Georgia Institute of Technology

Introduction to Electronics

An introduction to electronic components and a study of circuits containing such devices.

School of Electrical and Computer Engineering

Georgia Institute of Technology

Week 6: MOSFETs

School of Electrical and Computer Engineering

Georgia Institute of Technology

Introduction and MOSFET Physics

Dr. Bonnie Ferri
Professor and Associate Chair
School of Electrical and
Computer Engineering

Study the physics of MOSFETs

Lesson Objective

- Introduce the uses of transistors
- Investigate the physics of MOSFETs

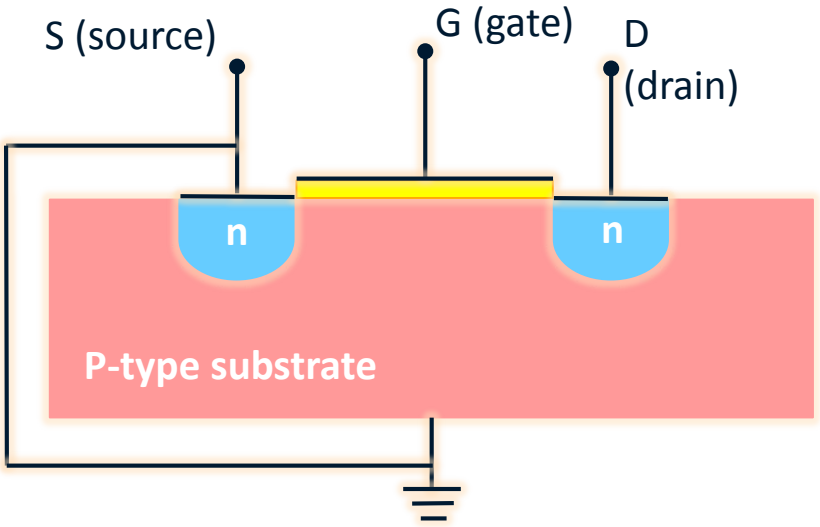
Types of Transistors

- MOSFET (metal-oxide-semiconductor silicon field-effect transistor)
- BJT (bipolar junction transistor)

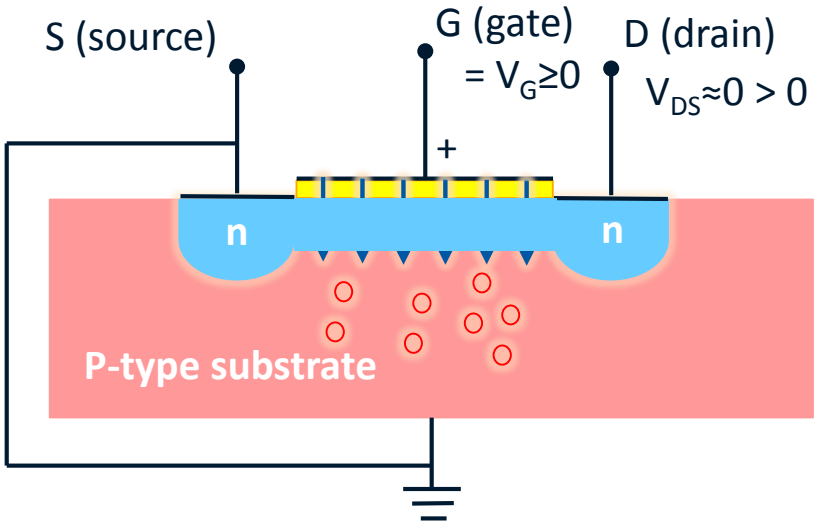
Uses of Transistors

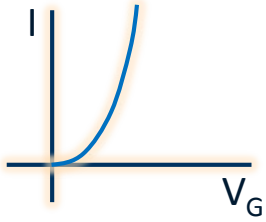
- Electrically controlled switch (digital circuits/computers)
- Amplifier (op amps)
- Resistor with value electrically controlled

NMOS (N-type MOSFET)



