Dynamic Op-Amp control via MOSFET regions

SAMPREETH G R
Electronics and Communication Engineering
National institute of Engineering
Mysuru, India
2023ee_sampreethgr_a@nie.ac.in

PAVAN R
Electronics and Communication Engineering
National institute of Engineering
Mysuru, India
2024lec_pavanr_a@nie.ac.in

POOJA R K
Electronics and Communication Engineering
National institute of Engineering
Mysuru, India
2024lec_poojark_a@nie.ac.in

POOJA K N
Electronics and Communication Engineering
National institute of Engineering
Mysuru, India
2023ec_poojakn_a@nie.ac.in

I. ABSTRACT

This project proposes a practical and educational hardware system designed to identify the operating region (Q-point) of an N-channel enhancement-mode MOSFET in real time. The system employs a combination of analog voltage sensing, comparator-based decision circuits, and a microcontroller interface to determine whether the transistor is in the Cut-off, Triode (Ohmic), or Saturation (Active) region. The MOSFET's Gate-Source Voltage (Vgs) and Drain-Source Voltage (Vds) are continuously monitored using voltage divider networks and precision op-amp comparators. Based on the comparison with reference thresholds (e.g., Vth ≈ 2V, Vds > Vgs−Vth), the outputs of the comparators drive LEDs to provide a visual indication of the transistor's state.
Further enhancement is implemented by interfacing the output of the comparators with an ARM microcontroller (e.g., LPC2148) which processes the logical outputs and displays the active MOSFET region on a 16x2 LCD screen. This enables both physical and textual verification, adding robustness and clarity to the analysis. The logic output is also processed using logic gates (AND operation) to ensure only accurate combinations reflect triode behavior.
The system is particularly suitable for use in laboratories, academic demonstrations, and electronics diagnostics. It provides an intuitive method for students and engineers to visualize the MOSFET's dynamic behavior, bridging the gap between theoretical understanding and practical implementation.

II. INTRODUCTION

Understanding the biasing regions of a MOSFET—cut-off, triode, and saturation is essential for designing efficient analog and digital systems. Each region defines how the MOSFET conducts current and responds to voltage inputs, directly impacting circuit performance. However, visualizing these regions dynamically in hardware can be challenging, especially in a learning environment.

This project focuses on developing a hardware-based Q-point detection system for an N-channel MOSFET. By utilizing voltage comparators to analyze the gate-source and drain-source voltages, the system identifies the transistor's operating region. Indicators such as LEDs are used to provide real-time visual feedback of the region.

To improve interactivity and digital integration, the system is interfaced with an ARM7 microcontroller, which reads the comparator outputs and displays the current operating region on an LCD screen. This approach combines analog circuit behavior with embedded system capabilities, making it a valuable educational and diagnostic tool in the field of electronics.

III. DESIGN DETAIL AND CIRCUIT DIAGRAM

Voltage divider bias
Voltage divider biasing is a common technique used to bias n-type MOSFETs, providing a stable DC operating point for the transistor. In this configuration, a resistive voltage divider network is connected to the gate terminal, consisting of two resistors: one between the supply voltage V_{CC} and the gate, and the other between the gate and ground.

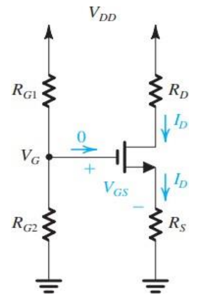

Fig:1 voltage divider circuit

Circuit Description:
The midpoint of the voltage divider, where the two resistors connect, is then connected to the gate terminal of the MOSFET.

This setup ensures that a fraction of the supply voltage is applied to the gate, determining the bias point. The voltage divider to only establishes a stable DC bias but also helps improve the amplifier's stability and tolerance to variations in temperature and transistor characteristics.

