Design & Performance Evaluation of Switching Mode Class F Power Amplifier

Md. Jashim Uddin,[1] R. M. Murad Hasan ,[2] Mohammad Saiful Islam [3]

[1]Department of Electronic & Telecommunications Engineering, International Islamic University Chittagong, Bangladesh

[2]Department of Electrical and Electronic Engineering, Chittagong University of Engineering & Technology, Bangladesh

jashimcuet@yahoo.com, murad_eee@cuet.ac.bd,saifuliiuc92@gmail.com

***Abstract*— A design of a switching mode class F power amplifier is proposed and analysed. A power amplifier deals with broad frequency typically from megahertz (MHz) to gigahertz (GHz). The main purpose of a power amplifier is to boost radio signal to a sufficient power level for transmission. Designing a switching mode class F power amplifier is critical because it involves solving several contradicting requirement. The most important parameter is the linearity and the gain of the amplifier. This research paper presents the design technique and the development of switching mode class F power amplifier operating at 2.5 GHz frequency using specified gain method. At 2.5 GHz, gain of the amplifier is obtained 8.80 dB and the input/output return loss is less than -5 dB. Theoretical analysis and simulated characterizations confirm the amplifier's performance.**

***Index Terms*- SMPA, S-parameter, Return loss, VSWR.**

I. Introduction

In this fast-growing world, telecommunication technology is being developed quickly with a rapidly increasing demand. The appearance of smart phones is a big evolution and it changes the way people use cell phones. With all the nice features of smart phones such as internet browsing, video conferencing, online gaming, file transferring and GPS, the speed of communication is getting faster in order to meet the needs. As data transfer rate increases, more power is consumed in those cellular network infrastructures. An important figure of merit, gain is the focus of this document and will be discussed later. The goal of this project is to provide solutions for improving the gain of those infrastructures [1].

Switching-mode power amplifiers have been proposed and developed for the applications that require high efficiency. By operating the transistor as a switch rather than a current source and employing appropriate output harmonic terminations, the amplifiers can achieve 100 % efficiency in principle [2]. The linearity of switching-mode amplifiers, however, is very poor since the amplifiers are driven into a deep saturation region. Therefore, typical applications of switching-mode amplifiers are RF power generation systems in ISM fields and communication systems modulated with a constant-envelope signal.

A power amplifier is an electronic device that receives an electrical signal and reprocesses it to amplify, or increase, its power [2]. The boost in power is achieved by significantly increasing the input signal's voltage. A power amplifier is used to power an output source, such as a stereo speaker, a relay or a motor. The three main components of power amplifiers are the power supply, the input stage and the output stage. The power supply receives alternating current (AC) from an electrical outlet and converts it to direct current (DC). The power supply sends the DC signal to the input stage, where it is processed and prepared for the output stage. The signal is then transferred to the output stage, where the actual amplification of the signal takes place. The output stage is connected to the speaker.

Amplifiers can also be classified into two categories: biasing class and switching class [3]. In biasing class, amplifiers such as Class A,B, AB and C amplifiers are classified based on their quiescent point (bias point) or output Current Conduction Angle (CCA) θ. θ is defined as the fraction of RF input drive signal where non-zero current is flowing through the device [4]. Fig. 1 shows the family tree of amplifier classes.

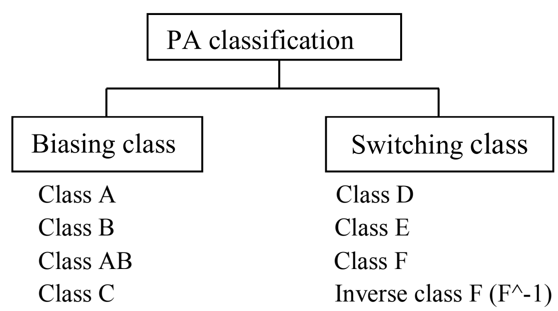

Fig. 1 Family tree of PA classification.

II. Principles of Class F Power Amplifier

Class-F is basically derived from Class-B with multiple harmonic resonant filters. The sinusoidal voltage waveform of Class-B is shaped to a rectangular one for Class-F by appropriate harmonic tuning: open circuit at all odd harmonics and short circuit at all even harmonics. The ideal Class-F amplifier is implemented conceptually with bandstop filters, as in Fig. 2. The ideal drain voltage and current waveforms of Class-F amplifiers are shown in Fig. 3. Obviously, the output circuitry of Class-F amplifiers is very complicated in order to obtain the ideal voltage and current waveforms. However, in practical Class-F amplifiers, harmonic filters are usually employed only up to third harmonic although the efficiency is a little degraded. Class-F^1 (inverse Class-F) is the dual mode of Class-F operation. By terminating open circuit at even harmonics and short circuit at odd harmonics, the voltage and current waveforms are swapped from those of Class-F, so that half sinusoidal voltage and rectangular current waveforms are produced.

