Reduction of the THD in the Class F3 Amplifier System

G Padmanabha Sivakumar[1], K.Umapathy[2]
[1].Research Scholar, Department of EIE, SCSVMV University, Kanchipuram, Tamilnadu.
[2] Associate Professor, Dept.of ECE, SCSVMV University, Kanchipuram, Tamilnadu

Abstract— This work deals with the modeling and the simulation of the closed loop controlled class F3 power amplifier. The commercial low frequency AC is converted into DC using an uncontrolled rectifier. The DC is converted into high frequency AC using class F3 amplifier. Open loop systems with and without EMI filter are simulated and the corresponding results are presented. The EMI filter is proposed at the input side to reduce the THD in the source current.

Keywords— nonlinear capacitance, nonoptimum operation and zero-voltage switching (ZVS), power amplifier.

I. Introduction

The nonoptimum operation of the amplifier occurs when the zero-voltage switching (ZVS) condition is satisfied, but the zero-voltage-derivative switching (ZDS) is not equal to zero at the switch turns ON instant. The concept of nonoptimum operation of the Class-E amplifier was defined in the beginning of the Class-E history [3][5]. The first research on nonoptimum operation has been done by Raab [7]. In this paper, the degree of freedom for the design amplifier was increased, and the ZDS condition was removed. The mixed-mode power amplifiers are the good choice for obtaining high-power and high conversion efficiency. The optimum conditions of the mixed-mode power amplifier families with a shunt capacitor have been presented in [9]–[10]. But the exact analysis on switch mode PAs are not presented. However, all of the Class-E/F amplifier analyses focus on how to achieve the optimum operation. Many power electronic devices only need to ZVS or zero-current switching (ZCS) condition [1]. In order to reach a Class E/F power amplifier with good performance, some methods have been suggested and implemented. The first method employs the push/pull topology to Class E/F inorder to short odd harmonic like inverse Class F (demonstrated Class E/F PA). This configuration improved the amplifier performance such as maximum operating frequency and caused the reduction of maximum switching voltage to have maximum output power capability [11], which only in the ZVS is considered. But the nonoptimum condition in the push/pull topology is considered with linear shunt capacitance. The second method is harmonic tuning in which a resonance network is inserted between the drain node and ground. In comparison with Class E/F amplifier, the performance of the power amplifier can be improved at the cost of the complicated circuit design [10].

In this paper, the simulink results of the Class-E/F_3 power amplifier with a shunt capacitor at the nonoptimum operation are presented. For the verification of our analytical expressions, design examples of the Class-E/F_3 ZVS amplifier are presented. The design equations, switch, and output waveforms are obtained as a function of the phase shift and DC supply voltage. By changing the peak switch voltage and the peak switch current, the phase

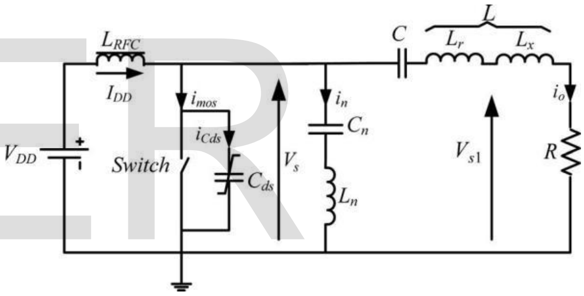

Fig. 1. Circuit and model of class-E/F_n power amplifier

shift is changed, so these two parameters can be considered as a design specification. The measurement and simulation results are in good agreement with the analytical results. Design procedures are given for one example of Class E/F_3 amplifiers for nonoptimum operation. In the example, operating frequency, input DC supply voltage, load resistance, and peak switch voltage are given as design specifications. In the nominal circuit, only three parameters such as operating frequency, input DC supply voltage, and load resistance can be designated. On the contrary, the example procedures presented here have four given parameters. The additional parameters, peak switch voltage or peak switch current can be taken into account in the design procedure. This power amplifier is implemented with the MOSFET. From the breakdown voltage point of view, it is proven that the MOSFET is a proper device. The above literature does not deal with reduction of THD in the source current of class F3 amplifier system. This work proposes EMI filter at the input to reduce harmonics in the source current.

