Application Note

How EZShunt Technology Simplifies and Reduces Error in Shunt-Based Designs

David Chacko

ABSTRACT

Current sense amplifiers measure differential voltages across a shunt resistor to derive a single-ended output voltage, crucial for current, power, energy calculations in a variety of modern systems. Traditional variations are designed utilizing external shunt resistors to monitor power while our EZShunt™ technology helps integrate shunt functionality and digital conversions, eliminating the need for external components such as resistors and additional ADCs. These advancements not only reduce system complexity and footprint but also enhance precision through advanced calibration techniques that compensate for drift and temperature variations. By evaluating the performance and error characteristics of both traditional and EZShunt™ enabled designs, the data helps provide comprehensive total error specifications inclusive of integrated shunt-related factors for both designs.

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Trademarks

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1 Introduction

Current sense amplifiers help measure the differential voltage across a shunt resistor and amplify this value to provide a single-ended output voltage. This output voltage is then measured by an external ADC and a Microcontroller to calculate the current present on each rail. Meanwhile, a Digital power monitor helps measure this voltage and performs mathematical processing on-chip with the use of a built-in ADC, freeing up system processors to handle separate tasks. This helps enable higher bit-depth with the digital power monitor providing additional features such as an alert functionality, energy, power, current, voltage, and die temperature monitoring on certain devices. When designing a design to measure power, an external shunt resistor is designed in series using kelvin connections to measure a differential voltage across the shunt.

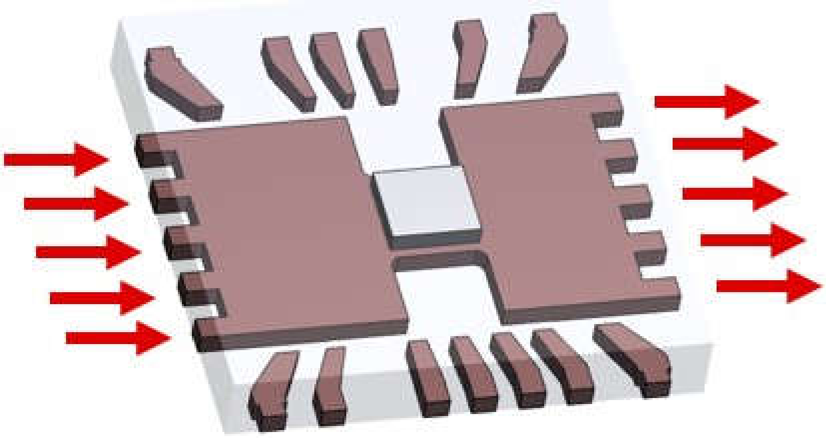

Figure 1-1. EZShunt™ Leadframe

This input is then processed to be a single-ended digital output by the device. On the contrary, EZShunt™ technology eliminates the need for an external shunt resistor, or ADC while measuring multi-modal values since the lead frame functions as the shunt resistor as shown in Figure 1-1.

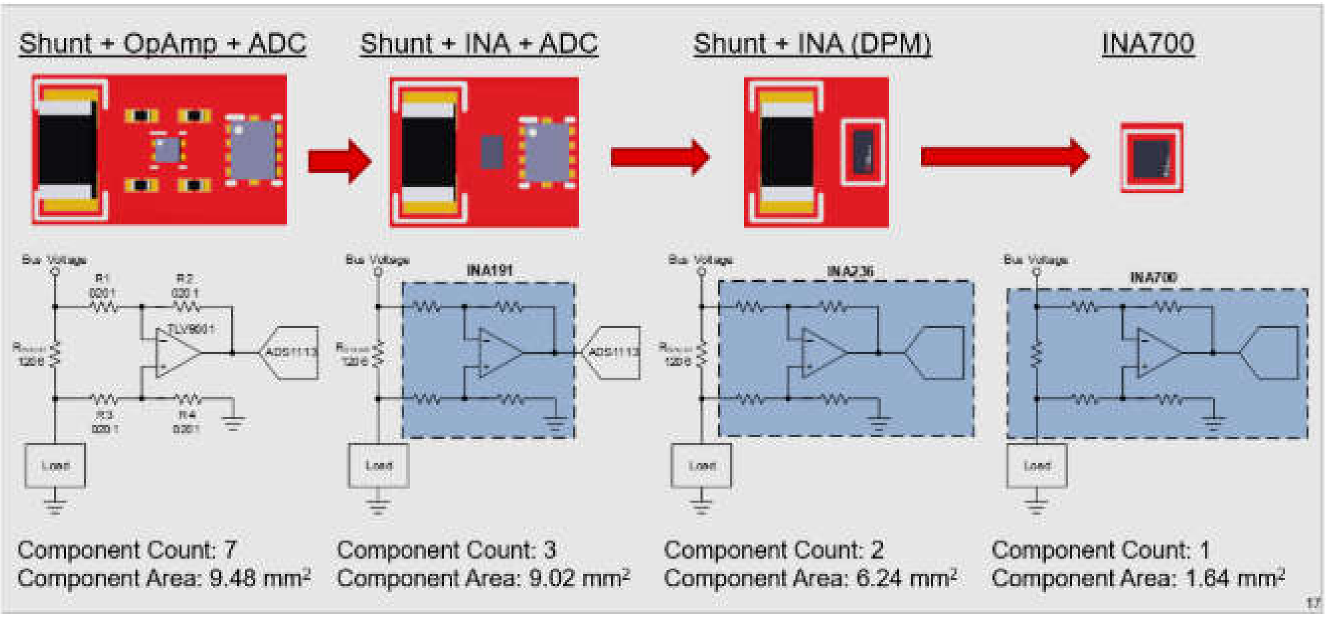

Figure 1-2. Current Sense Design Variations in Size and Component Count

In comparison to alternative current sensing designs using a shunt, opamp, current sense amplifier, or digital power monitor, we can see the footprint and component count reduction EZShunt™ technology offers using Figure 1-2. Reduction in component count and footprint also offers a cost-optimized path toward sensing power, current, voltage, energy while maintaining highly precise accuracies.

