermodulation distortion components, we must sacrifice some power-added efficiency. This was the case in our optimization of the class E PA by using this new linearization technique. Though we were able to linearize the class E PA by 38.245 dBm, we had to lose 22.45% of the power-added efficiency.



(a) Before linearization

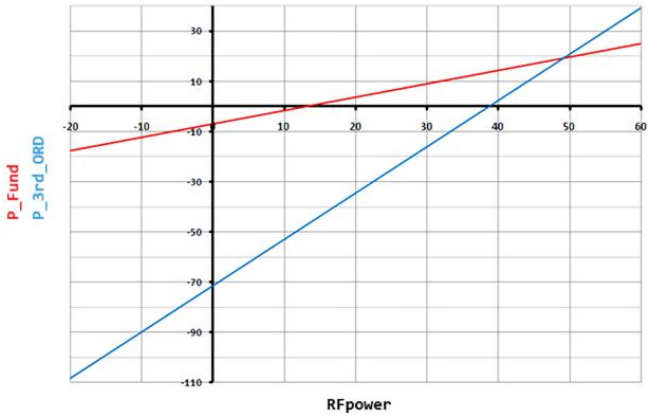


(b) After linearization

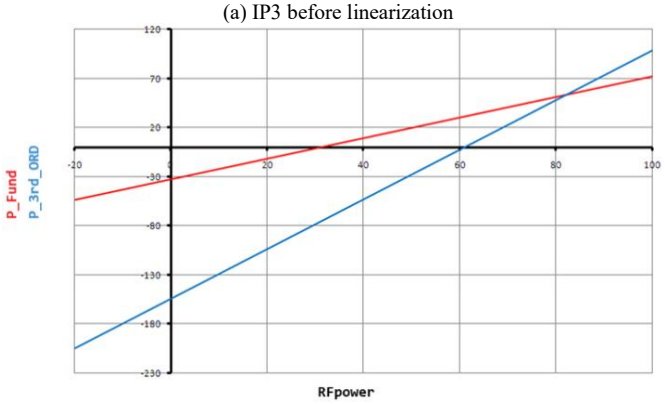
Fig. 6. Power-added efficiency curve of the class E PA before and after feedforward combined with adaptive RF/digital predistortion linearization.

C. *Third Order Intercept Point (IP3)*

In Fig. 7, the red colored curve corresponds to the fundamental component, and the blue colored curve corresponds to the 3rd-order nonlinear component.



(a) IP3 before linearization



(b) IP3 after linearization

Fig. 7. P_{out} vs P_{in} graph to determine the IP3 point before and after feedforward combined with adaptive RF/digital predistortion linearization.

It is seen that both curves meet at a certain point where the third-order signal power is equal to the fundamental component, and it is termed IP3. If the IP3 is taken from the output axis, it is named the output third-order intercept point (OIP3). If the reading is taken from the input axis, then it is called the input third-order intercept point (IIP3). The simulation results of the IP3 curve showed a rise in OIP3 and IIP3 values by 38 dBm and 34 dBm, respectively. This increase in the OIP3 and IIP3 points indicates that the linearity of the class E PA after feedforward, combined with an adaptive RF/digital predistortion linearization technique, improved.

D. Comparative Analysis

The ADS software simulation results are tabulated in Tables I and II to show the superiority of our simulation results of various parameters of the RF power amplifier. Table I shows a comparison of the 3rd-order intermodulation distortion (IMD3) and power-added efficiency (PAE) results before and after the linearization of a Class E power amplifier using a combination of feedforward and adaptive RF/digital predistortion techniques. In terms of IMD3, before linearization, the value was 339.51 dBm. After applying linearization, the IMD3 value reduced to 301.265 dBm, indicating a sizable enhancement in reducing distortion.

Conversely, power-added efficiency (PAE) shows a reduction after linearization. Initially, the PAE was 53.763%, and following linearization, it dropped to 41.695%. This suggests that the linearization process not only effectively reduces distortion but also results in a decrease in efficiency. Linearization improves signal linearity (IMD3), but this comes at the cost of reduced efficiency (PAE).

TABLE I
COMPARATIVE RESULTS OF IMD3 AND PAE BEFORE AND AFTER LINEARIZATION

Technique	Before Linearization		After Linearization	
	IDM3 **(dBm)**	***PAE*** **(%)**	***IDM3*** **(dBm)**	***PAE*** **(%)**
Feedforward combined with adaptive RF/digital predistortion linearization	339.51	53.763	301.265	41.695

Table 2 provides a comparative analysis of output third-order intercept point (OIP3) and input third-order intercept point (IIP3) values before and after linearization for two different methods, viz., analog predistortion linearization done in [6], and feedforward combined with adaptive RF/digital predistortion linearization used in our study.

