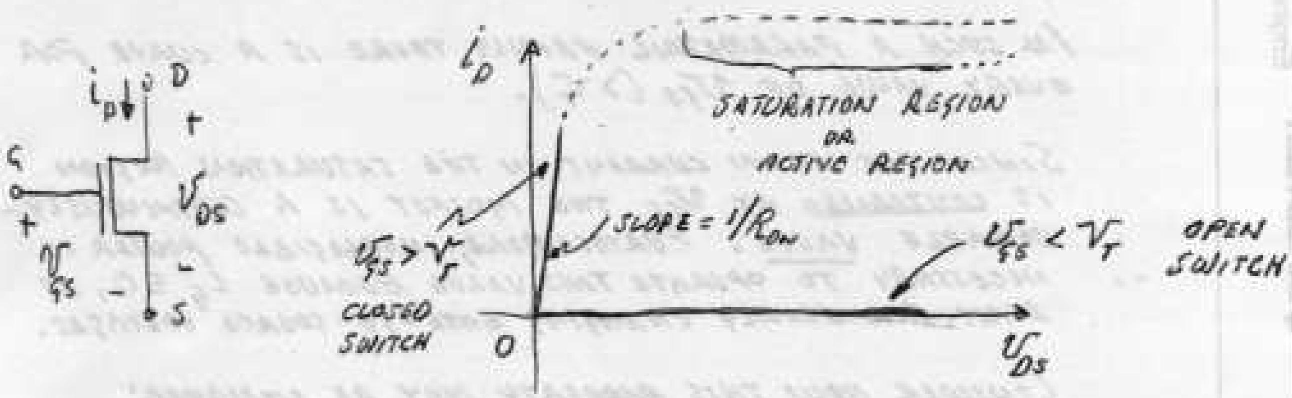
NOTES FOR 6.002 LECTURE # 7 THURSDAY, FEBRUARY 27, 2003

READ: 7.1 THROUGH 7.4

THE MOSFET HAS USES OTHER THAN AS A SWITCH.

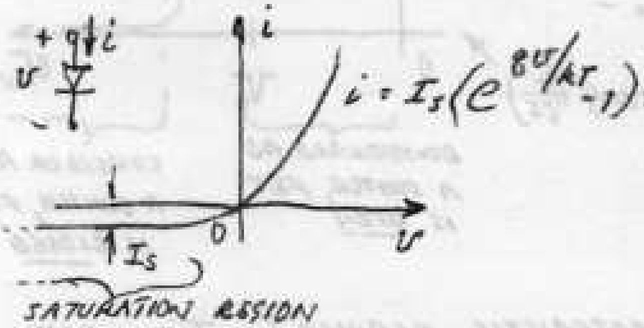
(DEMO #1)

OUTPUT (OR DRAIN) CHARACTERISTICS:



FOR $v_{GS} > V_T$ AND v_{DS} LARGE ENOUGH, THE DRAIN CURRENT i_D FLATTENS OFF OR BECOMES NEARLY CONSTANT. THIS IS REFERRED TO AS THE SATURATION REGION OF OPERATION.

COMPARE USE OF THE PHRASE IN THE SEMICONDUCTOR DIODE:



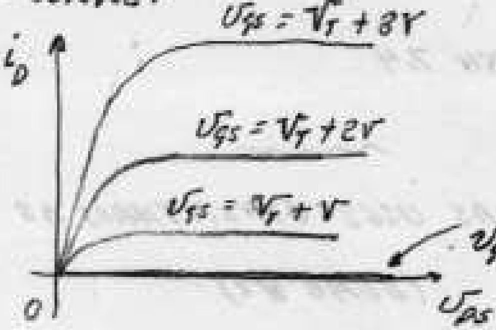
FOR $v \ll -\frac{kT}{q}$ ("REVERSE BIAS")
THE CURRENT IS CONSTANT AT $i = -I_S$ – THE SATURATION CURRENT.

FOR THE FET, THE DRAIN CURRENT IN THE SATURATION REGION IS CONTROLLED BY THE GATE-TO-SOURCE VOLTAGE

(DEMO # 2)

EACH CURVE OF i_D vs v_{DS} CORRESPONDS TO A PARTICULAR VALUE OF v_{GS}.

