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Class-F Microwave Amplifier Design Using GaAs-HBT and GaN-HEMT

Kazuhiko Honjo, Ryo Ishikawa, Tsuyoshi Yoshida and Cong Zheng

The University of Electro-Communications
1-5-1, Chofugaoka, Chofu, Tokyo 182-8585, Japan
Phone: +81-42-443-5237, E-mail: honjo@ice.uec.ac.jp

1. Introduction

Increasing power efficiency is a fundamental requirement for microwave power amplifiers. A basic principle to achieve high power efficiency is to avoid overlapping of current and voltage waveforms at transistor terminals. To reach this ideal goal, there are two categories of the methods. The first category called as class-D is a time domain approach, where switching devices are necessary to shut-down or switch on the amplifier circuit with a sufficient switching speed. The second category is a frequency domain approach, where the transistor load impedances are set to be open for odd-order higher harmonic frequencies, while retaining a power factor as be unity for a fundamental frequency as described in Fig.1. However, up to the 3rd order higher harmonic frequency has been considered in the previous class-F amplifier design reports. This paper reports further design consideration for class-F amplifiers.

2. Increase in Harmonic Frequency Number

Circuit topologies for a class-F load circuit treating more than 4th order harmonic frequency both with the distributed circuit form (Fig.2) and with the lumped element circuit form were proposed (Fig.3) by one of the present authors [1]-[2]. Inverter characteristics for a quarter wave length line, and alternatively appearing zeros and poles in a reactance network are effectively used. For real implementation of proposed circuits, low loss characteristics are required not only for a fundamental frequency but also for the other harmonic frequencies. However, commercially available microwave discrete lumped element inductors and capacitors are still insufficient for 1.9GHz applications in viewpoints of circuit loss and self-resonance frequency. Meanwhile, recent advances in low tanδ(=0.0023) microwave resin material (ε_r=3.7) with thick Cu metal enable low loss and low cost planar micro-stripe circuits up to Ku band.

For class-F circuit operation, active devices have to possess sufficient power gain even at the highest order of harmonic frequency. A frequency region retaining maximum stable power gain (MSG), where K factor is less than unity, is suitable for the harmonic frequency treatments. And also, parasitic shunt capacitances for an active device deteriorate class-F load circuit condition especially for the open circuit condition for odd-order higher harmonic frequencies even if some readjustment are made for the load circuit. As an example, Fig.4 shows simulated dependences of the power added efficiency, PAE, on the treated harmonic number and on the collector doping density for an InGaP/GaAs HBT

