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Review of Tuned Power Oscillators

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Abstract—This paper presents a review of tuned power oscillators. Tuned power oscillator provides ac output power from dc input power by using switching devices. One of the most important points of tuned power oscillator is that the switching devices are driven by the feedback voltage from the ac output. It is possible to make a self- oscillation by using the feedback mechanism. This paper introduces some tuned power oscillator for high-frequency applications. Each oscillator achieves high power-conversion efficiency by applying the soft switching technique.

1. Introduction

The increase in the power density is a major purpose in the power electronics research field. For enhancing the power density, the circuit scale should be smaller. The magnetic components such as inductor and transformer are dominant factor for determining the circuit volume. Therefore, it can be stated that high frequency operation is effective to reduce the circuit volume. Switching-device driver design is a covert problem in high-speed switching devices. The square-driving voltage is strained due to parasitic capacitances and resistances of the switching device. Because a precise switching pattern is required for achieving the soft-switching conditions at high frequencies, the driver-circuit designs, taking into account the parasitic components, are the technical barrier for high-frequency power-electronics circuit.

The tuned power oscillators, which are autonomous circuit without driver, is one of the solutions for high-frequency power-electronics circuit. The tuned power oscillator is driven by the feedback signal from the sinusoidal output voltage. In addition, it is possible to apply the soft-switching techniques and high power-conversion efficiency can be achieved. Namely, the tuned power oscillators are suitable to high-power density converters. Actually, there are wide-area applications of tuned power oscillators, for example dc-ac inverter part of the dc-dc converters and transmitters of the wireless power transfer systems and wireless communications. Tuned power oscillators, however, have problems of design difficulty and frequency unstability. It is useful and effective for tuned-power oscillator usages to understand the operation mechanism and design strategies of high-frequency high-efficiency tuned power oscillators.

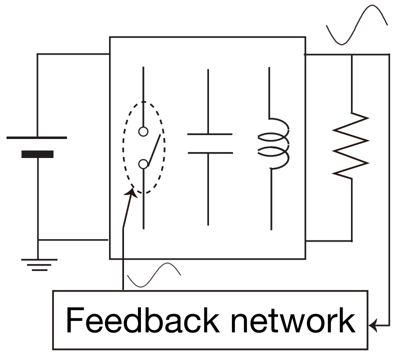

Figure 1: Configuration diagram of tuned power oscillator.

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2. Review of Tuned Power Oscillator

A fundamental configuration diagram of tuned power oscillators is shown in Fig. 1. The switching devices of tuned power oscillators are driven the voltage through the feedback network from the output voltage. By applying the feedback voltage as the driving signal, the circuit works with self-oscillation and designers can be relieved from the implementation difficulty of driver circuit. The driving signal is not a square waveform but a sinusoidal waveform in the tuned power oscillator because the output voltage is regarded as a sinusoidal waveform. Namely, the feedback network should have roles to adjust phase shift between output voltage and gate-source voltage and amplitude of the gate voltage, which should be less than the permissive value.

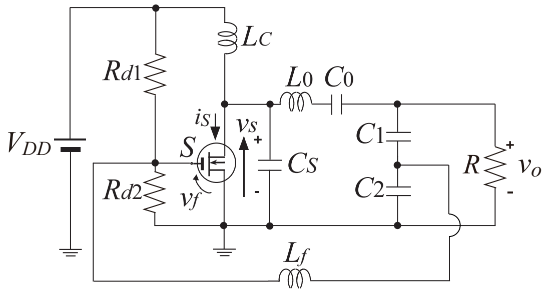


Figure 2: Circuit topology of the Class-E free-running oscillator.

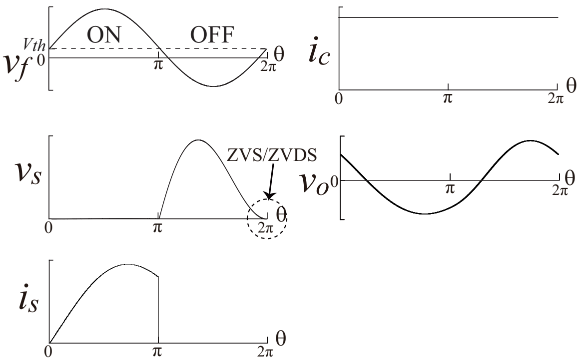


Figure 3: Nominal waveforms of the class-E free-running oscillator.

