Report: Designing a Mixed-Signal ASIC for Medical Applications

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Introduction

The development of mixed-signal application-specific integrated circuits (ASICs) for medical applications, particularly for cardiac pacemakers, requires a keen focus on power efficiency and functionality. Modern pacemakers are sophisticated devices that need to operate reliably within the stringent constraints of power consumption and size.

System Architecture

The proposed system architecture for the triple-chamber pacemaker ASIC integrates various functional blocks essential for acquiring heart signals, processing them, and generating appropriate pacing stimuli. The architecture includes:

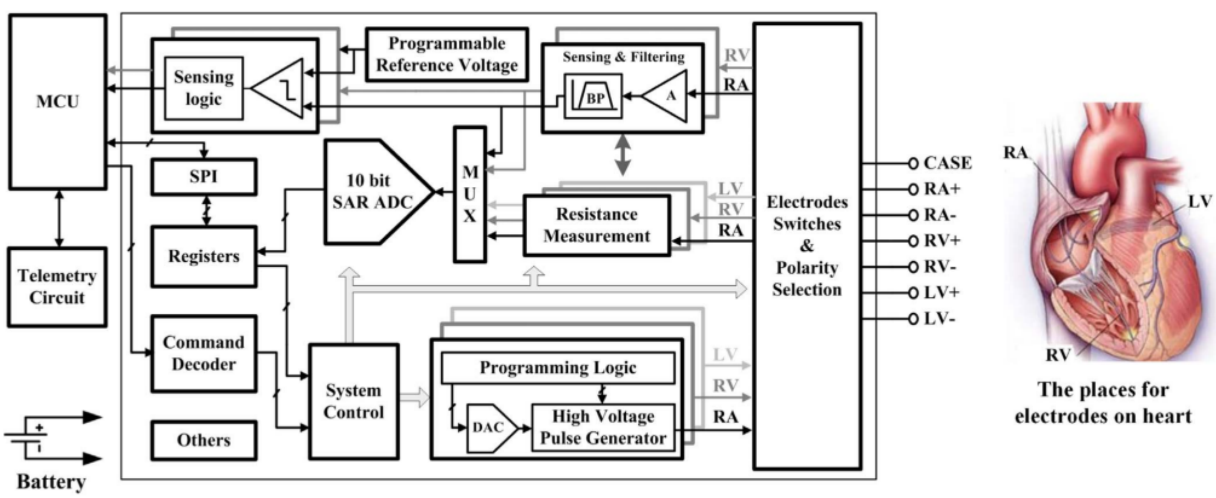

Fig. 1. System diagram of the proposed triple-chamber pacemaker.

- **Heart Signal Acquisition and Processing**: Amplifying and filtering heart signals from the right atrium (RA) and right ventricle (RV) to estimate their magnitude and rate.

- **Contact Resistance Measurement**: Assessing the attachment status of electrodes and the pathological status of the heart by injecting bidirectional currents and measuring the resulting voltages.
- **Programmable Stimulus Generation**: Delivering voltage pulses with adjustable magnitudes and pulse widths to stimulate the heart chambers based on the heart's rhythm.

Power Efficiency Strategies

1. Programmable High-Voltage Pulse Generators

Traditional high-voltage pulse generators in pacemakers rely on charge pumps or high-voltage SC amplifiers, which consume significant power. The proposed system improves power efficiency through:

- **Low-Voltage DAC**: A 5-bit DAC reduces the capacitive load on the charge pump.
- **Triple-Mode Voltage Multiplier**: This broadens the voltage range of output pulses while reducing the clock frequency of the charge pump to 100 Hz, significantly lowering dynamic power consumption.

2. Low-Power Sensing Channels

The sensing channels in the ASIC employ a fully differential active-RC topology, ensuring accurate gain and bandwidth with low power consumption. A low-power control strategy is implemented:

- **On-Demand Amplifier Activation**: The operational amplifier is turned on by a sensing command and automatically turned off after a valid sensing event to minimize power usage.

Contact Resistance Measurement

The contact resistance measurement function is critical for detecting the attachment status of the electrode leads and providing insights into the heart's condition. The ASIC uses a bidirectional current injection method for this purpose:

- **Bidirectional Current Injection**: Short current pulses in opposite directions are injected into the heart, and the resulting voltage is measured and converted to digital values for further analysis.

- **10-bit SAR ADC**: This ADC, shared by heart signal conversion and resistance measurement, ensures low power consumption and compact design.

Implementation and Measurement Results

The ASIC is fabricated using a 0.35-μm Bipolar-CMOS-DMOS (BCD) process, with a chip area of 3.8 mm x 3.8 mm. The measurement results demonstrate:

- **Programmable Stimulus Pulse**: The magnitude can be programmed from 0.1 to 7.5 V with 0.1-V steps.
- **Heart Resistance Measurement**: Achieved linear measurement in the resistance range of 250-4000 Ω.
- **Power Consumption**: The average current consumption is 4 μA under typical pacing algorithms from a 2.8-V power supply.

Conclusion

The proposed low-energy mixed-signal ASIC for triple-chamber cardiac pacemakers integrates essential functions with a focus on power efficiency and accurate performance. By implementing innovative strategies in stimulus generation and sensing channel design, the ASIC achieves significant power savings, ensuring a longer operational life for implantable medical devices.

References

- Jie Zhang, Hong Zhang, Jiangtao Xu, Yang Zhao, Jia Li, Guoyu Hu, Jialu Wang, Ruizhi Zhang, Yong Lian. "A low energy ASIC for triple-chamber cardiac pacemakers with contact resistance measurement." *Microelectronics Journal*, Volume 60, 2017, Pages 65-74.