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Frequency-tunable, Broadband, Class-J Power Oscillator using GaN HEMT

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Abstract— In this paper, a frequency-tunable, broadband, Class-J power oscillator is proposed for the first time. The Class-J amplifier of the oscillator was designed to obtain broadband and high efficiency characteristics with a Gallium Nitride High Electron Mobility Transistor (GaN HEMT). Steady state oscillation occurs in a delay line feedback loop where the length is adjusted to tune the oscillation frequency. The measured output power and conversion efficiency for the proposed oscillator are over 39 dBm and over 50% with a drain bias voltage of 28 V. The measured fractional bandwidth is 47.62% at 2-3.25 GHz band.

Keywords— Class-J amplifier, Broadband oscillator, frequency-tunable oscillator, high efficiency oscillator

I. INTRODUCTION

High efficiency, high power, and broadband characteristics of power oscillators are required for a variety of systems including wireless communication, radar, etc. Recently, output power and conversion efficiency characteristics for the power oscillator have been improved in many reports [5]-[8]. However, most of power oscillators are operated at single frequency or in narrowband.

To date, switch-mode topologies such as Class-F, Class-E and Class-F^{-1} have been proposed to obtain high efficiency and high output power characteristics. In switch-mode topologies, a transistor is operated as an ideal switch by controlling harmonic components [1]. However, due to the output capacitance of the transistor, controlling second and third harmonic components is difficult. Also, such topologies are not appropriated to obtain a broadband characteristic, since conditions of the harmonic components are effective at specific frequency. Such limitations degrade the overall performance.

Lately, the Class-J amplifier has been proposed [2], which provides a solution for the adverse effects of switch-mode amplification, therefore potentially exhibiting high efficiency, linearity and wideband behavior concurrently.

In this paper, the Class-J power oscillator for RF power sources is designed and fabricated using a delay-line oscillator configuration for the first time.

II. IMPLEMENTATION OF CLASS-J POWER AMPLIFIER

Highly efficiency and broadband operation of the power amplifier (PA) can be obtained by Class-J topology. This topology increases the fundamental voltage component aided by the second harmonic voltage by employing a reactive termination. As a result, there is a phase shift between the output current and voltage waveforms. Therefore, broadband and high efficiency characteristics can be obtained using the Class-J topology [3]-[4].

The transistor used in this design is a CGH40010 GaN HEMT from Cree. The load-pull simulation using the Agilent Advanced Design System was performed with a non-linear model provided by vendor to determine the optimum fundamental and harmonic load conditions for the Class-J PA. The bias condition of the designed power amplifier was set at a drain voltage of 28 V and a gate voltage of -2.8 V. Fig. 1 shows the confirmed simulation results in the Smith chart by matching network that design load impedance and voltage/current waveforms. The second-harmonic impedance has a small real part and a large reactance part. The optimum load impedances of fundamental and second-harmonic are 16.924+j9.828 Ω and 0.596+j74.836 Ω, respectively.

