

# HKN ECE 110 Final Exam Review Session

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COREY SNYDER

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# Before we get started...

- There are special office hours for finals week
- HKN PHYS 212 Review Session 6-8pm in ECEB 1013 TODAY!
- HKN PHYS 213 Review Session 2-4pm in ECEB 1013 on Sunday (5/6)!

- Don't forget about HKN!
  - Review Sessions
  - Tutoring
  - Tech Talks
  - Peer Mentoring
  - Resume Reviews
  - Mock Interviews

	Thursday (5/3)	Friday (5/4)	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday (5/10)
10:00 AM								Micki
11:00 AM		Prof. Schmitz						Micki
12:00 PM	Review Session			Steven				
1:00 PM	Review Session		Micki	Steven	Prof. Fang	Corey	Corey	Corey
2:00 PM	Review Session	Prof. Gruev	Micki			Corey	Corey	Corey
3:00 PM					Prof. Choi			
4:00 PM	Steven	Steven						
5:00 PM	Steven	Steven						
6:00 PM								
All office hours are held in ECEB 1005 (lab classroom)								

# Legit Tips and Tricks to Show Off Your Wits

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# Concise Advice to Make Your Grade Look Nice

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# Wise Words to Make your Score Soar

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# Lessons to Lend to a Friend for the End (of the semester)

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- Use your study sheet more like a study tool
- Spend your time showing what you know
- Pace yourself, you have three hours!
- Take some time to relax before the exam

Beyond ECE 110...

- You have a right to be skeptical
- “You’re not as good as you think you are when you win, and you’re not as bad as you think you are when you lose”
- Don’t forget about HKN!

# Topics

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- Circuit Analysis Fundamentals
  - Ohm's Law, KVL, KCL, Resistor Combinations, CDR, VDR
- Power Conventions
  - Standard/Non-standard Current,  $V_{rms}/P_{avg}$
- I-V Characteristics and Thevenin/Norton Equivalents
- Node Method
  - Supernode
- Diodes
  - Clippers, "How many are on?"
- BJTs
  - CE BJT Circuit, I-V Characteristic, BJT Amplifier
- MOSFETs
  - CS MOSFET Circuit, I-V Characteristic, CMOS
- Signal-to-Noise Ratio
- Sampling and Quantization
  - Nyquist, Data Conversion
- Information Theory and Compression
  - Entropy, Huffman Coding
- Solar Cells and Photodiodes

# Ohm's Law, Resistance, and Power

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- Ohm's Law describes the relationship between the voltage *across* and current *through* a resistive element
  - Ohm's law only applies for linear components, i.e. resistors
  - More on linear components with Thevenin/Norton Equivalents (and in ECE 210!)
- $V = IR$
- Resistance of an element can found by:  $R = \frac{\rho l}{A}$
- Power dissipated by an element can be found by:  $P = IV, P = I^2R, P = \frac{V^2}{R}$ 
  - You can go between the three forms using Ohm's Law!
- Resistors in series share the same current
- Resistors in parallel share the same two nodes and thus the same voltage



# Nodes, KVL, and KCL

- A node is any part of a circuit that is at an *equipotential*

- Wires are equipotentials

- Kirchhoff's Voltage Law

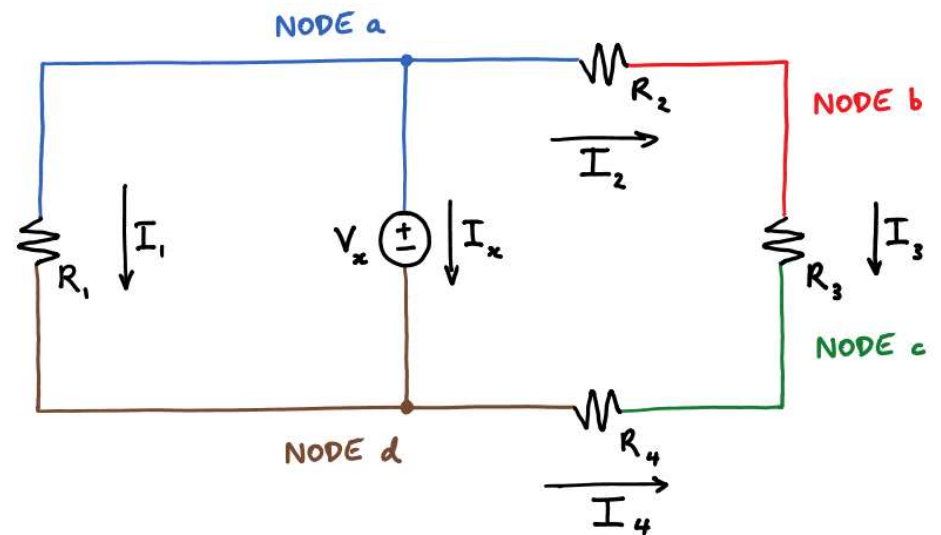
- Conservation of Energy
- Performed on a loop

- $\sum V_{rises} = \sum V_{drops}$

- Kirchhoff's Current Law

- Conservation of Charge
- Performed at a node
- Bubble method

- $\sum I_{in} = \sum I_{out}$

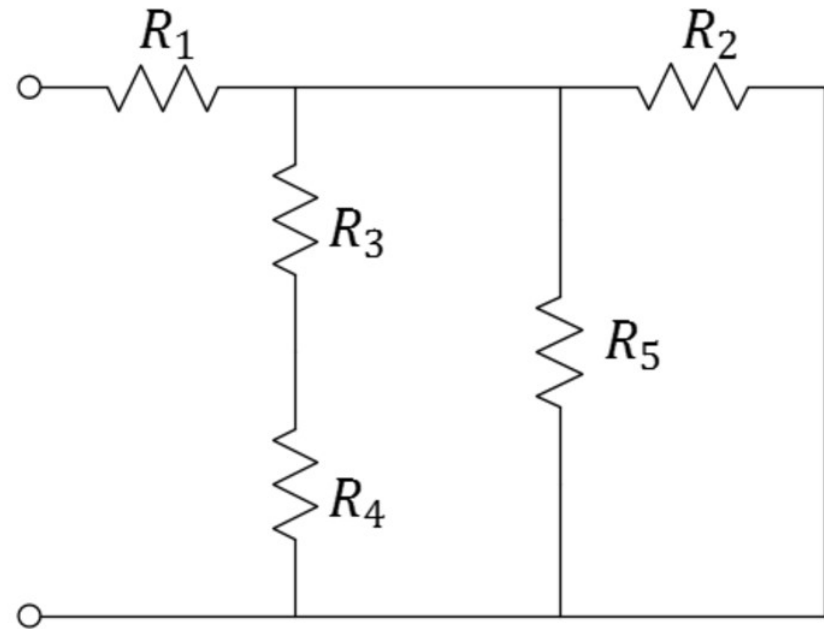


# Equivalent Resistance Example #1

For the following circuit:

What is the relationship between  $R_3$  and  $R_4$ ?

- A. Series
- B. Parallel
- C. Neither



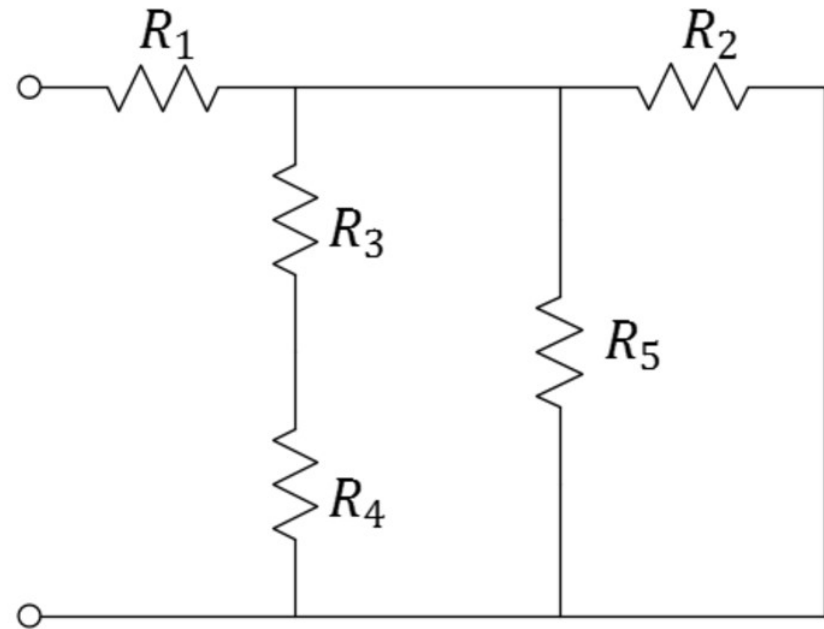
# Equivalent Resistance Example #1

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For the following circuit:

What is the relationship between  $R_1$  and  $R_2$ ?

- A. Series
- B. Parallel
- C. Neither

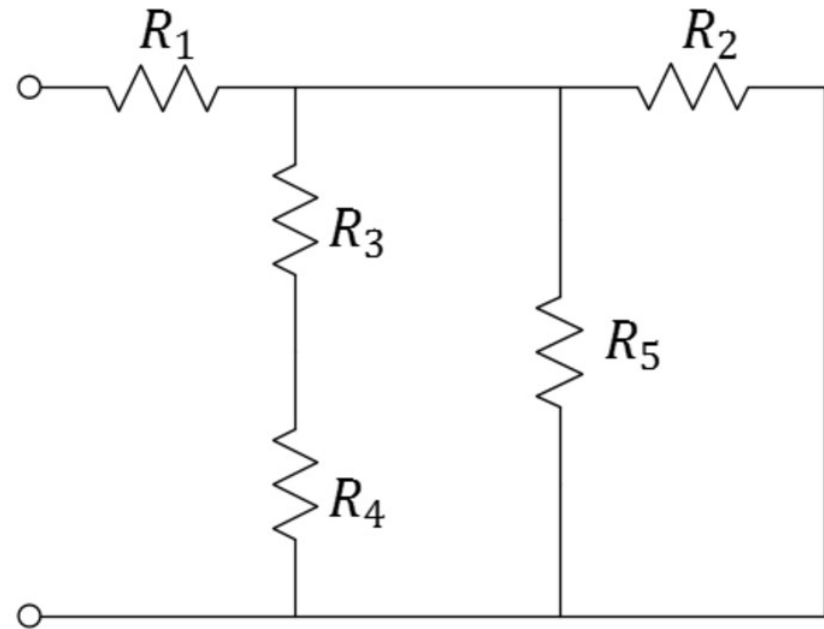


# Equivalent Resistance Example #1

For the following circuit:

What is the relationship between  $R_2$  and  $R_5$ ?