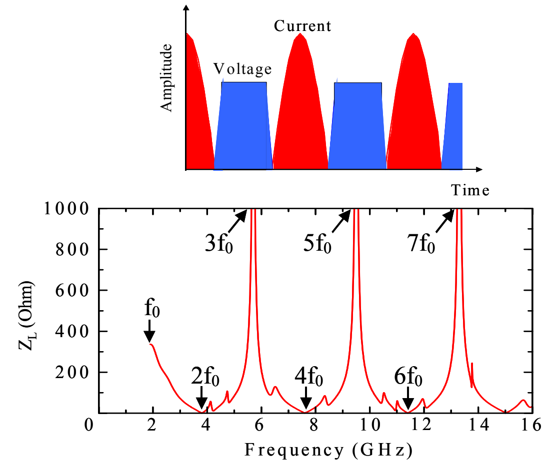

Fig.1 Load condition and time domain wave form

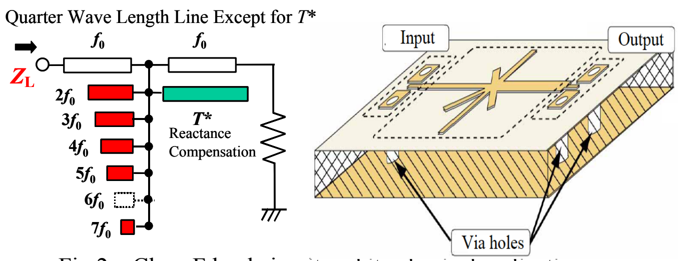

Fig.2 Class-F load circuit and its physical realization

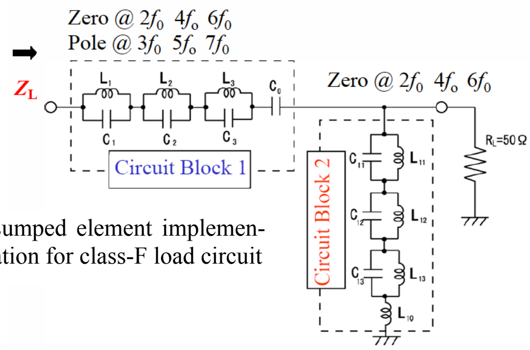

Fig.3 Lumped element implementation for class-F load circuit

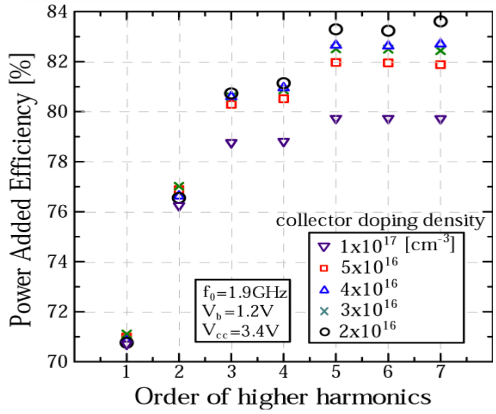

Fig.4 Simulated PAE dependance on collector doping level for InGaP/GaAs HBT

amplifier, operating at 1.9 GHz. The collector doping optimization delivers 4% increase in PAE.

3. Class-F Amplifier using GaN-HEMT

The distributed element class-F circuit was applied to AlGaN/GaN HEMT's supplied from Toshiba (gate length: 0.4 microns, gate width: 100 X 4 microns, f_{max} : 50GHz). To confirm sufficient power gain for the class-F amplifier, a conversion point frequency, f_{con}, from MSG to MAG (maximum available power gain) was checked by simulation and measurement for the AlGaN/GaN HEMT. In the simulation, Maxwell's equations and semiconductor device equations were co-simulated using FDTD (Finite Difference Time Domain) method [4]. A sufficient power gain (f_{con}, = 18GHz) was observed with the gate finger length shorter than 100 microns for 1.9 GHz class F amplifiers. A set of large signal parameters for an EE-HEMT model was extracted for the AlGaN/GaN HEMT using an on-wafer probe station. DC characteristics were measured and modeled under a long bias pulse condition so that the simulated device temperature can be set to be close to physical operating device channel temperature as shown in Fig.5.

Fig. 6 shows a photograph for a fabricated 1.9 GHz AlGaN/GaN HEMT class-F amplifier considering up to 5^{th} order of higher harmonic frequency. Measured impedance for the class-F load and a modified class-F load are shown in Fig.7. The modification was made for adjusting amplifier nonlinear transfer functions including a transistor to retain the ideal output waveform. As shown in Fig.8, the amplifier delivered an 80.1% drain efficiency and a 75.2 % PAE, which includes whole circuit losses. A loss for fabricated class-F load circuit was 0.25dB at 1.9 GHz. A maximum drain efficiency of 84.8 % and a maximum PAE of 79.6 % are estimated for the AlGaN/GaN HEMT chip.

4. Conclusion

Design considerations for class-F microwave amplifiers considering more than 4^{th} order harmonic frequency are described. Applying this method to InGaP/GaAs HBT and AlGaN/GaN HEMT, excellent power efficiency has been obtained.

Acknowledgement

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References

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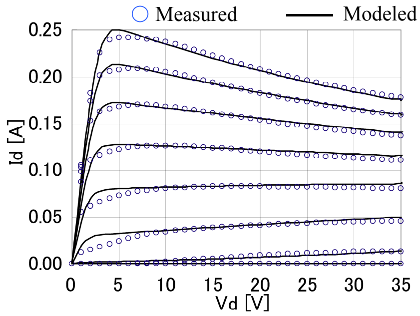


Fig.5 I-V characteristics fitting using EE-HEMT model

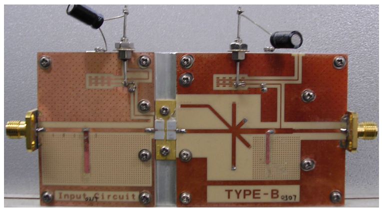


Fig.6 Photograph for GaN HEMT class-F amplifier

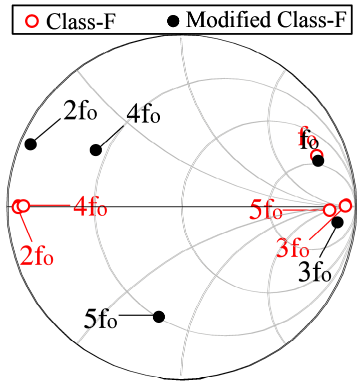
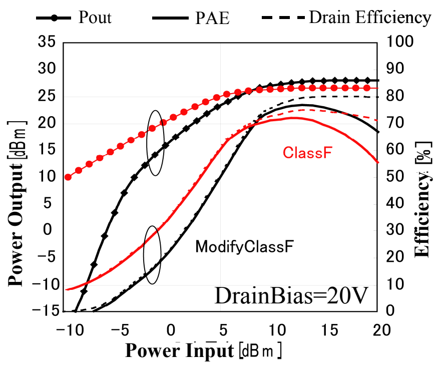


Fig.7 Measured impedance for class-F load circuit and modified class-F load circuit



	PAEmax	ηmax
Class-F	72.0%	76.9%
Modified Class-F	75.2%	80.1%

Fig.8 Measured characteristics for GaN HEMT class-F amplifier operating at 1.9 GHz