Experiments with electronics

Build your own Gaussmeter

Have you ever wanted to find out how strong a magnet really was, or how the strength of the magnetic field varied as you changed the distance from the magnet or the temperature of the magnet, or how well a shield placed in front of the magnet worked? Voltmeters are fairly inexpensive and easy to find, but where do you purchase a Gaussmeter (also known as a magnetometer). I built a hand-held Gaussmeter for measuring the polarity and strength of a magnetic field. It uses a linear Hall effect device and some op-amps and resistors and things from Radio Shack.

I will first describe a very simple, inexpensive Hall effect device Gaussmeter you can build for as little as $6. Then I will describe a Gaussmeter with a few more bells and whistles.

An inexpensive Hall effect Gaussmeter

Here is a parts list for the low-cost Gaussmeter:

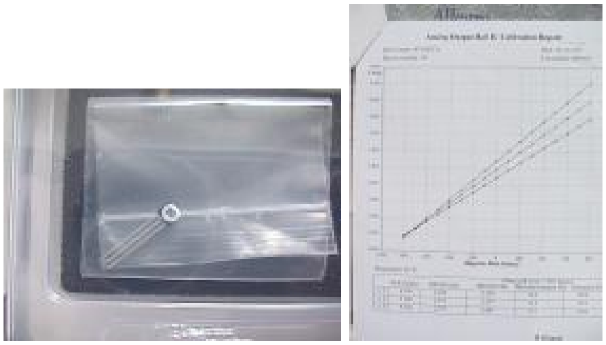
Description	Qty	Radio Shack P/N	Approximate Cost, each
9v Battery	1		
Battery Clips	1	270-325	1.39/5
7805 Voltage Regulator	1	276-1770A	1.49
Uncalibrated Hall Effect Device -or- Uncalibrated Hall Effect Device -or- Calibrated Hall Effect Device	1	(see text) RSU 12035713 RSU 12033684	2.01 4.79 59.99
IC Breadboard -or- Perf circuit board	1	276-175 276-150A	7.99 1.19
Digital voltmeter, 3-1/2 digits	1	22-802	24.99 or more

First, you need a 9v battery. You can get them most anywhere.

Next is a battery clip to connect to the top of the battery. You get a package of 5 for $1.39.

The 7805 is a +5v regulator which takes the +9v from the battery and reduces it to +5v which the Hall effect device will need. It only costs about $1.49.

You have a couple of choices for the Hall effect device. If you go with a calibrated unit, it will cost a lot more, about $60. With this, though, you get the device and a calibration chart, which tells you exactly what the output voltage is going to be when a certain magnetic field strength is present. These photos show you what you get:



On the left is the Hall effect device, an Allegro A3516LUA. On the right is the calibration chart, showing output voltage from the Hall device vs magnetic field, plotted every 100Gauss from 800Gauss north to 800Gauss south, at three different supply voltages.

Another choice is to purchase an uncalibrated Hall device, take a good guess at the calibration, but still use it for accurate comparisons from one test to another. It just wouldn't have an absolute accuracy. To obtain this, There are a couple of easy choices.

1. Purchase a Radio Shack RSU 12035713 for $4.79. This is an Allegro A3515EU. It has a sensitivity of 5.0 mV/G, and does not have a calibration chart. (This is great for weak magnetic fields, but may saturate when measuring strong NIB magnets up close. To use this with the stronger magnets, you will need to keep the magnet about an inch away from the Hall device. The device will not be damaged if a very strong magnet is placed against it, the only thing that will happen is that the output of the device will reach a certain voltage limit when the magnet is, say, a half inch away, and the voltage will not change as the magnet gets closer, since its amplifier is saturated. The voltage will again drop as the magnet is moved further away again.)
2. Purchase an Allegro A3516LUA, but without the calibration chart, from Arrow Electronics, for about $2.01. It has a sensitivity of 2.5 mV/G.

Allegro can be reached directly at:
Allegro
115 Northeast Cutoff
Worcester, MA 01615
Phone: 508-850-3325
Fax: 508-853-7895

You will need something to mount these parts onto, so here again are two possibilities. Use an inexpensive perf board and solder the parts to it, or use the breadboard and just plug the parts in - no soldering! Unless you've built electronic things before, I would recommend the breadboard since it is easy to use, easy to change, and can be used for other projects in the future. So that would cost $7.99.

You need a voltmeter for all the projects you're going to work on anyway, so I won't add that in for this project. There are different types available, and their cost goes up with features and functions. A basic one that will work well is noted in the table above.

There! Going with the perf board, it is only $6.08!!! With the A3515EU from Radio Shack and the breadboard, it will be about $16! These will have great relative accuracy! For better absolute accuracy, it will cost about $71. (Again, batteries and voltmeter not included.)

Now, how do you make it?

Connect the + (red) of the battery clip to the input of the 7805 (pin 1).

Connect the - (black) of the battery clip to the common of the 7805 (pin 2).

Connect the +5V input of the Hall device (pin 1) to the output of the 7805 (pin 3).

Connect the common of the Hall device (pin 2) to the common of the 7805 (pin 2).

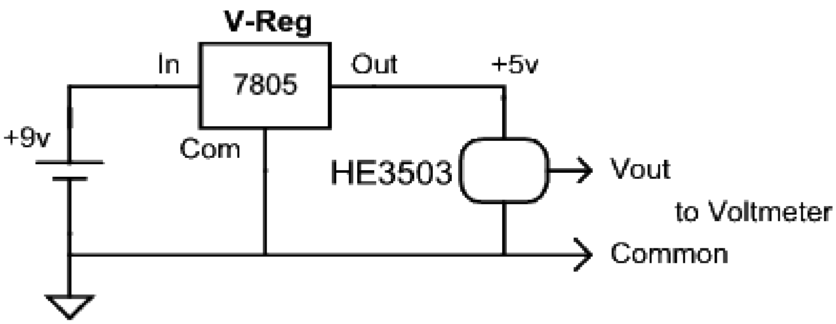
Set the voltmeter to read 20Vdc max.

Attach the + of the voltmeter to the output of the Hall device (pin 3).

