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New approach to 150 kHz WPT by sinusoidally modulated step-down converter

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Abstract– This paper proposes an original approach to the development of a power converter for wireless-power-transfer applications. The idea is to use a *buck* topology modulated sinusoidally, so as to remove the need for resonating circuits and be able to exploit conventional inductive coupling solutions. The advantage of this approach is twofold: first, the synthesized voltage can be controlled on the primary side by a simple voltage feedback loop and kept at nominal value even in the presence of varying load and coupling conditions; second, the efficiency can be made much higher than in conventional resonant approaches. As a case-study, a 150 kHz fast-charging system for drone battery is presented, with a nominal power rating of 25 W.

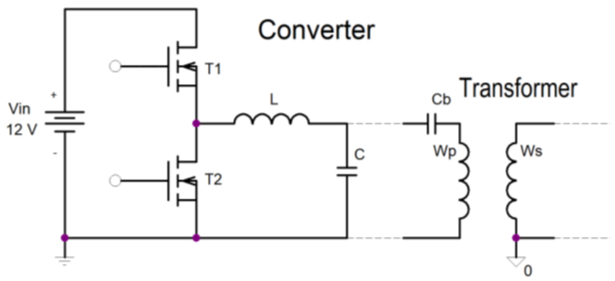
1. Introduction

Power converters used in wireless-power-transfer (WPT) applications typically rely on resonant coupling between primary (input) and secondary (output) side. The required transformer sinusoidal voltage is produced by generating a 50% duty-cycle square-wave fed into a resonant (LC) tank. The frequency of the square waveform and the resonant tank must be matched. The inductor in the tank represents the primary of a transformer. The disadvantages of this approach are that the resonating circuit parameters (i.e., the values of *Ls* and *Cs* on the primary and secondary side) need to be trimmed exactly on a defined value of the coupling coefficient *k* [1, 2], which can however be not constant during operation, due to variable distance/position of the coils relative to each other. Moreover, control of the output voltage is not straightforward, especially in the presence of varying loads. Finally, the efficiency tends to be rather low due to high leakage magnetic flux.

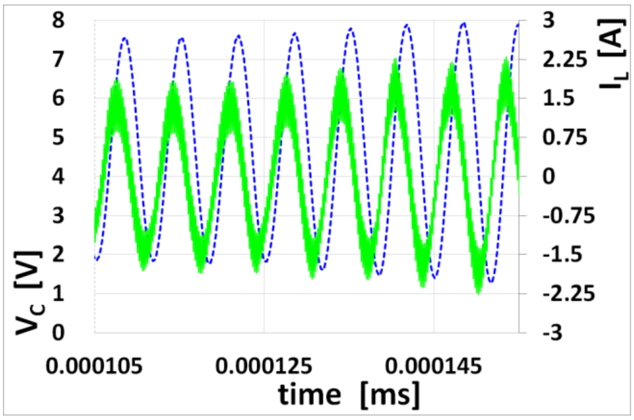
Here, a different approach is pursued, which consists in generating the primary-side voltage by means of a sinusoidally modulated buck-converter. Coupling with the secondary side takes place by means of conventional inductive coupling solutions, without the need to trim the circuit design for resonance. The primary side input voltage can be easily controlled and the output kept within a well-regulated range for a broad range of load variation. The circuit is design for a nominal DC input voltage of 12 V, to deliver 5.5 V_{DC} on the output, which are used to charge the battery of a small drone: the power converter and transformer primary are installed on a fixed platform; the secondary is connected to the bottom of the drone and the drone just needs to land upon the platform to be re-charged. The nominal power rating is 25 W and the fundamental frequency of the sinusoidal voltage is 150 kHz. So, the switching frequency of the converter is chosen in the MHz region and its design relies on state-of-the-art GaN HEMTs [3]. A non-unity transformer turns-ratio can also be used to set the output voltage value.

2. *S*-PWM buck-only WPT system

Fig. 1 shows the circuit schematic, (a), and some simulated representative waveforms, (b, c): the voltage across the output capacitor *C*, V_C, is the controlled variable, which is fed into the primary of a transformer, *Wp*; the series capacitor *Cb* has the only function of removing the DC bias offset from V_C. In these results, the circuit is operated with a voltage feedback loop only; at time=120 µs the load is stepped from 2.4 to 16.7 Ω and while the current into Wp is seen to decrease noticeably, the voltage across it is maintained at the nominal value. The switching frequency here is 5 MHz and the estimated efficiency is above 80% at all load conditions, with values of k varying between 0.9 and 0.99; L=600 nH, C=680 nF.



(a)



(b)

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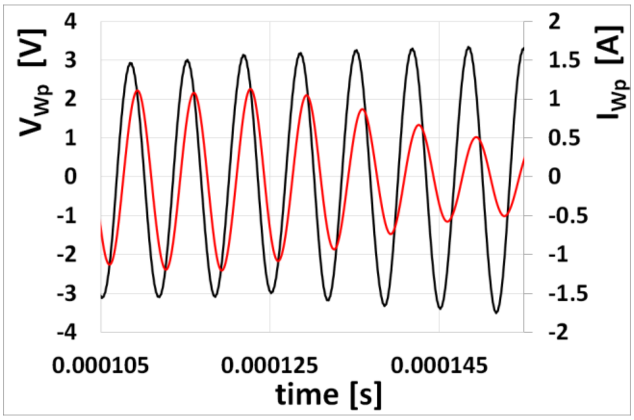

Fig. 1: (a), circuit schematic; (b), controlled output capacitor voltage, V_C, and inductor current, I_L; (c), voltage across, V_{Wp}, and current into the primary winding, I_{Wp}.

3. Conclusions and future work

This paper presents the design of a non-resonant power converter for WPT applications. It is based on very high-frequency sinusoidally modulated step-down converter, producing a fundamental sinusoidal waveform at 150 kHz. The sinusoidal voltage can be fully controlled by a voltage feedback loop. Technical challenges to address next reside in the detailed definition of the control loop and its hardware implementation platform to meet the very high switching frequency targets.

Acknowledgments

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