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Comparative efficiency analysis of RF power amplifiers with fixed bias and envelope tracking bias

Ambily Babu[1], Bangalore Gangadharaiah Shivaleelavathi[2], Veeramma Yatnalli[2]
[1]Department of Electronics and Communication Engineering, CHRIST University, Bengaluru, India
[2]Department of Electronics and Communication Engineering, JSS Academy of Technical Education, Bengaluru, India

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ABSTRACT

RF power amplifier (RF PA) finds its application in almost all the areas of electronics, mobile communication being identified as a major area. The paper performs a comparative efficiency analysis of RF power amplifiers operating with a fixed bias and an envelope tracking bias. Simulations are performed using Keysight advanced design system (ADS) tool. A class a RF PA operating at a 12 dB gain is fixed for the work. 16 QAM LTE signal operating at 5 MHz input frequency, with a peak to average power ratio (PAPR) of 6.0 dB is used as input signal. An envelope simulation at 2.5 GHz is performed on the RF power amplifier. Simulation result shows an improvement of 12% in power added efficiency (PAE) at 6 dB back-off and 6.422% in mean PAE while using envelope tracking power amplifiers, compared to RF PA with fixed supply. Envelope tracking power amplifiers reduced AM/AM distortions also by a factor of 0.248. The results obtained are much better than that obtained using a conventional RF PA with fixed bias. RF PA being the most power dissipative block in a mobile handset, improving its efficiency contributes directly to a great improvement in the battery lifetime of mobile phones. The major challenges faced by envelope tracking PA (ETPA) designers in achieving this efficiency improvement is also delineated in the paper.

Corresponding Author:

Ambily Babu
Department of Electronics and Communication Engineering, CHRIST University
Bengaluru, Karnataka, India
Email: ambily_babu@outlook.com

1. INTRODUCTION

As the mobile phone industry is moving from 4G to 5G, the uplink and downlink data rates has been continuously on the rise. Complex modulation schemes like quadrature phase shift keying and quadrature amplitude modulation are incorporated in the mobile transmitter to cater to the ultra-fast internet and multimedia experience for customers. This resulted in an increase in the peak to average power ratio (PAPR) of the RF signals, above 13 dB. A major problem faced by mobile phone users in the present scenario is the limited battery life time between charges and users are ready to pay the extra price for the extra battery life. The underlying cause for the problem is the existence of the power dissipating RF power amplifier (RF PA) block as last stage in the mobile handset, which accounts to almost 55% of the total power dissipation. Mobile battery technology, being still in the developing phase doesn't offer much promising solutions to improve the battery life time between charges. Hence the only viable option is to work on improving the efficiency of RF PA block to improve the battery lifetime of mobile phones. Due to the tremendous increase in PAPR of the RF signals, the traditional way of operating an RF PA using fixed power supply resulted in huge amount of power losses. Load modulation [1]-[3] and supply modulation [4] techniques can provide better efficiency, compared to RF PA using fixed power supply.

Zhu *et al.* [5], a Doherty PA using GaN is implemented. The PA could achieve a drain efficiency of 48% at an average output power of 48.8 dBm. A continuous wave RF input signal in the frequency range of 1.7-2.1 GHz was utilized. Authors have implemented a Doherty PA using GaN HEMTs in paper [6]. The PA could accomplish a drain efficiency of 60% at 6 dB. A WCDMA signal of 6.5 dB PAPR in the frequency range of 1.4-2.1 GHz was used as input signal. An out phasing PA was designed using GaN HEMTs in paper [7]. Average drain efficiency of 59.4% could be achieved with a 10 MHz LTE signal having a PAPR of 9.6 dB. Operating frequency was 1.9 GHz. Garcia *et al.* [8], an out phasing PA using GaN HEMT is realized. Average drain efficiency that could be achieved with a 5 MHz LTE signal having a PAPR of 12.6 dB was 62%. Operating frequency of the circuit was 1.4 GHz. Liu *et al.* [9] realizes an envelope elimination & restoration (EE&R) PA that could measure a power added efficiency (PAE) of 35.7%. A 16 QAM, 20 MHz LTE signal was used as input signal. PA was operating at a frequency of 2.4 GHz. Lin and Chen [10], an envelope tracking PA (ETPA) operating at 2.4 GHz is realized. A 5G NR 40 MHz, 256 QAM RF signal having a PAPR of 12 dB is used as input signal. The design could accomplish a PAE of 13.9% for a maximum output power of 25 dBm. An improvement of 3.1% in PAE could be achieved, compared to operating the same RF PA with fixed bias. Karimi and Ehsanian [11] proposed a parallel hybrid envelope tracking power supply (ETPS) for the CMOS Class AB Power amplifier, operating at 0.9 GHz. A 37% PAE could be achieved for a 20 MHz LTE signal at 6dB back-off. Jing and Zhu [12], Yongkang *et al* presents an ETPA using a 2.4 GHz, SiGe PA. A hybrid ETPS topology is made use of. The design could achieve an average PAE of 24% at an average output power of 24.6 dBm.

