*Application Note*

# *Hall-Effect (In-Package TMCS1143) vs. Other Isolated CS Methods*

*Eunize Tobias, Carolus Andrews*

**ABSTRACT**

This application report compares Texas Instruments (TI) TMCS1143 hall-effect in-package current sensor and other isolated current sensor methods by showcasing the benefits of each.

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# 1 Introduction

Today's market offers different designs for current measurements. Each technology offers different advantages and limitations which can make deciding what device to use for applications challenging. The goal of this application report is to compare Hall-effect in-package ICs, current transducers and modules and showcase the benefits of each.

# 2 Detailed Description

## 2.1 Hall-Effect In-Package Current Sensors

Hall-effect in-package current sensors are a type of galvanically isolated sensor where the current passes through the device package. The magnetic field generated by the current flow is measured internally with an isolated sensor which is converted to a voltage signal without any direct electrical connection. They are commonly used for AC and DC current sensing across multiple applications due to their high accuracy, low drift, isolation, fast response time and compact solution size for space-constrained designs.

For more comprehensive understanding of Hall-Effect current sensing principles and implementation techniques, our Hall-Effect Current Sensing Video provides detailed explanations and practical application examples.

## 2.2 Current Transducers and Modules

Current transducers are another widely used method for AC current sensing across multiple applications due to the isolation between high-current and low-current circuits. Open-loop transducers measure the magnetic field produced by the current directly and convert it to a proportional output signal. Closed loop is another configuration which uses a compensation circuit where the magnetic field is counterbalanced. Even though current transducers and modules have a higher current capability than in-package current sensors they have some limitations. One such example is flux saturation of the magnetic core, which makes the device unable to perform measurement until the flux inside the core is brought back within spec.

## 2.3 Design Requirements

Designing systems that require high-current measurements might come with a challenge based on the advantages and limitations that the different technologies offer. Each technology offers distinct advantages in terms of accuracy, isolation, frequency response, size, and cost, making them suitable for different applications. These factors will be explained and compared in this application note by doing some lab measurements or by comparing them directly with the devices' datasheets.

The devices being compared are:

1. TI TMC1143: Galvanically isolated Hall-effect sensor supporting up to 125A RMS continuous current in a compact package.
2. Competitor 1 (Comp1): Hall-effect based current sensor with integrated galvanic isolation in SMT lead form, measuring up to 100A.
3. Competitor 2 (Comp2): Open-loop transducer using Tunnel Magnetoresistance (TMR) technology with isolation in a through-hole package; rated for 50A RMS with family options up to 180A.
4. Competitor 3 (Comp3): Bidirectional, open-loop Hall-effect based current sensor in a through-hole package with 50A primary nominal current.
5. Competitor 4 (Comp4): Open-loop Hall-effect current transducer with galvanic isolation; family ranges up to 600A with the tested device rated for 100A.
6. Competitor 5 (Comp5): Closed-loop current transducer with galvanic isolation measuring both AC and DC, designed for 75A primary nominal RMS current

## 2.4 Current Capability

Different current sensor methods have different current capabilities based on their construction. Current transducers and modules usually have a higher AC current capability because of their electrical architecture and thermal performance. Current transducers and modules typically have an opening for the primary conductor to pass through which generates a magnetic field that has a magnitude proportional to current. Also, because of their package physical size and non-invasive current measurement method it doesn't have the same heat dissipation limitation as in-package Hall-effect.

## 2.5 Accuracy

For accuracy measurement there are three components considered: electrical offset error, magnetic offset error and sensitivity. The electrical offset error (also referred as voltage offset error), $V_{OE}$ , is the deviation from the ideal $V_{out}$ when no input current is flowing. This test was run by inputting zero current and measuring the zero current output voltage, $V_{out,0A}$ . $V_{OE}$ was then calculated by using Equation 1. For the magnetic offset error, the devices were saturated to 110% of their maximum current, returned to the quiescent point, then $V_{out}$ was captured at no current. The offset voltage was calculated to determine if there were any changes due to any residual effects caused due to the saturation of magnetic fields. Lastly, sensitivity is the change from the sensor $V_{out}$ due to the change in input current, $I_{IN}$, which can also be seen as the slope as shown on Figure 1. Sensitivity testing was done by measuring the sensors $V_{out}$ at no input current flowing and then loading a different currents and recording the corresponding $V_{out}$ to then calculate the slope. Then the error of the sensitivity, $e_{SENS}$, was calculated using Equation 2.

From the results we can see that TI TMCS1143 has the lowest offset voltage and similar to all other competitors apart from the closed-loop current transducer (Comp5), no hysteresis is observed after the device was saturated. It's interesting to note that Comp5 shows a 3mV difference since this is a closed-loop current transducer and it is known that hysteresis effect is minimized for this type of method. For the sensitivity results we can see that the sensors with the lower sensitivity like Comp4, TMCS1143, and Comp5 could be a better solution for high current applications where this is important to allow the full current range without saturating.

