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Prediction of Class-Amplifiers with the Aid of Neural Network

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***Abstract*—This paper presents a strategy addressing the problem of selection of the class of the amplifiers to be used in future wireless communication systems. The proposed methodology uses a scheme based on neural networks (NN): the characteristics of each class of amplifier (i.e., A, B, AB, C, D, F, G, J, S, T, etc.) are determined and then the 'classification NN' is constructed for distinguishing various classes from each other. To validate the method, firstly the designs of various class-amplifiers are collected from the recently published literature, and then the specifications of the amplifiers are extracted in terms of voltage (V), current (I) and efficiency; finally with these data the classification NN is trained. After building this black-box NN, providing the required specifications of each amplifier, designer are informed about the class of amplifier that is predicated by the classification NN and that better fits the characteristics of the considered application. This methodology is important as it leads the way of amplifier class selection in the complex communication systems.**

***Index Terms*—Amplifier, class-amplifier, neural network (NN), classification neural network, conductive angle, efficiency.**

I. Introduction

In the fifth generation (5G) and next generation technologies as sixth generation (6G), amplifiers are one the most important part of communication systems that lead to improve the special specifications of systems [1]. There are various configurations of amplifiers each one having its own main operating characteristics; the types of amplifiers are named as 'class'. The term 'amplifier class' is used for differentiate among the various amplifier types. The different amplifiers are classified with their own configurations and design specifications where some of them are known as: A, B, AB, C, D, F, inverse-F, G, I, J, S, and T class-amplifiers. Figure 1 presents some of the various classes of amplifiers categorized in terms of efficiency and conductive angles.

In the following a short description of the main characteristics of the different classes is provided, focusing on linearity, and efficiency. Class-A amplifiers are simple devices with perfect linearity, excellent gain, and low signal distortion that can be used, for example, as the switching transistor inside the amplifier designs. This class of amplifier is typically used in audio amplifier designs, but it suffers from thermal stability. The used transistor remains conducting for all the time with the conduction angle of 360°. This type has low efficiency of 15-35%, for this reason other classes of amplifiers have been developed. Class-B amplifiers are more common that the class-A amplifiers and the maximum power added efficiency (PAE) of this class is around 78.5%. This type uses two complimentary transistors where each of them amplifies half of the waveform. Here the DC power is low, as there is no DC base bias, resulting in a much higher efficiency with respect of the Class-A amplifier. In the necessary coupling transformer, each of the transistors is driven by the conduction angle of 180°. Class-AB is the combination of Class-A and Class-B; it exhibits a good linearity and an efficiency of 50% to 60%.

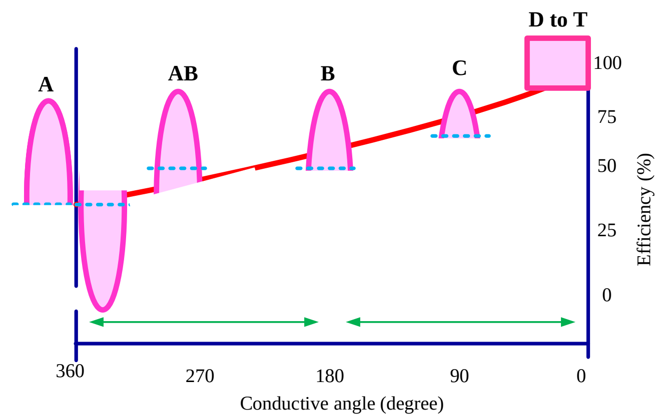

Fig. 1. Comparison between various amplifier classes in terms of efficiency and conductive angles.

For the Class-C, the conduction angle is lower than for the Class-B configuration; it has high harmonic levels and it is employed where higher than Class-B efficiency is needed. It has poor linearity and the conductive angle is 90° with the efficiency of 80%. Other types as Class-D and Class-S amplifiers can reach 100% efficiency while the Class-F can have efficiency of more than 90%. All the classes from D to T are like an on-off nonlinear switching with the conduction angle of 0°.

