

Hall Effect and Sensor Technologies

by

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Abstract

This paper navigates the intricate landscape of the Hall effect, delving into its fundamental role in understanding electron behavior within magnetic fields. Beginning with an exploration of the underlying principles, the study reveals the dynamic interconnection between Lorentz force and electron movement. Progressing to the hallmark manifestations of Hall voltage and the accumulation of charge, the narrative unveils the intrinsic nature of this phenomenon. Transitioning seamlessly, the focus shifts to the crucial role of materials in Hall effect sensors, acting as a conduit to a detailed examination of diverse applications. From switches and latches to linear sensors and brushless DC motors, each application represents a unique facet of the hall effect's versatility in modern technology. This comprehensive study contributes not only to the theoretical understanding of electron dynamics but also sheds light on practical implementations, propelling technological advancements across various fields.

Historical Background

In 1879, Edwin Hall, a young graduate student at John Hopkins University, stumbled upon a discovery that altered the course of science and technology. His experiment involving electromagnets and a sliver of gold foil ended in the realization of the Hall effect. Initially applied in magnetism and electricity studies, its power emerged in the mid-20th century with semiconductor and transistor advancements. This birthed Hall effect sensors, small and useful devices that are found in countless technologies, from cars to smartphones. Hall's pioneering work, recognized with Nobel prizes, continues to shape modern technological innovation.

Hall Effect: Understanding Electron Behavior in Magnetic Fields

The Hall effect is a phenomenon that occurs when a conducting material encounters a magnetic field perpendicular to the current flow. Electrons, being charged particles, experience Lorentz Force when interacting with a magnetic field. This force acts perpendicular to both the direction of electron motion and the applied magnetic field, and results in the deviation of electron paths.

Lorentz Force and Electron Movement

The Lorentz Force ($\vec{F}_{Lorentz}$) is given by $\vec{F}_{Lorentz} = q \cdot \vec{v} \times \vec{B}$, where q is the charge of the electron, \vec{v} is its velocity, and \vec{B} is the magnetic field strength. In the context of the Hall effect, this force causes electrons in a conductor to collect on one side, generating an accumulation of charge on that side.

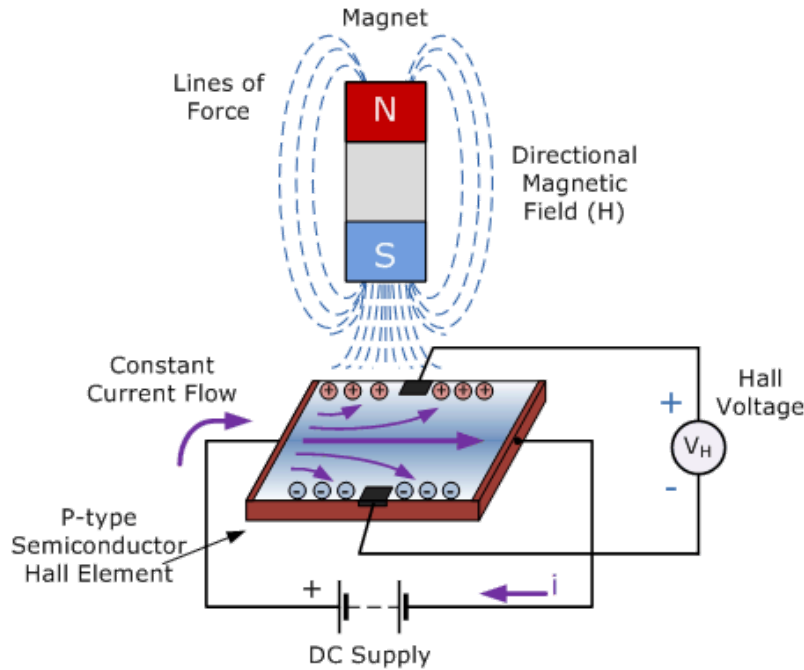


Figure 1 - Visual Representation of the Hall Effect. Wojciechowicz, Tyler. "Tech 101 from Symmetry Electronics: Hall Effect Sensors." *Electronics*, 13 Oct. 2017

Hall Voltage: Accumulation of Charge

The accumulation of charge results in a measurable voltage difference across the material, called the Hall voltage, U_y . It's perpendicular to both the current flow and the magnetic field direction, and its magnitude is proportional to the strength of the magnetic field, the current, and the shape of the conductor. For rectangular conductors, the Hall voltage is given by

$U_y = R_H \left(\frac{I_x}{t} \right) \vec{B}$, where I_x is the current, \vec{B} is the magnetic field strength, and R_H is the Hall coefficient.

Hall Effect Sensors: Materials

These sensors rely on semiconductor materials for their Hall elements, each offering their own characteristics. Shown in the table below, we can see that Indium antimonide (InSb) stands out for its sensitivity, this is ideal for ultra-precise measurements. Indium arsenide (InAs) also provides high sensitivity, balancing performance and reliability. Gallium arsenide (GaAs) offers

low drift, ensuring stable and consistent readings over time. Silicon (Si) isn't used in Hall elements due to its lower sensitivity but finds utility in Hall Integrated Circuits (ICs). Selecting the right semiconductor material is important to match the sensor's performance to specific application requirements, impacting sensitivity and temperature stability.

