A Review of Highly Efficient Class F Power Amplifier Design Technique in Gigahertz Frequencies

D.A. Sa'Ahmad, R. Sapawi, S.M.W. Masra, D.H.A. Mohamad, D.S.A.A. Yusuf, S.K. Sahari, M. Sawawi
Department of Electrical and Electronic Engineering, Faculty of Engineering,
Universiti Malaysia Sarawak (UNIMAS), Kota Samarahan, Sarawak.
srohana@unimas.my

***Abstract*—Highly efficient class F power amplifier (PA) in Gigahertz (GHz) frequencies for wireless application is reviewed in this paper. The study focused on the technique used in designing a class F PA especially at GHz frequencies. Several works on the class F PA with different semiconductor technologies from year 2001 to 2016 are discussed. Recent works on class F PA in wireless applications are examined and a comparison of the PA performances of various techniques is presented. Key performance indicators for high efficiency class F PA include power added efficiency (PAE) and output power (P_{out}).**

***Index Terms*—Class F; High Efficiency; Power Added Efficiency; Power Amplifier.**

I. Introduction

Power amplifier (PA) is a key element that boosts the electrical signal in a wireless system such as ultrawide band (UWB) [1]-[3], wireless local area network (WLAN) [4], and Worldwide Interoperability for Microwave Access (WiMAx). Class F PA is among the switching class of PAs that has widely gain interest for high efficiency and longer battery life. Class F PA delivers high efficiency at any GHz frequencies by harmonically tuned the drain voltage and current waveforms. Class F PA enables low switching driver compares to class E PA and only needs a low voltage at the output node to allow low stress on the device. An ideal class F PA is 100% efficient when the voltage and current waveforms are completely flat either as a short circuit for even harmonics or an open circuit for odd harmonics. As zero-power dissipation is present, no overlapping occurs across the active device [4].

Along with the advancement in semiconductor technology, different designs are proposed to match the optimum performance of class F PA. Technologies such as Gallium Nitride (GaN), Gallium Arsenide (GaAS), and Complementary Metal Oxide Semiconductors (CMOS) are in demand due to its compatibility with class F PA. Different approaches are presented by using an infinite number of odd- or even harmonics with lowest order being added first. Class F PA design with different techniques are analyzed in this paper. Common techniques for load input and output matching networks used in a class F PA design are such as lumped elements, transmission lines and load-pull/source-pull techniques.

This review is divided into sections as follows. Section II will analyze the problems and limitations in designing class F PA. Section III will explain in details on the proposed high efficiency PA design with perspective techniques. Section IV discussed the finding summary and the conclusion is given in Section V.

II. Problem and Limitation

A demanding PA is a PA with high efficiency, high output power, good gain and high linearity. Class F PA approach is first developed to increase the efficiency of linear PAs such as class A and AB. Among the switching (non-linear) PAs, class F PA is developed in frequency domain while class D and E are in time domain. This allow class F PA to boost the efficiency [5]. Basic component in any class F PA design is the matching input and output networks, which consist of an inductor and a capacitor. The designing and implementation of class F in radio frequency (RF) PAs remain challenging prior to the impedance adjustments for each harmonic network, which must be terminated per the number of order harmonic. The number of orders in a circuit can be up to fourth order. The number of harmonic determines the voltage and current waveforms as an overlapped waveform will reduce the efficiency. The number of harmonic presents in a class F design is a trade-off between linearity and efficiency while reducing power consumption in a transistor enables efficiency enhancement. Thus, the research is still being performed on the design of class F as termination of harmonics are impractical as well as the ability to compromise with other performance parameters such as gain, output power and stability.

III. Load Matching Network Techniques

Class F PA design is first recognized after it is being implemented and its general descriptions are presented in 1919. The problems in applying lumped element into the output networks of very high frequency (VHF) PA designs are noted in [6]. Thus, quarter-wavelength transmission lines are proposed to control the harmonics. Then, the first application of ultra-high frequency (UHF) class F PA is presented in [7]. Switching class D, E and F PAs are increasingly became a popular approach to improve the efficiency of UHF and microwave PAs although it is a difficult task to find transistors which capable to quickly switch the PAs at VHF. However, [8-9] proposed the idea of a class F PA with maximally flat waveform in 1997 before expanding his work to determine the relation of number of harmonics used in the design with the efficiency and upper