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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.

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 λ/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 λ/8 stubs (TL\(_3\) and TL\(_4\)) make the drain shorted at \((4m-2)\)\(^{th}\) and \((4m)\)\(^{th}\) harmonics, respectively, where \(m = 1, 2, 3, \ldots\). 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.

![Fig. 2. The fabricated third-harmonic peaking Class-EF PA.](image)

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.

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

Table 1. Comparison with previous relevant works.

<table>
<thead>
<tr>
<th>Class</th>
<th>Freq (GHz)</th>
<th>$P_{OUT}$ (dBm)</th>
<th>$\eta_D$ (%)</th>
<th>$V_{DC}$ (V)</th>
</tr>
</thead>
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<tr>
<td>[2] E</td>
<td>2.5</td>
<td>38.3</td>
<td>79</td>
<td>28</td>
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<tr>
<td>[3] E/F</td>
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<td>40</td>
<td>76</td>
<td>30</td>
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<tr>
<td>[4] F-1</td>
<td>2.45</td>
<td>39.4</td>
<td>73.9</td>
<td>28</td>
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<td>This work</td>
<td>EF</td>
<td>2.22</td>
<td>39.2</td>
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</table>

REFERENCES


