A 2.2 GHz High-Efficiency Third-Harmonic-Peaking Class-EF Power Amplifier


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A 2.2 GHz High Efficiency Third-Harmonic-Peaking Class-EF Power Amplifier

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Abstract—This paper presents the design and implementation of a low-voltage-stress Class-EF power amplifier (PA) with extended maximum operating frequency, named as ‘third-harmonic-peaking Class-EF PA’. A novel transmission-line load network is proposed to meet the Class-EF impedance requirements at the fundamental, all even harmonics, and third harmonic components. It also provides an impedance matching to a 50 Ω load. A more effective λ/8 open- and shorted-stub network is deployed at the drain of the transistor replacing the traditional λ/4 transmission line. Implemented using GaN HEMTs, the PA delivered 39.2 dBm output power with 80.5% drain efficiency and 71% PAE at 2.22 GHz.

Index Terms—Class-EF, high efficiency, low voltage stress, power amplifiers, switched mode amplifiers, harmonic termination.

I. INTRODUCTION

The Class-EF power amplifier (PA) combines the advantages of both Class-E and Class-F PAs. It offers a soft-switching operation inherited from Class-E as well as a low peak switch voltage (i.e. twice the supply voltage) inherited from Class-F, [1].

The maximum operating frequency \( f_{\text{MAX}} \) of the Class-EF PA for a prescribed output power and supply voltage is strictly constrained by the transistor output capacitance \( C_{\text{OUT}} \). At high frequencies, this output capacitance is typically larger than the shunt capacitance \( C \) required for optimum Class-EF mode operation. To overcome this problem, a new Class EF topology, Fig. 1, is proposed where an extra capacitance \( C_X = C_{\text{OUT}} - C \) is incorporated in the circuit.

\[ \text{Fig. 1. Low-voltage-stress Class-EF PA with enhanced maximum operating frequency.} \]

II. PRINCIPLES OF OPERATION

The transmission lines TL_1-TL_4 combined with \( C_X \) in Fig. 1 are designed to provide a short-circuit termination for all even harmonics, an open-circuit termination for the third harmonic and an optimum load impedance \( (R + j\omega L) \) at the fundamental frequency. It also simultaneously provides an impedance matching to a 50 Ω load.

At the third harmonic frequency, the \( \lambda/4 \)-open stub TL_2A would short the series transmission line TL_1. This shorted line will act as an inductance, which resonates with \( C_X \) at \( 3f_0 \). The open and shorted \( \lambda/8 \) stubs (TL_3 and TL_4) make the drain shorted at \( (4m-2)^{th} \) and \( (4m)^{th} \) harmonics, respectively, where \( m = 1, 2, 3, \) etc. They both should resonate at the fundamental frequency and odd harmonics. At the fundamental frequency \( f_0 \), the load network elements are designed, based on the theory and mathematical approach given in [1], such that the optimum load is seen at \( f_0 \). A wave trap (TL_2B) is added to suppress the fifth harmonic component.
III. FABRICATION AND MEASUREMENT

We have designed the amplifier on a ROGERS RO4003C printed circuit board with squared dimensions of 4.2 cm using 10-W CREE CGH40010F GaN HEMTs, Fig. 2. The amplifier was fed by a continuous-wave signal from Agilent Technologies E8257D signal generator, and the output power was measured by Agilent Technologies N9320A spectrum analyser. Gate and drain biasing was applied using a Thurlby 32-V DC supply. Since the maximum output power of the signal generator is limited to 16 dBm, an identical replica of the amplifier is inserted as a driver.

![Gate biasing circuit](image)

Fig. 2. The fabricated third-harmonic peaking Class-EF PA.

Fig. 3 shows measured output power, gain, drain efficiency and PAE when sweeping the input power at 2.22 GHz, gate-source voltage $V_{GS} = -2.7$ V, and drain-source voltage $V_{DC} = 28$ V. Best efficiency performance was realized at output power of 39.2 dBm and gain $G = 9.3$ dB when both drain efficiency and PAE peaked at 80.5% and 71% respectively. The dc voltage was swept at input power = 29.9 dBm and 2.22-GHz frequency, as shown in Fig. 4. Results show that drain efficiency and PAE remained above 77.4% and 63.2% respectively when the voltage varied from 21 to 32 V. Table 1 shows a comparison with previous relevant works.

![Output power, gain, drain efficiency and PAE versus input power](image)

Fig. 3. Measurement results: output power, gain, drain efficiency and PAE versus input power ($V_{GS} = -2.7$ V, $V_{DC} = 28$ V, $f_0 = 2.22$ GHz).

![Output power, gain, drain efficiency and PAE versus dc voltage](image)

Fig. 4. Measurement results: output power, gain, drain efficiency and PAE versus dc voltage ($V_{GS} = -2.7$ V, $V_{DC} = 29.9$ dBm, $f_0 = 2.22$ GHz).

Table 1. Comparison with previous relevant works.

<table>
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<th>Class</th>
<th>Freq (GHz)</th>
<th>$P_{OUT}$ (dBm)</th>
<th>$\eta_D$ (%)</th>
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REFERENCES