Identifying and distinguishing the class of amplifiers among various configurations and specifications is not straightforward and requires additional effort. For this reason, this paper presents an intelligent-based approach for predicting and determining the class of amplifier with the acceptable accuracy. The prediction task is performed using the classification neural network (NN) that is trained with three specifications of amplifiers, namely voltage (V), current (I), and efficiency.

Designers can get benefit of this study for determining the class of amplifier that better fits the requirements for the considered application.

The rest of paper is organized as follows: Sec. II describes the theory of amplifier. Sec. III presents the theory of the proposed classification NN for predicting the class of amplifiers to be used. The practical implementation of classification NN with simulation results are described in Sec. IV. Finally, Sec. V concludes this work.

II. Theory of Amplifiers in a Nutshell

This sections devotes to describe the theory of amplifiers in terms of 'V', 'I', and efficiency leading to have diverse specifications and configurations.

Tuning the harmonic impedances and bias can enhance efficiency in class-F [2], inverse F [3], J [4] and E [5] up to 100%. Other type of PAs such as class-A, AB [6], B [7], and C [8] can have maximum efficiency as 50%, 50-78%, 78.5%, $> 78.5\%$, respectively. For achieving high efficiency in amplifiers, voltage and current waveforms must be non-overlapped at the internal drain. Figure 2 shows ideal waveforms that can produce maximum efficiency in class-F power amplifier (PA) and there is no knee voltage (V_k) in different harmonics. In this case power is not dissipated as heat and sum of dissipated power (P_{diss}) and output power in different harmonics are zero.

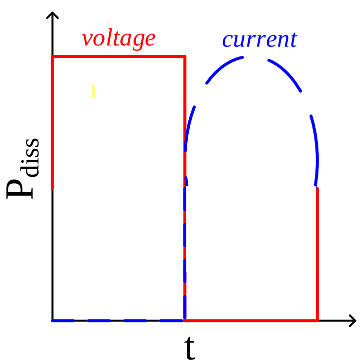

Fig. 2. Ideal non-overlapped waveforms for class-F PA.

As described above, the drain efficiency (η) in class-F is 100%. The explanation is as follows: Fig. 3 shows the peak magnitudes of fundamental current and voltage. In (1) by substituting $\frac{I_{peak}}{I_{DC}}$ as $\frac{4}{\pi}$ and $\frac{V_{peak}}{V_{DC}}$ as $\frac{\pi}{2}$ drain (or collector) efficiency will be 100% [9].

$$\eta = \frac{1}{2}\left(\frac{I_{peak}}{I_{DC}}\right)\left(\frac{V_{peak}}{V_{DC}}\right) \tag{1}$$

As Fig. 2 demonstrates, by shaping V/I waveforms maximum efficiency can be obtained with the help of harmonic termination approach. Figure 4 shows the ideal PA structure and explains how PA receives power. In Fig. 4, it is shown how the V/I wave forms that affect the efficiency are drain voltage (v_{ds}) and drain current (i_{ds}). The η parameter is calculated by (2) and detailed generation of each parameter is defined from (3) to (5). Hereby, the η has an inverse relation with P_{diss}.

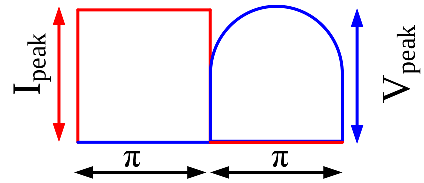

Fig. 3. Peak magnitudes of rectangular current and half-sinusoidal voltage waveforms.

