D20-010 DESIGN GROUP

作品名稱

一個使用旁路逐漸趨近式電容數位轉換器之指叉擴展型 CMOS MEMS 壓力感測系統

An Interdigitated Extended CMOS-MEMS Capacitive Sensing System with Bypass Successive Approximation Register Capacitance to Digital Converter Readout

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作品摘要

3–D 指叉式擴展型 CMOS MEMS 電容式壓力傳感器

CMOS 微機電電容式傳感器設計為近年來的熱門研究議題。與壓電材料傳感器相比較，CMOS 微機電電容式傳感器通常有著較小的功率消耗並與讀出電路有較佳的整合度。此外，受限於 CMOS 製程的要求，傳統 CMOS 電容傳感器通常透過擴大 2–D 的電容面積來增加靈敏度。而在顱內壓感測器應用中，降低傳感器結構的面積是必要的條件之一。因此在本研究中提出全新的 3–D 的壓力電容來提升靈敏度及降低面積。由於傳統的電容式壓力感測器電容值僅由上、下平行板的初始間距與面積決定，而初始間距往往受限於製程規定，只能用面積去換取較大的壓力靈敏度。本研究為了能夠達到面積微小化的目地，將指叉式電容與平行式電容式感測器結構整合為 3–D 傳感器架構。指叉式電容利用電容上下極板互相交錯產生出左右兩側的額外感應電容值，故本研究提出之感測器結構相較於傳統的平行式結構，靈敏度提升了 85%。此外本設計相對於傳統平行式電容傳感器也節省了 59% 面積，為目前現今的 CMOS MEMS 的單晶片中單位面積下的最高靈敏度。

高能源效率逐漸式旁通電容數位轉換器

在本作品中，一個 10 位元逐漸逼近式類比數位轉換器（SAR ADC）與 3–D 電容式感測器整合在同一晶片上。3–D CMOS MEMS 電容式傳感器被整合設計於類比數位轉換器之電容陣列中。當壓力變化引起感測電容值變化時，ADC 會將電容的變化轉換為數位碼輸出。旁路窗口是根據顱內壓（ICP）信號設計的。在顱內壓極度異常的情況下，顱內壓約為 10.66 ～ 12kPa，患者可能會遭受腦損傷。在輕度腦功能不正常的狀態下，顱內壓約為 2.66 ～ 5.33 kPa。對於健康人，顱內壓保持在低於 2.66 kPa 的壓力下。

通過使用 Bypass 演算法，可以根據 ICP 的狀態避免電容器陣列的不必要切換，並降低了功耗，使其更適合於無線生物醫學感測應用。整體整合感測系統包括旁路 SAR ADC，3–D 指叉擴展 MEMS 壓力傳感器和旁路控制邏輯。在 0–40kPa 的壓力範圍內，靈敏度為 53.25 pF / Mpa。功耗為 0.861μW/1.579μW（使用 / 不使用 Bypass），FoM 分別為 0.102 pJ / conv.–step 和 0.186 pJ / conv.–step。

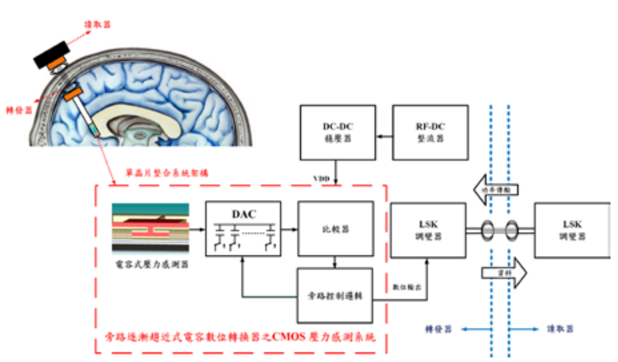

圖 1. 系統應用架構圖

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Abstract

3D Interdigitated extended CMOS MEMS capacitive pressure sensor

CMOS MEMS technology for biomedical applications has been a hot research topic in recent years. CMOS MEMS transducers have the advantages of higher integration and lower power consumption in comparison with piezoresistive ones. However, the sensitivity of traditional CMOS MEMS capacitive sensors is limited by the design rules of the process, and usually can be improved by increasing the 2-D area. In the application of intracranial pressure sensors, reducing the area of the sensor is indispensable. Therefore, a novel 3-D capacitive pressure sensor is proposed to improve the sensitivity with minimized area in this study. The interdigitated capacitor is integrated with the traditional 2-D capacitive transducer. The interdigitated capacitor uses the upper and lower plates of the capacitor to generate additional sensing capacitance. The sensitivity of the structure is increased by 85%. In addition, this design can save 59% of the area compared with the traditional 2-D transducers.

High energy-efficiency bypass capacitance-to-digital converter

In this work, a 10-bit successive-approximation register (SAR) analog-to-digital converter (ADC) is integrated on the same chip. The MEMS capacitive transducer is inserted in the capacitor array with a bypass searching algorithm. When the sensing capacitance value changes, the SAR ADC will convert the change of capacitance to digital codes. The bypass window is designed based on the intracranial pressure (ICP) signal. In an extremely abnormal state of intracranial pressure, the intracranial pressure is about 10.66~12kPa, and the patient may suffer from brain damages. In a state of minor brain dysfunction, the intracranial pressure is about 2.66~5.33 kPa. For healthy people, the intracranial pressure stays at pressure lower than 2.66 kPa.

By using the bypass algorithm, unnecessary switching of the capacitor array can be avoided according to the state of ICP and lowered the power consumption, making it more suitable for wireless biomedical applications. The integrated sensing system includes the bypass SAR ADC, 3-D interdigitated extended MEMS pressure transducer, and bypass control logics. The sensitivity is 53.25 pF/Mpa in the pressure range of 0-40kPa. The power consumption is 0.861μW/1.579μW (with/without bypass), achieving a FoM of 0.102 pJ/conv.-step and 0.186 pJ/conv.-step respectively.

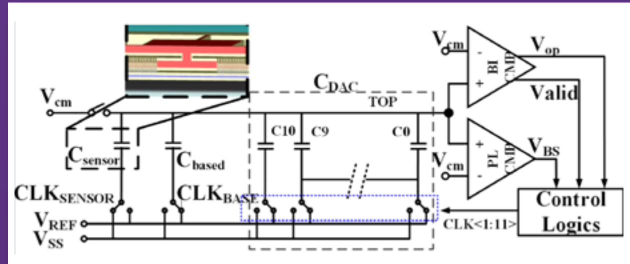

Fig. 2 Bypass SAR capacitor to digital converter based pressure sensing circuit