Stepper-Motor Operation and Interfacing Fundamentals

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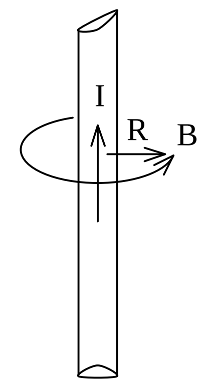
Ampere's Law & Biot-Savart Law

An electrical current I in a ware causes (induces) a magnetic field B. The direction of B is given by the "right-hand rule".



Magnetic Fields for a Long Thin Wire

For a long thin wire, the strength of the magnetic field B a distance R from the wire is

$$B = (U_0 I)/(2\pi R) \tag{1}$$

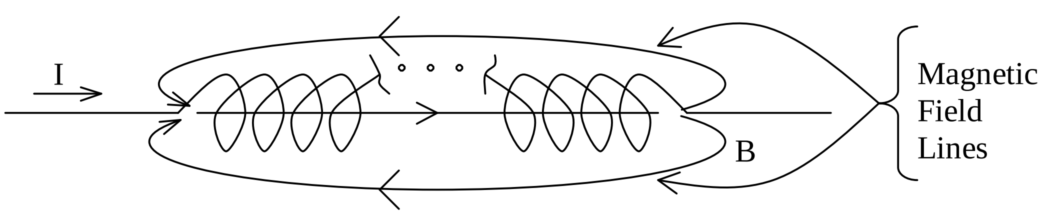
where μ_0 = permeability of vacuum,
$\mu_0 = 4\pi x10^{-7}$ henry/meter

The Solenoid

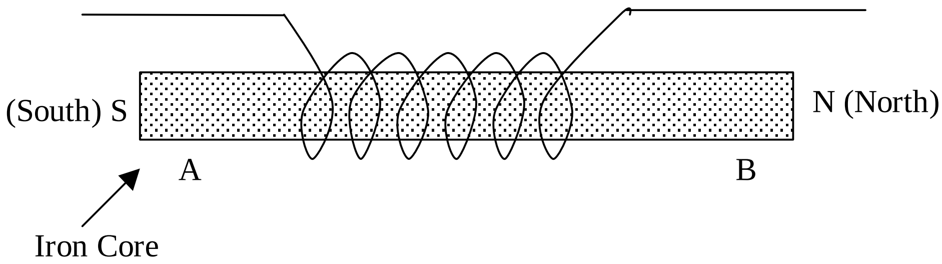
A coil of wire with N turns creates a magnetic field B in the direction illustrated, where

$$B = kNI, \tag{2}$$

with k being a constant. Hence, B is proportional to N and I.



The Electromagnet



If you place a compass and in the vicinity of the iron core, you would discover that one end (say A) would be similar to the "South Magnetic Pole" of the earth, while the other end (say B) would be similar to the Earth's "North Magnetic Pole".

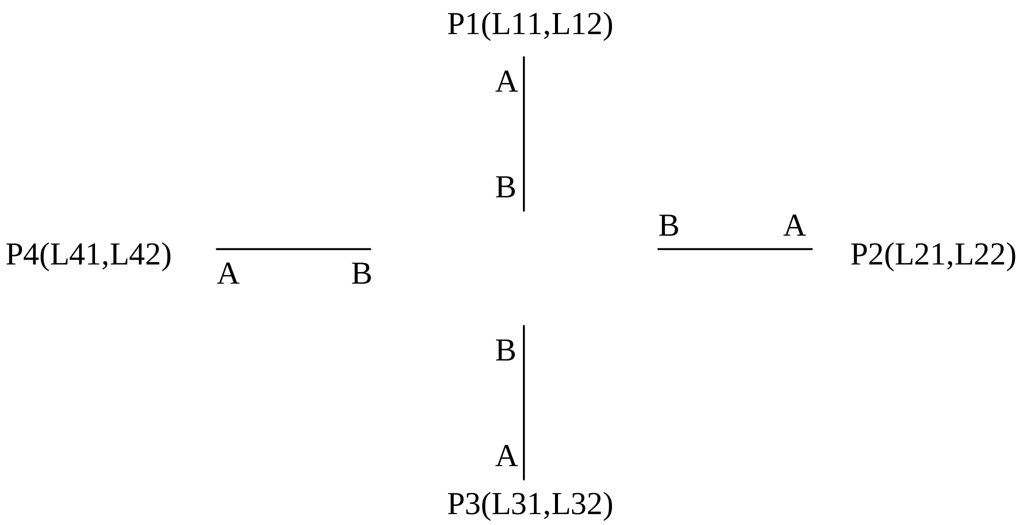
Two important properties of electromagnets are the following:

1. All Electromagnets are dipoles; i.e., they have a North Pole (N) and a South Pole (S).

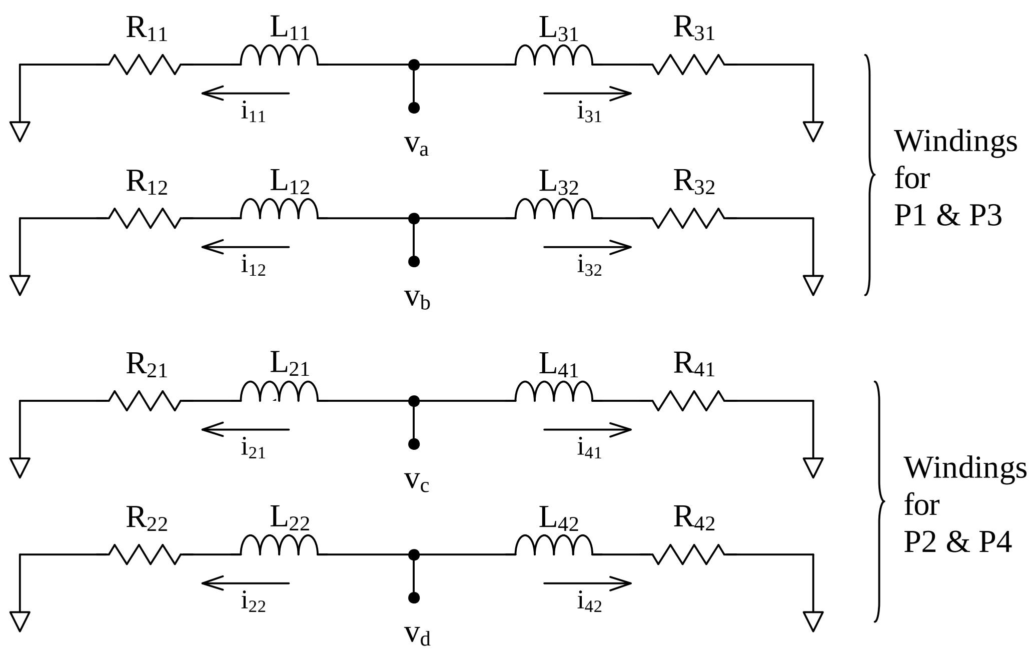
2. The position of the Poles (at A or B) is determined by the direction of the current I and the direction of the winding.

Basic Model for a Stepper Motor

Consider the four electromagnets physically arranged as illustrated.