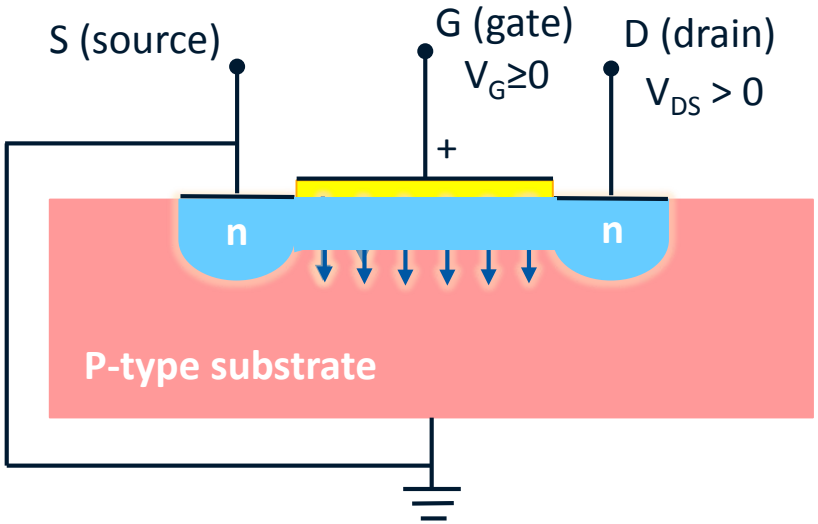
NMOS: Vary V_G

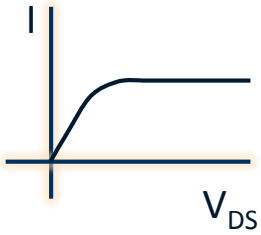




V_{DS} small and constant

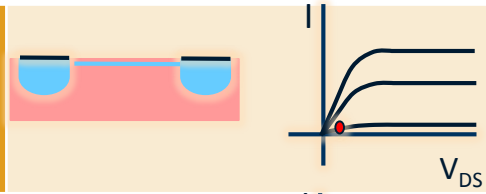
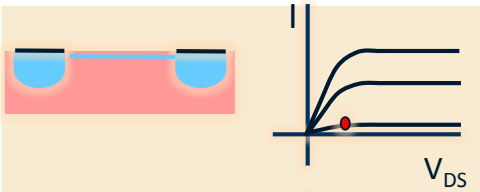
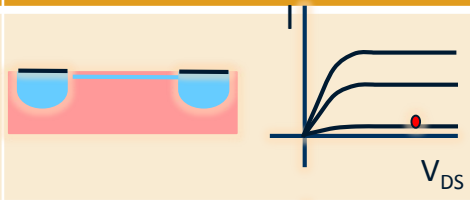
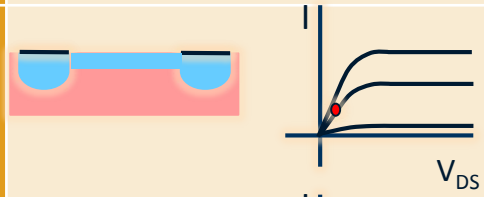
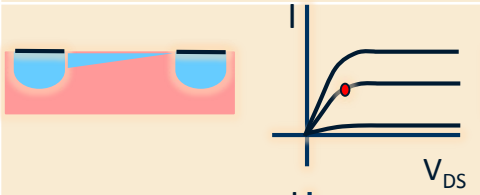
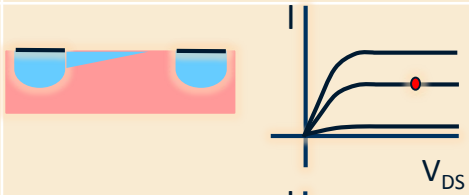
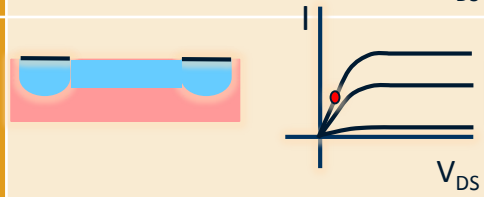
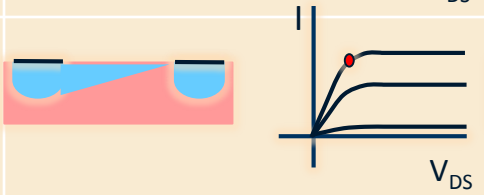
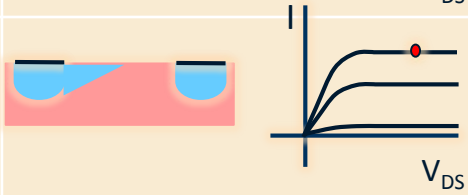
NMOS: Vary V_{DS}





V_G constant

Summary

	V_{DS} small	V_{DS} medium	V_{DS} large
V_G small			
V_G medium			
V_G large			

Remainder of Module

- MOSFET switches
- MOSFET amplifiers
- BJTs

Georgia Institute of Technology

MOSFET Switches

Dr. Bonnie Ferri
Professor and Associate Chair
School of Electrical and
Computer Engineering

