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3D HALL-EFFECT SENSORS REDUCE THE COST AND COMPLEXITY OF MAGNETIC TAMPER DETECTION FOR SMART HOME SYSTEMS

By Joseph Hollins, Product Marketing Engineer, Allegro MicroSystems

INTRODUCTION

Tampering with electronics by applying a strong magnet to their surfaces can cause a multitude of issues including permanent, catastrophic damage. Generally, it is recommended to implement security measures to protect vulnerable electronic equipment from disruption. This is especially true in applications such as smart locks, video doorbells, smart meters, and other connected home devices that commonly use sensitive electronic components.

While various multi-sensor methods for magnetic tamper detection are available, using a true 3D Hall-effect sensor provides significant design advantages. Hall-effect sensors are impervious to the strong magnetic fields used in magnetic tampering and the 3D type such as those from Allegro's 3DMAG™ sensor lineup cover a larger proximity detection area with only a single IC. These integrated design advantages make them excellent tools for detecting and mitigating malicious tampering. The result is a secure and robust smart home system.

EFFECTIVE TAMPER DETECTION SENSOR CRITERIA

To be effective for tamper detection, a magnetic sensor must have the following features:

- High sensitivity: Typically, the tamper detection sensor is located in the middle of the electronic equipment.
- High dynamic range: Unlike the sensitive equipment it is protecting, the tamper detection sensor must not be incapacitated when exposed to high magnetic fields.
- Omnipolar sensitivity: Permanent magnets produce both north and south pole magnetic fields, but not all magnetic sensors detect both. Either are threats to electronics and thus should not be ignored.
- Omnidirectional sensitivity: Any surface of a smart electronic device is susceptible to external magnetic field exposure, requiring the tamper detection sensor to have a 360-degree view.

MAGNETIC TAMPER DETECTION SENSOR TECHNOLOGIES

Planar Hall-Effect Sensor

The Hall-effect sensor IC is the most popular legacy solution for magnetic tamper sensing. As shown in Figure 1, a current (I) is applied to a conductive plate. A magnetic field perpendicular to the plate (current flow) causes a differential voltage to be developed across the plate proportional to the applied field. A traditional planar Hall-effect sensor can only measure this perpendicular magnetic field, indicated by the vector line B. In the case of surface-mount ICs, the plate is usually in parallel with the plane of the printed circuit board (PCB) on which the sensor is mounted. Only fields in this one dimension are effectively sensed when using a surface-mount IC component (see Figure 1).

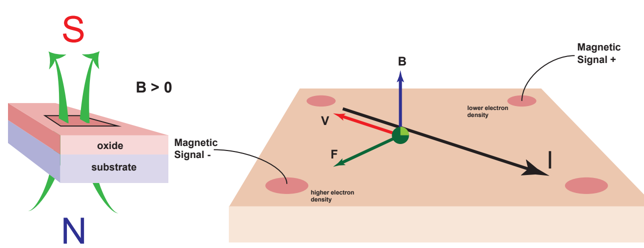

Figure 1: Planar Hall-effect sensor plate

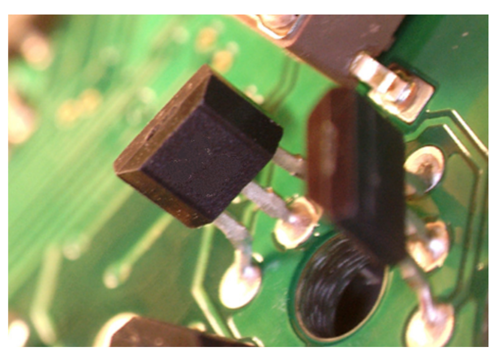

Figure 2: Planar Hall-effect sensor PCB mounting

Sensing magnetic fields in the other two Cartesian planes requires additional surface-mount sensors on separate PCBs at right angles to each other or leaded sensors installed and lead-formed such that the Hall-effect plates are oriented correctly in the three Cartesian dimensions (see Figure 2). Both approaches drive up component count and cost, system complexity and assembly cost.

