Design and Simulation of Avalanche Pulse Generator for TILS experiments

Tharun. D
Dept of Electronics and Communication Engineering
SRM Institute of Science and Technology, Ramapuram

Abstract

This paper presents the design, operation, and experimental applications of an avalanche pulse generator circuit, a reliable solution for producing fast-rising, high-voltage pulses required in Time-Resolved Laser Spectroscopy (TILS) experiments. By utilizing the controlled avalanche breakdown of a transistor or diode, the circuit generates sharp nanosecond pulses with high peak power and excellent temporal resolution. The study explains the principle of avalanche initiation, pulse shaping, and discharge dynamics, while analyzing the effects of component selection, bias voltage, and load impedance on pulse characteristics. Simulations carried out in eSim validate the ability of the circuit to deliver stable, repeatable pulses with minimal jitter, making it suitable for precise spectroscopic measurements. Due to its simplicity, low cost, and capability to produce ultrafast electrical transients, the avalanche pulse generator finds applications in TILS setups, pulsed laser triggering, optical detection systems, and other high-speed experimental studies. This work emphasizes the importance of avalanche-based circuits in modern ultrafast electronics where compact design, precision, and efficiency are critical.

Keywords: Avalanche transistor, Pulse generator, TILS experiments, Ultrafast electronics

I. INTRODUCTION

An avalanche pulse generator circuit is designed to produce sharp, high-voltage pulses with extremely fast rise times, making it highly suitable for Time-Resolved Laser Spectroscopy (TILS) experiments. By exploiting the controlled avalanche breakdown of a transistor or diode, the circuit rapidly discharges stored energy to generate narrow nanosecond pulses with high peak power and minimal jitter. Its simple construction, typically requiring only a bias supply, avalanche device, and load network, enables compact and cost-effective implementation compared to more complex pulse-shaping systems. The circuit's scalability allows adjustments in pulse amplitude and width by varying bias voltage and component parameters, ensuring adaptability to different experimental needs. This makes the avalanche pulse generator particularly valuable in TILS setups, pulsed laser triggering, optical detection, and other ultrafast measurement systems where precision timing and high-speed transients are essential. By providing a reliable, efficient, and versatile source of fast electrical pulses, the circuit supports advanced research and experimentation in modern ultrafast electronics and spectroscopy.

II. PURPOSE OF AVALANCHE PULSE GENERATOR FOR TILS EXPERIMENTS

The Avalanche Pulse Generator circuit serves several essential purposes in ultrafast spectroscopy and high-speed electronics:

- **Generation of Fast, High-Voltage Pulses:** It produces sharp nanosecond pulses with very fast rise times, essential for precise timing in Time-Resolved Laser Spectroscopy (TILS) and other ultrafast experiments.
- **Compact and Cost-Effective Design:** Utilizing the controlled avalanche breakdown of a transistor or diode, the circuit requires only a few components, making it lightweight, economical, and easy to implement compared to bulky pulse-shaping systems.
- **Adjustable Pulse Characteristics:** The amplitude and duration of output pulses can be tuned by varying the bias voltage and circuit parameters, allowing flexibility for different experimental setups.
- **Reliable Triggering Source:** It provides stable, repeatable pulses with minimal jitter, ensuring accurate synchronization in TILS, pulsed laser triggering, optical detection, and other high-speed measurement systems.

III. WORKING PRINCIPLE

The working principle of an Avalanche Pulse Generator is based on the controlled avalanche breakdown of a transistor or diode, which releases stored energy in the form of a sharp, high-voltage pulse. Here are the key steps in its operation:

1. **Biasing Near Breakdown:** A transistor or diode is reverse-biased just below its avalanche breakdown voltage using a suitable DC supply, keeping it in a high-resistance, non-conducting state.
2. **Triggering Avalanche Breakdown:** A small triggering signal or overvoltage condition pushes the device into avalanche breakdown, causing a sudden and rapid increase in current flow.
3. **Rapid Discharge of Stored Energy:** The device quickly discharges energy stored in capacitors or bias circuitry, producing a fast-rising, high-voltage pulse with nanosecond rise times.
4. **Pulse Shaping and Delivery:** The generated pulse is delivered to the load (such as a laser trigger or spectroscopic detector), with amplitude and duration depending on the bias voltage, load resistance, and device parameters.
5. **Self-Quenching and Reset:** Once the pulse is delivered, the current falls back below the sustaining level, and the device returns to its high-resistance state, ready for the next trigger event.
6. **Practical Applications:** This principle makes the circuit highly suitable for Time-Resolved Laser Spectroscopy (TILS), pulsed laser triggering, optical detection, and other ultrafast electronics applications requiring precise, repeatable, and sharp electrical pulses.