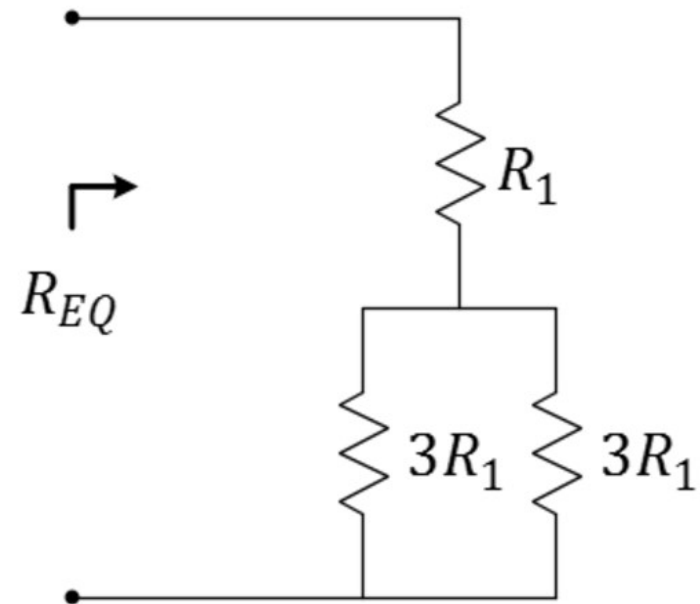
- A. Series
- B. Parallel
- C. Neither



## Equivalent Resistance Example #2

Find the value of  $R_1$  that makes  $R_{eq} = 27.5\Omega$

- A.  $4\Omega$
- B.  $8\Omega$
- C.  $11\Omega$
- D.  $12\Omega$
- E. Unsure



# KVL and KCL Example

Find the unknown voltages,  $V_2, V_3, V_5$ .

- A.  $V_2 = 0V, V_3 = -3V, V_5 = 0V$
- B.  $V_2 = 6V, V_3 = -3V, V_5 = 6V$
- C.  $V_2 = 6V, V_3 = 3V, V_5 = -6V$
- D.  $V_2 = 6V, V_3 = -3V, V_5 = -6V$
- E. Yeah, uh, no.

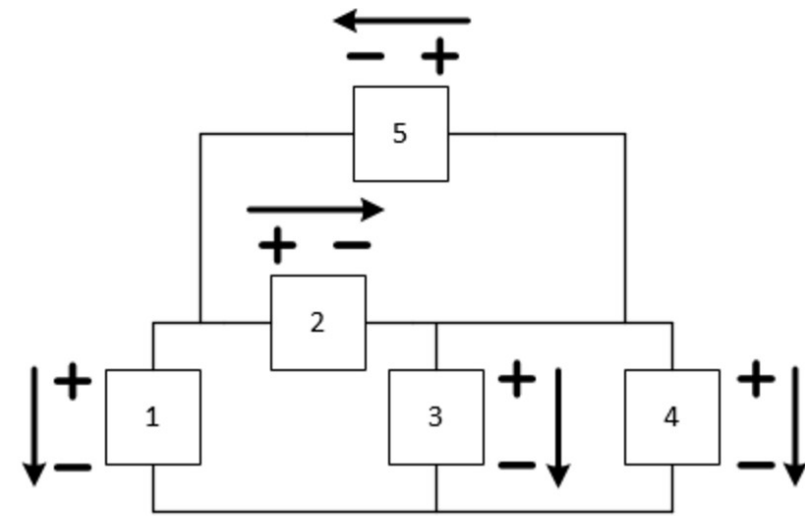
$$V_1 = 3V$$

$$V_4 = -3V$$

$$I_2 = -2A$$

$$I_3 = -1A$$

$$I_5 = 3A$$



# KVL and KCL Example

Find the unknown currents,  $I_1, I_4$ .

- A.  $I_1 = 5A, I_4 = -4A$
- B.  $I_1 = 1A, I_4 = -4A$
- C.  $I_1 = 1A, I_4 = -1A$
- D.  $I_1 = 5A, I_4 = -1A$
- E. Please. Help me.

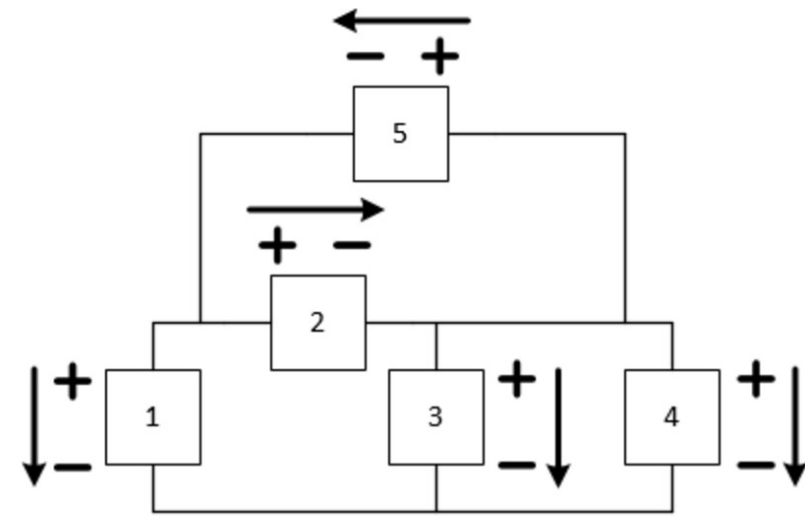
$$V_1 = 3V$$

$$V_4 = -3V$$

$$I_2 = -2A$$

$$I_3 = -1A$$

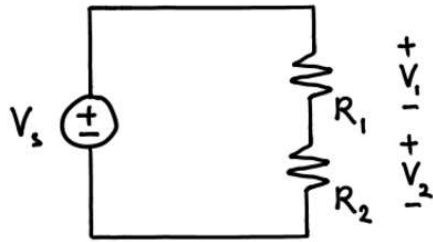
$$I_5 = 3A$$



# Voltage Divider and Current Divider

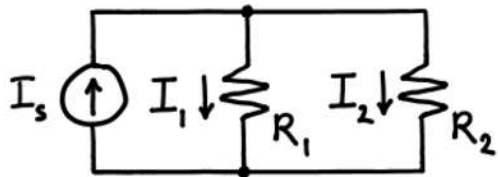
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- We can use voltage divider rule (VDR) in order to find the voltage across individual resistors in series



$$V_1 = \frac{R_1}{R_1 + R_2} V_s \quad V_2 = \frac{R_2}{R_1 + R_2} V_s$$

- We can use current divider rule (CDR) in order to find the current through individual resistors in parallel



$$I_1 = \frac{R_2}{R_1 + R_2} I_s \quad I_2 = \frac{R_1}{R_1 + R_2} I_s$$



# Root-mean-square Voltage ( $V_{rms}$ )

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- The exact definition of  $V_{rms}$  is:

$$V_{rms} = \sqrt{\frac{\left(\int_0^T v^2(t) dt\right)}{T}}$$

- We will mainly ask you to use the following two formulas:

- $V_{rms}(\text{sinusoid}) = \frac{\text{Amplitude}}{\sqrt{2}}$

- $V_{rms}(\text{square wave}) = V_{p-p} \sqrt{\%DC}$

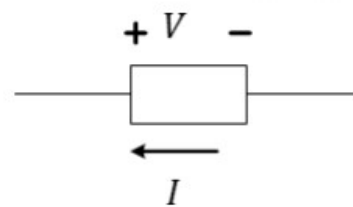
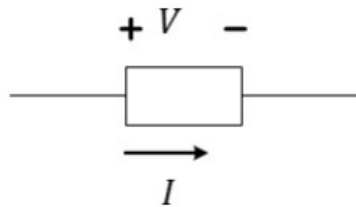
- We use  $V_{rms}$  to determine the power delivered to a load from a time-varying source

- $P_{avg} = \frac{V_{rms}^2}{R}$

# Power and Labeling

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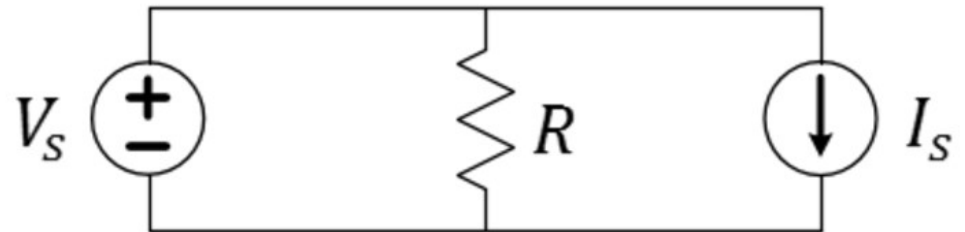
- We know that power can be expressed in three ways:  $P = IV = I^2R = \frac{V^2}{R}$
- If the value of power is positive, the element is absorbing power
- If the value of power is negative, the element is supplying power
- Standard vs. Non-Standard Labeling
- Standard:  $P = IV, V = IR$ , Current goes + to -
- Non-Standard:  $P = -IV, V = -IR$ , Current goes - to +



# Circuit Power Example

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For the following circuit, determine the power of the resistor, current source, and voltage source.



