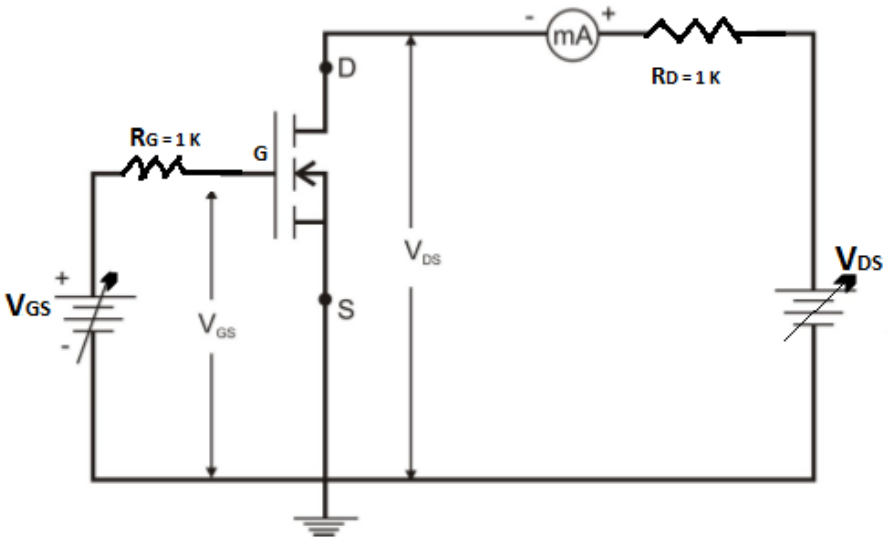
EXPERIMENT 3

OBJECTIVE: The aim of this experiment is to plot (i) the output characteristics and (ii) the transfer characteristics of n-channel and p-channel enhancement-type MOSFETs, and (iii) the voltage transfer characteristics (VTC) of a CMOS inverter by connecting the n-MOSFET and p-MOSFET.

APPARATUS: MOSFET n type (IRFZ44N), p type (IRFZ9540), Bread board, resistors (1KΩ), connecting wires, Ammeters (0-10mA/ 0-25mA), DC power supply (0-12V) and multimeter.

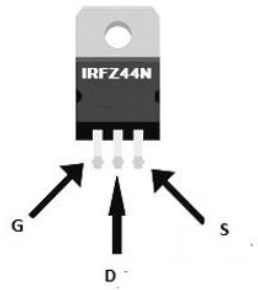
CIRCUIT DIAGRAM:



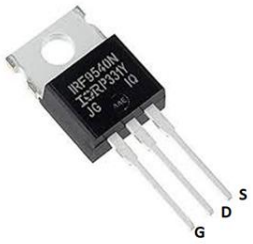
1. **Cut-Off Region**
   Cut-off region is a region in which the MOSFET will be OFF as there will be negligible current flow through it.
2. **Ohmic or Linear Region**
   Ohmic or linear region is a region wherein the current I_D increases with an increase in the value of V_{DS}.
3. **Saturation Region**
   In saturation region, the drain current I_D is quite constant irrespective of an increase in V_{DS}.

MOSFET	**Cut-Off**	**Ohmic/Linear**	**Saturation**
n-channel Enhancement-type	$V_{GS} < V_T$	$V_{GS} > V_T$ and $V_{DS} < V_{GS} - V_T$	$V_{GS} > V_T$ and $V_{DS} < V_{GS} - V_T$
p-channel Enhancement-type	$V_{GS} > -V_T$	$V_{GS} < -V_T$ and $V_{DS} > V_{GS} - V_T$	$V_{GS} < -V_T$ and $V_{DS} < V_{GS} - V_T$

Pins of IRFZ44N (NMOS)



Pins of IRF9540 (PMOS)



