EECE 310 L

Electric Circuits Laboratory

03/01/2012

**Lab Report**

**Experiment #10**

**MOS Transistors**

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Section 2

Group 7

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# Objectives The main objectives of this experiment are studying the characteristics of the MOSFET in the different regions of operation (cutoff, linear, saturation), and learning about its applications (voltage-controlled resistor, Logic inverter, NOR gate, Amplifier, Current Source).

1. **Lab Equipment Used**
   1. Tektronix PS280 Power Supply
   2. Fluke 45 Digital Multi Meter
   3. HP Agilent 33120A Function Generator
   4. Tektronix TDS220 Oscilloscope
   5. Breadboard
2. **Lab Tools Used**
   1. Wire stripper
   2. Long nose pliers
3. **Components Used**

|  |  |  |  |
| --- | --- | --- | --- |
| **Component** | **Theoretical Value** | **Measured Value** | **% error** |
| Resistor | 100 Ω | 99.2 Ω | 0.8 |
| Resistor | 470 Ω | 467.3 Ω | 0.57 |
| Resistor | 1000 Ω | 991.8 Ω | 0.82 |
| Resistor | 3300 Ω | 3238 Ω | 2.07 |
| Resistor | 4700 Ω | 4610 Ω | 1.91 |
| Resistor | 10000 Ω | 9850 Ω | 1.5 |
| Resistor | 15000 Ω | 14902 Ω | 0.65 |
| Capacitor | 10 µF | N/A | N/A |
| MOSFET (BS170) | N/A | N/A | N/A |

Table 1: Component list

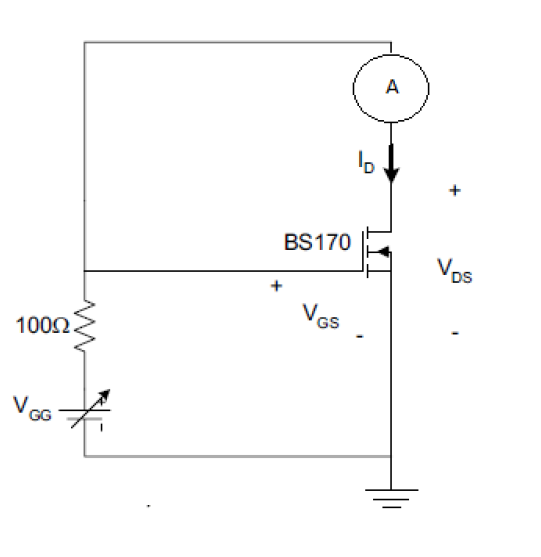
1. **Experimental Procedure and Discussion**
   1. **** MOSFET Characteristics
      1. Circuit Diagram:

Figure A: Circuit Diagram (MOSFET Characteristics)

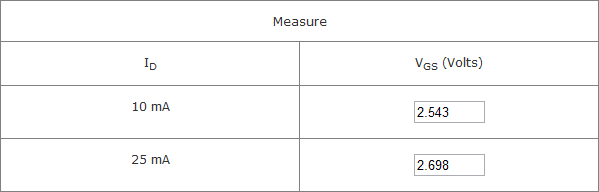
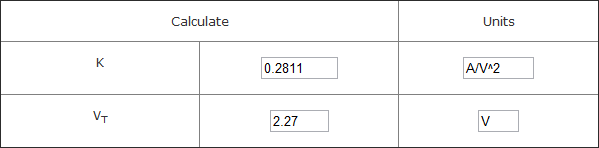
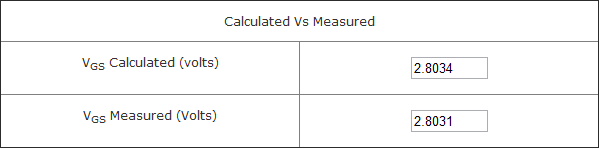
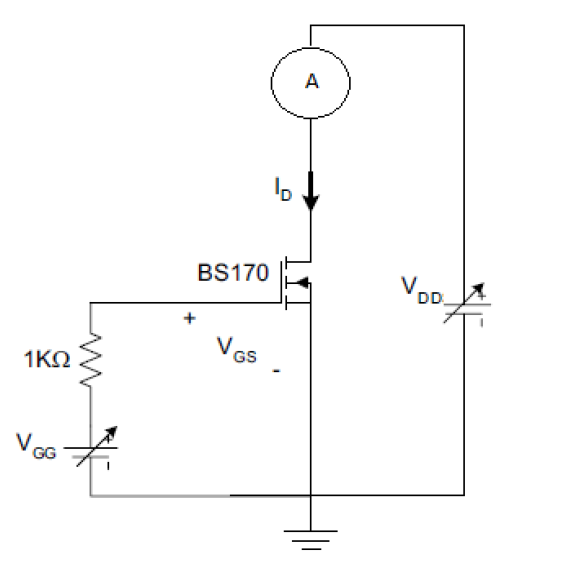
* + 1. Procedure:
       1. In PART 1, our aim is to calculate k and VT for the MOSFET. The above circuit biases the MOSFET in the saturation region, so ID = ½ k (VGS – VT)2.  
            