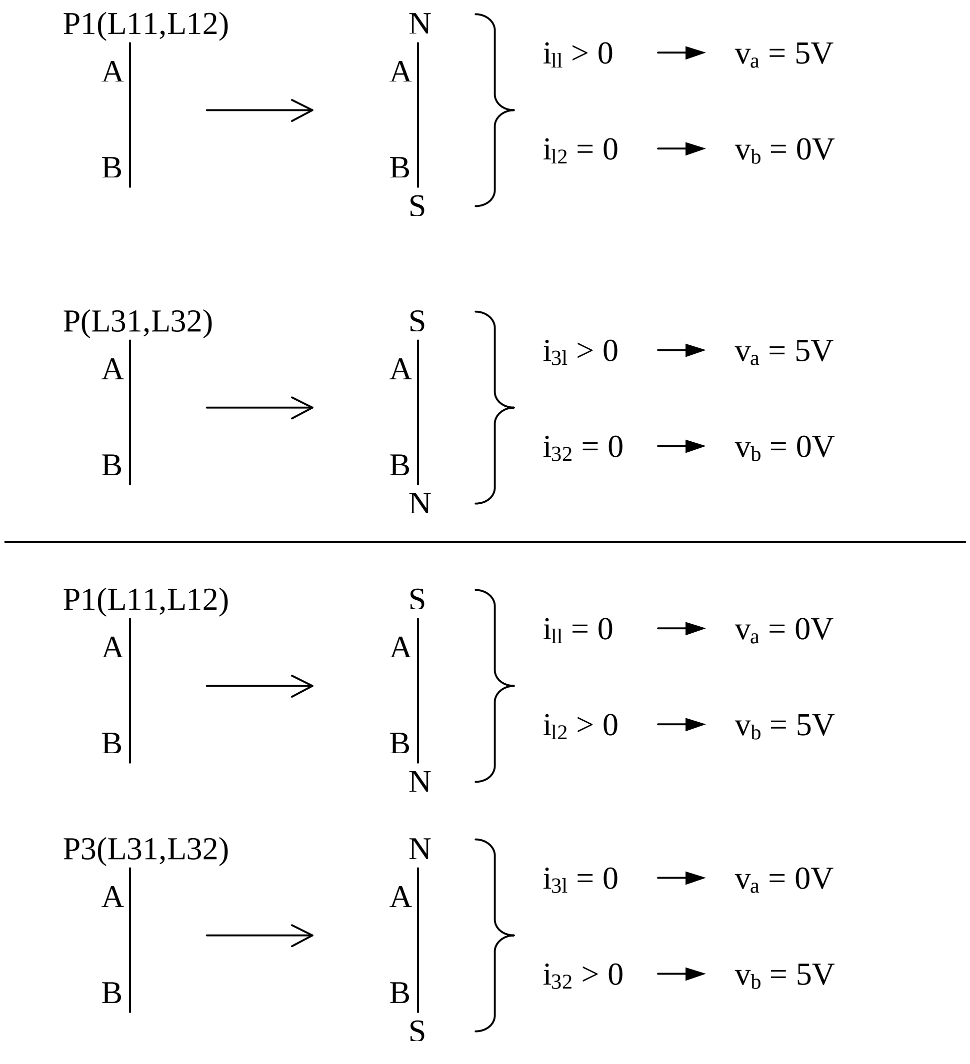
where



Controlling Magnetic Polarities with Winding Voltages (v_a, v_b, v_c and v_d)