Table 1. Semiconductor materials



Material	Electron Mobility [cm ² /Vs]	Sensitivity	Band Gap [eV]	Temperature Characteristics	AKM Products
InSb	75000		0.16		HW series
InAs	35000		0.33		HQ series*
GaAs	8000		1.43		HG series
Si	1450		1.12		

Figure 2 - Semiconductor Material Sensitivity and Temperature characteristics. Asahi Kasei Microdevices (AKM)

Hall Sensor Applications

Switch, Latch, and Linear Sensors

Hall sensors have several functions in electronic systems, acting as switches, latches and linear sensors based on their applications. In a digital switch application, the Hall sensor works like an on/off switch, giving a binary output (high or low) based on the proximity and strength of the magnetic field. This happens as the magnet approaches the sensor and triggers ON, or moves away returning to an OFF state. Switches are found in laptops and refrigerator doors.

The latch acts similar to the switch, except it requires an alternating magnetic field polarity to switch its output voltage state. Applications include motor commutation, where the rotational aspect is great for continuously monitoring the position of a rotating shaft.

For linear analog signal detection, the Hall sensor provides a continuous output that varies in the magnetic field's strength or position. The linear response can be thought of as a

proximity sensor, whereas as the magnet approaches the Hall sensor, a light will illuminate brighter. Linear sensors can accurately measure the displacement of an object. The active state (ON) is referred to as B_{OP} and the inactive state (OFF) can be referred to as B_{RP} . Below are the respective transfer functions of the three Hall-effect sensors discussed.

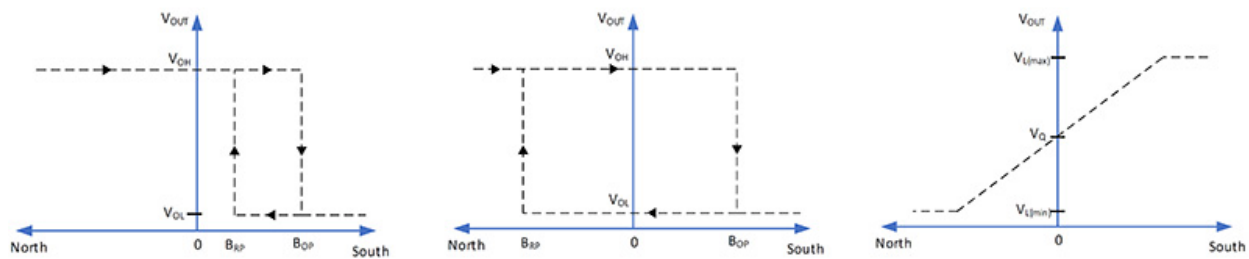


Figure 3 - Switch, Latch, and Linear Sensor Transfer Functions. Soltero, Manny. "What Is a Hall-Effect Sensor?" SSZT164 Technical Article | TI.Com

Circuit Layout and Components

Hall Sensor - The core component that detects the presence, strength, and polarity of a magnetic field. It generates an electrical signal (Hall voltage) proportional to the strength of the magnetic field it encounters.

Output Leads - These connections relay the output signal from the Hall sensor to the rest of the circuit. They convey the measured Hall voltage to subsequent stages for processing.

Regulator - A regulator is included to stabilize the input voltage supplied to the circuit. It ensures consistent and reliable power supply and ensures the sensor's performance.

Schmitt Trigger - This component converts the analog signal from the Hall sensor into a digital output and ensures that the digital output remains stable.

High Gain Op-Amp - The op-amp amplifies the Hall voltage signal. Its high gain helps boost the signal to a level that allows for processing or driving other components in the circuit.