$$V_{OE} = V_{out,0A} - V_{REF} \tag{1}$$

$$e_{SENS} = \frac{S_{MEAS} - S_{IDEAL}}{S_{IDEAL}} * 100\% \tag{2}$$

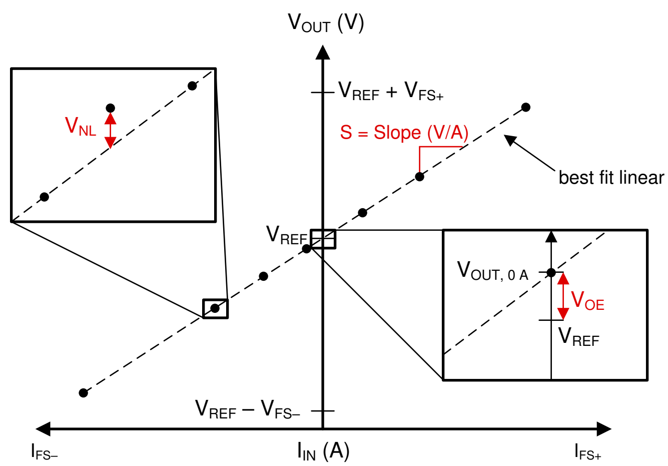


**Figure 2-1. Sensitivity, Offset and Nonlinearity Error**

**Table 2-1. Offset Error Comparison**

| Device | Technology | Electrical Offset Error, $V_{OE}$ | Magnetic Offset Error | Sensitivity Error, $e_{SENS}$ |
|---|---|---|---|---|
| TI TMCS1143 | Hall-effect in-package IC | 3mV | 3mV | 0.24% |
| Comp1 | Hall-effect in-package IC | 18mV | 18mV | 1.45% |
| Comp2 | Current module | 10mV | 10mV | 4.91% |
| Comp3 | Current module | 11mV | 11mV | 1.22% |
| Comp4 | Current Transducer | 8mV | 8mV | 0.0005% |
| Comp5 | Current Transducer | 6mV | 9mV | 1.69% |

## 2.6 Transient Response

As part of the transient step response section four parameters were considered: propagation delay ( $t_{pd}$ ), response time ( $t_r$ ), slew rate (SR) and bandwidth (BW). The period between the input current, $I_{In}$ , reaching 10% of the final value and the $V_{out}$ reaching 10% of the final value is defined as $t_{pd}$ . The period between $I_{In}$ , reaching 90% of the final value and $V_{out}$ , reaching 90% of the final value for an input current step enough to make a 1V change in the output voltage is defined as $t_r$ . Different competitors measure $t_{pd}$ and $t_r$ differently, therefore, to verify impartiality we measure them as shown in Figure 2. Bandwidth is important to verify the current sensor meets the application requirements as it sets the limit at which the input signal, as well as its associated harmonics, will be fully amplified by the device. This helps reconstruct an accurate output signal without distorion due to harmonic attenuation.

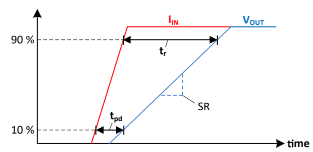


**Figure 2-2. Transient Step Response**

The response time, $t_r$ , and propagation delay, $t_{pd}$ were measured for each device and the bandwidth was compared from the datasheet which is listed in Table 2-2.

**Table 2-2. Response Time and Bandwidth**

| Device | Technology | $t_{pd}$ | $t_r$ | Bandwidth |
|---|---|---|---|---|
| TI TMCS1143 | Hall-effect in-package IC | 0.14 µs | 1.03µs | 275kHz |
| Comp1 | Hall-effect in-package IC | 1.42 µs | 3.42µs | 200kHz |
| Comp2 | Current module | 0.087 µs | 0.10µs | 400kHz |
| Comp3 | Current module | 0.84 µs | 0.76 µs | 400kHz |
| Comp4 | Current Transducer | 3 µs | 3.74 µs | 240kHz |
| Comp5 | Current Transducer | 0.124 µs | 0.78 µs | 300kHz |

