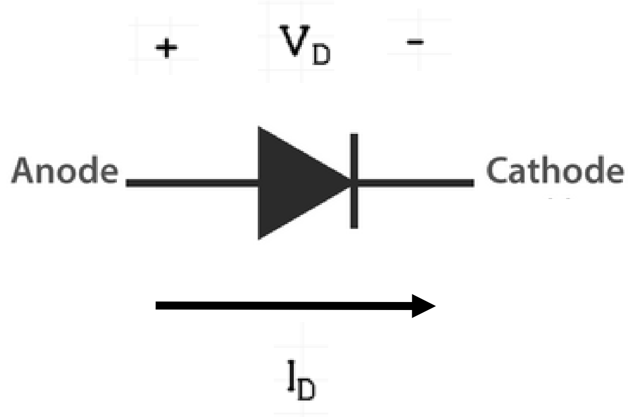
Mini-Project Description – EECE 211, Fall 2022

Make sure that you have read the "Mini-Project Information" document

The circuit symbol for a diode (with its terminals labeled) is shown below.



Analogous to a resistor, a diode is a two-terminal device (component). Unlike a resistor, it allows current to flow through it **ONLY** in one direction ("from" anode "to" cathode). When the voltage $\mathbf{V_D}$ is positive, there is positive current "flowing" from anode to cathode. When the voltage $\mathbf{V_D}$ is negative, there is negligible current flowing through the diode and it can be treated as an open circuit.

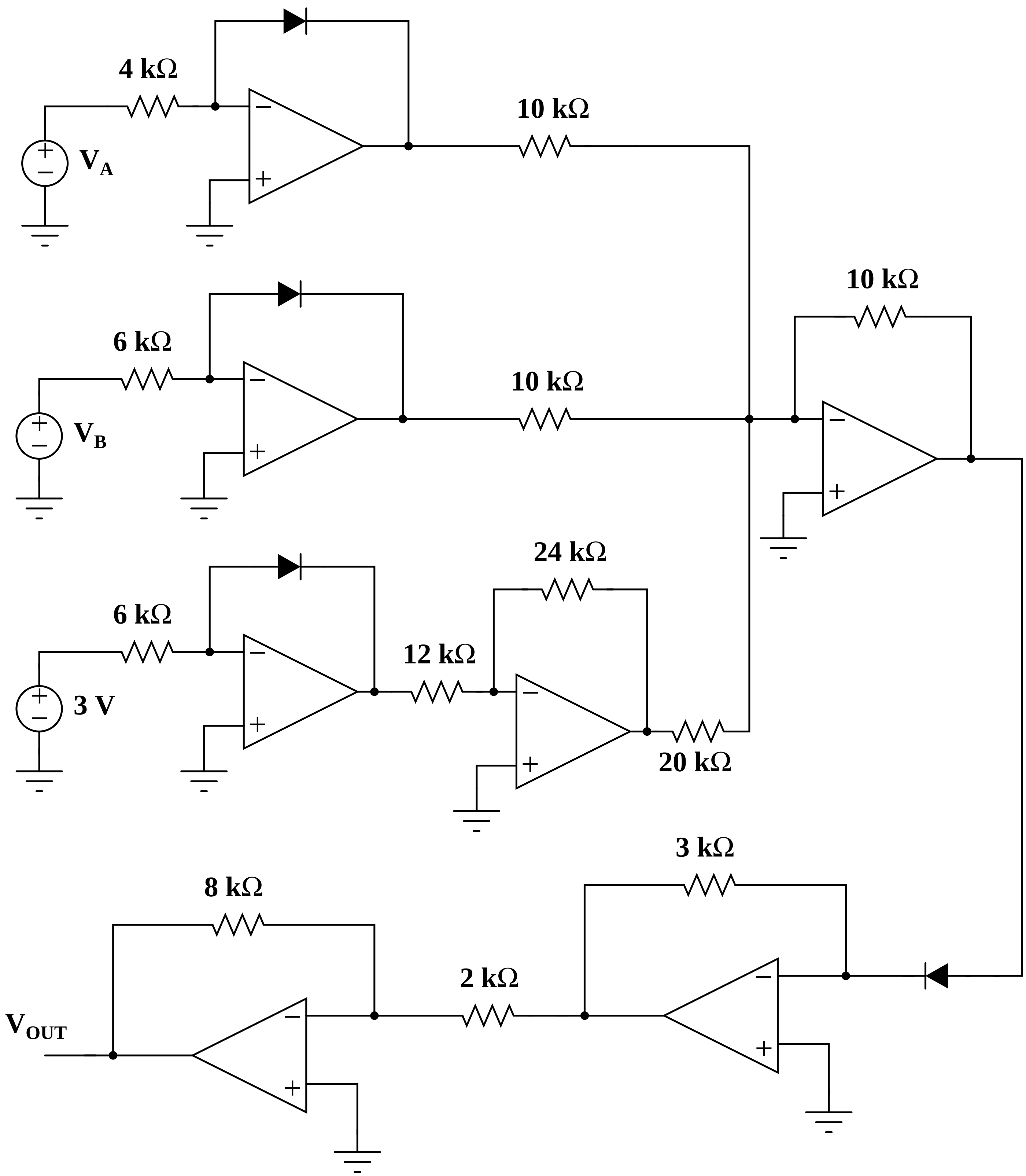
Due to the internal semiconductor physics of a diode, the quantitative relationship between $\mathbf{I_D}$ and $\mathbf{V_D}$ (when $\mathbf{V_D}$ is positive) is **exponential**. More specifically,

$$I_D = I_S \cdot e^{\frac{V_D}{V_T}} \qquad \textit{[EQN 1]}$$

, where $\mathbf{I_S}$ and $\mathbf{V_T}$ are constants associated with the diode (analogous to the resistance of a resistor)

It turns out that diodes can be used for various circuits-related applications. One application is the realization of an **analog multiplier**.

