The Lenkurt Demodulator

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THE HALL EFFECT

A simple electrical phenomenon first observed in 1879 by physicist Edwin Hall, is now the center of considerable new interest in communications research. For many years, the Hall effect was hardly more than a laboratory curiosity, little used for any practical purpose. Today, this has changed. New semiconductor materials have opened the way to simpler and better means of performing many important communications functions with Hall effect devices. This article reviews the Hall effect and some of its applications.

One of the oldest and most fundamental electrical effects is the sideward thrust imposed on a current-carrying conductor in a magnetic field. The galvanometer, the voltmeter, and the electric motor all operate on this principle.

In the course of conducting basic research on the nature of electrical conduction, Hall reasoned that it was not the conductor, but the mobile electric charges flowing through it that were deflected by the magnetic field. Since the current carriers were trapped within the conductor, they, in effect, dragged the conductor with them.

Hall believed that there should be a greater accumulation of carriers at one side of the conductor than at the other, and that this should produce a measureable voltage across the two sides of the conductor. If such voltage could be detected, its polarity and magnitude would yield important information about the basic nature of electrical conduction.

Hall set up his experiments as shown in Figure 1. The conductor was a very thin foil of gold which passed at right angles through the field of a powerful electro-magnet. A sensitive galvanometer was connected across the two edges of the ribbon where it intercepted the magnetic field.

When a current was passed through the length of the ribbon, but with the electromagnet not energized, no voltage could be detected between the two edges of the conductor. When the magnet was energized, a definite current was observed to flow, and it was found to be directly proportional to the strength of

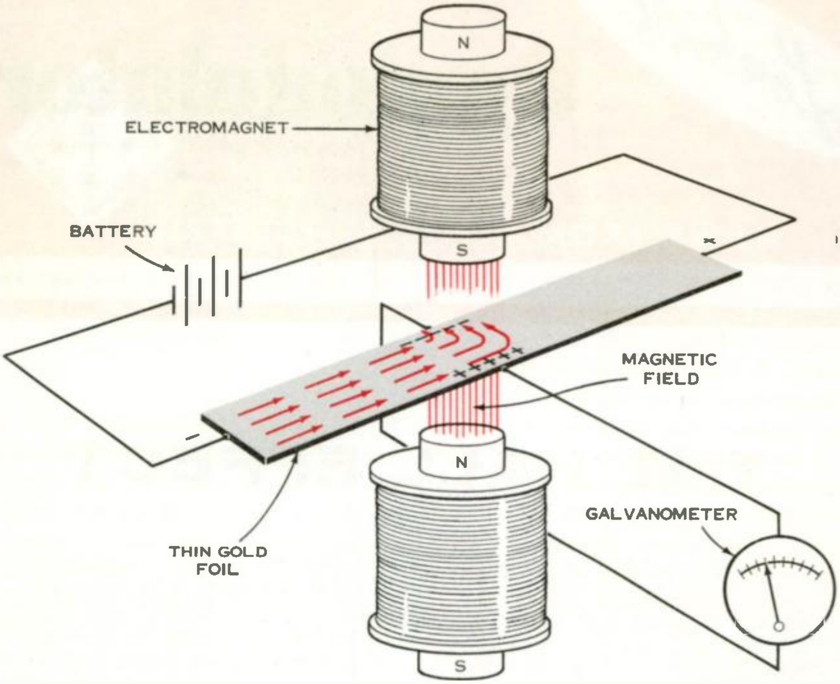


Figure 1. Original Hall experiment measured deflection of electrons in conductor by magnetic field. This important experiment contributed to basic knowledge by the nature of electrical conduction, and paved the way for future semiconductor developments.

the magnetic field and the strength of the current carried by the conductor.

This historic experiment added considerably to our knowledge of electricity and conduction. Although the Hall effect was easy to duplicate in the laboratory, it was too weak for any practical use. The voltage developed across the width of the conductor was in the order of a microvolt, and amplifiers had not yet been invented.