The choice of resistor values in the voltage divider is crucial in determining the proper biasing conditions. This biasing method is commonly used in amplifier circuits, balancing the need for stable operating points with efficiency considerations. Engineers carefully select resistor values to achieve the desired performance characteristics while minimizing power dissipation and ensuring proper transistor operation.

IV. Components Required

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1. N-Channel MOSFET (IRF540)
2. Operational Amplifiers (LM741 or LM339)
3. 16x2 LCD Display
4. Resistors.
5. Potentiometer
6. LEDs (Red, Green, Blue)
7. Power Supply
8. Bread board, connecting wires, jumpers

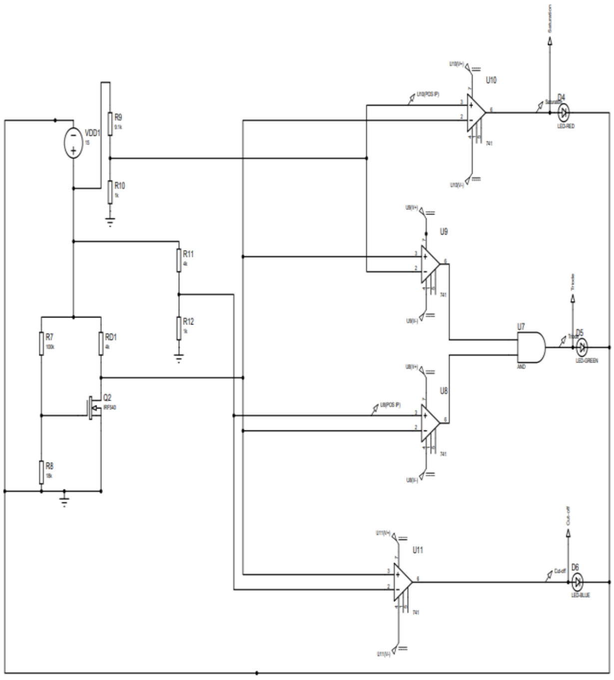

Fig:2 Q point detection using comparetor

The Q-point detector circuit uses comparators to determine the operating point (Q-point) of a transistor amplifier and identify whether it is operating in cut off, triode (linear), or saturation regions.

Circuit Operation:

1. Comparator-based Detection: The circuit employs comparators to compare the voltage levels at specific points in the transistor amplifier circuit against predefined thresholds.

2. Thresholds for Operating Regions: The thresholds are set based on the conditions for cut off, triode, and saturation regions. For example, in a MOSFET amplifier, the drain voltage and gate-source voltage are monitored to determine the operating region.

3. Comparator Outputs: The outputs from the comparators indicate the operating region of the transistor. These outputs can be used to drive an LCD display.

V. *Advantages*

1. Real-time Monitoring: The circuit provides real-time monitoring of the transistor amplifier's operating point.
2. Region Identification: The circuit can identify the operating region (cut off, triode, or saturation) of the transistor amplifier.
3. Improved Reliability: The Q-point detector circuit can help identify potential issues in transistor amplifiers before they become major problems, improving overall system reliability.
4. Enhanced Flexibility: The Q-point detector circuit can be designed to be flexible and adaptable to different types of transistor amplifiers and operating conditions.

VI. *Calculations:*

- In the cut-off region, the red led is connected to the U1 comparator. Both the Triode and Cutoff should light up when
  VGS< VTH.
  R2<=16Kohms (green and blue led)
- In the triode region, the LED connected to the AND gate through U2 comparator. This indicates that the MOSFET is operating in the triode region, where it acts like a variable Resistor.
  R2=16K<=R2<=16.4Kohms (green led)
  VGS>VTH or VGD>VTH
  VDS<Vov or Vds<Vgs-Vth
  In triode region only red led will glow
- For Saturation Region: R2>=16.4Kohms (blue led)