$$V_s = 2.4 \text{ V}$$

$$R = 100 \, \Omega$$

$$I_s = 15 \text{ mA}$$

# I-V Characteristics

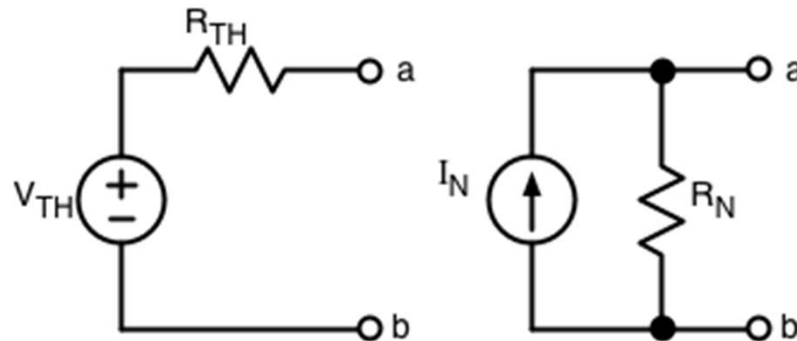
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- We can characterize circuits where the current is a function of the voltage
- For ECE 110, we typically want to characterize linear circuits, where the I-V Characteristic is of the form
  - $I = mV + b$
- In order to obtain this equation, we want to find two points:
  - $V_{oc}$  and  $I_{sc}$
- $V_{oc}$  is the  $x$  – intercept,  $I_{sc}$  is the  $y$  – intercept

# Thevenin and Norton Equivalents

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- We can express any linear circuit as a simple circuit involving a source and a resistor (Wow)
  - More on this in ECE 210!
- We want to find  $V_{OC}$ ,  $I_{SC}$ , and  $R_{eff}$
- If we find two of these parameters, we can find the third through Ohm's Law!
- If current is defined as standard:
  - $I = \frac{-I_{SC}}{V_{OC}} V + I_{SC}$
- If current is defined as non-standard:
  - $I = \frac{I_{SC}}{V_{OC}} V - I_{SC}$



# Thevenin and Norton Equivalents

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- There is a lot of vocabulary with Thevenin and Norton Equivalents, and this can be confusing! Keep the following things in mind:

$$\begin{aligned}I_{sc} &= I_N \\V_{oc} &= V_T \\R_T &= R_N = R_{eff} = R_{eq}\end{aligned}$$

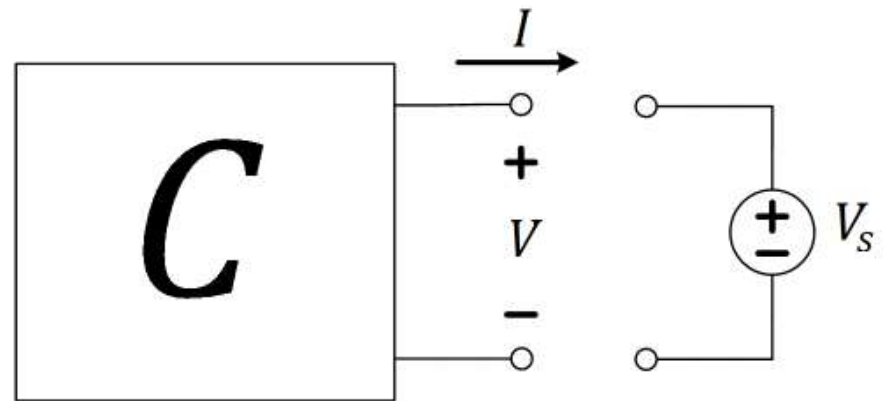
- Remember what each parameter represents in the IV characteristic and the corresponding graph.
- $I_{sc}$  is the y-intercept
- $V_{oc}$  is the x-intercept
- $\frac{1}{R_{eff}}$  is the **magnitude** of the slope. Remember the sign is determined by whether the current definition is standard or non-standard

# Thevenin and Norton Example #1

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The open-circuit voltage of the component  $C$  is  $6V$ , its short-circuit current is  $400mA$ , and  $V_s = 3V$ . Determine the power of the component  $C$ .

- A.  $P = 0.6W$
- B.  $P = -0.6W$
- C.  $P = 2.4W$
- D.  $P = -2.4W$
- E. I have a moral objection to Thevenin and Norton Equivalents.

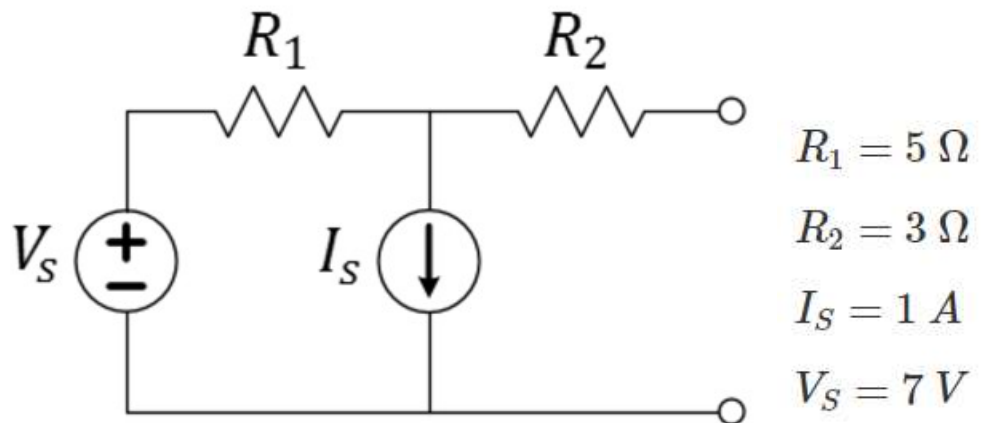


# Thevenin and Norton Example #2

For the following circuit, determine the Thevenin Equivalent. That is, find  $V_T$ ,  $I_N$ , and  $R_T$ .

What is  $R_T$ ?

- A.  $0\Omega$
- B.  $3\Omega$
- C.  $8\Omega$
- D.  $10\Omega$



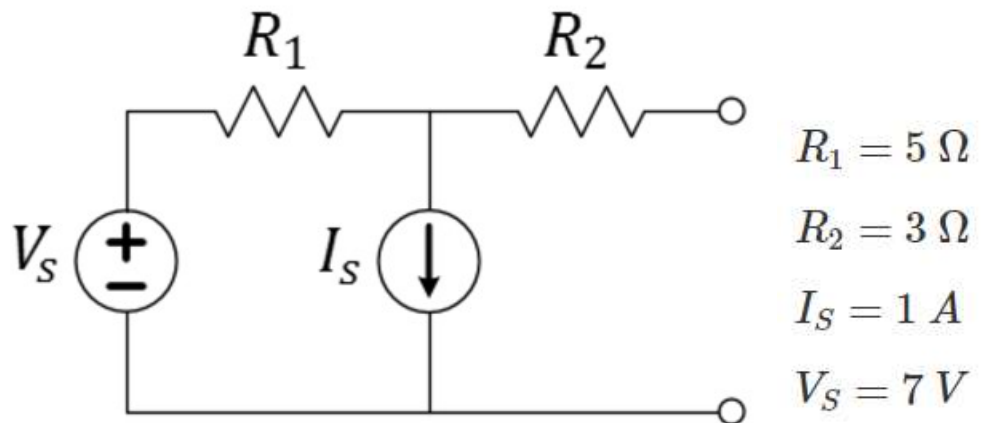


# Thevenin and Norton Example #2

For the following circuit, determine the Thevenin Equivalent. That is, find  $V_T$ ,  $I_N$ , and  $R_T$ .

What is  $V_T$ ?

- A.  $\frac{7}{5} V$
- B.  $2V$
- C.  $5V$
- D.  $7V$

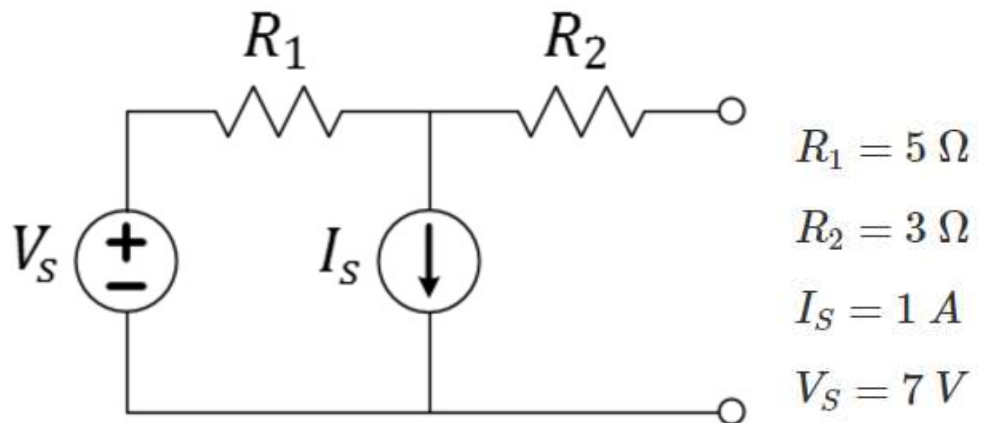


# Thevenin and Norton Example #2

For the following circuit, determine the Thevenin Equivalent. That is, find  $V_T$ ,  $I_N$ , and  $R_T$ .

What is  $I_N$ ?

- A.  $\frac{1}{4} A$
- B.  $1 A$
- C.  $\frac{7}{8} A$
- D.  $4 A$
- E. PLEASE MAKE IT STOP



# Node Voltage Method

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• We want to express the KCL in terms of node voltages using Ohm's Law. How do we do this?

