Introduction to Stepper Motors

Part 1: Types of Stepper Motors

 Introduction to Stepper Motors Slide 1

Hello, my name is Marc McComb, I am a Technical Training Engineer here at Microchip Technology in the Security, Microcontroller and Technology Division. Thank you for downloading Introduction to Stepper Motors. This is Part 1 in a series of webseminars related to Stepper Motor Fundamentals. The following webseminar will focus on some of the stepper motors available for your applications. So let's begin.

Agenda

- **Topics discussed in this WebSeminar:**
  - **Main components of a stepper motor**
  - **How do these components work together**
  - **Types of stepper motors**

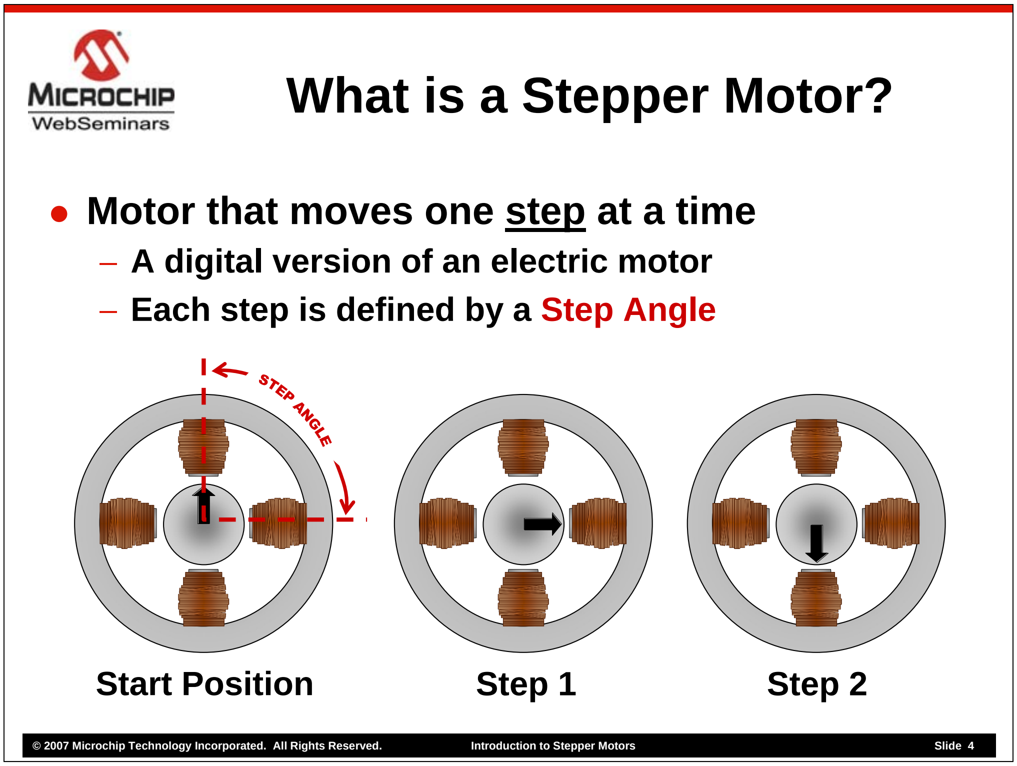
 Introduction to Stepper Motors Slide 2

During this webseminar I will discuss the main components of a stepper motor and how these components work together to actually turn the rotor. We will also explore three types of stepping motors as well as two sub categories.

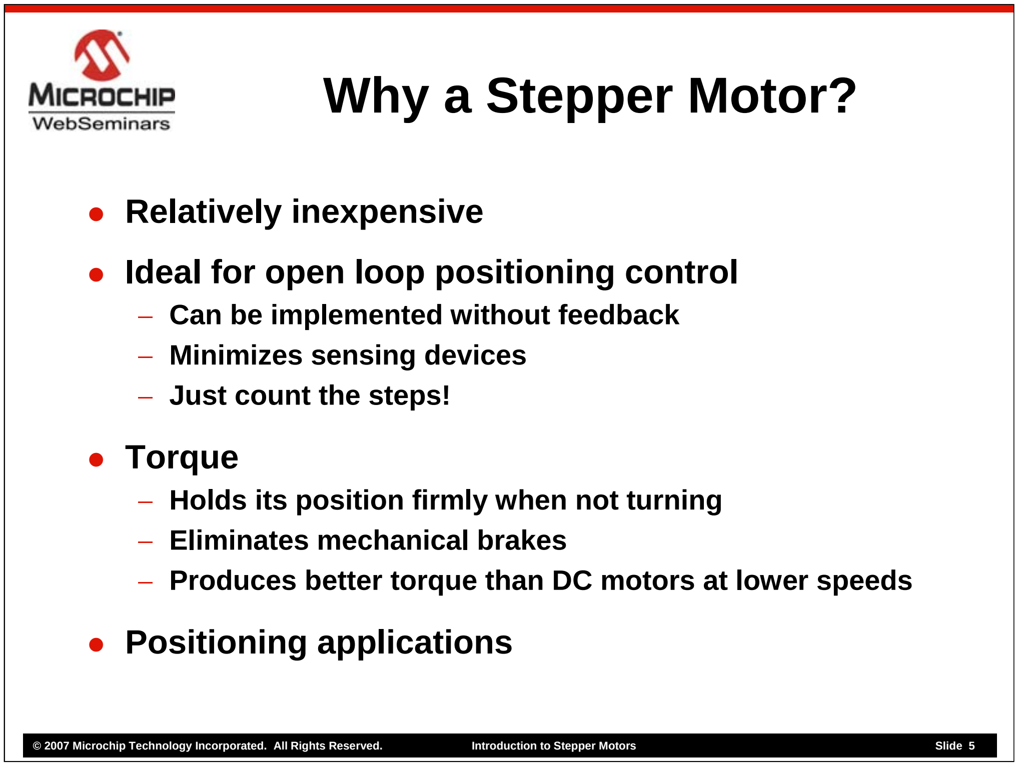
Stepper Motor Basics

 Introduction to Stepper Motors Slide 3

So let's start off with some stepper motor basics



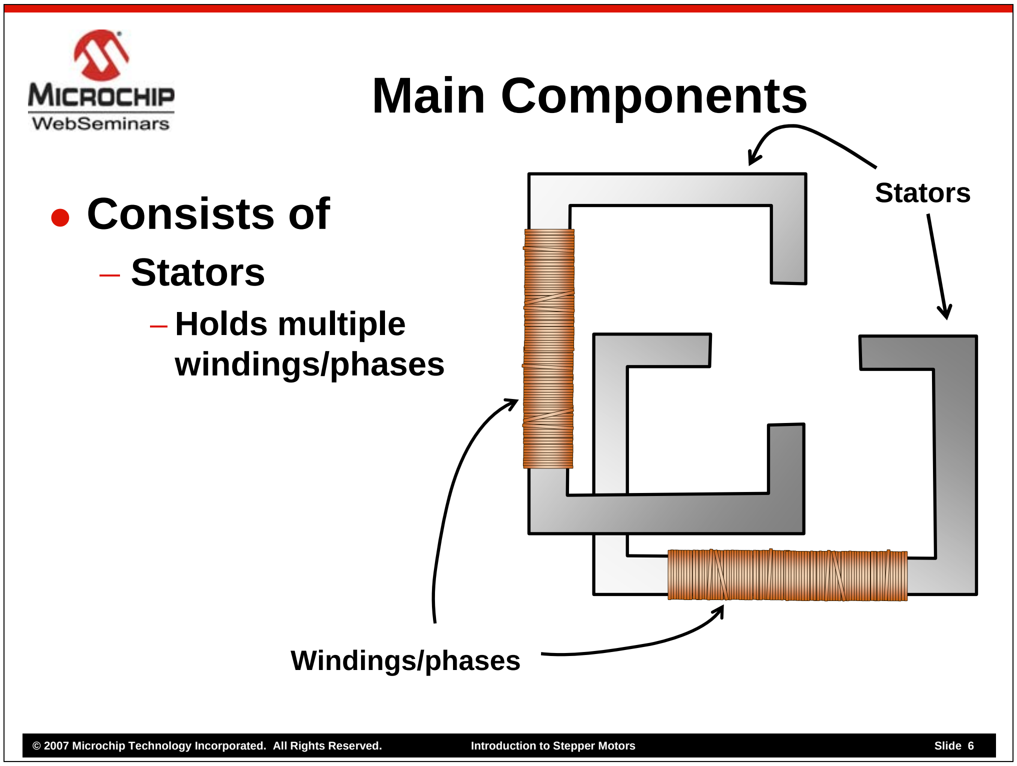
First, what is a stepper motor? As the name implies, the stepper motor moves in distinct steps during its rotation. Each of these steps is defined by a Step Angle. In the example above you may notice that there are 4 distinct steps for the rotor to make a complete 360 degree rotation. This defines the step angle at 90 degrees. Since this motor does move in a discreet fashion, we can say that a stepper motor is actually a digital motor. This characteristic makes it very suitable for digital interfaces such as with a microcontroller.



OK…so we have this motor that moves in distinct steps…where and why would I use it? Stepper motors are relatively inexpensive as compared to other motor types. Let me emphasize the word relatively. There are a number of stepper motor designs that run from the most basic to very complex….depending on the motor you choose, the resolution required and the application at hand will determine the cost of the motor required.

More important is the fact that a stepper motor can actually be used without any type of feedback loop. Since the motor moves in distinct steps as defined by a step angle, we need only count the number of steps to position the motor accordingly. This doesn't mean you wouldn't use a feedback loop in some applications. However, if feedback isn't required, board real estate can be maximized by minimizing these sensing components.

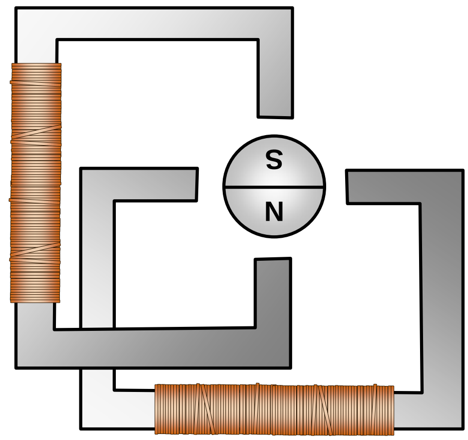
The unique torque characteristics of the stepper motor make it ideal for position applications. In fact, stepper motors have been used for years in such applications as printers and machining equipment. This type of motor will hold its position firmly at a given step providing a relatively high holding torque. Other torque related benefits include the higher torque at lower revolutions per minute than your typical DC motor as well as no need for mechanical braking.



