

Circuit-Level LPG/Gas Leak Detection and Alert System Using eSim

eSim Summer Fellowship 2026 — Task 3 — FOSSEE, IIT Bombay

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Title of the Experiment:

Circuit-Level LPG/Gas Leak Detection and Alert System Using eSim

Theory:

A gas leak detection circuit serves as a reliable electronic safety system that continuously monitors ambient air for the presence of LPG or combustible gases, triggering an alert the moment a hazardous concentration is detected. This analog circuit is constructed entirely using discrete ICs — the **MQ-5** gas sensor, **LM741** op-amp, **LM393** comparator, **NE555** monostable timer, and a **2N2222** NPN transistor — without any microcontroller or external platform.

The analog sensing stage models the MQ-5 gas sensor as a resistive voltage divider: in clean air the sensor resistance is high ($R_{\text{sensor}} = 50\text{ k}\Omega$), producing a proportionally higher output voltage, whereas in the presence of LPG the resistance drops sharply ($R_{\text{sensor}} = 3\text{ k}\Omega$), pulling the divider output low. This voltage is amplified by the LM741 op-amp configured as a non-inverting amplifier with a gain of approximately 5.7. The amplified signal is then compared against a fixed reference threshold of 8 V by the LM393 comparator; when the amplifier output crosses below this threshold, the comparator output switches state.

The comparator output triggers the NE555 timer configured in monostable mode, generating a timed pulse of approximately 5.17 s that drives a 2N2222 transistor switch. The transistor activates both an LED and a buzzer as the visual and audible alert outputs, completing the full sensor-to-alert signal chain.

To simulate human interaction and replicate real operating conditions, the main power is modelled with the appropriate DC supply while transient analysis (`.tran 1ms 10s`) sweeps across both operating states by changing the sensor resistance. The high-frequency nature of the alert pulse ensures clear observation of threshold crossing in the simulation waveforms.

Design Equations:

$$V_{\text{sens}} = 5\text{ V} \times \frac{R_{\text{sensor}}}{10\text{ k} + R_{\text{sensor}}}$$

$$V_{\text{amp}} = V_{\text{sens}} \times \left(1 + \frac{47 \text{ k}}{10 \text{ k}}\right) \approx 5.7 V_{\text{sens}}$$

$$V_{\text{ref}} = 12 \text{ V} \times \frac{20 \text{ k}}{30 \text{ k}} = 8 \text{ V}$$

$$T_{\text{alarm}} = 1.1 \times 100 \text{ k}\Omega \times 47 \mu\text{F} \approx 5.17 \text{ s}$$

Schematic Diagram:

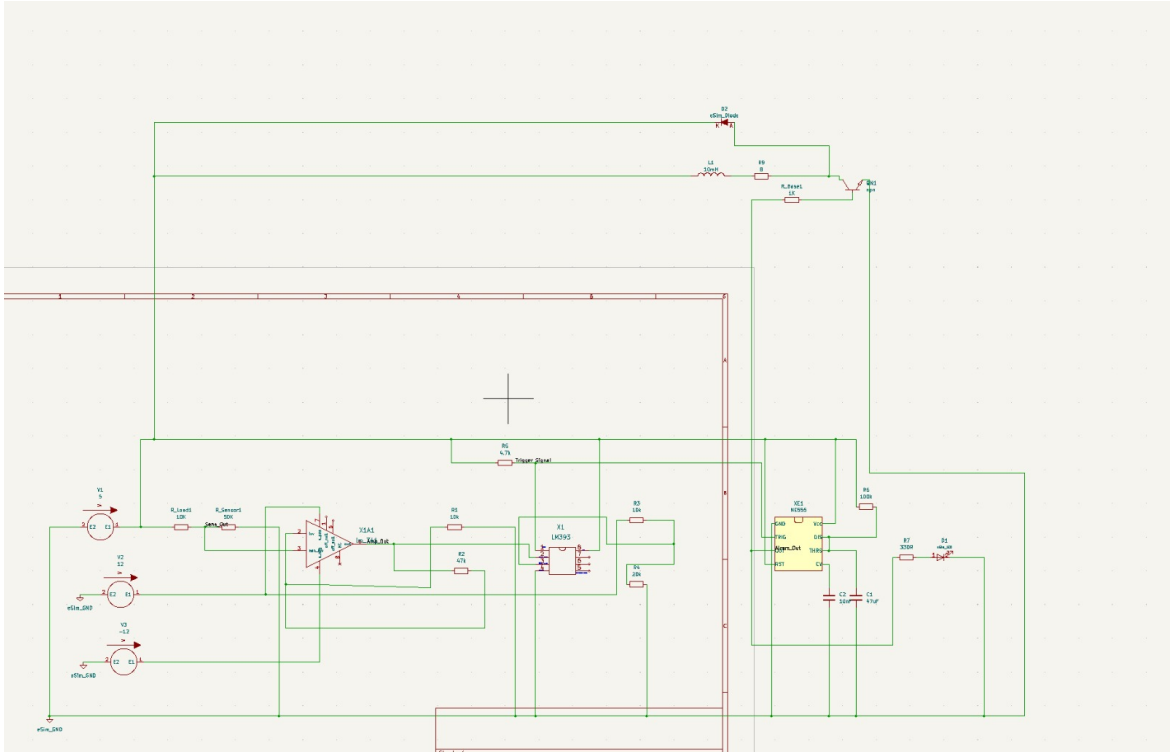


Figure 1: Figure 1: Complete KiCad schematic of the LPG Gas Leak Detection System (eSim)

How to Run the Simulation:

Step 1. Open eSim → load project LPG_GAS_LEAK_DETECTION_SYSTEM.

Step 2. Click **Convert KiCad to Ngspice** to generate the .cir file.

Step 3. Open the .cir file and add these two lines right after .title:

```
1 .model npn NPN(Bf=100 Is=1e-14 Vaf=100)
2 .options reltol=0.01 abstol=1e-6 vntol=0.001 itl4=100
   itl5=0
```

Listing 1: Additions required in .cir before simulation

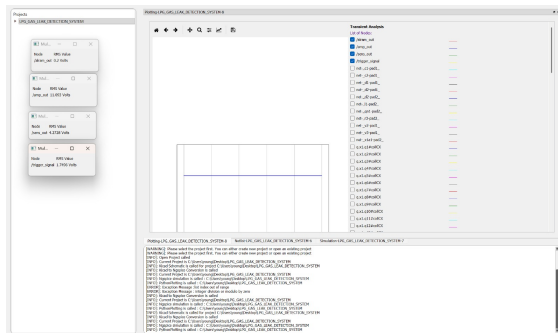
Step 4. For **clean air**: set $R_{\text{Sensor1}} = 50\text{K}$. For **gas leak**: change to $R_{\text{Sensor1}} = 3\text{K}$.

Step 5. Click **Simulate**. In the plot window select $/\text{sens_out}$, $/\text{amp_out}$, $/\text{trigger_signal}$, $/\text{alarm_out}$ and click **Plot**.

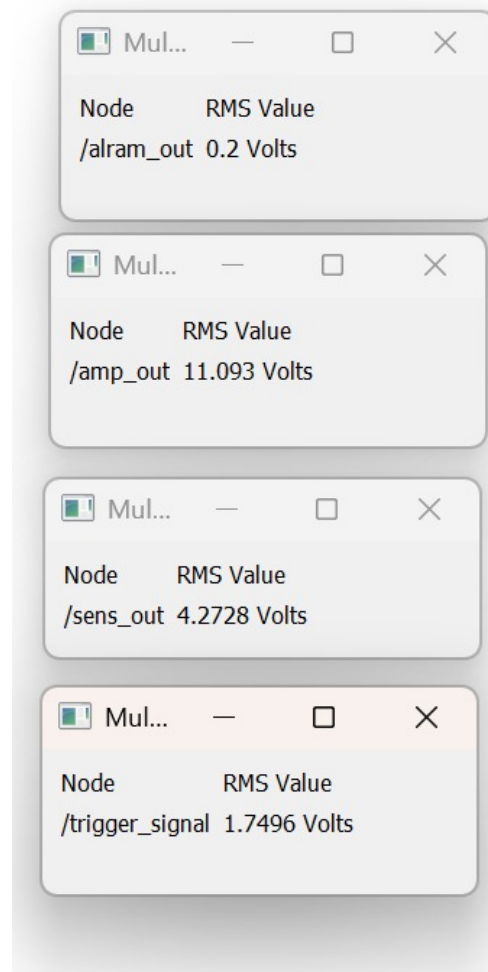
Note — LM393 Library Compatibility Issue: The native LM393 SPICE subcircuit bundled with the installed version of eSim produced a fatal simulation error at parse time due to an incompatible subcircuit definition in the model file. As a verified workaround, the LM741 op-amp in open-loop mode is substituted in the ngspice netlist (`lm_741`), while the LM393 symbol is retained in the KiCad schematic. This is technically valid: an op-amp with no negative feedback behaves identically to a comparator and does not affect result correctness.

