APPLICATIONS INFORMATION

Application Note **27705***

UNDERSTANDING BIPOLAR HALL-EFFECT SENSORS

by Joe Gilbert

There are three general categories of digital Hall-effect switches*. Unipolar, latching, and bipolar. Unipolar, and latching sensors appear to be well understood. However, bipolar Hall-effect sensors continue to mystify and confuse many designers and users. The following will review unipolar and latching characteristics and provide an in-depth discussion of the Bipolar sensor.

Unipolar sensors

Unipolar Hall-effect sensors, often simply referred to as "switches", require a *single polarity magnetic field* for operation (see figure 1). When the magnetic flux density increases above the operate point (B_{OP}) most unipolar sensors will switch ON (output changing from high to low). When the flux density drops below the release point (B_{RP}) most unipolar sensors will switch OFF (output changing from low to high).

With few exceptions, unipolar sensors require a positive magnetic field (a south pole), directed towards the branded face of the sensor, for activation. Having said this, some special-purpose sensors do not meet this norm. For example, the Allegro dual-output UGN3235 has one output switching in response to a positive field and the second output switching in response to a negative field. Each output retains unipolar characteristics though the field polarities are opposite.

* A special type of unipolar sensor is the "omnipolar" sensor where the output is activated with *either* a north pole *or* a south pole. This type is not discussed here.

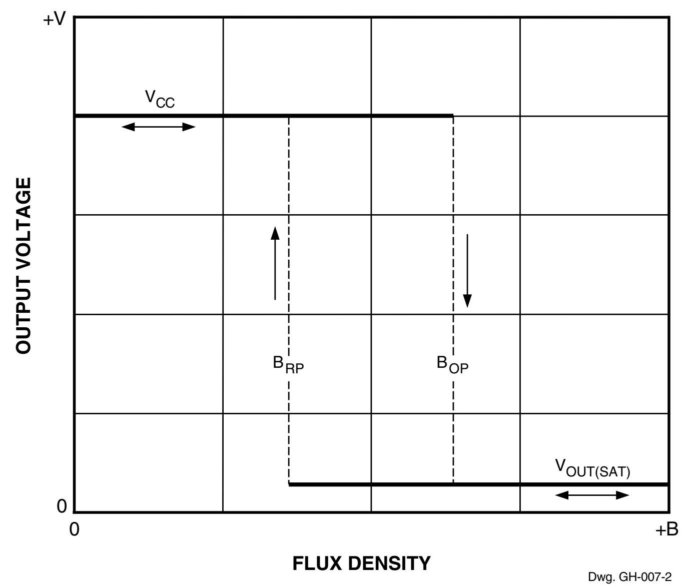

Figure 1. Unipolar (switch) characteristic

An important characteristic of a unipolar sensor is that this sensor will always power-up with its output in a known state for a magnetic field less than B_{OP} or will power-up in the opposite state for a magnetic field greater than B_{OP}. This characteristic is referred to as true-power-on state or TPOS.

Latching sensors

Latching Hall-effect sensors require *both positive and negative magnetic fields* for operation (see figure 2). Like the unipolar sensor, when the magnetic flux density increases above the operate point (B_{OP}) most latching sensors will switch ON (output changing from high to low), remaining in this state until a

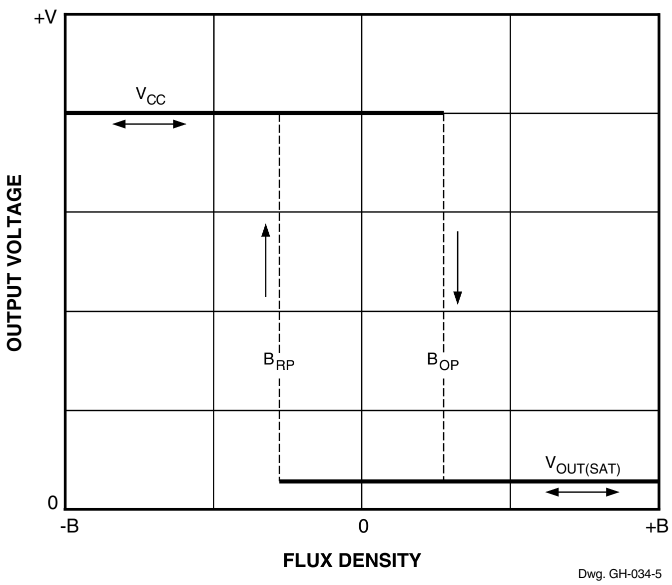

Figure 2. Latching characteristic

negative magnetic field, below (algebraic notation) the release point (B_{RP}), is applied. Thus the characteristic that once ON the output remains ON even as the magnetic field drops towards zero.