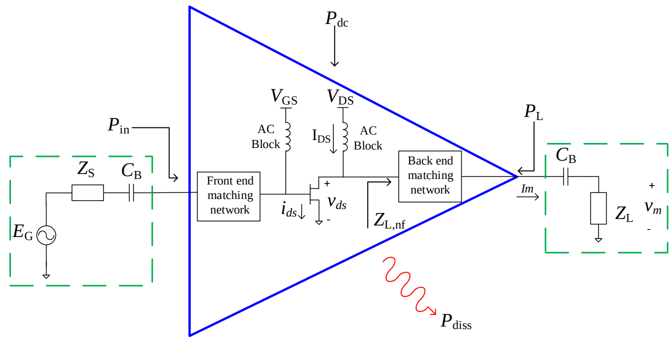

Fig. 4. Structure of ideal PA design [10].

$$\eta = \frac{\frac{V_m I_m}{2}}{v_{ds} i_{ds}} = \frac{P_{L,1f}}{P_{dc}} \tag{2}$$

where

$$P_{dc} = P_{diss} + P_{L,1f} + \sum_{n=2}^{\infty} P_{L,nf} \tag{3}$$

The output power at the fundamental frequency is $P_{L,1f}$ and the output power at the various harmonics is $P_{L,nf}$. And also,

$$P_{diss} = \frac{1}{T}\int_0^T v_{ds}(t) \cdot i_{ds}(t) d_t \tag{4}$$

$$\sum_{n=2}^{\infty} P_{L,nf} = \frac{1}{2}\sum_{n=2}^{\infty} V_n \cdot I_n \cdot \cos(\theta_n) \tag{5}$$

In (5), V_n and I_n are drain voltage and current at the n^{th} harmonic with intersection angle θ_n.

III. Proposed Method

This section presents the theory of the proposed method for predicting the class of amplifiers. Firstly the suitable amount of data is collected, then the layers of classification NN (input layer, hidden layer, and output layer) are employed. In the next section, it will be proved that the proposed approach is effective and it can be used as flexible 'black-box' modeling.

A. Data generation

Any NN for training requires training, validation, and testing data namely as: X_{Train}, X_{Val}, and X_{Test} and also the corresponding outputs as Y_{Train}, Y_{Val}, and Y_{Test}. After generating suitable amount of data, the whole amount of them can be

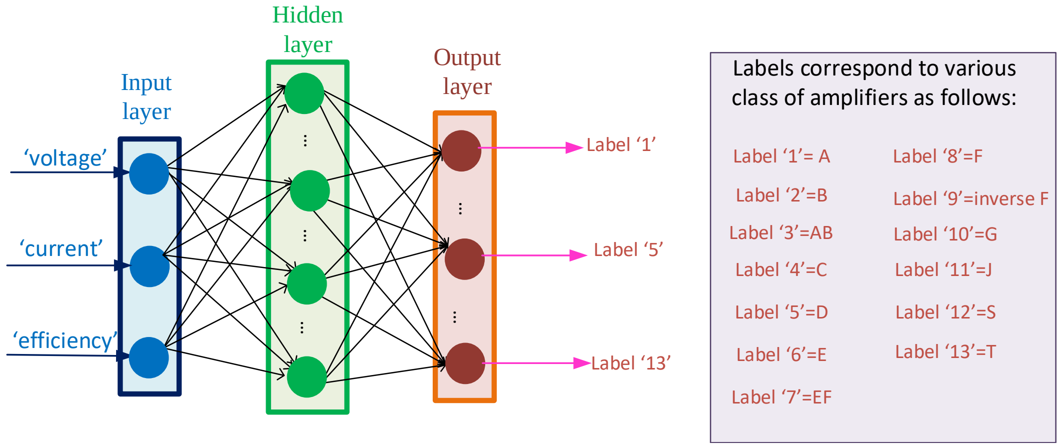

Fig. 5. Proposed classification neural network for predicting the class of amplifiers.

divided into these three parts with the ratio of 70%, 15%, and 15%, respectively.

In order to obtain training, validation, and testing data, we provide various class of amplifiers from the previously published literature. The selected amplifier designs for each class is as follws: Class-A [11], [12], Class-B [13] , Class-AB [14], Class-C [15], Class-D [16], [17], Class-E [18], [19], Class-EF [20], Class-F [21], Class-inverse F [22], Class-G [23], [24], Class-J [25], [26], Class-S [27], and Class-T [28].