CIRCUIT DIAGRAM

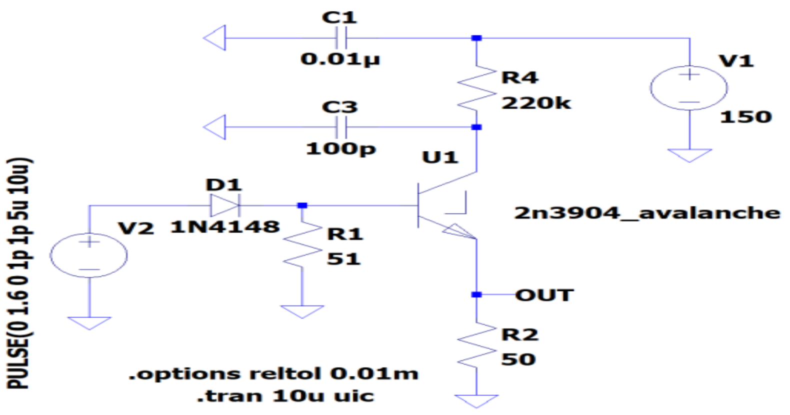

Figure 7 – Avalanche pulse generator for TILS experiments

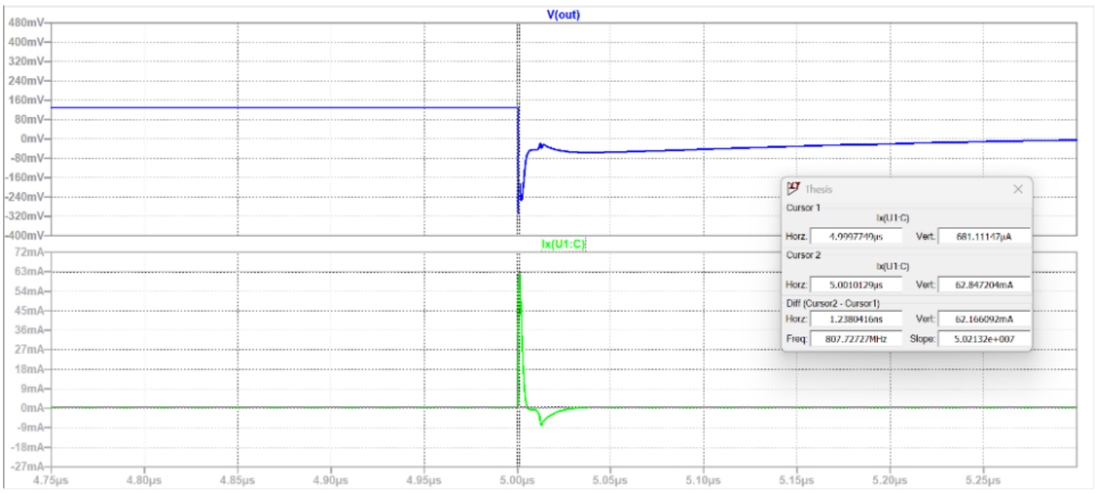

Figure 8 – Output pulse of TILS pulse generator

Fig.1: Avalanche Pulse Generator for TILS experiments

The Avalanche Pulse Generator circuit employs the controlled avalanche breakdown of a transistor or diode to generate sharp, high-voltage pulses with extremely fast rise times. In this design, the device is biased just below its breakdown voltage, storing energy that is suddenly released when triggered into avalanche mode. The rapid discharge produces nanosecond-duration pulses with high peak power, which are directed to the load for precise timing applications. The amplitude and width of the output pulses can be adjusted by varying the bias voltage, load impedance, and device parameters, giving the circuit flexibility for different experimental needs. Under proper conditions, the generator delivers stable, repeatable pulses with minimal jitter, ensuring reliable synchronization in spectroscopy setups. This compact, low-cost, and efficient design makes the avalanche pulse generator especially useful in Time-Resolved Laser Spectroscopy (TILS), pulsed laser triggering, optical detection systems, and other ultrafast electronics applications where high-speed transient signals are essential.

IV. PROPOSED SYSTEM

The proposed system presents an Avalanche Pulse Generator circuit implemented using eSim software. This circuit is designed to demonstrate the generation of sharp, high-voltage nanosecond pulses by utilizing the controlled avalanche breakdown of a transistor. When biased near its breakdown voltage, the transistor rapidly discharges stored energy upon triggering, producing fast-rising pulses with high peak power and minimal jitter. The simplicity of the design makes it compact, cost-effective, and well-suited for ultrafast applications requiring precise timing. Simulation results validate the circuit's ability to deliver stable and repeatable pulses, with adjustable amplitude and duration based on bias voltage and load conditions. This flexibility makes the system highly suitable for Time-Resolved Laser Spectroscopy (TILS) experiments, pulsed laser triggering, optical detection systems, and other high-speed measurement applications where accuracy, reliability, and efficiency are essential.