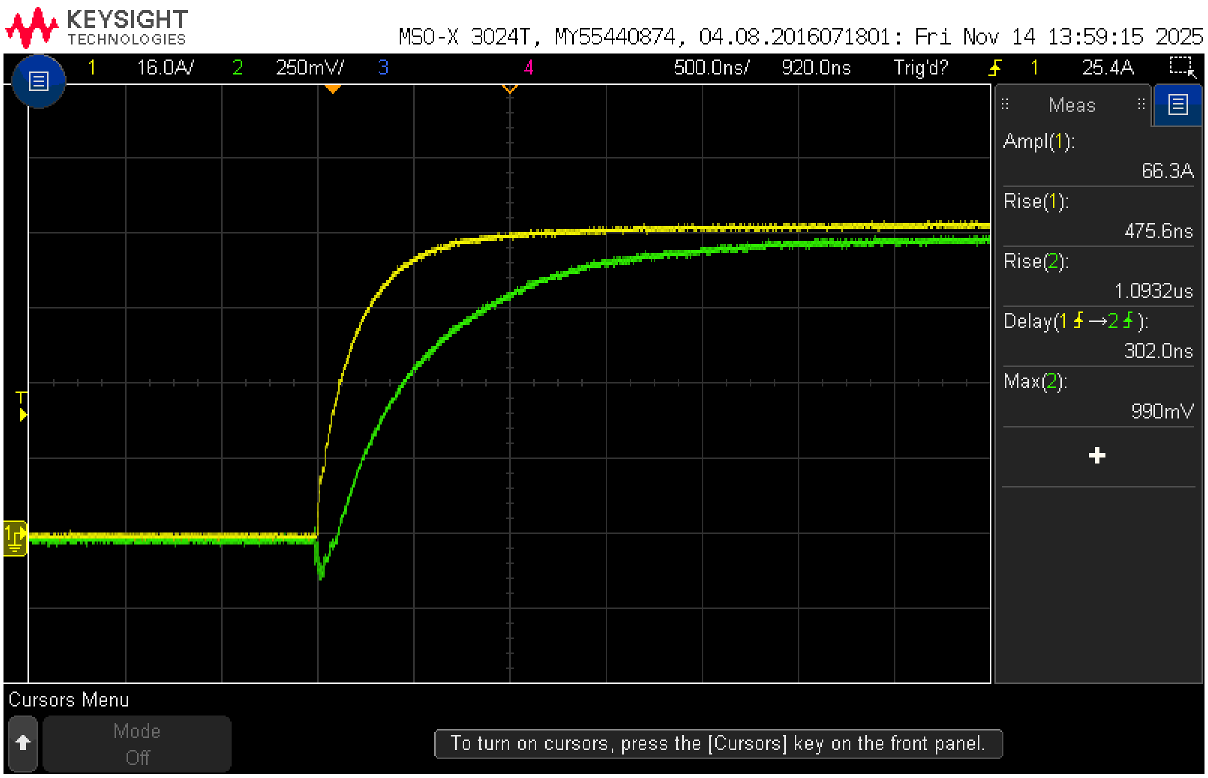


**Figure 2-3. TI TMCS1143 Response Time**

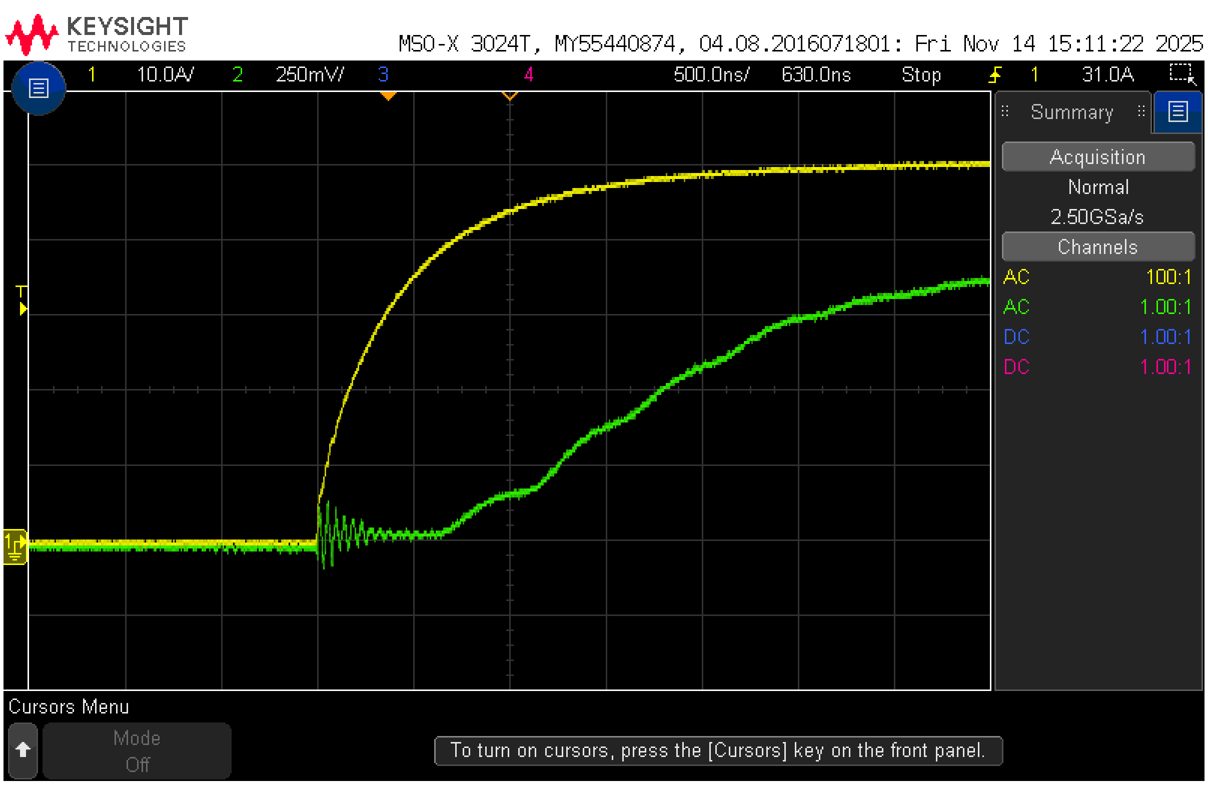


**Figure 2-4. Comp1 Response Time at 500ns per horizontal division**

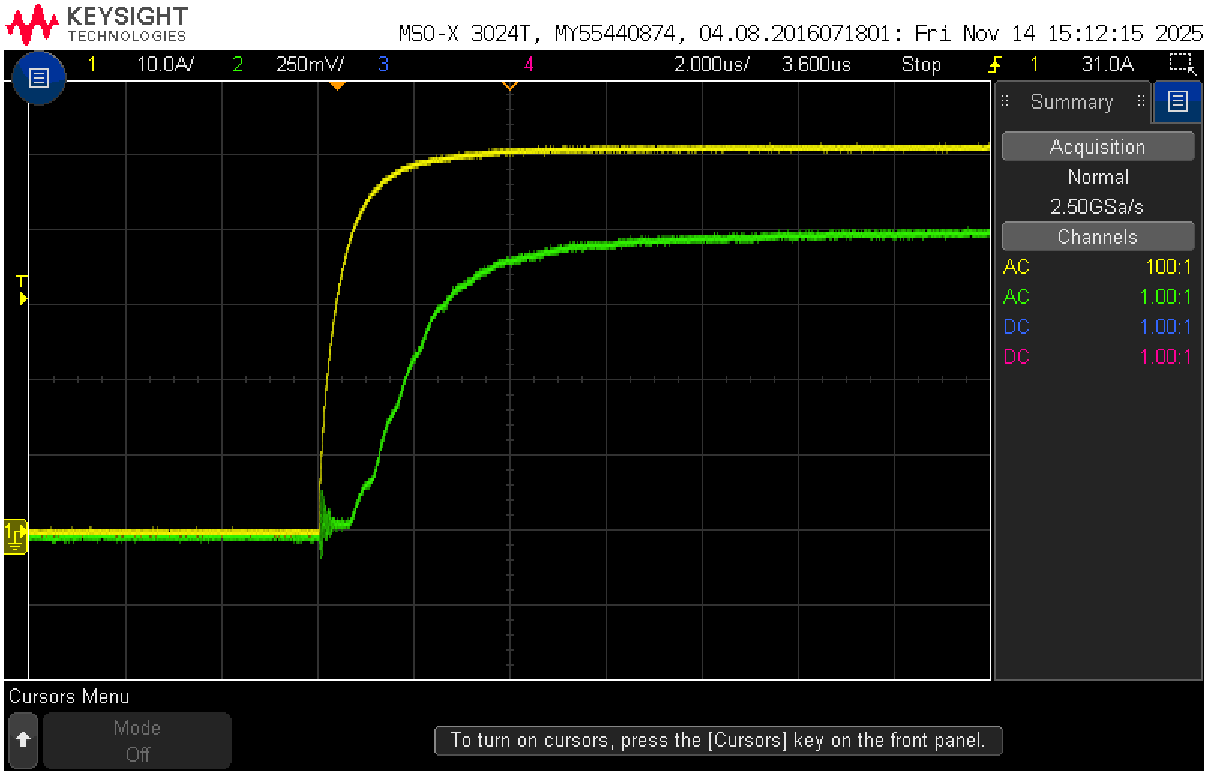


**Figure 2-5. Comp1 Response Time at 2us per horizontal division**

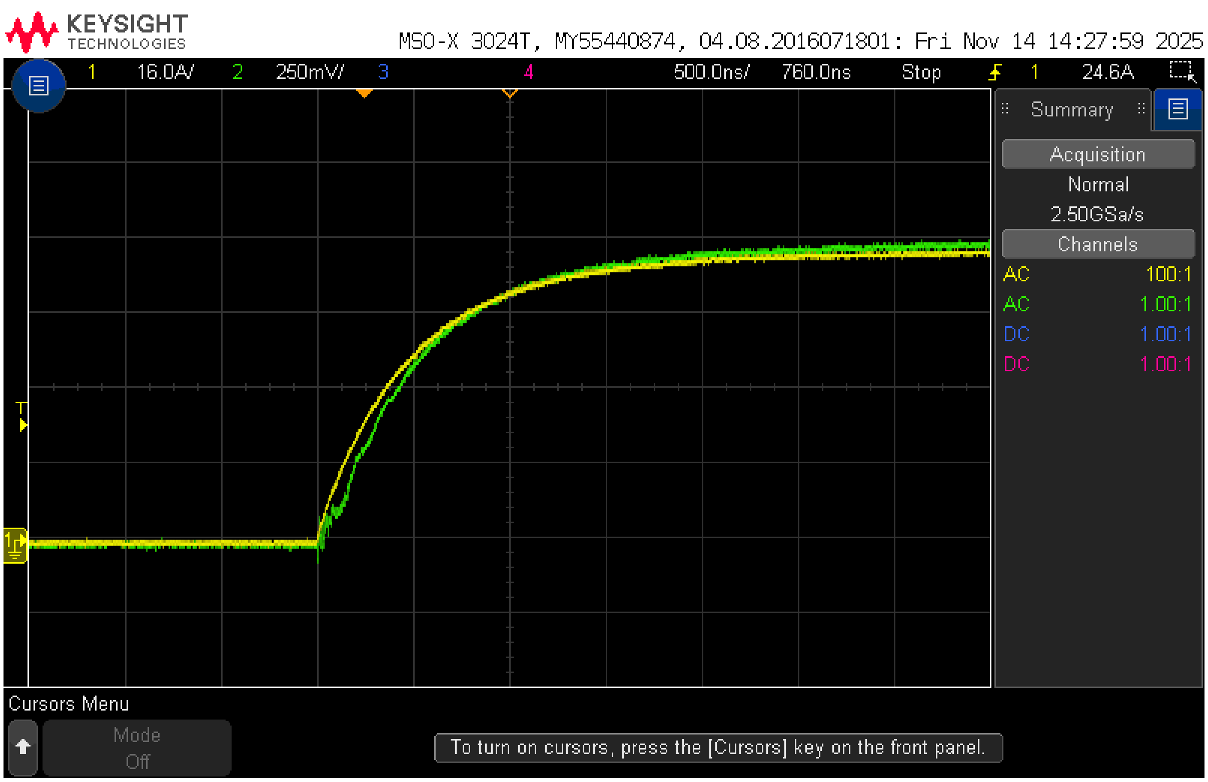


**Figure 2-6. Comp2 Response Time**

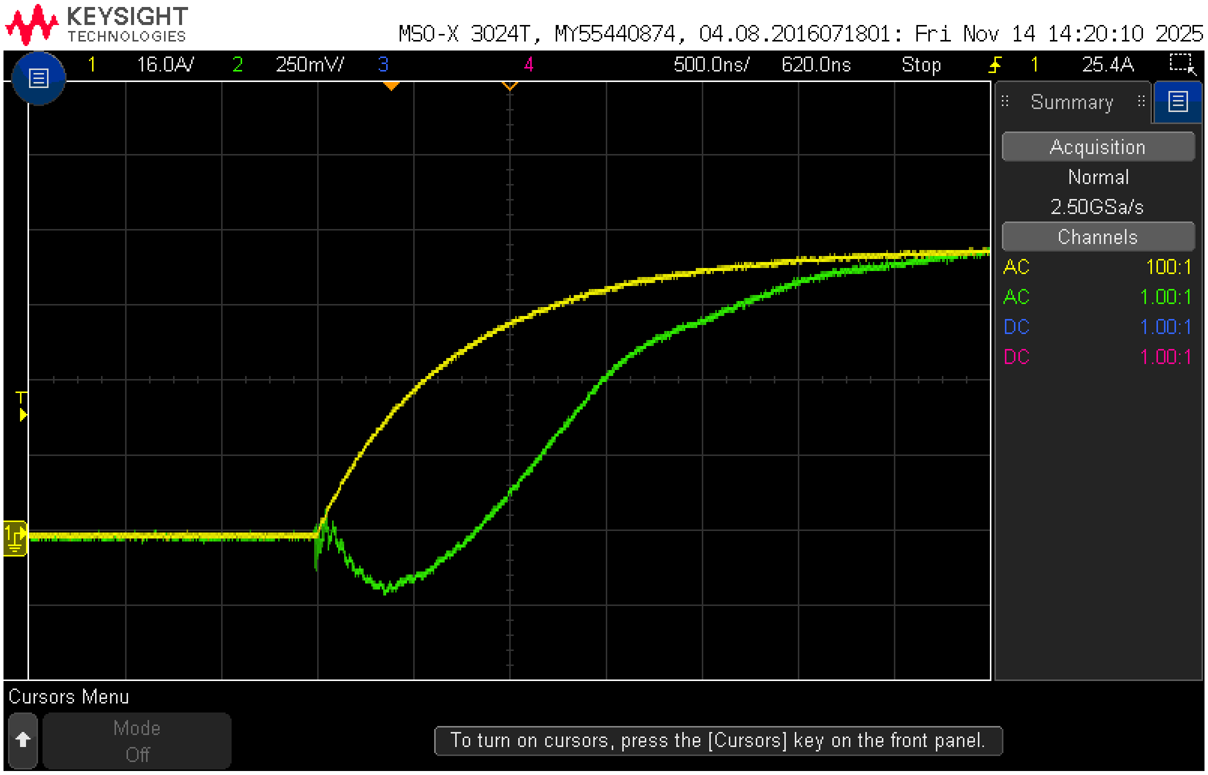


**Figure 2-7. Comp3 Response Time**

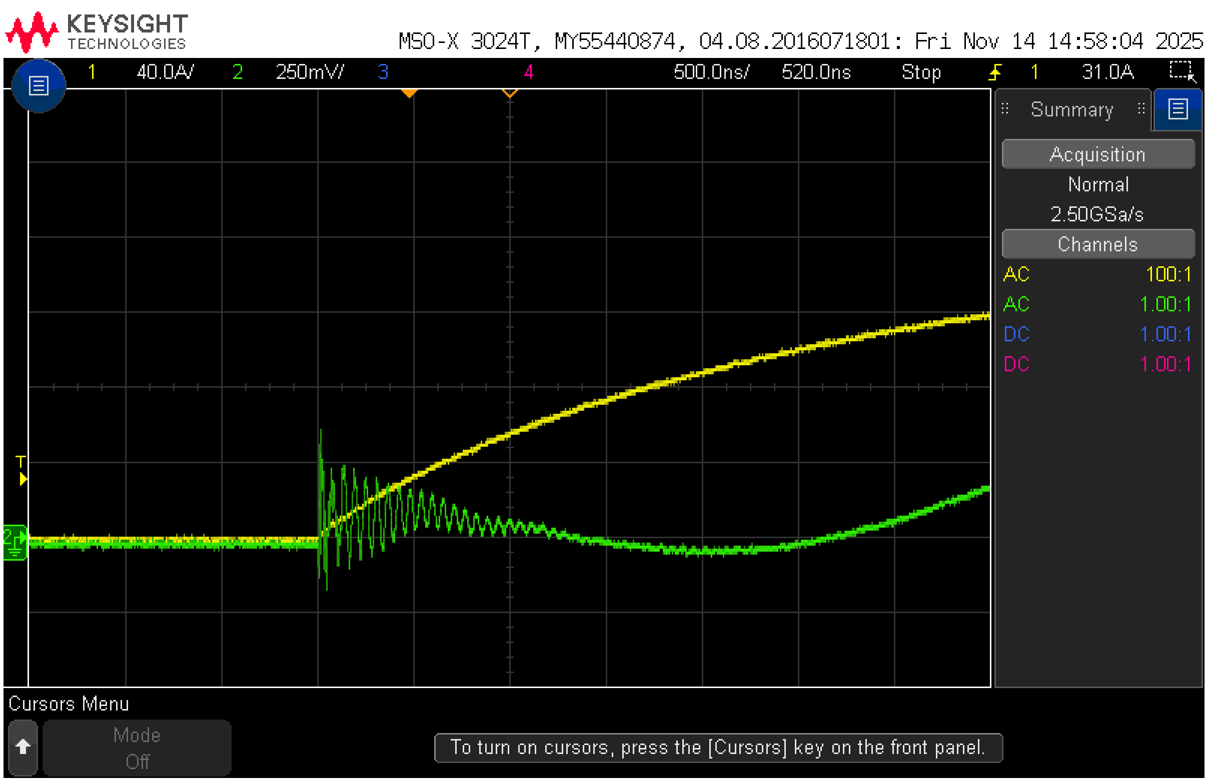


**Figure 2-8. Comp4 Response Time at 500ns per horizontal division**

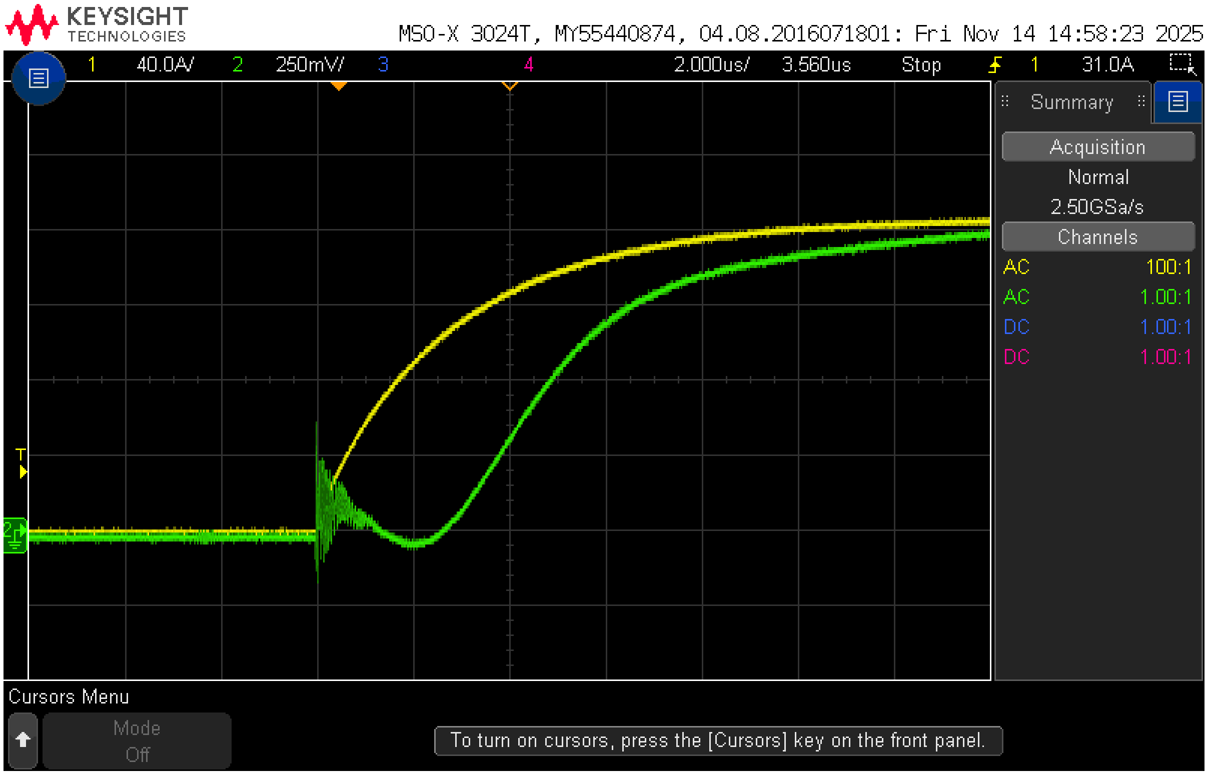