          To calculate k and VT, we measure ID and VGS at two different points and use the 2 obtained equations with 2 unknowns.  
            
          After connecting the circuit, we set to VGG =0.5. We increase VGG until ID = 10 mA, and record VGS at that point. We increase VGG further until ID = 25 mA and record VGS again. The measurements are done using the DMM.
       2. In PART 2, the characteristics are calculated using the 2 equations obtained in PART 1.
       3. In PART 3, we wish to verify our obtained values. We measure VGS at a known value of ID (40 mA) and compare the measured quantity to the one obtained using the MOSFET equation VGS = VT + sqrt(2ID/k)  (where k and VT are the values obtained above)
    2. Results obtained:
       1. PART 1
       2. PART 2
       3. PART 3  
            
          Error = 0.01 %  
          The error between the two value of VGS was very small, this indicates that the values obtained for k and VT are accurate.
  1. MOSFET as Voltage-Controlled Resistor
     1. Circuit Diagram:

Figure B: Circuit Diagram (MOSFET as Voltage-Controlled Resistor)

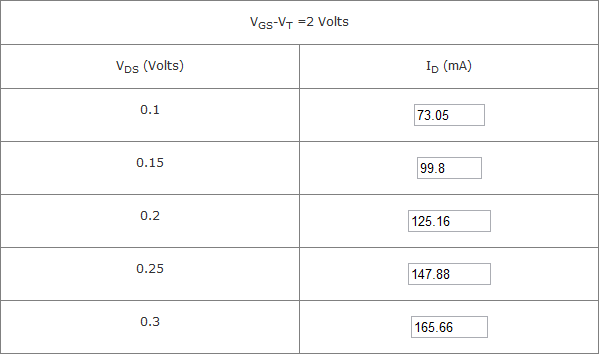
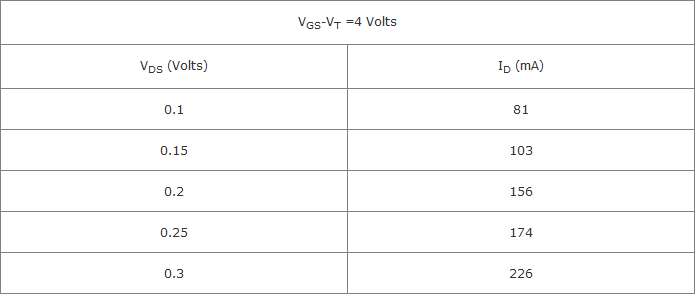
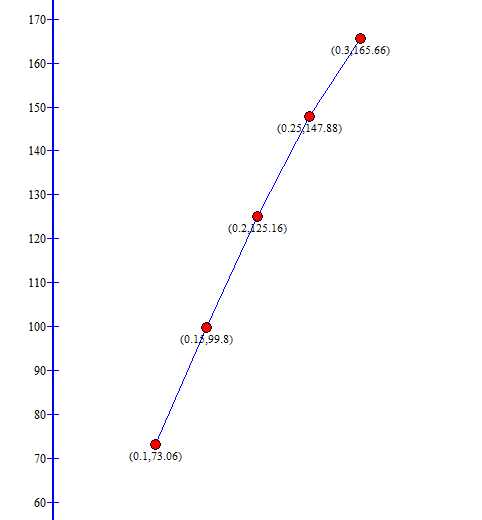
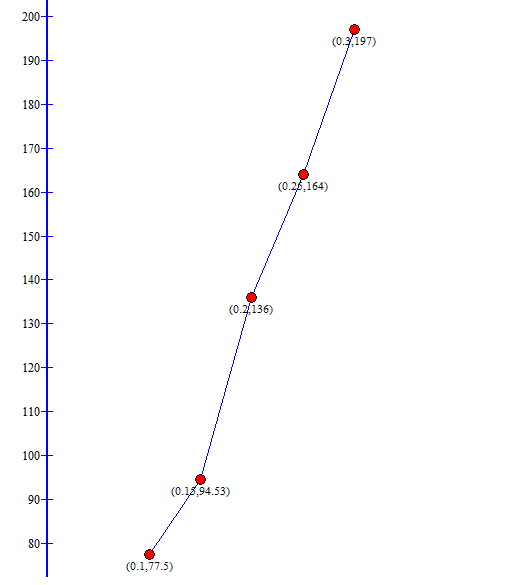
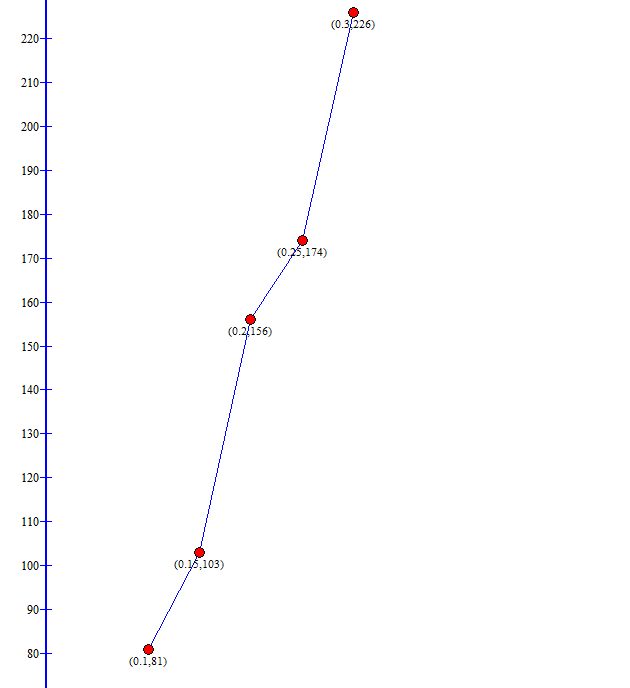
* + 1. Procedure:
       1. In PART 1 of this experiment, we intend to bias the MOSFET in the linear region so as to use it as a voltage-controlled resistor. After constructing the circuit as shown, we fix the value of VGG (and therefore VGS) to VT + 2V (VT’s value is the one from the previous experiment), and we measure ID for different values of VDD (i.e. VDS).  
            
          ID is measured using an ammeter. VDS and VGS are measured using an oscilloscope *while the ammeter is still connected.* This is to negate the effect of the ammeter’s internal resistance.
       2. In PART 2, we repeat the measurements of PART 1 but with VGS – VT = 3V.
       3. In PART 3, we repeat the measurements of PART 1 but with V­GS – VT = 4V.
    2. Results Obtained:
       1. PART 1
       2. PART 2
       3. PART 3
    3. Discussion:
       1. ID vs. VDS curves:

Figure 3: ID vs VDS  (VOV = 4)

Figure C: ID vs VDS (VOV= 2)