In accordance with design size, total design accuracy is a crucial component in analyzing the effectiveness of each variant. Since the EZShunt™ leadframe is composed of copper, there is a tendency for the leadframe to drift according to temperature. However, TI technology leverages active calibration techniques that compensate for lead frame drift and variation in error based on temperature utilizing the capabilities of monitoring die temperature as shown by the typical behavior in Figure 1-3.

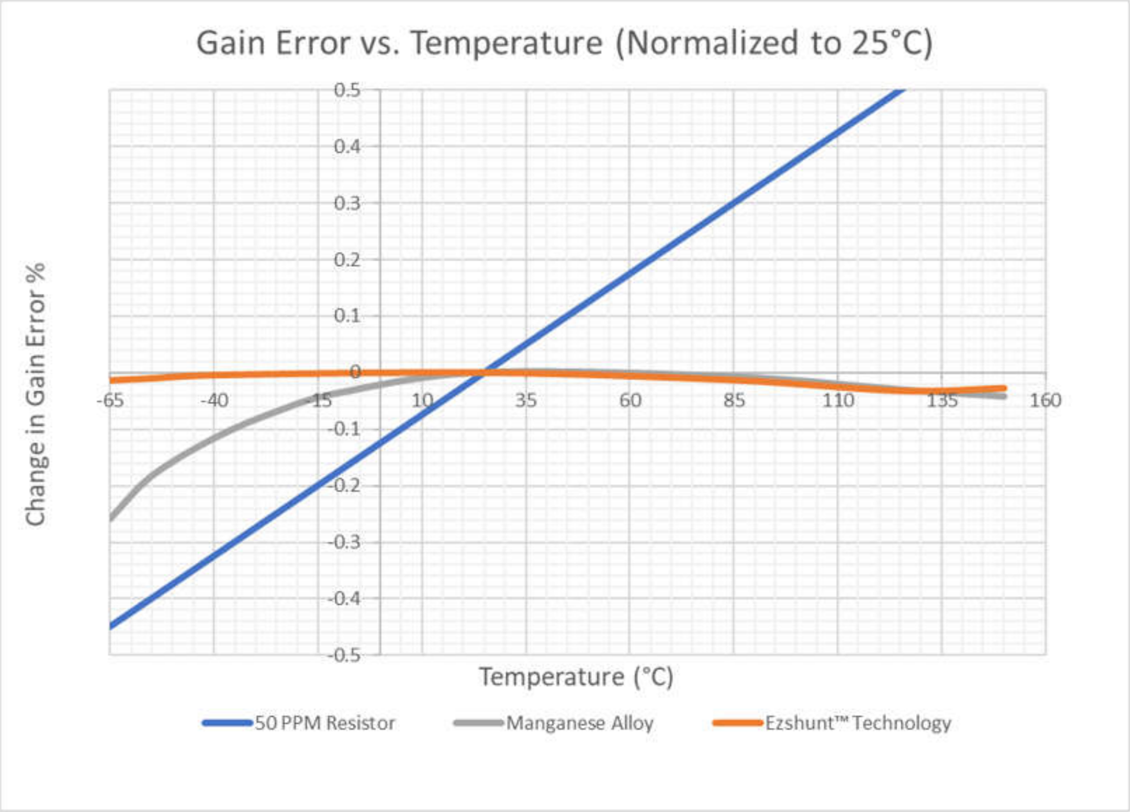

Figure 1-3. Gain Error vs. Temperature (Normalized to 25°C)

This form of compensation alongside precise measurement procedures allows for an all-in-one device providing telemetry requirements for any application. In accordance with the benefits, analyzing factors that culminate to form errors allows us to visualize the true accuracies and error comparisons between traditional external shunt and integrated current sensing designs. Data sheets and errors specified for traditional Current sense amplifiers and Digital power monitors do not include the additional error produced by an external shunt. This error is often considered by the end user and defined according to the ambient field temperature depending on the total design. Meanwhile, accuracies and parameters defined by our EZShunt™ products include all errors associated with the integrated shunt and are specified according to ambient field temperature as well.

2 Design Size

EZShunt™ technology eliminates the need for external shunts alongside ADC’s and kelvin connection helping reduce the overall design size by 84% against traditional designs in the current market. Our device sizes vary based on voltage, and current capability.

The smallest device within this family is our INA700 which can help support 15A at 25°C ambient temperature, 40V of common Mode voltage, with an internal resistance of 2mΩ. This device is provided in a 1.2mm x 1.33mm WCSP package totaling an area of 1.637mm^2. Meanwhile, the traditional external shunt design can use 10.33mm^2 . Figure 2-1 shows such arrangement.

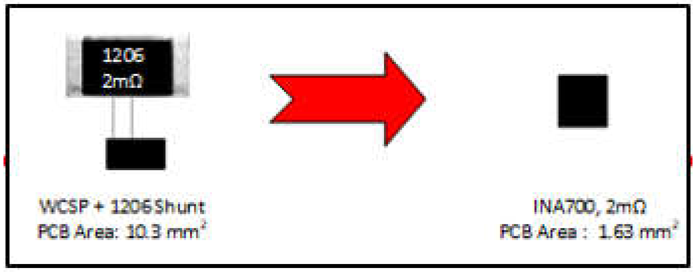

Figure 2-1. EZShunt™ vs Digital Power Monitor Footprint

The INA745A/B, capable of 35A and 25°C ambient temperature, with an internal resistance of 0.8mΩ, and V_{cm} capability of 40V comes equipped with a design size of 18.44mm^2 in comparison to the traditional 20mm^2 illustrated by Figure 2-2.