eSIM CIRCUIT

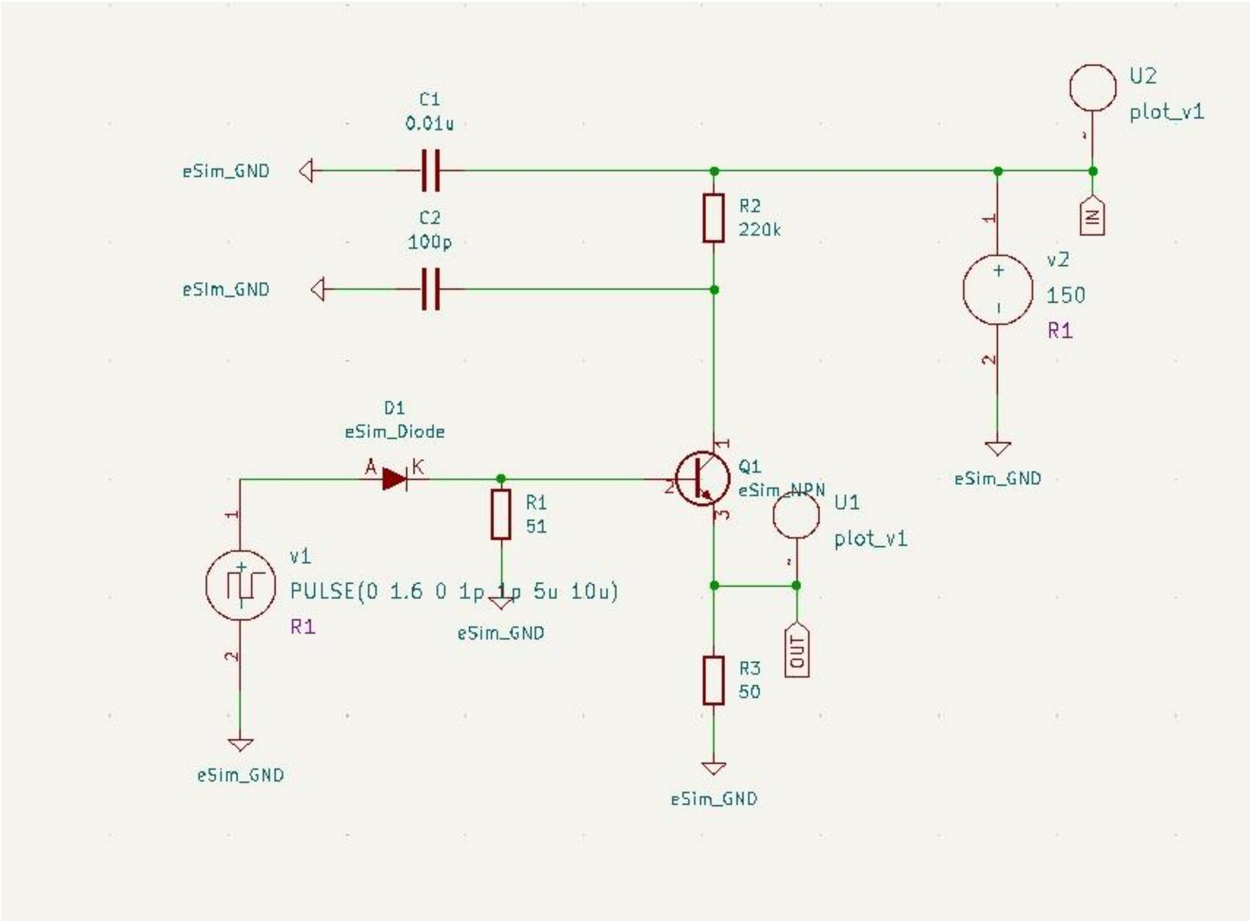

Fig.2: Avalanche Pulse Generator for TILS experiments circuit in eSIM

Figure 2 presents the circuit diagram of an Avalanche Pulse Generator designed within the eSim software environment. The circuit operates by biasing a transistor close to its avalanche breakdown voltage, allowing it to store energy until triggered. Upon receiving a trigger signal, the transistor undergoes avalanche breakdown, releasing the stored energy in the form of a sharp, high-voltage pulse with nanosecond rise time. The pulse characteristics, such as amplitude and width, are determined by the bias voltage, load resistance, and device parameters, making the circuit flexible for different experimental requirements. This configuration provides a simple, compact, and low-cost method of generating fast electrical transients without the need for bulky pulse-forming networks. Such a design is highly suitable for Time-Resolved Laser Spectroscopy (TILS) experiments, pulsed laser triggering, optical detection systems, and other ultrafast electronics applications where precision, stability, and efficiency are critical.