A stepper motor has some basic components. First, we have a soft iron stator. As the name implies this is a stationary component. Each stator will be wrapped with multiple windings or phases that will be energized using a voltage source, initiating current flow through the winding to produce a polarity on each end or pole of the stator.

Main Components

- **Consists of**
  - Stators
    - Holds multiple windings/phases
  - **A Rotor**
    - **Magnetized**
    - **Non-magnetized**



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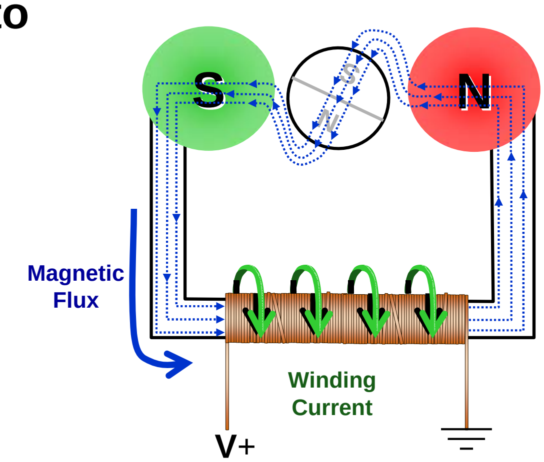
The rotor is the actual rotating component on the motor. This can either be magnetized, as shown here, or non-magnetized depending on the type of motor you select. We will discuss some of these different motor types later in the presentation.

Main Components

- Voltage applied to winding initiates current flow
- Magnetic flux begins to flow



In this example, if we apply a voltage across the windings around a stator, current will flow through the winding. If you remember back in school, your professor may have discussed the right hand rule. If you take your right hand and position your fingers over a winding in the direction of current flow, you thumb will point in the direction of the magnetic flux. Here we can see that each end of the stator is magnetized to opposite poles. Magnetic flux will flow from North to South thereby continuing through the magnetic rotor to the opposite stator pole. The flux will want to travel the path of least resistance or decrease the reluctance of the path.

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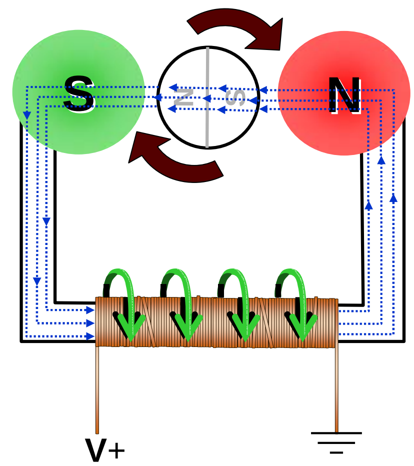
Main Components

- Voltage applied to winding initiates current flow
- Magnetic flux begins to flow
- **Rotor rotates to minimize flux path (or reluctance)**



Since the rotor does rotate it will position itself to minimize this reluctance. As you can see, by adding more stators and phases, we can charge a winding attracting the rotor poles accordingly then remove the applied voltage allowing other stators to attract the rotor poles.

As I mentioned there are a number of different types of stepper motors.

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Types of Stepper Motors

- **Permanent Magnet**
  - **Magnetic rotor**
- **Variable Reluctance**
  - **Non-magnetic, geared rotor**
- **Hybrid**
  - **Combines characteristics from PM and VR**
  - **Magnetic, geared rotor**

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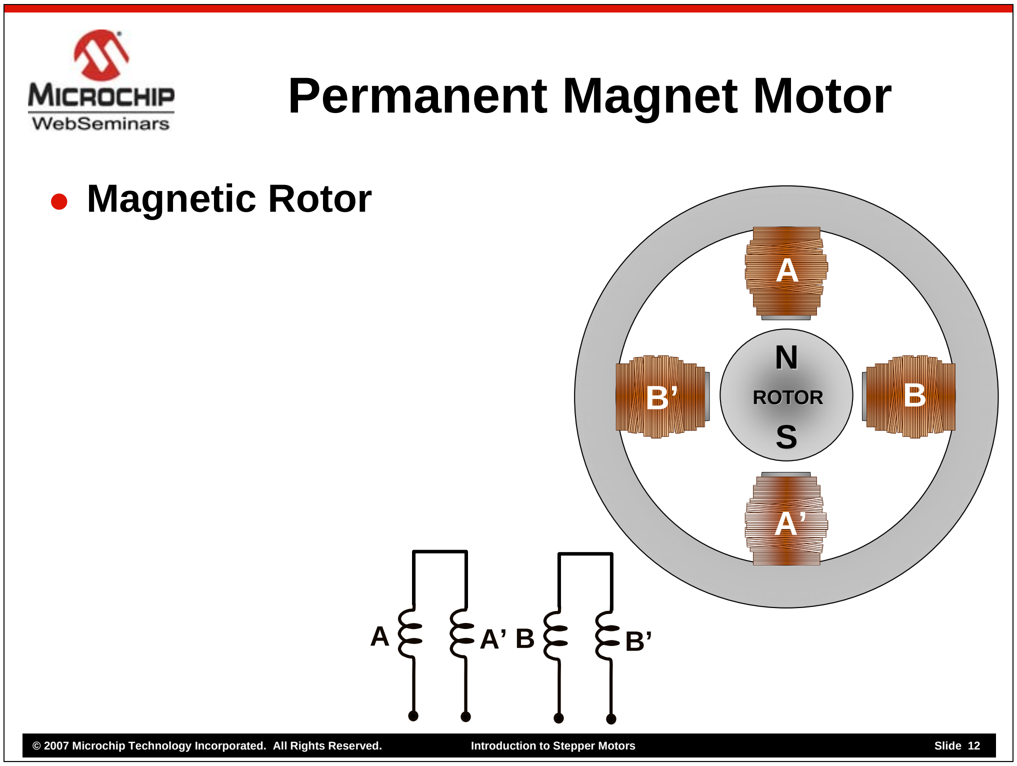
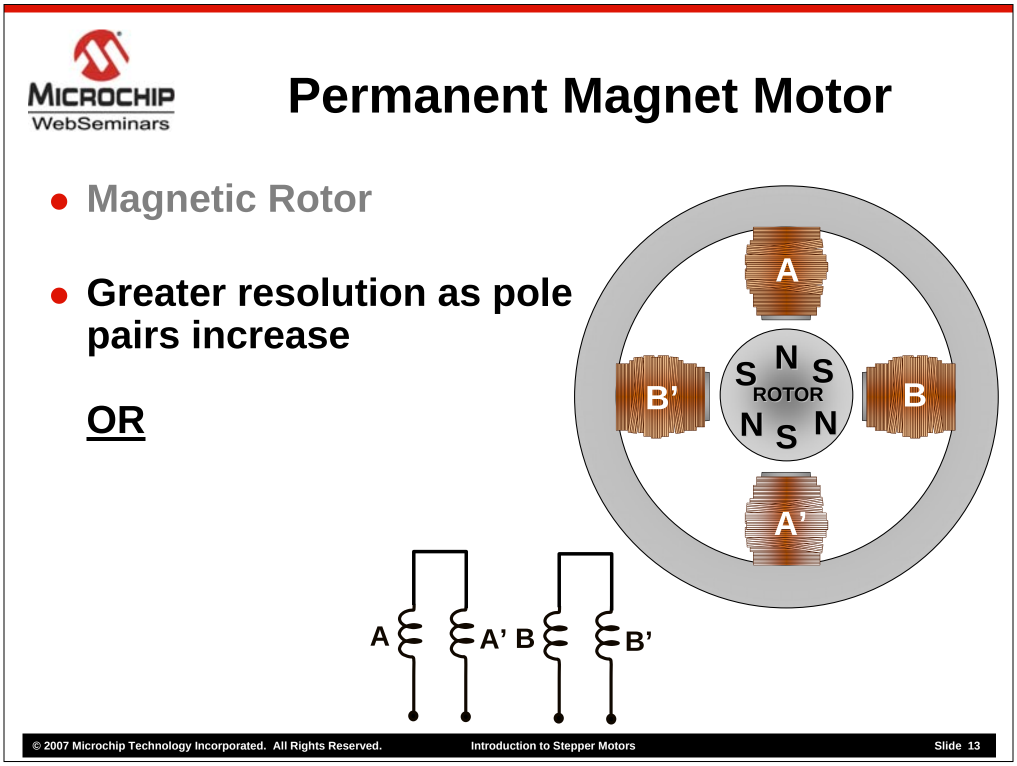
The first type, we have already seen in this web seminar the Permanent Magnet Stepper Motor. This is the motor that has the magnetized rotor.

A variable reluctance type motor replaces the magnetic rotor with a geared, non-magnetized, soft-iron rotor.

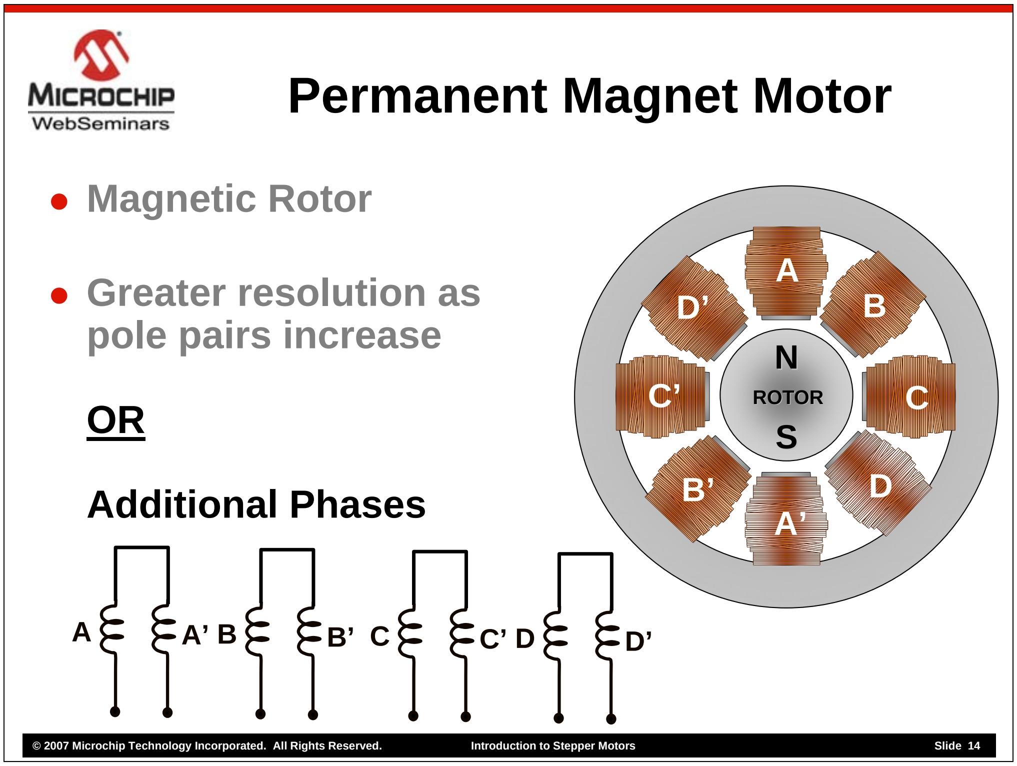
Finally, the hybrid type of motor combines characteristic from both the Permanent Magnet and Variable Reluctance motors. As you will see, this type of motor offers very high rotational resolutions as well as improved torque.



