Lossless and Low-Power ECG Compression Using a Hybrid Approach

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***Abstract*—The increasing prevalence of cardiovascular diseases necessitates efficient long-term ECG monitoring. However, the large volumes of generated data pose transmission and storage challenges. This work presents a real-time signal compression system for ECG designed to address this need while maintaining the diagnostic integrity of ECG data. The system's first stage involves an analog-to-digital conversion (ADC) step. A low-power sample-and-hold circuit captures the ECG signal, followed by precise conversion using a Successive Approximation Register Analog-to-Digital Converter (SAR ADC). Crucially, the traditional comparator within the SAR structure of ADC is replaced with a stacked inverter design. This innovation yields higher gain, improved noise immunity, and reduced power consumption, optimizing the ADC for ECG applications. The second stage employs lossless Golomb coding to compress the digital ECG data. This technique preserves all original information, ensuring no loss of diagnostic detail. Golomb coding's efficiency and computational simplicity make it ideal for real-time ECG systems. This integrated solution addresses the need for compact ECG signal storage and management. Its key contributions lie in the power-optimized ADC design featuring the stacked inverter comparator and the implementation of lossless Golomb coding. The system holds potential for clinical diagnostics, wearable ECG monitoring, and ECG data storage for research.**

***Keywords*—ECG, analog-to-digital conversion, successive approximation, stacked inverter comparator, Golomb coding, lossless compression**

I. INTRODUCTION

Electrocardiography (ECG) has a pivotal role in modern healthcare. Its ability to non-invasively assess cardiac function makes it indispensable for diagnosing arrhythmias, ischemia, and other cardiovascular conditions [cite relevant sources]. An ECG waveform comprises a series of deflections, termed the PQRST complex, representing the electrical events related to atrial and ventricular activity [add citation]. The proliferation of wearable ECG devices empowers continuous monitoring, offering potential benefits for patient care and research. However, this trend generates large volumes of data, posing challenges in storage, transmission, and analysis. Efficient compression techniques are crucial for addressing these challenges. Lossless compression stands out as a preferred approach in medical applications, as it ensures the preservation of all diagnostic information within the ECG signal, including the nuances of the PQRST complex. Golomb coding, known for its efficiency and adaptability to various data distributions, presents a promising solution. This paper investigates a real-time ECG compression system that leverages Golomb coding alongside hardware optimizations in the analog-to-digital conversion (ADC) stage.

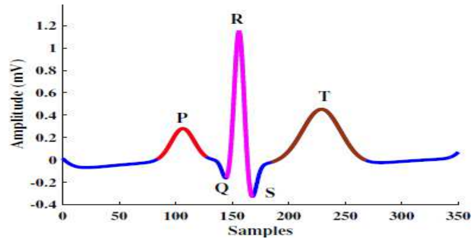

Fig 1.1 A typical signal of Electrocardiogram (ECG) along with its constituent waves

Accurate acquisition of low-frequency ECG signals necessitates addressing leakage currents in Switched-Capacitor (SC) amplifiers, which can degrade signal fidelity [cite source on SC leakage]. To mitigate this, we incorporate leakage cancellation techniques within the sampling stage. Furthermore, we employ a Successive Approximation Register Analog-to-Digital Converter (SAR ADC) for its precision and speed in digitizing the ECG signal. Crucially, a novel stacked inverter comparator architecture is proposed within the SAR ADC. This design aims to enhance gain, noise resilience, and power efficiency, making it well-suited for ECG acquisition. The proposed system integrates these components into a comprehensive solution. A leakage-optimized sampling circuit, a high-performance SAR ADC with the stacked inverter comparator, and the implementation of Golomb coding collectively address the critical requirements of ECG monitoring: power efficiency, noise

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C. Golomb Encoder and Decoder

The Golomb encoder was simulated using Xilinx Vivado. Digital data sets with long runs of zeroes were given as input. The input datasets were sampled at various bit sizes such as 16,20,24,32 and their compression ratios were analyzed. The simulation analyzed using Xilinx Vivado revealed that the compression ratio was lower when the runs of zeroes between the ones were longer, hence yielding better compression.

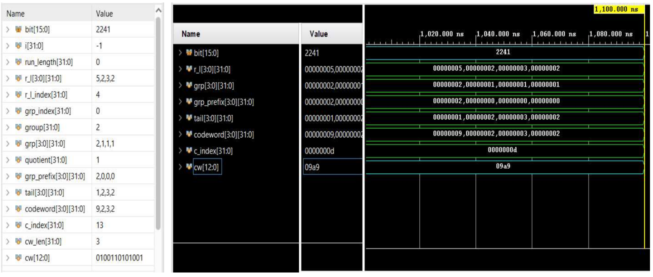

Fig 4.1 Golomb Encoder Output

The Golomb decoder yielded the original data with minimal error. The encoded code word is given as input to the decoder. The code word is encapsulated with a header byte and that header byte is used as a reference to decode the size of the decoder. The decoder is simulated in Xilinx Vivado and it is observed that the original data stream is obtained with minimal error from the code word.

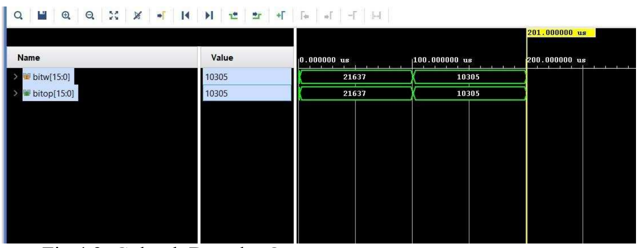

Fig 4.2 Golomb Decoder Output

V. Conclusion

The implementation of Golomb-Rice coding with hardware optimizations offers a powerful solution for efficient ECG data compression. Golomb-Rice's ability to exploit the redundancy within ECG signals leads to a substantial reduction in data size. This translates into benefits like reduced storage requirements, faster transmission, and optimized power consumption in wearable devices. To address leakage currents in sample-and-hold circuits, a replica sampling circuit with leakage cancellation was utilized, safeguarding the accuracy of the sampled ECG signal. Furthermore, the stacked inverter comparator provides an alternative within SAR ADCs, demonstrating power efficiency, noise resilience, and reduced transistor count. This approach holds promise for resource-constrained ECG acquisition systems.

This work demonstrates the effectiveness of combining Golomb-Rice coding with tailored hardware optimizations for ECG compression. Further exploration into refining the stacked inverter design could enhance its performance. These findings pave the way for improved management of ECG data, empowering the development of advanced wearable ECG devices and facilitating efficient long-term monitoring for healthcare applications.

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