SUCH FUNCTIONAL RELATIONSHIPS ARE REPRESENTED BY A PARAMETRIC FAMILY OF CURVES.



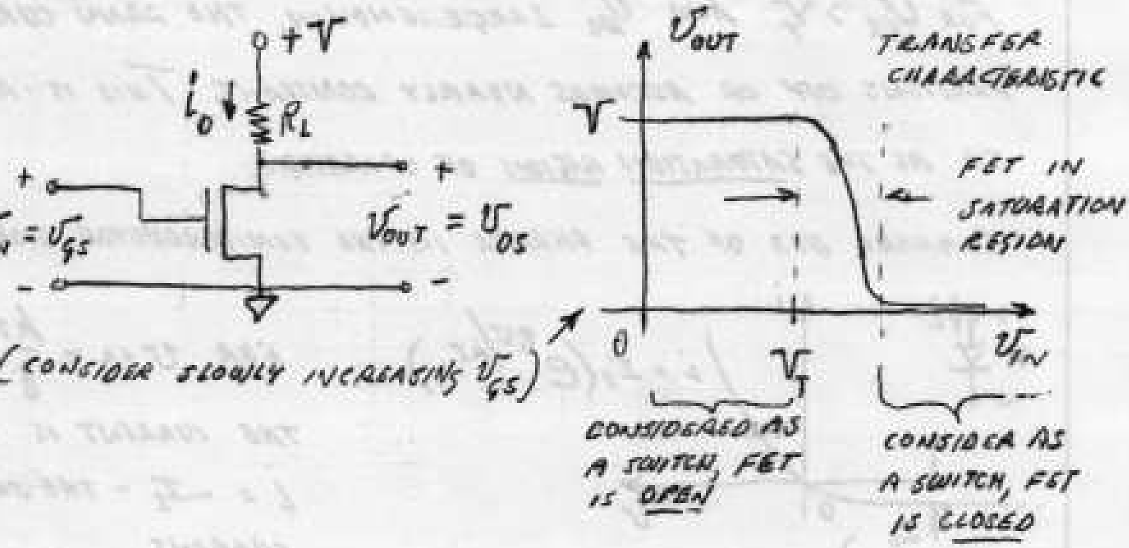
DEPENDENT ON v_{GS} IS NONLINEAR.

(DEMO #3)

IN SUCH A PARAMETRIC FAMILY THERE IS A CURVE FOR EVERY VALUE OF v_{GS} ($> V_T$).

SINCE THE DRAIN CURRENT IN THE SATURATION REGION IS CONTROLLED BY v_{GS} THE MOSFET IS A CONTINUOUSLY-VARIABLE VALVE. FURTHERMORE, NEGLIGIBLE POWER IS NECESSARY TO OPERATE THIS VALVE BECAUSE $i_G \equiv 0$, AT LEAST FOR SLOWLY CHANGING GATE-TO-SOURCE VOLTAGES.

CONSIDER HOW THIS PROPERTY MAY BE EMPLOYED:



(CONSIDER SLOWLY INCREASING v_{GS})

