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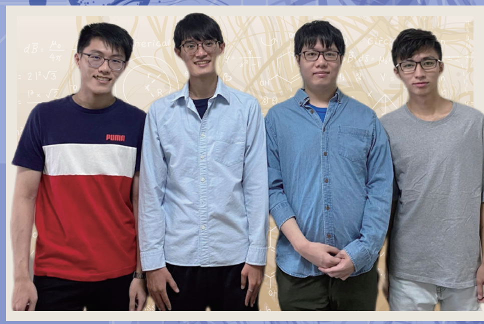
低靜態電流及交越變動率單電感多輸出升降壓轉換器

A Low Crosstalk and Ultra-Low Quiescent Current Single-Inductor Multiple-Output Converter with 5-Input Error Amplifier for High Efficiency and Driving Capability



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作品摘要

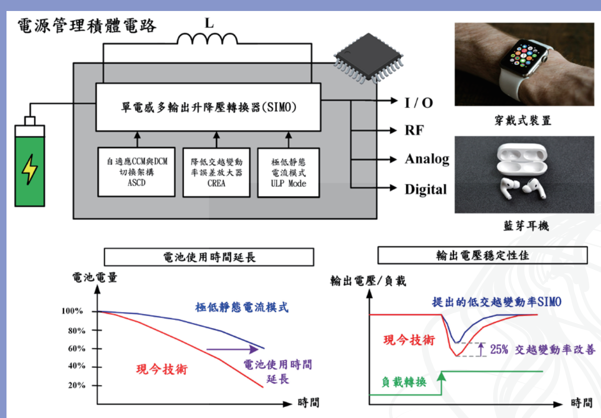
隨著穿戴式裝置的發展以及興起，PMIC的需求也隨之發生變化。為了應用於智慧型手錶、藍芽耳機等攜帶式裝置上，PMIC需要達到小體積，高效率等特性。縮小體積使產品更加便於攜帶，提高效率能使裝置上的電池使用壽命延長。可攜式裝置中包含類比、數位、無線傳輸等多個模組，因此PMIC需能提供多個電壓、電流源。

本作使用單電感多輸出（SIMO）轉換器的架構，以降低外部元件電感的使用，並達成同時提供多個電壓、電流源的功能。但是在目前現有技術下SIMO轉換器所遭遇的挑戰如下：在待機模式下過大的靜態電流會降低輕載效率，並縮短電池使用時間。此外，SIMO轉換器操作在連續導通模式（CCM）和斷續導通模式（DCM）時，多個輸出之間會受到嚴重的交越變動（crosstalk），進而導致穩定性問題並降低供電設備的性能。為了解決上述問題，本作提出了採用創新控制方法的SIMO轉換器架構。

在ASCD控制中，當輸出皆為重載時，系統透過將各個輸出電感電流疊加，提升電感電流峰值，藉此提升負載能力。若任何輸出負載由重轉輕，則將轉變為輕載的輸出從疊加電感電流中分離並操作在DCM，藉此降低輸出受交越變動影響。通過ASCD控制，可以同時確保系統的負載驅動能力並同時降低輸出的交越變動率。

在CREA控制中，其使用單一誤差放大器配合回授電壓選擇器，解決傳統架構需用多個誤差放大器所面臨硬體成本增加的問題。此外 CREA 中包含誤差訊號校正機制，可以根據其餘輸出的回授電壓產生校正電流，藉此調整輸出的誤差訊號，降低輸出交越變動影響，進而保持各輸出電壓的穩定。極低功耗（ULP）模式可以在系統處於極輕載的狀態時，實現超低靜態電流並提高輕載效率。為達到超低靜態電流，在ULP模式下只有極低功耗輸出電壓偵測器與恆定導通時間（COT）產生器會運作，當任何輸出需要能量時，輸出電壓偵測器將觸發COT產生器產生訊號控制系統充放電時間供給輸出足夠能量。有了ULP模式，可大幅降低待機時間的耗電與延長電池使用壽命。