Introduce the use of MOSFETs as switches in circuits

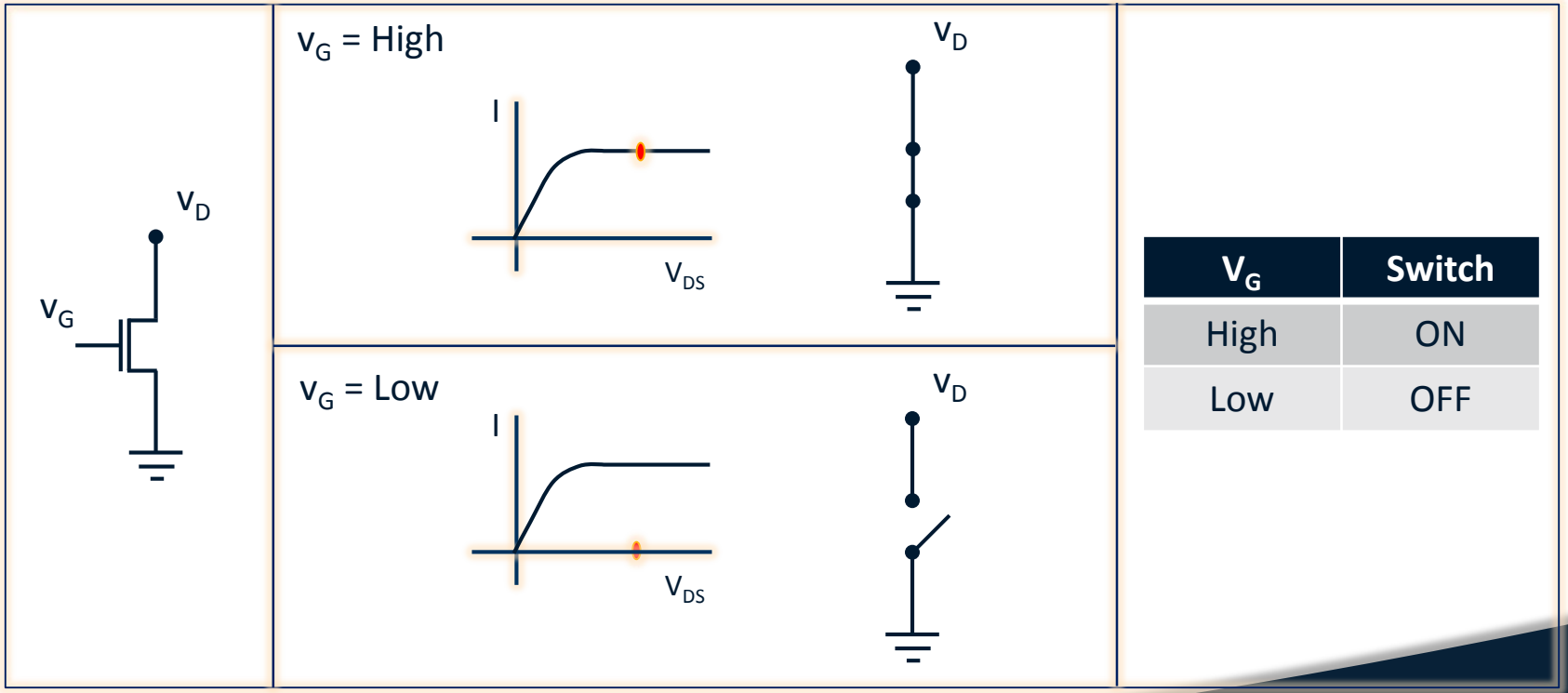
Previous Lesson

- Introduction to MOSFETs
- The physics of MOSFETs

Lesson Objectives

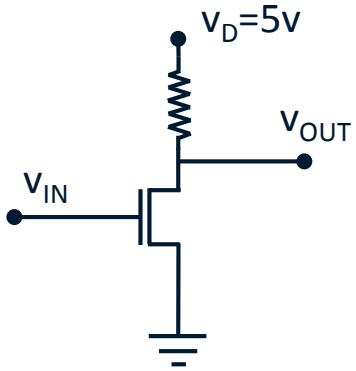
- Examine the use of MOSFET as a switch in a circuit
- Introduce CMOS devices

NMOS Switch Behavior

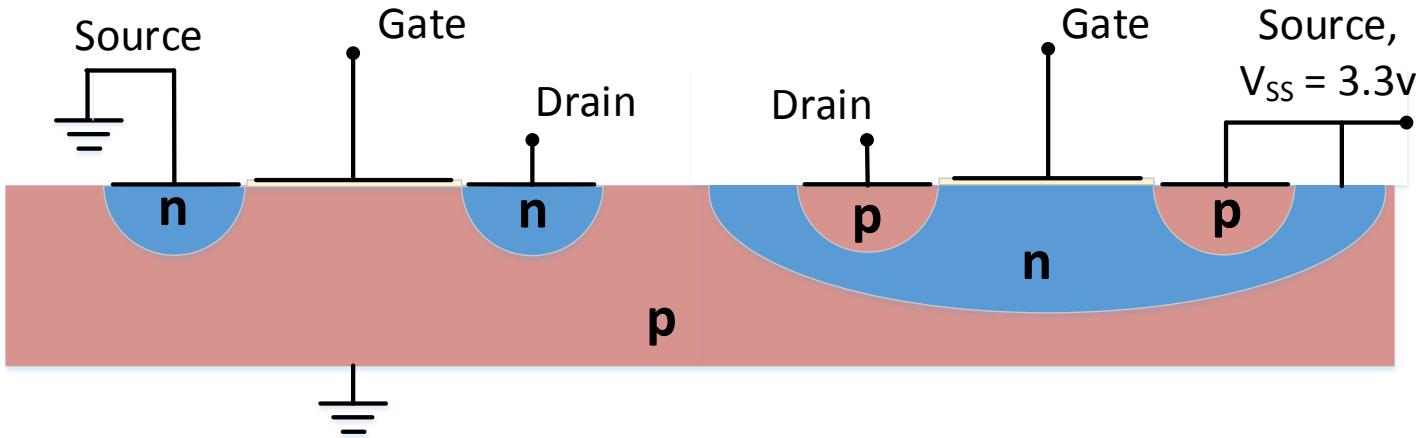


V_G	Switch
High	ON
Low	OFF

Simple NMOS Inverter Circuit



CMOS Devices



NMOS:

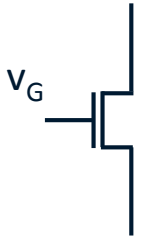
V_G	Switch
High	ON
Low	OFF

PMOS:

V_G	Switch
High	OFF
Low	ON

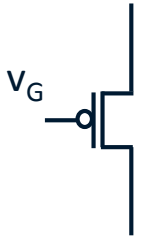
Summary of Switch Behavior

NMOS



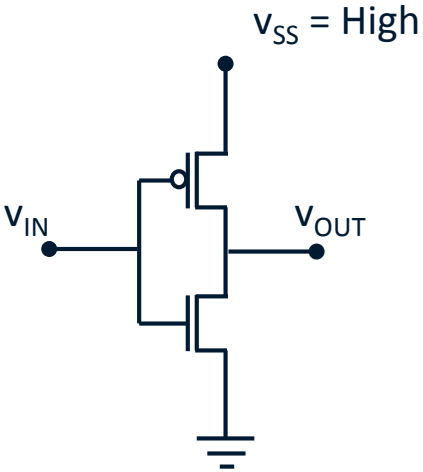
V_G	Switch
High	ON
Low	OFF

PMOS



V_G	Switch
High	OFF
Low	ON

CMOS Inverter Circuit



V_{IN}	V_{OUT}
High	Low
Low	High

Summary

- Examine the use of MOSFET as an electrically controlled switch in a circuit
- Introduced CMOS for complementary p-type and n-type transistor behavior
- Introduced inverter circuits

Georgia Institute of Technology

CMOS Logic Gates

Dr. Bonnie Ferri
Professor and Associate Chair
School of Electrical and
Computer Engineering

