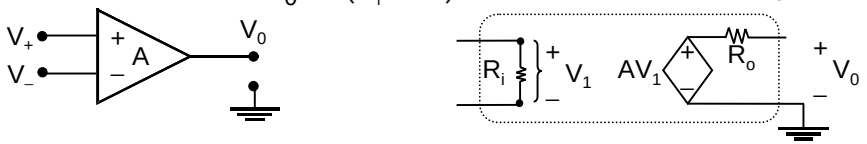
## OPERATIONAL AMPLIFIERS: REVIEW

- We use differential amplifiers with **feedback** (output and input connected) to perform mathematical operations
- We also use amplifiers to provide predictable voltage and additional current to output "loads"
- We can analyze amplifier circuits using the circuit model

Differential Amplifier $V_0 = A(V_+ - V_-)$ Circuit Model *in linear region*




- Or, we can analyze using the simpler "ideal" assumptions
- We can design an amplifier to perform a certain operation by choosing the right form and then choosing resistor values



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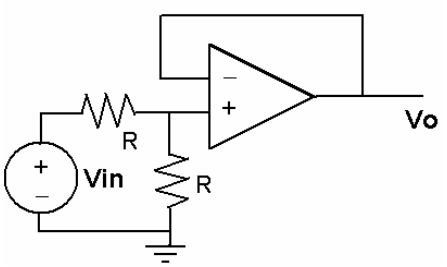
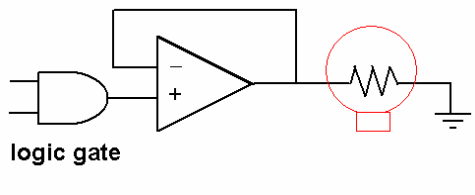
## OPERATIONAL AMPLIFIER: USES




Vo is Vin/2 **regardless** of what is attached to output.

Not true without voltage follower!




Output of logic gate will turn light bulb on or off.

Light bulb connected directly to logic gate may draw too much current from logic gate!

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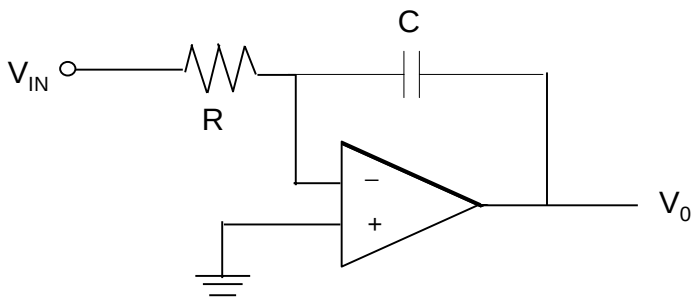
# INTEGRATING AMPLIFIER




$$V_0(t) = -\frac{1}{RC}\int_0^t V_{IN}(T)dT + V_C(0)$$

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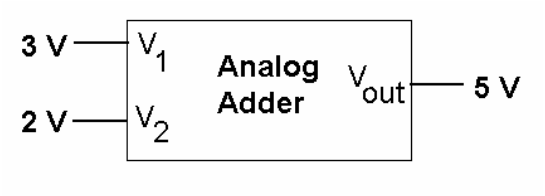
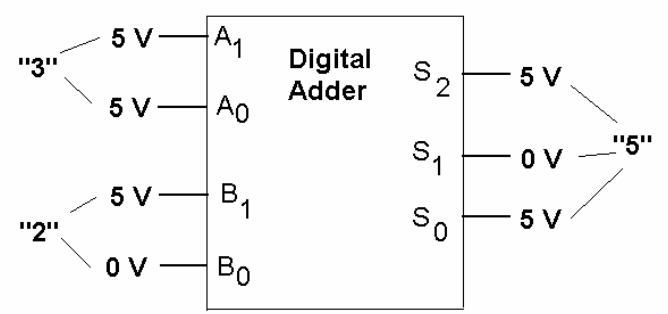
# ANALOG VS. DIGITAL