Doherty and Out phasing load modulation techniques are able to provide better efficiency as given by literature survey, but they suffer from two drawbacks. The structure demands for two RF power amplifiers, which escalates the cost tremendously. Another constraint is the requirement of an RF power combining network at the output side, which has an inherent limitation of being narrowband. Supply modulation techniques like envelope tracking and envelope elimination & restoration (EE&R) on the other hand, involves only one RF power amplifier. Thus, supply modulation techniques are more appropriate for higher bandwidth applications and can work with higher efficiency as well, as given by literature. Among supply modulation techniques, envelope tracking is more promising than EE&R for high frequency operations. The favorable features of envelope tracking are detailed in sub section 2.1.2. Objectives of the research work, as derived from extensive literature survey is as follows:
- To investigate different efficiency enhancement techniques of RF PA.
- Study of RF PA using fixed bias.
- Analyze the efficiency improvement of RF PA with envelope tracking bias.
- Challenges faced by ETPA designers.
- Identifying future research areas for ETPA designers.

Section 2 of the paper gives an insight into the various efficiency enhancement techniques of RF PA. Section 3 gives the results and discussions to prove that RF PA with variable bias works with better efficiency compared to RF PA with fixed bias. Section 4 concludes the paper by establishing the merits of the paper, challenges faced by designers and the scope for future work in the area.

2. METHOD

Improving the efficiency of RF PA helps to improve the battery lifetime of the mobile and the various efficiency improvement techniques are given in Figure 1. Load modulation techniques like Doherty [13] and out-phasing [14], [15] varies the load impedance of the RF PA, with respect to its input power level. In supply modulation techniques like EE&R and ET, RF power amplifier's supply voltage gets adjusted based on the variation of input envelope.

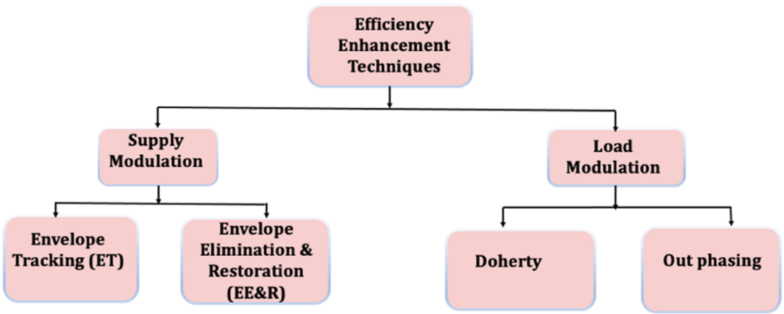


Figure 1. Efficiency improvement techniques

2.1. Supply modulation techniques

Supply modulation techniques being able to work for higher bandwidth applications with higher efficiency makes it the most relevant technique for 5G applications. They are brodly classified into envelope elimination and restoration and envelope tracking. Features of both the techniques are detailed in Figure 2.

2.1.1. Envelope elimination and restoration technique

In EE&R technique [16], [17], the RF signal path is divided into two as shown in Figure 2(a) Envelope of the RF signal is sensed by the envelope generation block and is passed to the ETPS block. Phase information is passed through the limiter and reaches the non-linear RF PA. ETPS block provides a supply voltage that varies in accordance with the input envelope signal, to the RF PA. Features of EE&R technique:

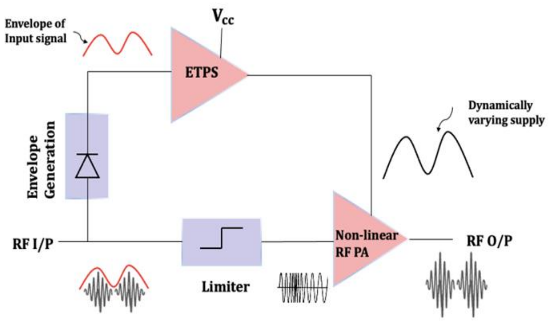
- Strict timing alignment is mandatory between envelope and phase paths, and it makes the technique less suitable for wideband applications.
- Output linearity is completely dependent on the timing alignment between the envelope and phase paths.
- ETPS needs to operate at a higher bandwidth since it must provide the complete envelope information to the RF PA.
- ETPS needs to exactly replicate the envelope information since phase and envelope paths of the RF signal are separated.

2.1.2. Envelope tracking technique

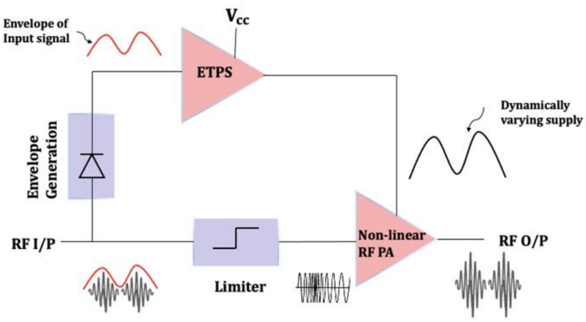
In envelope tracking technique [18], both phase and amplitude information reach the RF PA as shown in Figure 2(b) ETPS makes sure that the linear RF PA is always operated near to saturation and at maximum efficiency, regardless of the input signal's PAPR. Features of envelope tracking technique:

- Strict timing alignment is not mandatory between envelope and phase paths in envelope tracking and hence envelope tracking [19], [20] is the preferred technique in broadband applications.
- Improved output linearity since there is not much dependency on the timing alignment between envelope and phase paths.
- As both phase and envelope information of the signal are passed through the RF PA, the ETPS can operate at a reduced bandwidth.