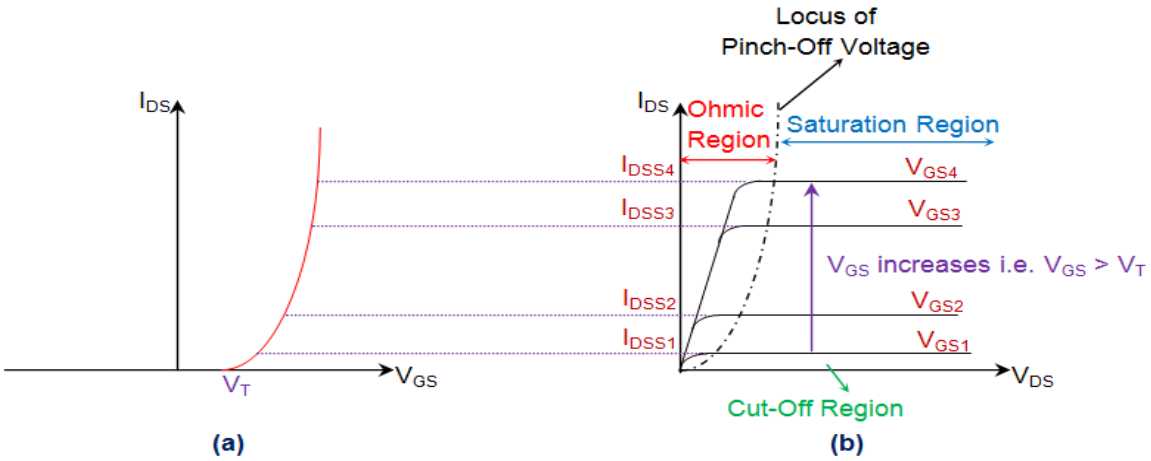


Figure 1 *n*-Channel Enhancement type MOSFET (a) Transfer Characteristics (b) Output Characteristics

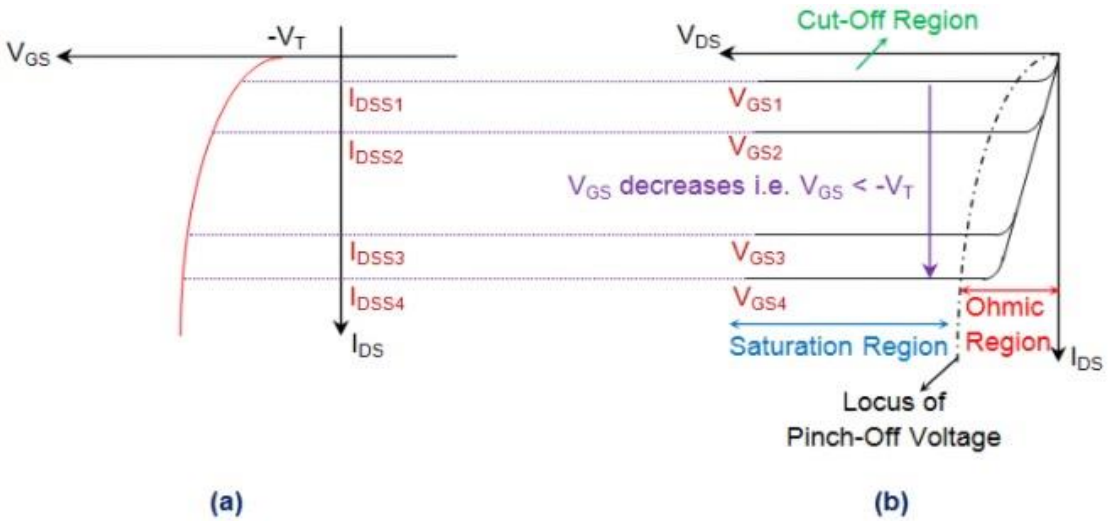


Figure 2 *p*-Channel Enhancement type MOSFET (a) Transfer Characteristics (b) Output Characteristics

PROCEDURE:

OUTPUT CHARACTERISTICS: V_{DS} vs. I_D for different V_{GS}.

1. Connect the circuit as per given diagram properly.
2. Keep V_{GS} constant to 1 V and sweep V_{DS} and take readings of I_D. Vary V_{DS} in step of 1 V up to 11 V and measure the drain currents I_D. Tabulate all the readings.
3. Repeat the above procedure for V_{GS} as 2.5 V, 3 V, 3.5 V, 4 V, 4.5 V and 5 V.

TRANSFER CHARACTERISTICS: V_{GS} vs. I_D for different V_{DS}.

1. Connect the circuit as per given diagram properly.
2. Set the voltage V_{DS} constant at 3 V, 8 V and 11 V.
3. Vary V_{GS} in the step of 0.5 V from 0 to 11 V and note down value of drain currents I_D. Tabulate all the readings.
4. Plot the output characteristics V_{DS} vs I_D (for different values of V_{GS}) and transfer characteristics V_{GS} vs I_D.
5. Calculate V_T, g_m from the graphs and verify it from the data sheet.