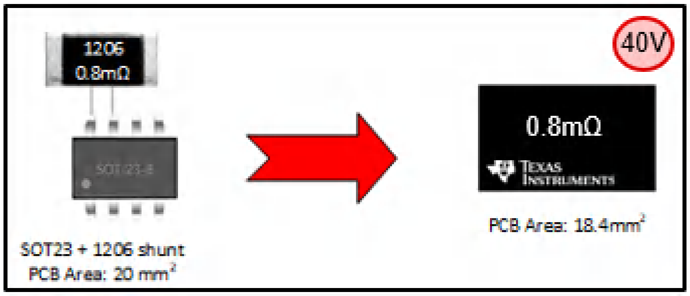

Figure 2-2. EZShunt™ vs Digital Power Monitor Footprint

Our INA740A/B, capable of 35A and 25°C ambient temperature, with an internal resistance of 0.8mΩ, and V_{cm} capability of 85V come equipped with a design size of 24mm^2 in comparison to the traditional design size 24mm^2 shown by Figure 2-3.

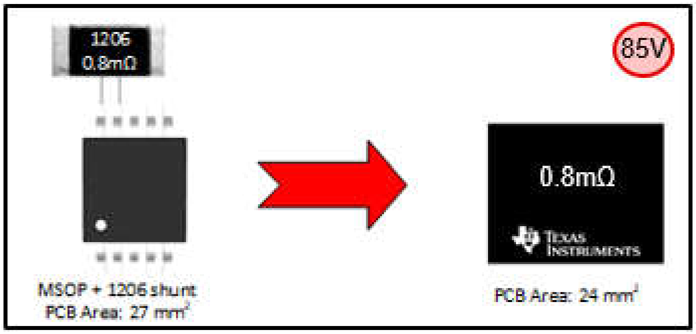

Figure 2-3. EZShunt™ vs Digital Power Monitor Footprint

Ultimately, Our INA780A/B devices which help support 85V-110V of common mode voltage and a current rating of 75A at 25°C ambient temperature, equipped with a 0.4mΩ shunt can provide a design size of 41mm^2 against the traditional 45mm^2 illustrated by Figure 2-4.

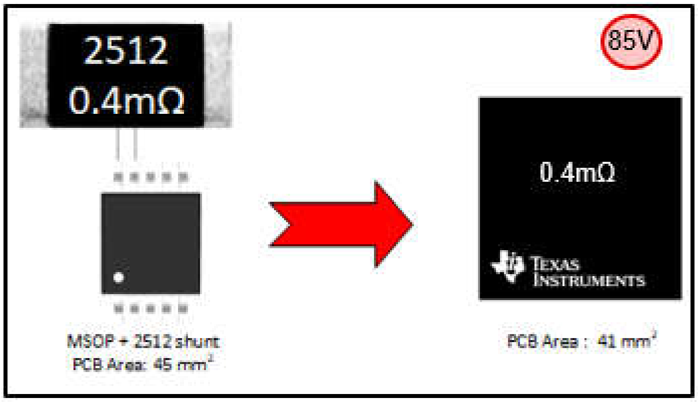

Figure 2-4. EZShunt™ vs Digital Power Monitor Footprint

3 Performance and Functionality

When using a design to measure current, power, voltage, or Energy, you can either use a Digital Power Monitor with a shunt resistor or an EZShunt™ device. For the first interpretation, the Digital Power Monitor can have a certain accuracy and adding a shunt resistor can include an additional source of error including Shunt drift, and tolerance percentage. The value of these error sources from each shunt resistor can vary based on cost and subsequent performance.

To analyze this performance against our EZShunt™ technology and traditional design sets, we collected benchmarking data by choosing resistors classified to support up to 15A, 25A, and 50A over temperature from three separate providers ranging between Cost and performance. These resistors were then paired with Digital Power Monitors which provide similar performance, functionality, and cost to respective EZShunt™ devices. Although each resistor is classified for specific parameters, a total of 20 resistors from each of the 9 chosen products were hand-measured in an unsoldered state, and 50% were tested after soldering using both hand and reflow methods at 0.5A. Multiple providers were used in sourcing each resistor to make sure variety and measured at 125°, 95°, 60°, 25°, 0°, and -40° Celsius. The main sources of error produced by a sense resistor can be classified between Tolerance percent and Drift.

The tolerance percent for each resistor was calculated using Ohms law:

$$R = \frac{V}{I} \tag{1}$$

Where the voltages at variant temperature ratings were measured at 0.5A of current being implicated upon the system in an unsoldered state. The calculated resistor value was then compared to the nominal resistance value of the shunt to measure the tolerance percentage.

Meanwhile, the drift is calculated using the following formula:

$$Drift = \frac{\left(\frac{R_2 - R_1}{T_2 - T_1}\right)}{R_{Nominal}} \tag{2}$$

Where R_2 is the measured current at 125°C, R_1 is the measured current at -40°C, T_2 is 125°C, T_1 is -40°C, and $R_{Nominal}$ equates to the nominal shunt value.

In addition, the data was then cross-examined according to Current vs Total error at room temperature (25°C) and 125°C. The total error on both discrete designs and EZShunt™ was calculated according to the following formula:

$$C_{RSS}\left(\%\right) \approx \sqrt{V_{OS}^2 + CMRR^2 + PSRR^2 + Gain\_Error^2 + Linearity^2 + Shunt\_Tolerance^2 + Bias\_Current^2} \tag{3}$$

To calculate total Error, only consider a typical use case where the main sources of error on both designs are gain error, gain drift, offset error, and offset drift.

3.1 Total Error Comparison for Current ≤ 15A Over Temperature

For this data set, the EZShunt™ device selected is the INA700, which is characterized for **15A at 25°C**, along with the INA234 and three separate resistor sets shown in Table 3-1

Table 3-1. Resistors A, B, and C (≤ 15A)

		Data Sheet		Measured				
Resistor	**Resistance (mΩ)**	**Tolerance**	**Drift (ppm)**	**Tolerance**	**Drift (ppm)**	**Wattage**	**Case Size**	**1K price**
A	2	1%	50	0.66%	17.6	0.5W	0805	$0.081
B	2	1%	150	0.44%	56.7	0.5W	1206	$0.18
C	2	1%	275	1.76%	54.5	0.5W	0603	$0.63

The Benchmark data with our EZShunt™ against Discrete implementations with consecutive resistor sets are shown in Figure 3-1.