For OIP3, the analog predistortion method showed an improvement from 35.45 dBm before linearization to 41.77 dBm after linearization, indicating a moderate enhancement in linearity. In contrast, our method yields a more significant improvement, with OIP3 increasing from 19 dBm before linearization to 57 dBm after linearization, demonstrating a much larger improvement in terms of linearity.

Similarly, in terms of IIP3, the analog predistortion method of [6] resulted in an increase from 20.45 dBm to 36.77 dBm after linearization. Our method shows substantial progress with IIP3 rising from 48 dBm to 82 dBm.

The linearization method used in our paper achieves far greater improvement in both OIP3 and IIP3 values compared to the results of [6] with the analog predistortion linearization method, indicating a superior enhancement of linearity in our approach.

TABLE II
COMPARATIVE RESULT ANALYSIS OF OIP3 AND IIP3 BEFORE AND AFTER LINEARIZATION BETWEEN THIS WORK AND REFERENCE PAPER

Reference	Before Linearization		After Linearization	
	IIP3 **(dBm)**	***OIP3*** **(dBm)**	***IIP3*** **(dBm)**	***OIP3*** **(dBm)**
[6]	20.45	35.45	36.77	41.77
This work	48	19	82	57

In addition to the comparisons with analog predistortion, a comparative analysis was conducted against a Class-E Doherty amplifier utilizing a g_m3 cancellation method [18], which achieved an IMD3 improvement of 11 dB while maintaining a high power-added efficiency (PAE) of 50.2%. As shown in Table III, the proposed hybrid feedforward-predistortion technique achieves a dramatically higher IMD3 improvement of 38.25 dB, underscoring its superior effectiveness in linearity enhancement. This significant performance gain, while resulting in a lower final PAE of 41.70%, highlights the fundamental trade-off between linearity and efficiency and establishes the proposed technique as the superior solution for applications where minimizing distortion is the main objective.

TABLE III
PERFORMANCE COMPARISON BETWEEN THIS WORK AND CLASS-E DOHERTY AMPLIFIER

Parameter	This work	[18]
IMD3 Improvement	38.25 dB	11 dB
Final PAE	41.70%	50.2%

V. CONCLUSIONS

The class E power amplifier (PA) was linearized in the ADS software by using the adaptive approach of the feedforward, combined with the adaptive RF/digital predistortion linearization technique. The simulation results with satisfactory outcomes proved the feasibility of this technique. The spectral analysis of the feedforward combined with the adaptive RF/digital predistortion linearization technique showed an improvement of the IMD3 value by 38.245 dBm without any alterations of the desired fundamental responses. The power-added efficiency (PAE) is decreased by 22.45% which indicates that there is a trade-off between linearization and efficiency in this technique. The simulation results of the IP3 curve showed a rise in OIP3 and IIP3 values by 38 dBm and 34 dBm, respectively. After considering all the results, we can see that a large decrease in PAE was accompanied by a notable improvement in the linearity in terms of IMD3 and IP3 for the Class E power amplifier (PA). The hybrid feedforward–predistortion technique introduces additional circuit complexity due to dual loops, but this is mitigated by the adaptability of the predistorter, and group delay compensation is explicitly included in the design to address timing misalignments.

VI. Limitations And Future Works

The present work focused on demonstrating the feasibility of a hybrid feedforward–predistortion technique for linearizing Class E power amplifiers through detailed ADS simulations. While the results confirmed significant improvements in linearity with manageable efficiency trade-offs, future research will extend this work in several directions. These include experimental hardware implementation to validate the simulation results, incorporation of additional RF performance metrics such as adjacent channel power ratio (ACPR) and error vector magnitude (EVM), and evaluation of the approach over wider bandwidths and multiple frequency points. Furthermore, future studies will explore circuit complexity, delay, and adaptability considerations in greater depth to assess suitability for real-time wireless communication systems.

Acknowledgment

The authors sincerely express their gratitude to the Department of Electrical and Electronic Engineering and the management of the American International University-Bangladesh for their invaluable support, providing access to laboratory and computer facilities, and offering expert guidance during this research period.

References

[1] P. Wambacq and W. Sensen, "Distortion Analysis of Analog Integrated Circuits," Boston: Kluwer Academic Publishers, 1998.

[2] M. H. Bhuyan, "RF Semiconductor Devices Technology: History and Evolution, Prospects and Opportunities, Current and the Future," Southeast University Journal of Science and Engineering (SEUJSE), ISSN: 1999-1630, vol. 12, no. 2, December 2018, pp. 28-39.