From the above study, it can be deduced that envelope tracking is the optimal selection for upcoming mobile phone handsets, as they can provide better efficiency for high frequency applications.



(a)



(b)

Figure 2. Supply modulation techniques (a) envelope elimination and restoration and (b) envelope tracking

2.2. Envelope tracking PA versus RF PA with fixed supply

Figure 3 gives a comparison of fixed supply versus variable supply for RF PA. RF PA operating with variable supply is known as ETPA. Figure 3(a) shows the block diagram representation of RF PA operated with fixed power supply and Figure 3(b) displays the block diagram representation of RF PA operated with an ETPS. Simulations are performed using keysight advanced design system (ADS). A class A RF PA operating at a 12 dB gain is implemented using the power transistor MWT-671HP_19931015. A 16 QAM, 5 MHz LTE signal with a PAPR of 6.0 dB is used as input signal. An envelope simulation at 2.5 GHz is performed on the RF PA.

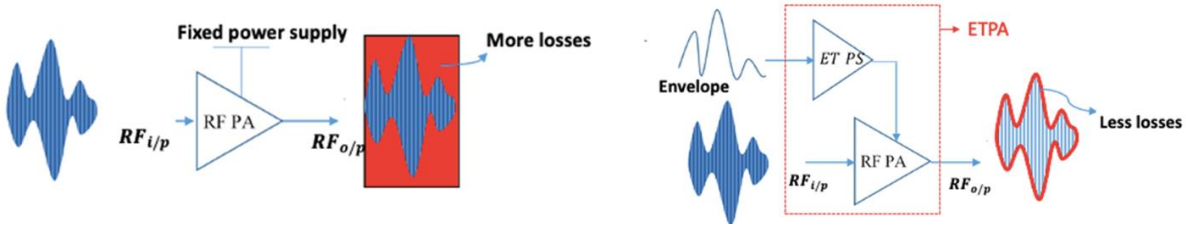


Figure 3. Fixed supply versus variable supply (a) RF PA with fixed supply and (b) RF PA with variable supply

2.2.1. RF PA with fixed bias

Figure 4 shows an RF PA implemented using MWT671HP_19931015, operated at a fixed bias of 6V. The PA is made to operate in Class A region of operation. Envelope simulation of the RF PA is performed using keysight ADS tool. An input RF signal of 5 MHz, 16-QAM LTE having a PAPR of 6.0 dB is applied. The VtDataSet block provides the dataset for creating the modulated input RF signal. At 2.5 GHz, an envelope simulation is performed on the power amplifier.

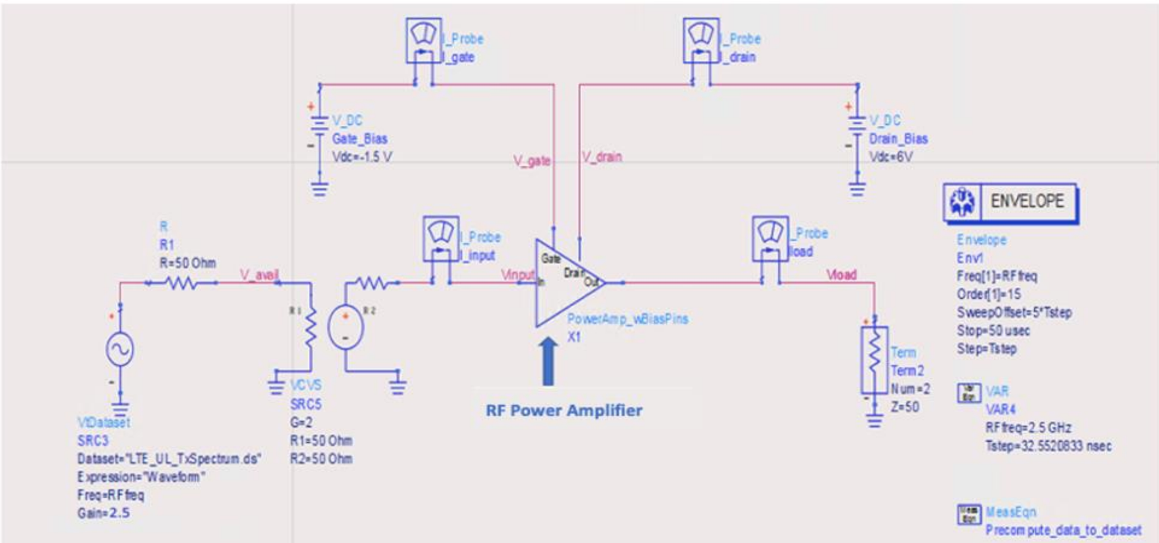


Figure 4. Simulation of RFPA with fixed supply

2.2.2. RF PA with envelope tracking bias

Implementation of ETPA using behavioral model components in keysight ADS is shown in Figure 5. The real part and imaginary part of the modulated RF signal is first separated by an IQ _ Demod Tuned block, in behavioral modelling. Symbolically defined device (SDD3) block now generates a current, given by the (1).

$$I\,[2,0] = -(\_v1 ** 2 + \_v3 ** 2)\,/\,50 \quad (1)$$

where _v1 is the voltage at port1 and _v3 is the voltage at port3 and –ve sign indicates a positive current flow from port2.

