Research on Nonlinear Modeling for RF Power Amplifier

Xiang Chen[1], Jie Chang[1], Hui Han[2], Ruowu Wu[1], and Yun Lin[2](✉)

[1] State Key Laboratory of Complex Electromagnetic Environment Effects on Electronics and Information System (CEMEE), Luoyang, Henan 471003, China

[2] College of Information and Communication Engineering, Harbin Engineering University, Harbin 150001, China

linyun_phd@hrbeu.edu.cn

Abstract. The research of radio-frequency (RF) power amplifier model has always been one of the most important breakthroughs in the emitter feature extraction and specific emitter identification. Through the establishment of RF power amplifier model, we can extract feature parameters of the specific emitter. In this paper, we discuss the research issues of the specific emitter feature extraction and individual identification based on RF power amplifier nonlinear model, summarize the nonlinear distortion and modeling method of the power amplifier. Furthermore, we analyzed the applicability of these models.

Keywords: Power amplifier · Emitter feature extraction · Individual identification · Nonlinear distortion

1 Introduction

In the integrated electronic warfare system, it is of great significance to study the fine feature extraction and individual identification of specific emitter. Even if two pieces of device of the same type are produced at the same time, due to the differences in the individual parameters of the internal components and use environment and so on, the working characteristics thereof will produce subtle differences. For wireless communication systems, under the same input conditions, there will be slight differences in the output radiation signal. Because the power amplifiers (PA) is indispensable module in communication emitter and RF power amplifiers work unavoidably under nonlinear conditions, RF power amplifiers are often the main aspects of the specific emitter manifesting its individual differences [1].

The modeling of the power amplifier was first established by Saleh in 1981 based on the statistical analysis of the input and output data of the TWT power amplifier TWTA [2]. Saleh model is appropriative PA model and not widely applicable. With the development of information technology, we cannot ignore the PA nonlinearity and memory effect. They become the focus of research gradually, various models about nonlinearity and memory effect of RF power amplifier have also emerged. The nonlinear application of power amplifiers in the fine-feature extraction and individual identification of specific emitter was presented in 2007 [3]. Selecting the optimal model

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of the RF power amplifier, extracting parameters that do not change due to signal changes and that can reflect the characteristics of the specific emitter itself, use these parameters to achieve individual identification of the emitter. To understand the significance of the establishment of the PA model for the study of the nuanced feature extraction and individual identification, we first review some of the previous studies on PA modeling and conduct a specific review of the PA modeling technique.

The remainder of the paper is organized as follows. In Sect. 2, we first introduce the development of RF power amplifiers. On this basis, we explain the nonlinear and memory characteristics of the RF power amplifier and the corresponding indicators. In Sect. 3, we will mainly describe the common modeling methods and research process of the power amplifier. In Sect. 4, we mainly discussed the application of power amplifier modeling technology in the subtle feature extraction and individual identification technology. In Sect. 5, we conclude the paper.

2 Nonlinear Distortion

In this section, we discussed the development of PAs, memory effects and nonlinear distortion characteristics.

2.1 RF Power Amplifier

RF power amplifier is one of the key components in RF microwave system. Its performance directly affects the system's transmission distance and quality. The development of power amplifiers has gradually evolved with the development of wireless communications [4]. Since 1920, Class A and Class AB amplifiers have been introduced. To solve the problem of inefficiency, Doherty invented Doherty power amplifier in 1936 [5]. From the end of the 1950s to the beginning of the 21st century, the development of Class F, Class E, and inverse Class F and inverse Class D power amplifiers came into being [6, 7]. In 2003, for improving efficiency and linearity of power amplifier, Doherty PAs were combined with class AB PAs [8]. In 2005, the advent of inverse Class E power amplifiers has greatly improved the stability of the circuit [9]. Class J power amplifiers were proposed to solve the bandwidth problem in 2006 and realized design in 2009 [10]. In 2010, Continuous Class F Power Amplifiers and Envelope Tracking Amplifiers were designed, PAs have gradually become a hot research topic in wireless communications [11]. Figure 1 shows the development of PAs intuitively.