Introduction to logic gates made from CMOS transistors

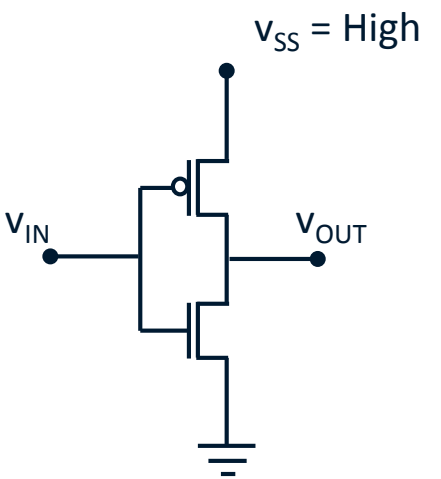
Previous Lesson

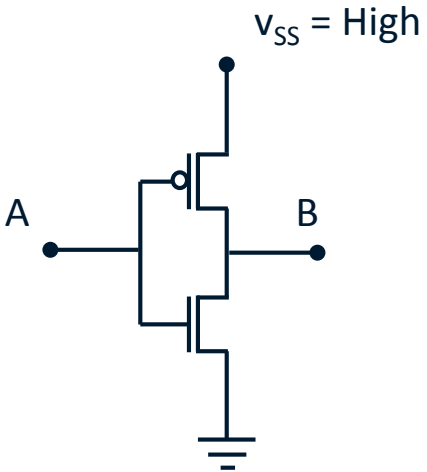
- MOSFET Switches

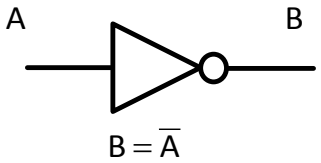
Lesson Objectives

- Introduce logic gates and their transistor circuits
  - NOT, NAND, NOR, AND, OR

CMOS NOT Gate (Inverter Circuit)