II. Simulation Results

The class F3 amplifier with RL load is shown in Figure 2.1.The DC output voltage of rectifier is shown in

ISSN 2229-5518

Figure2.2. The voltage across the load and the output current are shown in figures 2.3 and 2.4 respectively. The voltage and current are sinusoidal due to the series resonance. The average power output is shown in figure 2.5. The output power is 180 watts. The gate voltage and the output voltage of the MOSFET are shown in figure 2.6.The simulation is done for various values of Toff and the corresponding powers are summarized in Table 1. The variation of power with increase in Toff is shown in the figure 2.7. The power decreases with the increase in the Toff value.

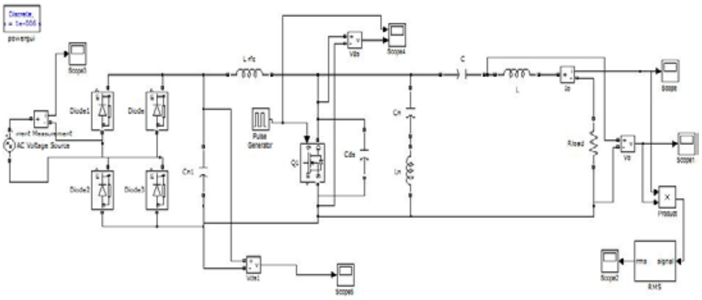

Fig 2.1: Class F3 Amplifier

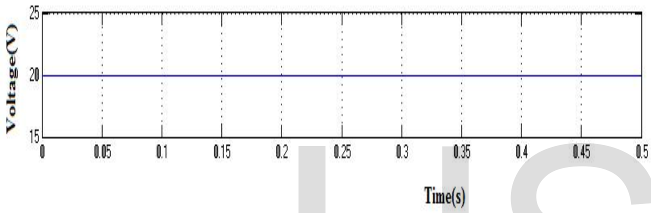

Fig 2.2: DC output voltage of rectifier

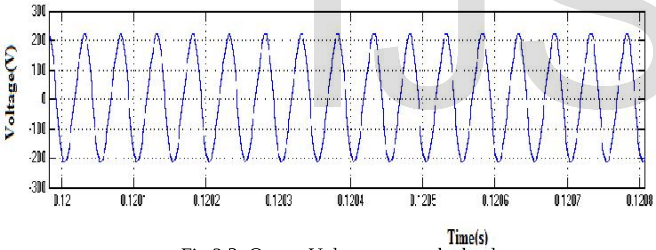

Fig 2.3: Output Voltage across the load

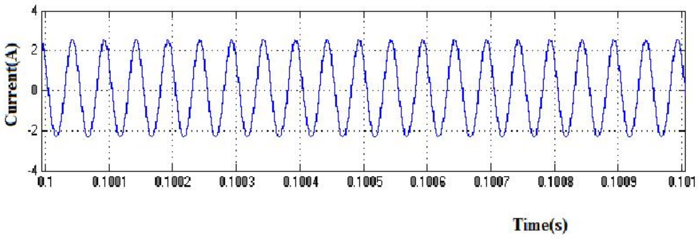