Attach the - of the voltmeter to the common of the 7805 (pin 2) or the common of the Hall device (pin 2).

You are now ready to snap a battery onto the battery clip.

Here's a schematic of the circuit (using the 3503 Hall-Effect Device):



With no magnet near the Hall device, measure and note the output voltage reading. Call this V0. It should be about 2.50Vdc.

Now, with a magnet near the Hall device, you will see the output voltage change. If it is a South pole, the voltage will increase. If it is a North pole, the voltage will decrease. Call this voltage reading V1.

We will say that the sensitivity of the Hall device is 2.50mV/G as found on their data-sheet. Call this k.

Therefore, the Magnetic Flux Density you are measuring from that magnet can be calculated as:

B = 1000*(V0-V1)/k, in Gauss.

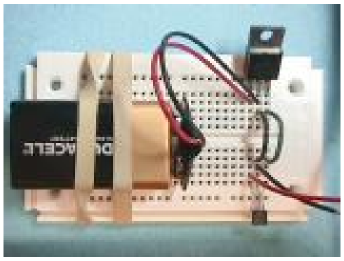
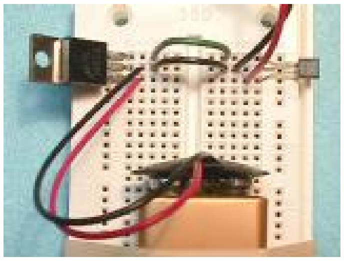
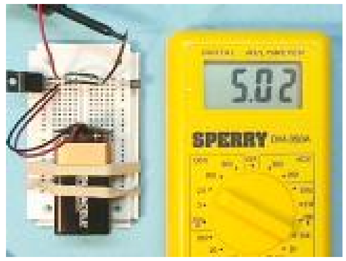
Please note that with a calibrated Hall device, you would be given actual data measurements for the V0 value and for the k value.

For example, suppose you measured 2.48Vdc for V0 and 1.32Vdc for V1. Then B = 1000*(2.48-1.32)/2.50 = 464Gauss, North pole (because it is positive).

For another example, suppose you now measured 4.56Vdc for V1 with the same Hall device. Then B = 1000*(2.48-4.56)/2.50 = -832Gauss, South pole (because it is negative).

See how easy that is? You can make your own plot using Excel so you don't have to calculate all the time. If you're taking measurements, just write down the output voltage and do the calculations later. You can simply use it to tell you if you have a North if the output voltage decreased from V0, or a South pole if the voltage increases from V0.

Here are some photos of this simple, inexpensive Gaussmeter.

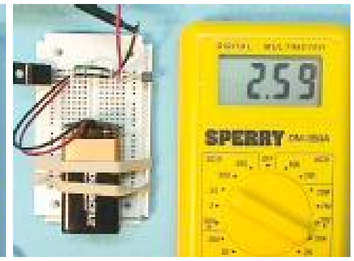
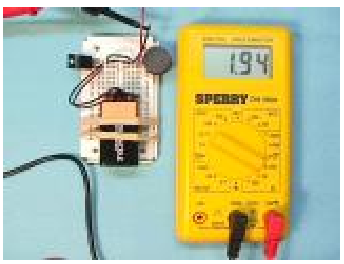


Photo 1 is an overall photo of the breadboard circuit. Let's look at the close-up in photo 2. The 9V battery is at the bottom, the 7805 voltage regulator is on the top left, the Hall device is on the top right. The red lead from the 9V battery goes to pin 1 of the 7805. The black lead from the battery goes to pin 2 of the 7805.   The output of the 7805 (pin 3) is connected by a green wire to pin 1 of the Hall device. Pin 2 of the 7805 is connected by a black wire to pin 2 of the Hall device.   Please note that the marking on the Hall device (giving its part number) is facing the camera. The voltmeter common (black) is connected to pin 2 of the Hall device.   The voltmeter input (red) is connected to pin 3 of the Hall device. (I got the voltmeter from a Home Depot store near here for about $20.) That's all there is! Great, or what?!

Photo 3 shows the voltage at pin 3 of the voltage regulator. Ideally it is 5.00 volts, but we measured 5.02, which is close enough.

Photo 4 shows the output of the Hall device when no magnet is nearby. Ideally it is 2.50 volts, but we measured 2.59. This would be our V0 as noted above. The Hall device I have here is an Allegro UGN3503U, with a sensitivity of about 1.3 mV/G.



With a disk magnet sitting on top of the Hall device, the voltmeter is measuring 1.94 volts. This means that the Gauss measurement is 1000*(2.59-1.94)/1.3 = 500 Gauss, North pole.

With the disk magnet flipped over, the voltmeter is measuring 3.22 volts. This means that the Gauss measurement is 1000*(2.59-3.22)/1.3 = -485 Gauss, South pole.   You will notice that the placement of the magnet with respect to the Hall device is very critical, since the measurement varies across the surface of the magnet (as it is supposed to, being strongest at the edge, not the middle!).

With a NIB magnet sitting on top of the Hall device, the voltmeter is measuring 0.99 volts. This means that the Gauss measurement is 1000*(2.59-0.99)/1.3 = 1231 Gauss, North pole.

With the NIB magnet flipped over, the voltmeter is measuring 4.30 volts. This means that the Gauss measurement is 1000*(2.59-4.30)/1.3 = -1315 Gauss, South pole.

Now, the absolute value is not going to be correct since I don't have a calibration chart with this device, but the relative measurement will be as accurate as the Hall device, typically within 10 Gauss for the A3515 and the A3516 devices from Allegro.   From the measurements, I know that the NIB is 1231/500 = 2.46 times stronger that the disk magnet! So, this gaussmeter will work well for measuring the variation of a magnet's flux density with respect to temperature very well!

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THE ATTACK GAUSSMETER

What makes a pickup a pickup? Basically wire and a magnet. We all know how to measure the resistance of a pickup -- get out the old volt-ohm meter and check it out! However, how do we check the strength of the magnet(s) in the pickup? Doesn't matter? Critical? I decided to find out.

Luthiers and repairmen measure the strength of magnets with a device called a Gaussmeter (teslameter in Europe). A gaussmeter measures the gauss of a magnet, and can tell you whether the magnet you are checking is oriented north or south.

