Pulse Duration Detector

PS:
Mission Brief: Pulse Duration Detector You have been assigned a critical mission in a cutting-edge research lab. Your objective is to design and build an electronic circuit that monitors a non-periodic digital pulse signal from a specialized sensor. The circuit must turn ON an LED indicator only if the input pulse stays HIGH continuously for a predefined minimum duration. Any pulse shorter than this duration should be ignored to prevent false triggering.

There is no need to hold the output — the LED must automatically turn OFF when the input pulse goes LOW, ensuring the circuit is ready to detect the next incoming pulse at any moment.

Power is limited to the provided ±12 V dual supplies only — no other power sources may be used. Using additional supplies will incur a penalty of 15 points.
You may only use basic analog components: op-amps, resistors, capacitors, diodes, and transistors.

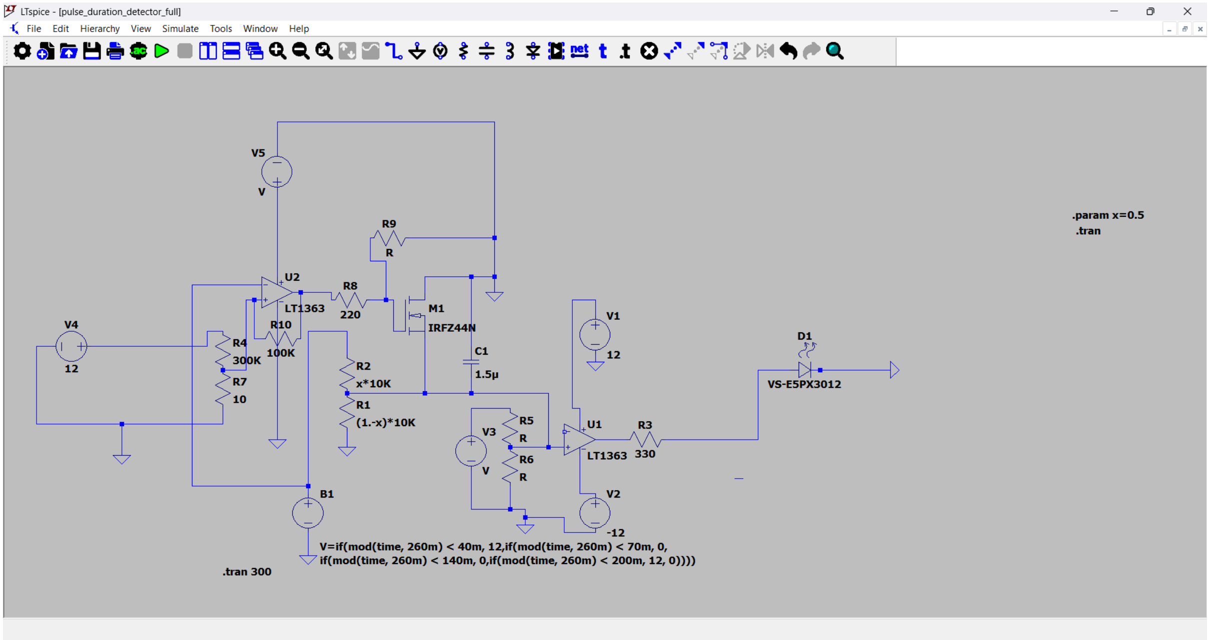
No special-purpose ICs (e.g., timers, logic gates, microcontrollers, comparators other than op amps) are allowed. Your design should combine key analog concepts, including operational amplifiers, RC timing networks, and diode circuits, to accurately detect the duration of the non-periodic pulse and control the LED output. The LED should switch ON exactly when the pulse exceeds the threshold and reset immediately after the pulse ends.

Important: If your circuit does not automatically reset itself after the pulse ends, the maximum score you can earn is 90 points. Total points for this task are 100.

To challenge your skills further, a bonus of 40 points will be awarded if your circuit can detect and respond to variable pulse durations, allowing the threshold time to be adjusted dynamically (e.g., with a potentiometer).

Good luck! This project requires precision timing and effective integration of multiple analog components under real-world constraints.