V_{IN}	V_{OUT}
High	Low
Low	High

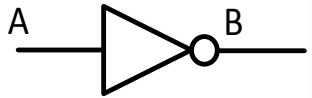
Truth Table

A	B
0	1
1	0

Logic Gates

NOT

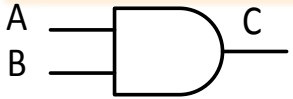
A	B
0	1
1	0



$B = \overline{A}$

AND

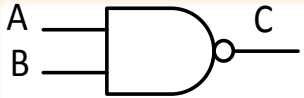
A B	C
0 0	0
0 1	0
1 0	0
1 1	1



$C = A \bullet B$

NAND

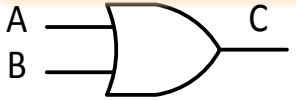
A B	C
0 0	1
0 1	1
1 0	1
1 1	0



$C = \overline{A \bullet B}$

OR

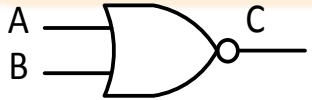
A B	C
0 0	0
0 1	1
1 0	1
1 1	1



$C = A + B$

NOR

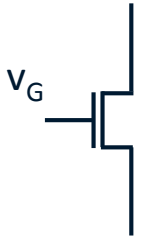
A B	C
0 0	1
0 1	0
1 0	0
1 1	0



$C = \overline{A + B}$

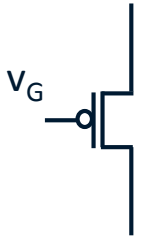
PMOS Switch Behavior

NMOS



V_G	Switch
High	ON
Low	OFF

PMOS

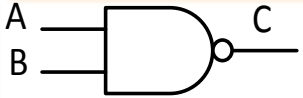


V_G	Switch
High	OFF
Low	ON

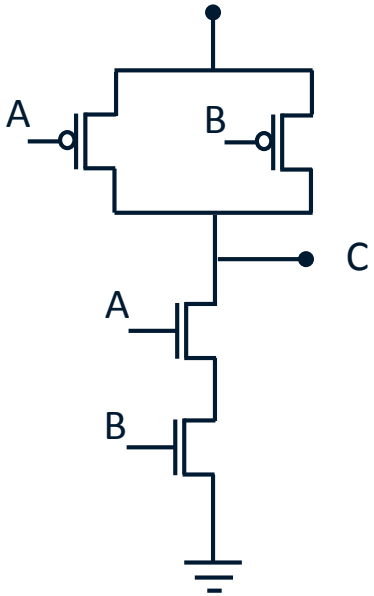
NAND Gate

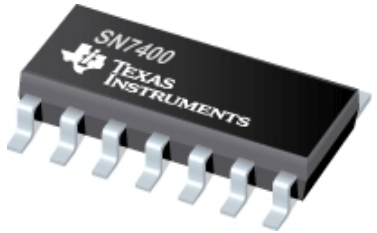
NAND

A B	C
0 0	1
0 1	1
1 0	1
1 1	0



$C = \overline{A \bullet B}$

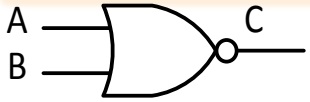




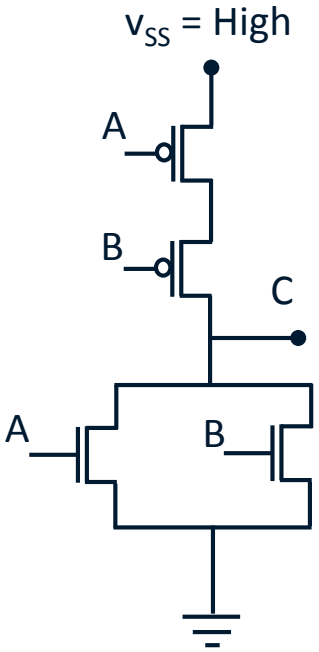
NOR Gate

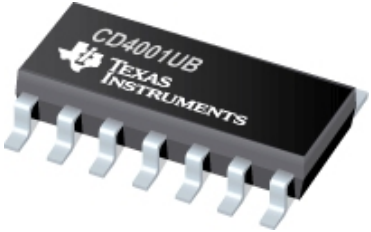
NOR

A B	C
0 0	1
0 1	0
1 0	0
1 1	0



$C = \overline{A + B}$

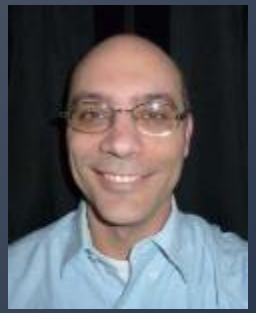




Summary

- Logic gate circuits are made from CMOS n-type and p-type transistors

Georgia Institute of Technology

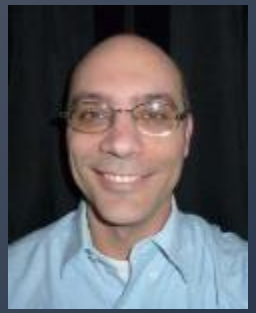


Introduction to Electronics

Dr. Allen Robinson
Academic Professional
School of Electrical and Computer Engineering

An introduction to electronic components and a study of circuits containing such devices.

Georgia Institute of Technology



MOSFET Characteristics

Dr. Allen Robinson
Academic Professional
School of Electrical and
Computer Engineering