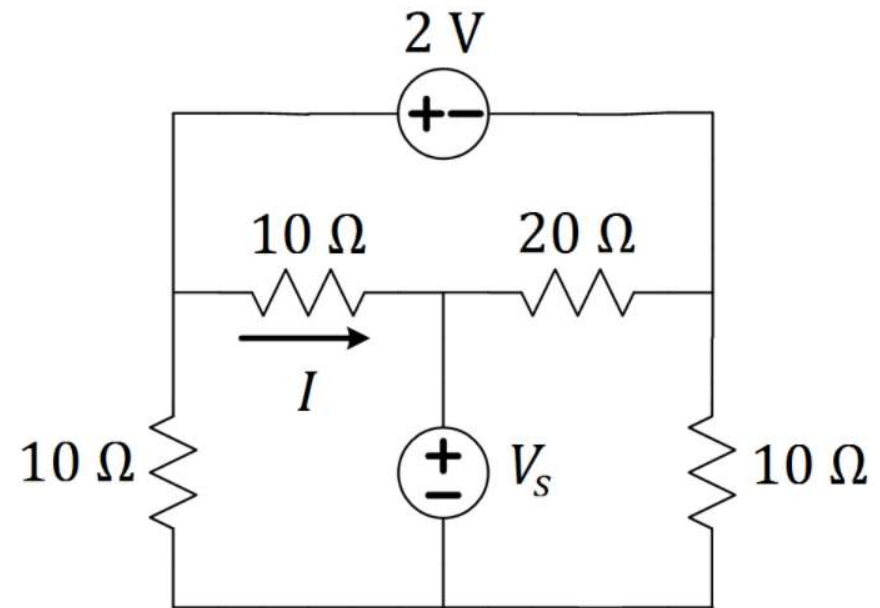
1. Pick a ground node that touches as many sources as possible.
2. Label the nodes that touch ground through a voltage source.
3. Pick a node where you need to find the node voltage. Write KCL at that node.
4. Express each current using Ohm's Law and the node voltages. Be careful of your current directions. We express each current as the voltage "where you start" minus the voltage "where you end" over the resistance.

$$I_x = \frac{V_{start} - V_{end}}{R_x}$$

5. Solve! (May need a system of equations if there is more than one unknown node)

# Supernode Example

Given  $V_s = 5V$ , find the value of the current  $I$  in amps.



# Diodes

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- Diodes are non-linear devices that allow current to pass in only one direction

- Offset-Ideal Model

- How do we know if a diode is on? Guess and Check!

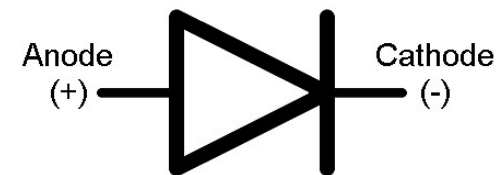
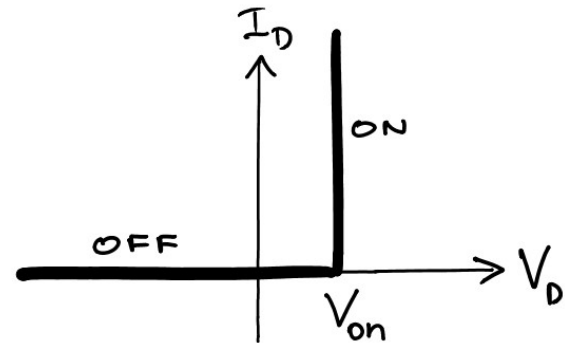
- If we guess off, we say the current is zero and  $V_D < V_{on}$

- Guess on, positive current flows and  $V_{on}$  volts are across diode

- If our guess is wrong, one of these conditions will be violated

- E.g. We guess on, but reverse current flows through the diode

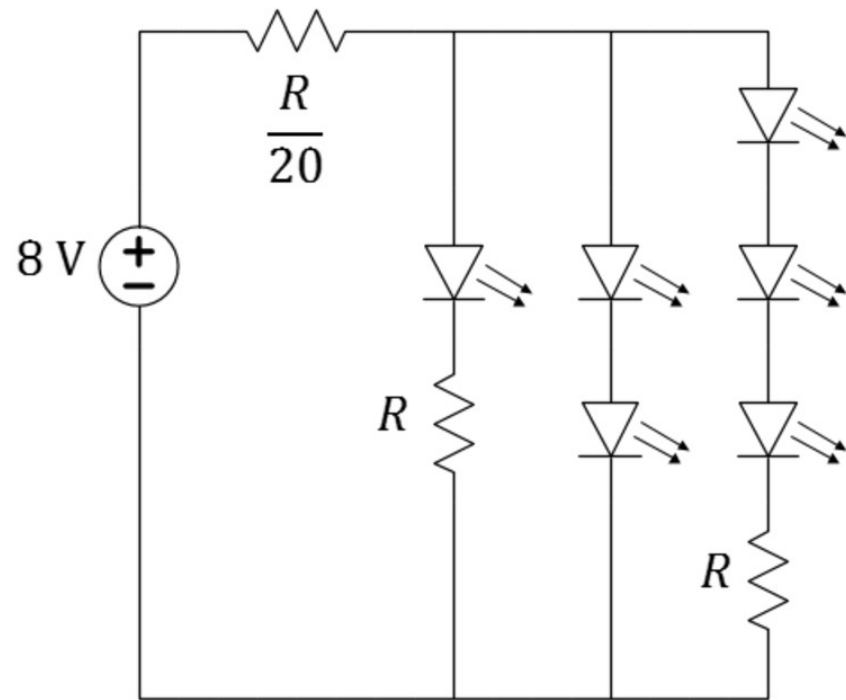
- Clipper circuits



# Diode Example – How many are on?

In the following circuit,  $V_{ON} = 2V$ . How many diodes are on?

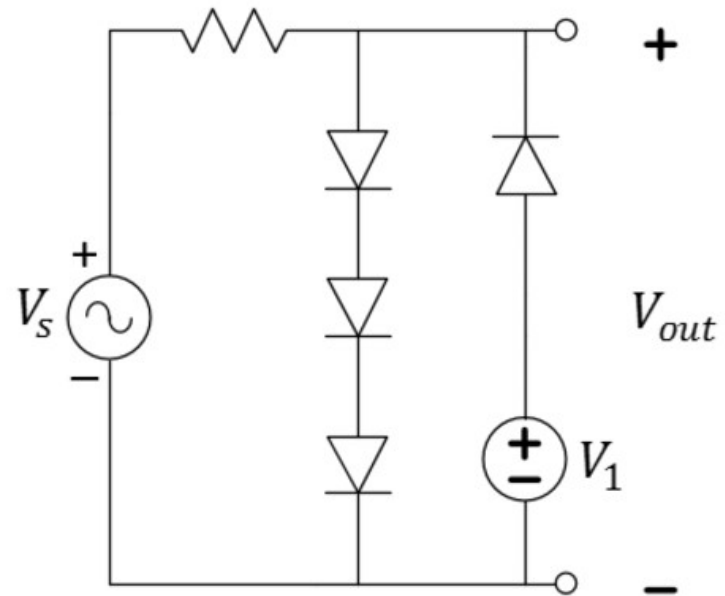
- A. 1
- B. 2
- C. 3
- D. 6
- E. Good Question.



# Diode Example – Clipper Circuit

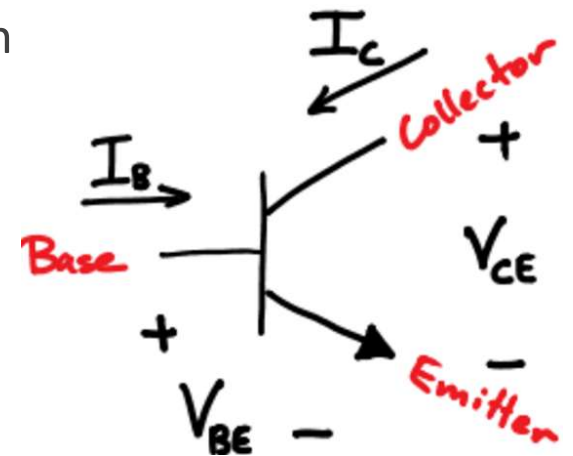
For the following clipper circuit, determine the minimum and maximum output voltages.

$V_S = 3.3 \cos(\omega t)$ ,  $V_{ON} = 0.7V$ , and  $V_1 = -0.5V$ .



# Bipolar Junction Transistor (BJT)

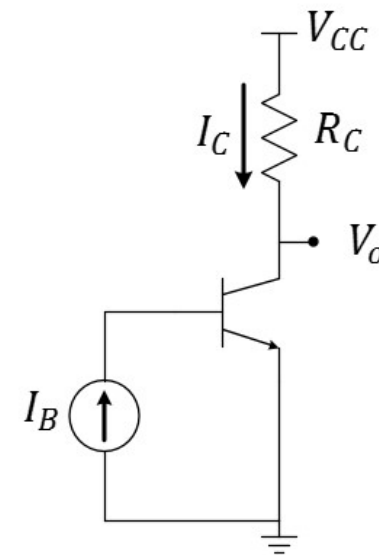
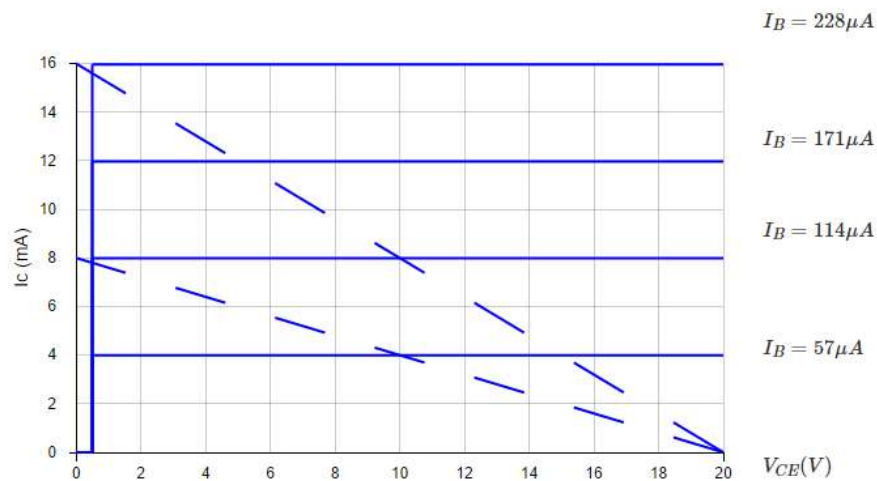
- Three terminal device: Base, collector, emitter
- $V_{BE,ON}$  and  $V_{CE,SAT}$  are properties of the BJT
- In ECE 110 we consider the Common-Emitter (CE) configuration
- Three regions of operation: Off (Cutoff), Active, Saturation
- Off:  $V_{BE} < V_{BE,ON}$ , all currents are zero!
- Active:  $V_{BE} > V_{BE,ON}$ ,  $I_C = \beta I_B$
- Saturation:  $V_{BE} > V_{BE,ON}$ ,  $V_{CE} = V_{CE,SAT}$ ,  $I_C \neq \beta I_B$ !