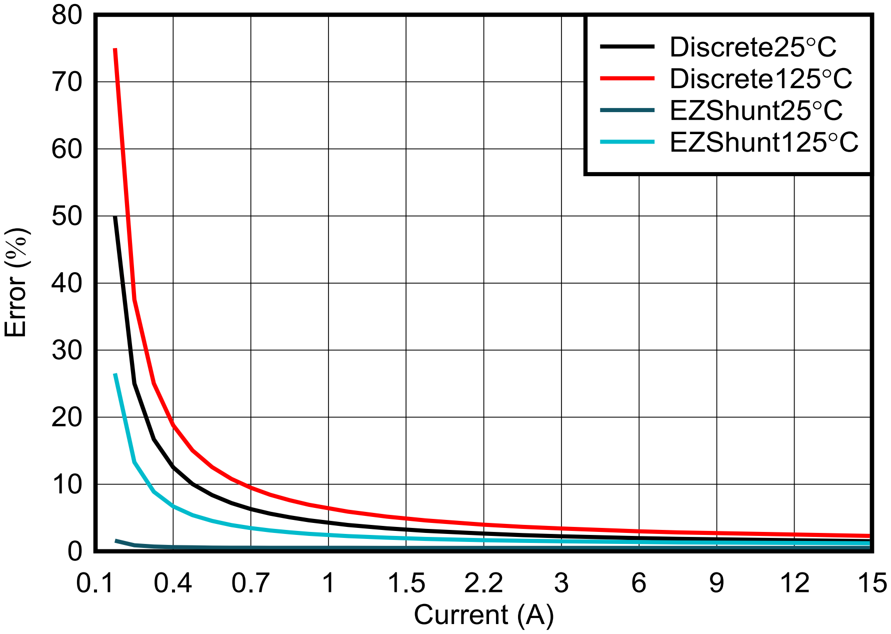

Figure 3-1. INA700 vs INA234 and Resistor A

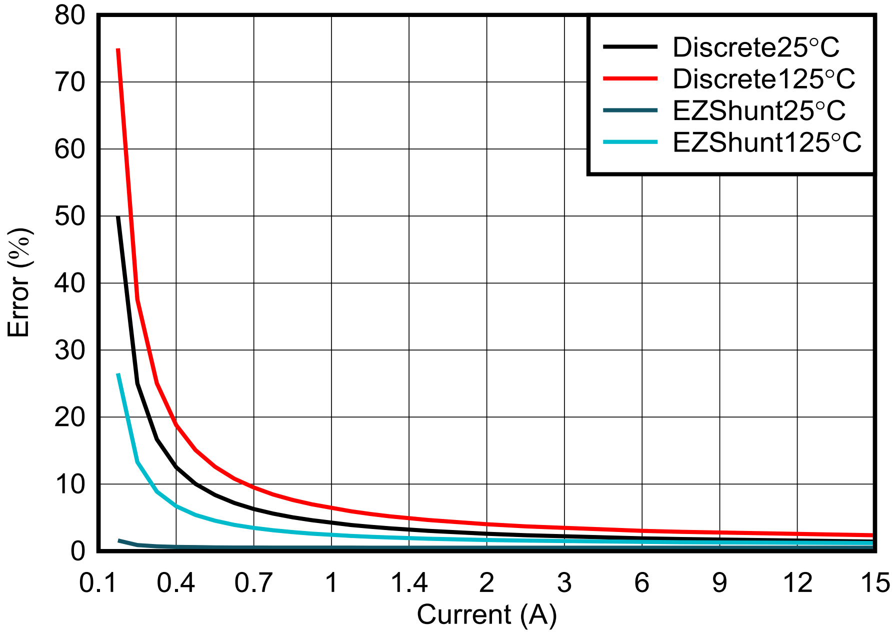

Figure 3-2. INA700 vs INA234 and Resistor B

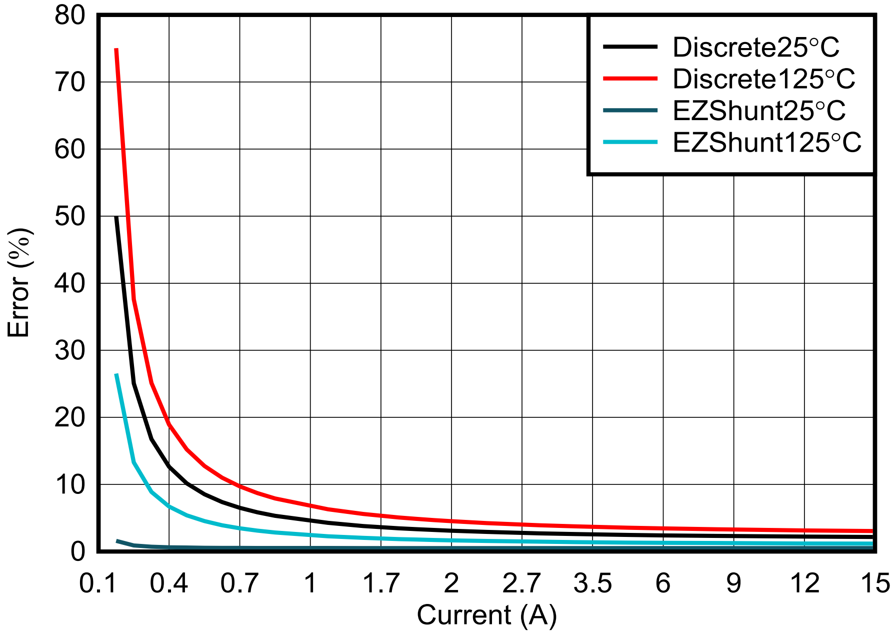

Figure 3-3. INA700 vs INA234 + Resistor C

When comparing the total error for each design from 0A to 15A at 25°C and 125°C ambient field temperatures, we can determine the overall accuracy of the discrete design used in conjunction with either Resistor A, B, or C is far less in comparison to the INA700 at both temperature (25°C and 125°C) points throughout the data set regardless of current nor temperature. Thus, helps us infer, regardless of resistor type, or cost for use cases measuring below 15A, INA700 can offer the most accurate design for similar cost in the market.