**Figure 2-9. Comp4 Response Time at 2us per horizontal division**

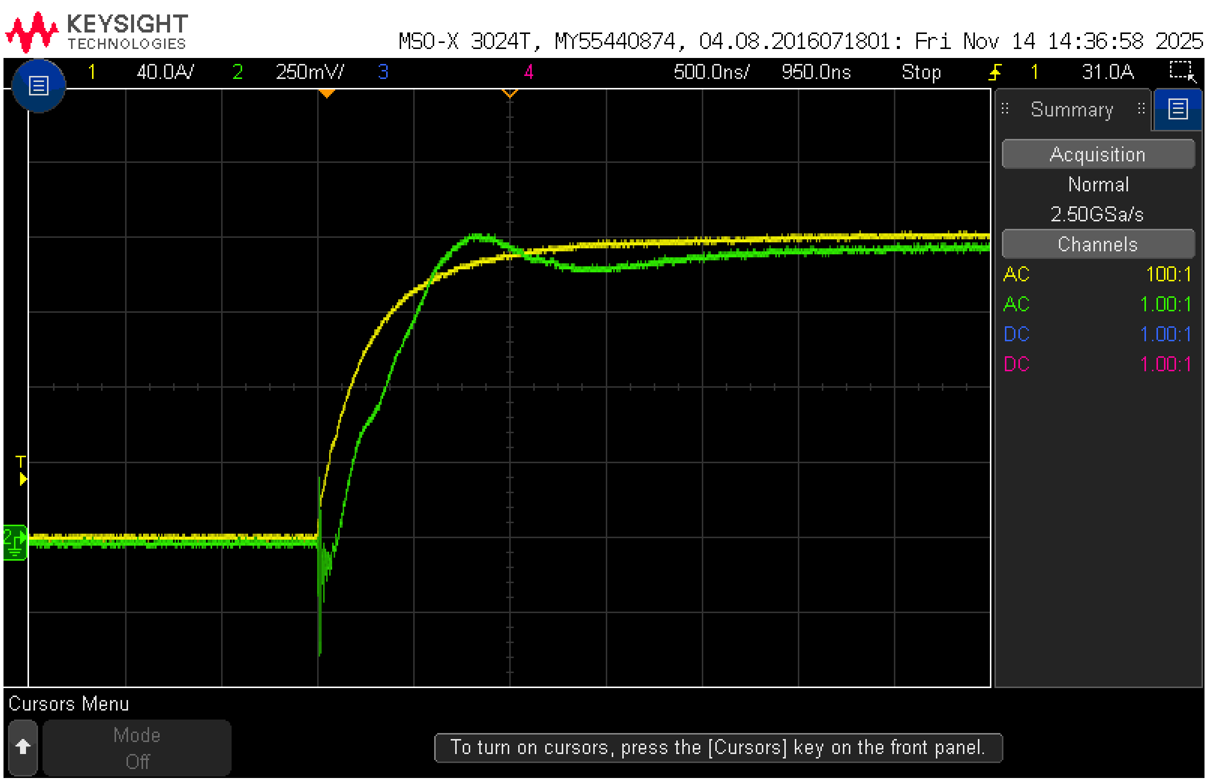


**Figure 2-10. Comp5 Response Time**

By comparing all the bandwidth of devices specified on the datasheets, the bidirectional open-loop current sensor (Comp3) and the open-loop current transducer (Comp4) can have a faster and accurate response to fast changing current but might come with some tradeoffs like sensitivity to noise. The open-loop current transducer

(Comp4) is particularly slow compared to the other devices due to the external primary conductor as it adds inductance based on the wire used. The inductance can be reduced with larger wires, but the tradeoff is total cost of the system.