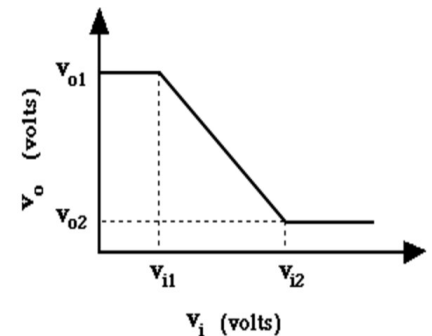
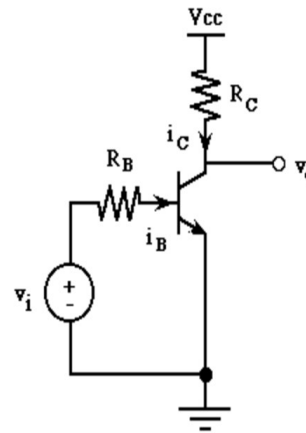
# BJT IV Characteristics

- The solid lines represent the IV characteristics of the BJT. Note that the IV characteristic depends on the bias conditions: the value of  $I_B$
- The dotted line represents the IV characteristic of the right-hand loop: the collector side



# BJT Transfer Characteristic

- The transfer characteristic of a BJT relates the output voltage,  $V_{CE} = V_o$ , to its input voltage,  $V_i$ .
- We can deduce the regions of operation and thus the important values from the graph
- $V_{o1} = V_{CC}$
- $V_{o2} = V_{CE,SAT}$
- $V_{i1} = V_{BE,ON}$
- $V_{i2} = V_i^* = \text{minimum input to enter saturation}$
- Gain =  $G = -\frac{\beta R_C}{R_B} = \text{slope in active region}$



# BJT Power

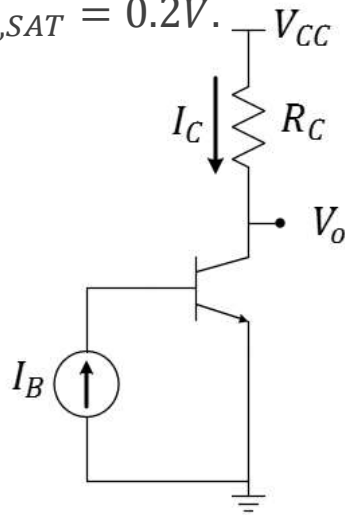
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- In order to calculate the power of a BJT, we consider the power contributed by each junction we analyze: Base-Emitter and Collector-Emitter
- $P_{BJT} = V_{BE,ON}I_B + V_{CE}I_C$
- If the BJT is off, power is zero.
- We must check to see if the transistor is in the active or saturated region as usual
- Notice that the Base-Emitter (1<sup>st</sup>) term is typically much smaller than the Collector-Emitter (2<sup>nd</sup>) term since  $I_C \gg I_B$  due to  $\beta$

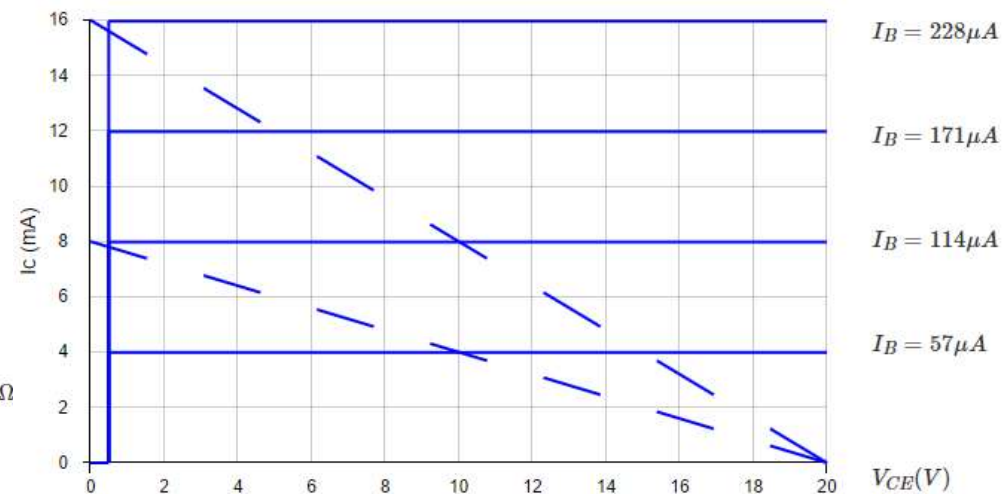
# BJT Example – IV Characteristic

Let's examine the values of  $I_C$  and  $V_o$  for different biasing currents,  $I_B$ .  $V_{CE,SAT} = 0.2V$ .

- $I_B = 57\mu A$
- $I_B = 114\mu A$
- $I_B = 228\mu A$
- What is  $\beta$ ?



$V_{CC} = 20V$   
 $R_C = 1.2500k\Omega$



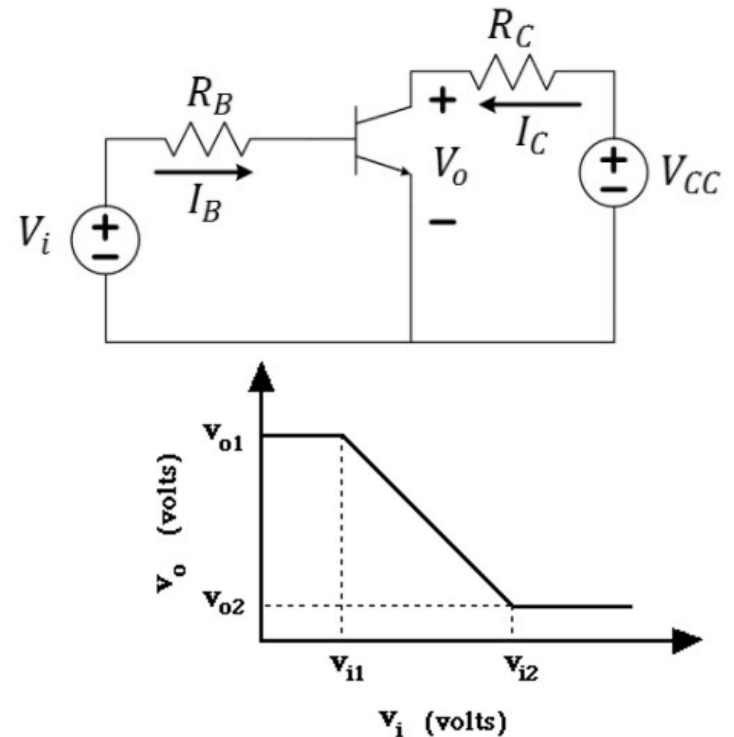
# BJT Example – Transfer Characteristic

Determine  $V_{i1}$ ,  $V_{i2}$ ,  $V_{o1}$ , and  $V_{o2}$  and the Gain for the following BJT circuit.

What is  $V_{i1}$ ?

- A. 0.7V
- B. 0.2V
- C. 9V

$$\begin{aligned}V_{CC} &= 9\text{ V} \\V_{CE,sat} &= 0.2\text{ V} \\V_{BEon} &= 0.7\text{ V} \\R_C &= 6\text{ k}\Omega \\R_B &= 12\text{ k}\Omega \\\beta &= 160\end{aligned}$$



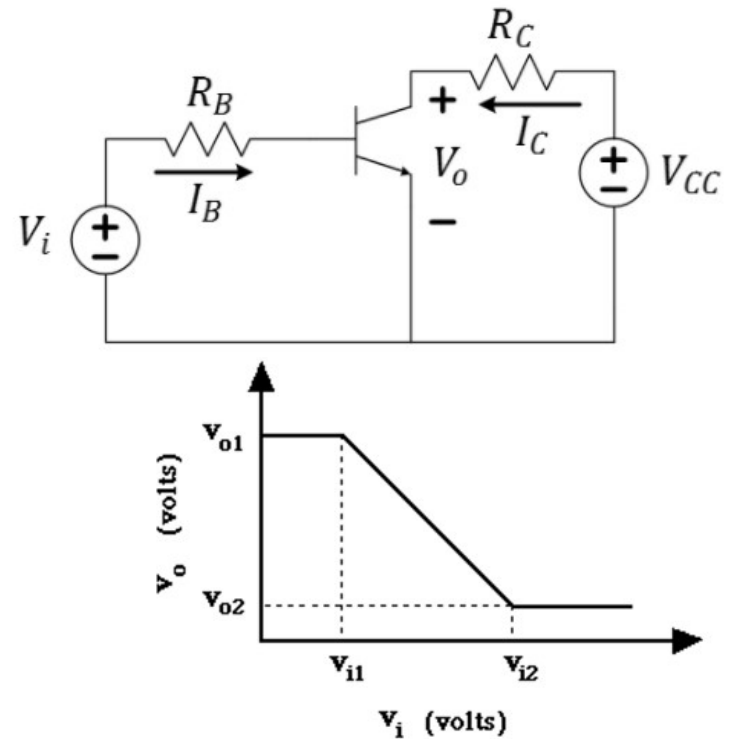
# BJT Example – Transfer Characteristic

Determine  $V_{i1}$ ,  $V_{i2}$ ,  $V_{o1}$ , and  $V_{o2}$  and the Gain for the following BJT circuit.