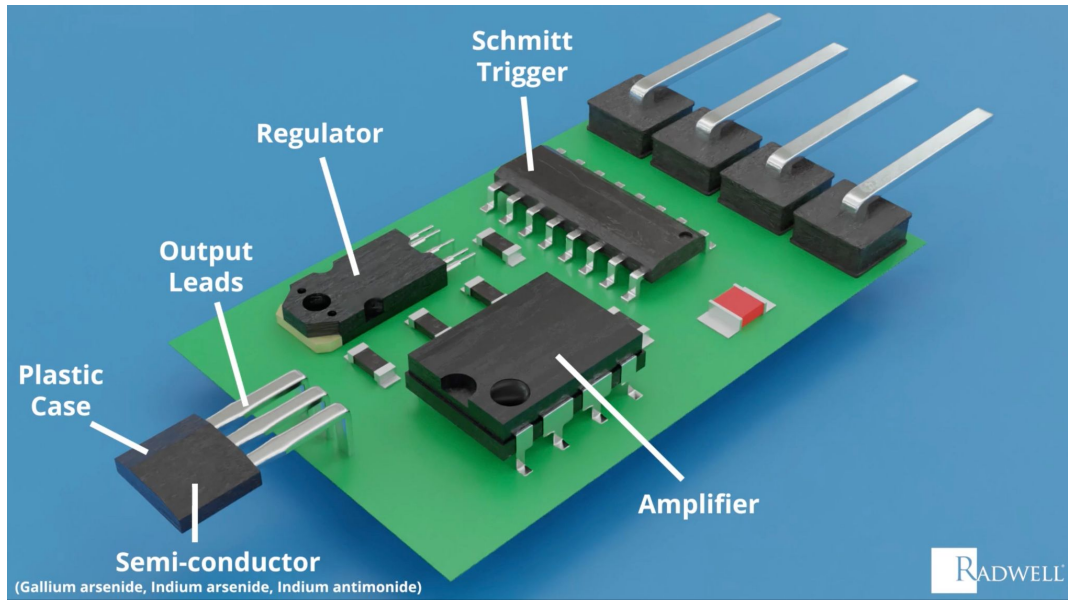


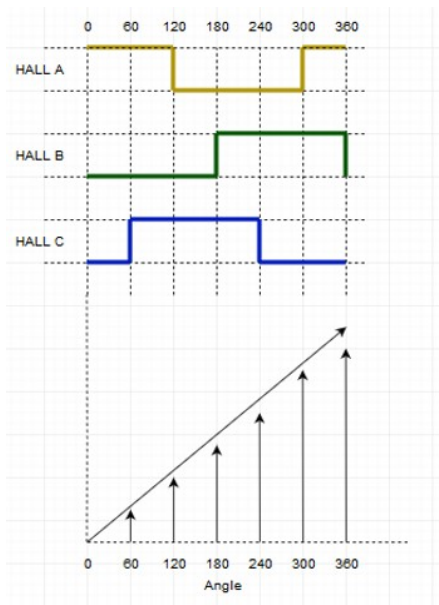
Figure 4 - Hall-effect Sensor Circuit. Radwell International. "How It Works: Hall Effect Sensor." YouTube, 5 Apr. 2023

Application in Industry - Brushless DC Motors

Throughout our studies, we've taken on internships to apply concepts learned in class to real-world applications. In these internships, concerning two industries—Aeronautics and Oil and Gas—we found a common application used in both: Brushless DC (BLDC) motors. BLDC motors drive pumps and compressors in oil and gas refineries. They're also found in systems such as actuators and avionics due to their size, weight efficiency, and reliability. These motors rely on Hall-effect sensors for precise position tracking, strategically positioned 120 degrees apart on either the rotor or stator. The sensors detect the motor's position within its 360-degree rotation. Hall-effect sensors generate digital signals to monitor the motor's rotation, enabling control of motor operations, and aiding in regulating speed, direction, and torque.

How it works

Hall-effect sensors convert magnetic field changes into signals read by the control system. This data allows accurate calculation of the motor's angle and speed. When the rotor's magnet passes a sensor, it generates a signal—either low or high—based on whether it's the



North or South pole of the rotor. As the rotor moves across all three sensors, they alternately switch between low and high signals, indicating the rotor's position every 60 degrees. A typical BLDC Motor Controller, shown in the diagram, displays three lines connecting the motor to the controller, denoting the signals transmitted by the three Hall Effect Sensors.

Figure X - Signals of the three Hall monitors in the motor. "Hall Effect Sensor and Its Role in a Motor Controller." Embitel, 30 Mar. 2023

Circuit Diagram

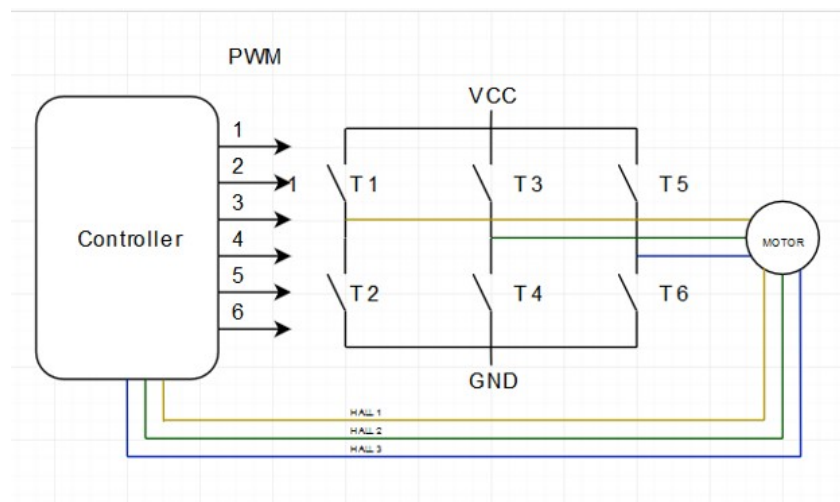


Figure 5 - Circuit Layout. "Hall Effect Sensor and Its Role in a Motor Controller." Embitel, 30 Mar. 2023

The diagram illustrates a typical BLDC Motor Controller with three lines conveying signals from Hall Effect Sensors in the motor to the controller. These sensors distinguish between positive and negative charges moving in opposite directions. They convert the detected magnetic field into analog or digital signals, providing crucial input to electronic systems, particularly motor control systems.

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