3.2 Total Error Comparison for Current ≤ 25A Over Temperature

For this data set, the EZShunt™ device selected is the INA745A, which is characterized for **35A at 25°C**, along with the INA236 and three separate resistor sets shown below to support a common mode voltage of 40V. Meanwhile, the INA740A that is characterized for 35A at 25°C was also used against the INA238 to support 85V. Both designs were paired with the Table 3-2 resistor set:

Table 3-2. Resistors D, E, and F(≤ 25A)

		Data sheet		Measured				
Resistor	**Resistance (mΩ)**	**Tolerance**	**Drift (ppm)**	**Tolerance**	**Drift (ppm)**	**Wattage (W)**	**Case Size**	**1K price**
D	1	1%	50	0.29%	96.9	1	1206	$0.161
E	1	1%	50	0.99%	118.2	2	2010/5025	$0.314
F	1	0.5%	300	0.2%	95.2	2	2512	$1.024

3.2.1 Common Mode Voltage ≤ 40V

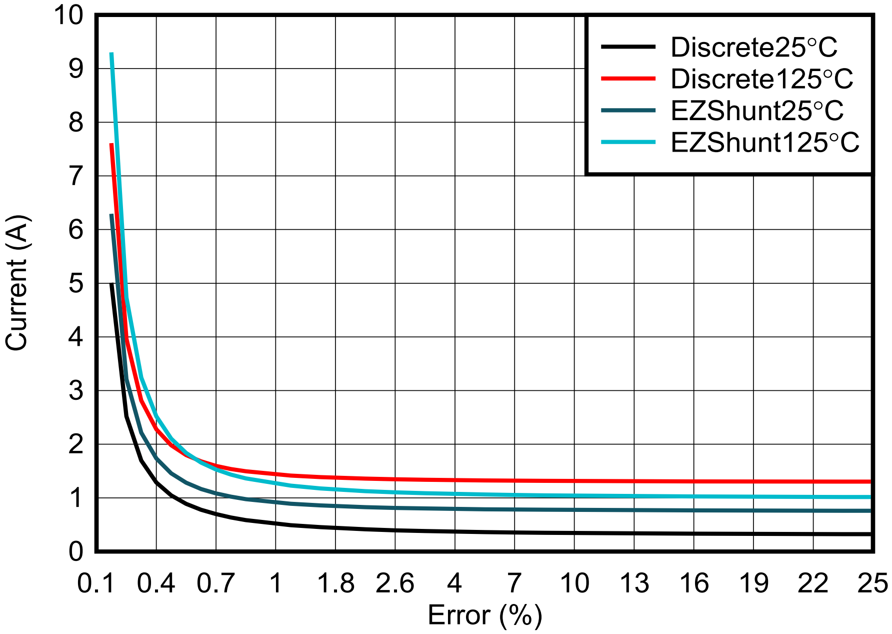

Figure 3-4. INA745A vs INA236 + Resistor D

At higher ambient temperatures such as 125°C , Our INA745A can provide a more accurate design from 0.7A to 25A in comparison to the Discrete design due to the total Drift imposed by both the Digital power monitor and Resistor variant. While the discrete design can remain more accurate from 0A to approximately 0.7A. This behavior can be attributed to the active calibration our EZShunt devices perform in conjunction with lower overall system drift when compared to INA236 + resistor D.

However, at 25°C , our data shows the overall accuracy of the EZShunt™ design is less than the discrete design due to the total error subjugated upon the system being slightly greater for the INA745A against the INA236 & Resistor D variant.

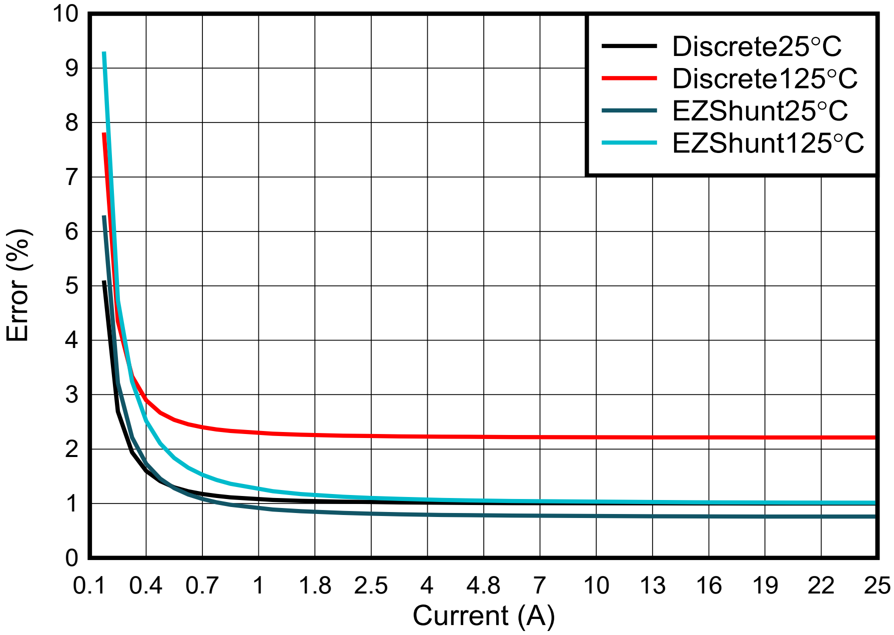

Figure 3-5. INA745A vs INA236 + Resistor E

The previous data set helps us understand a few differences when using Resistor E in the design. Here, we see from approximately 0.3A to 25A, at both 25°C & 125°C, the INA745A can provide a more accurate design in comparison to the discrete design. Meanwhile, from 0A to approximately 0.3A, at both 25°C & 125°C, the Discrete design can be slightly more accurate. The higher performance on the discrete design at lower current levels can be attributed to the lower voltage offset drift, and error present.