2.2 Memory Characteristics

When the input of the PA is a wideband signal, the PA will show obvious memory characteristics. The memory characteristic, that is, the current output of the amplifier, is not only related to the current input but also related to the previous input. In general, memory effects are divided into electrical memory effects and thermal memory effects according to the causes of memory effects. Among them, the reason for the electrical memory effect is impedance matching. In addition, when the modulation frequency is changed, the envelope change, the fundamental frequency, and the second harmonic

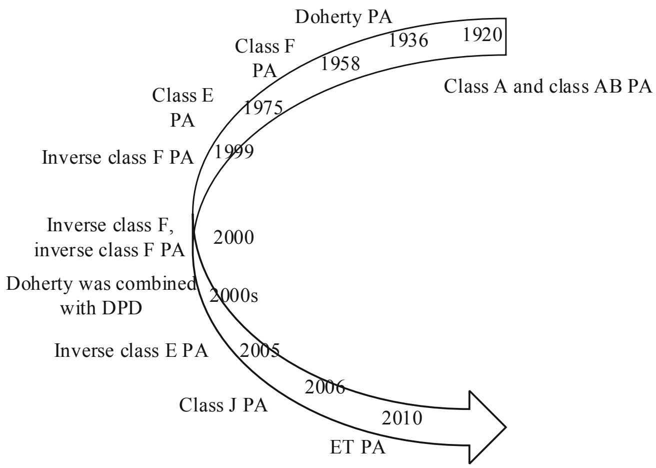

Fig. 1. The PA development process.

impedance are all important factors causing the electrical memory effect [12]. The main reason for the thermal memory effect is the change of the junction temperature of the transistor. When the power amplifier operates under high power conditions, the transistor will rapidly heat up, resulting in changes in the characteristics of the power amplifier [13].

2.3 Nonlinear Characteristics

The power amplifier is essentially a nonlinear device, which means that the amplifier output does not exhibit an ideal linear amplification relationship with the input, the gain of the power amplifier is not a constant, and generally varies with the operating frequency. The nonlinear effect characterization of power amplifiers mainly includes harmonic distortion, intermodulation distortion, amplitude/amplitude (AM-AM) and amplitude/phase (AM-PM) characteristics [14].

3 Nonlinear Models

RF power amplifier modeling is mainly divided into two kinds of physical models and behavioral models. Physical models are based on a physical description of the components of the PA and how they interact and are typically formulated as equivalent circuit models [15]. Behavioral models are models that collect input and output data of PAs and fits the data. It does not care about the actual principle of the PA, but only requires the same input and output characteristics of the PA [16].

3.1 Physical Models

In 1995, Angelov proposed an equivalent circuit model for transistors based on Ohm's law and David's law for HEMTs and MESFETs. This model can be directly used for circuit simulation [17]. In 2007, Aean and Wood et al. constructed the transistor physical model based on the physical structure of the transistor, the device size, and the physical equation [18].

3.2 Behavioral Models

In 1981, A. A. M. Saleh proposed the Saleh model for Traveling-wave tube amplifier (TWTA). According to the AM/AM and AM/PM characteristics of the amplifier, only four parameters were used to describe the amplitude and phase characteristics of the PA. However, the Saleh model is a memoryless nonlinear model because the memory effect of the amplifier at that time is not obvious. It is limited to the narrow band amplifier. In 1991, Rapp proposed a memoryless non-linear model that ignores AM-PM changes. This model only consider the AM-AM effect and compliant solid state power amplifier (SSPA) [19]. The polynomial-based memoryless model is essentially the Taylor series form used to analyze memoryless nonlinear systems. This model can be used for TWTA amplifiers as well as SSPA amplifiers. However, the degree of approximation to the actual situation is lower than both.

The Volterra series proposed by Italian mathematician Volterra was widely used in the modeling of memory amplifiers. Since 1999, the Volterra series model has been applied to PA modeling with memory effect. Because the parameters of the model will grow rapidly as the memory length of the amplifier increases, the traditional Volterra series model is only suitable for weakly nonlinear systems. Thus, in 2004, A. Zhu et al. jointly proposed the tailored Volterra model [20], which removes the secondary items in the traditional Volterra series model, and only retains the most important items, thus greatly reducing the number of parameters and the computational complexity of PA behavioral modeling. Moreover, H. Ku and JS Kenney of the Georgia Institute of Technology in the United States have proposed a power amplifier model based on memory polynomials. This model is actually a simplified version of the Volterra series model because the number of parameters is much less than the same order. With the Volterra series model of memory length, the computational complexity of model identification is greatly reduced [21].