What is  $V_{o1}$ ?

- A. 0.7V
- B. 0.2V
- C. 9V

$$\begin{aligned}V_{CC} &= 9\text{ V} \\V_{CE,sat} &= 0.2\text{ V} \\V_{BEon} &= 0.7\text{ V} \\R_C &= 6\text{ k}\Omega \\R_B &= 12\text{ k}\Omega \\\beta &= 160\end{aligned}$$



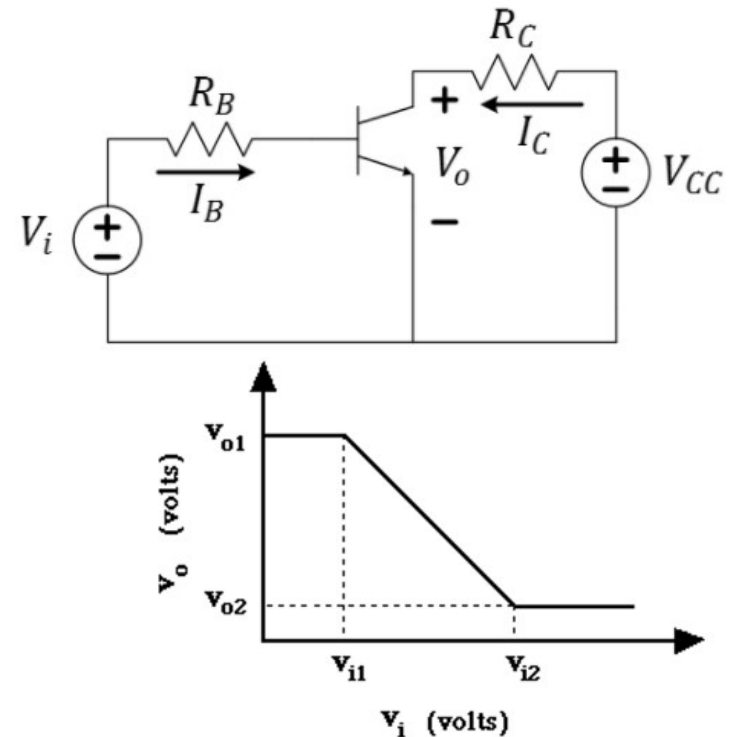
# BJT Example – Transfer Characteristic

Determine  $V_{i1}$ ,  $V_{i2}$ ,  $V_{o1}$ , and  $V_{o2}$  and the Gain for the following BJT circuit.

What is  $V_{o2}$ ?

- A.  $0.7V$
- B.  $0.2V$
- C.  $9V$

$$\begin{aligned}V_{CC} &= 9\text{ V} \\V_{CE,sat} &= 0.2\text{ V} \\V_{BEon} &= 0.7\text{ V} \\R_C &= 6\text{ k}\Omega \\R_B &= 12\text{ k}\Omega \\\beta &= 160\end{aligned}$$



# BJT Example – Transfer Characteristic

Determine  $V_{i1}$ ,  $V_{i2}$ ,  $V_{o1}$ , and  $V_{o2}$  and the Gain for the following BJT circuit.

What is  $V_{i2}$ ?

- A. 0.810V
- B. 1.111V
- C. 1.909V
- D. 2.000V
- E. True.

$$V_{CC} = 9\text{ V}$$

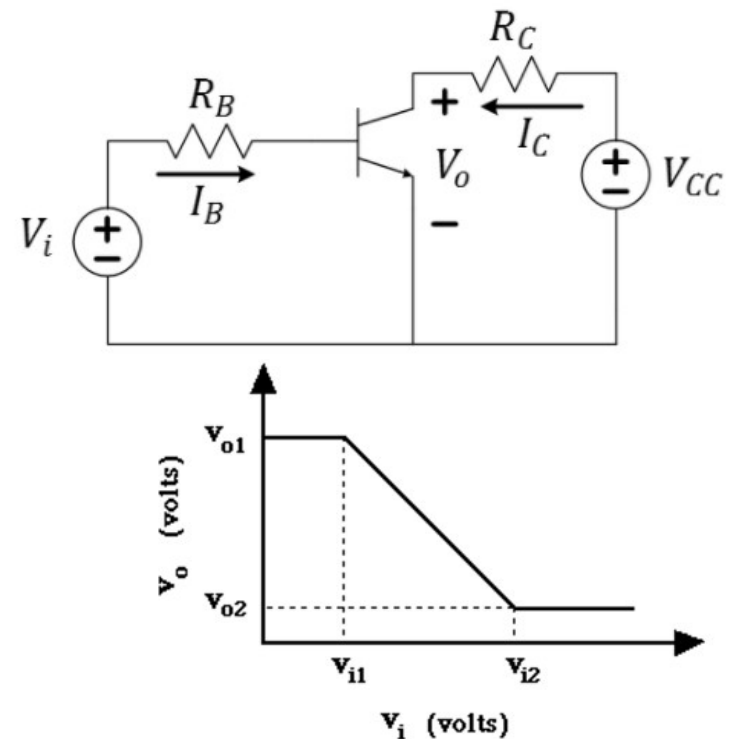
$$V_{CE,sat} = 0.2\text{ V}$$

$$V_{BEon} = 0.7\text{ V}$$

$$R_C = 6\text{ k}\Omega$$

$$R_B = 12\text{ k}\Omega$$

$$\beta = 160$$





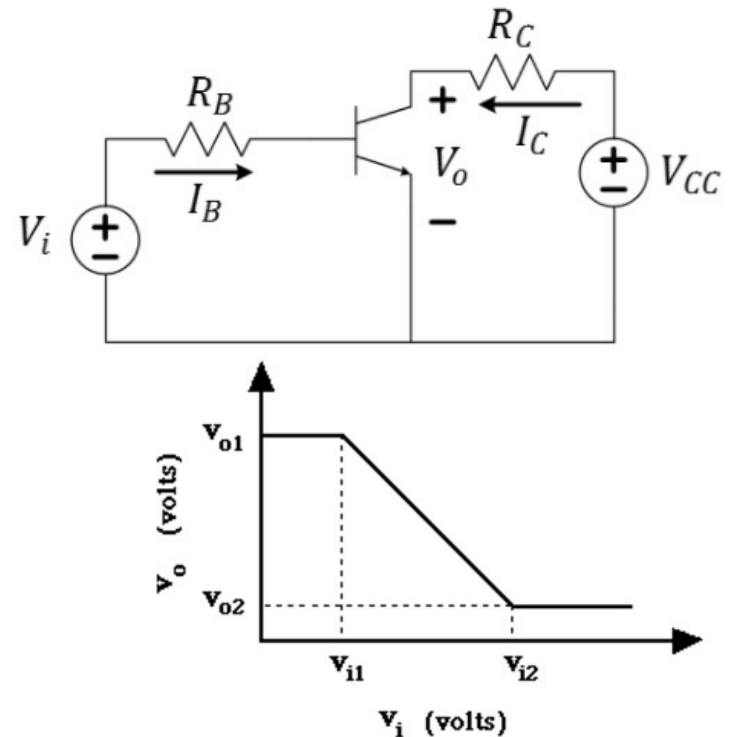
# BJT Example – Transfer Characteristic

Determine  $V_{i1}$ ,  $V_{i2}$ ,  $V_{o1}$ , and  $V_{o2}$  and the Gain for the following BJT circuit.

What is the Gain?

- A.  $-80 V/V$
- B.  $80V/V$
- C.  $\frac{-1}{80} V/V$
- D.  $\frac{1}{80} V/V$
- E. This joke is getting old.

$$\begin{aligned}V_{CC} &= 9 V \\V_{CE,sat} &= 0.2 V \\V_{BEon} &= 0.7 V \\R_C &= 6 k\Omega \\R_B &= 12 k\Omega \\\beta &= 160\end{aligned}$$



# Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET)

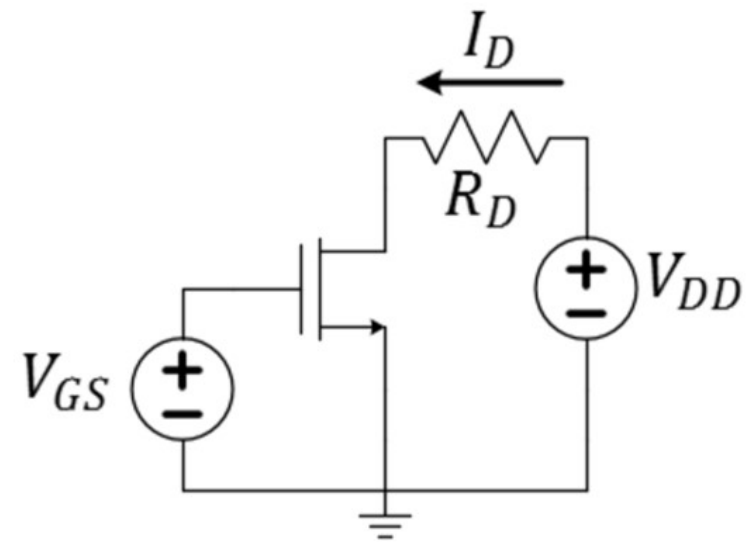
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- Three terminal device: gate, source, drain
- Comes in two flavors, NMOS and PMOS, more on this in the next slide!
- $V_{TH}$  is a property of the specific MOSFET
- Be comfortable interpreting I-V Characteristic of MOSFET

Conditions	Mode	Behavior under Linear Model
$V_{GS} < V_{TH}$	OFF	$I_D = 0$
$V_{GS} > V_{TH}$ $V_{DS} > V_{GS} - V_{TH}$	ACTIVE	$I_D = k(V_{GS} - V_{TH})^2$
$V_{GS} > V_{TH}$ $V_{DS} < V_{GS} - V_{TH}$	OHMIC	$I_D = k(V_{GS} - V_{TH})V_{DS}$