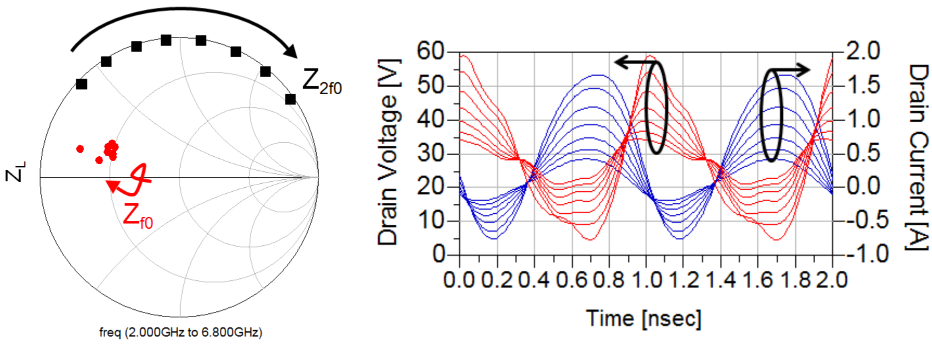

Fig. 1 Simulated load impedances and voltage/current waveforms of Class-J PA

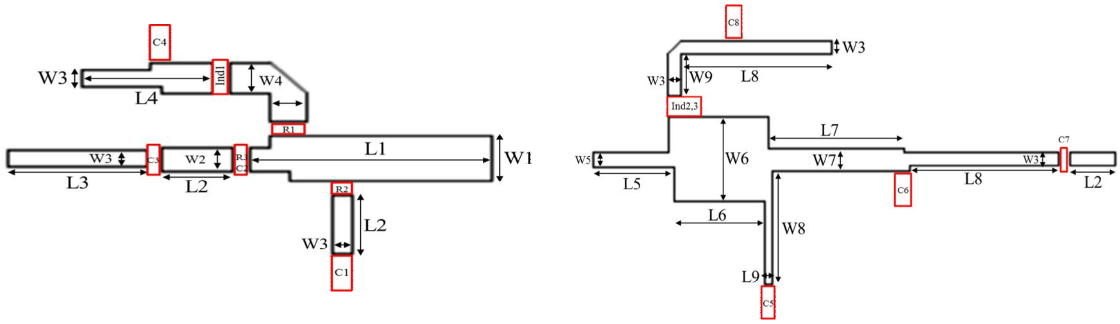

Fig. 2. Design of Class-J PA Input matching network and Output matching network.

The designed Class-J PA is shown in Fig. 2. Table I shows the Class-J PA dimension parameter. The Class-J PA was fabricated on a TACONIC TLX-5 substrate with a dielectric constant of 2.33 and a thickness of 0.504 mm. Fig. 3 shows the results of output power, gain, drain efficiency of the fabricated amplifier with a drain bias voltage of 28 V, and a gate bias voltage of -2.8 V as a function of the input frequency. As shown in figure 3, the output power is over 39 dBm, and the drain efficiency is over 40% between 2 GHz and 3.25 GHz.

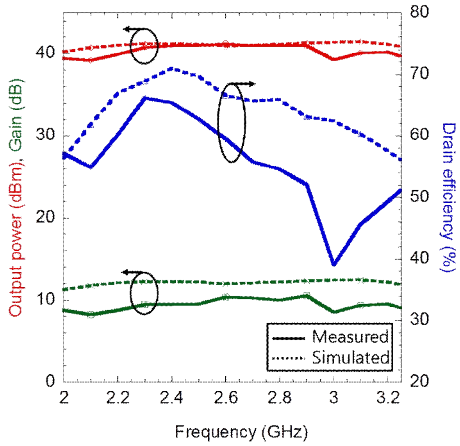

Fig. 3. Results of drive characteristics of Class-J PA as a function of frequency.

TABLE I - DIMENSIONAL PARAMETERS SUMMARY

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value
W1	4	L1	17.58	R1	200Ω
W2	2	L2	5	R2	1kΩ
W3	1.47	L3	10	R3	100Ω
W4	2.68	L4	9.42	Ind1,2,3	10nH
W5	1.67	L5	8.2	C1,3,8	10pF
W6	9.37	L6	9.75	C2	2.2pF
W7	2.5	L7	14.73	C4,7	5.6pF
W8	12.43	L8	16.2	C5	100pF
W9	4.5	L9	1	C6	1.2pF

III. IMPLEMENTATION OF THE BROADBAND POWER OSCILLATOR

We propose a broadband power oscillator using Class-J PA. The delay-line oscillator is a positive-feedback oscillator, which enables the output power of the transistor to feedback to the input of the transistor through a coupling capacitor [5]-[8]. The oscillation frequency is decided by the saturation power of the amplifier. In order to obtain the proper phase of the feedback loop line length, it is necessary to optimize $n\lambda(n=1,2,3,\cdots)$. That is, oscillation occurs at the frequency when the phase of the feedback loop satisfies '0' and the output power is maintained at the saturation power of the transistor.

The positive-feedback loop was composed of a variable directional coupler, coaxial cables, a circulator and mechanical phase shifters. The phase of the feedback loop is adjusted by using the coaxial cables and mechanical phase shifters, the output power is controlled that coupling into the feedback loop by using the variable directional coupler. To acquire the same results as the output power and drain efficiency from the Class-J PA, the coupling factor has to be same value as the gain of the Class-J PA.

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The measured level of coupling by the directional coupler when the oscillation occurs was 6.6 dB and the power gain of the fabricated Class-J PA was 8.4 dB. The difference of 1.8 dB is due to the insertion loss of passive components. The photograph of the measurement setup for the oscillation is shown in Fig. 4. As it is shown, the output power of the Class-J PA is coupled to the feedback loop through a variable directional coupler in this circuit. The phase shifter and coaxial lines control the phase in order to create oscillation in the expected frequency. The circulator is used to prevent the mismatching of input impedance by the feedback loop.

