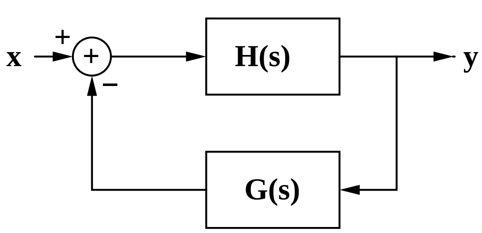
# Motors and Position Determination



## Controlling Position

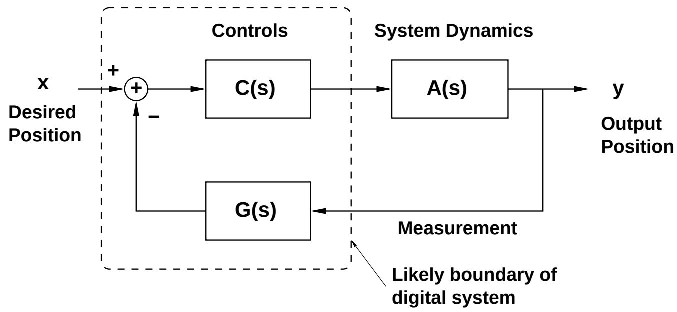
- Feedback is used to control position.
  - Measure the position, subtract a function of it from the desired position and then use this resulting signal to drive the system towards the desired position. This is negative feedback.
  - The natural frequencies of the feedback system are the “zeros” of 1 + G(s)H(s).
    - The total system is unstable if these “zeros” are in the right half plane (RHP). With 180 degrees phase shift, “negative” feedback becomes “positive” feedback.
    - So we want these “zeros” to be in the left half plane (LHP).
    - Putting an integrator into H(s) drives steady state error to zero.
    - But high order systems are more likely to have RHP zeros.
    - Time delay and high gain lead to RHP zeros.




$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1 + G(s)\,H(s)}$$

# Servos

- We can control  parts of the servo, but the system dynamics is  often a part we can't control.
  - The system dynamics results from masses. springs, losses, etc.
- Likely, we will implement servos as digital systems.
  - Digital systems are more flexible to design.
    - They are more repeatable; they are not subject to gain drift.
    - We can use as many bits as we like so we can keep the computation noise small.
  - Digital systems can have significant delays.
    - These delays are sometimes fixed, but are sometimes stochastic.






# Analog Position Measurements

Voltage is proportional to position.

A linear or rotary potentiometer can be used.

Accuracy is limited to that of the potentiometer and the noise of the power supply voltage.

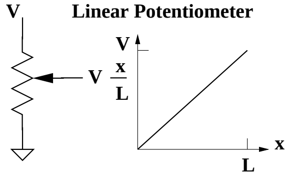
Two sinusoidal potentiometers are used.

V1 = V0 cos (theta)
V2 = V0 sin (theta)

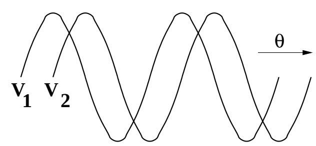
This can also be done magnetically.

This is called a resolver and requires a complex analog signal detection. The computation can be done with either analog or digital circuitry.

Position Sensing: Analog

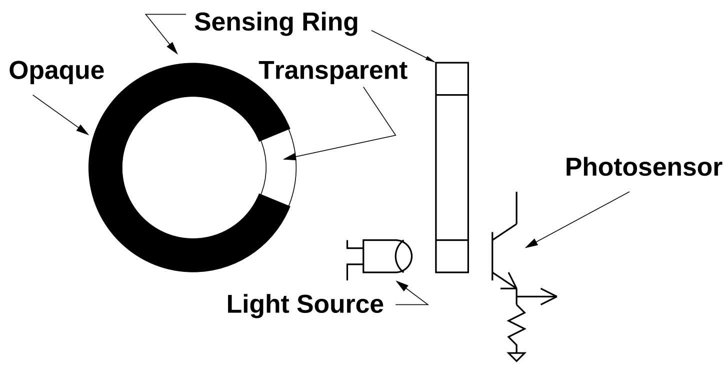



Sinusoidal Potentiometer



# Digital Position Measurement

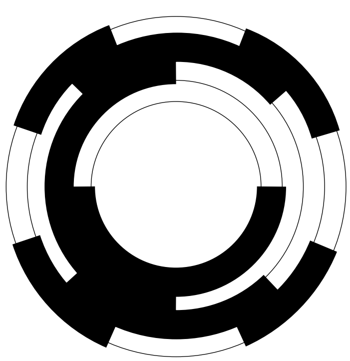
- Sense light transmission to determine position.
  - Typically through a transparent sector
  - Gives a reading over a range of positions.
    - Depends on extent of transparent sector.
  - One may need a lot of sensors to determine multiple positions.