Solution:



1. Summary

This project implements a non-periodic pulse detection circuit using op-amps and a MOSFET, where an LED turns on only if the input pulse stays high for a minimum defined time. The circuit validates pulse duration using an RC integrator and a voltage comparator, with controlled discharging implemented using a MOSFET. Unlike traditional designs, no current amplification transistor is used between the op-amp and LED because the chosen op-amp (LT1363) can directly supply sufficient current. The design ensures noise immunity, efficient discharge, and avoids unnecessary amplification stages.

2. Objective
To build a circuit that:

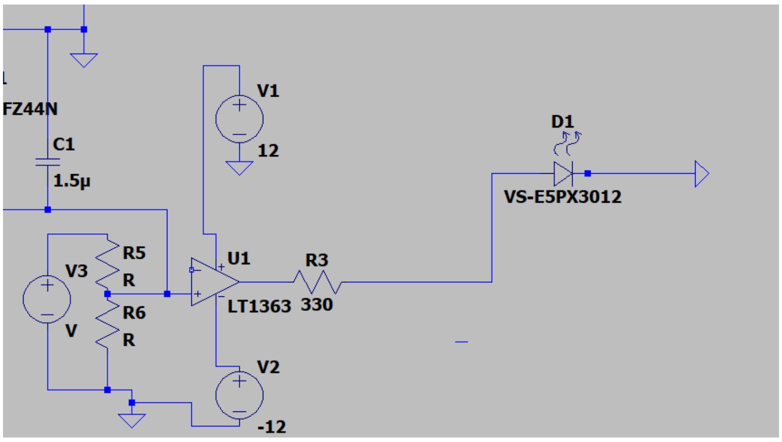
- Detects when a digital input stays HIGH for longer than a defined minimum time.
- Ignores short pulses to avoid false triggering.
- Turns ON an LED only during valid HIGH durations.
- Automatically turns OFF the LED otherwise.
- Uses only analog components (no microcontroller).

3. Circuit Design Breakdown

a. Comparator Stage (Op-Amp U1)

- **Purpose**: Compares capacitor voltage to a reference to validate input pulse duration.
- **Configuration**: Non-inverting comparator using the LT1363 with ±12V supply.
- **Why op-amp**: LT1363 was chosen for its high slew rate (1000 V/μs) and output drive (±50 mA), suitable for driving an LED directly.
- **Why no transistor**: With the LED's average current around 20–30 mA, LT1363 can supply this directly, making an additional NPN transistor (like BC547) unnecessary.

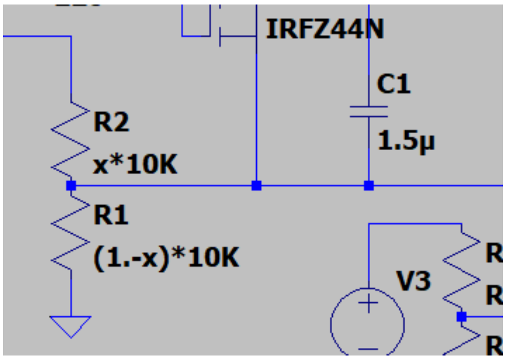
This simplifies the design and reduces component count.



b. RC Integrator (Pulse Duration Monitor)

- **Components**: R1, R2, and C1 form an RC charging circuit.

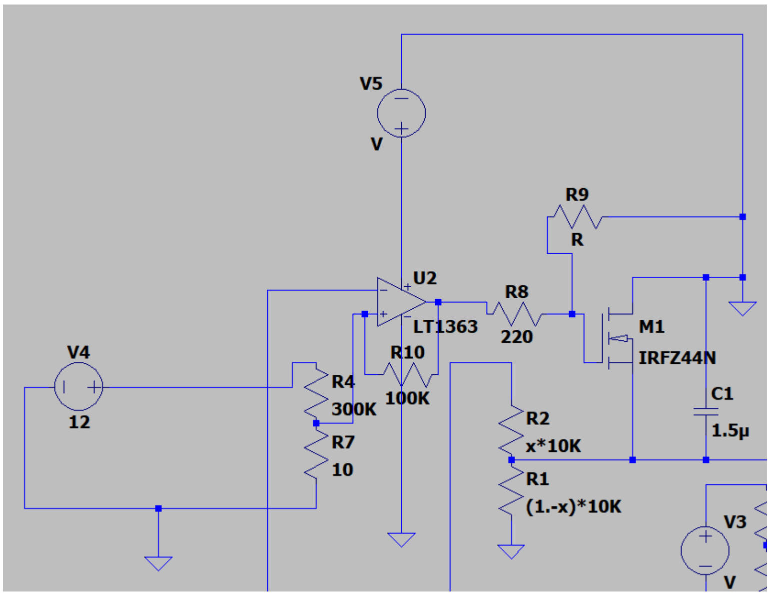
- **Working**: Input pulses charge the capacitor. If the pulse is long enough, the voltage exceeds the threshold set by a reference, triggering the output.



c. Discharge Control using MOSFET (Q1)

- **Purpose**: Rapidly discharges the capacitor after each pulse to prepare for the next.