I started pricing gaussmeters on eBay, and I got sticker shock. They were in the neighborhood of $200-500 for a cheap one, and multiple thousands for the expensive ones. There had to be a better (cheaper) way because I just wanted to establish baselines with famous pickups, and use those as standards for my pickups.

I started searching the Internet, and found a great site. This site will show you how to build an inexpensive measuring device for magnets.

The URL is -- http://www.execpc.com/~rhoadley/magmeter.htm and the fellow that built the site shows the layman how to measure the relative strength of a magnet. This is very important -- as stated in *Guitar Electronics for Musicians* by Donald Brosnac, more windings and lower gauss lowers the resonant frequency of a pickup, while fewer windings and higher gauss raises the frequency. Mr. Larry Dimarzio states that resonant frequency is a great predictor of how a pickup will sound. Well, if you don't have a gaussmeter or some way to measure gauss, how can you adjust the sound of a home made pickup? The answer is painful, slow-paced experimentation, which I'm not in to right now.

I decided to take the plunge and build the base gaussmeter model first. I ordered the parts from Parts Express, but they backordered the perf board and wouldn't ship the rest of the items. Frustrated, I then ordered the parts from MCM Electronics. Ironically, both orders shipped the same day even though I tried to cancel the Parts Express order! I took them both, and started soldering!

I bought the Hall Effect Sensor from Radio Shack last summer when I was in the States. It was the more expensive model that came with calibration charts. Using the calibration charts, I believe it reads pretty accurately.

Assembly was easy and exciting, and here is what I've found so far (NOTE: You may know all of this already):

1. Pickup covers do affect the magnetic field that the strings vibrate in. The most pronounced drop in gauss is over the slug polepieces. The adjustable polepieces have significantly more power than covered ones.

2. Strat magnets can have a significant difference in gauss in the same pickup.

3. All magnets are not the same, and PAF pickups have a significant difference in gauss from pickup to pickup.

4. The Dimarzio PAFs have almost exactly the same magnetic characteristics of a Gibson PAF.

The bottom line is that if you are interested in pickups, build your own attack gaussmeter and start assessing those pickups!

This is a photo of the gaussmeter. The volt-ohm meter is a combination VOM that can read capacitance and inductance. It has been a good one and forms the core of the pickup measuring universe. Inside the little blue box is a power supply for the Hall Effect sensor and the wires that go to the VOM and the "probe". In the foreground you can see the wooden probe with the sensor attached to the end (on right side -- see the white dot). I used a broken paint brush to hold the sensor to avoid any magnetism.

Operation is easy: plug in the battery, set the VOM to read dc voltage, move the sensor toward the magnet and start measuring! The VOM gives the reading and I plug the numbers into an Excel spreadsheet to arrive at the gauss numbers.

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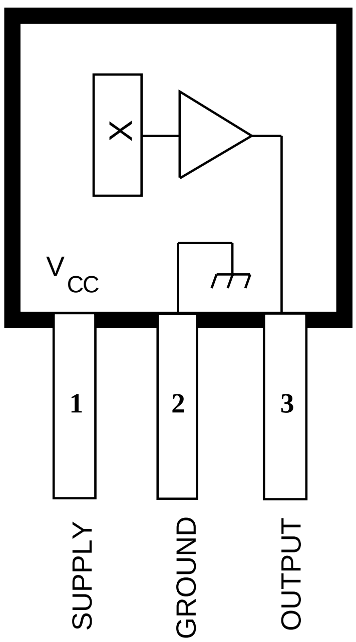
3515 AND 3516

RATIOMETRIC, LINEAR HALL-EFFECT SENSORS FOR HIGH-TEMPERATURE OPERATION



Dwg. PH-006

Pinning is shown viewed from branded side.

ABSOLUTE MAXIMUM RATINGS

Supply Voltage, V_{CC} .... **8.0 V**
Output Voltage, V_O .... **8.0 V**
Output Sink Current, I_O .... **10 mA**
Magnetic Flux Density, B .... **Unlimited**
Package Power Dissipation,
P_D .... **See Graph**
Operating Temperature Range*, T_A
Suffix ‘E–’ .... **-40°C to +85°C**
Suffix ‘L–’ .... **-40°C to +150°C**
Storage Temperature Range,
T_S .... **-65°C to +170°C**

* Infrequent excursions permitted; see Applications Information.

The A3515– and A3516– are sensitive, temperature-stable linear Hall-effect sensors with greatly improved offset characteristics. Ratiometric, linear Hall-effect sensors provide a voltage output that is proportional to the applied magnetic field and have a quiescent output voltage that is approximately 50% of the supply voltage. These magnetic sensors are ideal for use in linear and rotary position sensing systems in the harsh environments of automotive and industrial applications over extended temperatures to -40°C and +150°C. The A3515– features an output sensitivity of 5 mV/G, while the A3516– has an output sensitivity of 2.5 mV/G. See the Magnetic Characteristics table for complete, individual device parametrics.

Each BiCMOS monolithic circuit integrates a Hall element, improved temperature-compensating circuitry to reduce the intrinsic sensitivity drift of the Hall element, a small-signal high-gain amplifier, and a rail-to-rail low-impedance output stage.

A proprietary dynamic offset cancelation technique, with an internal high-frequency clock, reduces the residual offset voltage, which is normally caused by device overmolding, temperature dependancies, and thermal stress. This technique produces devices that have an extremely stable quiescent output voltage, are immune to mechanical stress, and have precise recoverability after temperature cycling. Many problems normally associated with low-level analog signals are minimized by having the Hall element and amplifier in a single chip. Output precision is obtained by internal gain and offset trim adjustments during the manufacturing process.