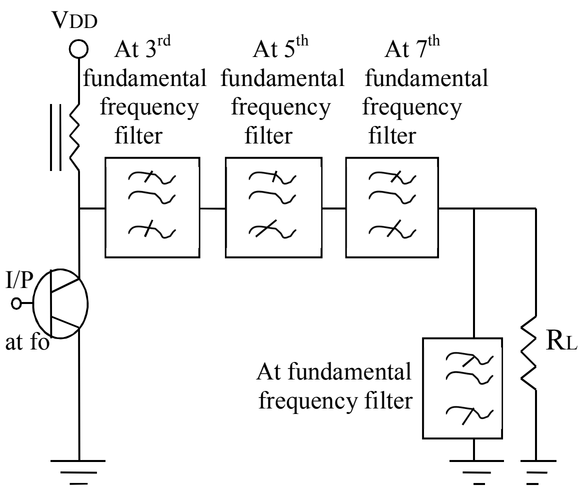

Fig. 2 Basic circuit diagram of class F amplifier.

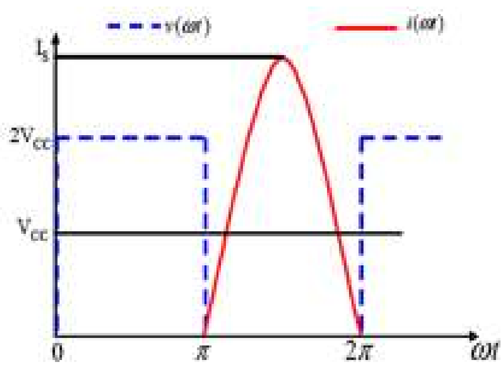

Fig. 3 Ideal class F drain current and voltage waveforms [5].

III. Design Methodology

Ansoft Designer SV 2.2 is used for the simulation of the microwave amplifier. The transistor chosen is BFR91 and it is biased at V_{DD}= 28 V. The design is based on the S-parameters of the transistor. The S-parameter of BJT at 3 GHz is used in this design. For the specified gain method the effective measure for the stability test is $S_{11} < 1$ and $S_{22} < 1$ in place of the K-Δ test, if this condition is satisfied then transistor is unconditionally stable.

$$K = \frac{1 - S11^2 - S22^2 - \Delta^2}{2\ S12\ S21} > \tag{1}$$

$$\Delta = S11\ S22 - S12\ S21 < 1 \tag{2}$$

Maximum gain at source and load values are given by-

$$G_{SMAX} = \frac{1}{1 - S11^2} \tag{3}$$

$$G_{LMAX} = \frac{1}{1 - S22^2} \tag{4}$$

IV. Analytical Analysis

Designing of the class F power amplifier, the BJT has been considered because it satisfies the frequency range of the designing frequency. For which the S-parameters at 2.5GHz (Zo=50Ω) are listed in table1.

TABLE I
S-Parameter for Transistor

Scattering parameter	Magnitude	Angle
S_{11}	0.17	128.2
S_{12}	0.14	62.0
S_{21}	3.21	61.3
S_{22}	0.34	-36.2

From the above parameter value, G_{SMAX} and G_{LMAX} are calculated by using equation (1) and (2):

$$G_{SMAX} = 0.13 \text{ dB}$$
$$G_{LMAX} = 0.53 \text{ dB}$$

The gain of mismatching transistor is

$$G_0 = S_{21}{}^2 = 10.13 \text{ dB}$$

The maximum unilateral transducer gain is

$$G_{TUMAX} = 10.79 \text{ dB}$$

V. Simulation Results

The calculations done in the analytical section have been applied in the ANSOFT Designer SV 2.2. The design of the proposed amplifier is shown in Fig. 4.