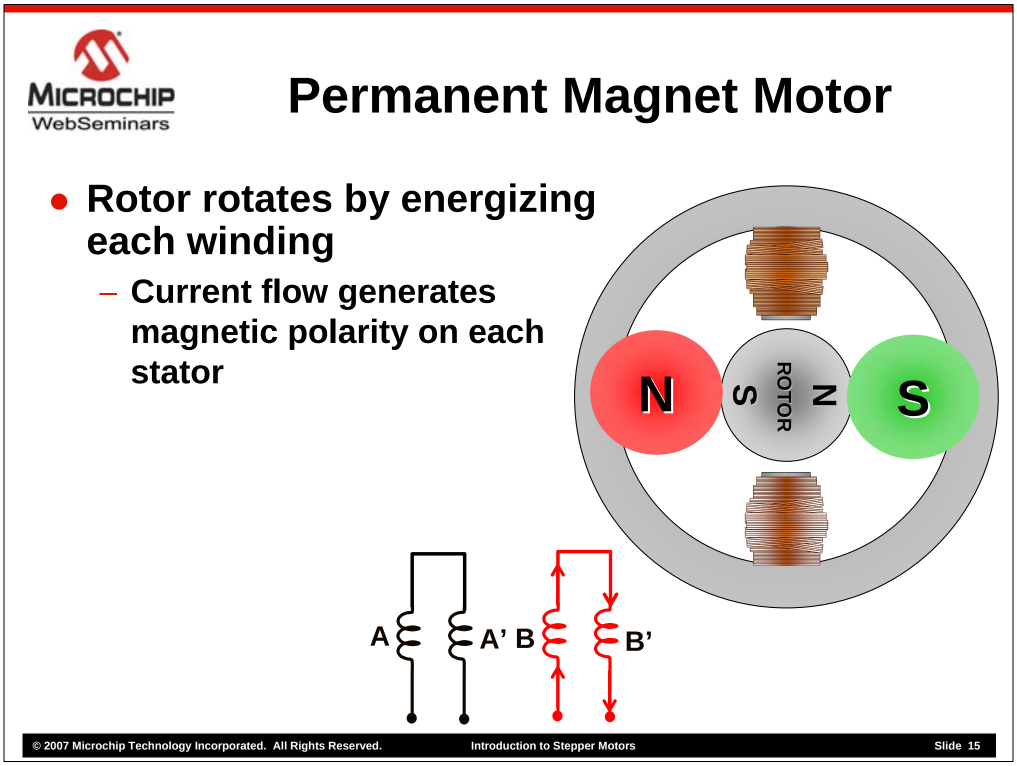
The permanent magnet type of stepper motor has the characteristic magnetized rotor. During the rest of this webseminar we will use the nomenclature shown on the above slide. Each winding, although one entity, will be subdivided. Above I've labeled Winding A, for example, as A and A' and Winding B as B and B'. Keep this in mind as we continue through this web seminar.



We discussed Step Angles earlier. Well we can improve the resolution of rotor rotation, or decrease the step angle in a permanent magnet rotor by either increasing the number of pole pairs on the rotor itself.



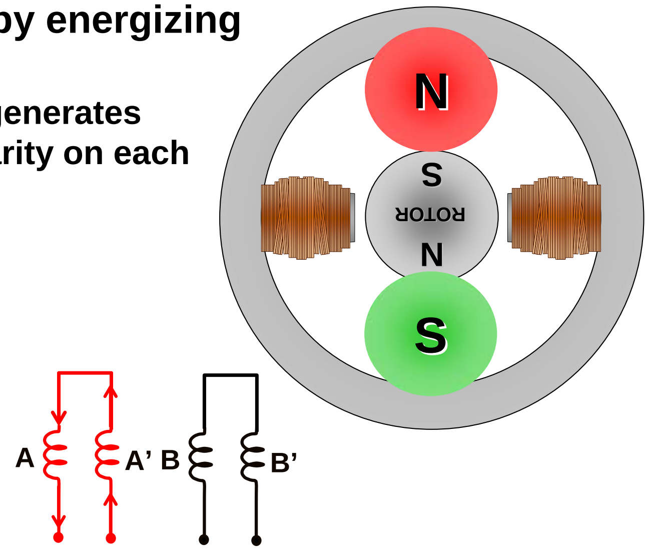
We could also increase the resolution by adding more stators and phases. As we will see in subsequent web seminars, we can also increase the resolution in a third way using different stepping techniques.



To rotate the rotor, voltage is applied to each phase sequentially, again current begins to flow creating a polarity on each pole of that stator.

Permanent Magnet Motor

- Rotor rotates by energizing each winding
  - Current flow generates magnetic polarity on each stator



Permanent Magnet Motor

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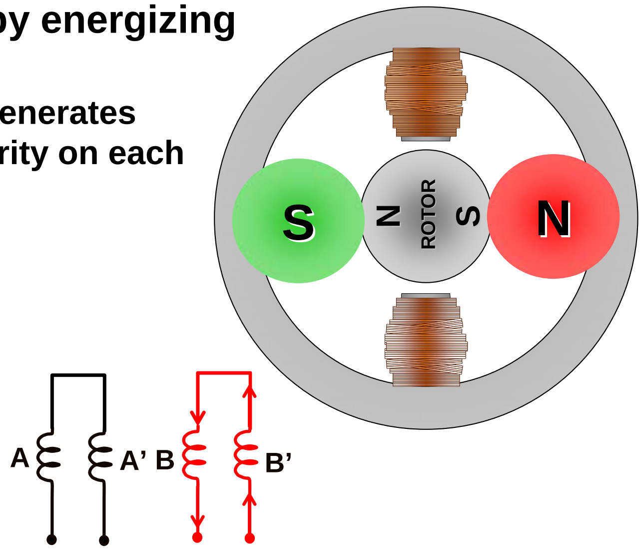
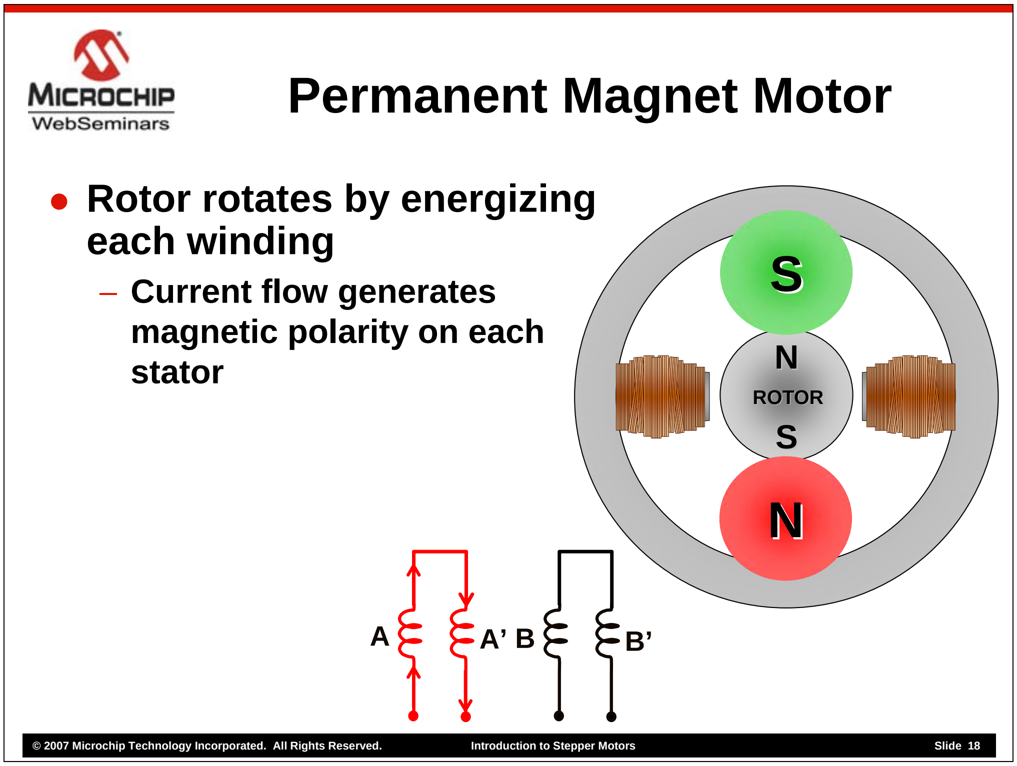
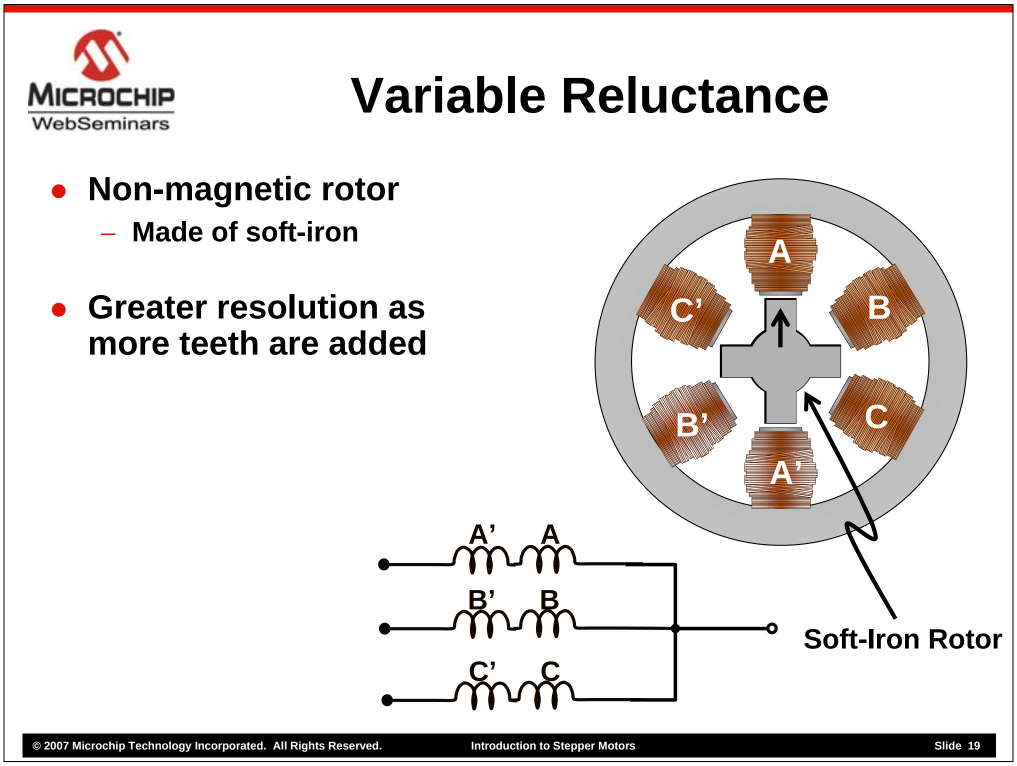
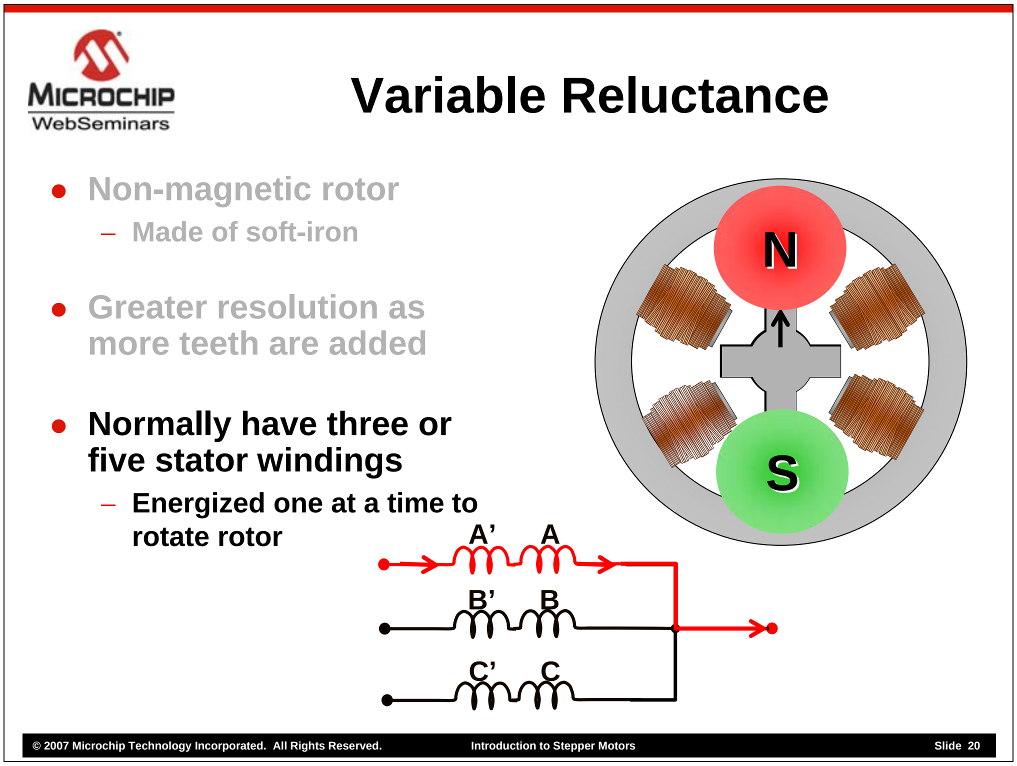