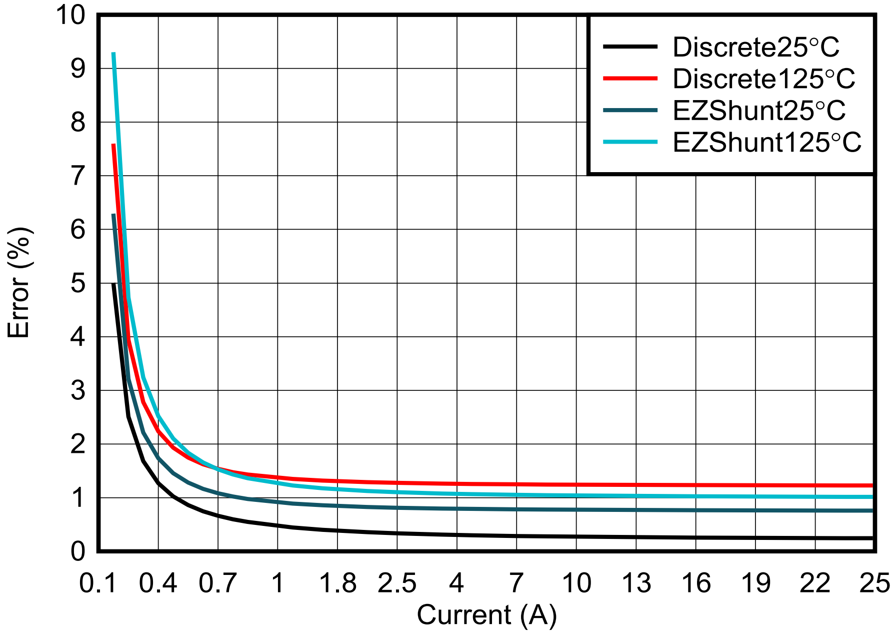

Figure 3-6. INA745A vs INA236 + Resistor F

When comparing the data sets attributed to performance at 25°C, we are able to see the total error formed by our discrete design is less than our EZShunt™ design. This helps us understand the more expensive Resistor E combined with our INA236 can be more accurate at lower temperatures. While at 125°C, Our INA745A provides a design with less total error and higher accuracy from 0.7A – 25A against the discrete design while the discrete design performs slightly better from 0 – 0.7A.

3.2.2 Common Mode Voltage ≤ 80V

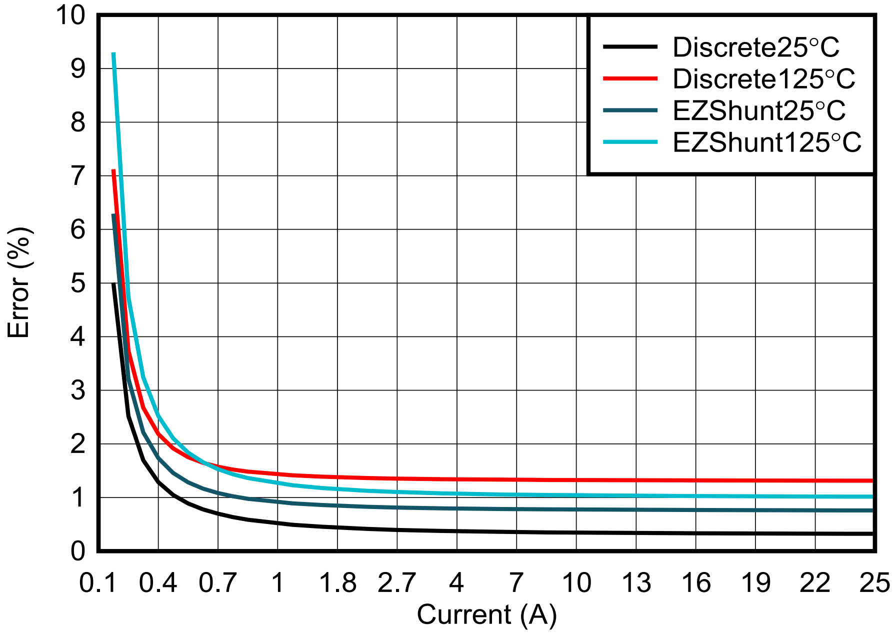

Figure 3-7. INA740A vs INA238 + Resistor D

At 125°C, INA740A provides a much more accurate design with less total error from 0.7A to 35A against the discrete design. Meanwhile, the Discrete design conveys less total error from 0A to 0.7A at higher temperatures. On the contrary, at 25°C the discrete design is more accurate across current from 0A – 15A in comparison to the EZShunt™ method. This performance at higher temperatures can be attested to the total drift and tolerance percent provided by the Digital power monitor and Shunt resistor outweighing the error from our INA740A.