## 2.7 Ambient Field Rejection (AFR)

Ambient field rejection (AFR) is crucial to ensure measurements are accurate by rejecting interference from external magnetic fields close to the device. Having a device that has good AFR ensures accurate measurements and simplifies main design challenges. To test the magnetic rejection ratio a Helmholtz coil and cryotronics probe were used. Helmholtz coils generate a uniform magnetic field by having two parallel coils with an equal current flowing through both coils in the same direction. A current was given to the Helmholtz coils to establish a desired uniform field; the probe was used to measure the magnetic field in the Z-orientation, and the devices compared were positioned in close proximity to the probe. $V_{out}$ was then measured for each device and recorded as shown on Figure 2-11. Testing the open-loop current transducer (Comp4) had some limitations as the component requires external cables to connect to the PCB which might interfere with the results. Figure 9 shows that TI TMCS1143 has the best AFR as the $V_{out}$ is not affected as much as the other components, especially the open-loop transducer (Comp2).


**Figure 2-11. Vout Across Magnetic Fields**

## 2.8 Package and Size

All tested components have different package sizes. Some of the components such as Comp4, which is a bigger design, have some limitations when it comes to PCB space and layout. Devices such as TI TMCS1143, because these devices do not have bulky cores, can enable more compact designs and reduce PCB space, which can also lead to lower cost designs. Out of all the components compared, TI's TMCS1143 is the smallest design at $138.43mm^2$ as shown in Figure 2-12 and Figure 2-13. Smaller options in the isolated space do exist, but often provide only basic isolation, where the TMCS1143 provides reinforced isolation.