# Digital Absolute Position

- Typically, this is used for relatively low resolutions.



**Here is a 4−bit (22.5 degree) resolution wheel.**
**One source per sensor bit**

**Can make these wider. Resolution is**

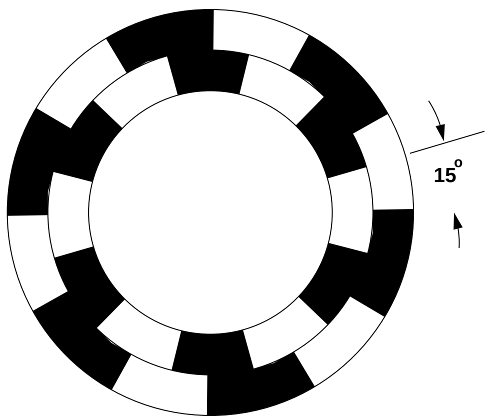
$$\frac{360^{o}}{2^{N}}$$

**Use a Gray Code to eliminate chatter.**

| | | | |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 |
| 0 | 0 | 1 | 1 |
| 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 0 |
| 0 | 1 | 1 | 1 |
| 0 | 1 | 0 | 1 |
| 0 | 1 | 0 | 0 |
| 1 | 1 | 0 | 0 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 0 |
| 1 | 0 | 1 | 0 |
| 1 | 0 | 1 | 1 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 0 | 0 |

# Two-Phase Encoder

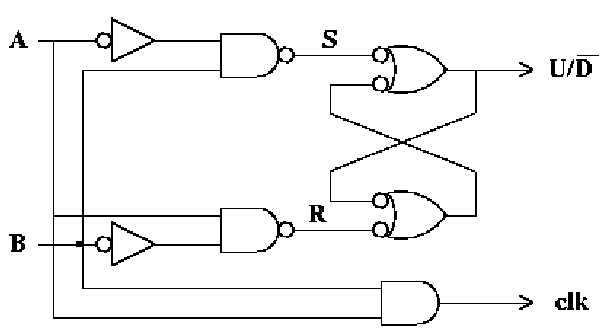
- Two Source – Sensor Sets
  - Their position is offset by half the sector width.
  - This example has 30 degree sectors
  - and 15 degree resolution.

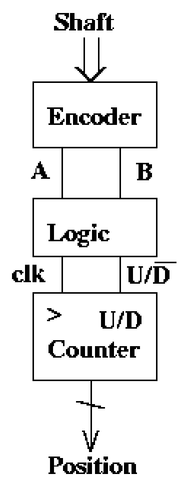





# Use of Two-Phase Encoder

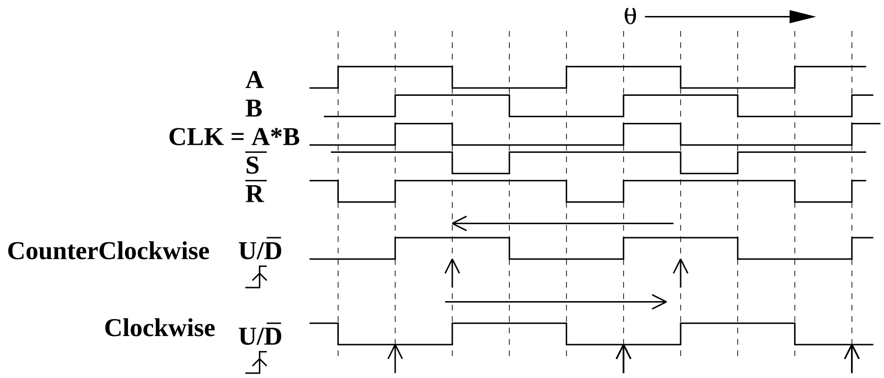
- This circuit generates:
  - An Up/Down signal depending on whether the motion is clockwise (CW) or counterclockwise (CCW).
  - A clk signal which rising edge is to operate the counter.