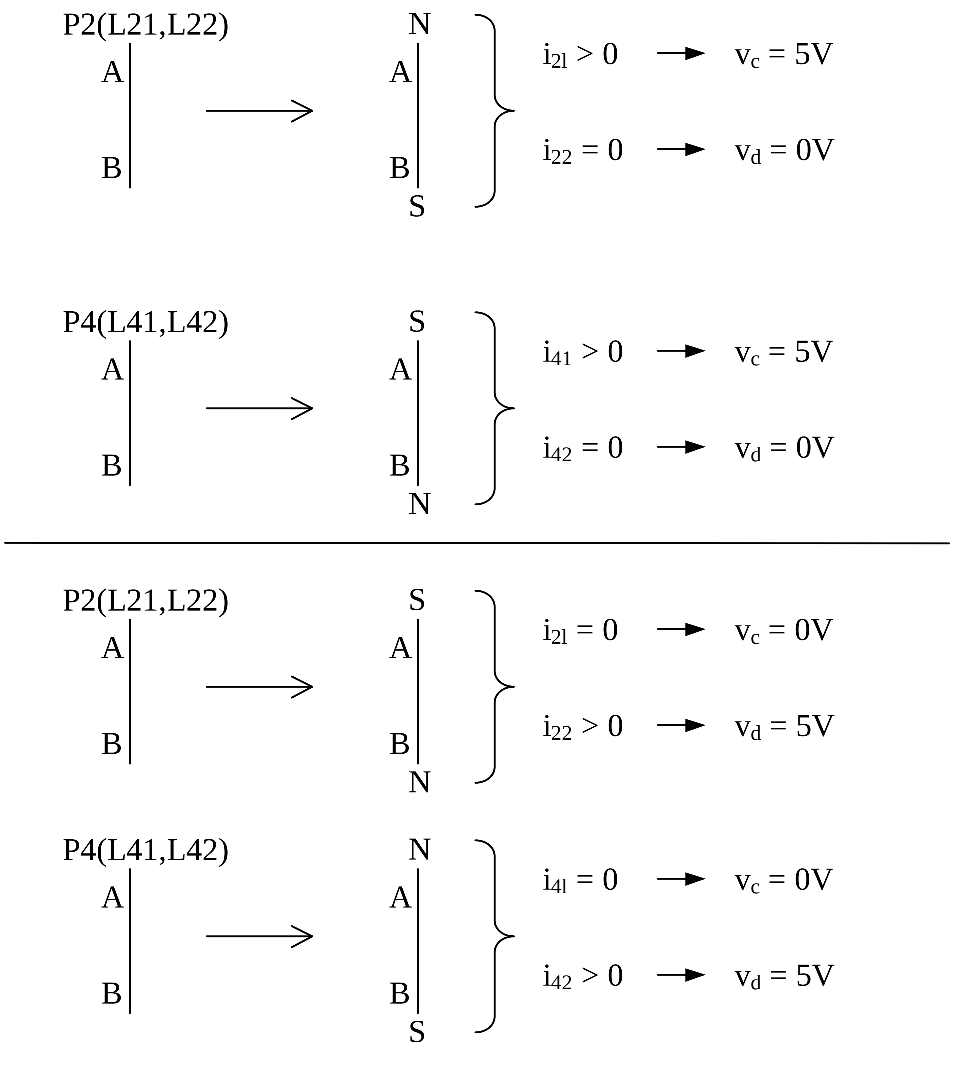
The magnetic polarities of the electromagnets can be controlled by varying the winding voltages v_a, v_b, v_c and v_d. Consider the following two cases.

Case I – P1 and P3



Note: Winding voltages v_a and v_b control the polarities for electromagnets P1 and P3.

<u>Case II</u> – P2 & P4

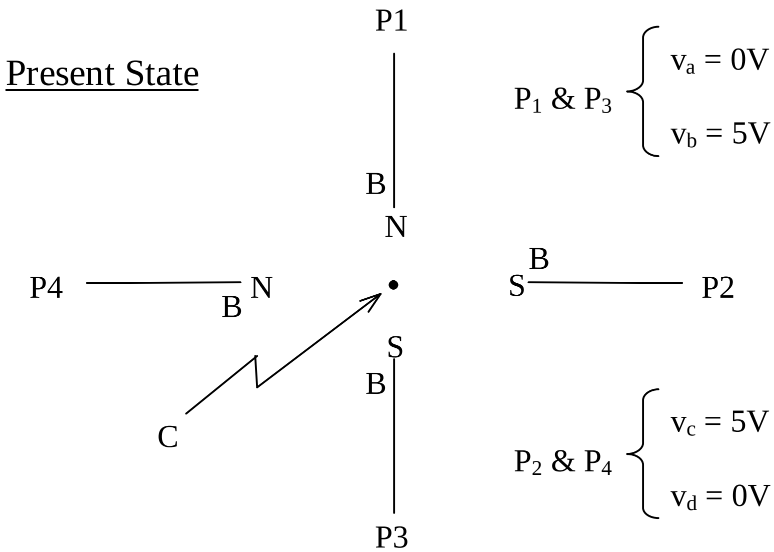


Note: Winding voltages v_c and v_d control the polarities of electromagnets P2 and P4.