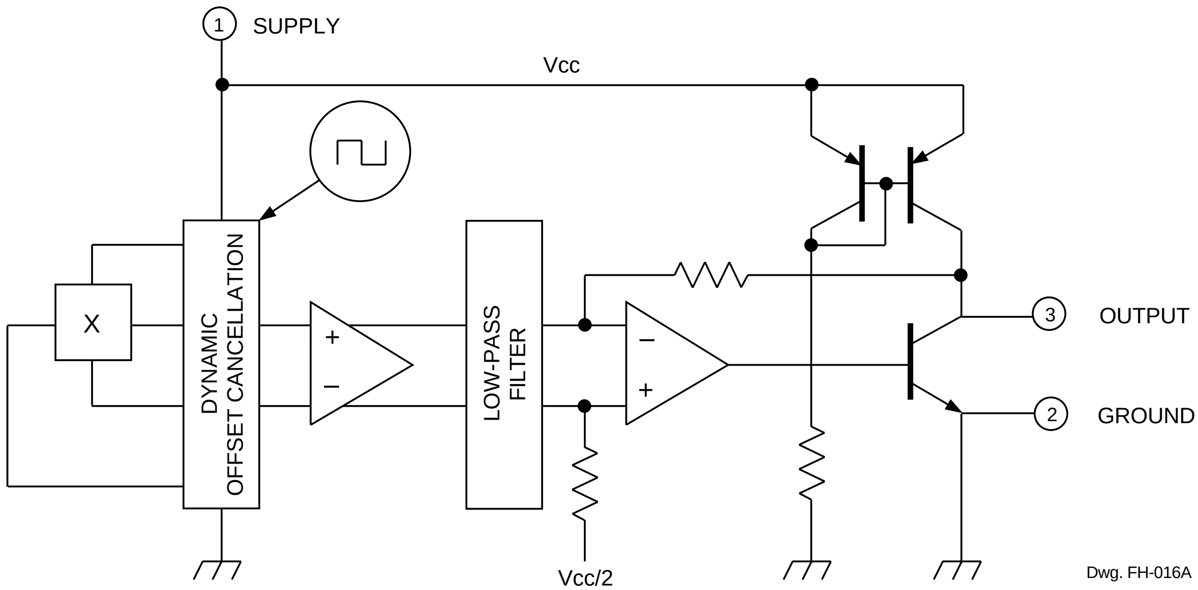
These devices are supplied in a 3-pin ultra-mini-SIP ‘UA’ package.

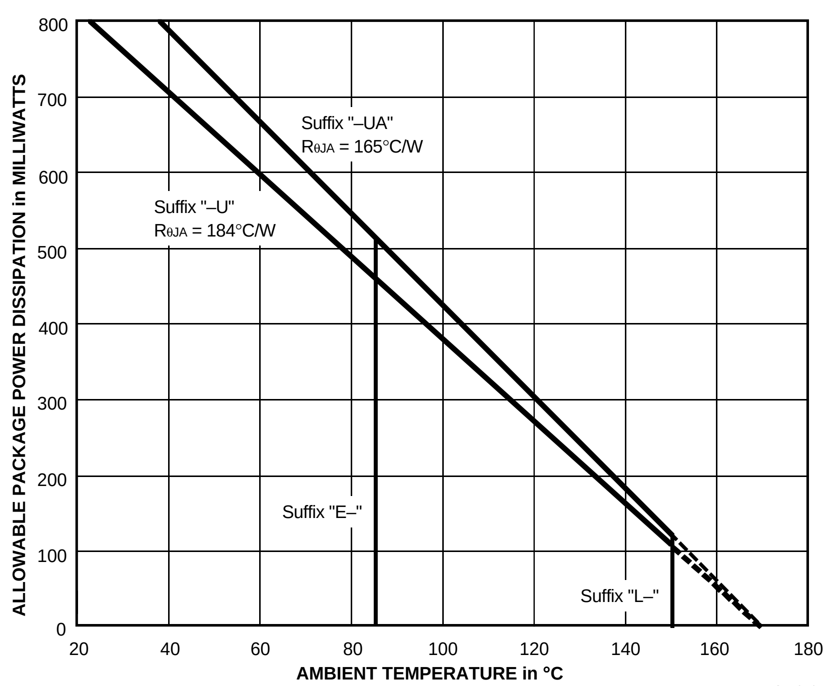
FEATURES

- Temperature-Stable Quiescent Output Voltage
- Precise Recoverability After Temperature Cycling
- Output Voltage Proportional to Applied Magnetic Field
- Ratiometric Rail-to-Rail Output
- Improved Sensitivity
- 4.5 V to 5.5 V Operation
- Immune to Mechanical Stress
- Small Package Size
- Solid-State Reliability

Always order by complete part number, e.g., **A3515LUA** .

FUNCTIONAL BLOCK DIAGRAM





115 Northeast Cutoff, Box 15036
Worcester, Massachusetts 01615-0036 (508) 853-5000

ELECTRICAL CHARACTERISTICS over operating temperature range, at V_{CC} = 5 V (unless otherwise noted).

Characteristic	Symbol	Test Conditions	Limits			
			Min.	Typ.	Max.	Units
Supply Voltage	V_{CC}	Operating	4.5	5.0	5.5	V
Supply Current	I_{CC}	B = 0, V_{CC} = 6 V, I_O = 0	–	7.2	10	mA
Quiescent Voltage Output	V_{OQ}	B = 0, I_O = 1 mA, T_A = 25°C	2.425	2.500	2.575	V
Output Voltage	V_{OH}	B = +X*, I_O = 1 mA	–	4.7	–	V
	V_{OL}	B = -X*, I_O = -1 mA	–	0.2	–	V
Output Source Current Limit	I_{OLM}	B = -X*, V_O = 0	-1.0	-1.5	–	mA
Bandwidth (-3 dB)	BW		–	30	–	kHz
Clock Frequency	f_C		–	170	–	kHz
Output Resistance	r_O	$I_O \leq$ -2 mA	–	1.0	–	Ω
Wide-Band Output Noise (rms)	e_o	B = 0, BW = 10 Hz to 10 kHz, $I_O \leq$ -1 mA, C_O = 100 pF	–	400	–	μV

NOTE 1 – Typical data is at T_A = 25°C and is for design information only.

NOTE 2 – Negative current is defined as coming out of (sourcing) the output.

* This test requires positive and negative fields sufficient to swing the output driver between fully OFF and saturated (ON), respectively. It is NOT intended to indicate a range of linear operation.