- **Configuration**: Controlled by an inverting op-amp/comparator.



- **Why MOSFET over BJT**:
    - Faster switching.
    - Lower on-resistance → less power loss.
    - No base current required — gate is voltage-controlled.
- **Chosen Component**: IRFZ44N (N-channel MOSFET).
    - Low Rds(on), supports high gate voltages, readily available.
    - Gate is driven via a 220-ohm resistor to limit gate ringing.

d. Feedback Resistor (Rf)

- **Purpose**: Positive feedback adds hysteresis to prevent noise-triggered false switching.
- **Value**: 100kΩ — high enough to prevent excessive current, adds small offset to switching threshold.
- **Why optional**: Circuit can function without it, but it improves stability.

4. Component Justifications

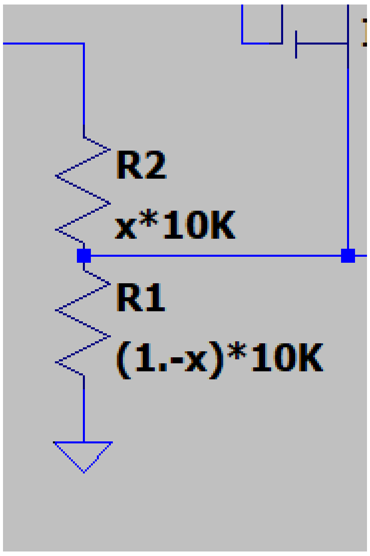
Component	Reason
Op-Amp (LT1363)	High current output (±50 mA), fast slew rate, rail-to-rail, dual supply
MOSFET (IRFZ44N)	Efficient, fast switching, low Rds(on), supports 12V logic levels
Capacitor (1.5 μF)	Determines RC delay, tuned for ~40 ms window
Resistors (10k, 300k, 220Ω)	Set reference, feedback, and gate drive respectively
LED (VS-E5PX3012 from Vishay)	Iavg of 30 mA, matches op-amp output capability, consistent Vf ~2V
Rled (1kΩ)	Limits current through LED at 12V, safe operation

Why Vishay LED model VS-E5PX3012?

- Offers consistent Iavg options (15/30/60/75 mA).
- Compatible with the LT1363 output current.
- Stable breakdown voltage and current specification.
- Easy to model in LTspice.

5. Potentiometer & Threshold Voltage (x)

- **Working**: Adjusting R1/R2 (or a potentiometer) changes the reference voltage applied to the comparator.
- **Purpose**: Calibrate the required duration (i.e., how long the input must stay HIGH to trigger output).
- **Formula**: Threshold Voltage = x × 12V.



6. Simulation Behavior

- Controlled waveform simulation with if(mod(time)) logic.
- Valid pulses cross the threshold → LED turns ON.
- Short pulses → capacitor doesn't charge enough → LED remains OFF.

- Capacitor rapidly discharges after each pulse via the MOSFET.

7. Key Design Choices Explained

- **Why no transistor for LED**: LT1363 provides sufficient current (~50 mA), no extra transistor needed.
- **Why MOSFET over BJT**: Faster, more efficient for discharging; avoids base current losses.
- **Why positive feedback**: Adds hysteresis to the comparator, improves noise immunity.
- **Why LT1363**: Combines speed, current, and simplicity for both comparator and drive.
- **Why comparator-like op-amp**: Keeps design analog and avoids digital ICs or MCUs.
- **Why Vishay LED**: Matched current specs, easily available, supported in LTspice.

8. Possible Expansions

- Add Schmitt trigger for robust noise immunity.

- Swap op-amp for dedicated comparator IC (LM393) for faster switching.
- Replace LED with opto-isolator or relay for external load switching.
- Add a buzzer or audio feedback.
- Interface with microcontroller for event logging.
- Add variable RC timing with rotary switches or digital pots.