Fig 2.4: Output current in the load

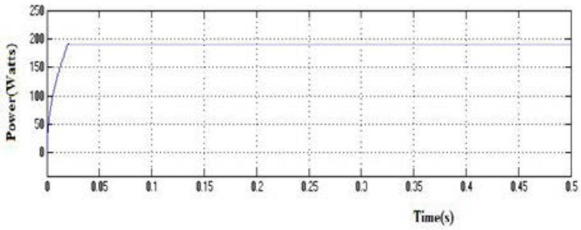

Fig 2.5: Output power across the load

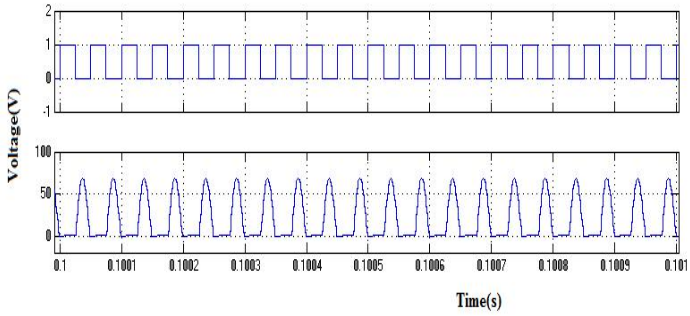

Fig 2.6: Switching Pulses for Q1 & V_{ds}

Table 1: Variation of power with T_{off}

S.No	Toff	Power
1	20	248
2	30	227.5
3	40	196.5
4	50	191
5	60	191
6	70	188.5
7	80	134
8	90	41

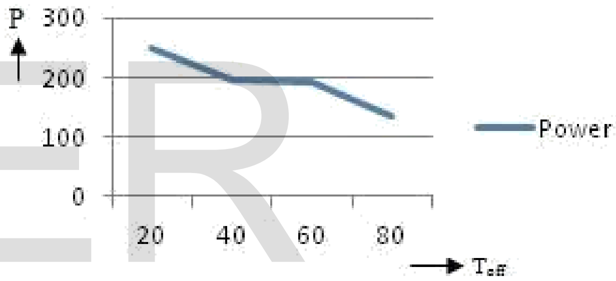

Fig 2.7: The variation of power with increase in voltage

The class F3 amplifier without EMI filter is shown in figure 3.1. FFT analysis is done for the source current and THD is obtained. The frequency spectrum is shown in Fig 3.2.

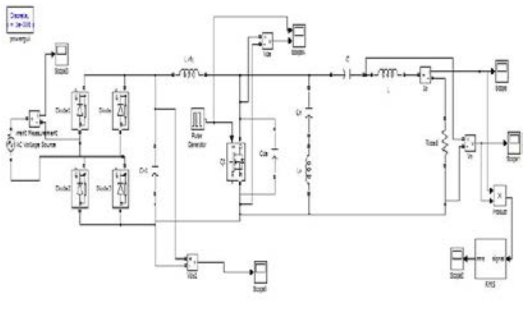

Fig 3.1: Class F3 Amplifier without filter

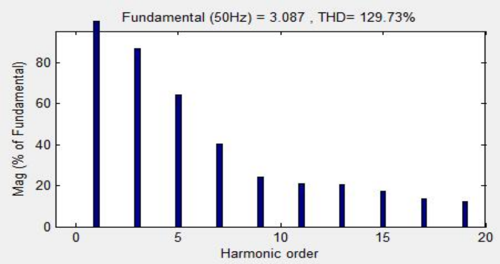

Fig 3.2: FFT Analysis for source current without filter

ISSN 2229-5518

The THD is 129%. The class F3 amplifier with EMI filter is shown in the Fig 3.3. The EMI filter is connected at the input to reduce the THD. The THD value is 1.1%.