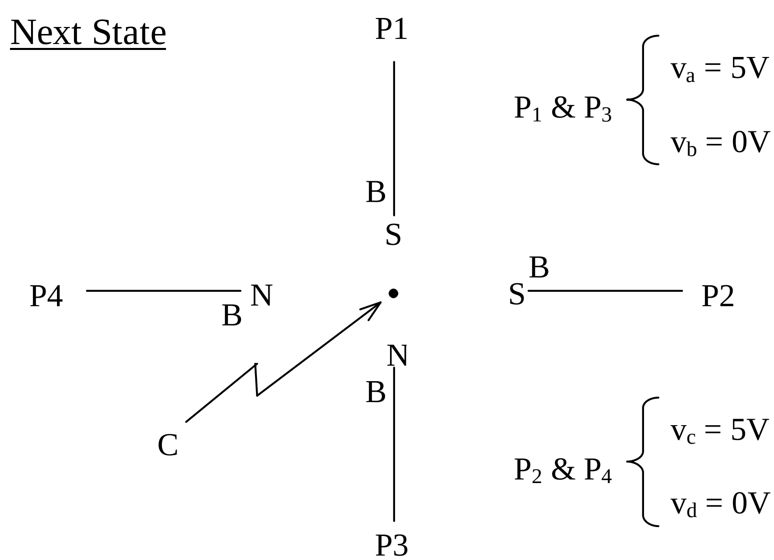
Controlling Stepper-Motor State Transitions

The “state” of a stepper motor can be controlled by controlling the winding voltages of the electromagnets. Consider the following example.

Present State



Next State



Note: The polarities of electromagnets P1 and P3 can be reversed by simultaneously changing v_a from 0V to 5V and v_b from 5V to 0V.

Important Questions and Conclusions

With respect to the previous example, answer the following questions.

1. Assume that the stepper motor is in its “initial state.” If a compass is positioned with the pivot point of its needle at point C, in what direction would the needle point?

2. Assume that the stepper motor is in its “next state.” If a compass is positioned with the pivot point of its needle at point C, in what direction would the needle point?

3. Did the compass needle move clockwise or counter clockwise?

4. What voltages do we need to change to have the compass needle rotate in the opposite direction?

5. How many “steps” does it take to make a 360° rotation?

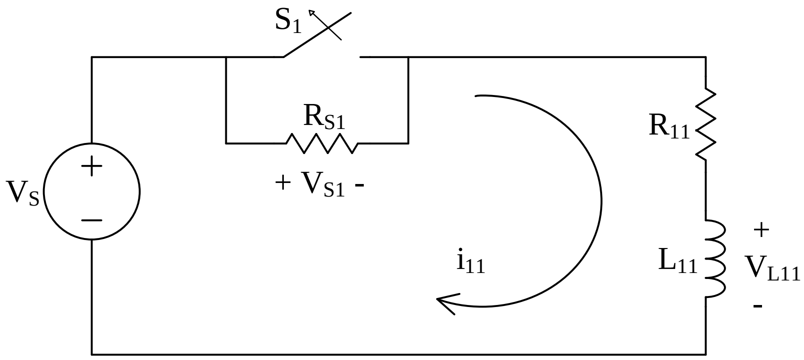
6. How might you add the number of steps for a 360° rotation? Identify two distinct approaches.

7. Why might you want to add steps?

8. What are the engineering design considerations that must be addressed as a new stepper-motor assembly is designed for a new commercial application?

Stepper-Motor Interface Circuit Model

There are a number of significant challenges facing the computer engineer who must interface a stepper motor to a microcontroller. For example, consider the following transient circuit response problem.