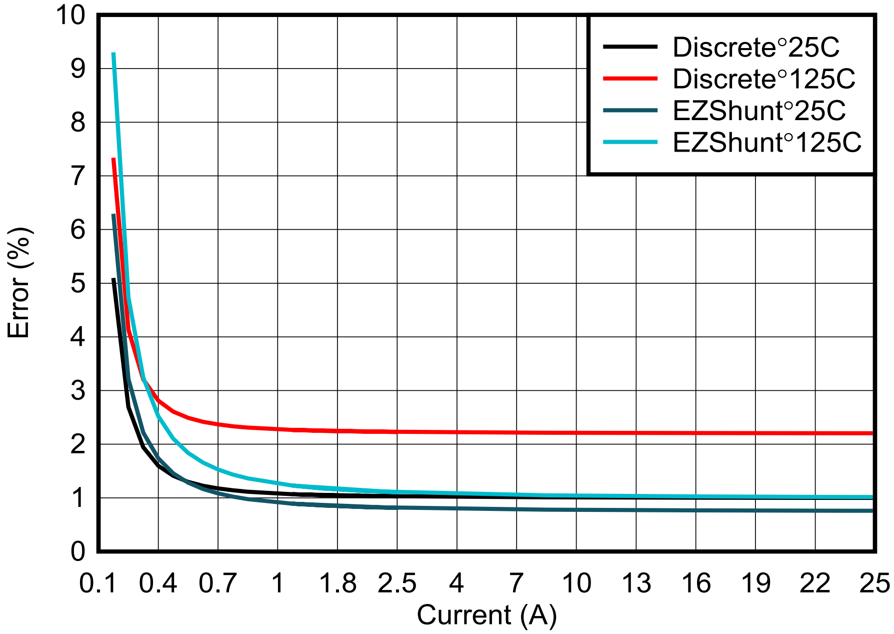

Figure 3-8. INA740A vs INA238 + Resistor E

When using Resistor E which provides a measured tolerance error of 0.99% and drift of 118.2ppm, at 25°C, the EZShunt™ design has improved accuracy over the discrete implementation from approximately 0.4A to 35A despite the INA238 + Resistor E being slightly better from the 0 - 0.4A range.

Meanwhile, at 125°C, we see a similar situation where the Discrete design has slightly improved accuracy from 0 to 0.4A while the INA740A is able to provide roughly 50% less Error than the discrete design from 0.4A to 25A.

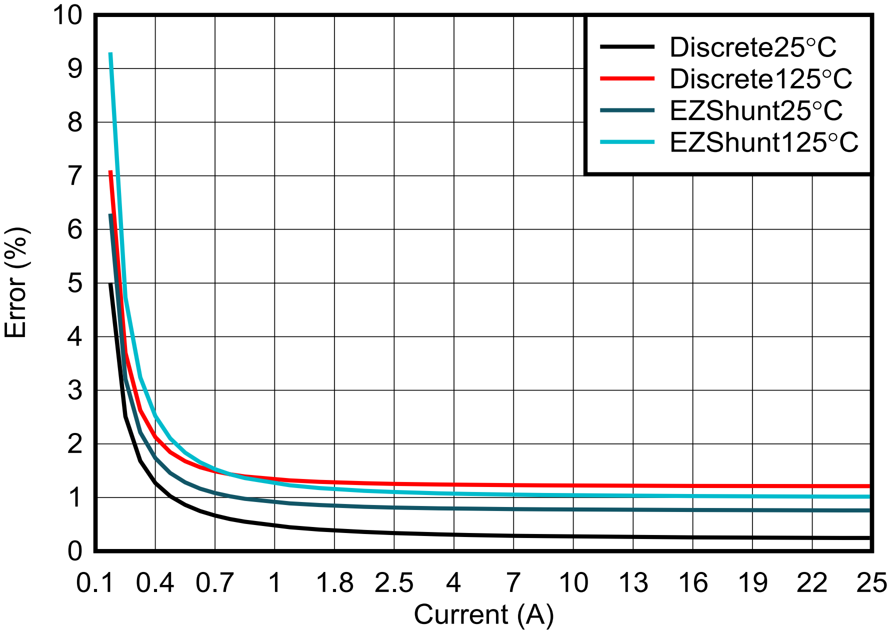

Figure 3-9. INA740A vs INA238 + Resistor F

For the design set using Resistor F, At 25°C, The Discrete design can provide higher accuracy Throughout current ranges between 0A – 25A against the INA740A.

At 125°C, the accuracy follows our previous designs where the INA740A offers slightly less accuracy than the INA238 + Resistor F from 0A to approximately 0.9A. Meanwhile, the INA740A helps perform better which higher accuracy from 0.9A to 35A.

3.3 Total Error Comparison for Current ≤ 50A Over Temperature

The INA780A characterized for 75A at 25°C was the EZShunt™ device selected alongside our INA238 and the below resistor set to calculate the performance difference between our external and integrated shunt designs:

Table 3-3. Resistors G, H, and I (≤ 50A)

		Data sheet		Measured				
Resistor	**Resistance (mΩ)**	**Tolerance**	**Drift (ppm)**	**Tolerance**	**Drift (ppm)**	**Wattage (W)**	**Case Size**	**1K price**
G	0.5	1%	50	0.3%	44.8	3	1216	$0.26
H	0.5	1%	50	4.74%	65.5	2	2512	$0.34
I	0.5	1%	75	0.4%	3.6	3	2726	$0.42