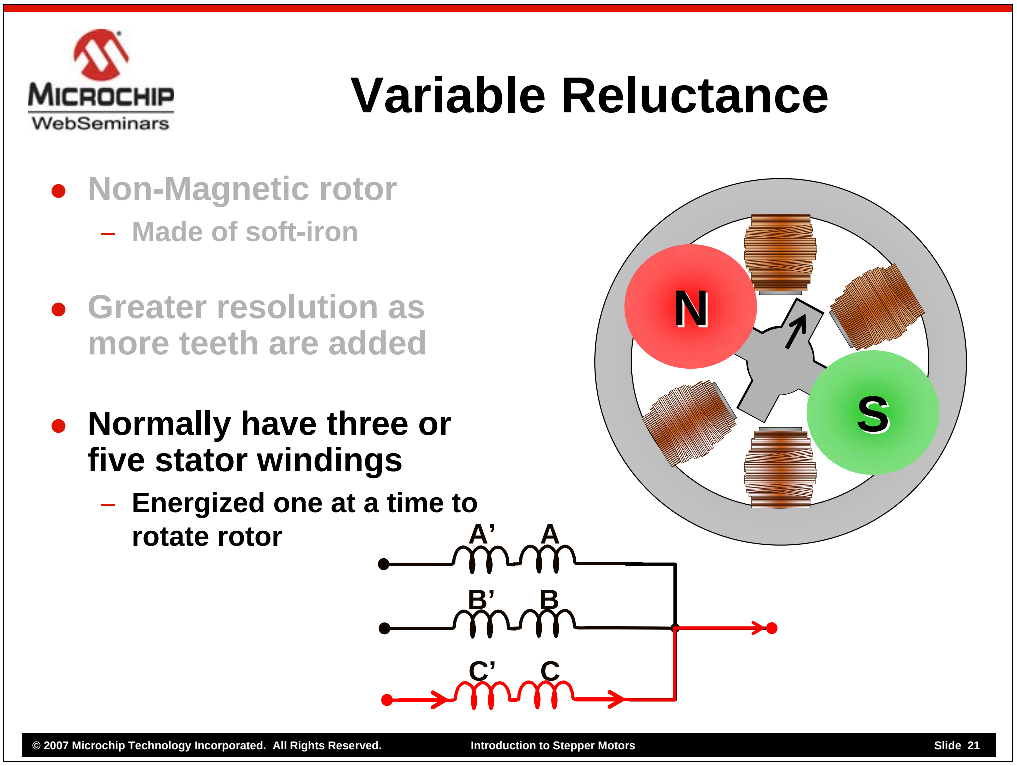
As you can see, rotation in a particular direction is accomplished by applying voltage to the individual phases in a particular sequence. This means that to rotate the rotor in the opposite direction, simply reverse this voltage sequence. To hold the rotor at a particular position, step it to that angle and then stop the sequence maintaining voltage on the appropriate phase. Again, in subsequent web seminars you will come to understand that this isn't the end of the story. Current limiting will need to be implemented in certain applications. However, for now this is the fundamental operational characteristics of this type of motor.



The next motor type is the Variable Reluctance type of Stepping Motor. This motor uses a non-magnetized, soft-iron rotor. The rotor here actually has teeth that are carefully offset from the stator poles to accomplish rotation. Notice also that the individual stator windings are configured differently than what we have discussed so far. All windings have a common terminal that will be connected to a voltage source. The opposite end of each winding is kept separate from the other windings. To increase the resolution on this type of motor, typically more teeth are added to the geared rotor. So how does this type of motor rotate?



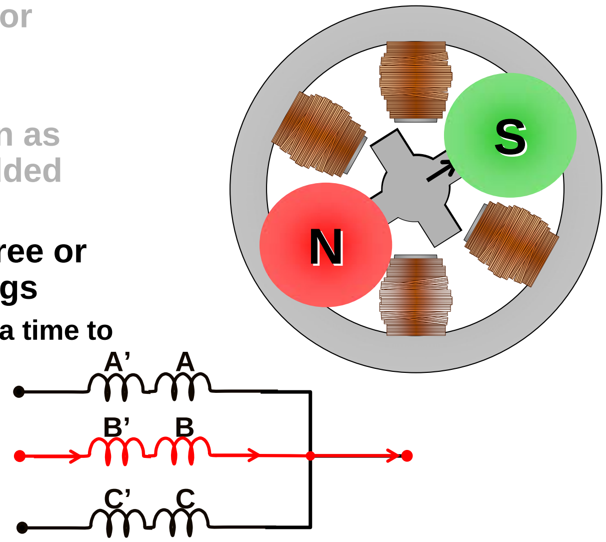
Each winding is again energized one at a time to create a polarity on the appropriate stator poles. The rotor rotates to minimize the reluctance of the magnetic flux path. What happens next differentiates the variable reluctance motor from most other Stepping Motor types.



Notice that to rotate the motor in a particular direction, the stator pole/winding energizing sequence is actually reversed to that used in a permanent magnet motor. Also, note that the motors step angle is actually half what it is with a permanent magnet motor with the same number of stator/windings.

Variable Reluctance

- Non-Magnetic rotor
  - Made of soft-iron
- Greater resolution as more teeth are added
- Normally have three or five stator windings
  - Energized one at a time to rotate rotor



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Variable Reluctance

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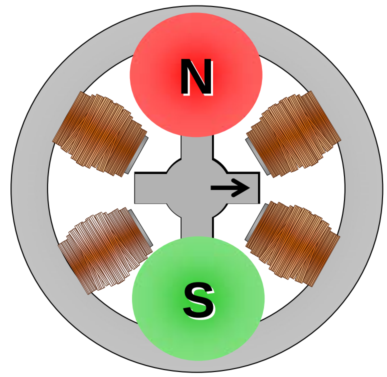
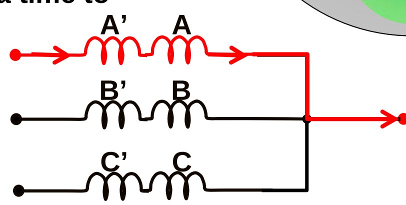
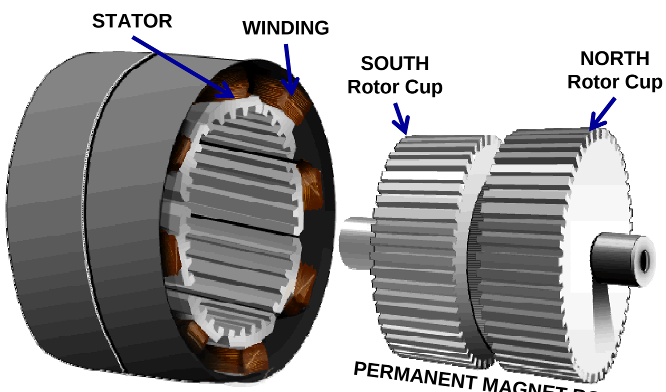