# Solving MOSFET IV Questions

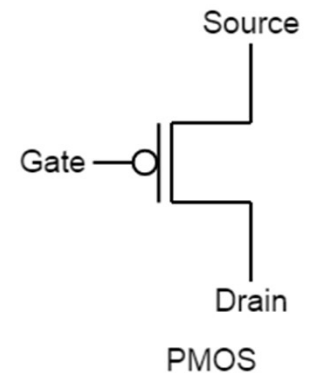
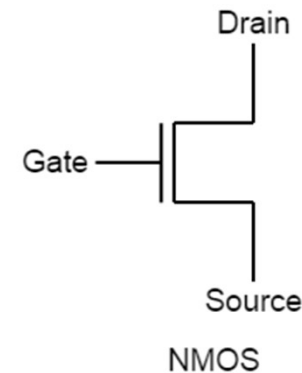
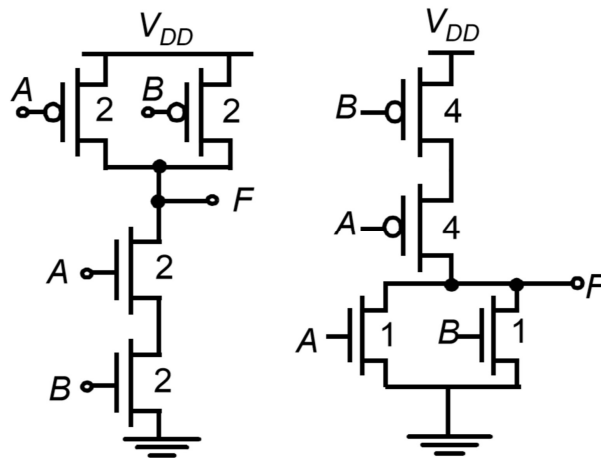
- You are frequently asked to solve for the operating point of a Common-Source MOSFET circuit. The best approach for solving is the graphical method involving the MOSFET IV characteristics.
- Notice that the right side of the circuit, including  $R_D$  and  $V_{DD}$ , represents a Thevenin equivalent!
- We can use the load-line method to plot the IV characteristics against each other to determine the operating point
- If the operating point is in the active region, the  $I_D$  should be easy to read and  $V_{DS}$  will follow by KVL.
- If the operating point is in the Ohmic region, we set the Ohmic region current equation equal to the current equation we can derive through KVL.



# Complementary MOS Logic (cMOS)

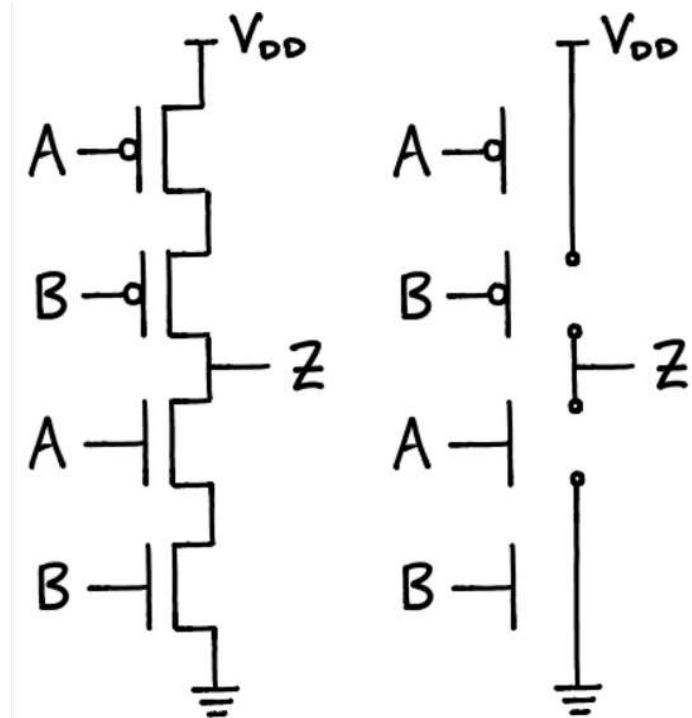
- Combine NMOS and PMOS transistors in order to perform a logical operation
  - i.e. AND, NOR, NOT
- NMOS and PMOS are biased differently
  - NMOS, source connects to ground; PMOS, source connects to  $V_{DD}$

Input (at gate)	nMOS	pMOS
0	Non-conducting	Conducting
1	Conducting	Non-conducting



# Improper CMOS

- A CMOS circuit is considered *proper* if:
  - The output can only be connected to one of  $V_{DD}$  **or** Ground at a time
- A CMOS circuit is considered *improper* if:
  - The output can be connected to both  $V_{DD}$  **and** Ground simultaneously by some input combination
  - The output can be connected to neither  $V_{DD}$  **nor** Ground simultaneously by some input combination



# CMOS Power

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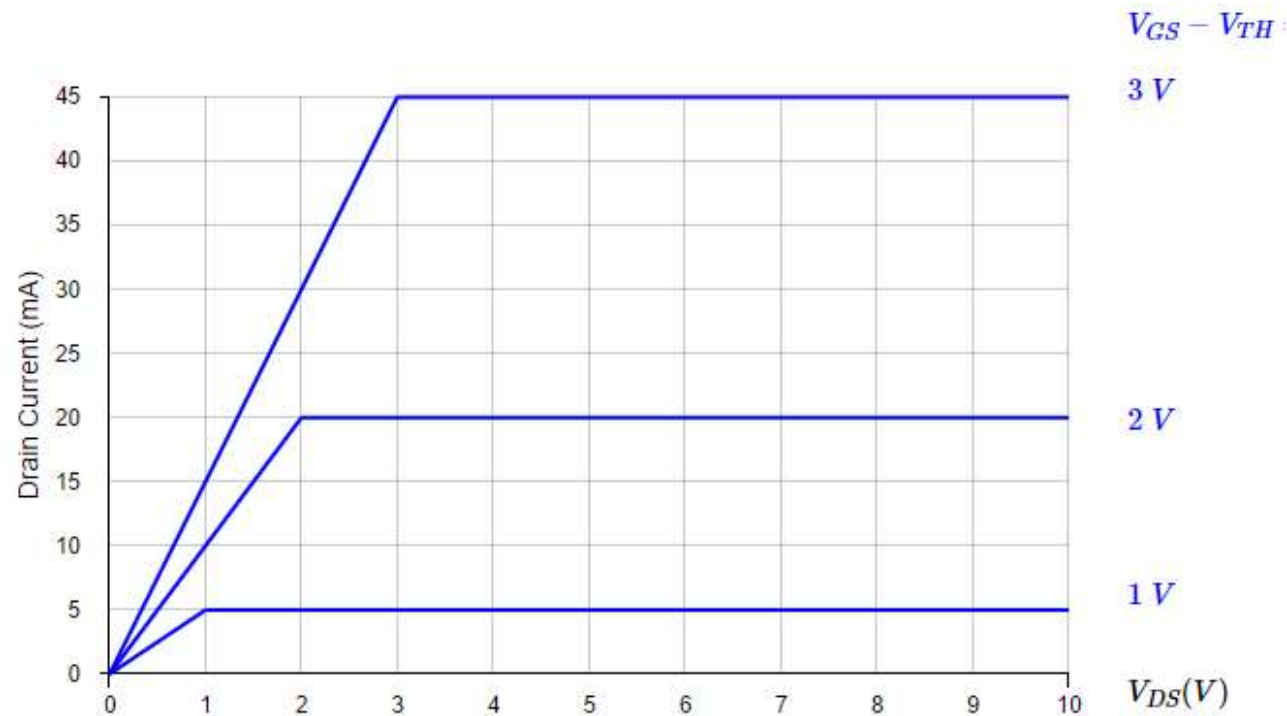
$$P = n a f C V_{DD}^2$$

- $n$  = number of capacitors/transistors
- $a$  = activity factor
- $f$  = frequency
- $C$  = capacitance
- $V_{DD}$  = supplied voltage

# MOSFET Example – IV Characteristic

The I-V Characteristic of a MOSFET is shown at right.  $V_{TH} = 1V$ ,  $R_D = 400\Omega$ ,  $V_{DD} = 6V$ , and  $V_{DS} = 1.2V$ .

- What is  $k$ ?
- What is  $V_{GS}$ ?

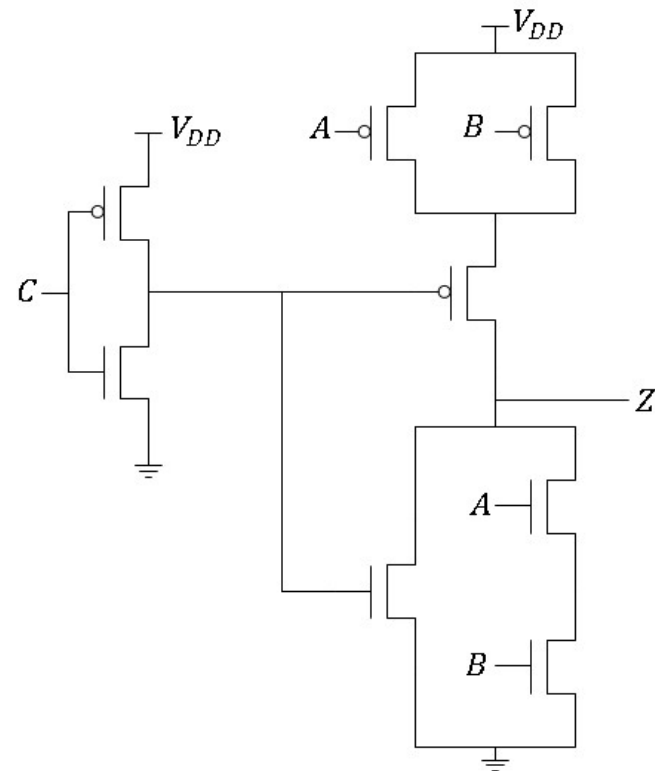


# MOSFET Example – CMOS # 1

Fill in the following truth table for the provided CMOS circuit.