MAGNETIC CHARACTERISTICS over operating temperature range, at V_{CC} = 5 V, I_O = -1 mA (unless otherwise noted).

Characteristic*	Part Numbers												Units
	A3515EUA			A3515LUA			A3516EUA			A3516LUA			
	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Operating Temp. Range, T_A	-40	–	+85	-40	–	+150	-40	–	+85	-40	–	+150	°C
Sensitivity at T_A = 25°C	4.50	5.00	5.50	4.50	5.00	5.50	2.25	2.50	2.75	2.25	2.50	2.75	mV/G
$\Delta Sens_{(\Delta T)}$ at T_A = Max.	-2.5	2.5	7.5	-2.5	2.5	7.5	-2.5	2.5	7.5	-2.5	2.5	7.5	%
$\Delta Sens_{(\Delta T)}$ at T_A = Min.	-9.0	-1.3	1.0	-9.0	-1.3	1.0	-9.0	-1.3	1.0	-9.0	-1.3	1.0	%
$\Delta V_{OQ(\Delta T)}$†	–	–	±10	–	–	±10	–	–	±10	–	–	±10	G
Ratiometry, $\Delta V_{OQ(\Delta V)}$	–	100	–	–	100	–	–	100	–	–	100	–	%
Ratiometry, $\Delta Sens_{(\Delta V)}$	–	100	–	–	100	–	–	100	–	–	100	–	%
Positive Linearity, Lin+	–	100	–	–	100	–	–	100	–	–	100	–	%
Negative Linearity, Lin–	–	100	–	–	100	–	–	100	–	–	100	–	%
Symmetry	–	100	–	–	100	–	–	100	–	–	100	–	%

NOTE 1 – Magnetic flux density is measured at most sensitive area of device located 0.0195" (0.50 mm) below the branded face of the “UA” package.

NOTE 2 – 10 G = 1 mT, exactly.

NOTE 3 – Except for $\Delta Sens_{(\Delta T)}$, typical data is at T_A = 25°C and is for design information only.

* See Characteristics Definitions for test conditions.

† This calculation (formula 1, next page) yields the device’s equivalent accuracy, over the operating temperature range, in gauss.

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CHARACTERISTICS DEFINITIONS

Quiescent Voltage Output. In the quiescent state (no magnetic field), the output is ideally equal to one-half of the supply voltage over the operating voltage and temperature range (V_{OQ} ∪ $V_{CC}/2$). Due to internal component tolerances and thermal considerations, there is a tolerance on the quiescent voltage output and on the quiescent voltage output as a function of supply voltage and ambient temperature. For purposes of specification, the quiescent voltage output as a function of temperature is defined as

$$\Delta V_{OQ(\Delta T)} = \frac{V_{OQ(TA)} - V_{OQ(25°C)}}{Sens_{(25°C)}} \quad (1)$$

This calculation yields the device's equivalent accuracy, over the operating temperature range, in gauss.

Sensitivity. The presence of a south-pole magnetic field perpendicular to the package face (the branded surface) will increase the output voltage from its quiescent value toward the supply voltage rail by an amount proportional to the magnetic field applied. Conversely, the application of a north pole will decrease the output voltage from its quiescent value. This proportionality is specified as the sensitivity of the device and is defined as

$$Sens = \frac{V_{O(500G)} - V_{O(-500G)}}{1000\ G} \quad (2)$$

The stability of sensitivity as a function of temperature is defined as

$$\Delta Sens_{(\Delta T)} = \frac{Sens_{(TA)} - Sens_{(25°C)}}{Sens_{(25°C)}} \times 100\% \quad (3)$$

Ratiometry. The A3515xUA and A3516xUA feature a ratiometric output. The quiescent voltage output and sensitivity are proportional to the supply voltage (ratiometric).

The per cent ratiometric change in the quiescent voltage output is defined as

$$\Delta V_{OQ(\Delta V)} = \frac{V_{OQ(VCC)} / V_{OQ(5V)}}{V_{CC} / 5\ V} \times 100\% \quad (4)$$

and the per cent ratiometric change in sensitivity is defined as

$$\Delta Sens_{(\Delta V)} = \frac{Sens_{(VCC)} / Sens_{(5V)}}{V_{CC} / 5\ V} \times 100\% \quad (5)$$

Linearity and Symmetry. The on-chip output stage is designed to provide a linear output to within 500 mV of either rail with a supply voltage of 5 V. This is equivalent to approximately ±800 gauss of ambient field. Although application of stronger magnetic fields will not damage these devices, it will force the output into a non-linear region. Linearity in per cent is measured and defined as

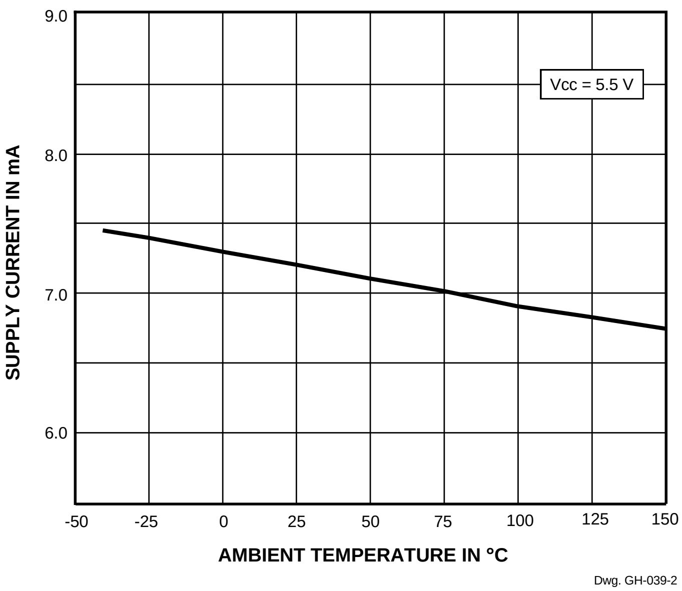
$$Lin+ = \frac{V_{O(500G)} - V_{OQ}}{2\ (V_{O(250G)} - V_{OQ})} \times 100\% \quad (6)$$