Figure D: ID vs VDS (VOV= 3)

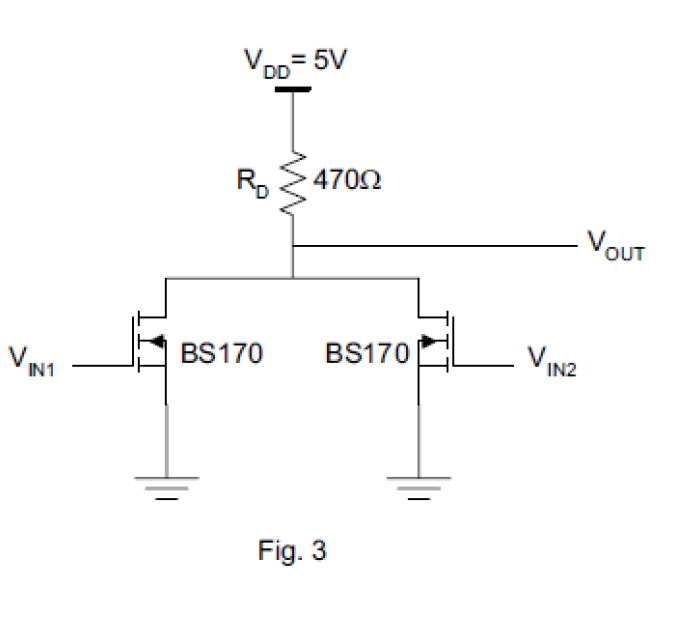
* + - 1. We get a curve that’s almost linear.
      2. Slope(VOV = 2) = 0.463  
         Slope(VOV = 3) = 0.5975  
         Slope(VOV = 4) = 0.725
      3. RDS (VOV = 2) = 1/0.463 = 2.16 Ω  
         RDS (VOV = 3) = 1/0.5975 = 1.67 Ω  
         RDS (VOV = 4) = 1/0.725 = 1.38 Ω
      4. The MOSFET is in the linear region. It is called as such because for a constant overdrive voltage VOV, the relationship between the voltage and current across the transistor is approximately linear. (i.e. it follows Ohm’s law)
      5. When VDS is small, VDS2 is very small and can be neglected, the equation becomes:  
         ID = k. VOV. VDS and VOV is constant, therefore VDS = RDS. ID (where RDS = 1/k. VOV)
      6. This approximation is valid for small VDS, namely VDS
      7. The value of RDS = 1/k. VOV: RDS (VOV = 2) = 1.78 Ω, RDS (VOV = 3) = 1.19 Ω, RDS (VOV = 4) = 0.89 Ω. The calculated values are smaller than the theoretical values. This is due to the additional internal resistance of the MOSFET.
      8. We can use voltage-controlled resistors in attenuator circuits, Amplitude Modulation circuits, and for controlling devices (like the volume of an amplifier).
  1. MOSFET as a Logic Gate
     1. Circuit Diagram:

Figure E: Circuit Diagram (MOSFET as a Logic Gate)