Latching sensors are designed for symmetrical operation. That is to say that the manufacturers design the switch points to be equal, but opposite polarities, i.e., if the actual operate point is +85 gauss, the release point should be –85 gauss. Today's latching sensors closely conform to this design target.

An important characteristic of the latching sensor is that, unless the sensor incorporates a power-up logic function, latching sensors may power up with the output in either an ON or OFF state if the magnetic field is near zero. If the field is $>B_{OP}$ or $<B_{RP}$ the sensor will assume the correct state. The Allegro A3197 sensor is an example of a latching sensor that has a guaranteed power-up state (OFF) regardless of the status of the magnetic field.

Bipolar sensors

Bipolar sensors are designed to be sensitive switches and are most often latching sensors but, bipolar sensors are not warranted to be classical latches as just described. If you aren't confused yet you soon will be.

It should first be stated that the term "bipolar" here refers to the function of the sensor and not to the silicon process that might have been used to produce it. Coincidently, there is a "bipolar" silicon process (majority and minority carriers, pnp and/or npn devices), and yes, traditionally this process has been used to produce very robust Hall-effect sensors, including bipolar sensors. Moving forward, most new sensor designs utilize a BiCMOS (bipolar plus CMOS) or pure CMOS process to achieve the circuit density necessary for improved functions and stability.

Back to the bipolar sensor. To appreciate why bipolar sensors were offered, one must go back several years, to a time when sensitive, low hysteresis, true latching sensors could not be produced … at least not with acceptable yields. The flip side of poor yields is high cost. A large market developed for sensors to commutate brushless dc motors and driving the demand was the need for low-cost sensors for the small fan markets. In a stroke of brilliance, a savvy marketing person rose to the occasion with the solution being the bipolar sensor. The bipolar sensor is a latch-like sensor with magnetic switch points being lowered to support the use of low-cost, low-strength, ring-magnet materials. Because, at the time, high sensitivity and true latching characteristics were not possible, the bipolar specification placed only outside limits on B_{OP} and B_{RP} without inside limits. From the specification one might incorrectly assume that the bipolar sensor is a latching sensor. Though this is the general case (a high percentage of bipolar sensors are indeed latches) a problem occurs with the 10% that are not latching. Within this small group are two types of sensors: 1) our friend the unipolar sensor, which, performance wise, we understand; and 2) a “negative switch”, which truly adds to the confusion (see figure 3). Let’s look at a typical bipolar Hall-effect specification and see if we can’t explain this better.

The following is excerpted from the popular UGL/UGN/UGS3132 bipolar switch specifications. Note the lack of the term “latch”.

Table 1. 3132 Magnetic characteristics

Characteristic	Symbol	Limits Min.	Limits Typ.	Limits Max.	Units
Operate Point	B_{OP}	—	32	95	G
Release Point	B_{RP}	–95	–20	—	G
Hysteresis	B_{hys}	30	52	—	G

From this specification we can see that this sensor operates between +95 gauss and –95 gauss and that hysteresis is typically 52 gauss. We can also see that the typical switch points are not symmetrical, basically to optimize manufacturing yields. Note that nothing in this specification warrants that this is a latch. (A latching specification will give a range for B_{OP} and B_{RP}, for example, B_{OP} +25 to +75 gauss, B_{RP} –75 to –25 gauss.) In fact, if the operate point of the 3132 is towards the high end of the specification, say +80 gauss, the hysteresis will still typically be 52 gauss (hysteresis remains very consistent for a particular sensor design) therefore the release point will be about +28 gauss. This sensor has unipolar characteristics. The other sensor that can squeeze into the distribution is the notorious negative switch. If the release point approaches its minimum value the sensor will be what is called a negative switch. If B_{RP} is for example –80 gauss, the hysteresis will still typically be 52 gauss therefore the operate point will be about –28 gauss. Did we say the operate point is negative? Yes, we did! And where is that marketing person when we need him? A negative switch is still a unipolar sensor. Rethinking power-up states may help us to understand the negative (unipolar) switch.