**ABCZ**

000	
001	
010	
011	
100	
101	
110	
111	

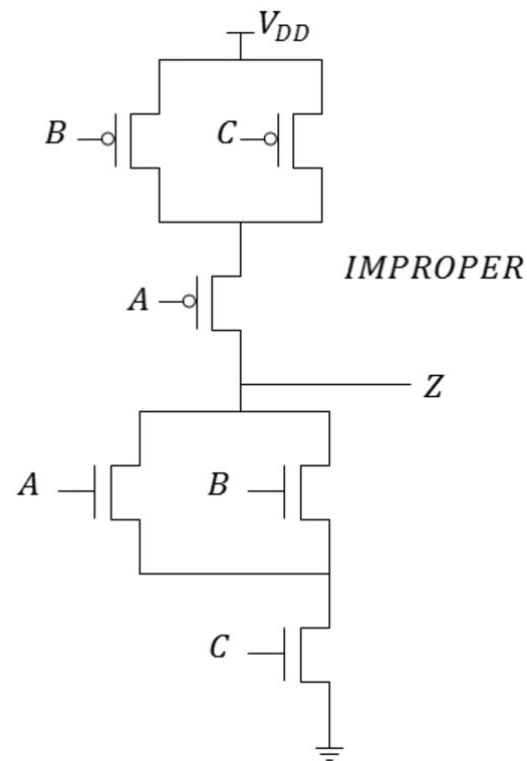




# MOSFET Example – CMOS #2

What input combination  $ABC$  will result in an improper output for  $Z$ ?

- A. 000
- B. 111
- C. 011
- D. 110
- E. 101



# Signal-to-Noise Ratio (SNR)

---

- Signal-to-Noise Ratio gives us an expression of the amount of noise distortion in a system

- $SNR = \frac{P_{signal}}{P_{noise}}$

- Remember that the average power for a time-varying signal requires  $V_{rms}$

- $P_{avg} = \frac{V_{rms}^2}{R}$

- We can also express SNR as follows

- $SNR = \frac{P_{signal}}{P_{noise}} = \frac{\frac{V_{rms,signal}^2}{R}}{\frac{V_{rms,noise}^2}{R}} = \left( \frac{V_{rms,signal}}{V_{rms,noise}} \right)^2$

# SNR Example

---

A sinusoidal signal is measured across a  $50\Omega$  resistor. If the sinusoidal signal component is given by  $s(t) = 16 \sin(\omega t) V$ , what rms noise voltage  $V_{rms,noise}$  must also be present to give a signal-to-noise ratio of 8?

- A. 2V
- B. 4V
- C. 6V
- D. 8V
- E. I'm good. Thanks.

# Sampling and Quantization

---

- When we convert from a continuous-time analog signal (function of time) to a discrete-time digital signal (function of  $n$ ), we are performing sampling, or Analog/Digital (A/D) conversion
- We relate the sampled (digital) signal to the original (analog) signal by:

$$x[n] = x(nT_s)$$

- $n$  is the index for the “nth” sample,  $T_s$  is the sampling period
- In order to retain all the information in the original signal, we must sample above the Nyquist Rate

$$f_{Nyquist} = 2f_{max}$$

# Sampling and Quantization

---

- We cannot store every single sampled value exactly since computers do not have infinite storage!
- Therefore, we must quantize our digital values to a finite set of representative values
- Each quantized level is represented by a bit pattern
  - *Number of levels =  $2^n$ ,  $n$  = number of bits*
- For example, if I know my digitized signal is bounded in the range  $[-2, 1.5]V$  and I want to quantize eight unique values, I will assign them as follows

1	1	1	= 1.5V
1	1	0	= 1.0V
1	0	1	= 0.5V
1	0	0	= 0.0V
0	1	1	= -0.5V
0	1	0	= -1.0V
0	0	1	= -1.5V
0	0	0	= -2.0V

# Quantization Example

---

What is the minimum number of bits per sample needed to digitize a 0 to 8 volt signal if the quantization error (half of the level spacing) should be less than 0.2 volts?

- A. 3
- B. 4
- C. 5
- D. 6
- E. A lot.

# Entropy

---

- Entropy represents the amount of information or uncertainty in a system.
- “Bits/symbol”
- In information theory, we refer to this as the minimum amount of information that must be retained for the signal or system to be accurately represented.
  - In other words, if we compress a signal below entropy, we cannot completely recover it upon decompression

$$Entropy = H = \sum_{i \in symbols} p_i \log_2 \left( \frac{1}{p_i} \right)$$

# Compression and Huffman Encoding

---

- *Data Compression Ratio* =  $\frac{\text{original data rate}}{\text{compressed data rate}}$
- *Savings* =  $1 - \frac{1}{DCR}$
- There are two types of compression, lossless and lossy
  - Example of lossless compression: PNG
  - Examples of lossy compression: JPEG, MPEG, mp3, mp4, H.264, HEVC/H.265,
- Huffman Encoding
  - Used for Lossless compression
  - 1. Pick two least frequent elements
  - 2. Pair these elements, pick a standard (bigger on the left or right)
  - 3. Eliminate paired elements, replace with new combined node
  - 4. Repeat 1-4 until you reach root node (sum is 1)
  - 5. Label left branches 1's, right branches 0's (technically the opposite works too, again be consistent!)



# Entropy and Compression Example

---

Consider the set of symbols  $X_1, X_2, \dots, X_5$  with probabilities  $\frac{1}{16}, \frac{1}{8}, \frac{1}{8}, \frac{3}{16}, \frac{1}{2}$ .

If we were to use the same number of bits per symbol for all symbols in this set, how many bits would we need for each symbol?

- A. 1
- B. 2
- C. 3
- D. 4
- E. I don't want to talk about it.

# Entropy and Compression Example

---

Consider the set of symbols  $X_1, X_2, \dots, X_5$  with probabilities  $\frac{1}{16}, \frac{1}{8}, \frac{1}{8}, \frac{3}{16}, \frac{1}{2}$ .

What is the entropy of this symbol set?

- A. 1.000
- B. 1.953
- C. 2.163
- D. 2.500
- E. I plead the fifth.

# Entropy and Compression Example

---

Consider the set of symbols  $X_1, X_2, \dots, X_5$  with probabilities  $\frac{1}{16}, \frac{1}{8}, \frac{1}{8}, \frac{3}{16}, \frac{1}{2}$ .

What is the maximum possible compression ratio for this system and the corresponding savings?

# Huffman Coding Example

---

Suppose we have a collection of symbols with the following frequencies.

- A = 14
- B = 7
- C = 6
- D = 4
- E = 3
- F = 2

Form the corresponding Huffman Tree and Huffman Code

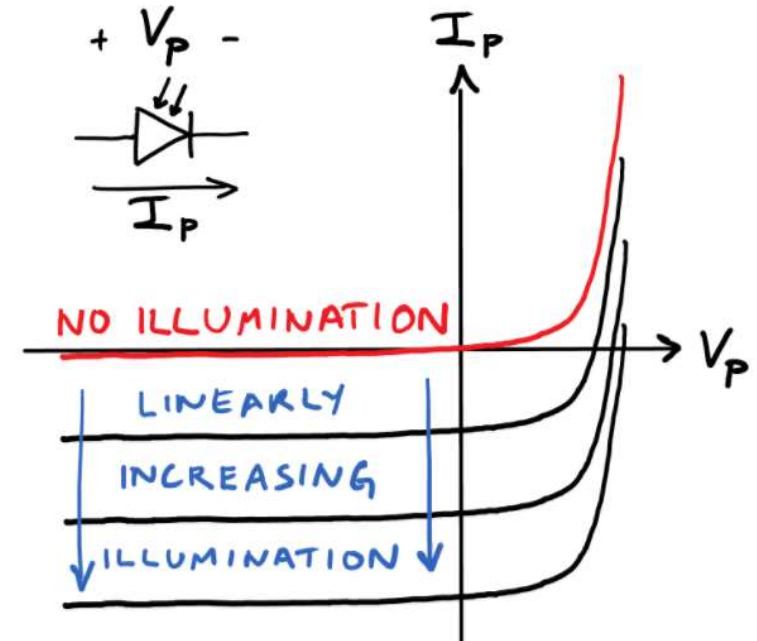
# Solar Cells and Photodiodes

- Solar cells are used to turn solar energy into electrical energy
- You are not expected to understand the underlying device physics. Instead, understand the following relations

$$E_{\text{photon}}[\text{eV}] = \frac{1240}{\lambda [\text{nm}]}$$

$$\text{Photon Emission Rate} = \frac{\text{Output Power}}{E_{\text{photon}}}$$

- Photons are absorbed only if their energy is greater than or equal to the bandgap energy
- Photodiodes have different  $V_{oc}$  and  $I_{sc}$  for different levels of illumination
  - $P_{\text{max}} = \text{FillFactor} * I_{sc} V_{oc}$



# Photodiode Example

---

We have three identical and equally illuminated photodiodes each with  $V_{oc} = 4V$  and  $I_{sc} = 1A$

If we were to connect these photodiodes together in series, what would be the new  $V_{oc}$  and  $I_{sc}$  of the resulting combination?

- A.  $V_{oc} = 4V, I_{sc} = 3A$
- B.  $V_{oc} = 4V, I_{sc} = 1A$
- C.  $V_{oc} = 12V, I_{sc} = 3A$
- D.  $V_{oc} = 12V, I_{sc} = 1A$
- E. Sorry, I was looking at my phone. What's up?

# Photodiode Example

---

We have three identical and equally illuminated photodiodes each with  $V_{oc} = 4V$  and  $I_{sc} = 1A$

If we were to connect these photodiodes together in parallel, what would be the new  $V_{oc}$  and  $I_{sc}$  of the resulting combination?

- A.  $V_{oc} = 4V, I_{sc} = 3A$
- B.  $V_{oc} = 4V, I_{sc} = 1A$
- C.  $V_{oc} = 12V, I_{sc} = 3A$
- D.  $V_{oc} = 12V, I_{sc} = 1A$
- E. Are we almost done?