Today, the Hall effect has received new life. If a semiconductor material is used instead of a good conductor such as gold or copper, the Hall voltage developed across the material may be a volt or more, and of sufficient power to energize a sensitive relay without requiring amplification.

Practical Uses

A wealth of ideas for using Hall devices has appeared, and the number of new applications is growing rapidly. The device can be used as a modulator or demodulator, amplifier, magnetic fluxmeter, wattmeter, computer function multiplier, sensor or readout for magnetic drum or tape, spectrum analyzer, discriminator, microwave isolator, ultrafast switch, and many others.

The "Hall Generator" or "Halltron," as it has been called, brings to these applications some rather remarkable characteristics. For instance, the inherent frequency response of a Hall effect device is probably greater than that of any other known device — from dc up to about 10^{12} cycles per second— a million megacycles bandwidth! There is no bottom frequency limit, and the upper frequency limit is determined by the time required for the current carriers to re-orient themselves to follow a changing electrical field. Actually, the practical frequency limit may be much lower. A limit is set by the electrical characteristics of the leads and the physical package. The problem of varying the magnetic input may impose very great frequency limitations.

Another unique property of the Hall device is its linearity. The basic device is equivalent to a resistor in this respect, so long as temperature effects are allowed for. Unfortunately, many semiconductors suitable for use in Hall devices exhibit considerable temperature sensitivity. Since the device is not very efficient in its use of power, the internal temperature of the material may change during operation. This is very slow, however, and does not result in significant distortion at frequencies above a few cycles per second.

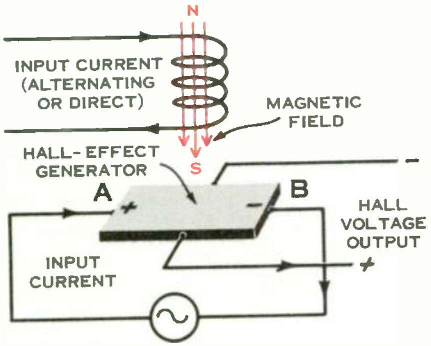


Figure 2. Modern Hall-effect device produces output voltage proportional to the product of magnetic field strength and input current (A and B leads).

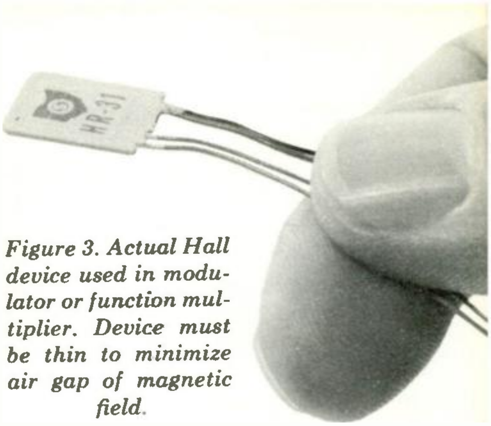


Figure 3. Actual Hall device used in modulator or function multiplier. Device must be thin to minimize air gap of magnetic field.

OHIO SEMICONDUCTORS

The basic device consists of a thin slab of semiconductor material with leads attached to the center of each edge, as shown in Figure 2. If a direct current is passed through the slab by means of leads A and B, and a magnetic field is passed through the device at right angles to its surface, an output voltage will appear across the remaining pair of leads. This voltage will be directly proportional to the product of the magnetic input and the current input.

If the magnetic input is varied according to some frequency or signal, such as a carrier frequency, and another signal is applied to the current leads (A and B), the device will behave as a balanced modulator, producing sum-and-difference products — upper and lower sidebands — but with both input signals suppressed some 80 to 100 db.

If an incoming signal is applied to both the magnetic and current inputs, the device becomes a square-law detector, producing a d-c output which is directly proportional to the square of the amplitude of the signal.

If the incoming signal is applied only to the current leads, and a sine wave of the same frequency as the input signal is applied to the magnetic input, the device becomes a linear detector.