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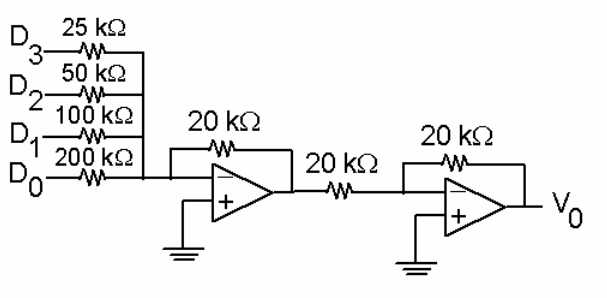
# D/A CONVERSION

Example: Digital sound (CD) to analog (speaker)

Let's have each "1" on the CD translate to 0.5 V at the speaker.




| Binary number | Analog output (volts) |
|---|---|
| 0 0 0 0 | 0 |
| 0 0 0 1 | 0.5 |
| 0 0 1 0 | 1 |
| 0 0 1 1 | 1.5 |
| 0 1 0 0 | 2 |
| 0 1 0 1 | 2.5 |
| 0 1 1 0 | 3 |
| 0 1 1 1 | 3.5 |
| 1 0 0 0 | 4 |
| 1 0 0 1 | 4.5 |
| 1 0 1 0 | 5 |
| 1 0 1 1 | 5.5 |
| 1 1 0 0 | 6 |
| 1 1 0 1 | 6.5 |
| 1 1 1 0 | 7 |
| 1 1 1 1 | 7.5 |

MSB LSB

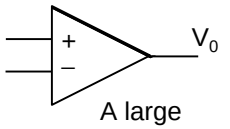
Another way is to sum **charges** instead of current with capacitor networks

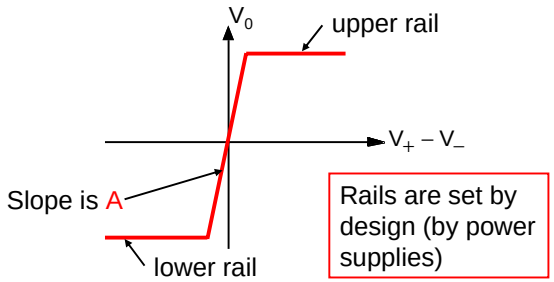




# COMPARATORS

Using differential amplifier without feedback:




Rails are set by design (by power supplies)

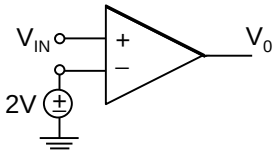
If $V_+ > V_-$, the output Vo will be at the upper rail.
If $V_+ < V_-$, the output Vo will be at the lower rail.

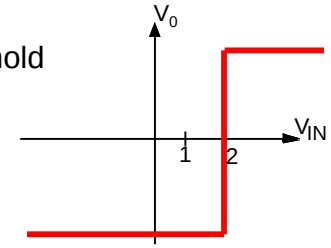
UNLESS…

$V_+$ is very close to $V_-$, such that $A(V_+ - V_-)$ is between the rails.

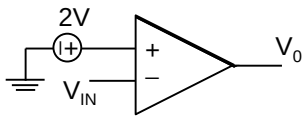
# COMPARATORS

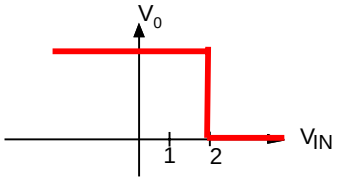
Comparator with 2V threshold



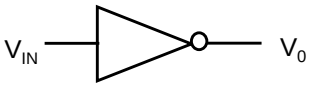




Comparator transfer curve




Inverter transfer curve



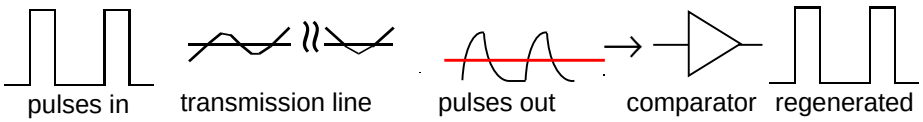

Symbol

To function as logic gate, set upper rail to logic 1 and lower rail to logic 0.





# ONE-BIT A/D CONVERSION IN DIGITAL SYSTEMS




Set comparator threshold at a suitable value (border between logic 0 and logic 1)

Comparator output goes to +rail (logic 1) if

$V_{IN} > V_{THRESHOLD}$

and to –rail (logic 0) if

$V_{IN} < V_{THRESHOLD}$.