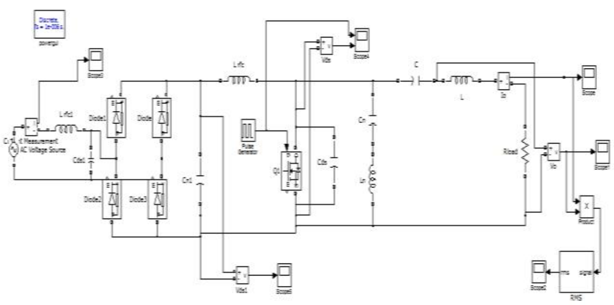

Fig 3.3: Class F3 Amplifier with filter

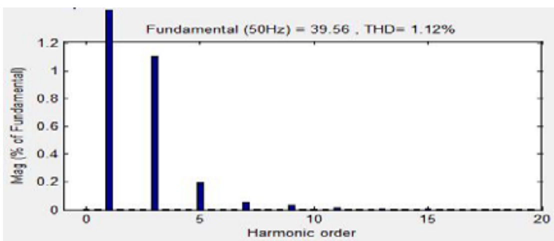

Fig 3.4: FFT Analysis for source current for with filter

III. Conclusion

The class F3 amplifier system is successfully designed, modeled and simulated using the elements of simulink library. Simulation results with and without EMI filter are compared and it is observed that the THD in the source current is drastically reduced by introducing the EMI filter. The variation of power with the variation in the off time is also presented. The advantages of this amplifier system are reduced number of passive elements and single power switch. The disadvantage is that the circuit requires three capacitors.

The scope of the present work is to simulate the open loop controlled class F3 system. The closed loop system will be investigated in the future.

IV. References

[1] B. Yuan, X. Yang, D. Li, Y. Pei, J. Duan, and J. Zhai, “A current-fed multi resonant converter with low circulating energy and zero-current switchingfor high step-up power conversion,” IEEE Trans. Power Electron., vol. 26,no. 6, pp. 1613–1619, Jun. 2011.

[2] Hayati, M.; Sheikhi, A.; Grebennikov, A., "Design and Analysis of Class E/F _{\bf 3} Power Amplifier with Nonlinear Shunt Capacitance at Nonoptimum Operation," Power Electronics, IEEE Transactions on , vol.30, no.2, pp.727,734, Feb. 2015

[3] T. Suetsugu and M. K. Kazimierczuk, “Design equations for suboptimum operation of class E amplifier with nonlinear shunt capacitance,” in Proc.IEEE Midwest Symp. Circuits Syst., vol. 5, Vancouver, Canada, May 2004,pp. 560–563

[4] F. You, S. He, X. Tang, and T. Cao, “Performance study of a Class-E power amplifier with tuned series-parallel resonance network,” IEEE Trans. Microw. Theory Tech., vol. 56, no. 10, pp. 2190–2200, Oct.2008.

[5] A. Mediano and N. O. Sokal, “A Class-E RF Power amplifier with a flat-top transistor-voltage waveform,” IEEE Trans. Power Electron., vol. 28, no. 11, pp. 5215–5221, Nov. 2013.

[6] T. Suetsugu and M. K. Kazimierczuk, “Design procedure of class-E amplifier for off-nominal operation at 50% duty ratio,” IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 53, no. 7, pp. 1468–1476, Jul. 2006.

[7] T. Suetsugu and M. K. Kazimierczuk, “Analysis of subnominal operation of Class-E amplifier.” Presented at the IEEE Midwest Symp, CircuitsSyst., Cairo, Egypt, Dec. 2003., Cairo

[8] F. H. Raab, “Suboptimum operation of Class-E RF power amplifiers,” in Proc. RF Technol. Expo., Santa Clara, CA, USA, Feb. 1989, pp. 85–98.

[9] R. Beiranvand, B. Rashidian, M. R. Zolghadri, and S. M. H. Alavi, “A design procedure for optimizing the lc resonant converter as a wide out-put range voltage source,” IEEE Trans. Power Electron., vol. 27, no. 8,pp.3749–3763,Aug.2012.

[10] Z. Kaczmarczyk, “High-efficiency class E, E/F, and E/F inverters,” IEEETrans. Ind. Electron., vol. 53, no. 10, pp. 1584–1593, Oct. 2006.

[11] F. You, S. He, X. Tang, and X. Deng, “High-efficiency single-ended Class-E/F2 power amplifier with finite DC feed inductor,” IEEE Trans. Microw. Theory Tech., vol. MTT-58, no. 1, pp. 32–40, Jan. 2010.

[12] S. D. Kee, I. Aoki, A. Hajimiri, and D. Rutledge, “The class- E/F family of ZVS switching amplifiers,” IEEE Trans. Microw. Theory Tech., vol. 51, no. 6, pp. 1677–1690, Jun. 2003.