In recent years, artificial neural networks have been used in various fields for nonlinear modeling. In the field of radio frequency, they have also been used for nonlinear modeling of power amplifier circuits and devices. Many commonly used neural network methods can be used to construct the performance of power amplifiers. Modules, such as Dynamic Neural Networks and Recurrent Neural Networks [22]. In 2006, Magnus Isaksson et al. analyzed and compared the behavior models of RF Power Amplifiers, including static polynomial, parallel Hammerstein (PH), Volterra, and radial basis function neural networks (RBFNN). For practical applications, 2G and 3G PAs are calculated and analyzed. The results show that the accuracy of the RBFNN in the entire model is better slightly than that of the PH, but the precision and accuracy outside the band are much higher than the PH model [23].

3.3 The Summary of This Section

The memoryless model mainly includes Saleh model, Rapp model and complex coefficient polynomial model, which is suitable for narrowband input and constant temperature PAs.

Wiener model and Hammerstein model are more suitable for power amplifiers with linear memory effect. Volterra models are generally suitable for weakly nonlinear power amplifiers because they have more model parameters.

Parallel Wiener model and parallel Hammerstein model are more suitable for power amplifiers with strong memory effect. The neural network model can better simulate and predict the power amplifier characteristics with strong memory effect.

Figure 2 shows the main model of the power amplifier model, from the figure can be seen the development process and progress of power amplifier model.

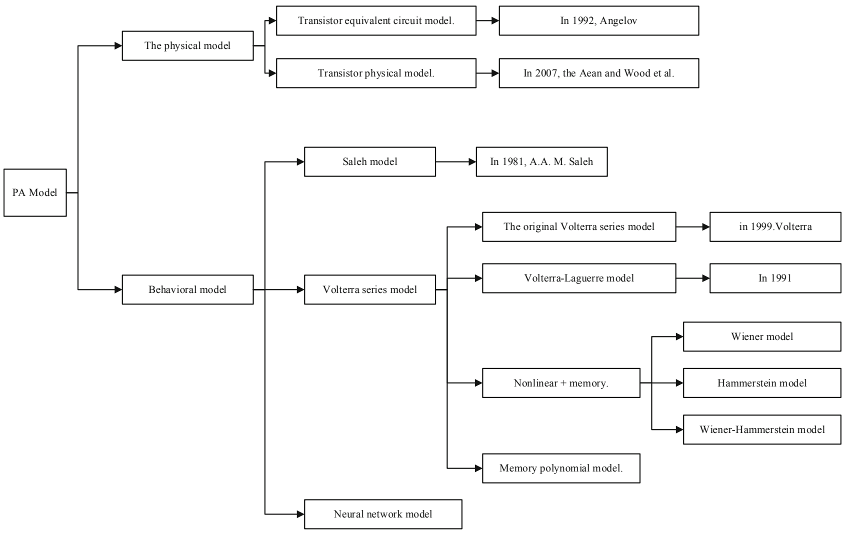

Fig. 2. The main model of the PA.

4 Application

The extraction of subtle features of radiation sources can be divided into transient signal feature extraction and steady-state signal feature extraction. Transient signal extraction mainly performs feature extraction during the startup and shutdown of radio equipment. Its advantage is that the transient signals between equipment individual are greatly different and easy to process and recognize when they are turned off [24]. However, due to the short time of transient signals. The timing is unpredictable and therefore difficult to capture and extract. Steady-state signal feature extraction is based on the signal characteristics of the wireless communication system for stable feature recognition. Signals are easily captured and extracted. However, the individual differences between devices are very small, and more complex processing and identification are required [25].

5 Conclusion

With the increasing importance of microscopic feature recognition in wireless communication field, the subtle feature recognition method based on power amplifier modeling has received more and more attention. This article aims to review the development of PA modeling, provide a great perspective for the understanding of nonlinear memory behavior modeling of PAs. From the point of view of the article, the PA modeling technology can effectively extract parameters, but we still need to pay attention to some issues, such as how to improve the parameters of the power amplifier model to build, enlarge individual feature differences, how to control the noise of the model construction effectively, and feature recognition effects.

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