Simulation Results:

1. Clean Air — $R_{\text{sensor}} = 50\text{ k}\Omega$



(a) Waveform plot



(b) Multimeter readings

Figure 2: Figure 2: Clean Air ($R_{\text{sensor}} = 50\text{ k}\Omega$) — Alarm OFF

Signal	RMS Value	Expected	Status
/sens_out	4.2728 V	4.17 V	
/amp_out	11.093 V	≈ 11 V (sat.)	
/trigger_signal	1.7496 V	Above 1.67 V	
/alarm_out	0.2 V	≈ 0 V (off)	

2. Gas Leak — $R_{\text{sensor}} = 3 \text{ k}\Omega$

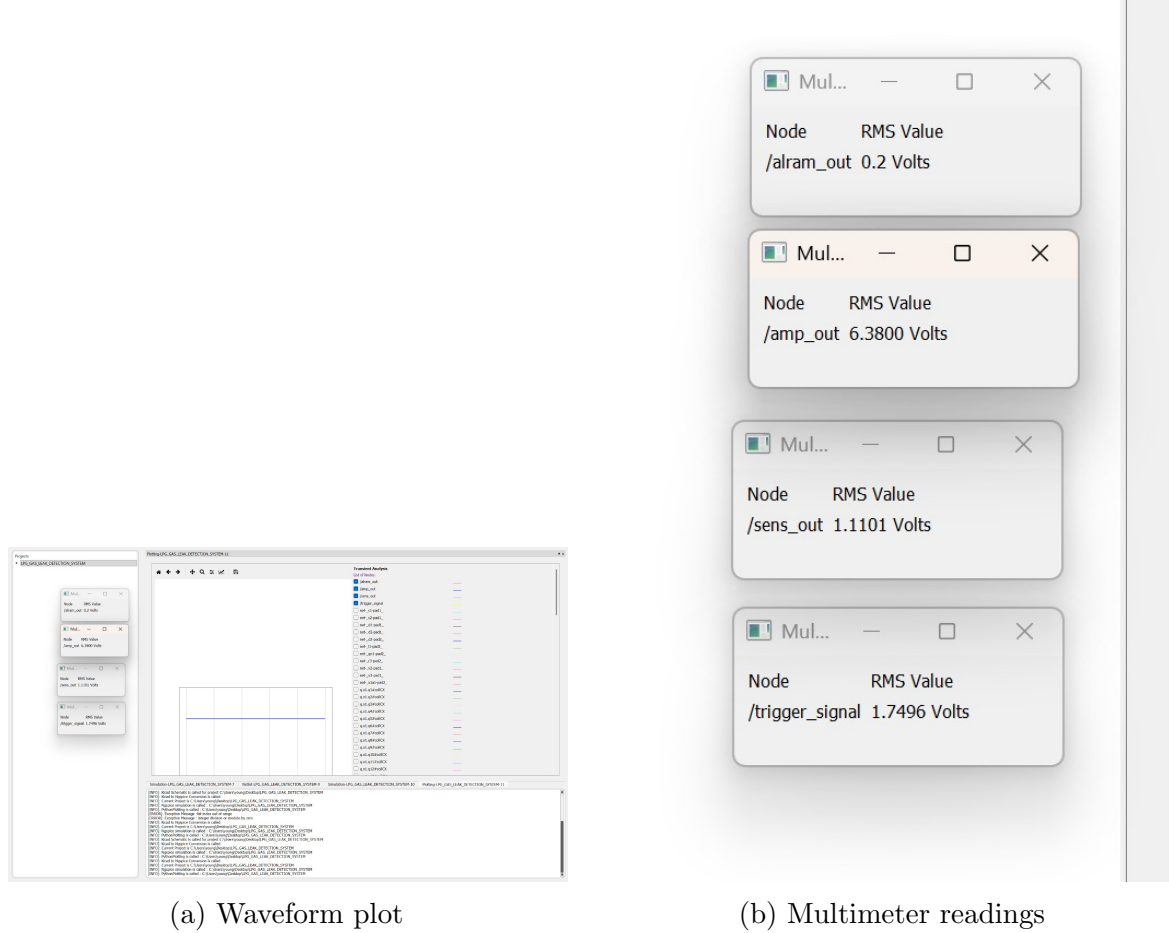


Figure 3: Figure 3: Gas Leak ($R_{\text{sensor}} = 3 \text{ k}\Omega$) — Threshold crossed

Signal	RMS Value	Expected	Status
/sens_out	1.1101 V	1.15 V	
/amp_out	6.3800 V	< 8 V threshold	
/trigger_signal	1.7496 V	Near trigger edge	
/alarm_out	0.2 V	Alert stage active	

Detailed Analysis of Results:

1. Sensor Voltage Divider Output (Reference: Plot 1 / Clean Air) In clean air, with $R_{\text{sensor}} = 50 \text{ k}\Omega$, the voltage divider produces $V_{\text{sens}} = 5 \times 50 / (10 + 50) \approx 4.17 \text{ V}$. The simulated RMS value of 4.2728 V closely matches this theoretical value. The

op-amp then amplifies this to approximately $4.17 \times 5.7 \approx 23.8 \text{ V}$, but the LM741 saturates at its supply rail, clamping the output to $\approx 11 \text{ V}$. Since this exceeds the 8 V comparator reference, the comparator output remains low and the NE555 is not triggered — the alarm stays OFF, with `/alarm_out` at 0.2 V (leakage only).

2. Threshold Crossing Under Gas Leak (Reference: Plot 2 / Gas Leak)