[3] M. L. Rahman and M. H. Bhuyan, "Linearization of Voltage-Controlled Oscillator by Microcontroller-Based PLL Frequency Synthesizer," Proceedings of the Conference on Engineering Research, Innovation and Education (CERIE), Shahjalal University of Science and Technology, Sylhet, Bangladesh, 11-13 January 2011, pp. 628-631.

[4] J. L. Dawson, "Feedback Linearization of RF Power Amplifiers," Ph.D. dissertation, Stanford University, Stanford, CA 94305, United States, August 2003.

[5] D. P. Kimber, "Class E Amplifiers and their Modulation Behavior," Ph.D. dissertation, The University of Birmingham, Edgbaston, Birmingham, West Midlands B15 2TT, United Kingdom, December 2005.

[6] P. Sampath and K. Gunavathi, "Class E Power Amplifier and its Linearization using Analog Predistortion," Indian Journal of Engineering and Materials Science, vol. 19, pp. 144-152, April. 2012.

[7] M. M. Ebrahimi, M. Helaoui, and F. M. Ghannouchi, "Trading-off Stability for Efficiency in Designing Switching-Mode GaN PAs for WiMAX Applications," Proc. IEEE Microwave Conference 2009 (APMC 2009), Asia Pacific, pp. 2348–2351, December 2009.

[8] C. L. Larose and F. M. Ghannouchi, "Optimal Adaptation Methods and Class of Operation: Keys to Improving Feedforward Amplifier Power Efficiency," IEEE Transactions on Vehicular Technology, vol. 54, issue 2, 2005, pp. 456–467.

[9] H. Choi, Y. Jeong, C. D. Kim, and J. S. Kenney, "Efficiency enhancement of feedforward amplifiers by employing a negative group-delay circuit," IEEE Trans. Microw. Theory Tech. 2010, vol. 58, pp. 1116–1125.

[10] G. Bhargava and S. Majumdar, "Pre-Distortion: An Effective Solution for Power Amplifier Linearization," in a Book titled RF Circuits For 5G Applications: Designing with mmWave Circuitry, Ch. 12, published on 15 March 2023, DOI: https://doi.org/10.1002/9781119792949.ch12.

[11] A. Borel, V. Barzdėnas, and A. Vasjanov, "Linearization as a Solution for Power Amplifier Imperfections: A Review of Methods," Electronics, MDPI, 1 May 2021, vol. 10, no. 9, 1073, DOI: https://doi.org/10.3390/electronics10091073.

[12] L. Taijun, S. Bumaiza, and F. M. Ghannouchi, "Augmented Hammerstein Predistorter for Linearization of Broad-Band Wireless Transmitters," IEEE Transactions on Microwave Theory and Techniques, vol. 54, issue 4, 2006, pp. 1340–1349.

[13] F. Abbasnezhad, M. Tayarani, A. Abrishamifar, and V. Nayyeri, "A Simple and Adjustable Technique for Effective Linearization of Power Amplifiers Using Harmonic Injection," IEEE Access, vol. 9, March 2021, pp. 37287-37296, DOI: 10.1109/ACCESS.2021.3063286.

[14] X. Fang, A. Chung, and S. Boumaiza, "Linearity-enhanced Doherty power amplifier using output combining network with predefined AM–PM characteristics," IEEE Transactions on Microwave Theory and Techniques, vol. 67, no. 1, pp. 195–204, January 2019.

[15] S. P. Stapleton, "Adaptive Feedforward Linearization for RF Power Amplifiers," Part 2, British Columbia: School of Engineering Science, Canada, 1999.

[16] S. Stapleton, "Agilent EEsof EDA Presentation on RF Predistortion of Power Module 1: RF Predistortion of Power Amplifiers,"

[17] A. S. Sappal, "To Develop a Linearization Technique for Mitigating the RF Power Amplifier's Non-linearity Effects in a Multicarrier W-CDMA Base Station," Punjabi University, 2012, pp. 120-123.

[18] H. Kim, C. S. Cho, J. W. Lee, and J. Kim, "Linearity improvement of class-E Doherty amplifier using gm3 cancellation," Electron. Lett., vol. 44, no. 5, pp. 1–2, Feb. 2008, doi: 10.1049/el:20083536.



Protik Parvez Sheikh received a Bachelor of Science (B.Sc.) in Electrical and Electronic Engineering from American International University-Bangladesh in 2014, and a Master of Science (M.Sc.) in Electronics Engineering from Nanyang Technological University, Singapore in 2015.

From October 2016 to January 2023, he was a Senior Lecturer and Coordinator at Uttara University, Dhaka. From January 2023 to September 2025, he worked as a Senior Lecturer at the Department of Electrical and Electronic Engineering of American International University-Bangladesh. He was promoted to Assistant Professor in October 2025 in the same department.