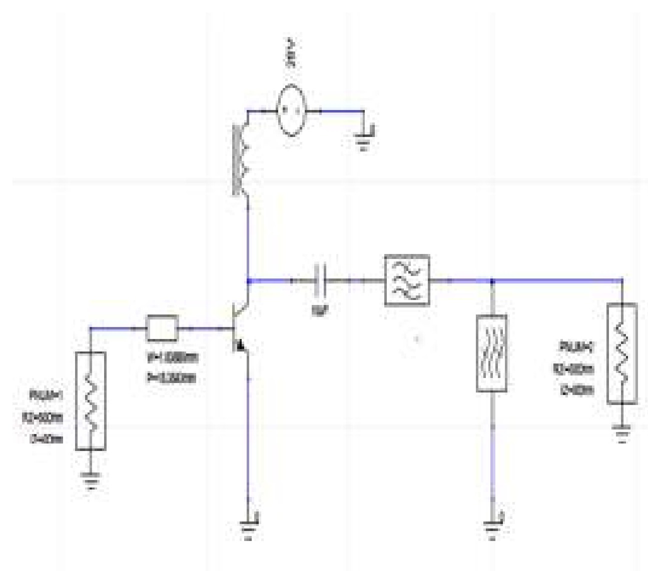

Fig. 4 Schematic diagram of class F power amplifier

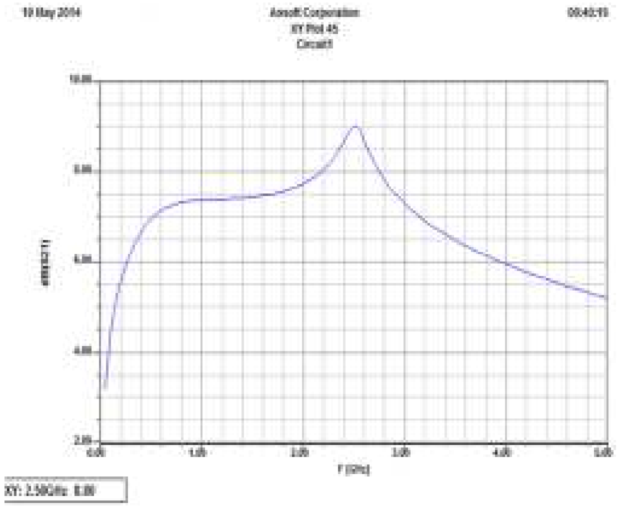

Fig. 5 Gain (S21) vs. Frequency.

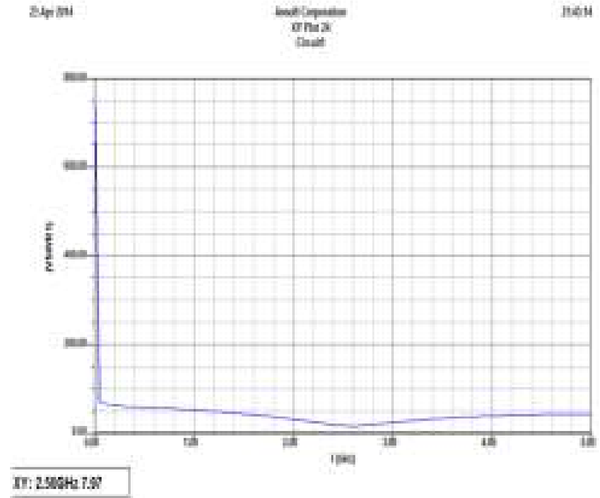

Fig. 8 VSWR (input) vs. Frequency.

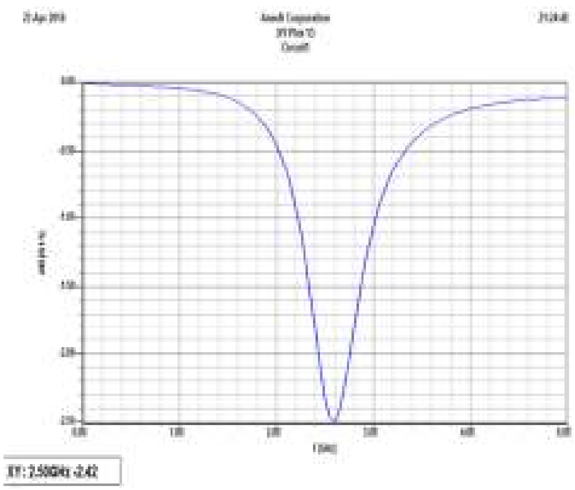

Fig. 6 Return loss (S11) vs. Frequency.

