FPGA-Based Defibrillator Pulse Simulation Using ECG Signal Detection ​

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*of*

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**ASIC& FPGA DESIGN, ANALOG VLSI DESIGN with 23EC2237F, 23VLS3101A**

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**Introduction**

An FPGA-based defibrillator pulse simulation system is designed to mimic the working of a medical defibrillator by detecting abnormal ECG signals and generating corrective electrical pulses.

The project integrates ECG signal acquisition, signal processing, and pulse generation modules on a reconfigurable FPGA platform, ensuring real-time performance.

The ECG input is first amplified and filtered to remove noise, then digitized and fed into the FPGA. Using digital signal processing (DSP) algorithms, the FPGA continuously monitors heart activity to detect arrhythmias such as ventricular fibrillation or tachycardia.

Once an abnormal rhythm is identified, the FPGA triggers a simulation of a defibrillator pulse, modeled as a biphasic damped exponential waveform.

The design uses PWM-based digital pulse generation with adjustable amplitude and duration, controlled by Verilog or VHDL modules. Simulation results can be visualized using MATLAB or oscilloscopes, while safety constraints are maintained since the design only simulates and does not deliver actual shock energy.

This project demonstrates the potential of FPGA-based biomedical systems, offering low-latency detection, flexibility in algorithm implementation, and reconfigurability for various ECG conditions.

It provides a valuable educational and research platform for developing real-time medical signal processing and life-saving therapeutic device prototypes.

Additionally, the design highlights how FPGA hardware acceleration ensures speed, parallel processing, and adaptability for future improvements.

With further development, it can be extended to portable monitoring systems, training kits for medical students, and experimental testbeds for advanced healthcare applications, ultimately bridging the gap between biomedical engineering and digital hardware design.

**Literature Review/** **Application Survey**

Cardiovascular diseases (CVDs) are a major cause of death worldwide, with sudden cardiac arrest (SCA) being one of the most critical conditions. Defibrillators play a vital role in restoring normal cardiac rhythm by delivering controlled electrical pulses to the heart during arrhythmias such as ventricular fibrillation. Traditionally, defibrillators are implemented as bulky hardware with limited programmability. However, with the advancement of digital hardware, particularly Field Programmable Gate Arrays (FPGAs), it is now possible to design real-time and reconfigurable systems that simulate, monitor, and analyze cardiac signals such as ECG. Literature shows a significant trend in using FPGA-based platforms for biomedical applications because of their parallelism, low latency, and reconfigurability, which are essential in life-critical applications.

1. **Review of ECG Signal Processing Techniques**

The electrocardiogram (ECG) is the primary non-invasive method to monitor cardiac activity. Detecting anomalies such as arrhythmias requires efficient preprocessing, filtering, and detection algorithms. Researchers have explored several digital signal processing methods, such as Finite Impulse Response (FIR) filters, Fast Fourier Transform (FFT)-based spectral analysis, and wavelet transforms, for denoising ECG signals. FPGA implementations of these techniques provide hardware-level acceleration, which is critical for real-time monitoring. Studies have demonstrated that FPGA-based FIR filters achieve higher throughput and lower power compared to microcontrollers or DSP processors.

1. **FPGA in Defibrillator Pulse Simulation**

Defibrillator pulses are typically modeled as biphasic truncated exponential or damped sine waveforms. Conventional systems use analog circuitry to generate such pulses, but FPGA-based designs allow digital modeling of these waveforms using PWM (Pulse Width Modulation) or Direct Digital Synthesis (DDS). Several studies have demonstrated FPGA-generated biomedical signals, including ECG and pacemaker pulses, proving the feasibility of applying similar techniques for defibrillator pulse simulation.

Research also highlights that FPGA implementations ensure timing precision, essential in medical systems where delays can be life-threatening. Unlike software simulation on PCs, FPGA hardware provides deterministic execution. In academic works, FPGA-based models have been used in laboratory environments to simulate defibrillator output without delivering harmful energy, making them useful for education, training, and validation of medical devices.

1. **Applications of FPGA-Based Defibrillator Simulation**
2. **Medical Training And Education:**

Simulation-based training is critical for medical students and clinicians. FPGA-based defibrillator pulse simulation systems allow safe demonstration of how ECG abnormalities are corrected using electrical pulses, without exposing learners to risks. These systems can replicate different arrhythmias and simulate appropriate corrective action, enhancing hands-on understanding.

1. **Research**   
   Biomedical engineers can use FPGA-based simulators to design and test new defibrillator algorithms before deploying them in real devices. Since FPGAs are reprogrammable, multiple waveform generation strategies and detection techniques can be compared in real-time.
2. **Portable and Embedded Healthcare Systems:**

Literature shows a growing interest in portable and low-power FPGA-based systems for telemedicine and remote monitoring. A defibrillator simulation module can be integrated into wearable healthcare devices for continuous ECG monitoring, early arrhythmia detection, and emergency response triggering.

1. **Advantages over Conventional Approaches**

Conventional software simulations using MATLAB or microcontrollers lack the speed and deterministic performance of FPGAs. Microcontrollers process instructions sequentially, which introduces latency in real-time applications. In contrast, FPGA hardware parallelism enables simultaneous ECG monitoring, noise filtering, arrhythmia detection, and pulse simulation. Moreover, FPGAs offer scalability; additional algorithms such as machine learning-based anomaly detection can be incorporated without redesigning the entire hardware.

Studies also emphasize the reconfigurability of FPGAs, which allows adapting the system to different patient needs. For example, defibrillator pulse amplitude and duration can be adjusted digitally, which is difficult in fixed analog hardware. Furthermore, FPGA-based systems consume less power compared to PCs running software simulations, making them more suitable for portable and wearable biomedical devices.

1. **Challenges Identified in Literature**

While FPGA-based biomedical systems are promising, challenges remain. One major issue is the need for efficient resource utilization, as complex DSP algorithms and waveform generation can consume significant logic blocks and memory. Another challenge is the verification of safety, since real defibrillator devices must comply with strict medical regulations. Literature also suggests that FPGA-based simulations should be integrated with user-friendly interfaces for medical practitioners, as not all end-users have technical expertise. Finally, cost considerations and the learning curve of FPGA design tools (VHDL/Verilog, Vivado, Quartus) remain barriers in widespread adoption.

1. **Future Directions**

Recent studies suggest integrating FPGA with machine learning accelerators for intelligent arrhythmia detection. Combining FPGA hardware acceleration with AI models can improve prediction of cardiac arrest and optimize defibrillator pulse parameters. Another promising direction is FPGA-based System-on-Chip (SoC) platforms such as Xilinx Zynq, which combine FPGA fabric with ARM processors, enabling hybrid hardware-software systems for smart healthcare. Future applications may also include cloud-connected FPGA devices for remote monitoring and defibrillator simulation across telemedicine platforms.

1. **Conclusion**

The literature highlights that FPGA-based defibrillator pulse simulation using ECG signal detection offers significant potential for healthcare, education, and research. By combining ECG signal acquisition, real-time arrhythmia detection, and digital waveform generation on FPGA, such systems provide accuracy, flexibility, and safety. Applications span from medical training to portable monitoring devices, making FPGA technology an attractive solution for next-generation biomedical systems. Despite challenges in resource utilization and regulatory compliance, continuous research is bridging these gaps, positioning FPGA-based solutions as a key enabler in digital healthcare innovation.