We design each of the nominated amplifiers in the electronic design automation (EDA) tool as ADS, AWR, and Cadence software. Then, the components values of each amplifier are tuned using the random iteration optimization (RIO) method in order to gather suitable dataset for each class. Each component of desigend amplifier is changed within the ± 10 and ± 15 range of current points. In each iteration, the outputs of each amplifier are extrcated as the $\mathrm{Y_{Train}}$, $\mathrm{Y_{Val}}$, and $\mathrm{Y_{Test}}$ data. Then, the network is trained using (6):

$$\mathrm{net} = \mathrm{trainNetwork}(X_{\mathrm{Train}}, Y_{\mathrm{Train}}) \tag{6}$$

Figure 5 presents the proposed classification NN leading to predict the class of different amplifiers. The input layer consists of three features as 'V', 'I', and efficiency where the output layer demonstrates the label of various amplifiers related to. The hyperparameters of the hidden layer is provided using the 'rule of thumb' where the number of neurons are achieved through this method. In this paper, we work on 13 different amplifiers where in Fig. 5, the corresponding labels are presented and the related labels are as the output layer features.

IV. Practical Development of Classification Neural Network

As described in Sec. III, the various amplifier designs from literature are collected and designed separately. Then for each design, 100 data are generated using the RIO method. In this paper, we use 13 design amplifiers hence in total 13×100=1300 data can be generated for constructing the classification NN. With these data, the classification NN is trained and constructed with one hidden layer and with

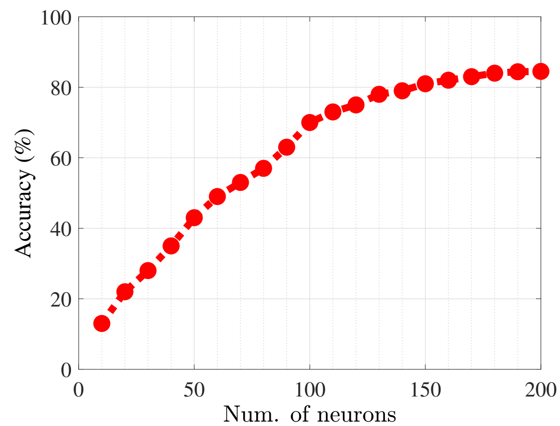

Fig. 6. Testing accurcay of proposed classification neural network.

provided neurons through rule of thumb method. Constructing an accurate NN is the most important factor in training any network. Figure 6 presents the accurcay of the classification NN where in 200^{th} neuron, the accurcay of the classification network reaches 84.5%. It demonstrates that the increased number of neurons leads to train an accurate NN.

After training and constructing the classification NN, three specifications of various amplifiers (i.e., voltage, current, and efficiency) are inserted to the network to validate the proposed black-box model and recognize that to what accuracy degree (%) it is responding to. Table I presents the accuracy prediction of each class. As it can be observed, the proposed NN can respond accurately with at least 72.5%, which is suitable.

V. Conclusion

Day-by-day, the wireless technology is improving, and amplifiers are playing an important role in accurate communication systems. There are various types of amplifiers grouped/identified in classes. In the complex system designs, distinguishing the class of amplifiers is not straightforward and requires engineer experiences. To tackle this problem, we propose the use of the classification NN for predicting the class of amplifiers to better fit the provided specifications. We train and construct this NN and validate that it can be used as a black-box model in the radio frequency systems

TABLE I
ACCURCAY PREDICTION OF EACH AMPLIFIER CLASS USING THE PROPOSED NEURAL NETWORK

Class	Accurcay (%)	Class	Accurcay (%)
Class-A [11]	78.3	Class-B [13]	74.4
Class-AB [14]	80.2	Class-C [15]	77.4
Class-D [16]	74.5	Class-E [18]	73.5
Class-EF [20]	72.8	Class-F [21]	79.6
Class-inverse F [22]	78.5	Class-G [23]	77.9
Class-J [25]	80.9	Class-S [27]	72.5
Class-T [28]	78.4	-	-

designs. The presented intelligence-based network leads the way of designers in selecting more effectively and easily the appropriate class-amplifier.

REFERENCES

[1] L. Kouhalvandi, "Design and implementation of high power GaN amplifiers with nonlinear optimization techniques," Ph.D. dissertation, Istanbul Technical University, 2021.

