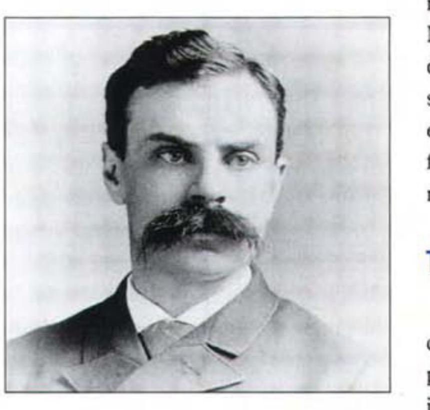
AN INTRODUCTION TO THE HALL EFFECT

Early Magnetics

Far back in the recesses of time man discovered the loadstone (Lodestone) in Magnesia in the district of Thessaly, Greece (hence the word "magnet"). They soon learned about its tendency to orient itself with the pole star, and used it as a guide to and from far away lands.

The first manufactured permanent magnets were needles that had been rubbed on the loadstone. The first electro-magnet was constructed in 1825, and the first scientific treatise in the nature of magnets was published 20 years later.

By the time that first electromagnet was built, permanent magnets had been in use for a variety of experimental and practical uses. Their strength was classified by the ratio of their weight to their lifting strength.



Photograph of Dr. Edwin Herbert Hall, 1887, courtesy of the Harvard University Archives

The Discovery of "Hall Effect"

Edwin Herbert Hall discovered the "Hall effect" in 1879 while working on his doctoral thesis in Physics under the supervision of Professor Henry A. Rollin.[1] Dr. Hall was pursuing the question as to whether the resistance of a coil excited by a current was affected by the presence of a magnet. Through a myriad of experiments and failures, Hall discovered that a magnetic field would skew equipotential lines in a current-carrying conductor. This effect is observed as a voltage (Hall voltage, V_H) perpendicular to the direction of current in the conductor.

Hall conducted an experiment by putting a thin gold leaf on a glass plate and then tapping off the gold leaf at points down its length. He then conducted other experiments using various materials in place of the gold leaf, and various experimental placements of tapping points. In 1880, full details of Hall's experimentation with this phenomenon formed his doctoral thesis and was published in the *American Journal of Science* and in the *Philosophical Magazine*.[2]

Kelvin, himself a most distinguished scientist, called Hall's discovery comparable to the greatest ever made by Michael Faraday. The magnitude of this discovery is even more impressive considering how little was known about electricity in Hall's time. The electron, for instance, was not identified until more than 10 years later.[3]

The Theory of the Hall Effect

The action of the Hall effect in a semiconducting medium is adequately explained by quantum physics. However, in spite of its shortcomings, the classical approach is chosen here for its brevity.

A particle with charge Q, velocity, $\bar{V}$, and moving within a magnetic field, $\bar{B}$, will experience the Lorentz force, $F=Q(\bar{V}x\bar{B})$. The force direction is mutually perpendicular to the directions of the particle velocity and the magnetic field. If a long, flat current-carrying conductor is placed in a magnetic field,

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the moving charges will experience a net force mutually perpendicular to the direction of the current flow (longitudinal conductor axis) and the magnetic field. Under the influence of this force, the electrons will "pile up" on one edge of the conductor, and positive charges will gather on the other edge. An uneven lateral charge distribution results and gives rise to an electric field, $\bar{E}$, which exerts a force, $\bar{F}=Q\bar{E}$, opposite in direction to the Lorentz force. At equilibrium, the resultant forces balance (Fig. 2). This field, superimposed on the $\bar{E}$ in the direction of the current flow, yields the skewed equipotential lines first noted by Hall (Fig. 1). The relation between the voltage, current, and magnetic field can be generalized as follows:

$V_H = \gamma IB$
V_H = Hall voltage
γ = a constant product sensitivity
I = Hall current
B = magnetic field perpindicular to Hall plate surface

