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A Digitally Controlled Pseudo-Hysteretic Buck Converter for Low Power Biomedical Implants

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Background

Low power biomedical implants usually harvest energy from a small inductor coil or optical energy sources. Those sources can supply very limited amount of energy to the target system because of poor power transfer efficiency and size limitation. Thus, we have to supply as much as energy directly to the load, without wasting energy from auxiliary devices from electrical driving. To save the energy dissipated as heat, when the power supply voltage is excessively large compared to the voltage at the load, we can choose a class-H amplifier-like strategy, where supply voltage tracks the voltage waveform at the load. Among many power conversion topologies that can modulate the supply voltage, the SMPS (Switching Mode Power Supply) is the most promising one; because reverse energy recovery can be used by taking back the charge accumulated on the load capacitor. The CCM buck converter, shown in Figure 1, can possibly work as a voltage tracking power supply modulator. However, we must employ a complicated auxiliary circuit components, such as the Type-III compensator, which greatly hampers its application for biomedical implant applications due to several external passive components.

Proposed Power Converter

Therefore we propose a proposed digitally controlled hysteretic buck converter that is composed of 3 parts: power conversion, digital control, and pulse generation. Its controller can be implemented without bulky external passive components, but can quickly adapt the fast transient with a simple digital controller which incorporates just 1 comparator.

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Figure 2 shows the power conversion part of the proposed buck converter. It is composed of power PMOS (W/L = 2 mm/0.5 μm), NMOS (W/L = 1 mm/0.5 μm), an active diode amplifier driving the NMOS, a 1 uH inductor, and a 1 uF capacitor. The power supply is 3.3 V. It adopts a typical buck converter configuration, where target switching frequency is 10 MHz. The NMOS active diode circuit is employed for minimizing the conduction loss across the NMOS body diode, when the energy stored in the inductor is released. The first stage of the active diode is common gate differential amplifier, of which the positive terminal is connected to GND and the negative input terminal is connected to the switching side of the inductor. The second stage of the active diode is common source amplifier stage, which serves to boost gain and increase the slew rate. Because it uses the negative feedback, the stability should be carefully checked. The simulated gain of the active diode was around 60 dB, with a 3 dB bandwidth of about 100 kHz.

In biomedical implant applications, the fast transient response is important, because the required power supply voltage can abruptly change, i.e. when an electrical stimulator changes the phase from anodic pulse to cathodic pulse. Thus, we propose a digital controller which can support such a fast transient response, which can make a voltage discursion of 1 V in less than 1 us. Figure 3 shows the proposed pseudo-hysteretic controller, for driving the power PMOS of the proposed power converter. It receives the reference voltage and the current output voltage as inputs, and then compares them. It asserts '1' to report to the digital pulse generator (fsm_pulse_gen), when the reference voltage is higher than output voltage. The digital pulse generator increases the duty ratio when the comparator output is '1', and decreases the duty ratio when the comparator output is '0'. The key of the control mechanism is binary weighted duty control. In this scheme, initially, the duty can jump by a predetermined maximum, being 16, and then, when the SMPS output approaches to the initial target voltage, the incremental amount decreased by half, being 8, and then again by half, being 4, and so on. The simulation result of the proposed power converter with the pseudo-hysteretic controller, which tracks reference voltage is shown in Figure 4. In the beginning the converter operates in CCM, when the output voltage rapidly catch up the reference voltage; this is done by the digital controller which crank up the duty cycle to the maximum in a short period. Once the output supply voltage begins to be stabilized by crossing the reference voltage line, the converter changes the operation mode from CCM to DCM.

Conclusion

We introduce a digitally controlled hysteretic buck converter with an active diode, intended for biomedical implant applications, featuring low-power consumption and fast transient response. For achieving these features, the associated digital controller employs the binary weighted duty update scheme, with overhead of a simple input processing comparator. An NMOS active diode can further decrease the wasted energy source by removing the loss that can be incurred from body diode conduction.