This current which is flowing from port2 of the SDD3 block flows into the 50 Ω resistor to produce the magnitude of the envelope of input signal, as given by the (2).

$$E\,nv\_Ma\,g = -(\_v1 ** 2 + \_v3 ** 2) = (I ** 2 + Q ** 2) \quad (2)$$

where I is the real part and Q is the imaginary part of the input envelope signal. Next step is to calculate the power of input RF signal in dBm. This is done by the (3).

$$Pin\_dBm = 10\ log\ (mag\ (\_v1)\ /\ 100 + 1e - 10)\ +\ 30 \quad (3)$$

where _v1 is the E nv_Ma g applied to port1 of the SDD2 block.

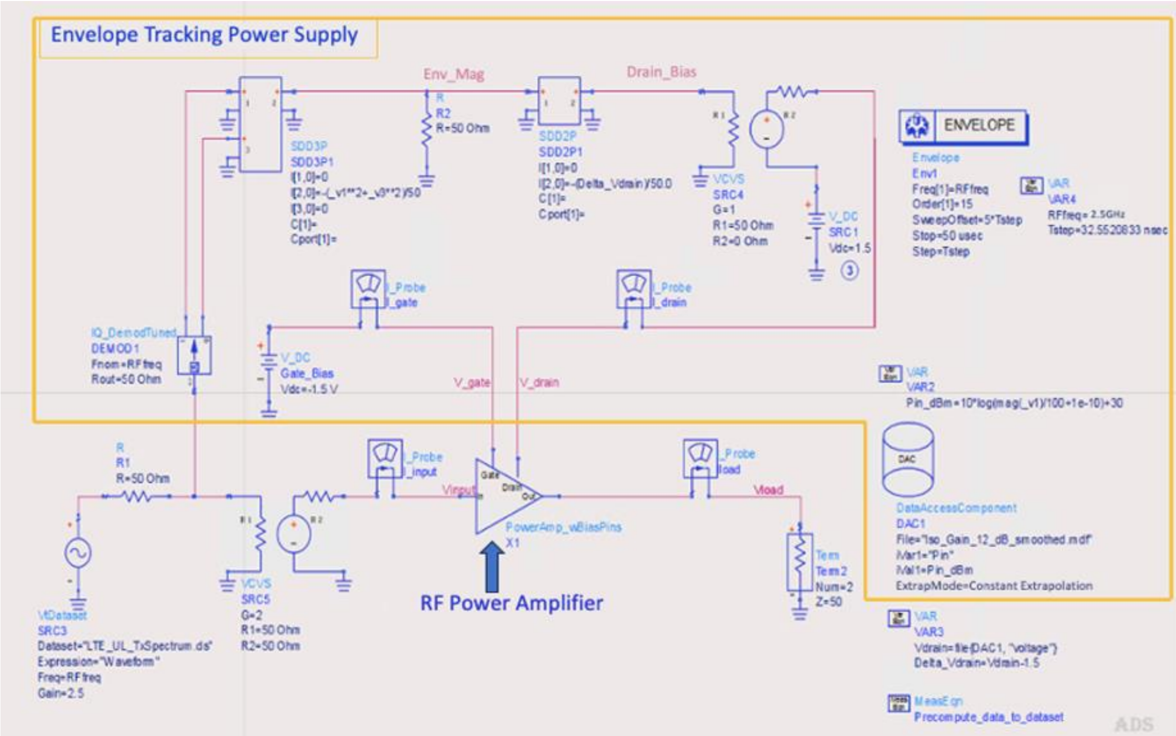


Figure 5. Simulation of RFPA for variable supply

The detected input power, Pin_dBm is applied as input to a data access component (DAC) block. This block acts as a look up table as shown in Table 1. To maintain a fixed gain of 12 dB, the drain voltage supply of the PA can be varied with respect to load power as shown in the Figure 6.

Since input power and load power follow (4), drain voltage supply of the RF PA can be varied with respect to variations in input power, as given by the look up Table 1. It can be observed that lower input power demands for a lower supply voltage.

$$P_{in} = P_{load} - Gain \quad (4)$$

where P_{in} is input power,P_{out} is output power and Gain is the gain of the RF PA.