Hybrid

- **Hybrid of Permanent Magnet and Variable Reluctance type motors**



Side View

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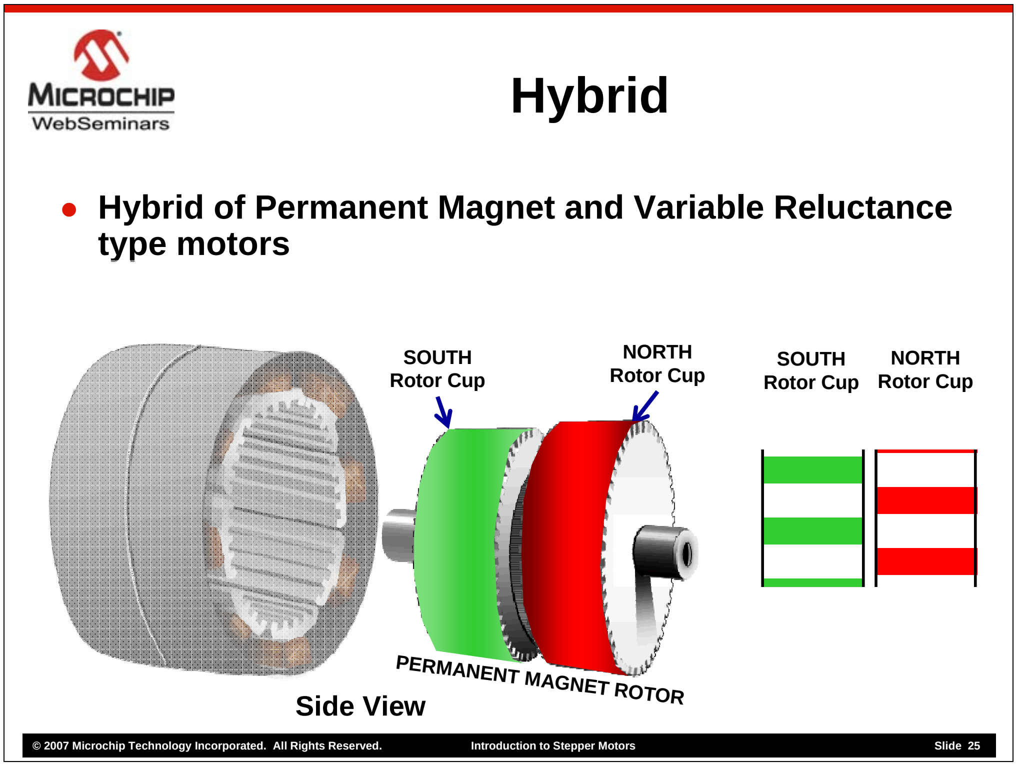
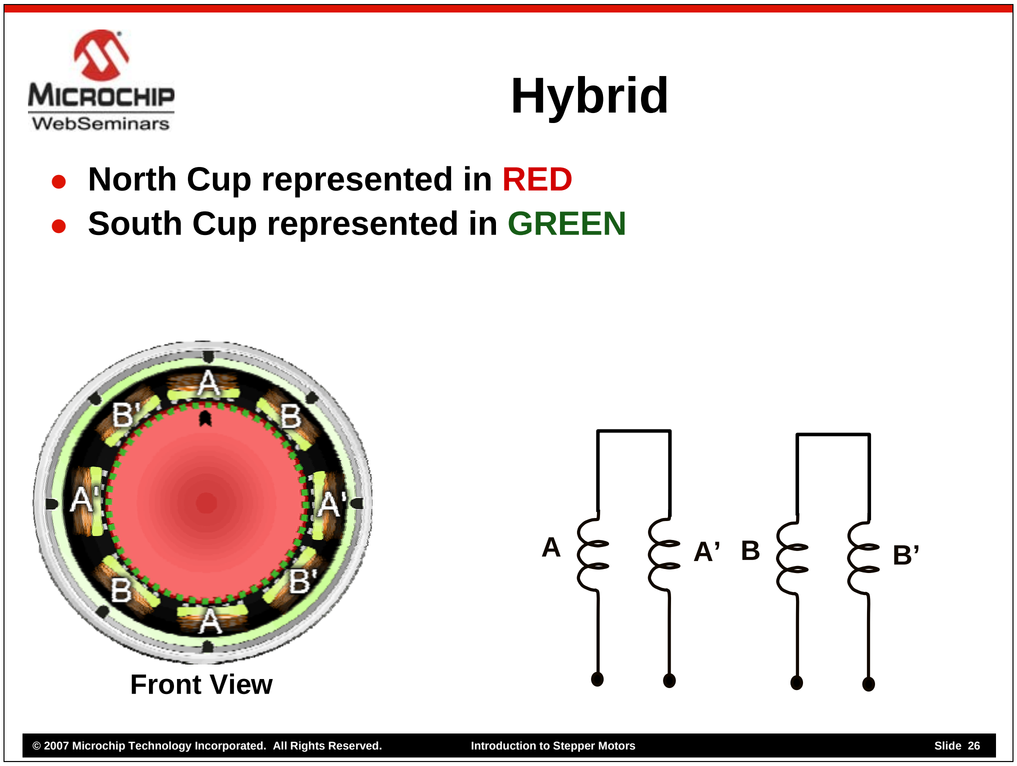
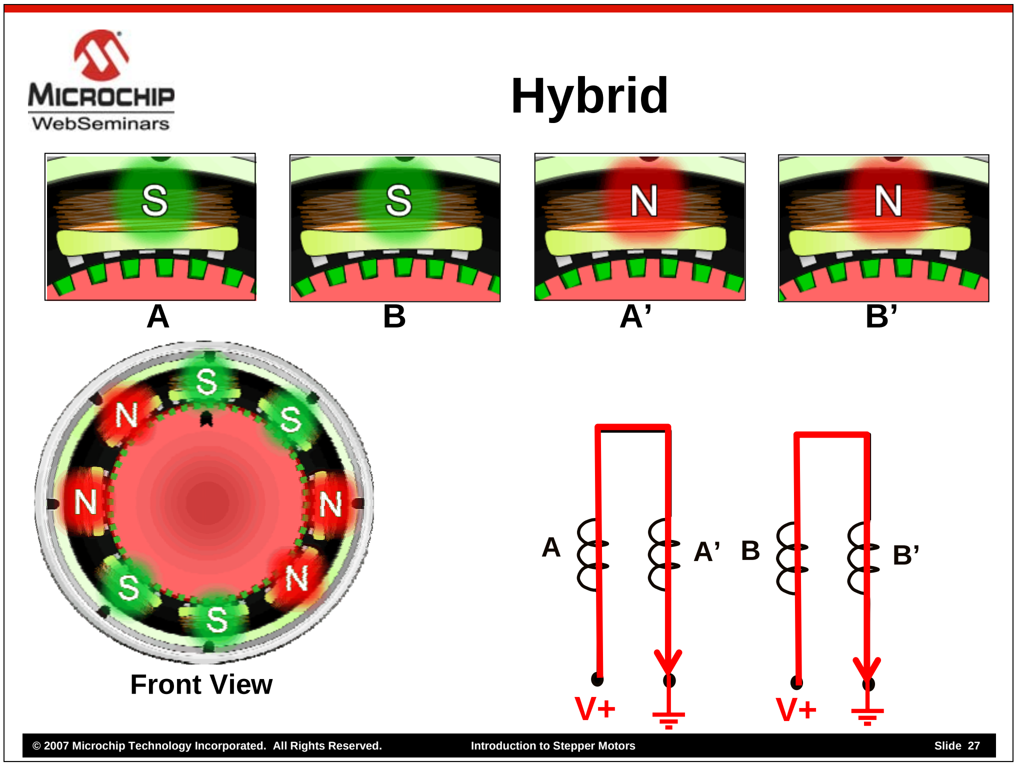
The last motor we will discuss is the Hybrid motor. This type of Stepping motor borrows characteristics from both permanent magnet and variable reluctance motors. This slide shows a side view of Hybrid Stepper Motor with the rotor removed. The rotor is magnetized and also has teeth. Each stator now has a number of teeth or poles. Looking closer at the rotor itself…



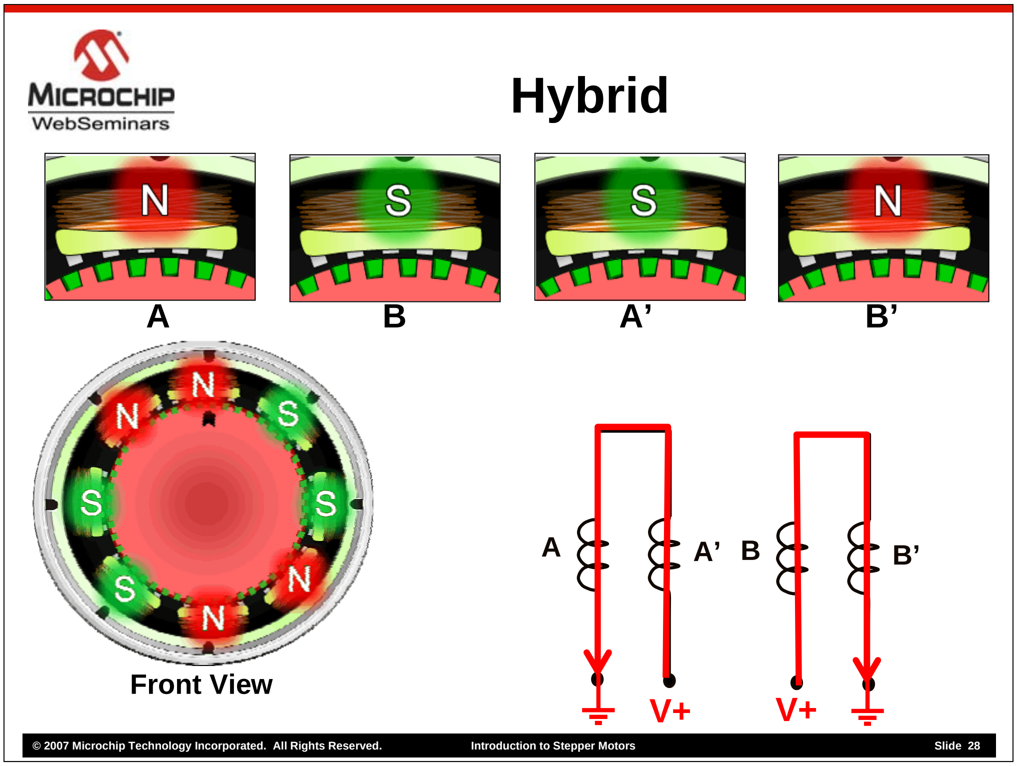
We can see that the rotor is actually in two sections or cups. One in the front and one in the back. The two rotor cups are opposite in polarity. On the right side of the slide is a close up view of the individual teeth on the rotor cups. The north rotor cup is represented in red and the south rotor cup in green. Notice that the teeth on one cup is offset by a tooth as compared to the other cup.



This slide shows the Hybrid stepper motor reassembled and turned for a front view. Referring to the winding diagram on the Right and the Stator pole configuration on the Left, we can see that each winding actually energizes four stator poles at once when energized.