Magnetoresistive Sensor

Various magnetoresistive (xMR) technologies have been used to create magnetic sensor ICs. These sensors usually have a uniplanar response, i.e., they may detect fields in the X-Y plane but have limited response to Z fields (see Figure 3). In addition, very high fields are likely to cause the magnetoresistive sensor to saturate (limited dynamic range), malfunction or become permanently damaged. The reason for this is the pinned reference layer, which is essentially pre-oriented by a strong magnetic field during xMR production, could become pinned in the wrong direction. Since magnetic tampering is often attempted using a very strong field, this is a significant limitation.

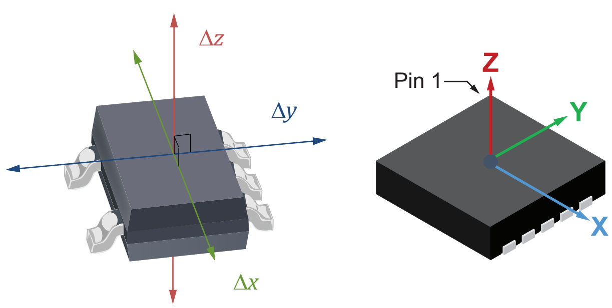

Figure 3: Three Cartesian dimensions, X, Y, and Z

3D Hall-Effect Sensor

An innovative step in Hall-effect sensing has enabled the creation of omnidirectional magnetic sensor ICs that match all the required criteria for magnetic tamper detection. For example, IC design and fabrication at Allegro MicroSystems combines planar and vertical Hall technologies into 3DMAG™ solutions, which offer robust, high-performing, three-axis magnetic field measurements in a single IC. The vertical and planar sensors are based on the same physical phenomena but use different construction methods:

Table 1: Hall-element comparison

Element Style	Construction
Planar	Laid out across the width and length of the chip; will only sense Z dimension regardless of orientation.
Vertical	Constructed from top to bottom along the depth of the chip; can be oriented to sense X, Y, or other directions (e.g. 360° circular vertical Hall, CVH).

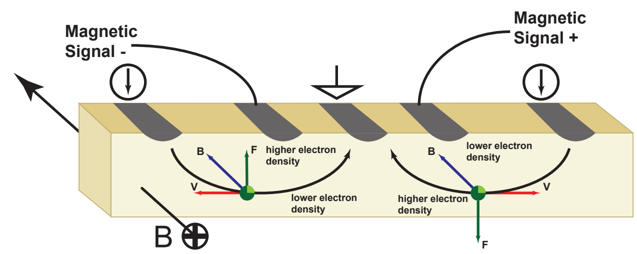

Figure 4: Vertical Hall-effect sensor

While a planar Hall-effect element is sensitive to field perpendicular to the face of the IC package, a vertical Hall-effect device is sensitive in an axis that is parallel to the die such as the X or Y dimension. Figure 4 shows the construction details of a vertical Hall-effect plate.

Two vertical Hall-effect sensors combined with a planar Hall-effect sensor in a single IC form a magnetic sensor that can sense fields regardless of direction (X, Y, and Z), providing immunity to exposure at high strength fields. In the past, this solution would have required three discrete ICs that required up to 56 mm^2 of PCB area. The A1266 3D sensor from Allegro MicroSystems is an example of such a device (See Figure 5) in a small, surface-mount SOT-23 W package requiring just 9 mm^2 of PCB space. The A1266 also has very high sensitivity so that it can detect magnetic tamper attempts over a large area or volume. Table 2 shows a comparison of the available technologies.