2.1. Free-Running Class-E Oscillator

Figure 2(a) shows a circuit topology of the free-running class-E oscillator [**?**]–[11]. The class-E oscillator consists of the class-E amplifier and feedback network C_1, C_2 and L_f. R_{d1} and R_{d2} give the bias voltage, which is the same as the threshold voltage V_{th}, for the gate of the switching device. Figure 3 shows example waveforms of the class-E oscillator with nominal conditions. The switching device of the class-E oscillator is driven by the feedback voltage v_f, which is from the output voltage v_o. The feedback voltage is a sinusoidal waveform because the feedback current flow through the resonant filter, which consists of L_f, gate-source parasitic capacitance C_g, and gate-source parasitic resistance r_g. Because C_g and r_g are fixed, which depend on the MOSFET type, the feedback network can be designed by choosing the component values of C_1, C_2, and L_f. By adjusting them, the amplitude and phase shift between the output voltage and the gate voltage are adjusted. The fundamental operation is the same as the class-E amplifier [12]-[15]. Namely, the switch voltage achieves the class-E zero-voltage switching and zero-voltage-derivative switching (ZVS/ZVDS) conditions. Because of the class-E ZVS/ZDS conditions, the class-E oscillator achieves high power-conversion efficiency at high frequencies.

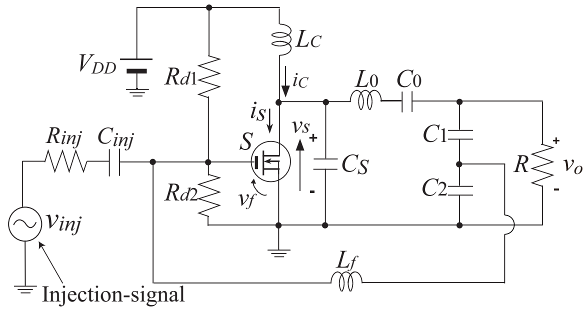


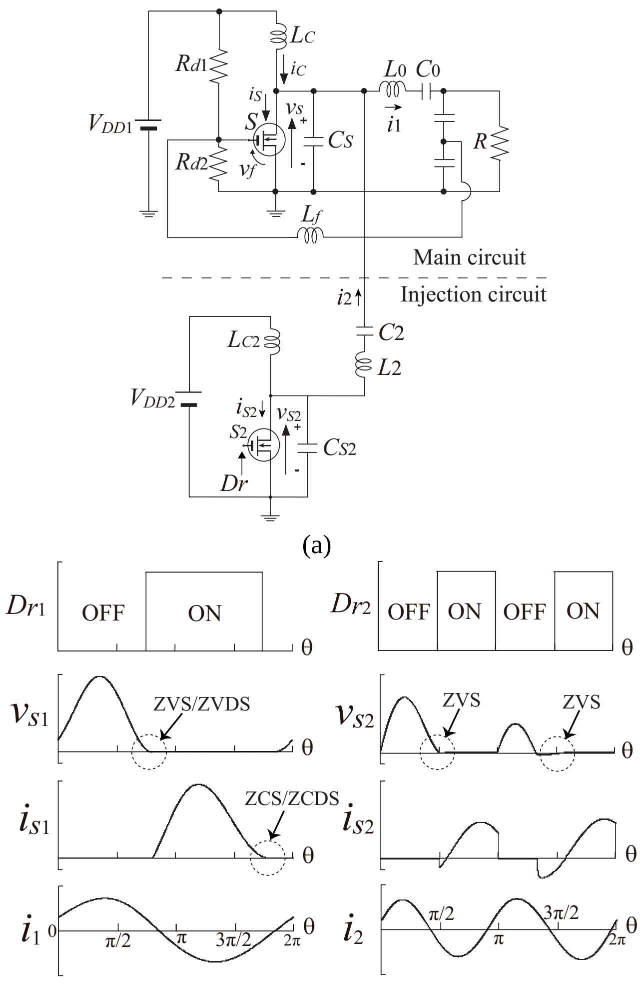
Figure 4: Circuit topology of the injection-locked class-E oscillator.