The circuit on the next page depicts a two-input analog multiplier, where the inputs of the multiplier are the voltages $\mathbf{V_A}$ and $\mathbf{V_B}$.


4 kΩ
10 kΩ
V_A
6 kΩ
10 kΩ
V_B
10 kΩ
24 kΩ
6 kΩ
12 kΩ
3 V
20 kΩ
3 kΩ
8 kΩ
2 kΩ
V_OUT

Task I

Using KCL, KVL, Ohm's Law, opamp rules, and/or [EQN 1], derive the relationship between V_{OUT} and the input voltages V_A & V_B

Make the following assumptions:

- V_A and V_B are each positive-valued voltages
- All four diodes are physically "identical" (that is, their I_S parameters all have the same value; likewise, their V_T parameters all have the same value)

In case it is helpful, some logarithm identities can be found on the next page (taken from online resource).

Task II

Use LTSPICE to perform a transient-simulation of the circuit and to verify the relationship found in Task I.

Appropriate **SUBCKT** definitions for an opamp and diode have been posted to BBL. For the input voltages V_A and V_B , use the **PWL** definitions posted to BBL. Note that V_A and V_B have been defined in such a way that they are each positive-valued at all times (per the assumption in Task I).

In case it is helpful, some information about PWL syntax can be found on the next page (taken from an online resource). Feel free to search online for additional syntax information and/or post questions on Slack

Task III

The two-input analog multiplier circuit depicted on the previous page works as intended when V_A and V_B are each positive-valued voltages. The circuit "fails" when either one of these input voltages becomes negative-valued. **Explain/describe why this is the case**.

Make appropriate adjustments and/or additions to the circuit so that it works as a two-input analog multiplier irrespective of the "sign" of V_A and/or V_B. That is, both inputs can be positive, both inputs can be negative, or one input can be positive while the other negative. Explain the thought process behind your design. Verify your design with appropriate LTSPICE transient-simulation(s).

In making your adjustments and/or additions, you have access to an unlimited supply of opamps, unlimited supply of identical diodes, and an unlimited supply of resistors (whose values you can specify).

Hint: You may find it easier to first focus on making appropriate adjustments and/or additions to handle the situation of V_A and V_B **both** being positive or negative. Afterward, you can use the lessons/observations learned to handle the remaining situations.

Useful logarithm identities

Note: we assume here that in all cases, variables are non-zero.

1. **Log of a product**

   Rule:

   $$\log_b(x \cdot y) = \log_b(x) + \log_b(y)$$

   Example:

   $$\log_2(4 \cdot 8) = \log_2(32) = 5 = 2 + 3 = \log_2(4) + \log_2(8)$$

2. **Log of a fraction**

   Rule:

   $$\log_b\left(\frac{x}{y}\right) = \log_b(x) - \log_b(y)$$

   Example:

   $$\log_2\left(\frac{32}{4}\right) = \log_2(8) = 3 = 5 - 2 = \log_2(32) - \log_2(4)$$

3. **Log of a power**

   Rule:

   $$\log_b(x^y) = y \cdot \log_b(x)$$

   Example:

   $$\log_2(4^3) = \log_2(64) = 6 = 3 \cdot 2 = 3 \cdot \log_2(4)$$

4. **Power of a log**

   Rule:

   $$x^{\log_b(y)} = y^{\log_b(x)}$$

   Example:

   $$4^{\log_2(8)} = 4^3 = 4 \cdot 4 \cdot 4 = 8 \cdot 8 = 8^2 = 8^{\log_2(4)}$$

5. **Change of base**

   Rule:

   $$\log_b(x) = \frac{\log_d(x)}{\log_d(b)}$$

   Example:

   $$\log_2(9) = 3.16992... = \frac{\log_3(9)}{\log_3(2)}$$

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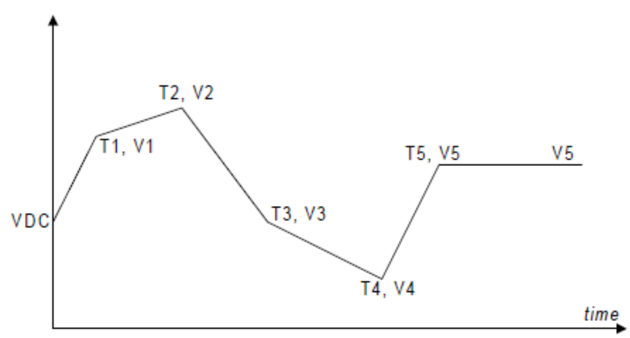
4. Piecewise linear waveforms

Format: **PWL**(T1 V1 [Tn Vn] ...)

Examples: V5 3 7 **PWL**(0 -7V 5us -7V 6us 5V 20us 5V 21us -7V 30us -8V)
V3 4 2 **PWL**(5ms 5V 20ms 5V 30ms 0V)

Parameters	*Meaning*	*Default*	*Units*
Tn	Time at corner	-	s
Vn	Voltage at corner	-	V

Each pair of values (**Tn**, **Vn**) specifies the value of the source **Vn** ([in V) at *time*=**Tn**. The value of the source at intermediate values of time is determined by using linear interpolation of the input values.

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Piece-Wise Linear

General Form:
     PWL(T1 V1 <T2; V2 T3 V3 T4 V4 ...>)

Examples:
     VCLOCK 7 5 PWL(0 -7 10NS -7 11NS -3 17NS -3 18NS -7 50NS -7)

Each pair of values (Ti, Vi) specifies that the value of the source is Vi (in Volts or Amps) at time=Ti. The value of the source at intermediate values of time is determined by using linear interpolation on the input values.
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