An important difficulty with such circuits is the "inertia" of the magnetic input circuit. Even with the most sensitive materials, such as indium antimonide, magnetic flux densities in the order of 1000 gauss are required. As the signal frequency increases it becomes rapidly more difficult to build up a strong field and then reverse it at the signal frequency rate. Even if ample power is available, hysteresis, eddy currents, and similar problems become increasingly formidable. Ferrite magnets may be used to increase operating frequency somewhat, but still don't allow operation at frequencies as high as a megacycle.

The physical thickness of the Hall device affects the upper frequency limit by determining the minimum air gap of the magnet. The wider the gap, the more ampere-turns required to achieve a given flux density.

The Hall device is ideal for certain types of electrical measurement. An ammeter may be built which measures the current flowing through a wire without opening the circuit to insert a meter. Figure 5 diagram one way of doing this. A loop or yoke of magnetic material, hinged so that it may be slipped around the conductor, concentrates some of the magnetic field surrounding the conductor through a Hall device. If a series current is passed through the Hall device, an output voltage will be obtained that is directly proportional to the current flowing through the conductor under measurement.

If the series current required by the Hall device is supplied by the circuit being measured, the device becomes a wattmeter, since the current through the Hall device will be proportional to the voltage in the conductor, and the magnetic field will be proportional to its current.

As indicated above, the most severe frequency limitation is imposed by the magnetic field. This limitation no longer applies if the magnetic field is the quantity being measured or detected. Hall effect devices have been used in magnetic tape readers. An unusual characteristic of the Hall device in this application is that it is not necessary to move the tape past the sensing head, as in the case of inductive tape readers. The Hall device can sense the presence or absence of a recorded signal even with the tape motionless.

The Hall device has been used in a microphone having particularly good low frequency response. Sound waves cause a diaphragm to vibrate, thus moving the Hall device in and out of the magnetic field. Similarly, instantaneous flux in electrical motors has been measured by Hall devices. It makes an ideal

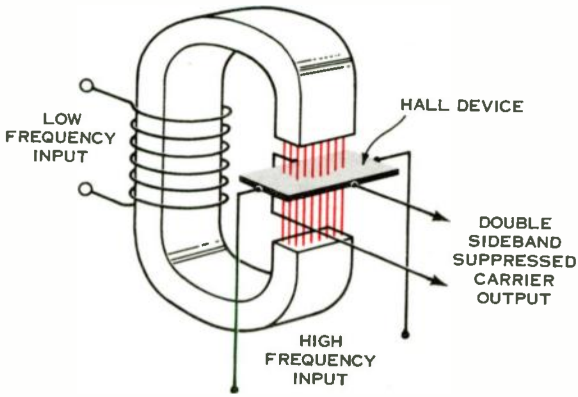
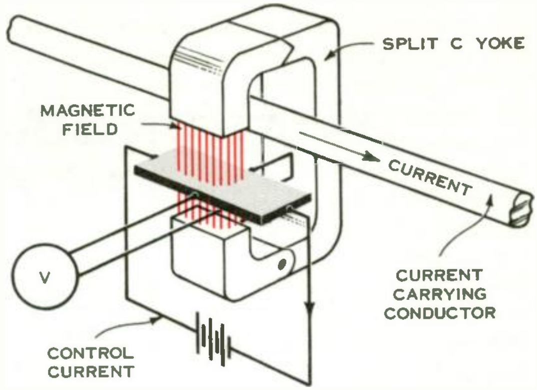


Figure 4. Simplified diagram of a Hall device modulator suitable for carrier applications. Magnetic input is restricted to relatively low frequency. High frequency input is limited by electrical characteristics of leads and physical structure.

Figure 5. One possible design for Hall-effect ammeter that would operate without breaking the circuit to be measured. C-yoke collects field around conductor, concentrates it through Hall device.



telemetering sensor for variables such as air pressure or mechanical strain, which may change at very slow rates.

Materials

Although the Hall effect occurs in all conductors, it becomes practical only when a suitable semiconductor material is employed. In a good conductor, there is a vast surplus of free electrons, and these are free to neutralize the Hall voltage. If a semiconductor is used, the number of current carriers (electrons or holes) is far lower than in a conductor, and the resistance of the material is much greater.