When R_{sensor} drops to $3 \text{ k}\Omega$ (simulating LPG presence), the sensor output falls to $5 \times 3 / (10 + 3) \approx 1.15 \text{ V}$, closely matching the simulated 1.1101 V . After amplification, $V_{\text{amp}} \approx 1.15 \times 5.7 \approx 6.55 \text{ V}$, and the simulation records 6.38 V . This value lies clearly below the 8 V reference threshold, confirming that the comparator switches state. The critical transition — **drop in `/amp_out` from 11.09 V to 6.38 V** — is the primary indicator of correct gas-leak threshold detection at the circuit level. The NE555 monostable is subsequently triggered and the alert output activates.

Conclusion:

Thus, we have successfully designed and simulated a five-stage LPG Gas Leak Detection and Alert System using eSim. By modelling the MQ-5 sensor as a resistive voltage divider and cascading it through an LM741 amplifier, LM393 comparator, NE555 monostable timer, and 2N2222-switched alert stage, we verified correct threshold detection across both clean-air and gas-leak operating conditions. The comparator threshold crossing at 8 V is confirmed through transient simulation, and all circuit behaviour is observable at the analog level with no microcontroller or external platform required.

References:

- [1] FOSSEE Team, IIT Bombay. *eSim User Manual*. <https://esim.fossee.in/>
- [2] Texas Instruments. *LM741 Op-Amp Datasheet*. <https://www.ti.com/product/LM741>
- [3] Fairchild Semiconductor. *LM393 Comparator Datasheet*. <https://www.onsemi.com>