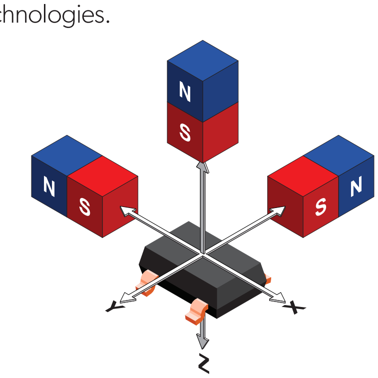

Figure 5: A1266 features a 3D omnipolar response ideal for tamper detection

Table 2: Comparison of available technologies for magnetic sensor ICs

Technology	Polarity	Directionality (Highest sensitivity)	Notes
Planar Hall	Omnipolar	Z only	Most popular legacy approach
Vertical Hall	Omnipolar	X, Y, or other in-plane directions	Leading-edge technology for magnetic sensing ICs
Magnetoresistance (xMR)	Omnipolar	X-Y plane	May invert at high field; High field may also cause damage

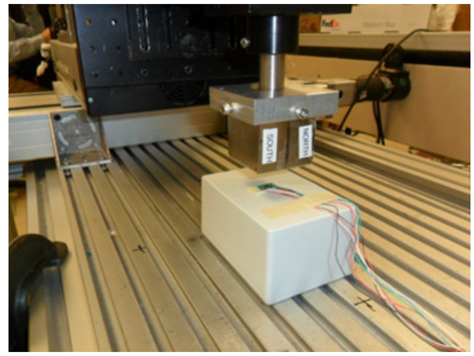

Figure 8: Robotic mapping station

LAB TEST: 3D SENSOR VERSUS THE COMPETITION

Experiment Setup

Measuring the response from different sensors clearly shows the superiority of a high-sensitivity, omnidirectional, omnipolar sensor in a tamper detection setting. The following measurements assume a large rectangular smart home component with face dimensions of up to 290 mm × 165 mm and a 50 mm^3 N45 neodymium magnet (see Figure 6 and Figure 7).

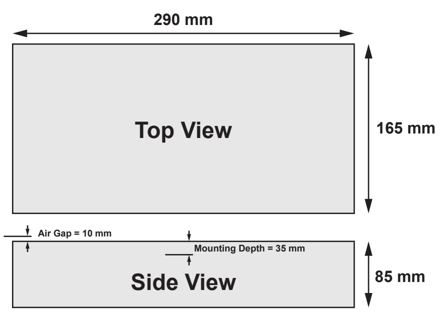

Figure 6: Hypothetical smart home component dimensions and sensor air gap

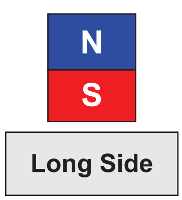

Figure 7: Magnet orientation (S-pole to face of smart home component)

The sensor under test is located in the middle of the electronic system below the main face. The magnet is moved across the entire length and width of the front face 10 mm above the component surface using a robotic mapping station. Figure 8 shows the mapping station set up to map the response of a sensor.

Experiment Results

Figure 9 shows the results of the measurements using a conventional 1D planar Hall-effect sensor (primary sensitivity in the Z dimension) and using a 2D xMR sensor (primary sensitivity in the X and Y dimensions). The area in blue is the region of magnet locations where the sensor under test is able to detect the presence of the magnet. For the 1D sensor, the magnet is easily detected when it is directly above the sensor. This is not the case for the 2D sensor, which recorded a blind spot directly above the sensor location. As the magnet moves in the X-Y plane, the distance to the sensor changes, and the field direction at the sensor may no longer be oriented in the sensitive axis. Nevertheless, the sensors are able to detect the magnet's south pole (see Figure 7) within a similar area of approximately 148 mm × 148 mm.