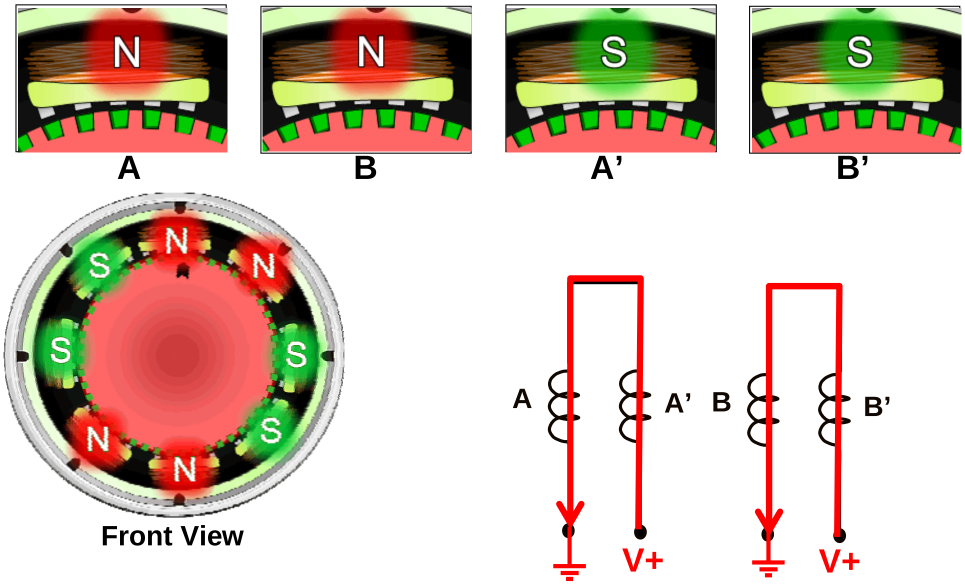


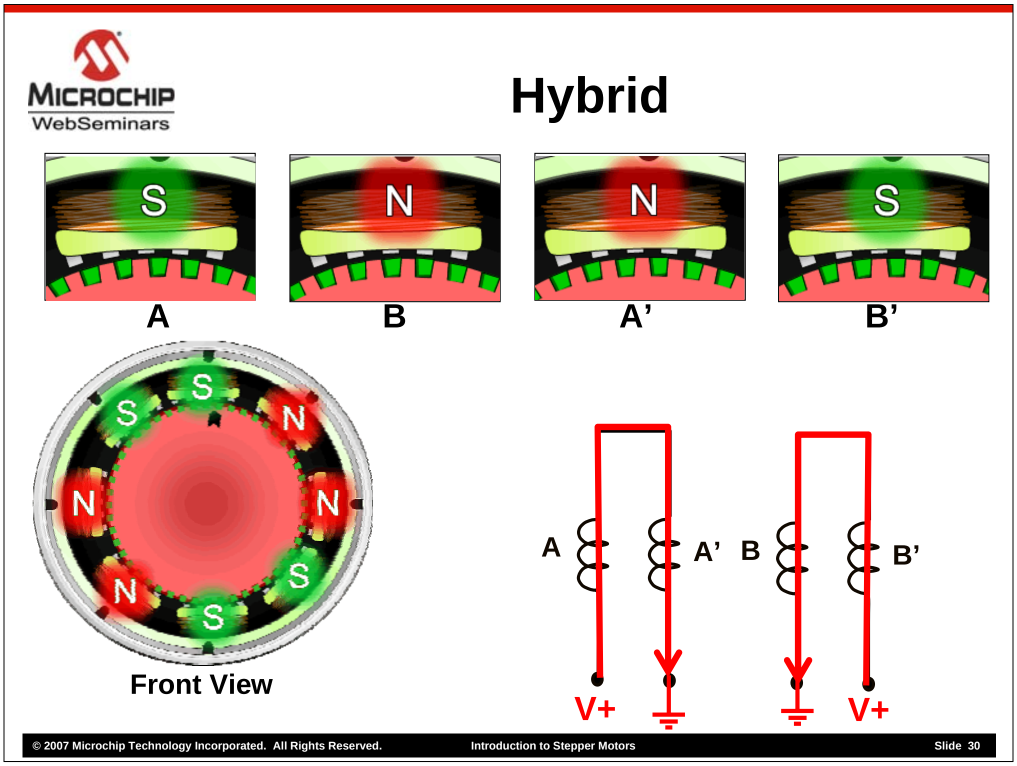
Lets look closer at how this motor actually rotates. Applying a voltage to each of the windings we will control the direction of current flow thereby controlling the polarity of each stator pole. In this slide, notice that Stator poles A and A' are aligned perfectly with one of the rotor cup's teeth. On the other hand B and B' stator poles are actually half-way with half of the pole attracting one cup's tooth while repelling the other.



The next step in the sequence changes current direction in winding A by reversing the applied voltage. Winding B maintains current direction from the previous state. Look how this affects the rotor position. Notice now that stator poles A and A' are now half on each rotor cup while stator poles B and B' line up perfectly with each cup. The rotor has rotated a very small amount thanks to the construction of the Hybrid motor components. The motor pictured has a step angle of 1.8 degrees per step. This is a significant improvement over the basic permanent magnet motor we looked at before. This step resolution can be further improved through the use of different stepping techniques that are discussed in Part 2 of this web seminar series.

Hybrid




Hybrid
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PM vs. VR vs. Hybrid

Characteristic	Permanent Magnet	Variable Reluctance	Hybrid
COST	Cheapest	Moderate	Most Expensive
		More expensive due to manufacturing processes	
Design	Moderately Complex	Simple	Complex
Resolution	30° - 3 °/step	1.8 °/step and smaller	
Torque vs. Speed		Less pronounced torque drop at higher speeds	
Noise	QUIET	Noisy no matter what type of excitation	QUIET
Stepping	Full, Half and Microstepping	Typically run in Full-Step only	Full, Half and Microstepping

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comparing various aspects of each motor type may make it easier for you to decide which motor suits your intended application. First thing is cost. Due to the manufacturing process for the permanent magnet motor it is cheaper. The stator's are fabricated using molds that will accept molten iron to cast the component. Hybrid and Variable Reluctance motors have a more intricate fabrication process. This is due to the geared rotor. The rotor is actually made up of thin laminates of soft iron to achieve the desired thickness. This process is implemented to reduce the occurrence of eddy currents within the rotor. A similar process is used when fabricating transformers for power supplies.

If we look at resolution of the step angle, Hybrid and Variable Reluctance can achieve very fine resolutions due to the geared construction of the rotor. Permanent Magnet rotors are physically limited by the number of pole pairs that they may have.

As with any stepper motor, as the revolution speed of the rotor is increased, there will be a pronounced decrease in the overall torque of the motor. Variable reluctance motor torque is maintained longer in relation to both permanent magnet and Hybrid types.

Noise may be a consideration in your application. Variable reluctance motors are typically noisier than their permanent magnet or hybrid counterparts.

Finally, as we'll discuss in Part 2 of this series, there are a number of stepping algorithms to produce a greater step resolution for a given motor. However, variable reluctance motors are limited to a single stepping algorithm. Therefore, the rated step angle for these motors are fixed.

Unipolar and Bipolar Stepper Motors

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Now that we have seen some of the types of stepper motors available, let’s take a look at sub-variations of both the permanent magnet and Hybrid motor types.

Unpolar and Bipolar

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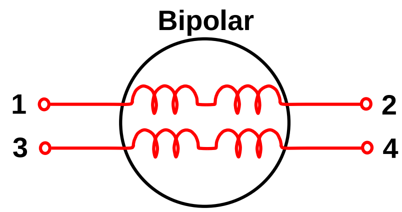
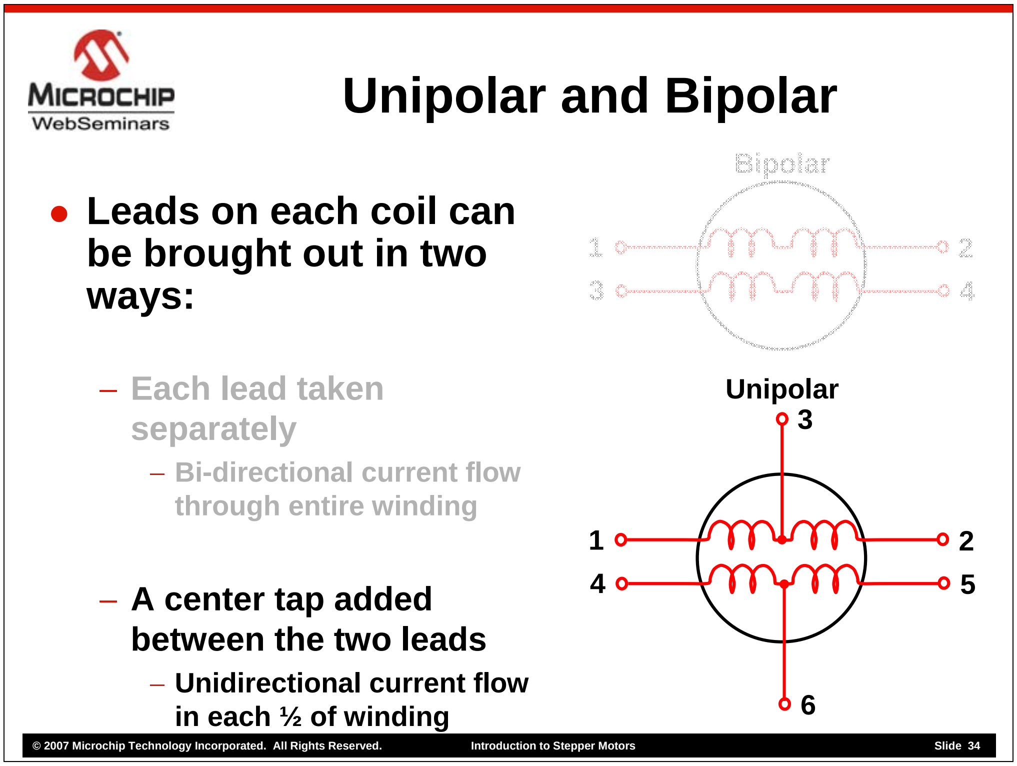
- **Leads on each coil can be brought out in two ways:**
  - **Each lead taken separately**
    - **Bi-directional current flow through entire winding**