2.2. Injection-locked Class-E Oscillator

Figure 5 shows an example topology of the injection-locked class-E oscillator [16], [17]. The small-power signal v_{inj} is injected to the gate terminal as shown in Fig. 5. Because the injection-signal power is low, it is possible to obtain the injection-locked oscillator by just adding the injection signal to the original free-running oscillator. If the feedback voltage of the class-E free-running oscillator is synchronized with the injection signal v_{inj}, the oscillation frequency is locked with the injection-signal frequency f_{inj}, which means the frequency of the output voltage is fixed with f_{inj}. It is easy to achieve synchronization as the injection-signal power increases. However, high power injection affects the waveforms of the feedback voltage and switch-on duty ratio, which yields the design complexity. It is necessary to conduct the total design of the free-running oscillator and injection circuits for large perturbation. Additionally, low injection-signal power is good from a power-added efficiency perspective.

2.3. Class-E$_M$ Oscillator With Second Harmonic Injection

Figure 5(a) shows a circuit topology of the class-E oscillator with second harmonic injection [18], which is composed of the main circuit and the injection circuit. The injection circuit is usualy operated as the class-E frequency doubler [19], [20]. The nominal waveforms of the oscillator are shown in Fig. 5(b). The main circuit is driven by the feedback voltage v_f from the output voltage. The switch voltage v_{S1} satisfies the class-E ZVS/ZVDS conditions at transistor turn-on instant. Additionally, the switch current i_{S1} achieves the zero-current switching (ZCS) and zero-current-derivative switching (ZCDS) conditions simultaneously at the transistor turn-off instant. Because of the ZCS/ZCDS conditions, the waveforms of both the switch voltage and current at the transistor turn-off are also smooth. Because of these switching conditions, which are called the class-E$_M$ ZVS/ZVDS/ZCS/ZCDS conditions, there are no jumps on the switch-voltage and switch-current waveforms in the main circuit. Therefore, the



(a)

(b)

Figure 5: Class-E_M oscillator with second harmonic injection. (a)Circuit topology. (b)Nominal waveforms

class-E_M amplifier enhances high power conversion efficiency even if the main-circuit transistor has long turn-off-switching time and suppresses the implementation cost. For achieving the ZCS/ZCDS conditions in the class-E_M amplifier, the injection circuit is mandatory [21]-[23]. The injection circuit should provide the second-harmonic current i_2 with the proper phase-shift and the proper amplitude for achieving the ZCS/ZCDS conditions in the main-circuit switch. The switch voltage v_{S1} is transformed into the sinusoidal output voltage v_o through the resonant filter $L_1 - C_1$.The injection circuit is driven by the input signal s_{in} whose fundamental frequency is the same as the output voltage. In other words, the output frequency is locked with the input frequency. In this sense, the proposed oscillator is regarded as one of the injection-locked oscillators.

From the above explanations, it can be stated that the injection circuit has multiple roles in the class-E_M oscillator. First, it offers the class-E_M ZVS/ZVDS/ZCS/ZCDS conditions, which enhance the power-conversion efficiency and allow to use a slow switching device. It is possible to reduce the circuit-implementation cost, especially, the main-circuit-MOSFET cost. Second, the output-voltage frequency is locked with the input-signal frequency, which is half as high as the injection-current frequency. Finally, the output power becomes high by adding the injection circuit, which is useful for high-power applications.

3. Conclusion

This paper has presented a review of tuned power oscillators. Tuned power oscillator provides ac output power from dc input power by using switching devices. One of the most important points of tuned power oscillator is that the switching devices are driven by the feedback voltage from the ac output. It is possible to make a self- oscillation by using the feedback mechanism. This paper introduces some tuned power oscillator for high-frequency applications. Each oscillator achieves high power-conversion efficiency by applying the soft switching technique.

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