Table 2. Power-up states

Sensor Type	Power-Up State (zero field)
Unipolar Switch	Off
Latch	Either state*
Negative Switch	On

* Unless power-up logic is incorporated in the design.

Figures 3a, 3b, and 3c show the three possible operating modes of bipolar sensors.

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Bipolar sensor having (positive) unipolar characteristics

As shown in table 3, this sensor output will be OFF until the field is above B_{OP} and then remains ON until the field is less than B_{RP}. It only reacts to the south pole (positive field), turning ON and OFF as this pole passes the sensor. The north pole has no affect on the output of this sensor.

Bipolar sensor having latching characteristics

This sensor requires both poles — south to turn the sensor ON and north to turn the sensor OFF.

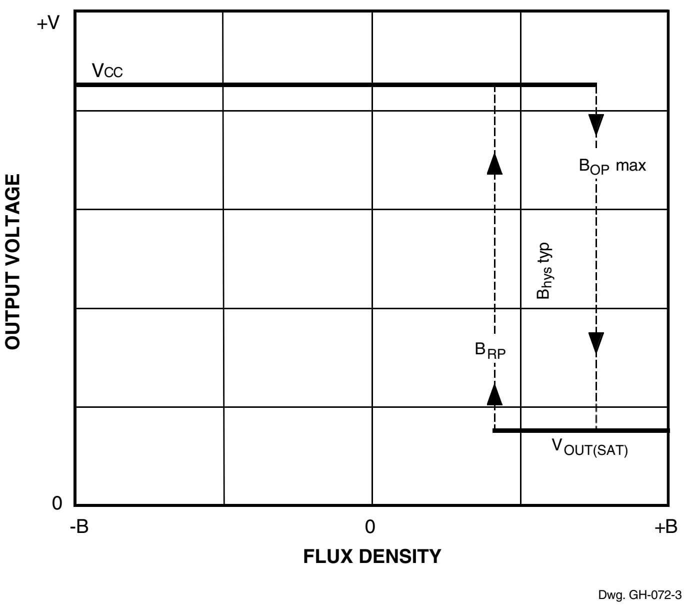

Figure 3a. Bipolar (unipolar mode) characteristic

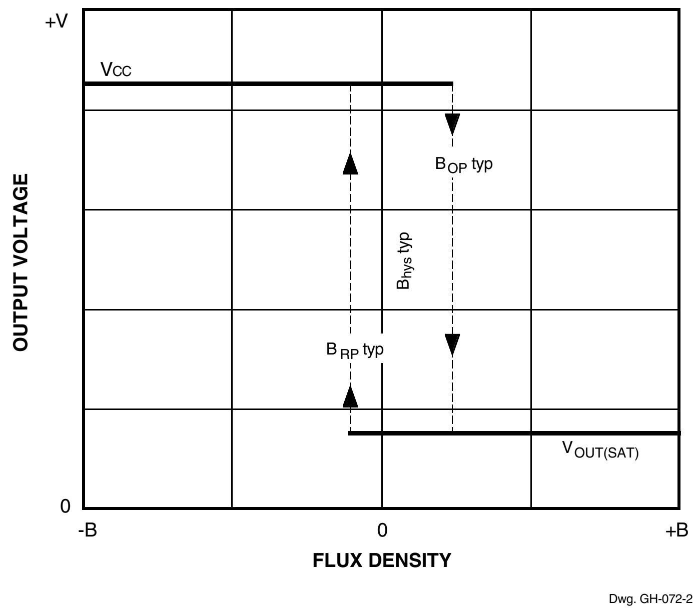

Figure 3b. Bipolar (latch mode) characteristic

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Bipolar sensor having negative (unipolar) switch characteristics

This sensor reacts only to the north pole (negative field) turning OFF as the field reaches the release point (B_{RP}) then turning back ON as the north pole moves away (B_{OP}). The south pole has no affect on the output of this sensor.