Introduce MOSFET characteristic curves and biasing

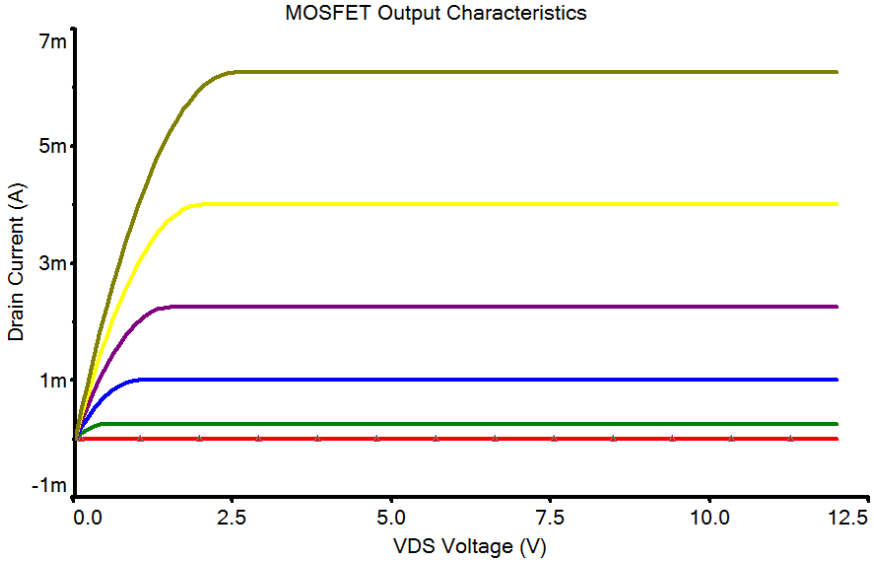
Previous Lesson

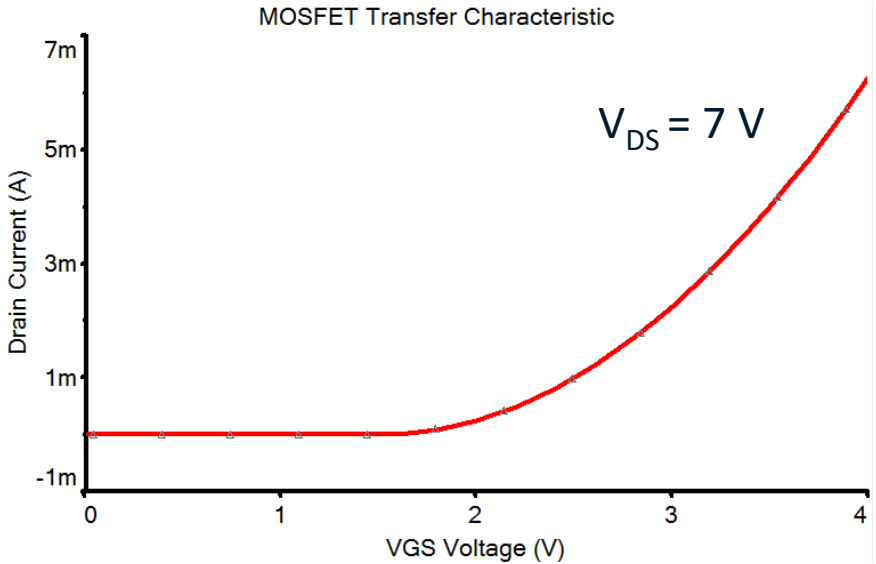
- Introduced CMOS logic gates

Lesson Objectives

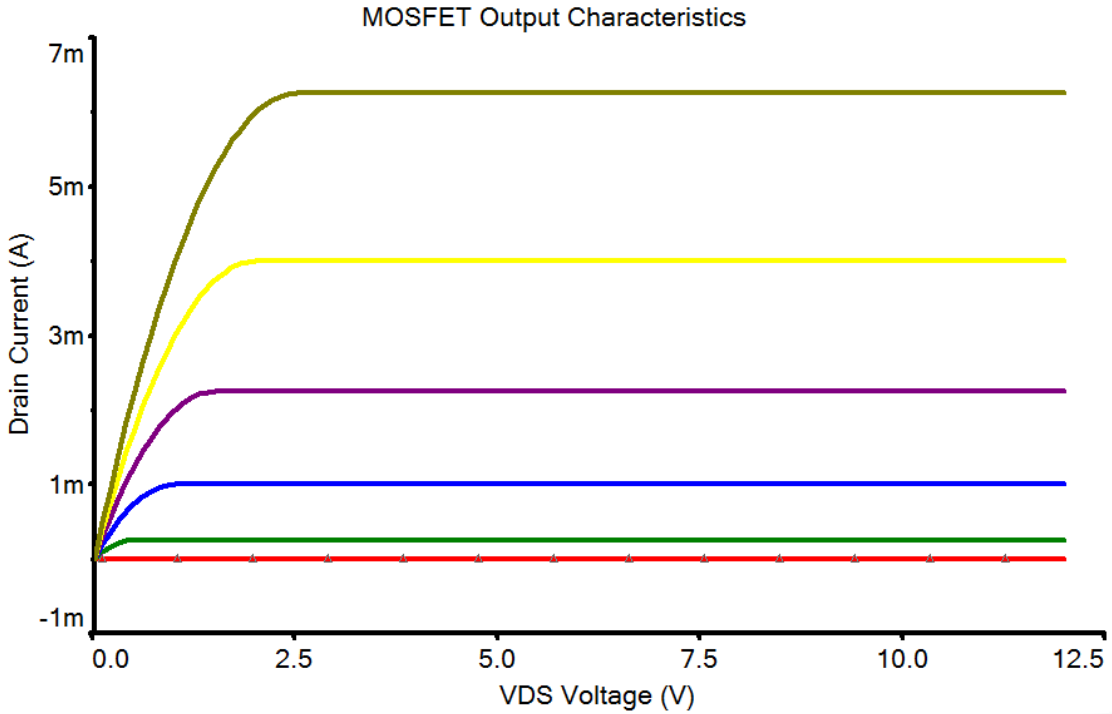
- Introduce MOSFET characteristic curves
- Introduce dc biasing

Characteristic Curves





Regions of Operation



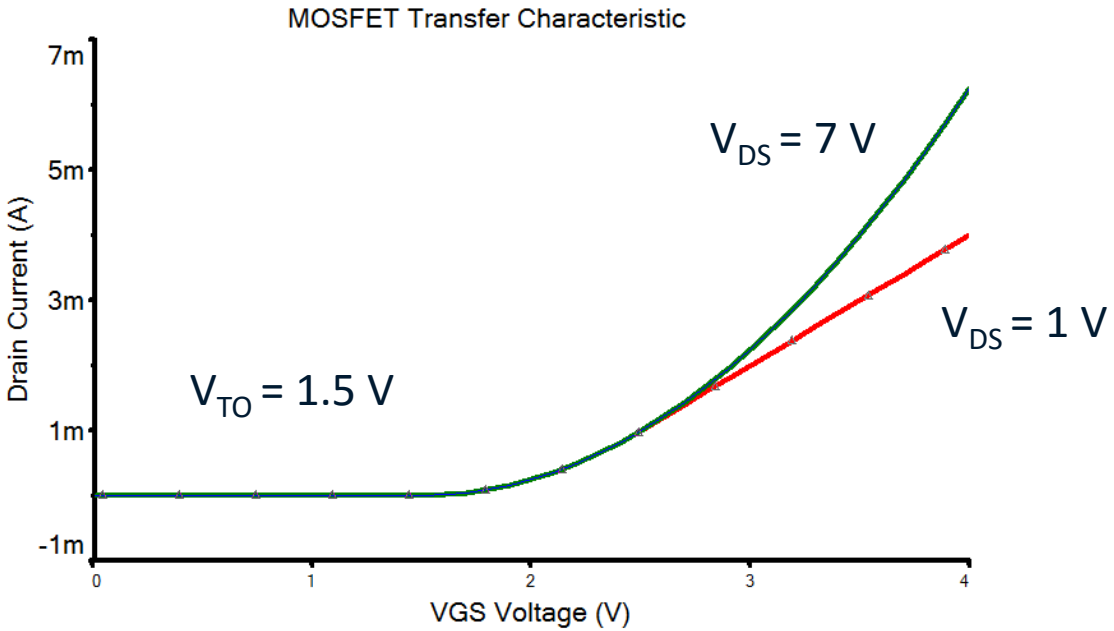
Regions of Operation

Cutoff Region	Linear/Triode Region	Saturation Region
$V_{GS} < V_{TO}$	$V_{GS} > V_{TO}$	$V_{GS} > V_{TO}$
	$V_{DS} < V_{GS} - V_{TO}$	$V_{DS} > V_{GS} - V_{TO}$
$I_D = 0$	$I_D = 2K\left[(V_{GS} - V_{TO})\,V_{DS} - \frac{V_{DS}^2}{2}\right]$	$I_D = K(V_{GS} - V_{TO})^2$

K = Transconductance parameter. Units of A/V^2

V_{TO} = Threshold or turn on voltage. Minimum value of V_{GS} for I_D to flow.

Transfer Characteristics



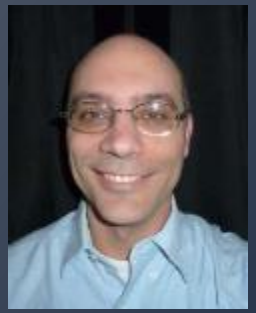
Summary

- Introduced MOSFET characteristics
- Introduced dc biasing

Next Lesson

- Common Source Amplifier: DC Analysis

Georgia Institute of Technology

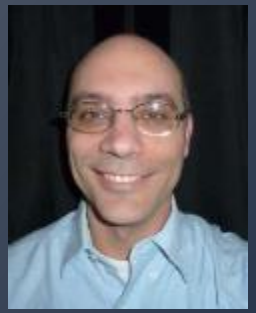


Introduction to Electronics

Dr. Allen Robinson
Academic Professional
School of Electrical and Computer Engineering

An introduction to electronic components and a study of circuits containing such devices.