[2] Z. Yang, Y. Yao, Z. Liu, M. Li, T. Li, and Z. Dai, "Design of high efficiency broadband continuous class-F power amplifier using real frequency technique with finite transmission zero," *IEEE Access*, vol. 6, pp. 61 983–61 993, 2018.

[3] Y. Dong, L. Mao, and S. Xie, "Extended continuous inverse class-F power amplifiers with class-AB bias conditions," *IEEE Microwave and Wireless Components Letters*, vol. 27, no. 4, pp. 368–370, April 2017.

[4] B. Liu, M. Mao, C. C. Boon, P. Choi, D. Khanna, and E. A. Fitzgerald, "A fully integrated class-J GaN MMIC power amplifier for 5-GHz WLAN 802.11ax application," *IEEE Microwave and Wireless Components Letters*, vol. 28, no. 5, pp. 434–436, May 2018.

[5] C. Liu and Q. Cheng, "A novel compensation circuit of high-efficiency concurrent dual-band class-E power amplifiers," *IEEE Microwave and Wireless Components Letters*, vol. 28, no. 8, pp. 720–722, Aug 2018.

[6] L. Kouhalvandi, O. Ceylan, and H. B. Yagci, "Power amplifier design optimization with simultaneous cooperation of EDA tool and numeric analyzer," in *2018 18th Mediterranean Microwave Symposium (MMS)*, Oct 2018, pp. 202–205.

[7] Shouxuan Xie, V. Paidi, R. Coffie, S. Keller, S. Heikman, B. Moran, A. Chini, S. P. DenBaars, U. Mishra, S. Long, and M. J. W. Rodwell, "High-linearity class B power amplifiers in GaN HEMT technology," *IEEE Microwave and Wireless Components Letters*, vol. 13, no. 7, pp. 284–286, July 2003.

[8] S. Rezaei, L. Belostotski, M. Helaoui, and F. M. Ghannouchi, "Harmonically tuned continuous class-C operation mode for power amplifier applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 62, no. 12, pp. 3017–3027, Dec 2014.

[9] Y. Y. Woo, Y. Yang, and B. Kim, "Analysis and experiments for high-efficiency class-f and inverse class-f power amplifiers," *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 5, pp. 1969–1974, 2006.

[10] L. Kouhalvandi, O. Ceylan, and S. Ozoguz, "Automated top-down pruning optimization approach in RF power amplifier designs," *Analog Integrated Circuits and Signal Processing*, vol. 106, no. 3, pp. 525–534, Mar 2021. [Online]. Available: https://doi.org/10.1007/s10470-020-01730-w

[11] J. H. Jeong, G. H. Kim, B. R. Min, C. H. Ahn, and G. H. Cho, "A high efficiency class A amplifier accompanied by class D switching amplifier," in *PESC97. Record 28th Annual IEEE Power Electronics Specialists Conference. Formerly Power Conditioning Specialists Conference 1970-71. Power Processing and Electronic Specialists Conference 1972*, vol. 2, 1997, pp. 1210–1216 vol.2.

[12] W. Wojtasiak, D. Gryglewski, T. Morawski, and E. Sedek, "A 45 W class A power amplifier for L-band T/R module," in *12th International Conference on Microwaves and Radar. MIKON-98. Conference Proceedings (IEEE Cat. No.98EX195)*, 1998, pp. 59–62 vol.1.

[13] J. Zhou, K. Morris, G. Watkins, and K. Yamaguchi, "Three-band high-efficiency modulator for envelope tracking power amplifier using class-B push-pull amplifiers," in *2012 42nd European Microwave Conference*, 2012, pp. 124–127.

[14] P. Pazhouhesh and J. kitchen, "A broadband class AB power amplifier with second harmonic injection," in *2020 IEEE 14th Dallas Circuits and Systems Conference (DCAS)*, 2020, pp. 1–5.