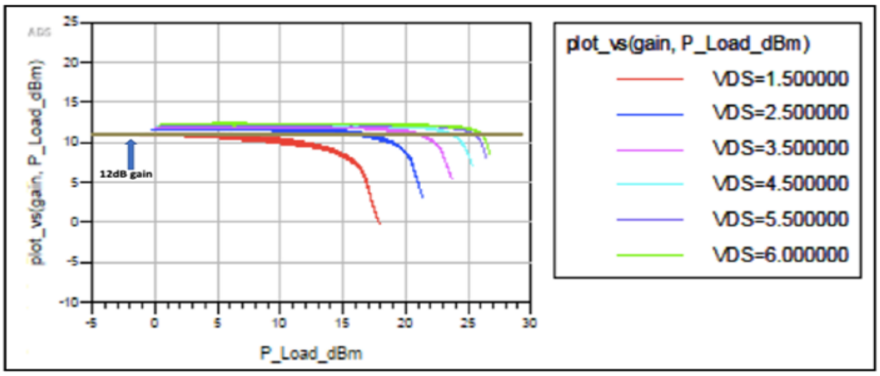


Figure 6. Drain supply variation with P_{load}

Table 1. Variation of supply with input power

Input power (dBm)	Supply voltage (V)
-9.0	1.5
4.5	2.5
8.5	3.5
11.5	4.5
13.4	5.5
14.0	6.0

3. RESULTS AND DISCUSSION

Previous works discuss about RF PA working with fixed bias and various issues like lower PAE, AM/AM distortions were not addressed. PAE of RF PA is given by the (5).

$$PAE = \frac{P_{load} - P_{input}}{P_{DC}} \quad (5)$$

Where P_{load}, P_{input} and P_{DC} are the load power, input power and the DC supply power respectively.

In the current work which is ETPA, drain supply is varied according to the input power. This helps the PA to operate close to saturation at all points, with maximum efficiency. An improvement of 12% in PAE could be achieved with ETPA, compared to RF PA with fixed supply at 6 dB back-off and an improvement of 6.42% in mean PAE could be achieved using ETPA, compared to RF PA with fixed supply. The performance of RF PA gets degraded due to nonlinear distortions occurring and AM/AM distortion is the major source behind this. Since the drain supply of the RF PA is varied in accordance with the variations in input power in ETPA, a reduction of 0.248 in AM-AM distortion could be observed using ETPA. Figure 7 depicts Figure 7(a) mean PAE, Figure 7(b) PAE at 6 dB back-off, and Figure 7(c) AM/AM Distortion comparisons of fixed supply/envelope tracking supply.