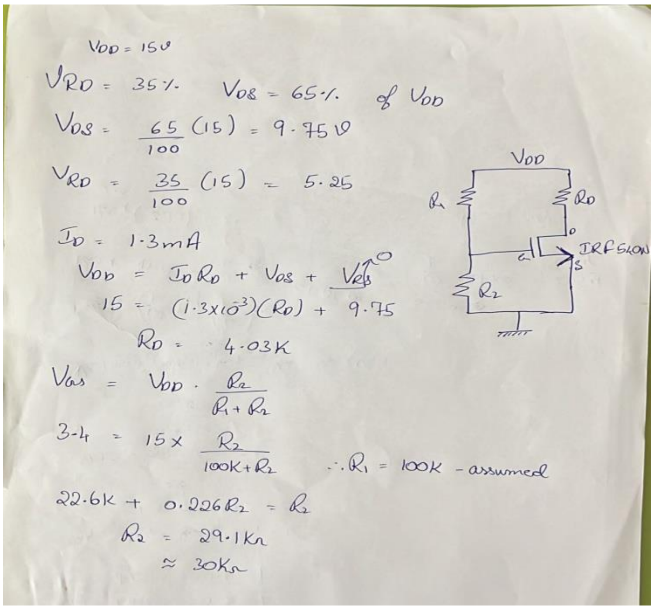

Fig:3 calculations

3 Regions of operation	Drain to Source voltage (Vds)
Cutoff	0V – 1.49V
Triode	1.5V – 2.99V
saturation	3V – 14V

Applications:

- Battery Charge State Indicator
- Fault Detection in Power Supplies
- Water Level Indicator
- Temperature Threshold Alarm
- Amplifier design
- Power electronics
- Audio equipment
- Industrial control system

The designed circuit was simulated using Proteus Design Suite, and the output was monitored using three Light Emitting Diodes (LEDs) to represent different resistance states of a variable resistor (R2). The circuit successfully demonstrated threshold-based behavior as controlled by the operating regions of the MOSFET. The observed results are summarized as follows:

- When the resistance of R2 is **less than 16.4 kΩ**, the **first LED** is turned ON, indicating that the MOSFET operates in a region that allows the corresponding op-amp comparator to activate that output.
- When the resistance is **exactly 16.4 kΩ**, the **second (middle) LED** is turned ON, representing a precise threshold detection condition.
- When the resistance of R2 is **greater than 16.4 kΩ**, the **third LED** is turned ON, confirming that the control mechanism correctly identifies the higher range.

This result validates the ability of the circuit to distinguish between three distinct resistance zones using analog control and comparator logic. The behavior of the MOSFET across its operational regions directly influences the switching logic of the op-amp stages, and the LED output serves as an intuitive indication of the resistance range.

In this project, the LCD display is successfully used to show the MOSFET's operating region—Cut-off, Triode, or Saturation—in real time. It is connected to the ARM microcontroller, which receives inputs from the comparators and processes them to identify the region. This information is then displayed on the LCD, providing clear and immediate feedback. The LCD enhances the user experience by making the output easy to understand, confirming that both the comparator logic and ARM code are working correctly.

VII. STM32F103C8T6 Integration for MOSFET Operating Region Display

To modernize the Q-point detection system, the ARM7-based controller was replaced with the **STM32F103C8T6** microcontroller, commonly known as the "Blue Pill." This 32-bit ARM Cortex-M3 microcontroller offers enhanced performance and flexibility, making it suitable for real-time applications.

Hardware Interfacing

The STM32F103C8T6 was interfaced with a **16×2 alphanumeric LCD** to display the MOSFET's operating region—Cut-off, Triode, or Saturation. The LCD was connected in **4-bit mode** to conserve GPIO pins. The connections were established as follows:

- **LCD RS (Register Select) → PB11**
- **LCD EN (Enable) → PB10**
- **LCD D4 to D7 (Data Lines) → PB0**, **PB1**, **PC13**, **PC14**
- **LCD RW (Read/Write) → GND** (set to write mode)
- **LCD VSS, VEE, LED- → GND**
- **LCD VCC, LED+ → 5V**

A potentiometer was connected to the VEE pin to adjust the display contrast.