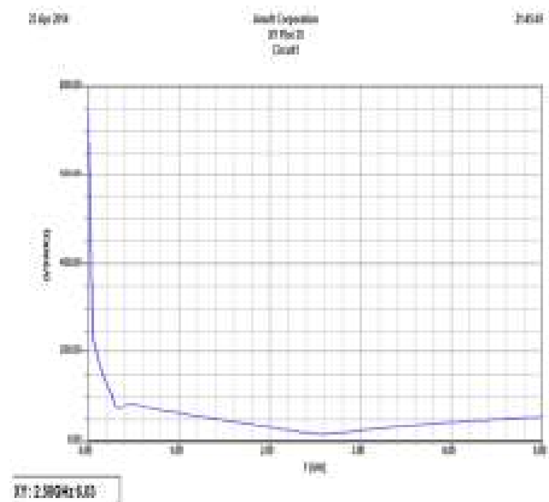

Fig. 9 VSWR (output) vs. Frequency.

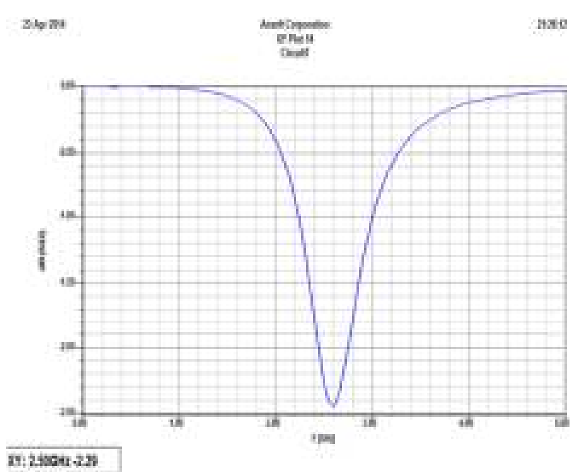

Fig. 7 Return loss (S22) vs. Frequency.

Fig. 5 shows the graph of gain versus frequency and the designed amplifier achieves the gain of 8.80 dB. Fig. 6 & Fig. 7 shows the graph of return loss versus frequency where the return loss of amplifier at port 1 is -2.42 dB and return loss at port 2 is -2.29 dB respectively. Fig. 8 shows the graph of VSWR at port 1 versus frequency where it is achieved of 7.97. The graph of VSWR at port 2 versus frequency is shown in Fig. 9 where amplifier achieved the VSWR of 6.03. In Table 2 it has been seen that at 2.5 GHz, the amplifier gain after calculation is 10.79 dB, which is greater than simulation result (8.80 dB). After all, the design parameters and simulated results proved that switching mode class F power amplifier can be designed for microwave application.

TABLE II
COMPARISON BETWEEN SIMULATED RESULTS AND ANALYTICAL RESULTS

Serial no.	Parameter	Simulated result at 2.5 GHz	Analytical result at 2.5GHz
1	S_{11}	-2.42 dB	-7.695 dB
2	S_{21}	-2.29 dB	-4.685 dB
3	S_{22}	8.80 dB	10.79 dB
4	VSWR(input)	7.97	2.8
5	VSWR(output)	6.03	2.3

VI. CONCLUSIONS

The purpose of this work is to design and simulate class F power amplifier operating at 2.5 GHz. From the design parameters and simulated results it is proved that class F power amplifier can be designed for microwave application which target the suitable gain (S21). The amplifier gain after simulation is 8.80 dB, which is less than analytical result (10.79 dB) and this gain result can be considered for the proposed design. The VSWR at port 1 is 7.97 and VSWR at port 2 is 6.03, it means VSWR at output port becomes less and less power reflection is obtained. The proposed procedure is shown to be very precise in designing power amplifier using specified gain technique and it is very efficient method for the low frequency amplification in microwave frequency range and it is often used in communication system.

ACKNOWLEDGMENT

Alhamdulillah, all praises to ALLAH for the strengths and His blessing in completing this thesis. I would like to thank the members of Microwave Application Group for helpful discussion and encouragement. Also, I would like to express my thanks to power amplifier group members.

REFERENCES

[1] P. Colantonio, F. Giannini, E. Limiti, "*High efficiency RF and microwave solid state power amplifier*", John Wiley & Sons, Ltd, 2009

[2] M. Albulet, *RF Power Amplifiers*. Atlanta, GA: Noble Publishing, 2001.

[3] D. M. Pozar, *Microwave Engineering*, 2nd ed. New York: Wiley, 1998.

[4] R. Gilmore and L. Besser, *Practical RF Circuits Design for Modern Wireless Systems, Volume II, Active Circuits and Systems*.

[5] S. Kee, "The Class E/F family of harmonic-tuned switching power amplifiers," *Ph.D. Thesis,* California Institute of Technology, Pasadena, CA, 2001.