OBSERVATION TABLE:

OUTPUT CHARACTERSTICS

V_{DS} (V)	$V_{GS} = 1\ V$	$V_{GS} = 2.5\ V$	$V_{GS} = 3\ V$	$V_{GS} = 3.5\ V$	$V_{GS} = 4\ V$	$V_{GS} = 4.5\ V$	$V_{GS} = 5\ V$
	I_D (mA)	I_D (mA)	I_D (mA)	I_D (mA)	I_D (mA)	I_D (mA)	I_D (mA)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

TRANSFER CHARACTERISTICS

V_{GS} (V)	$V_{DS} = 8\ V$	V_{DS} = 11 V	V_{GS} (V)	V_{DS} = 8 V	V_{DS} = 11 V
	I_D (mA)	I_D (mA)		I_D (mA)	I_D (mA)
0			6		
0.5			6.5		
1			7		
1.5			7.5		
2			8		
2.5			8.5		
3			9		
3.5			9.5		

4			10		
4.5			10.5		
5			11		
5.5					

CALCULATIONS: Do for both NMOS and PMOS.

1. **Threshold voltage V_T:** Gate to source voltage at which, drain current starts flowing
2. **Transconductance g_m:** Ratio of small change in drain current (ΔI_D) to the corresponding change in gate to source voltage (ΔV_{GS}) for a constant V_{DS}.

$$g_m = \Delta I_D / \Delta V_{GS} \text{ at constant } V_{DS}$$

3. **Output drain resistance:** It is given by the relation of small change in drain to source voltage (ΔV_{DS}) to the corresponding change in Drain Current (ΔI_D) for a constant V_{GS}.

$$r_d \text{ or } r_o = \Delta V_{DS} / \Delta I_D \text{ at a constant } V_{GS}$$

RESULTS:

1. V_T: _____
2. g_m: _____
3. r_o: _____

CMOS INVERTER:

Circuit Diagram:

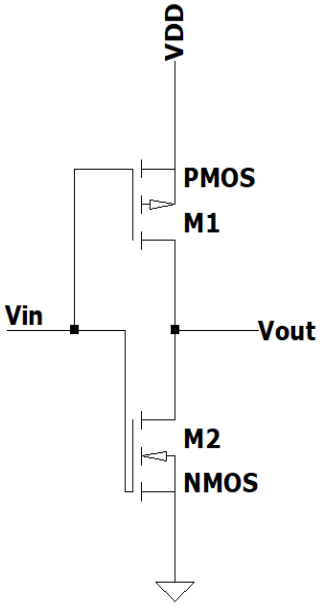


Figure 3: CMOS inverter

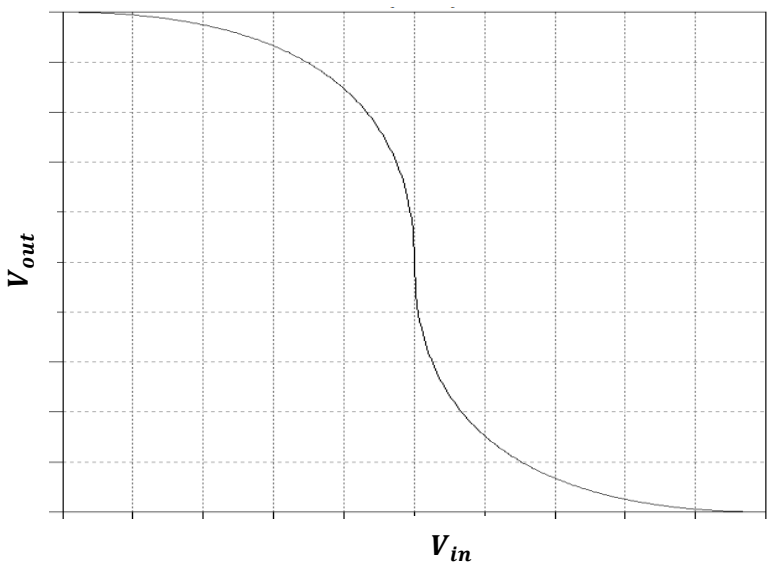


Figure 4: Voltage transfer characteristics

THEORY: A CMOS inverter consists of a PMOS and an NMOS transistor connected in series. The drain and gate terminals of the two transistors are connected. The supply voltage V_{DD} is connected to PMOS source terminal and the NMOS source terminal is connected to ground. The voltage V_{in} is applied at the gate terminals and V_{out} is the output voltage at the drain terminals. The input/output characteristics of a CMOS inverter is called voltage transfer characteristics and it has a sharp transition region, which makes it energy-efficient during switching between low and high voltage levels. At low input voltage circuit output high voltage and vice-versa, thereby it acts as an inverter.

Type of MOSFET	**Condition of MOSFET**	**State of MOSFET**
NMOS	$V_{GS} < V_{Tn}$	OFF
NMOS	$V_{GS} > V_{Tn}$	ON
PMOS	$V_{GS} < -V_{Tp}$	OFF
PMOS	$V_{GS} > -V_{Tp}$	ON