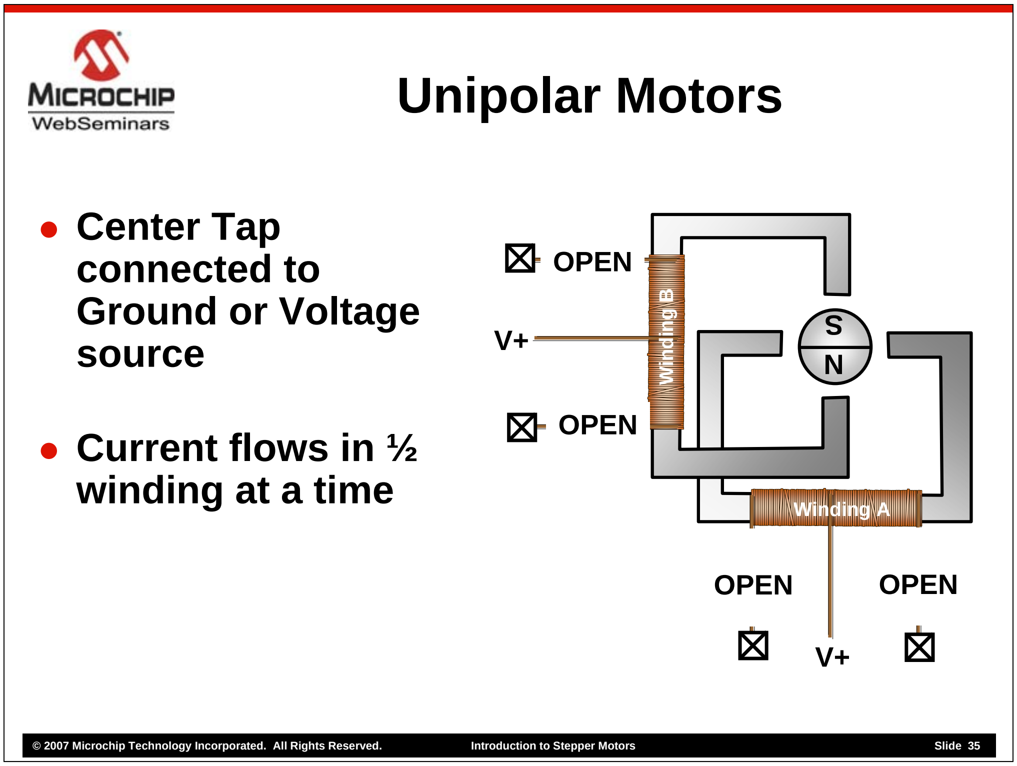


These two sub-categories are determined by how the leads from each phase winding is brought out of the motor.

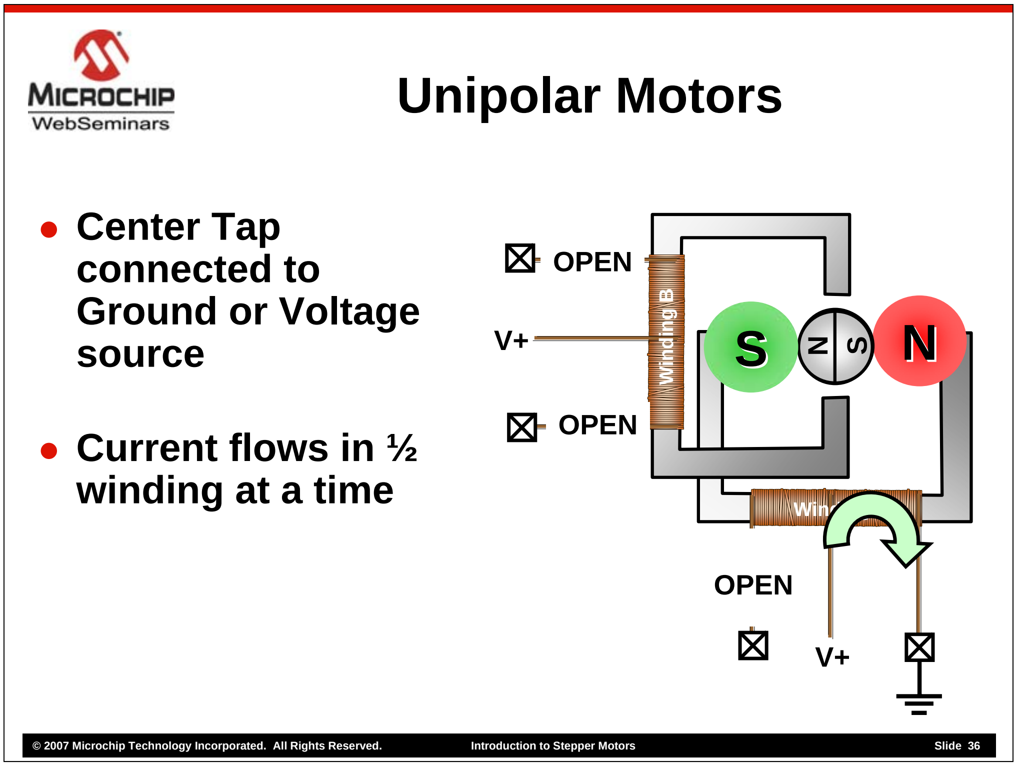
The first example is a Bipolar configuration. Here you can see that each winding lead is brought out separately. This type of winding, depending on the voltage applied and to which lead, can produce current flow in two directions. This allows each stator pole to be magnetized to North or South.



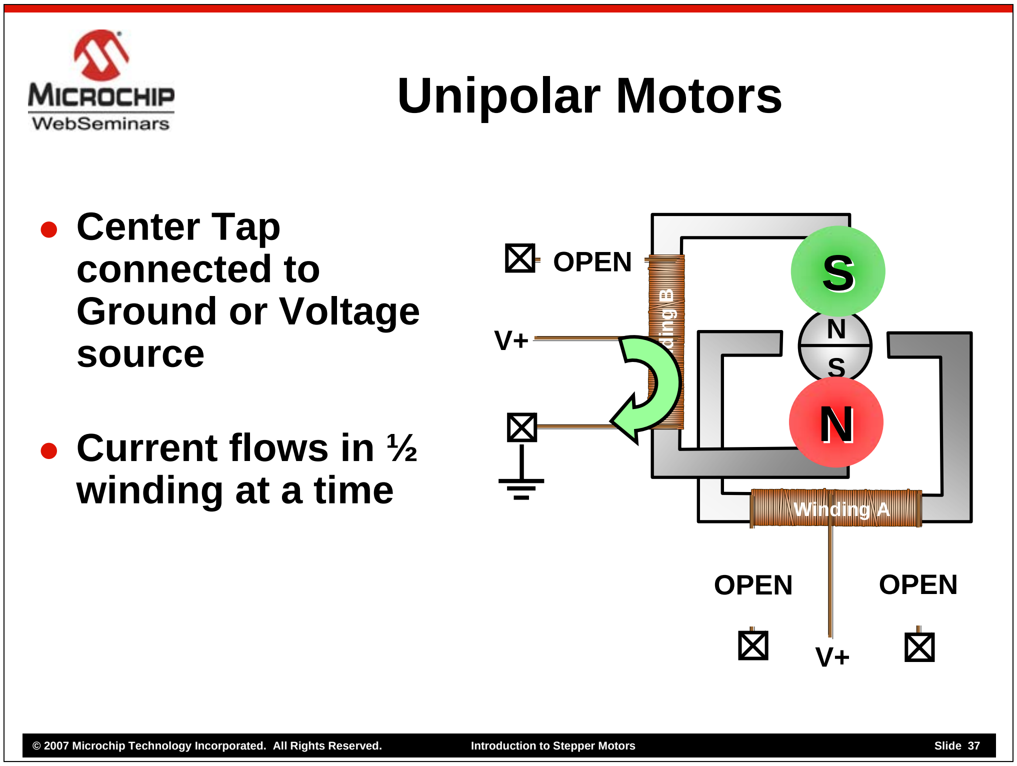
The Unipolar configuration, on the other hand, only allows current flow in half of the winding at one time. Notice that each winding has a center tap that is brought outside of the motor along with each winding lead.



Let's take a closer look at how the Unipolar type of motor works. The center-tap lead is connected to a positive voltage source in this example.



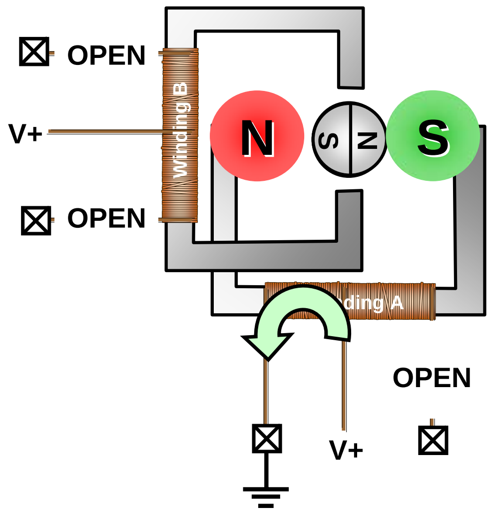
Driving one of the leads on winding A to ground allows current to flow in one half of the winding generating a polarity on the stator poles and the rotor rotates accordingly.



Next, the grounding source is removed from the winding A lead and one of winding B's leads is driven to ground. Again, current flows in half the winding and the appropriate stator poles are energized. This continues to rotate the motor 360 degrees.

Unipolar Motors

- Center Tap connected to Ground or Voltage source
- Current flows in ½ winding at a time



Unipolar Motors

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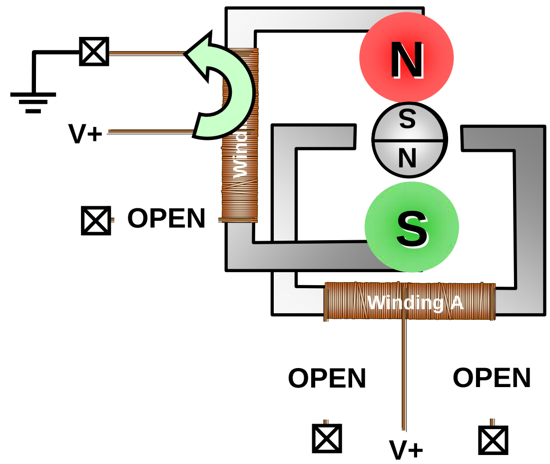
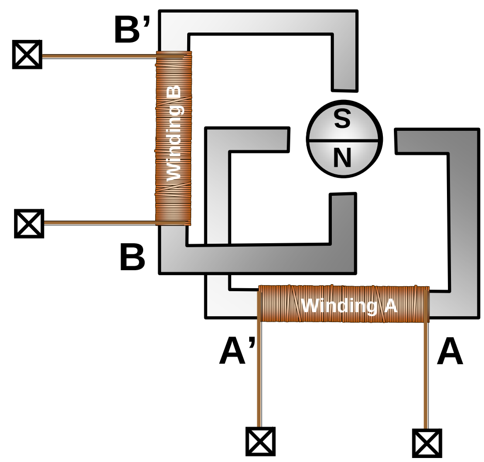