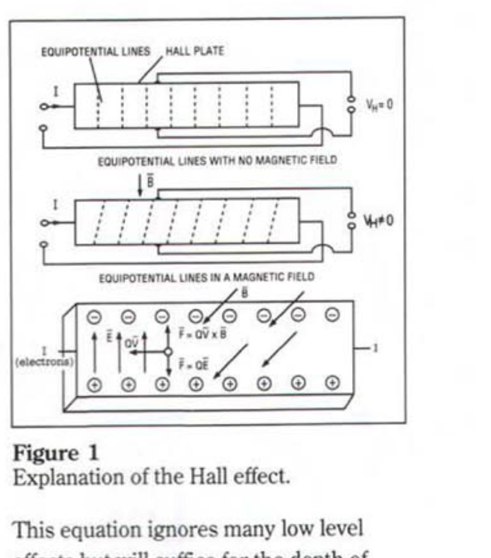


Figure 1
Explanation of the Hall effect.

This equation ignores many low level effects but will suffice for the depth of this discussion.

Note: All $\bar{B}$ fields in the article refer to the component of the external $\bar{B}$ field that is normal to the surface of the Hall plate. A more general equation for Hall voltage is $V_H = \gamma IB \cos\theta$, where θ is the angle between B and the normal to the Hall plate surface.

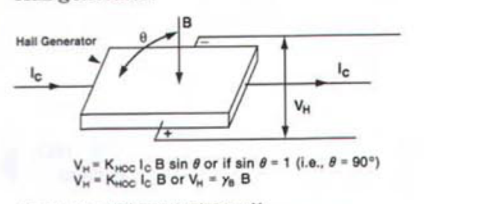
THE HALL GENERATOR

From Theory To Practice

The "Hall effect" remained a laboratory curiosity until the latter half of this century because materials available prior to recent years only produced low levels of Hall voltage. With the advent of semiconductor technology and the development of various III-V compounds, it became possible to produce Hall voltages many orders of magnitude greater than with earlier materials. Thus, semiconductor technology launched the practical design and production of the Hall generator.

What Is A Hall Generator

A Hall generator is a four-terminal, solid-state device capable of producing an output voltage, V_H, proportional to the product of the input current, I_C, the magnetic flux density, B, and the sine of the angle between B and the plane of the Hall generator.



$V_H = K_{HOC} I_C B \sin\theta$ or if $\sin\theta = 1$ (i.e., $\theta = 90°$)
$V_H = K_{HOC} I_C B$ or $V_H = \gamma_B B$

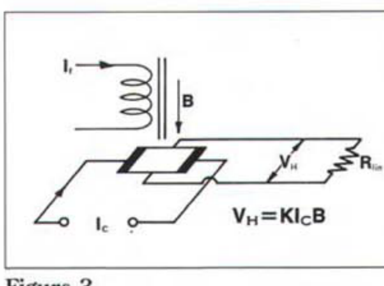
where: V_H = Hall output voltage, mV
$K_{HOC} = \gamma_{IB}$ (open circuit product sensitivity constant), mV/mA kG
γ_B = magnetic sensitivity (loaded or unloaded) at a specified control current, mV/kG
I_C = control current, mA (ac or dc)
B = magnetic flux density, kG (ac or dc)

Figure 2

A reversal in the direction of either the magnetic field or the control current will result in a polarity change of V_H. A reversal in the direction of both will keep

1. C.L.Chin and C.R.Westgate (Editors), "The Hall Effect and Its Applications," Plenum Press, New York, 1979, p. 535.
2. Ibid., p. 523
3. Charles Couleston Gillespie (Editor), "Dictionary of Scientific Bibliography," Charles Scribner's Sons, New York, 1970, p. 51.

See MIL-STD-793-1 (WP) for definitions



This schematic representation illustrates both the measuring and multiplying capabilities of a Hall generator. By holding I_c constant, V_H becomes a direct function of B, the magnetic flux density. If both I_c and B are variable, V_H is proportional to the product of the two functions. Holding B and I_c constant, V_H becomes a function of the angle between B and the plane of the Hall-generator active area.

The devices listed on the following pages are standard and available from stock.

Special units are available to fit your application.

Figure 3

the polarity the same. By holding the control current constant, the Hall voltage may be used to measure magnetic flux density. Multiplication may be accomplished by varying both the control current and the magnetic field.

Materials

The Hall effect is basically a majority carrier mechanism depending on the bulk-material properties of the semiconductor material. Unlike transistors and diodes, it is completely independent of surface effects, juncton leakage currents and junction threshold voltages. These factors account for its high stability, reproducibility and reliability when compared to other semiconductor devices.