CONSIDERED AS A SWITCH, FET IS OPEN

CONSIDER AS A SWITCH, FET IS CLOSED

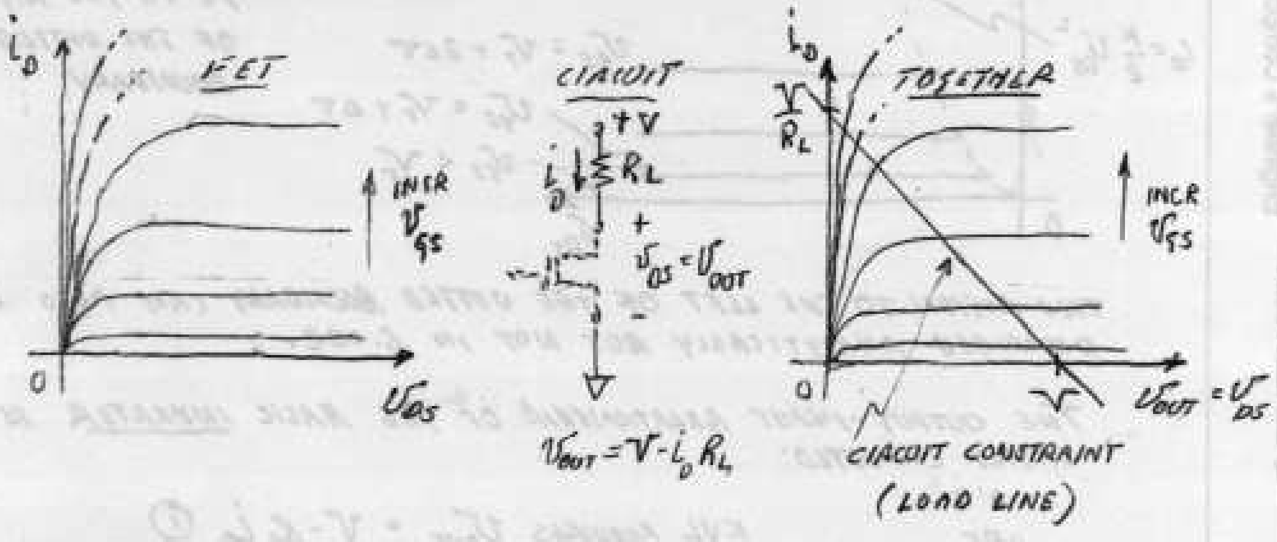
HOW IS A TRANSFER CHARACTERISTIC DERIVED? TWO WAYS:

I GRAPHICAL ANALYSIS USING THE PARAMETRIC OUTPUT OR DRAIN CHARACTERISTICS.

II ANALYTIC APPROACH USING A NONLINEAR MODEL DERIVED FROM DETAILED ANALYSIS OF THE PHYSICAL DEVICE, TAKING INTO ACCOUNT MATERIALS, STRUCTURE, AND THE EQUATIONS GOVERNING THE FLOWS OF CHARGE CARRIERS IN A SEMICONDUCTOR

I GRAPHICAL ANALYSIS: THE DRAIN CHARACTERISTICS (CURVES) IMPOSE, FOR EVERY VALUE OF v_{GS} A CONSTRAINT ON i_D vs v_{DS} IN THE FORM $i_D = f(v_{DS})$. THE CIRCUIT EXTERNAL TO THE FET IMPOSE A CONSTRAINT ON THE SAME VARIABLES: THAT IS KVL REQUIRES

$\underline{V = i_D R_L + v_{DS}}$ ← A LINEAR EQUATION IN THESE VARIABLES



FOR EVERY VALUE OF $v_{GS} = v_{IN}$ THERE IS A SPECIFIC CURVE OF i_{DS} vs $v_{DS} = v_{OUT}$ (ONLY A FEW OF THE INFINITE FAMILY ARE SHOWN) WHERE THAT SPECIFIC CURVE CROSSES THE LOAD LINE IMPOSED BY KVL. THIS UNIQUELY DETERMINES THE VALUES OF i_D AND $v_{OUT} = v_{DS}$ AT WHICH THE CIRCUIT CONSTRAINT AND THE FET CONSTRAINT ARE SIMULTANEOUSLY SATISFIED.

THE TRANSFER CHARACTERISTIC CAN BE READ OFF THE OUTPUT CHARACTERISTICS, INTERSECTION BY INTERSECTION. (DEMO #4)

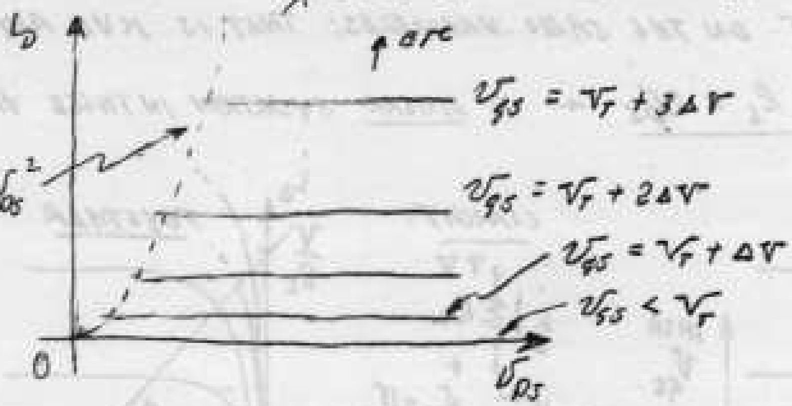
II ANALYSIS OF THE PHYSICAL ELECTRONICS YIELDS:

$$i_D = \begin{cases} 0 & \text{FOR } v_{GS} < V_T \\ \frac{K}{2}(v_{GS} - V_T)^2 & \text{FOR } \left\{ \begin{array}{l} v_{GS} > V_T \\ v_{DS} > v_{GS} - V_T \end{array} \right\} \text{ BOTH MUST BE SATISFIED} \end{cases}$$