Software Implementation

The system was programmed using the **Arduino IDE** with the STM32 board support package. The **LiquidCrystal** library facilitated LCD control. The microcontroller continuously reads the outputs from the comparator circuits, which determine the MOSFET's operating region based on the gate-source and drain-source voltages. Based on the comparator inputs:

- If $\mathbf{V_{GS}\ V_{TH}}$, the MOSFET is in the **Cut-off** region.
- If $\mathbf{V_{GS}\ V_{TH}}$ and $\mathbf{V_{DS}\ (V_{GS} V_{TH})}$ it's in the **Triode** region.
- If $\mathbf{V_{DS}\ (V_{GS} - V_{TH}\ )}$it's in the **Saturation** region.

The corresponding region is then displayed on the LCD in real-time.

Advantages of STM32 Integration

- **Enhanced Processing Speed**: Allows for rapid detection and display updates.
- **Reduced GPIO Usage**: 4-bit LCD interfacing conserves microcontroller pins.
- **Scalability**: Facilitates future enhancements like data logging or wireless communication.
- **Community Support**: Extensive resources and libraries available for STM32 development.

This integration not only modernizes the Q-point detection system but also provides a user-friendly interface for monitoring the MOSFET's operating state.

VIII. Inference

The Q-point detection system developed in this project demonstrates a reliable and efficient method for identifying the operating region of a MOSFET—cut-off, triode, or saturation—using voltage dividers, comparators, and modern microcontroller interfacing. By generating fixed reference voltages through a resistor network, the system accurately compares the gate and drain voltages (V_{GS} and V_{DS}) determine the transistor's state. The use of comparators ensures precise and real-time decision-making, while RGB LEDs offer immediate visual indication of the region of operation.
Further enhancement is achieved through the integration of the **STM32F103C8T6** microcontroller, which reads the comparator outputs and displays the corresponding region on a **16x2 LCD screen**. This provides a clear and user-friendly digital output alongside visual cues, combining analog behavior with embedded system features. The modular and flexible nature of this design makes it ideal for laboratory use, circuit diagnostics, and academic demonstrations. The STM32 also enables future scalability, including serial data logging, wireless monitoring, or automated calibration.

IX. Conclusion

The enhanced Q-point detector circuit using comparators and STM32F103C8T6 microcontroller provides an effective solution for real-time monitoring and identification of the operating region of MOSFETs. It bridges the gap between analog voltage sensing and digital display systems by combining op-amp-based comparators with microcontroller-driven logic interpretation and LCD output.
The system's flexibility, clarity, and responsiveness make it suitable for a wide range of applications, from academic learning environments to industrial diagnostics. The integration with STM32 not only simplifies firmware development and increases processing speed but also enables future expansion into areas like remote monitoring or automated data acquisition.
Overall, this system is a valuable educational and practical tool that enhances understanding of transistor operation and offers a scalable platform for embedded electronics experimentation and design.

X. ACKNOWLEDGMENT

I extend my thanks to my dedicated team members for their collaborative efforts and enthusiasm. Each team member played a pivotal role in the construction, testing, and refinement of the circuit. Their commitment and teamwork significantly contributed to the project's success. I would like to express my sincere appreciation to my project supervisor, Dr Remya Jayachandran and Mr. Lokesha H R for their invaluable guidance, unwavering support, and insightful Suggestions through out the development of this project. Their expertise has been instrumental in shaping the project's direction and enhancing its overall quality. Finally, we express our appreciation for the collective effort that went into the development of the Q Point Detector. The successful integration of the IRF540N MOSFET, comparators, and ARM microcontroller with LCD display to represent different regions of operation is a testament to the hard work, dedication, and collaborative spirit of everyone involve

XI. REFERENCES

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