[15] M. H. Montaseri, J. Aikio, T. Rahkonen, and A. Pärssinen, "Design of stacked-mos transistor mm-wave class c amplifiers for doherty power amplifiers," in *2018 IEEE Nordic Circuits and Systems Conference (NORCAS): NORCHIP and International Symposium of System-on-Chip (SoC)*, 2018, pp. 1–5.

[16] N. Elsayed, H. Saleh, B. Mohammad, and M. Sanduleanu, "A 28-GHz cascode inverse class-D power amplifier utilizing pulse injection in 22-nm FDSOI," *IEEE Access*, vol. 8, pp. 97 353–97 360, 2020.

[17] X. Wei, H. Wang, A. Luo, K. Wang, X. Zhu, R. Sun, and X. Chen, "Robust multilayer model predictive control for a cascaded full-bridge NPC class-D amplifier with low complexity," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 4, pp. 3390–3401, 2021.

[18] J.-C. Du, Z.-G. Wang, J. Xu, and Y.-F. Yang, "A current-injection class-E power amplifier," *IEEE Microwave and Wireless Components Letters*, vol. 30, no. 8, pp. 775–778, 2020.

[19] P. Afanasyev, A. Grebennikov, R. Farrell, and J. Dooley, "Analysis and design of outphasing transmitter using class-E power amplifiers with shunt capacitances and shunt filters," *IEEE Access*, vol. 8, pp. 208 879–208 891, 2020.

[20] C. Liu, X. Li, Y. Zhao, T. Qi, X. Du, W. Chen, and F. M. Ghannouchi, "Investigation of high-efficiency parallel-circuit class-EF power amplifiers with arbitrary duty cycles," *IEEE Transactions on Industrial Electronics*, vol. 68, no. 6, pp. 5000–5012, 2021.

[21] A. Alizadeh, M. Yaghoobi, M. Meghdadi, A. Medi, and S. Kiaei, "A 10-W X-band class-F high-power amplifier in a 0.25-um gaas phemt technology," *IEEE Transactions on Microwave Theory and Techniques*, vol. 69, no. 1, pp. 157–169, 2021.

[22] S. M. A. Ali and S. M. R. Hasan, "A 38-GHz millimeter-wave double-stacked HBT class-f^{1} high-gain power amplifier in 130-nm SiGe-BiCMOS," *IEEE Transactions on Microwave Theory and Techniques*, vol. 68, no. 7, pp. 3039–3044, 2020.

[23] N. Wolff, W. Heinrich, and O. Bengtsson, "Analysis of the switching threshold in dual-level class-G modulated power amplifiers," in *2015 Integrated Nonlinear Microwave and Millimetre-wave Circuits Workshop (INMMiC)*, 2015, pp. 1–3.

[24] T. Li, Y. Yin, Y. Zhu, L. Xiong, Y. Liu, N. Yan, H. Min, and H. Xu, "A wideband efficiency-enhanced class-G digital power amplifier for IoT applications," *IEEE Microwave and Wireless Components Letters*, vol. 28, no. 8, pp. 714–716, 2018.

[25] H.-C. Chang, P. Roblin, Y. Hahn, J. I. Martinez-Lopez, C. Liang, and K. Rawat, "Frequency-agile class-J power amplifier with clockwise fundamental- and second-harmonic loads," *IEEE Transactions on Microwave Theory and Techniques*, vol. 68, no. 7, pp. 3184–3196, 2020.

[26] W. Y. Refai and W. A. Davis, "A highly efficient linear multimode multi-band class-J power amplifier utilizing GaAs hbt for handset modules," *IEEE Transactions on Microwave Theory and Techniques*, vol. 68, no. 8, pp. 3519–3531, 2020.

[27] B. Sen, "A 60w class S and outphasing hybrid digital transmitter for wireless communication," in *2018 IEEE Topical Conference on RF/Microwave Power Amplifiers for Radio and Wireless Applications (PAWR)*, 2018, pp. 8–11.

[28] C. Raynal, D. Masse, P. Kasser, J.-p. Cances, and V. Meghdadi, "DVB-T power amplifiers modelling and compensation," in *2006 IEEE MTT-S International Microwave Symposium Digest*, 2006, pp. 1522–1525.