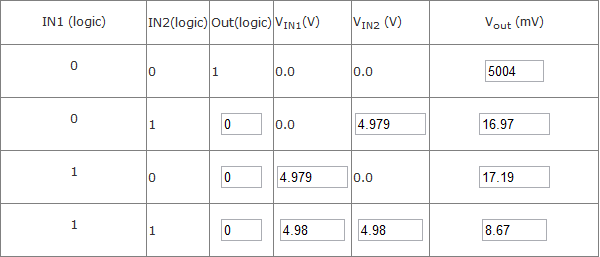
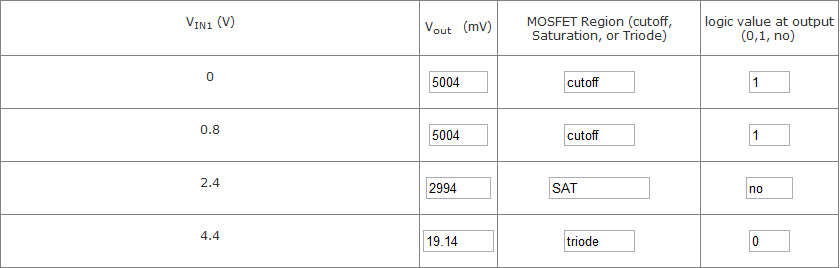
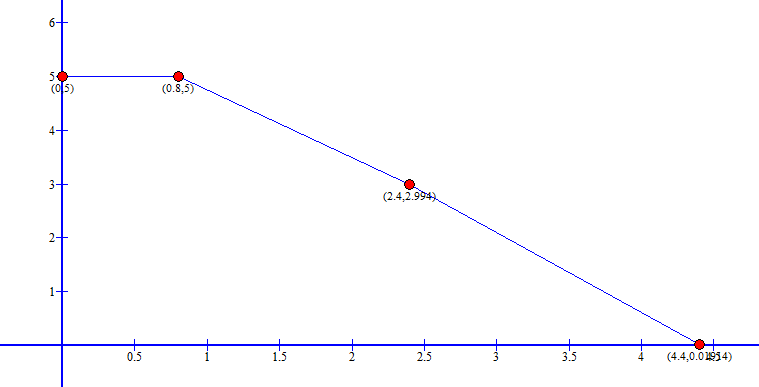
* + 1. Procedure:
       1. In PART 1, the aim is to use the MOSFET as a logic gate. After connecting the circuit shown in the diagram, we need to know which logic function the circuit implements. For this, we apply combinations of logic 0’s (input connected to ground) and logic 1’s (input connected to relatively high voltage) and observe the output.
       2. In PART 2, we cut the second MOSFET off by connecting VIN2 to ground. This turns the circuit into a different, unary logic gate. We try different values of voltage at the input and observe the output.
    2. Results Obtained:
       1. PART 1
       2. PART 2
    3. Discussion:
       1. From the truth tables, it’s apparent that the circuit in PART 1 represents a NOR gate while the circuit in PART 2 is a logic inverter.
       2. High voltage = 5 V (approx)  
          Low Voltage = 19 mV (approx)
       3. The low voltage value is inversely proportional to the resistor (assuming nothing else changes). Increasing it would make the output low value lower.
       4. The output switches states when VIN = VOH or VIN = VOL

Figure F: VOUT vs VIN

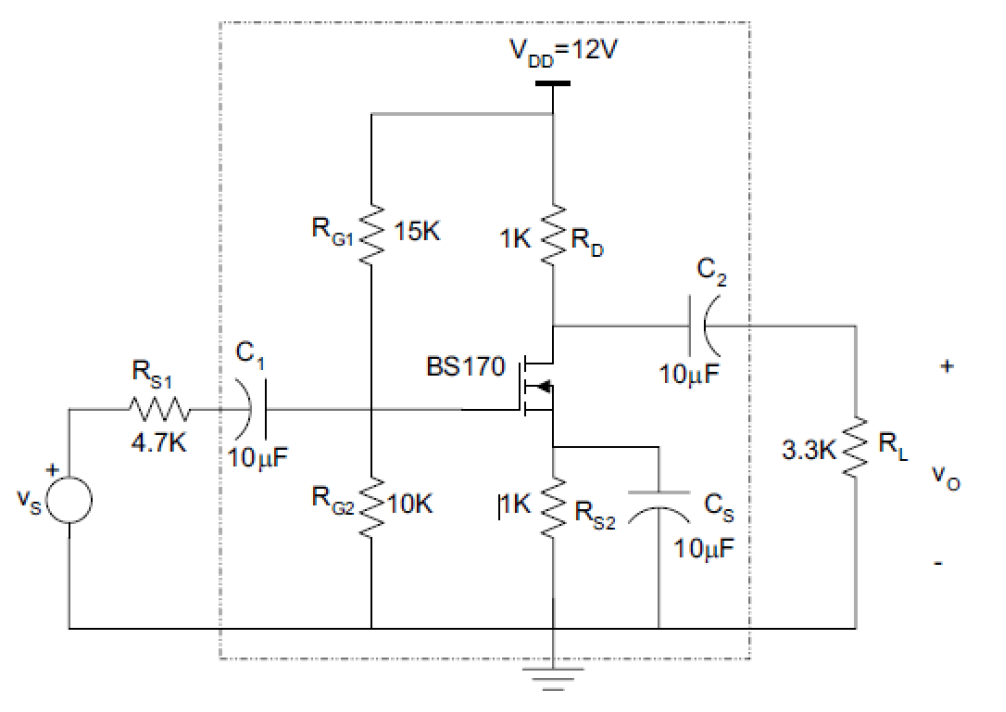
* 1. MOSFET as an amplifier
     1. Circuit Diagram:

Figure G: Circuit Diagram (MOSFET as an amplifier)

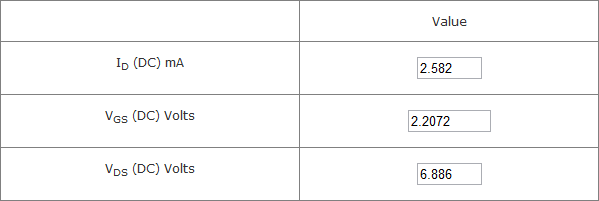
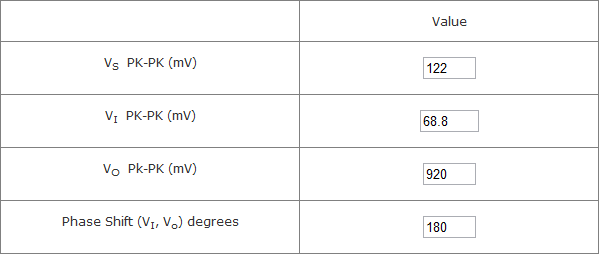
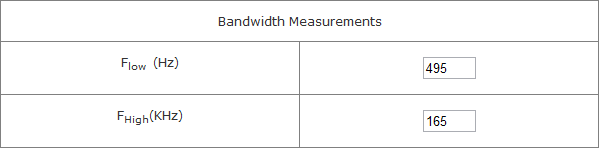
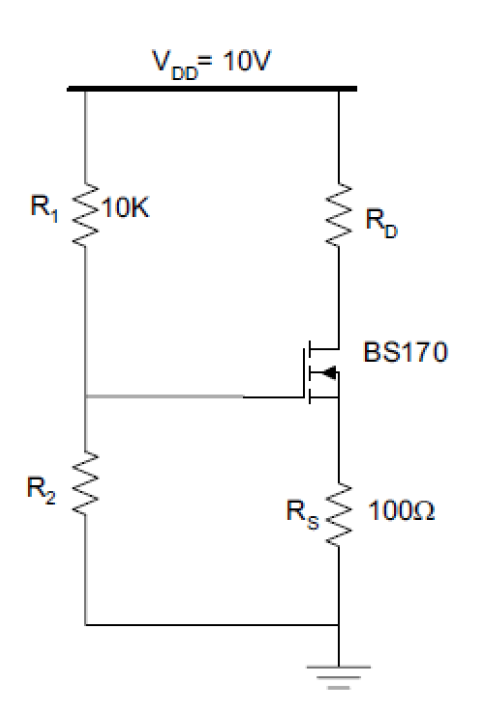
* + 1. Procedure:  
       In this experiment, we bias the MOSFET in saturation in order to use it as an amplifier and study its amplifying characteristics.
       1. In PART 1, after connecting the circuit as shown, we measure the DC values of ID, VGS, and VDS.
       2. In PART 2, we apply a 100 mV signal input and we measure the voltage at the input, the voltage at the input of the amplifier, the voltage at the output, and the phase shift.
       3. In PART 3, we determine the bandwidth of the amplifier by marking the frequencies at which the gain is divided by sqrt(2).
    2. Results obtained:
       1. PART 1
       2. PART 2
       3. PART 3
    3. Discussion:
       1. The gain drops at low frequencies due to the increased impedance of the capacitors on the input and output.
       2. At high frequencies, the gain drops due to the parasitic capacitance CS.
       3. When the input voltage becomes large, the MOSFET will be outside the saturation region for part of the input signal, and that will cause distortion.
    4. Theoretical values:
       1. DC analysis:  
          The capacitors become open circuits.  
          VG = 10/25 \* 12V = 4.8 V (by voltage division)  
          now ID = VS/ 1kΩ = ½ k (VG – VS – VT)2 (since MOSFET is in SAT)  
          => VS = 2.671 (rejected since VGS < VT) or VS = 2.396 (accepted)  
          => **VGS = 2.404**,**VDS =**  , **ID = 2.396 mA,** VOV = 0.134 V  
          => VD = 12 – 1k (ID) = 9.604 V => **VDS = 7.208**
       2. Comparison of DC values:  
          ID error = 2.396 – 2.582/ 2.396 = 7.76 %  
          VGS error = 2.404 – 2.2072 / 2.404 = 8.18 %  
          VDS error = 7.208 – 6.886 / 7.208 = 4.47 %
       3. Small signal analysis:  
          Capacitors have large capacitance => can be shorted  
          gm = 35.76 mA/V  
          VS = 100 mV  
          VI = 6 / 10.7 \* (100 mV) = 56.07 mA (by voltage division)  
          VO = 1.53 V
       4. Comparison of small signal values:  
          I will compare VS/VI instead of each one individually to eliminate the error coming from setting the function generator to exactly 100 mV.  
          VS/VI error = (100/56.07 – 122/68.8) / (100/56.07) = 0.57 %  
          VO error = 1530 – 920 / 1530 = 39.8 %MOSFET as a current source
    5. Circuit Diagram:

Figure H: Circuit Diagram (MOSFET as a current source)

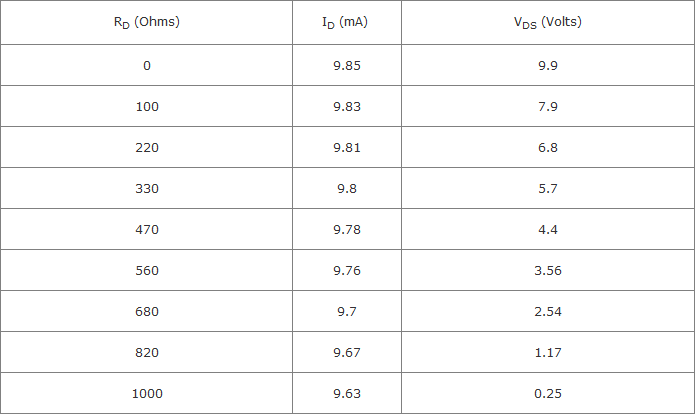
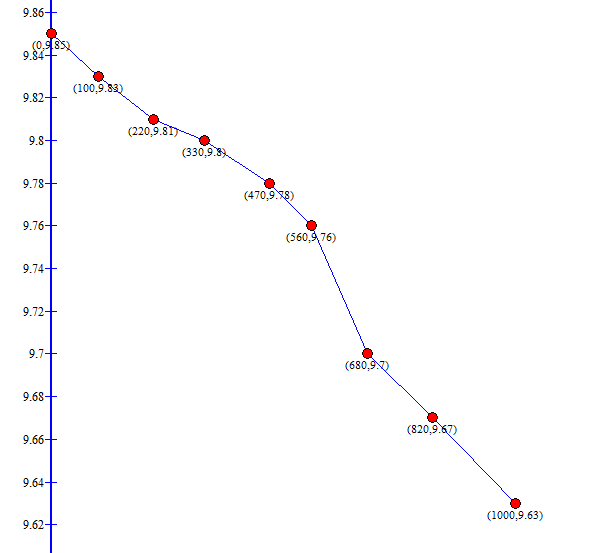
* + 1. Procedure:  
       The aim here is to use the MOSFET as a current source.  
       First, we need to calculate the value of R2 needed to get a drain current of 10 mA.  
       R2 = 5472 Ω (approx)  
       After connecting the circuit, we start with RD as a short circuit and gradually increase it according to the shown values. At every point, we measure ID and VDS.
    2. Results Obtained:
    3. Discussion
       1. The current is almost constant when RD is between 0 and 560 Ω