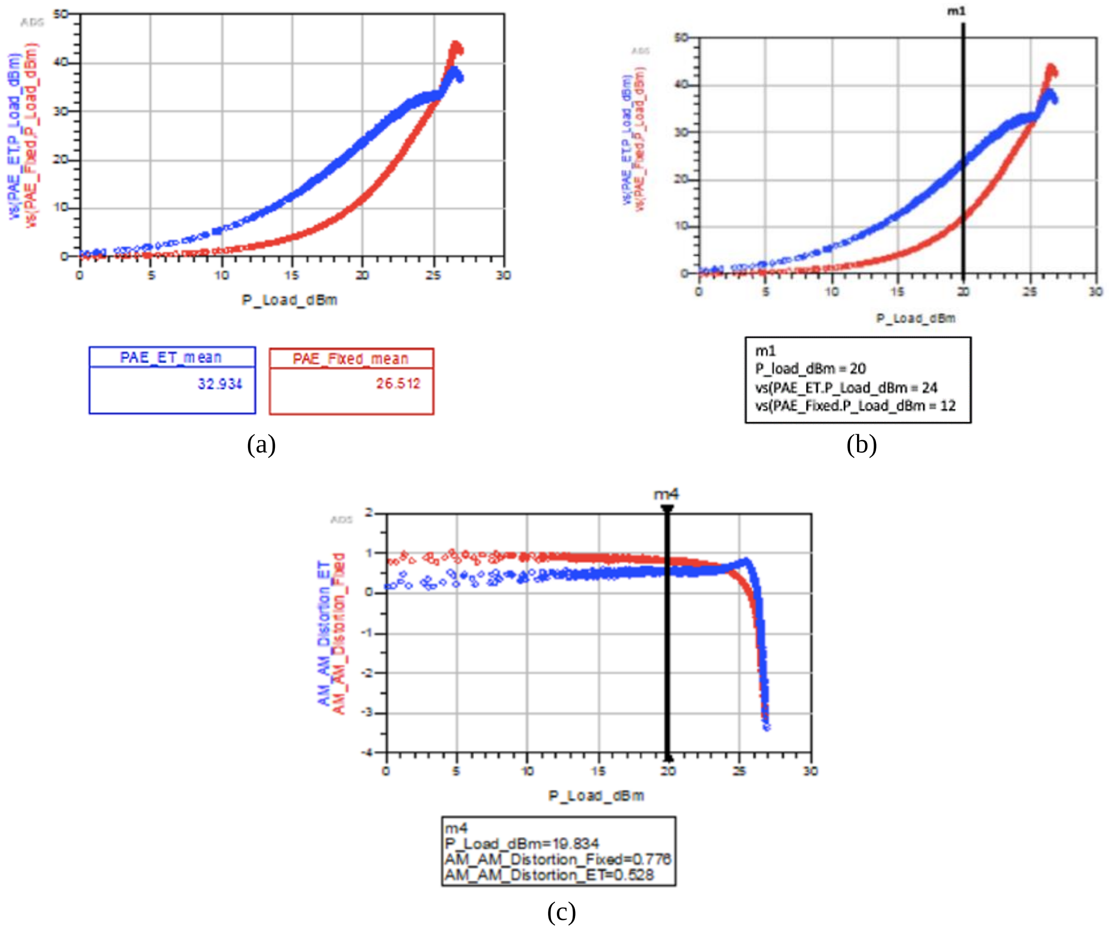


Figure 7. Result comparisons of fixed supply and envelope tracking supply: (a) mean PAE, (b) PAE at 6 dB back-off, and (c) AM/AM distortion

Table 2 gives a comparative analysis of the results obtained during simulation, in terms of PAE and distortions for RF PA with fixed bias and RF PA with variable bias. When compared to an RF PA with fixed supply, an improvement of 12% in PAE at 6 dB back-off could be achieved with an ETPA. Using ETPA, a further improvement of 6.42% in mean PAE could also be observed. ETPA could achieve a noticeable reduction of 0.248 in AM/AM distortion as well, without compromising PAE. The comparative analysis aligns very well with the objective of the research work. It proves how RF PA with fixed bias can be replaced with an ETPA, for better efficiency. The work is limited to behavioral modelling of variable supply. Designers can focus on carrying out the work using different topologies of the supply as mentioned in [21].

Table 2. Comparative analysis of the results obtained during simulation

Parameters	RF PA with fixed bias	RF PA with variable bias
Mean PAE	26.5%	32.9%
PAE at 6 dB back-off	12%	24%
AM/AM Distortion	0.776	0.528

3.1. Challenges faced by designers

Basic block diagram of an ETPA comprises of an RF PA block and an ETPS block is shown in Figure 4. Designers thus have the option of working in both the blocks to improve the efficiency. Overall efficiency of ETPA is given by the (6) which is the product of efficiencies of RF PA and ETPS blocks.

$$\eta_{\text{ETPA}} = \eta_{\text{ETPS}} * \eta_{\text{RF PA}} \quad (6)$$

3.1.1. RF PA block

With respect to RF PA block device technology, designers are facing challenge in developing high-power density transistors using wide band gap materials like silicon carbide (SiC), gallium indium arsenide (GaInAs) and gallium nitride (GaN). Compared to silicon (Si), such materials offer high data transmission rate, high power densities and high break down voltages. Designers are focusing on using non-linear power amplifiers like Class-F, Class J, Class F^{-1}, and Class P to improvise the envelope tracking efficiency.

3.1.2. Envelope tracking power supply block

With respect to ETPS block, a survey done on the available ETPS topologies [21]-[25] detail the challenges introduced by each topology, as listed:

- Linear ETPS topology offers high linearity, low output ripple, less circuit complexity and wide bandwidth tracking. Efficiency being low is a problem with the topology.
- Switching ETPS topology offers a better efficiency compared to linear ETPS topology. The problems associated with the switching ETPS topology are the increased output ripples, low output linearity and low bandwidth of operation.
- Hybrid ETPS topology combines the features of both linear ETPS and switching ETPS. Hybrid ETPS can achieve high efficiency at higher bandwidths, while maintaining high linearity and low output ripples. The use of this topology is still immature due to the increased complexity.

3.1.3. RF input signal

Increased input RF signal bandwidth, operating frequency and increase in PAPR of the RF input signal has become major design constraints for the ETPA designers [26]. Designers are often faced with the problem of efficiency reduction while operating the ETPA using the above-mentioned conditions. Efficiency drops tremendously with increase in input signal bandwidth. Future studies may explore addressing the above-mentioned challenges with respect to RF PA technology, ETPS topologies as well as increasing PAPR of the RF input signal.

4. CONCLUSION

This study investigates the role of RF power amplifiers in a mobile transmitter. Various efficiency improvement techniques to replace RF PA with fixed bias is presented. RF PA with fixed bias and envelope tracking bias is simulated using keysight ADS software and the simulation results prove that envelope tracking is an assuring technique for efficiency improvisation of RF power amplifiers in future mobile communication. An improvement of 12% in PAE at 6 dB back-off could be achieved with an ETPA, when compared to an RF PA with fixed supply. A further improvement of 6.42% in mean PAE could also be observed using ETPA. ETPA could achieve a noticeable reduction of 0.248 in AM/AM distortion as well. Various challenges faced by ETPA designers, in-terms of designing RF PA block and ETPS block, along with the design constraints associated with the increase in PAPR of RF input signal are also discussed.