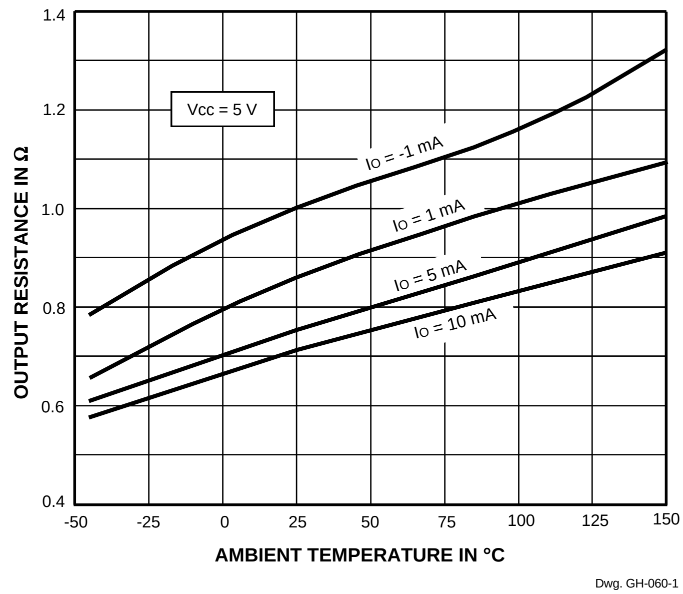
$$Lin- = \frac{V_{O(-500G)} - V_{OQ}}{2\ (V_{O(-250G)} - V_{OQ})} \times 100\% \quad (7)$$

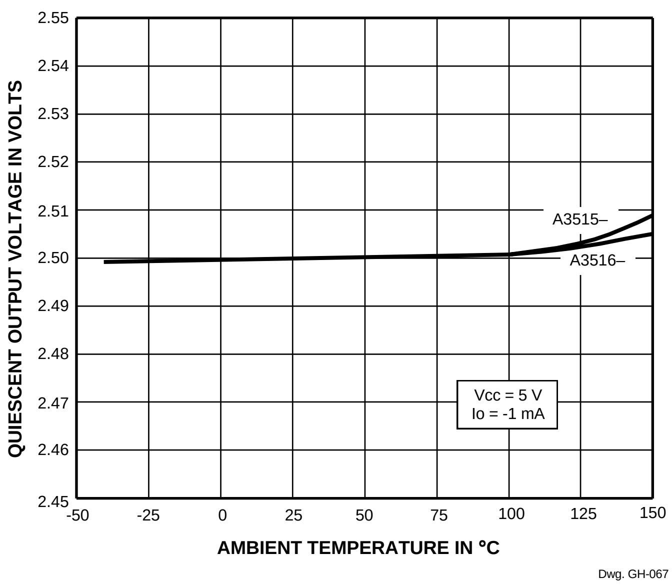
and output symmetry as

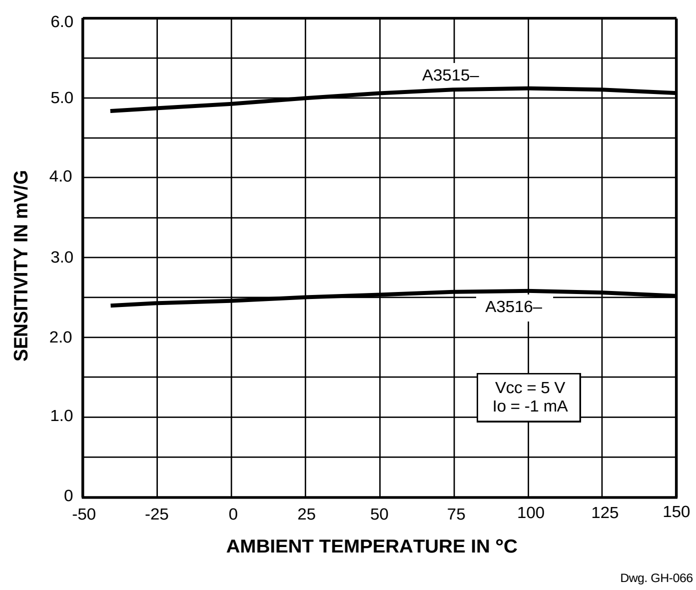
$$Sym = \frac{V_{O(500G)} - V_{OQ}}{V_{OQ} - V_{O(-500G)}} \times 100\% \quad (8)$$

TYPICAL CHARACTERISTICS









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APPLICATIONS INFORMATION

Calibrated linear Hall devices, which can be used to determine the actual flux density presented to the sensor in a particular application, are available.

For safe, reliable operation, the output should not be pulled above the supply voltage or pulled below the device ground.

For optimum performance, a 0.1 µF capacitor between the supply and ground, and a 100 pF capacitor between the output and ground, should be added.

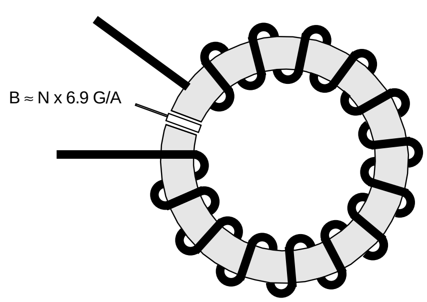
The ratiometric feature is especially valuable when these devices are used with an analog-to-digital converter. A/D converters typically derive their LSB step size by ratioing off a reference voltage line. If the reference voltage varies, the LSB will vary proportionally. This is a major error source in many sensing systems. The A3515xUA and A3516xUA can eliminate this source of error by their ratiometric operation. Because their gain and offsets are proportional to the supply voltage, if they are powered from the A/D reference voltage, the sensor output voltage will track changes in the LSB value.

These devices can withstand infrequent temperature excursions, beyond the Absolute Maximum Ratings, to T_A = 170°C provided the junction temperature, T_J, does not exceed 200°C.