The Hall voltage that can be developed in a semiconductor material is proportional to the *mobility* of the current carriers (electrons in *n* material, holes in *p* material). The term *mobility* defines how readily the carriers respond to an applied field. In general, materials which show high carrier mobility are particularly sensitive to temperature effects. The more sensitive the device to applied current or magnetic field, the lower the impedance of the device. Typical Hall devices may exhibit an output impedance well under an ohm.

Conclusions

The Hall effect is no universal answer to the needs of the communications engineer. However, the simplicity, reliability, linearity, and tremendously high bandwidth of the device make it particularly attractive for certain applications. The device has particular merit as a modulator and as a low-frequency transducer. Perhaps the frequency limitation on the magnetic input may be overcome by taking advantage of the magnetic fields which exist in waveguides and resonators. Once such problems are solved, the Hall effect may prove as useful and versatile as the electron tube and transistor. ●

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RADIO NOISE AND BANDWIDTH

Several types of radio noise must be overcome to obtain useful radio communication. Intermodulation noise, although impossible to eliminate entirely, can be reduced as much as necessary by suitable equipment design. Thermal noise, on the other hand, is more difficult to deal with, since it is generated in all objects in proportion to their absolute temperature. The hotter the object, the greater the noise produced.

The development of masers and parametric amplifiers has led to receivers which contribute so little noise of their own that this thermal background noise sets the limit of their sensitivity. For this reason, it may be more convenient to express the noise performance of a receiver or system as "effective noise temperature" instead of "noise figure." Both are given in the nomogram on the next page.

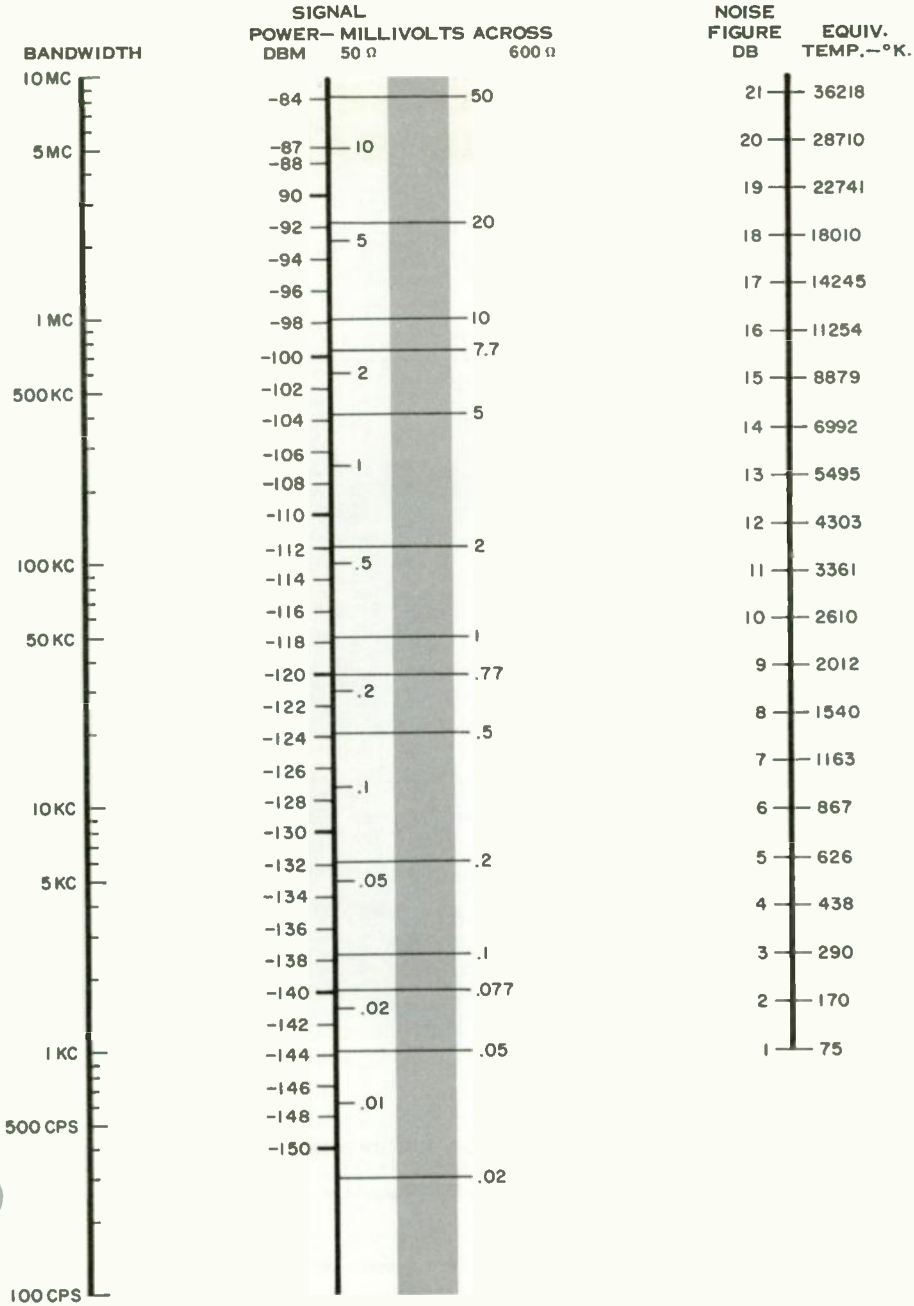
As a reference standard, the radio system is considered to have a nominal effective temperature (sometimes called "antenna temperature") of 290° Kelvin, which is 63° F. or 17° C., and this value was used in calculating the scale on the right in the nomogram. If any other reference temperature is used, the noise figure of the system may be recalculated using the formula