# Waveforms

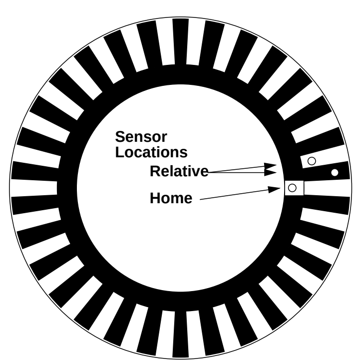
- A and B are signals derived from sensors.
- Rotating one way, the rising edge of clk is when U/D is high.
- Rotating the other way, the rising edge of clk is when U/D is low.





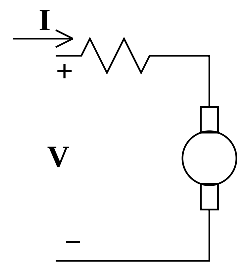

# Another Way of Making an Encoder

- Use two sensors like the two-phase encoder but use only one ring and displace the sensors by ½ band.
- Add another ring and a sensor to sense the "home" position.



# Motors

- Simple servomechanisms are made with DC motors.
  - DC motor model is very simple:
    - It consists of a resistor in series with a voltage source.
    - The voltage source is proportional to the rotational speed.
  - The mechanical system (controlled system) determines the speed as influenced by the torque.



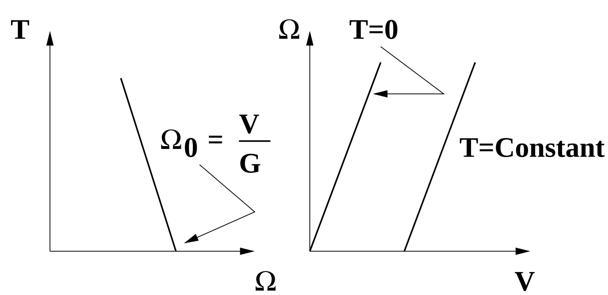

$$V = G\Omega + RI$$

$$\text{Torque } T = GI$$



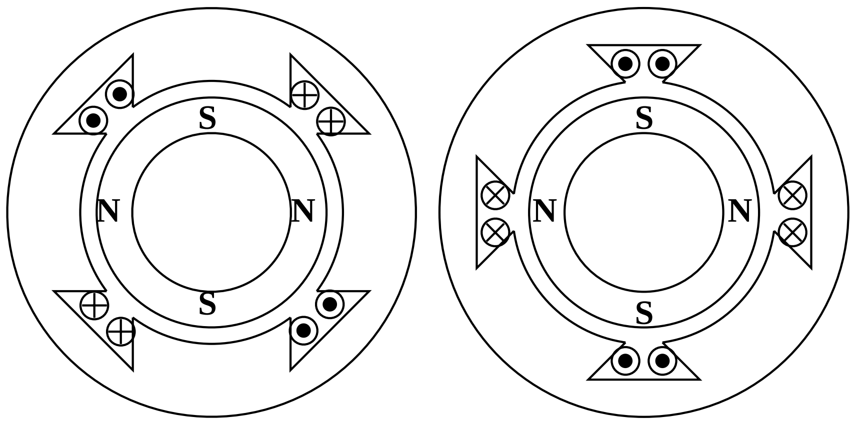
# Permanent Magnet DC Motors

- They are very commonly used.
  - The ‘Back Voltage’ is proportional to speed.
  - The torque is proportional to the current.
- Servo Strategy:
  - Command torque by setting current.
  - Measure the speed.
- Running open loop:
  - There is a ‘zero torque’ speed.
  - Torque is proportional to the difference from that speed.



# Stepper Motors

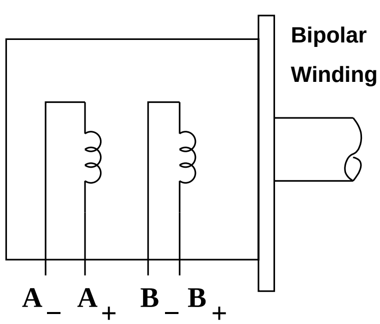
- Digital Motors
  - Two ‘stacks’ (phases)
  - Usually biased by permanent magnets
  - Move a discrete distance per ‘step’.
  - This is an axial view cut through both of two sections.