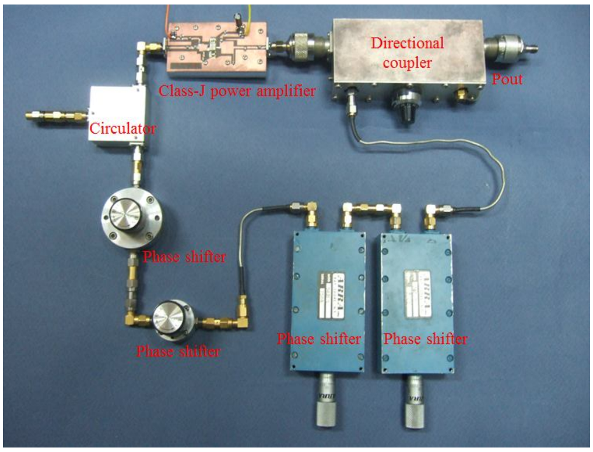

Fig. 4. Photograph of the measurement setup for oscillation.

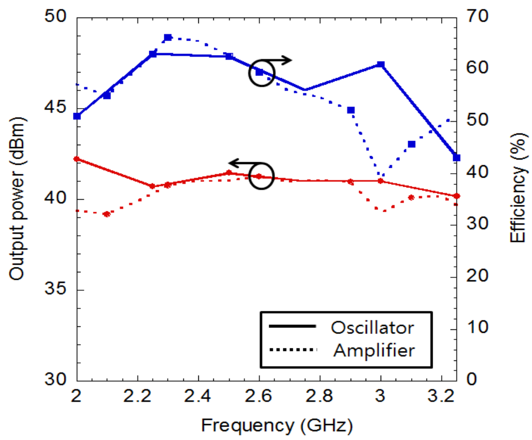

Fig. 5. Measured results of output power and conversion efficiency as a function of frequency

IV. EXPERIMENTAL RESULTS

Fig. 4 shows the photograph of the measurement setup for the oscillation test. Fig. 5 shows the characteristics of conversion efficiency and output power of the oscillator as a function of frequency. The output spectrum is measured by an Agilent performance spectrum analyzer (PSA) E4440 in the range of 470 kHz of RBW with a 50 MHz span. The measured results were the output power of over 40 dBm, the conversion efficiency of over 50%, and the fractional bandwidth of 47.62% at a frequency of 2-3.25 GHz. Table I shows the measured results of the phase noise characteristics at offset frequencies of 10 kHz and 100 kHz.

TABLE II - RESULTS OF DELAY-LINE AND PHASE NOISE

Frequency	Delay-line length	Phase noise
2 GHz	70 mm	10 kHz : -77.23 dBc/Hz 100 kHz : -106.97 dBc/Hz
2.25 GHz	48 mm	10 kHz : -98.33 dBc/Hz 100 kHz : -121.92 dBc/Hz
2.5 GHz	31 mm	10 kHz : -79.91 dBc/Hz 100 kHz : -105.71 dBc/Hz
2.75 GHz	14 mm	10 kHz : -58.32 dBc/Hz 100 kHz : -103.38 dBc/Hz
3 GHz	140 mm	10 kHz : -63.15 dBc/Hz 100 kHz : -111.44 dBc/Hz
3.25 GHz	116 mm	10 kHz : -61.78 dBc/Hz 100 kHz : -101.03 dBc/Hz

V. Conclusions

In this paper, we propose the frequency-tunable, broadband, Class-J power oscillator for the first time. The oscillator consists of a Class-J PA and a delay-line feedback loop circuit. The broadband PA with a Class-J was designed and fabricated using GaN HEMT. The oscillation frequency was tuned by a mechanical phase shifter in the delay-line feedback loop circuit. The measured drain efficiency of the amplifier has the output power of over 39 dBm and the drain efficiency of over 50% at 2-3.25 GHz with a drain bias voltage of 28 V. The broadband power oscillator using the fabricated Class-J PA was experimentally measured. The measured results demonstrated an output power of over 40 dBm, and the conversion efficiency of over 50% and a fractional bandwidth of 47.62% at 2-3.25 GHz.

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