Figure I: ID as function of RD

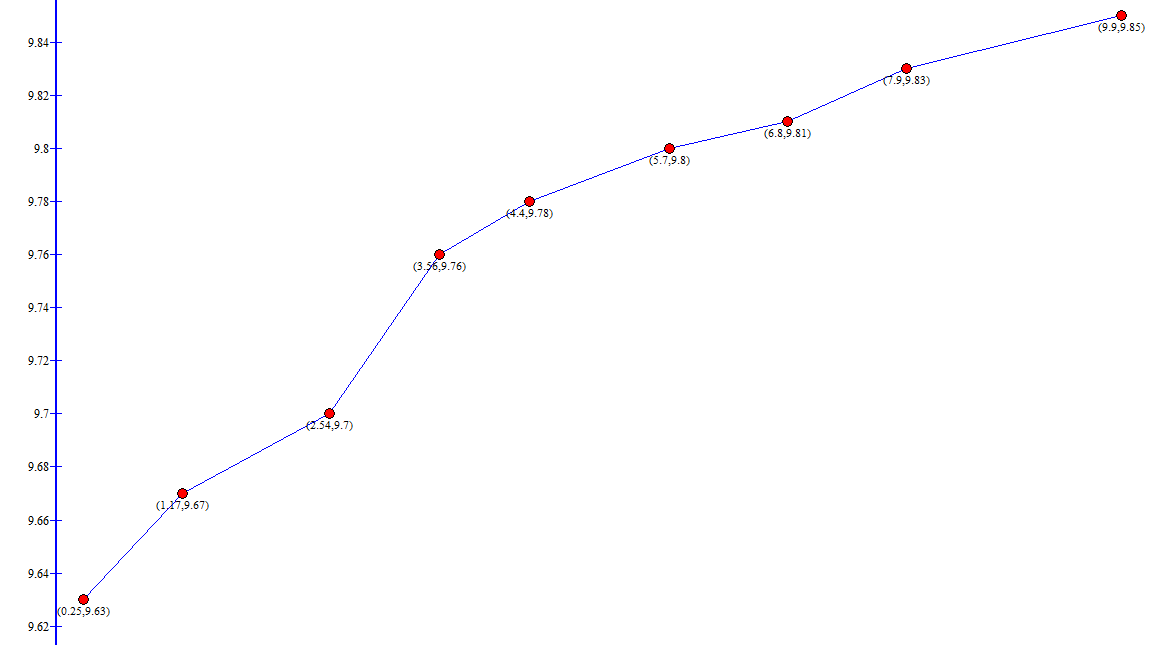
* + - 1. The current source Is­ is a 10mA source
      2. The current is almost constant for VDS between 3.56 and 9.9 V

Figure J: ID as function of VDS

* + - 1. This range corresponds to SAT. Outside this range, the MOSFET is not in SAT.
      2. ro = 1/slope = 9.9-3.56 V/ (9.85-9.76) mA = 70.4 kΩ

1. **References**
   1. Lab Manual
   2. "Using a MOSFET as a Switch". 090507 brunningsoftware.co.uk
2. **Mistakes and Problems faced in the Lab**
   1. Measurement errors
   2. Inexact component values (i.e. 450 Ω resistor instead of 470 Ω)
   3. Approximation errors
3. **Statement**

*“I HAVE NEITHER GIVEN NOR RECEIVED AID ON THIS REPORT NOR HAVE I CONCEALED ANY VIOLATION OF THE AUB STUDENT CODE OF CONDUCT.”*

***Signature:***