There is a huge research scope in ETPA design area, especially as more research is now happening in 5G. Designing non-linear RF power amplifiers for ETPA that can operate with high efficiency, at 5G frequency band could be a research area. Developing power transistors using materials other than Si, which can provide high power density and high breakdown voltages can also be investigated. ETPS designers can focus on improving the efficiency of hybrid ETPS topology, which is currently the most promising topology. Research work focusing on developing an improved control scheme other than the existing PWM and Hysteretic control for the ETPS could also be taken forward.

REFERENCES

[1] P. E. De Falco, W. Hallberg, and T. Barton, "Load modulated RF amplifiers for wireless communications," May 2020, doi: 10.1109/WMCS49442.2020.9172415.

[2] A. M. Abdulkhaleq *et al.*, "Load-modulation technique for next generation mobile," in *IEEE 5G World Forum, 5GWF 2019 - Conference Proceedings*, Sep. 2019, pp. 208–213, doi: 10.1109/5GWF.2019.8911689.

[3] V. Diez-Acereda, A. Diaz-Carballo, R. Rodriguez-Hernandez, J. Del Pino, and S. L. Khemchandani, "Power amplifiers load modulation techniques for 5G in GaN-on-Si techonology," Nov. 2019, doi: 10.1109/DCIS201949030.2019.8959923.

[4] P. H. Liao, Y. H. Yang, and Y. S. Hwang, "A hybrid supply modulator with envelop tracking technique for RF power amplifier," in *Proceedings - 2020 International Symposium on Computer, Consumer and Control, IS3C 2020*, Nov. 2020, pp. 146–149, doi: 10.1109/IS3C50286.2020.00045.

[5] N. Zhu, R. McLaren, J. S. Roberts, D. G. Holmes, M. Masood, and J. K. Jones, "Compact high-efficiency high-power wideband GaN amplifier supporting 395 MHz instantaneous bandwidth," in *IEEE MTT-S International Microwave Symposium Digest*, Jun. 2019, vol. 2019-June, pp. 1175–1178, doi: 10.1109/mwsym.2019.8700873.

[6] X. Y. Zhou *et al.*, "A mixed topology for broadband high-efficiency doherty power amplifier," *IEEE Transactions on Microwave Theory and Techniques*, vol. 67, no. 3, pp. 1050–1064, Mar. 2019, doi: 10.1109/TMTT.2019.2893178.

[7] H. C. Chang, Y. Hahn, P. Roblin, and T. W. Barton, "New mixed-mode design methodology for high-efficiency outphasing chireix amplifiers," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 66, no. 4, pp. 1594–1607, Apr. 2019, doi: 10.1109/TCSI.2018.2882770.

[8] J. A. Garcia, M. N. Ruiz, A. Cordero, and D. Vegas, "Current-injected load-modulated outphasing amplifier for extended power range operation," *IEEE Microwave and Wireless Components Letters*, vol. 31, no. 6, pp. 713–716, Jun. 2021, doi: 10.1109/LMWC.2021.3062150.

[9] X. Liu, H. Zhang, P. K. T. Mok, and H. C. Luong, "A multi-loop-controlled AC-coupling supply modulator with a mode-switching CMOS PA in an EER system with envelope shaping," *IEEE Journal of Solid-State Circuits*, vol. 54, no. 6, pp. 1553–1563, Jun. 2019, doi: 10.1109/JSSC.2019.2892555.

[10] Y. C. Lin and Y. J. E. Chen, "A CMOS envelope tracking supply converter for RF power amplifiers of 5G NR mobile terminals," *IEEE Transactions on Power Electronics*, vol. 36, no. 6, pp. 6814–6823, Jun. 2021, doi: 10.1109/TPEL.2020.3039786.

[11] M. Karimi and M. Ehsanian, "A high-performance CMOS hybrid envelope tracking PAfor wideband high PAPR applications," Dec. 2021, doi: 10.1109/IICM55040.2021.9730153.

[12] Y. Jing and B. Zhu, "A 2.4 GHz SiGe envelope tracking PAfor LTE applications," in *2023 6th World Conference on Computing and Communication Technologies, WCCCT 2023*, Jan. 2023, pp. 52–56, doi: 10.1109/WCCCT56755.2023.10052136.

[13] G. Nikandish, R. B. Staszewski, and A. Zhu, "Breaking the bandwidth limit: A review of broadband doherty PAdesign for 5G," *IEEE Microwave Magazine*, vol. 21, no. 4, pp. 57–75, Apr. 2020, doi: 10.1109/MMM.2019.2963607.

[14] M. P. Van Der Heijden, M. Acar, J. S. Vromans, and D. A. Calvillo-Cortes, "A 19W high-efficiency wide-band CMOS-GaN class-E Chireix RF outphasing power amplifier," Jun. 2011, doi: 10.1109/MWSYM.2011.5972564.

[15] H. Chireix, "High power outphasing modulation," *Proceedings of the Institute of Radio Engineers*, vol. 23, no. 11, pp. 1370–1392, Nov. 1935, doi: 10.1109/JRPROC.1935.227299.

[16] F. Wang *et al.*, "An improved power-added efficiency 19-dBm hybrid envelope elimination and restoration PAfor 802.11g WLAN applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 12, pp. 4086–4098, Dec. 2006, doi: 10.1109/TMTT.2006.885575.