His expertise spans embedded systems, electronics, semiconductor devices, III-V nitrides, and high-frequency power amplifiers for wireless applications. He has authored and co-authored several research articles and has a deep interest in academic development and coordination.



Prof. Dr. Engr. Muhibul Haque Bhuyan obtained his bachelor's degree of BSc in Electrical and Electronic Engineering (EEE) from the Bangladesh University of Engineering and Technology (BUET) in 1998; a Master's degree in MSc in EEE from BUET in 2002, and finally a doctoral degree of PhD in EEE from BUET in 2011. He obtained the most prestigious Dean's Award and the Dhaka Education Board Scholarship during his undergraduate studies.

He joined the Faculty of Engineering of American International University-Bangladesh as a Lecturer in June 1999, and currently, he is working here as a Professor in the EEE Department since March 2022. He went to Hiroshima University, Japan, as a Researcher under the Center of Excellence Program in 2003. He was the Head of the

Department of Electronics and Telecommunication Engineering at Daffodil International University. He joined as an Associate Professor and Chairperson of the Department of EEE of the Green University of Bangladesh (GUB) in July 2012. He became a Professor in August 2013 and a Proctor in June 2014 at GUB. He joined the Department of EEE at Southeast University in December 2015 and chaired the EEE Department for 5 years. He was appointed by the Honorable President of the People's Republic of Bangladesh as the Treasurer of SEU in November 2018.

He has published over 90 journals and 120 conference papers at home and abroad. He is the co-author of a book.

Prof. Bhuyan is involved in several national and international conferences held at home and abroad as an advisory member, as a session chair, technical committee chair, technical committee member, paper reviewer, judge, etc.

Prof. Bhuyan is a regular Program Evaluator of the Board of Accreditation for Engineering and Technical Education and Academic Auditor of the Bangladesh Accreditation Council.

Prof. Bhuyan is the recipient of the Bangladesh Education Leadership Award from the South Asian Partnership Summit in 2017. This is a Certificate as the Best Professor in Electrical Engineering for demonstrating exemplary leadership.

His research interests include semiconductor device design, modeling, and simulation, VLSI circuits, power electronics, embedded systems design, OBE, engineering education, etc.

He is a Life Fellow (LF) of the Institution of Engineers Bangladesh (IEB); a Life Member (LM) and an Executive Committee (EC) Member of the Bangladesh Electronics and Informatics Society (BEIS). He is a Senior Member of IEEE and a Member of IAS, EDS, etc.



Sadman Shahriar Alam attained his bachelor's degree of BSc in Electrical and Electronic Engineering (EEE) from the American International University-Bangladesh with a 'Magna Cum Laude' academic distinction in the year 2016. Following his undergraduate studies, he pursued and successfully obtained his master's degree in electronic systems design from the Norwegian University of Science and Technology (NTNU) in 2020.

Subsequently, he embarked on his professional journey by joining the esteemed Electrical and Electronic Engineering Department of American International University-Bangladesh as a Lecturer in September 2022 and worked till September 2025. He was promoted to Assistant Professor in October 2025 in the same department.

His academic and professional trajectory has been underscored by a profound interest and expertise in various domains, prominently including Signal Processing, wireless power transfer, and RF engineering. His dedication to advancing knowledge and innovation in these fields manifests in his ongoing research pursuits and contributions to academia.



Dr. M. Tanseer Ali completed his B.Sc. in Electrical and Telecom Engineering from North South University, Dhaka in 2007. Then, he pursued higher studies and received an M.Sc. in Communication Engineering with Distinction from Robert Gordon University, Aberdeen, UK, in 2008. He received a full scholarship from the University of Greenwich, London, UK, for his PhD program. He completed his doctorate in 2013.

Currently, Dr. Ali is working as an Associate Professor at the Department of EEE, Faculty of Engineering, American International University-Bangladesh, Dhaka.

His research interests are in Microwave Circuits and Systems, Antenna Design, Nanoelectronics, CMOS Circuits, VLSI, Analog and Mixed Circuit and IC Design, Quantum Properties of materials, Engineering Education, and Pedagogy.



Abu Shufian received his Bachelor of Science (B.Sc.) in Electrical and Electronic Engineering and his Master of Science (M.Sc.) in Renewable Energy Technology. He started his PhD program in 2023 at the Bangladesh University of Engineering and Technology (BUET). His doctoral research focuses on 'AI-based Advanced Power Systems and Smart Grids'. He is very active in research and has published several journal and conference papers at home and abroad.

He is working as a Lecturer in the Faculty of Engineering at American International University-Bangladesh. He also served as a research assistant in the Advanced Power System research group.

His main research interests include renewable energy, solar PV systems, wind energy, smart grids, power systems, control systems, energy management systems, machine learning, and deep learning.