$K \left(\frac{A}{V^2}\right)$ IS A CONSTANT OF THE FET

FOR THIS SUBJECT, THE SQUARE-LAW MODEL MUST BE TAKEN ON FAITH, JUST LIKE THE FET-AS-A-SWITCH MODEL AND THE EXPONENTIAL DIODE MODEL. ALL IS REVEALED IN 6.012!

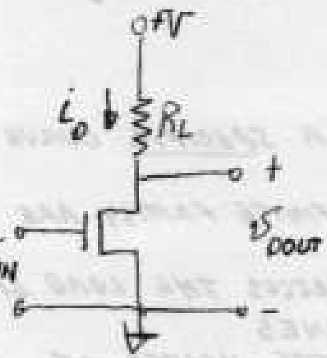
THE CORRESPONDING ANALYTICAL OUTPUT CHARACTERISTICS ARE:



SATURATION REGION IS TO THE RIGHT OF THE DOTTED BOUNDARY

THE REGION TO THE LEFT OF THE DOTTED BOUNDARY CAN ALSO BE DESCRIBED ANALYTICALLY BUT NOT IN 6.002.

THE OUTPUT-INPUT RELATIONSHIP OF THE BASIC INVERTER IS EASILY COMPUTED:



KVL REQUIRES $v_{OUT} = V - R_L i_D$ ①

$$i_D = \begin{cases} 0 & \text{FOR } v_{GS} < V_T \\ \frac{K}{2}(v_{GS} - V_T)^2 & \left\{ \begin{array}{l} v_{GS} > V_T \\ v_{DS} > v_{GS} - V_T \end{array} \right. \end{cases} \quad ②$$

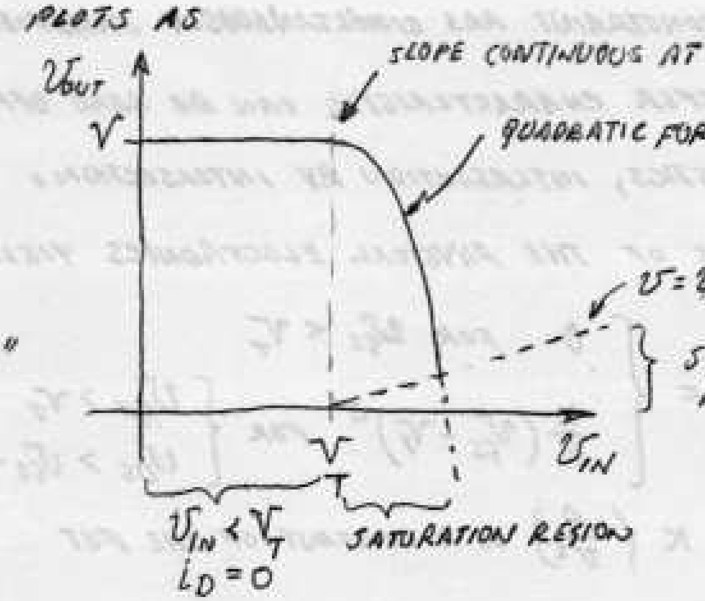
REPLACE v_{GS} BY v_{IN} AND SUBSTITUTE ② INTO ①

$$v_{OUT} = \begin{cases} V & \text{FOR } v_{IN} < V_T \\ V - \frac{KR_L}{2}(v_{IN} - V_T)^2 & \left\{ \begin{array}{l} v_{IN} > V_T \\ v_{OUT} > v_{IN} - V_T \end{array} \right. \end{cases}$$

WHICH PLOTS AS

NOTE THAT SCALES ARE DIFFERENT

NOTE THAT "VOLTAGE GAIN" CAN BE ACHIEVED



SQUARE-LAW MODEL FAILS BECAUSE $v_{OUT} < v_{IN} - V_T$