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## Adaptive Peak-Inductor-Current Controlled PFM Boost Converter with a Near-Threshold Startup Voltage

## 具趨近臨界電壓啟動及自適電感電流峰值脈寬頻率調變控制之升壓型轉換器

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## 作品摘要

節能減碳的議題在近年來備受注目，如何從太陽能、震動能、熱能等環境能源中獵取能源的研究在近年來快速發展。然而，這些綠色能源在轉成電能時，僅能轉換成較小的電壓能源，故無法直接供給後端電子電路使用。由於此原因，我們必須設計一升壓電路，將此較小的電壓能源升壓至較高的電壓，以作為後端電路的供給來源。

升壓型轉換器（Boost Converter）是常見的抬升電壓電源管理電路，藉由升壓型轉換器，其可將較低的輸入電壓抬升至較高位準的電壓，以有足夠能力驅動後端電子電路。因此，此轉換器可與同製程下的其他混和訊號電路整合於同一晶片以實現系統單晶片的目標。由於綠色能源提供的功率較小，因此，這次升壓型轉換器設計的控制方法選用脈寬頻率調變控制（pulse-frequency modulation）。與常見的脈波寬度調變（pulse-width modulation）控制相比，脈寬頻率調變控制方法在負載為輕載時，有更好的轉換效率。然而，目前現階段大多數的電流模式脈寬頻率調變的升壓型轉換器需要電感電流感測電路，已有多數文獻提出耗能更小抑或是感測準確度更高的電感電流感測電路。然而，為求更精準的感測電路，部分文獻在感測電路中增添運算放大器，其會增加感測電路的功耗，或是此類型電路無法在低輸入電壓時正常操作。因此，我們在這次設計實現一個高效率、可低電壓啟動及無需電感電流感測電路的脈寬頻率調變控制之升壓型轉換器。

以 TSMC 0.18μm CMOS 製程，設計一具趨近臨界電壓啟動及自適電感電流峰值脈寬頻率調變控制之升壓型轉換器。自適電感電流峰值控制方式可實現當輸入電壓增加時，電感電流峰值下降以抑制輸出漣波在傳統控制會隨輸入電壓增加一起增加的現象。另外，此設計採用兩階式啟動方法，有別於傳統的三階式啟動，其可使此轉換器在近臨界電壓（0.42V）的輸入電壓（0.43）啟動，並在成功啟動後，即使輸入電壓降至 0.22V 亦可使輸出電壓穩在 1.8V。

Energy saving and carbon reduction issues attract a lot of attention recently. How to get energy from environment has been developed quickly in these years, such as solar power, vibration, thermal, etc. Nevertheless, most of these green energy types can only provide a very low voltage, so it is difficult to power electronic circuits directly. Due to these factors, a circuit, which could operate at a low supply voltage and also boost it to a higher level for powering up its following electronic, is needed.

Boost converter is one common type of step-up power converters. By using a boost converter, the low supply voltage can be boosted up to a voltage high enough for powering up electronics. Therefore, it can be integrated with other CMOS mixed-signal systems in system-on-chip applications. Besides, due to the factor that green energy can only provide very low power, this design chooses pulse-frequency modulation (PFM), which is capable to get better efficiency at light loads rather than pulse-width modulation (PWM). However, most of the boost converters operating in current-mode PFM control often need an inductor-current sensor. There are many current-sensing schemes being proposed. However, some of them need an operation amplifier, which costs significant power consumption, or cannot be operated in low supply voltage. Hence, we propose a high-efficiency low-voltage boost converter using PFM control but no current-sensing circuits.

In this work, an integrated PFM-controlled boost converter without current-sensing circuits is implemented by using a 0.18μm CMOS mixed-signal process. A novel adaptive peak-inductor-current (APIC) control method without any current sensing circuit is proposed to suppress the growth of output voltage ripple as the input voltage increases, and a two-step startup procedure is used to efficiently reduce the control circuits and cost. Moreover, the theoretical minimal circuit operating voltage should be the threshold voltage, which is 0.42 V in the adopted process, and the proposed converter can successfully start up with a 0.43-V input voltage, which is near the transistor threshold voltage. Moreover, after startup, the converter can work with an even lower input voltage, as low as 0.22 V.