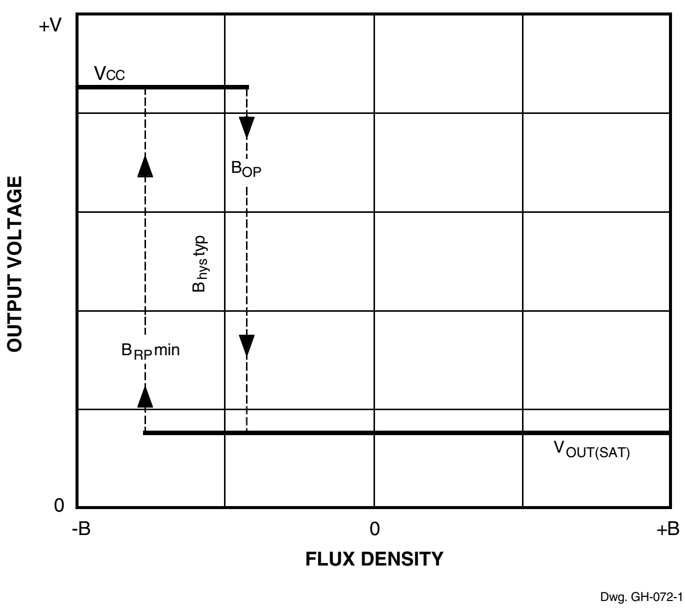

Figure 3c. Bipolar (negative unipolar mode) characteristic

What does it all mean? What are the trade offs?

Obviously the issue is with the non-latching bipolar switches (the 10% of the distribution that the marketing person also sold you) and the fact that these will most likely have less than a perfect duty cycle. Getting back to the brushless dc motor (as a good example), this motor uses ring magnets, which ideally the sensor will mimic, turning the magnetic sine wave generated by rotating magnetic poles into a digital representation. See table 3.

Table 3. Sensor switch operation vs field polarity

Sensor Type	Field Polarity North	South	North	South
Unipolar Switch	off	off-on-off	off	off-on-off
Latch	off	on	off	on
Negative Switch	on-off-on	on	on-off-on	on

As you can see, the latching sensor turns ON with each south pole and OFF with each north pole. The duty cycle will be a nearly 50% ON and 50% OFF. For motor commutation this is ideal, resulting in high efficiency. The unipolar sensor turns ON and OFF with the south pole and does nothing as the north pole passes. The unipolar sensor will have a duty cycle of perhaps 40% ON and 60% OFF. The negative switch turns OFF and ON with the north pole and does nothing as the south pole passes. The negative switch will have a duty cycle of perhaps 60% ON and 40% OFF.

Note especially, that turn OFF will *usually* occur when the magnetic field is removed but to ensure release, a field reversal is required. In application, for reliable operation, bipolar sensors must be treated as though they are all latches!

Like the bumblebee, which aerodynamically can’t fly, brushless dc motors will operate with unipolar or negative switch sensors, but as with the bumblebee, efficiency is not its calling card.

More about duty cycle

You will recall from the discussion on page two that the latching sensor has nearly symmetrical switch points. This tends to set the duty cycle to near perfection when working with equally spaced ring magnet poles. Having said that, even if the switch points were skewed, the duty cycle will still be close to 50/50.

We should not imply that only brushless dc motors need good duty-cycle control. It is not uncommon to use bipolar sensors for many other applications, i.e., speed sensing or measuring linear distance by counting poles. These applications may or may not require good duty-cycle control.

The future of bipolar sensors

The reason bipolar sensors were initially offered is no longer a valid issue. They were offered as sensitive, low hysteresis substitutes for latches. Allegro now has the capability, using chopper stabilization (also called quadrature offset cancelation), to produce very sensitive and very stable latches. Case in point, the A3280 and A3281 sensitive latches. The bipolar offerings will remain available for many years (due to the large customer base) but for applications that require a true latching sensor, the A3280 and A3281 are now available.

Table 4a. Bipolar switches

Part Number*	Switch Limits	Typ. Hysteresis
A3425	±30 G	19 G
A3260	±30 G	20 G
UGx3134	±50 G	27 G
UGx3133	±75 G	52 G
UGx3132	±95 G	52 G

Table 4b. High-sensitivity latches

Part Number*	Switch Limits	Typ. Hysteresis
A3280	±40 G	45 G
A3281	±90 G	100 G

* Complete part number includes additional characters to indicate package and operating temperature range.

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