Georgia Institute of Technology



Common Source Amplifier: DC Analysis

Dr. Allen Robinson
Academic Professional
School of Electrical and Computer Engineering

Introduce common source amplifier

Previous Lesson

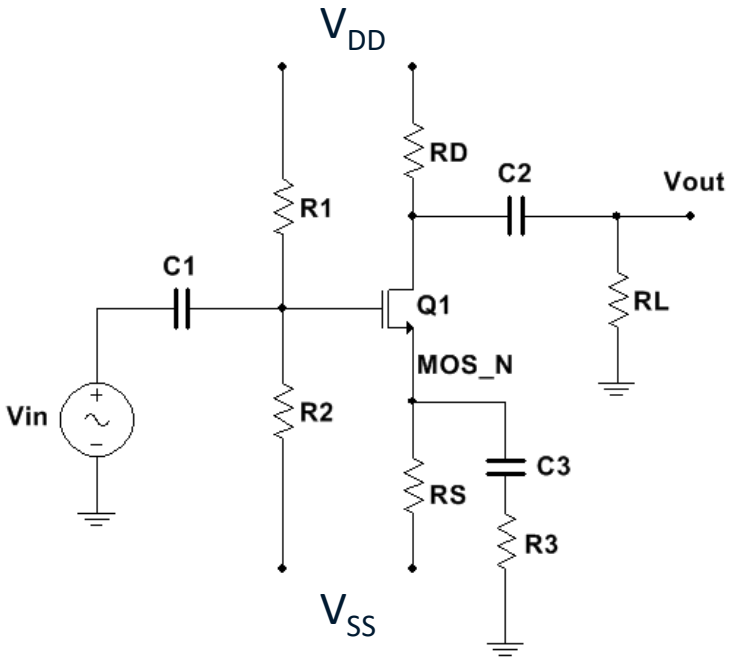
- Examined MOSFET characteristic curves and biasing

Lesson Objectives

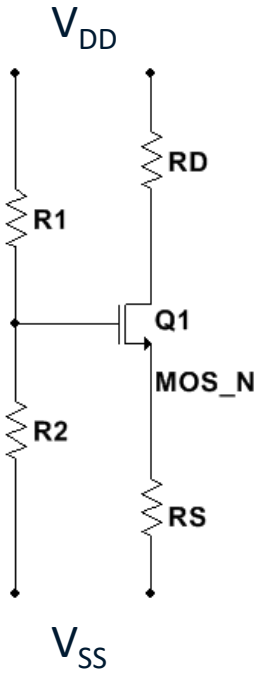
- Introduce common source amplifier
- Analyze common source amplifier dc circuit

MOSFET Gain Stage

Common Source Amplifier



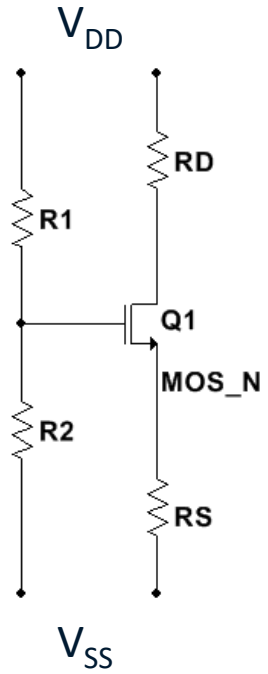
Common Source Amplifier DC Circuit



$$I_G = 0$$

$$I_D = I_S$$

Common Source Amplifier DC Formulas



$$I_G = 0$$

$$I_D = I_S$$

$$V_G = \frac{V_{DD}R_2 + V_{SS}R_1}{R_1 + R_2}$$

$$V_{GS} = \sqrt{\frac{I_D}{K}} + V_{TO}$$

$$V_1 = V_G - V_{SS} - V_{TO}$$

$$I_D = \left(\frac{\sqrt{1 + 4KV_1R_S} - 1}{2\sqrt{K}R_S}\right)^2$$

$$V_D = V_{DD} - R_D I_D$$

$$V_S = V_{SS} + R_S I_S$$

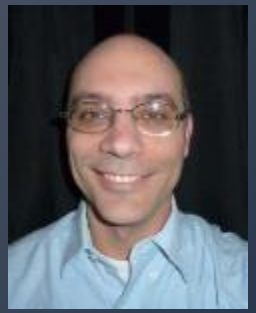
Summary

- Introduced common source (CS) amplifier
- Introduced dc analysis of CS amplifier

Next Lesson

- Common Source Amplifier: AC Analysis

Georgia Institute of Technology

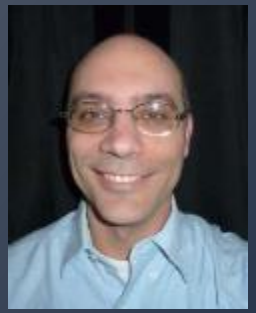


Introduction to Electronics

Dr. Allen Robinson
Academic Professional
School of Electrical and Computer Engineering

An introduction to electronic components and a study of circuits containing such devices.