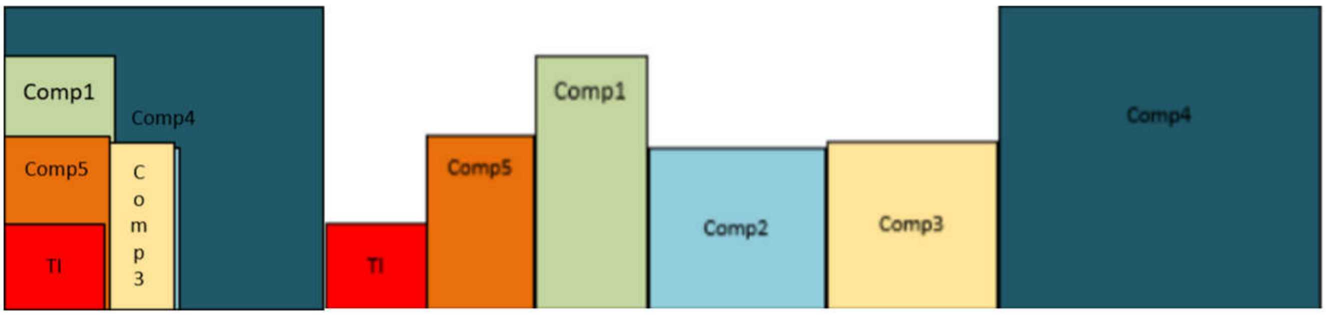


**Figure 2-12. 2D Top View Comparison**

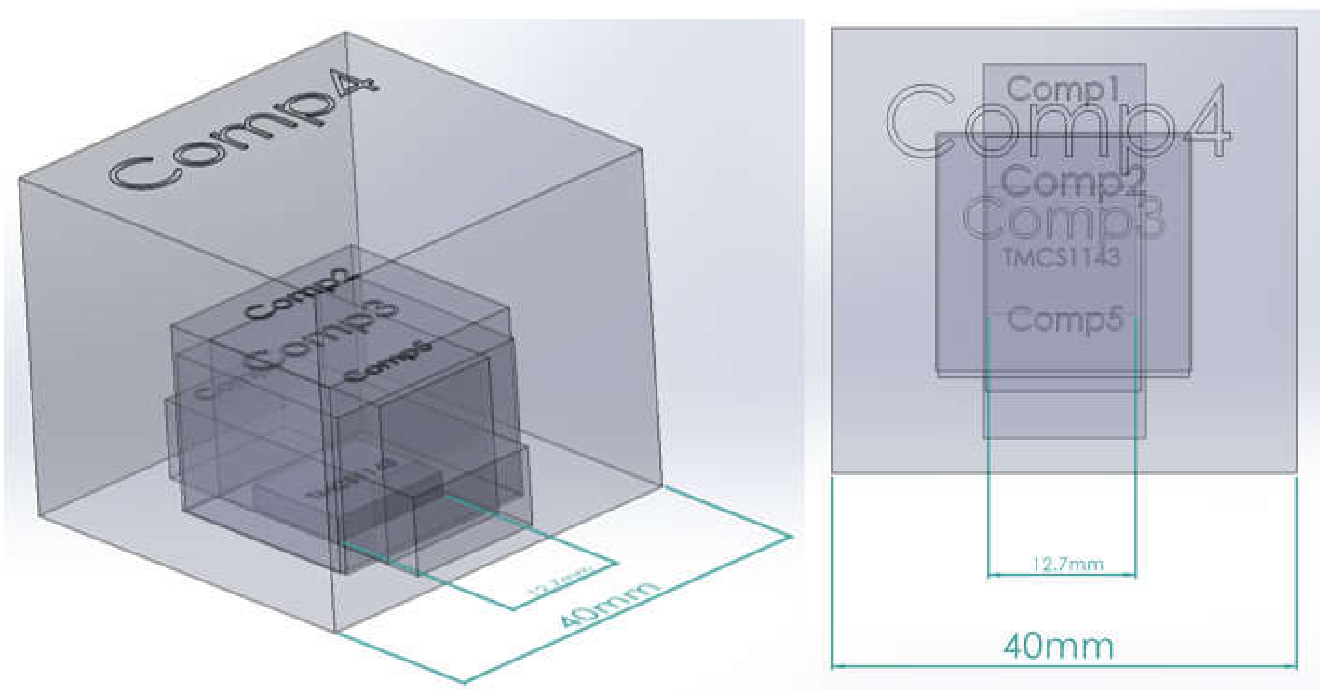


**Figure 2-13. 3D View of Total Area for all Components**

## 2.9 Price

Price is also an important factor when choosing a current sense device as the different methods have different prices. In order to be fair when comparing prices, the 1Ku price at DigiKey was compared. Pricing was divided into three categories, low cost $ ($0-$4.5), mid-cost $$ ($4.5-$9), and high cost $$$ (>$9). See Table 3-1 to see how the devices compare in price.

## 2.10 Additional Features

TMCS1143 has both an internal self-diagnostics alert feature and overcurrent detection. The alert feature helps warn when operating conditions invalidate current sensor measurements like temperature and sensitivity. The integrated overcurrent detection (OCD) can be used to trigger a warning or initiate a system shutdown to prevent damage from excessive current flow caused by different conditions such as short circuits or motor stalls. OCD has the flexibility to be set by using external resistor divider driven by the power supply voltage or by the internal reference voltage. Having these additional features enables a single chip solution for several applications making it easier to design, smaller solution size and lower cost.

# 3 Summary

In conclusion, there are different parameters that need to be taken into account when designing systems that require high-current. Trying to decide what technology or device to use can be a challenge, which is why it is important to understand what design requirements are a must for your application. Based on the parameters discussed on this paper, Hall-effect in-package TMCS1143 offers the most advantages as listed in Table 3-1.

**Table 3-1. Comparison Summary**

| | **TMCS1143** | **Comp1** | **Comp2** | **Comp3** | **Comp4** | **Comp5** |
|---|---|---|---|---|---|---|
| Technology | Hall-effect in-package IC | Hall-effect in-package IC | Current module | Current module | Current Transducer | Current Transducer |
| Current Capability | 125A | 100A | 50A | 50A | 100A | 75A |
| Sensitivity Error | 0.24% | 1.45% | 4.91% | 1.22% | 0.0005% | 1.69% |
| Offset Error | 3mV | 18mV | 10mV | 11mV | 8mV | 6mV |
| Magnetic Offset Error | 3mV | 18mV | 10mV | 11mV | 8mV | 9mV |
| Bandwidth | 275kHz | 200kHz | 400kHz | 400kHz | 240kHz | 300kHz |
| Propagation delay | 0.14 µs | 1.42 µs | 0.087 µs | 0.84 µs | 3 µs | 0.124 µs |
| Solution Size | 138.43 mm2 | 316.4 mm2 | 454.21 mm2 | 457.9 mm2 | 1,215 mm2 | 293.6 mm2 |
| Cost* | $ | $$ | $ | $$ | $$$ | $$$ |

# 4 References


1. Texas Instruments, An Engineer's Guide to Current Sensing, e-book
2. Texas Instruments, TMCS1143 Precision 275kHz Hall-Effect Current Sensor With Reinforced Isolation, Overcurrent Detection and Ambient Field Rejection, datasheet.