To obtain a high output voltage the active element must have a high Hall coefficient, R_H. Also, since the output is proportional to the current density through the element, its resistance should be as low as practical to prevent excessive heating. Since the noise output is essentially thermal[4], low resistance is also an important requirement for devices to be used at very low signal levels. Some of the semiconductor materials used for Hall generators are indium antimonide (InSb), indium arsenide (InAs) and gallium arsenide (GaAs). GaAs generators have high output and very high resistance making them relatively noisy and the temperature coefficient of the output voltage is less than -0.1%/°C. InSb has high output and low resistance, but the temperature coefficient of the output voltage is about -1%/°C. InAs has less output than InSb, but its temperature coefficient is less than -0.1%/°C and its resistance is also low. These considerations make InAs the most suitable material for many Hall effect applications.

InAs Hall generators may also be made of deposited thin films. These units do not exhibit the same low resistance and high mobilities as their bulk-material counterparts, but they do offer advantages which may be realized in many applications. These advantages include lower current requirements for comparable output voltages, and significantly lower cost. For those applications where excellent linearity and stability are required, bulk-material Hall generators are recommended.

Typical Applications Of Hall Generators

The following are just some of the many applications where Hall generators are used:

- Magnetic Card Readers
- Proximity Sensors
- Rotary Speed Sensors
- Watt Measurement
- Multipliers
- Magnet Field Measurements
- Electrical Power Measurements
- Current Sensors
- Brushless dc Motors
- Compasses
- Gaussmeters
- Watt-hour Meters
- Permanent Magnet Measurements
- Air Gap Measurements
- Magnetic Circuit design
- Flux Leakage Measurements

- Nondestructive Memory Readouts
- Linear/Angular Transducers
- Magnetic Tape Heads
- Guidance Systems
- Ignition Systems

Typical Shapes and Sizes

Hall generators are available in a wide variety of shapes and sizes for adaptability to many different applications. The two basic types are transverse and axial, as illustrated in Figure 4.

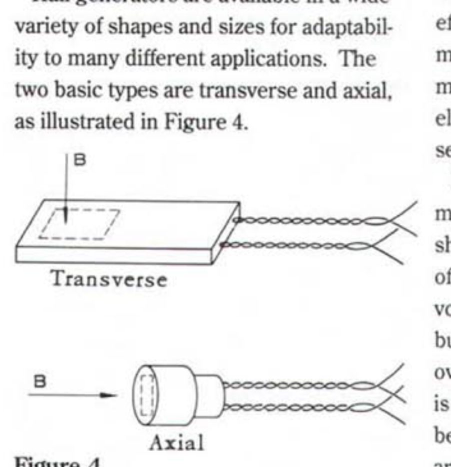


Figure 4
The two basic types of Hall generators are transverse and axial.

The transverse type is useful where the field must be measured in thin gaps and for multiplier applications. The axial type must be used where the field is parallel to the axis of a hole, such as in traveling wave tubes or solenoids. Standard transverse probes as thin as .006" and axial probes as small as .063" in diameter are available.

Bulk-material Hall plates may be sandwiched between ferrite pieces to obtain effective air gaps less than .003". This may be useful in applications requiring maximum magnetic efficiency, such as electronic compasses and proximity sensors.

For a Hall generator to accurately measure flux density, the Hall plate area should be smaller than the cross section of the field to be measured. The output voltage is proportional to flux density, but a Hall plate is not equally sensitive over its entire area. If a high resolution is important, the Hall plate area should be small. Active areas as small 0.010" are available, while even smaller ones have been made. Units with somewhat larger Hall plates are usually less expensive because they are easier to make, and since they can generally handle larger currents they can produce more output voltage and dissipate more power.

4. Epstein, M., et al, "Principles and Applications of Hall-Effect Devices", Proceedings of the National Electronics Conference, 1959, Vol. 15, p. 241.
5. Final Engineering Report on Hall Effect Device Investigation", Device Development Corporation, Weston 93, Massachusetts, Contract No. NOBsr-72823, July 1, 1958 to February 28, 1959, pp. 12-17.