✦ D24-099 ✦

應用於心電圖與光體積變化描記圖法之高解析度晶片系統

A High-Resolution System-on-Chip for ECG and PPG Body Signal Detection with VCO-Based ΔΣ ADC

隊伍名稱｜掉到水裡的金斧頭
Golden Axe Dropped in the Water

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研究領域

低功耗類比 / 射頻積體電路設計、生醫感測晶片、高效率能量管理晶片與感測器介面電路設計

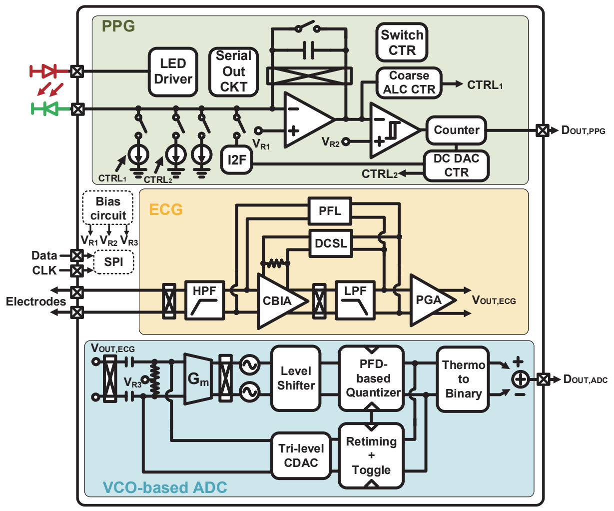
✦ 作品摘要 ✦

根據世界衛生組織（WHO）的統計，心血管疾病是全球第一大死因。其中有超過一半的事故是發生在家中，因此，發展一種可靠、方便的醫療監測系統對於降低心血管疾病所導致的死亡率至關重要。傳統的心血管疾病監測技術主要使用心電圖（ECG）技術，光電容積圖（PPG）則可以用來檢測心率、血氧飽和度等生理參數，這些技術已被應用於醫療設備、智慧手錶等領域。

本研究專注於開發非侵入式的監測方法，設計了一款即時檢測且便攜的晶片，以實現日常生活中的醫療監測系統。結合ECG和PPG的量測方式，能夠判斷出脈搏傳導時間（PAT）參數，使穿戴者即時判斷自己的血壓高低。此研究不僅實現了適用於穿戴式裝置的ECG與PPG，還為傳統血壓量測的不便提供了解決方案，同時能夠提供連續偵測的目的。圖一為系統架構圖，電路主要可以分成ECG讀取電路及PPG讀取電路。ECG讀取電路分為類比前端以及壓控振盪器式三角積分類比數位轉換電路（VCO-based Delta-Sigma Modulators ADC）。

ECG類比前端電路採用了雙級放大器結構，結合電流平衡式儀表放大器（CBIA）及可變增益放大器（PGA），可放大心電訊號，並且調整增益以確保輸出訊號的振幅在合理範圍內。加入正回授迴路（PFL）和直流伺服迴路（DCSL），以提升輸入阻抗及降低因電極造成的偏移電壓。VCO-based DSM ADC電路包括具有level shifter的差動VCO、PFD-based quantizers、電容回授DAC等。透過VCO將訊號從電壓轉換為頻率，再經過數位信號處理器進行後續處理。DSM具有一階noise shaping的效果，且透過閉迴路架構，DSM得以實現更高的動態範圍，同時處理更大的輸入振幅。PPG電路使用電流式DAC，以增加動態範圍和還原PPG訊號，並且使用電容轉向之方式實現相關雙採樣（CDS）消除環境光雜訊，在提升SNR的同時，降低電路複雜度。

本設計使用0.18 µm CMOS製程，全晶片整合ECG與PPG檢測電路，各自僅消耗19.2µW與37.2µW。ECG達到23至65 dB的增益範圍，可用於0.3至500Hz的頻寬，PPG的動態範圍達到了118dB，其LED duty cycle為0.744。本晶片能夠同時檢測ECG和PPG兩種生理訊號，從而使得生理訊號的偵測更加完整。微型化及低功耗的特點使其更容易與穿戴型裝置結合，有望降低未來醫療檢測的資源成本，並實現更完善的健康醫療體系。