Extensive applications information on Hall-effect sensors and magnets is also available in the "Hall-Effect IC Applications Guide", which can be found in the latest issue of the *Allegro MicroSystems Electronic Data Book*, AMS-702 or *Application Note* 27701, or at

www.allegromicro.com

TYPICAL CURRENT-SENSING APPLICATION



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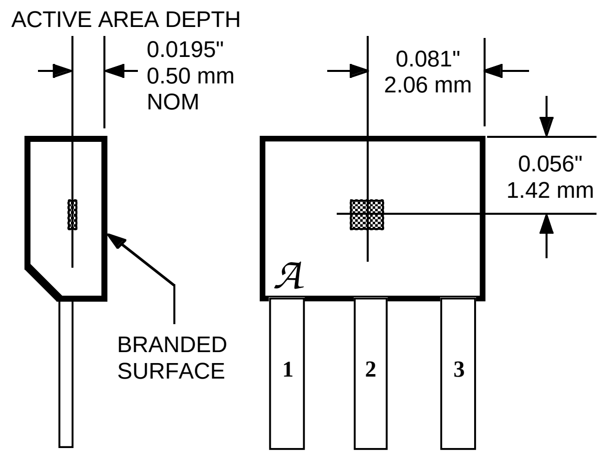
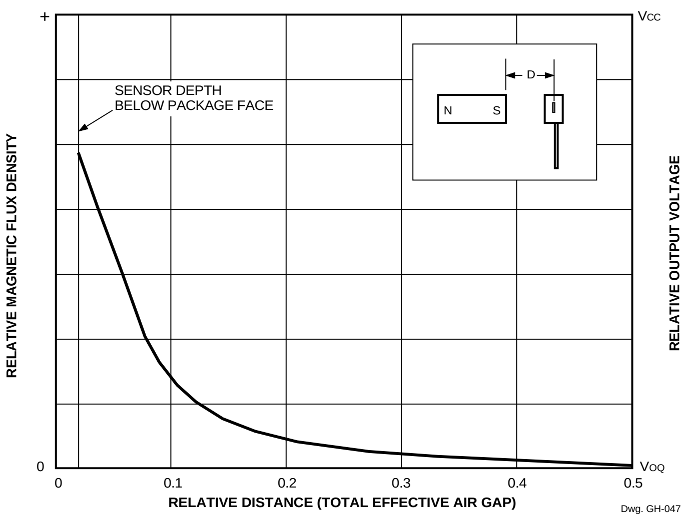
SENSOR LOCATION

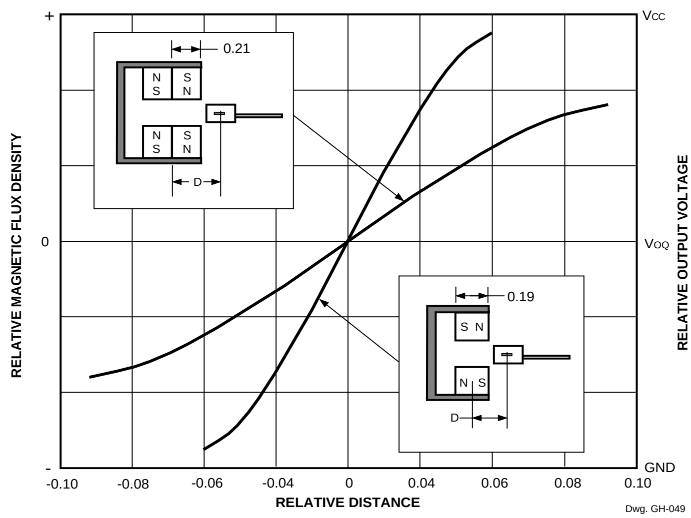
SUFFIX "UA"

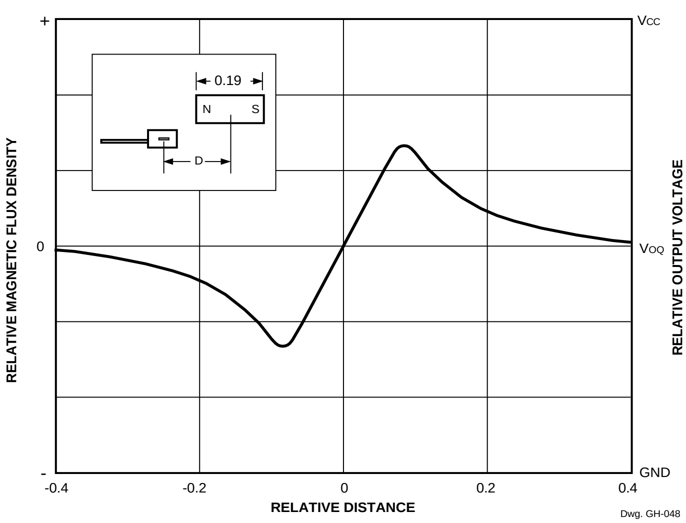


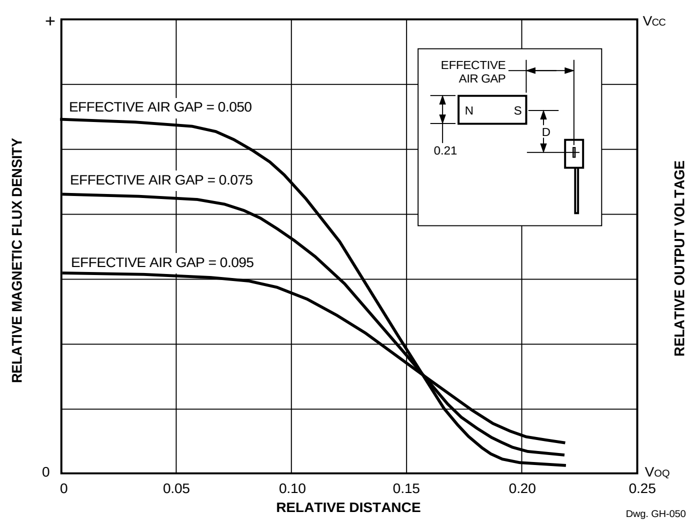
Dwg. MH-011-7A

TYPICAL POSITION-SENSING APPLICATIONS
(Alnico 8, dimensions in inches)