Bipolar Motors

- Current flows in entire winding at a time



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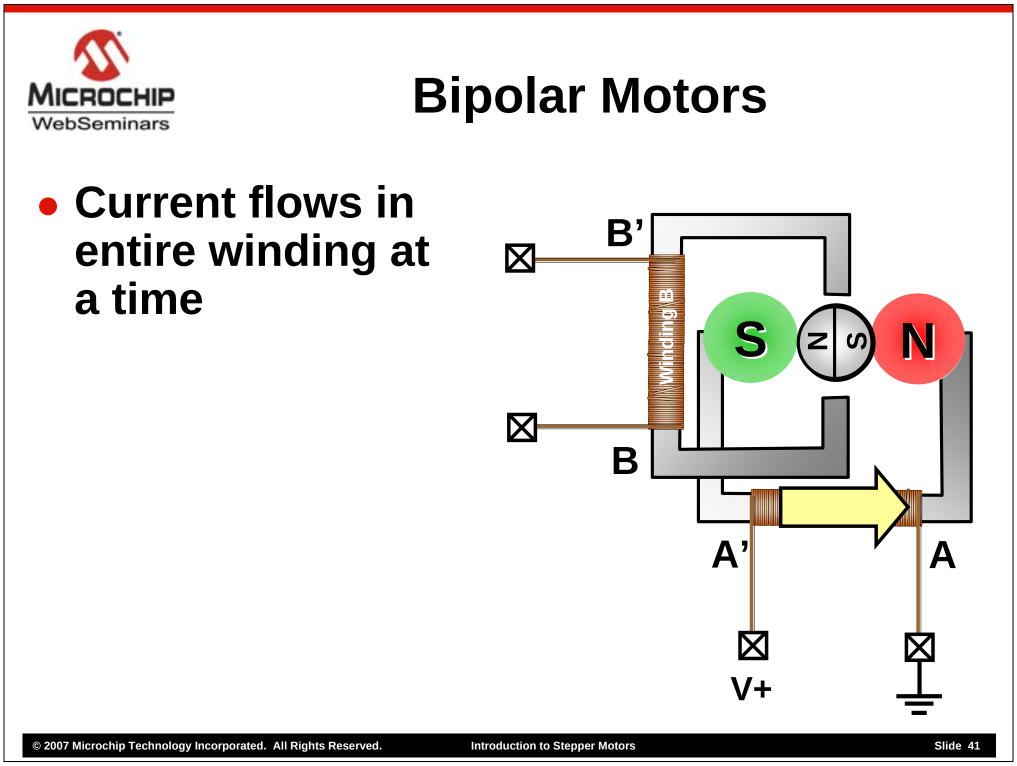
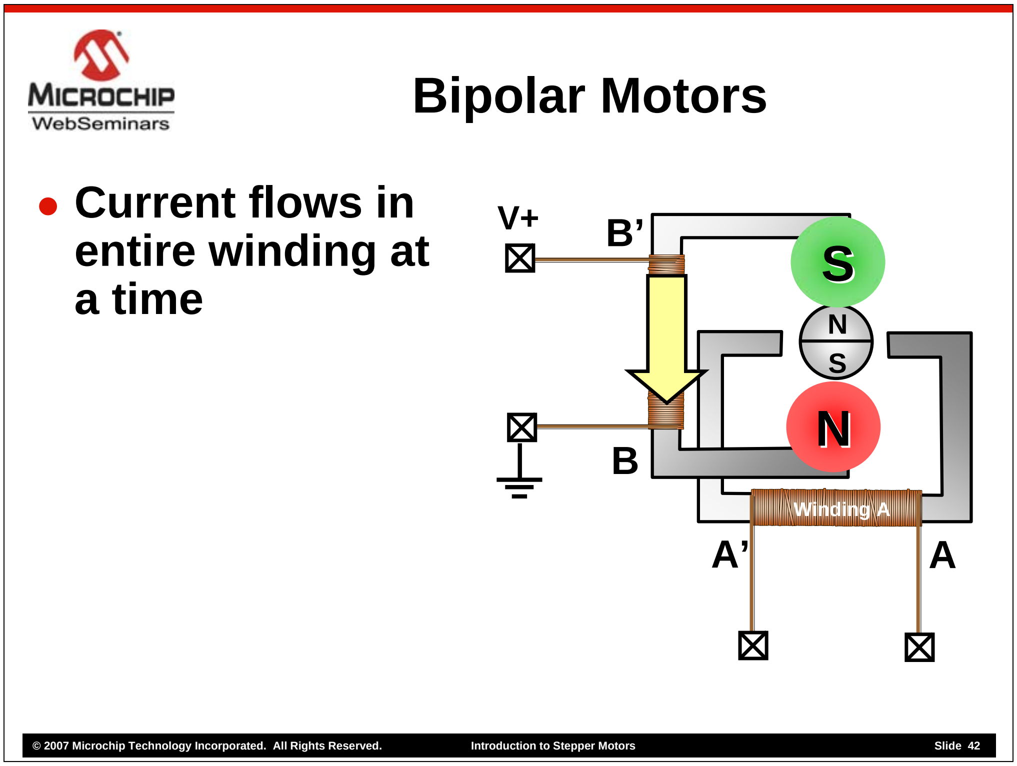
Again, Bipolar motors allow current flow in both directions through each winding.



Applying a voltage to lead A' and grounding lead A generates current flow resulting in the stator polarities shown above.



Removing the voltage from winding A and applying a positive voltage to lead B' on winding B and driving lead B to ground generates current flow and stator polarities as shown above.

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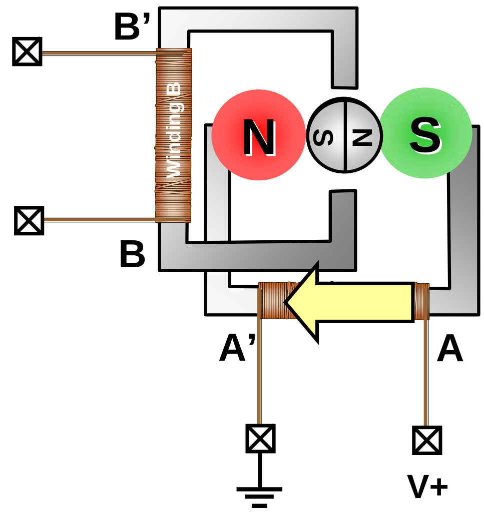
Bipolar Motors

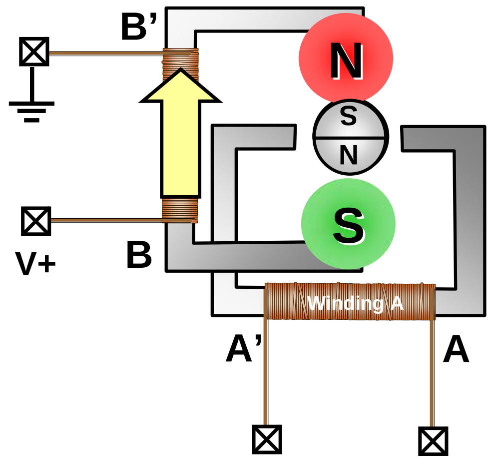
- **Current flows in entire winding at a time**



This continues to rotate the rotor 360 degrees.

Bipolar Motors

- Current flows in entire winding at a time



Unipolar and Bipolar Motors

- Bipolar uses entire winding
  - Unipolar uses half the winding at one time
- Unipolar motor coil wire is thinner
  - More wire needed = increased resistance
- Bipolar requires more complex circuitry
  - Increased cost
  - More real estate

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Let’s compare both winding configurations. Unipolar motors only allow current flow in half the winding while bipolar offers bidirectional current flow. Since torque is related to winding current, Bipolar motors will generate greater torque than unipolar motors. Furthermore, due to the fact that unipolar windings are thinner than bipolar motor windings, more wire is needed thereby increasing the winding’s resistance. This could cause increased power loss via the winding potentially raising the temperature considerably. However, using a bipolar motor will require more complex circuitry potentially increasing the cost of your design and use more board real estate. One other point to make here, since unipolar motors do have both ends of the windings being brought out of the motor. We could connect them in a bipolar configuration and simply omit the center tapped lead.

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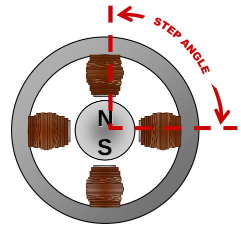
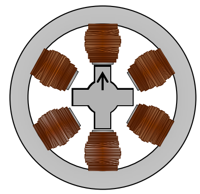
Summary

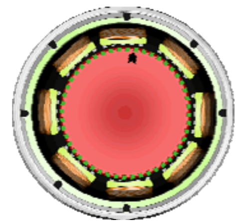
- **Stepper Motors are a digital motor**
  - **Moves in steps**
  - **Defined Step Angle**
- **Three types discussed**
  - **Permanent Magnet**
    - **Magnetic Rotor**
  - **Variable Reluctance**
    - **Non-Magnetic, geared Rotor**
  - **Hybrid**
    - **Combines characteristics of both Permanent Magnet and Variable Reluctance type motors**



Permanent Magnet



Variable Reluctance



Hybrid

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Summarizing all of this. Stepper motors by nature are a digital version of a motor moving in distinct steps as defined by their step angle. We looked at three very different types of motors. The first motor we discussed was a very basic permanent magnet stepping motor with its magnetized rotor. Next, Variable reluctance motors that characteristically offer a very high resolution thanks to the geared design of their non-magnetic rotors. Finally, Hybrid motors offer the best of both worlds using geared bipolar rotors to generate optimal torque and resolution.

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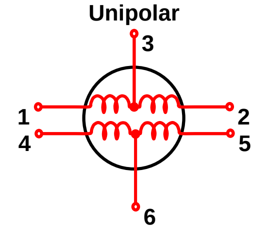
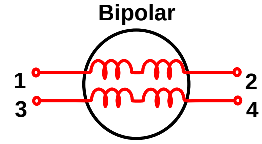
Summary

- Stepper Motors can be further subdivided:
  - Unipolar
    - unidirectional current flow
  - Bipolar
    - bidirectional current flow

Unipolar



Bipolar



Permanent magnet and Hybrid motors also offer a choice in winding configurations. Unipolar motors only support current flow in one half of the winding at a time reducing the possible torque generated. Bipolar motors offer bidirectional current flow but require more board real estate to accommodate more complex circuitry.

More Information

- AN906: "Stepper Motor Control Using the PIC16F684"
- AN907: "Stepping Motor Fundamentals"
- Motor Control Design Center at www.microchip.com
- Part 2: Introduction to Stepper Motors (Stepping the Motor) WebSeminar

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For more in-depth information on stepping motor fundamentals please refer to the application notes listed above. You may also be interested in visiting the Motor Control Design Center at www.microchip.com for recommended products, application notes and technical briefs related to Motor Control.

The Introduction to Stepper Motors series continues with Part 2 highlighting various stepping techniques to improve motor resolution.

My name is Marc McComb and I thank you for downloading this web seminar.