$$Noise\ Fig._{(db)} = \frac{T_{reference} + T_{effective}}{T_{reference}}.$$

Typical commercial microwave receivers have a noise figure of 10-15 db, according to frequency. This means that the receiver itself contributes some 10 to 30 times as much noise as it receives through the antenna, most of it originating in the first detector or mixer and the first IF amplifier.

Since thermal noise (which is actually energy of all frequencies) is distributed uniformly across the frequency spectrum, the greater the bandwidth of the receiver, the more noise received. Thus, wider bandwidth in a receiver has the effect of raising the noise threshold and, therefore, the signal level required to attain a given quality of transmission.

The center scale of the nomogram indicates the power or voltage of a signal barely detectable above the background noise, when receiver bandwidth and noise figure are known. This signal level, which might be termed "absolute noise threshold" is useful only as a comparative reference. This is the same as "tangential threshold," a radar term used to define the minimum pulse amplitude that could be detected above the background noise. This absolute noise threshold has no real meaning in an FM communications system. In such a system, the noise threshold is considered to be the "FM improvement threshold," that signal level where FM noise improvement first occurs—usually about 10 db above the "absolute" noise or tangential threshold. To obtain good quality transmission, even higher signal levels are required, always determined by the modulation index of the FM transmitter. •


BANDWIDTH
10 MC
5 MC
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10 KC
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500 CPS
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SIGNAL
POWER— MILLIVOLTS ACROSS
DBM 50 Ω 600 Ω
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11 3361
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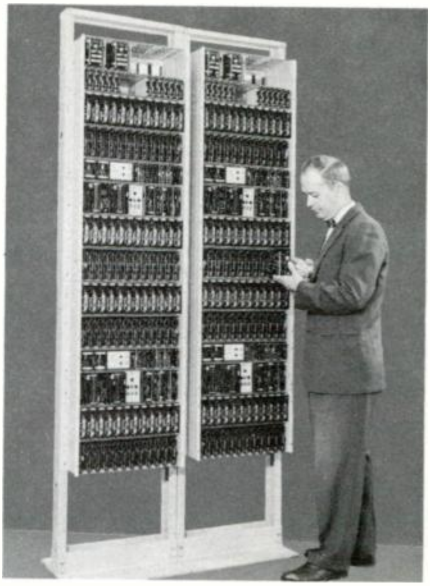

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