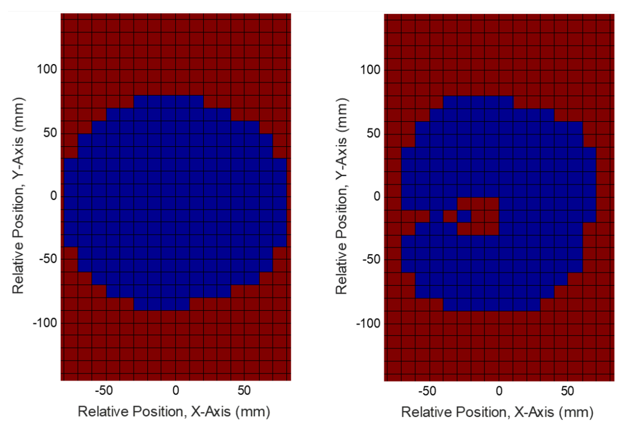

Figure 9: Tamper coverage with 1D Planar Hall-effect sensor, Left (43%), and with 2D (X and Y) sensitive xMR sensor, right (40%) (blue denotes detection region)

Figure 10 shows the results of mapping the same hypothetical smart home component while detecting the magnetic field using an omnidirectional 3D Hall-effect sensor. The Hall-effect sensor has ultra-high sensitivity and is composed of one planar

Hall-effect sensing element and two vertical Hall-effect sensing elements in a single IC package. The magnet is easily detected when it is positioned directly above the sensor. In this case, the sensor can detect the magnet over a much larger area, nearly the entire face of the hypothetical component (approximately 280 mm × 165 mm of coverage). The results were similar when the same 3D sensor characterization was performed with the magnet placed in all six possible orientations.

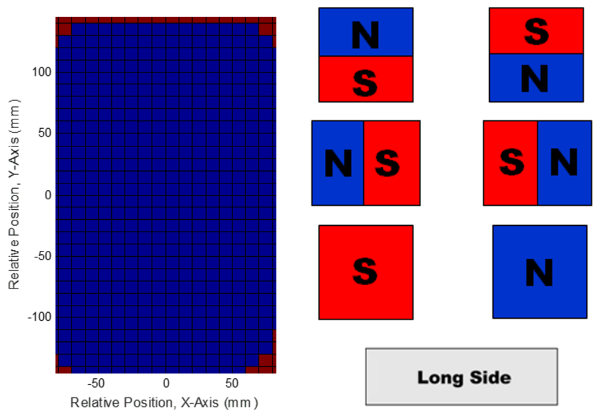

Figure 10: Tamper coverage (92%) with 3D Hall-effect sensor (blue denotes detection region)

In either case, multiple sensors can be used to cover larger areas or volumes. However, fewer instances of the 3D sensor are required to cover a large area and volume. In the case of a smaller electronic component, such as a smart lock or video doorbell, a single 3D sensor IC may suffice to cover the entire surface area. By combining both planar and vertical Hall elements, 3D sensing devices such as the A1266 omnipolar switch [1] and the ALS31300 linear sensor [2] from Allegro are able to detect magnetic tampering very effectively and virtually without regard to the orientation of the magnet. A complete list of 3DMAG™ position sensors from Allegro can be found on our website [3].

CONCLUSION

The experiment results highlight several advantages of 3D Hall-effect sensors such as their ability to detect strong magnetic fields that are randomly applied to the outside of a smart home device. Tampering by means of a strong magnet can cause malfunction or damage to electronics if the proper preventative measures are not engaged.

The first step to successful magnetic tamper prevention is the detection of these strong magnets. As the results show, the 3D sensor is a superior technology to employ when designing secure and tamper-proof smart home systems. The added benefit of using a single 3D tamper detection IC greatly reduces system design time and cost and enables the most effective tamper prevention solution using the fewest number of components.

REFERENCES

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3. 3D Magnetic Position Sensors webpage, Allegro MicroSystems (https://www.allegromicro.com/en/products/sense/linear-and-angular-position/3d-magnetic)

Revision History

Number	Date	Description	Responsibility
–	November 12, 2020	Initial release	J. Hollins
1	July 29, 2021	Editorial updates	J. Hollins

955 PERIMETER ROAD • MANCHESTER, NH 03103 • USA
+1-603-626-2300 • FAX: +1-603-641-5336 • ALLEGROMICRO.COM