Georgia Institute of Technology



Common Source Amplifier: AC Analysis

Dr. Allen Robinson
Academic Professional
School of Electrical and Computer Engineering

Examine ac behavior of the common source amplifier

Previous Lesson

- Introduced common source amplifier
- Introduced dc biasing

Lesson Objectives

- Introduce ac behavior of CS amplifier
- Analyze CS amplifier circuit

Small Signal Parameters and Gain

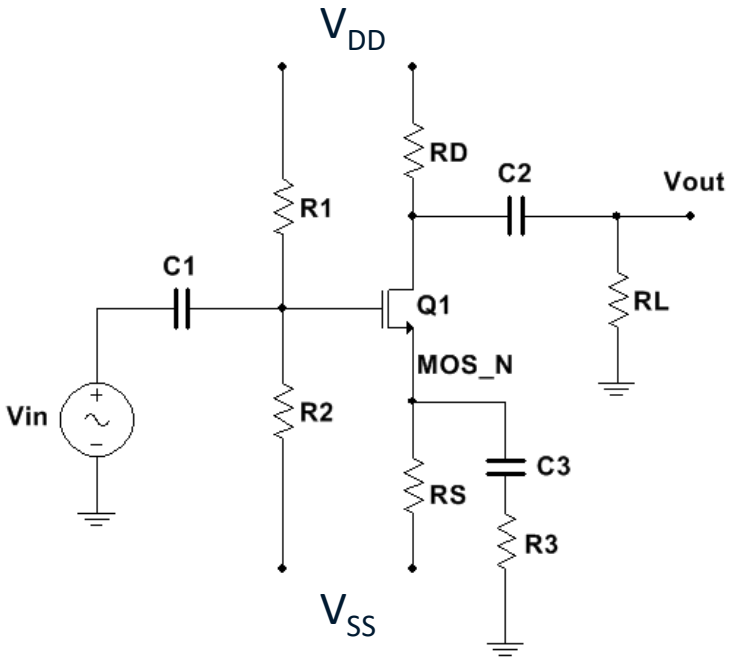
Perform small-signal analysis to obtain:

$g_m = 2\sqrt{KI_D}$ Transconductance

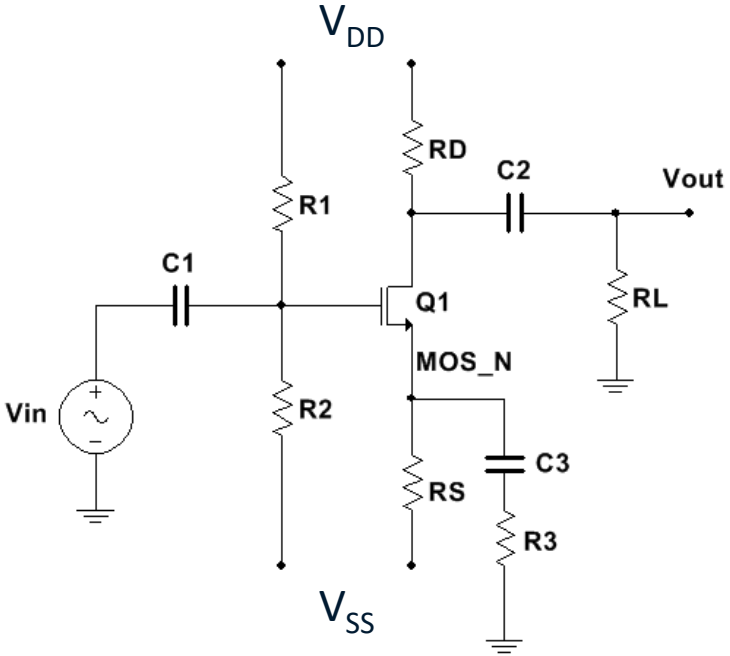
$r_s = 1/g_m$ Intrinsic source resistance

$\frac{V_{out}}{V_{in}} = -\frac{R_D||R_L}{r_s + R_S||R_3}$ Midband Gain

Common Source Amplifier



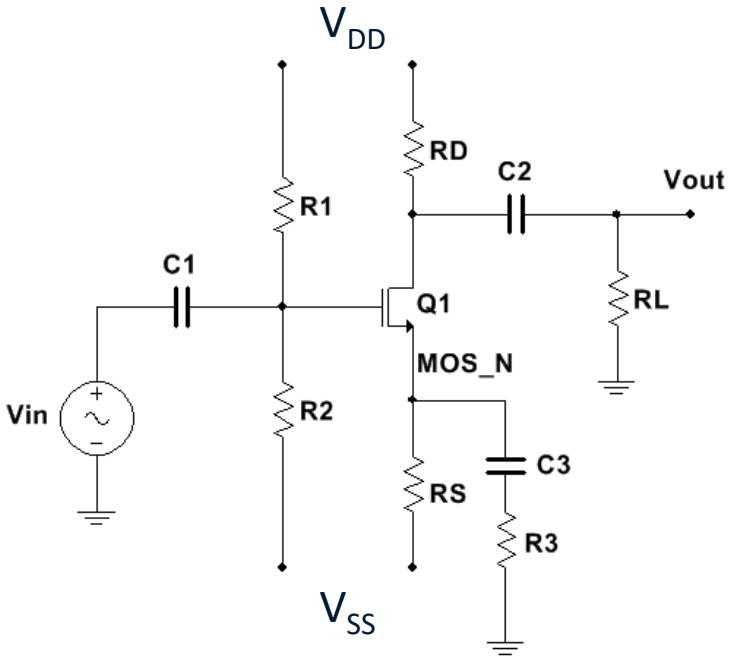
Common Source Amplifier Example



Determine Q point and Gain Given:

$$R_1 = 1\,\text{M}\Omega \qquad V_{DD} = +15\,\text{V}$$
$$R_2 = 200\,\text{k}\Omega \qquad V_{SS} = -15\,\text{V}$$
$$R_S = 3\,\text{k}\Omega$$
$$R_L = 20\,\text{k}\Omega$$
$$R_3 = 51\,\Omega$$
$$R_D = 15\,\text{k}\Omega$$
$$K = 0.001\,\text{A/V}^2$$
$$V_{TO} = 1.5\,\text{V}$$

Common Source Amplifier Example



Summary

- Introduced AC analysis of CS amplifier
- Analyzed CS amplifier circuit

Next Lesson

- Bipolar Junction Transistor (BJT)