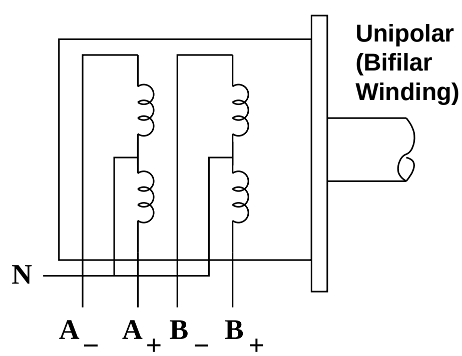





# Stepper Motor Windings

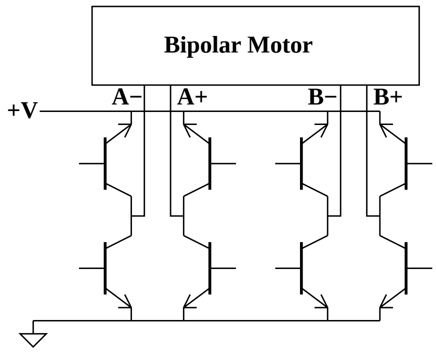
- Two distinct ‘phases’
  - May be driven as distinct windings.
  - Or may be driven as ‘bifilar’ windings.
  - Bifilar is easier but less efficient.

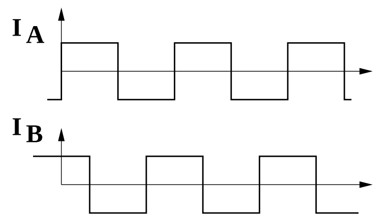


# Bipolar Winding

- Driven by 'H-bridges' of transistors
  - Can put current through windings in either direction.
  - But note that the upper transistor drive is tricky.
  - Uses all of the winding.



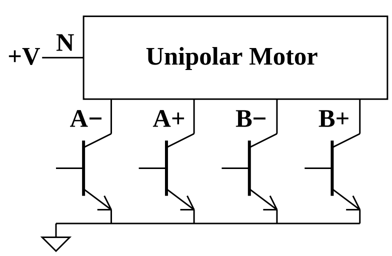



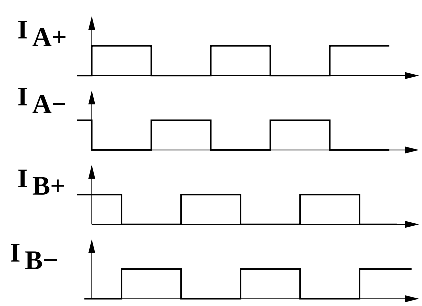



# Bifilar Winding

- Driven by four transistors to ground.
  - Note that the center of the windings is held high.

  - Transistors are between winding and ground.
  - NPN bipolar transistors work well.
  - Transistor drives are easily handled.



## Motors Run in Either Direction

- Current drive strategy:

**Bipolar Winding**

| Step | $I_A$ | $I_B$ |
|---|---|---|
| 1 | + | + |
| 2 | + | − |
| 3 | − | − |
| 4 | − | + |

Clockwise ↓ Counter−Clockwise ↑

**Bifilar Winding**

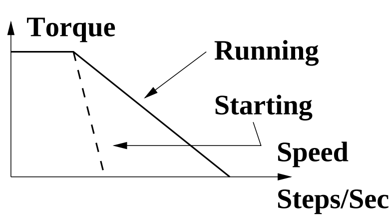
| Step | $I_{A+}$ | $I_{A-}$ | $I_{B+}$ | $I_{B-}$ |
|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 |
| 2 | 1 | 0 | 0 | 1 |
| 3 | 0 | 1 | 0 | 1 |
| 4 | 0 | 1 | 1 | 0 |

Clockwise ↓ Counter−Clockwise ↑



## Dynamics are Important

- Stepper can hold a certain torque.
- Stepper can carry more torque at low speed.
- At high speed, torque must be de-rated.
- Motors draw CURRENT! Make sure your power supply is adequate by measuring the power supply voltage with a ‘scope.
  - Use an external supply, not the kit supply.
    - You don’t want motor drive noise in your digital circuit (or analog circuit).
- You need to make sure that devices can handle the current and torque.




**Must sometimes ‘ramp up’ speed. Holding torque is limited by heating and by saturation.**