圖一 系統架構圖。

✦ Abstract ✦

According to statistics from the World Health Organization (WHO), cardiovascular disease is the leading cause of death globally. More than half of these incidents occur at home. Therefore, developing a reliable and convenient medical monitoring system is crucial to reducing mortality rates caused by cardiovascular diseases. Traditional cardiovascular disease monitoring techniques mainly use electrocardiography (ECG) technology, while photoplethysmography (PPG) can detect physiological parameters such as heart rate, blood oxygen saturation, and more. These technologies have been widely applied in medical devices, smartwatches, and other fields.

This study focuses on developing a non-invasive monitoring method and designing a real-time, portable chip to achieve medical monitoring in daily life. By combining ECG and PPG measurement methods, the system can determine Pulse Arrival Time (PAT) parameters, allowing wearers to assess their blood pressure in real-time. This research implements ECG and PPG, suitable for wearable devices, and provides a solution to the inconvenience of traditional blood pressure measurement while enabling continuous monitoring.

The system architecture comprises three main parts: the ECG AFE circuit, the ECG analog-to-digital circuit (VCO-based Delta-Sigma Modulators ADC), and the PPG circuits. The ECG circuit adopts a dual-stage amplifier structure, combining a Current-Balanced Instrumentation Amplifier (CBIA) and a Programmable Gain Amplifier (PGA) to amplify the ECG signal and adjust the gain to ensure the output signal's amplitude is within a reasonable range. Positive feedback loops (PFL) and DC servo loops (DCSL) are added to increase input impedance and reduce offset voltage caused by electrodes. The VCO-based DSM ADC circuit includes a differential VCO with a level shifter, PFD-based quantizers, and capacitive feedback DAC. The signal is converted from voltage to frequency through the VCO and then processed by a digital signal processor. The PPG circuit uses a current-mode DAC to increase dynamic range and restore the PPG signal. Along with capacitive transimpedance circuitry, it achieves correlated double sampling (CDS) for ambient light noise elimination, enhancing SNR while reducing circuit complexity.

This design, fabricated using 0.18 µm CMOS technology, integrates ECG and PPG detection circuits on a single chip, consuming only 19.2 µW and 37.2 µW, respectively. The ECG achieves a gain range of 23 to 65 dB, usable in a bandwidth of 0.3 to 500 Hz, while the PPG dynamic range reaches 118 dB and its LED duty cycle is 0.744. The chip micrograph and specification table are shown in Fig. 2 and Fig. 3. This chip can simultaneously detect ECG and PPG signals, making physiological signal detection more comprehensive. Its miniaturization and low power consumption make it easier to integrate with wearable devices, potentially reducing future medical monitoring resource costs and achieving a more comprehensive healthcare system.

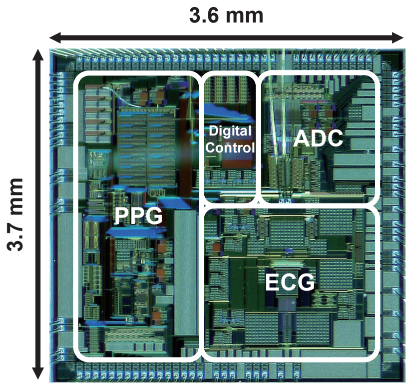


Fig. 2 Chip micrograph.

ECG		PPG		VCO-based ADC	
Technology(nm)	180				
Supply(V)	1.2				
Gain(dB)	23-65	Max. Input (A)	200µ	Input Range	600 mV
Bandwidth (Hz)	0.3-500	Ambient Curr. Removal(A)	50µ		
Input Range	27 mV_{pp}	Max. DR (dB)	118	SNDR (dB)	67.2
IRN(V_{rms})	2.25µ (0.5-150 Hz)	LED Duty Cyc.	0.744		
Power(W)	19.2 µ	Power(W)	37.2µ	Power(W)	3.4µ (w/Buffers)

Fig. 3 Chip specification.