[17] F. H. Raab, B. E. Sigmon, R. G. Myers, and R. M. Jackson, "L-band transmitter using kahn EER technique," *IEEE Transactions on Microwave Theory and Techniques*, vol. 46, no. 12 PART 2, pp. 2220–2225, 1998, doi: 10.1109/22.739200.

[18] P. Asbeck and Z. Popovic, "ET comes of age: envelope tracking for higher-efficiency power amplifiers," *IEEE Microwave Magazine*, vol. 17, no. 3, pp. 16–25, Mar. 2016, doi: 10.1109/MMM.2015.2505699.

[19] G. Chao and Y. Fei, "Research on PAbased on envelope tracking technology," *IOP Conference Series: Earth and Environmental Science*, vol. 1802, no. 2, p. 22091, Mar. 2021, doi: 10.1088/1742-6596/1802/2/022091.

[20] X. Liu, J. Jiang, C. Huang, and P. K. T. Mok, "Design techniques for high-efficiency envelope-tracking supply modulator for 5th generation communication," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 69, no. 6, pp. 2586–2591, Jun. 2022, doi: 10.1109/TCSII.2022.3165820.

[21] A. Babu, B. G. Shivaleelavathi, and V. Yatnalli, "A comprehensive review on supply modulators and control strategies for envelope tracking RF power amplifiers in mobile communication," *IETE Journal of Research*, vol. 69, no. 5, pp. 2337–2349, Oct. 2023, doi: 10.1080/03772063.2021.1987998.

[22] P. Y. Hsiung, C. J. Tsai, Y. M. Chen, and C. J. Chen, "An AC-coupling parallel hybrid supply modulator achieving 100MHz envelope tracking power amplifiers for wireless communications," in *Conference Proceedings - IEEE Applied Power Electronics Conference and Exposition - APEC*, Mar. 2022, pp. 640–645, doi: 10.1109/APEC43599.2022.9773673.

[23] A. Rifi, C. Hallepee, M. Ayad, G. Neveux, and D. Barataud, "An envelope tracking oriented, 17-20GHz, Average 64QAM modulated 2W, PAE>37%, OBO 8dB GaN MMIC power amplifier," Nov. 2023, doi: 10.1109/INMMIC57329.2023.10321786.

[24] N. Kumari, S. H. Yang, K. H. Chen, Y. H. Lin, S. R. Lin, and T. Y. Tsai, "A CMOS switched-capacitor boost mode envelope tracking regulator with 4% efficiency improvement at 7.7dB PAPR for 20MHz LTE envelope tracking RF power amplifiers," in *Proceedings - 2019 IEEE Asian Solid-State Circuits Conference, A-SSCC 2019*, Nov. 2019, pp. 255–258, doi: 10.1109/A-SSCC47793.2019.9056959.

[25] A. Pergushev, V. Sorotsky, and A. Ulanov, "Criteria for selection envelope tracking power supply parameters for high peak-to-average power ratio applications," in *Proceedings of the 2019 IEEE International Conference on Electrical Engineering and Photonics, EExPolytech 2019*, Oct. 2019, pp. 13–16, doi: 10.1109/EExPolytech.2019.8906793.
[26] H. Oh *et al.*, "Hybrid et supply modulator IC with an adaptive quiescent current controller for its linear amplifier," in *IEEE MTT-S International Microwave Symposium Digest*, Jun. 2021, vol. 2021-June, pp. 649–652, doi: 10.1109/IMS19712.2021.9574809.

BIOGRAPHIES OF AUTHORS

Dr. Ambily Babu received her M. Tech in VLSI & Embedded Systems from VTU, Karnataka, India in 2008. She holds a Ph.D. degree in Electronics & Communication Engineering with specialization in Envelope Tracking Power Amplifiers. Currently working as Assistant Professor in the Department of Electronics and Communication Engineering, CHRIST (Deemed to be University), Bengaluru, India. Her areas of research interest include ETPA, Power Electronics and VLSI. She has published several papers in International Conferences and Journals. She can be contacted at email: ambily_babu@outlook.com.

Dr. Bangalore Gangadharaiah Shivaleelavathi received her M. E from Mumbai University in 1997 and a Ph.D. from Bangalore University, in 2012. Worked in the Dept. of Electronics and Communication Engineering, JSSATE Bengaluru India, as Professor. Her interest areas include Renewable Energy Sources, Power Electronics and IoT. She has many funded projects to her credit and has published several papers in International Journals. She can be contacted at email: shivaleelavathi1963@gmail.com.

Dr. Veeramma Yatnalli received her M.E. from BVB College of Engineering, Hubli, Karnataka University Dharwad in the year 1998 and Ph.D. from VTU in the year 2018. She is associated with JSSATE Bengaluru, India as Assoc. Professor in the Dept. of Electronics and Communication Engineering. Her research areas include DSP, Image Processing and Communication. She has several papers in image compression and reconstruction domain, to her credit in various International Journals. She can be contacted at email: veeramma71@gmail.com.