本作提出多種創新技術，實現低靜態電流與低輸出交越變動率，有效改善現今應用於可攜式裝置之電源管理晶片所面臨的問題。本作提出的架構在極輕載效率達到85%以上，並且交越變動率方面，相較於現今頂尖IEEE論文有著25%顯著的改善。



▲ 圖一 系統應用與架構示意圖

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臺灣大學電機工程學士、碩士、博士，現為陽明交通大學電機工程學系教授。曾於 1996 至 1998 年任臺北飛利浦公司兼職 IC 設計人員，1998 至 2000 年任 Avanti 擔任項目經理，從事電源管理 IC 的設計。成立陽明交通大學混合信號和電源管理 IC 實驗室，在 IEEE 頂尖期刊（JSSC 及 TPE）和會議（ISSCC 及 VLSI symposium）上有卓越的貢獻，並擁有多項專利。

研究領域

電源管理積體電路設計、混合訊號電路設計、液晶顯示器（LCD）驅動器設計、氮化鎵驅動器設計

Abstract

With the development and rising need for wearable electronic devices, the requirements of power management IC (PMIC) are changing. First, in order to supply wearable devices such as smart watches and Bluetooth headsets, PMIC needs to reduce size. Second, because the wearable devices are supplied by batteries, the efficiency of the PMIC needs to be improved to increase the battery usage time. Third, wearable devices contain multiple modules such as analog, digital and RF circuits. Thus, PMIC should have the ability to provide distributive voltage and current sources at the same time.

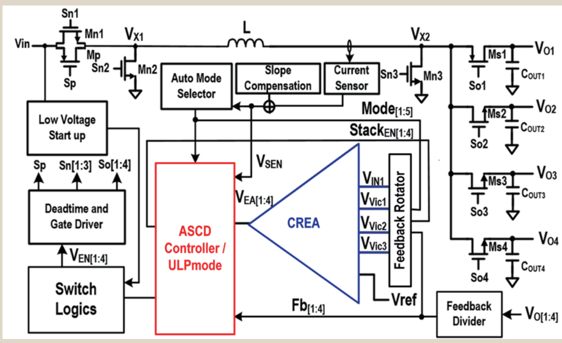
Single-inductor multi-output (SIMO) converter has the advantage of fewer external components and can provide distributive voltage and current sources. Thus, the size of the SIMO converter can be reduced and can be widely used in wearable electronic devices. The new control methods in SIMO can be divided into three parts: Switchable CCM and DCM control (ASCD), Crosstalk Reduction Error Amplifier (CREA) and Ultra-Low Quiescent Current Technique. The former two controls focus on reducing crosstalk, and the third control focuses on improving light load efficiency by reaching ultra-low quiescent current.

In ASCD control, when all outputs are in heavy load, the system increases the peak value of the inductor current by stacking the inductor current of each output, thereby increasing the load capacity. If any load in output turns lighter, the light load will be moved out of the stacked inductor current and operate in DCM, which decreases the output ripple caused by crosstalk. With ASCD control, the high driving capability of heavy load outputs and low crosstalk in light load outputs can be guaranteed at the same time.

CREA uses a single error amplifier with a feedback rotator to solve the problem of increased hardware costs caused by the traditional SIMO structure that requires multiple error amplifiers. In addition, CREA has an error signal correction mechanism, which can generate a correction current based on the feedback voltage of the other outputs to adjust the output error signal and reduce the crosstalk effect.

When all outputs are in ultra-light load, the system will operate in ultra-low power (ULP) mode to achieve ultra-low quiescent current and improve light load efficiency. To achieve ultra-low quiescent current, only ULP output detector and constant on time (COT) generator work in ULP mode. When any output needs energy, the Output detector will trigger COT generator to send on time signal and provide energy to output. With ULP mode, the light load efficiency is improved and the battery usage time is increased.

The proposed SIMO converter contains variety of technologies to achieve low quiescent current and low crosstalk, effectively improving the problems faced by PMIC used in portable devices in state-of-the-arts. The proposed SIMO converter achieves efficiency of more than 85% in ultra-light load, and the crosstalk has a 25% improvement compared with the IEEE papers in state-of-the-arts.



▲ Fig. 2 System block diagram