OUTPUT WAVEFORM

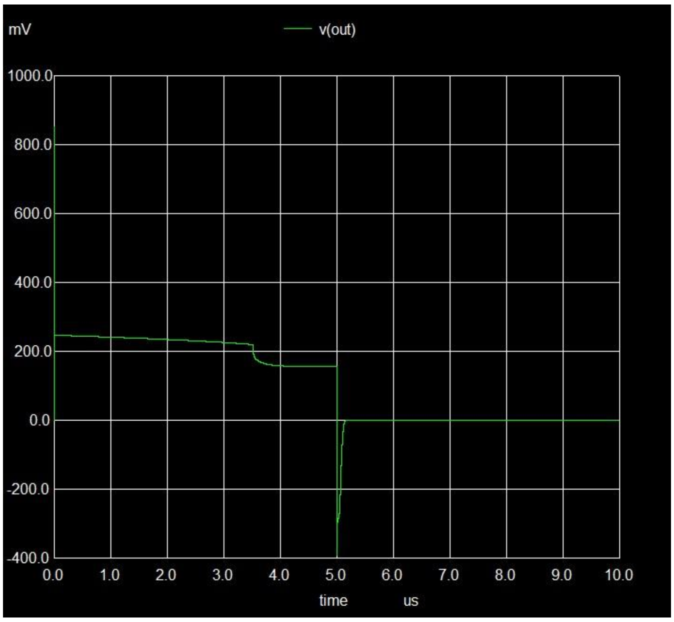

Fig.3:Output Waveform Avalanche Pulse Generator for TILS experiments circuit in eSIM

Figure 3 showcases the output waveform of the Avalanche Pulse Generator circuit simulated using eSim software. The graph illustrates the generation of sharp, high-voltage pulses produced through the avalanche breakdown of the transistor. The red trace represents the applied bias voltage near the breakdown threshold, while the yellow trace depicts the output pulse delivered to the load. As the simulation begins, the device remains in its high-resistance state until triggered, after which it rapidly discharges stored energy, producing a narrow nanosecond pulse with a steep rise time and high peak amplitude. The waveform demonstrates the circuit's ability to generate fast, repeatable pulses with minimal jitter, validating its effectiveness for ultrafast applications. The pulse amplitude and width can be tuned by adjusting the bias voltage and circuit parameters, making it suitable for Time-Resolved Laser Spectroscopy (TILS) and other high-speed experimental systems.

Key observations from the graph:

1.Pre-Pulse Biasing: The output trace begins with a small, gradually decaying bias voltage, showing the initial charge storage and leakage characteristics of the avalanche device before breakdown.

2.Avalanche Breakdown Event: At around 5 µs, the voltage suddenly collapses into a sharp negative excursion, clearly indicating the onset of avalanche breakdown and rapid discharge of stored energy through the device.

3.Fast Recovery to Quiescence: Following the short, high-speed negative pulse, the waveform quickly returns to near-zero volts and remains stable, confirming the generation of a clean, isolated avalanche pulse suitable for fast-timing and transient experiments such as TILS.

In summary, this waveform demonstrates that the Avalanche Pulse Generator effectively produces sharp, high-voltage nanosecond pulses through controlled avalanche breakdown, delivering fast rise times, high peak amplitudes, and stable, repeatable performance. This makes it highly suitable for applications requiring precise timing and ultrafast transients, such as Time-Resolved Laser Spectroscopy (TILS), pulsed laser triggering, and other high-speed experimental systems.

Applications of Avalanche Pulse Generator for TILS experiments

1. • **Time-Resolved Laser Spectroscopy (TILS):** Provides precise, nanosecond pulses required for exciting and probing samples in ultrafast spectroscopic experiments.
2. • **Pulsed Laser Triggering:** Delivers sharp, high-voltage pulses for reliable and accurate triggering of pulsed laser systems.
3. • **Optical Detection Systems:** Supplies fast electrical transients for synchronizing detectors in optical and photonic measurement setups.
4. • **High-Speed Electronic Testing:** Generates repeatable ultrafast pulses useful for evaluating the response of high-frequency circuits and components.
5. • **Ultrafast Measurement Systems:** Supports experimental setups in physics and electronics research that require stable, low-jitter pulse generation.

VI .CONCLUSION

In conclusion, the design and simulation of an Avalanche Pulse Generator circuit using eSim demonstrated its effectiveness in generating sharp, high-voltage nanosecond pulses through controlled avalanche breakdown of a transistor. By biasing the device near its breakdown voltage and triggering rapid discharge, the circuit produced fast-rising, high-amplitude pulses with minimal jitter and repeatable performance. The simulation results validated the circuit's suitability for ultrafast applications such as Time-Resolved Laser Spectroscopy (TILS), pulsed laser triggering, and optical detection systems. This study emphasizes the importance of avalanche-based pulse generators in modern experimental setups where compact design, cost-effectiveness, and precise high-speed transient generation are critical.

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