R_{S1} = Shunt Resistance of Switch

$R_{S1} >> R_{11}$

<u>Case 1</u>: *Switch closes at t = 0*

$$i_{11}(0^-) = i_{11}(0^+) = V_S/R_S \approx 0A \quad (3)$$
$$i_{11}(t) = (V_S/R_{11})e^{-t/\tau}, \text{ where } \tau = R_{11}/L_{11} \quad (4)$$
$$V_{L11}(t) = V_s e^{-t/\tau} \quad (5)$$

<u>Case 2:</u> *Switch Opens at t = 0*

Because currents through an inductor cannot change discontinuously,

$$i_{ll}(0^+) = i_{11}(0^-) = V_S/R_{11} \quad (6)$$

Applying Kirchhoff's Voltage Law (KVL) around the loop at time $t = 0^+$ yields:

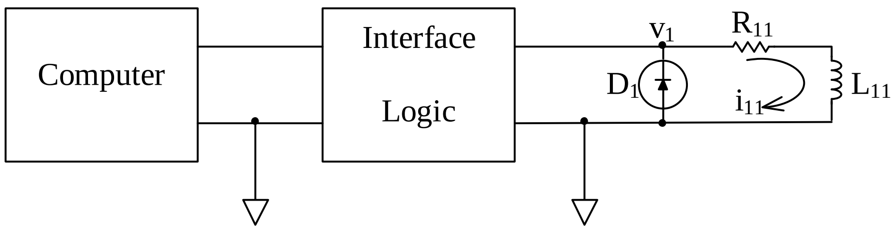
$$-V_S + V_{S1} + R_{11}i_{11} + V_{L11} = 0 \quad (7)$$
$$-V_S + R_{S1}i_{11} + R_{11}i_{11} + V_{L11} = 0 \quad (8)$$
$$V_{L11} = V_S - (R_{S1} + R_{11})i_{11} \approx V_S - (R_{S1}/R_{11})V_S, \text{ when } R_{S1} >> R_{11} \quad (9)$$
$$V_{L11} \approx -(R_{S1}/R_{11})V_S \approx -(1M\Omega/0.1k\Omega)V_S \approx \mathbf{-10^4 V_S} \quad (10)$$

These large voltages will destroy the solid-state switch.

Diode Protection

There exists a very standard solution to the problems which arise due to the desire to rapidly switch electrical currents in circuits containing inductive loads. The following example illustrates the solution.

The winding of an electromagnet can be modeled as a resistance in series with an inductance, as illustrated in the figure. Under computer control, current i_{11} is to be controlled by controlling voltage v_1. As we saw with the stepper-motor example, i_{11} will assume one of two steady-state values—i.e., $i_{11} = 0A$ and $i_{11} = V_S/R_{11}$. In the circuit illustrated, diode D_1 protects the interface logic from large transient voltages.



<u>Case 1</u>: $v_1 = 0V$

The voltage drop across the diode is $v_1 = 0V$, and the diode is turned off (an open circuit). Also, $i_{11} = 0A$.

<u>Case 2</u>: $v_1 = V_S$, where $V_S > 0V$

The voltage drop across the diode is $v_1 = V_S$, and the diode is turned off (an open circuit). Also, $i_{11} = V_S/R_{11}$.

<u>Case 3</u>: At $t = 0^-$, $v_1 = V_S$, where $V_S > 0V$. Then at time $t = 0$, the interface logic switches and presents a high impedance to the rest of the circuit.

At time At $t = 0^+$, the current $i_{11} = V_S/R_{11}$ and passes through the diode. The diode is forward biased with $v_1 = -0.7V$. With time, i_{11} drops to 0A, v_1 returns to 0V and the diode is turned off (an open circuit).

This is the solution to only one interfacing problem. Another common problem is the fact that actuators, such as the stepper motor, do not operate at standard “logic voltages.” This problem will be discussed as we investigate the electrical properties of a specific stepper motor and its computer-interface requirements.