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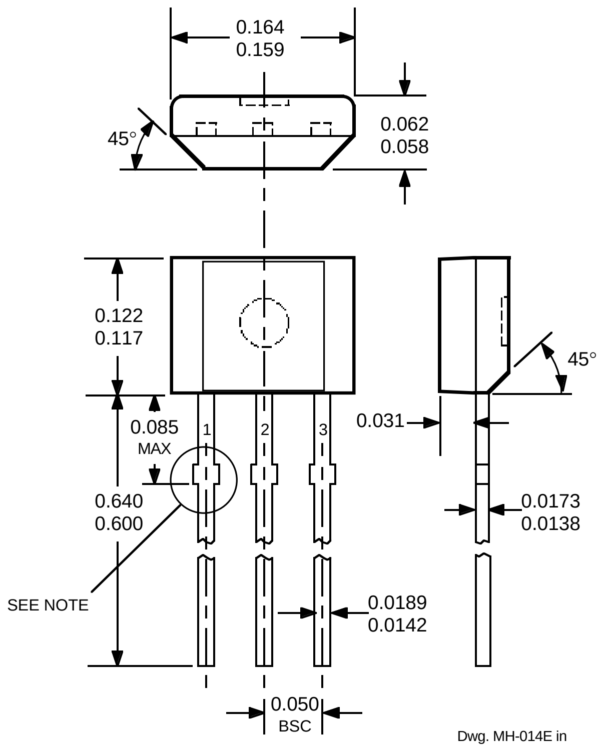
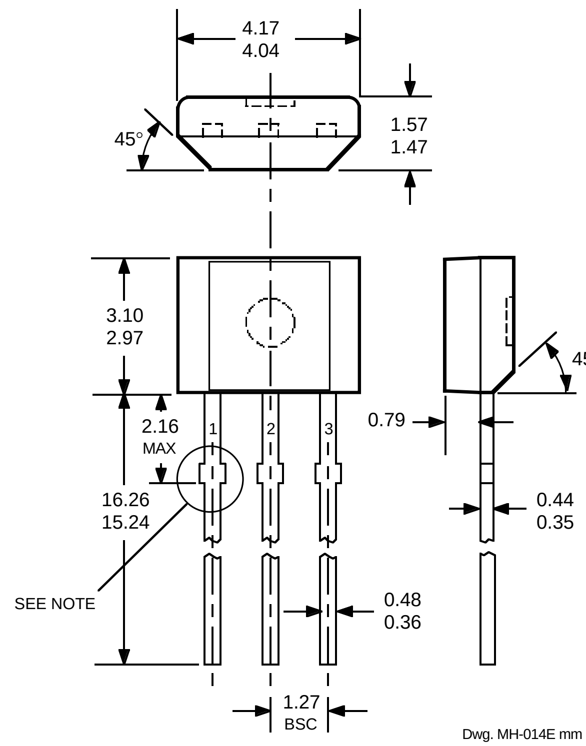
A3515xUA and A3516xUA

Dimensions in Inches
(controlling dimensions)

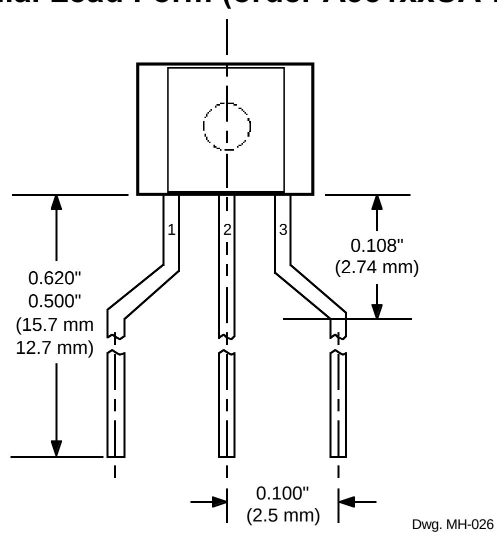


Dimensions in Millimeters
(for reference only)



NOTES:
1. Tolerances on package height and width represent allowable mold offsets. Dimensions given are measured at the widest point (parting line).
2. Exact body and lead configuration at vendor's option within limits shown.
3. Height does not include mold gate flash.
4. Recommended minimum PWB hole diameter to clear transition area is 0.035" (0.89 mm).
5. Where no tolerance is specified, dimension is nominal.
6. Supplied in bulk pack (500 pieces per bag).

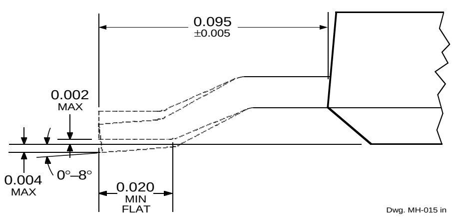
Radial Lead Form (order A351xxUA-LC)

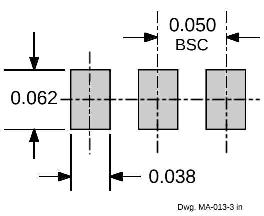


NOTE: Lead-form dimensions are the nominals produced on the forming equipment. No dimensional tolerance is implied or guaranteed for bulk packaging (500 pieces per bag).

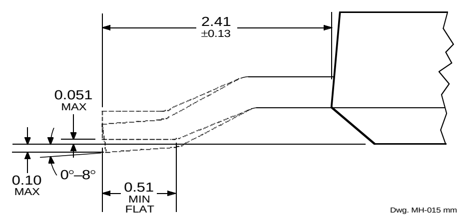
Surface-Mount Lead Form (order A351xxUA-TL)

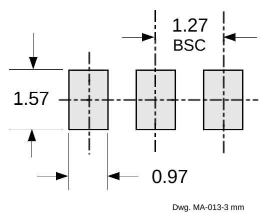
Dimensions in Inches
(controlling dimensions)





Dimensions in Millimeters
(for reference only)





NOTE: Supplied in bulk pack (500 devices per bag).

The products described herein are manufactured under one or more of the following U.S. patents: 5,045,920; 5,264,783; 5,442,283; 5,389,889; 5,581,179; 5,517,112; 5,619,137; 5,621,319; 5,650,719; 5,686,894; 5,694,038; 5,729,130; 5,917,320; and other patents pending.

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