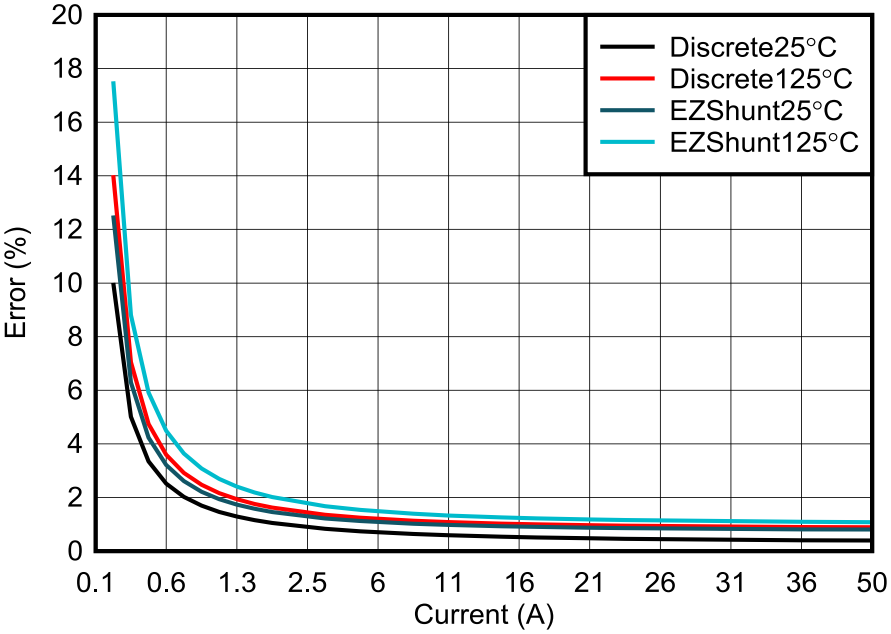

Figure 3-10. INA780A vs INA238 and Resistor G

By comparing both designs against one another at two separate ambient temperatures, we are able to see how the Discrete design comprised of our Ultra-precise INA238 and Resistor G with a measured tolerance of 0.3% and drift of 44.8ppm can have slightly greater accuracy at both 25°C and 125°C against our high voltage EZShunt™ device being the INA780A.

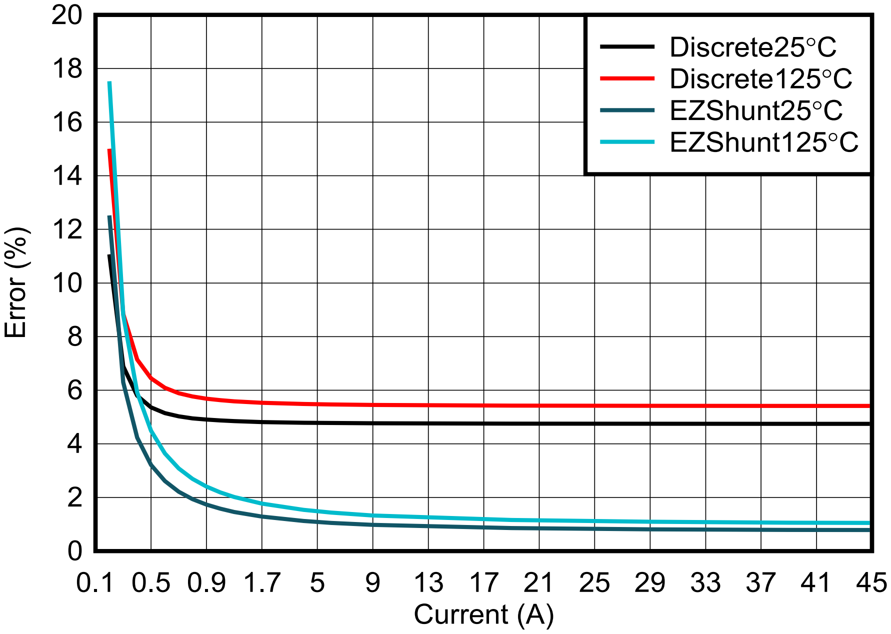

Figure 3-11. INA780A vs INA238 and Resistor H

When using Resistor H in the discrete design, we can visualize our INA780A can have much higher accuracy and less total error from approximately 0.1 to 50A while the discrete design can be slightly better from 0A to approximately 0.1 at both 25°C and 125°C. This can be attributed towards the measured tolerance percentage subjugated upon the system by Resistor E of 4.49%.

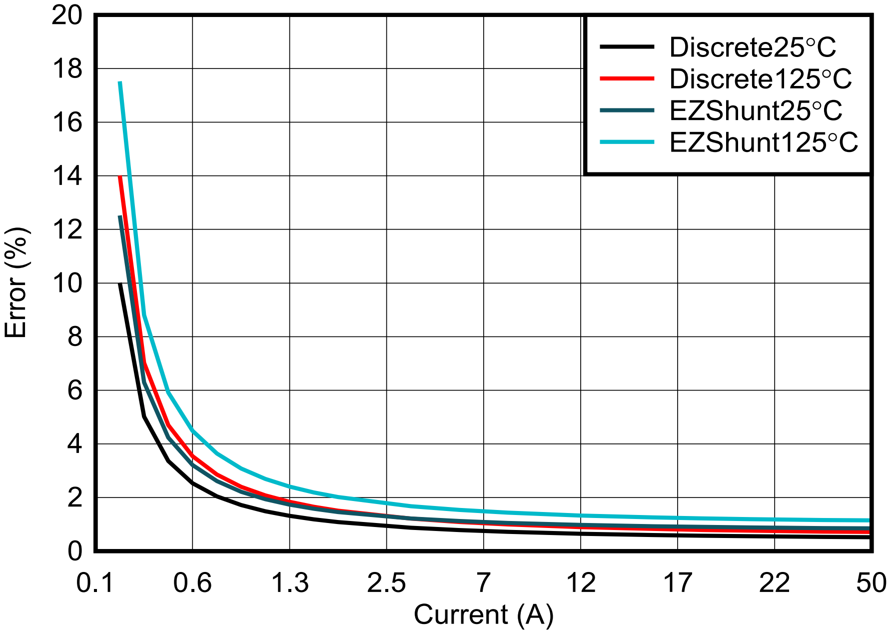

Figure 3-12. INA780A vs INA238 and Resistor I

According to this data set, using a more premium resistor I providing a tolerance error of 0.4% and drift of 3.6ppm, The discrete design comprised of our INA238 and Resistor I can help provide a more precise design at both 25°C and 125°C when compared to the INA780A.

4 Summary

By comparing EZShunt™ designs with Digital power monitors providing similar performance and cost in accordance with a variety of shunt resistors providing a range of accuracies, we are able to understand whether our EZShunt™ is indeed comparable or better than discrete traditional designs across current and temperature.

In terms of shunt resistors, regardless of how the resistors perform when measured, the recommendation is to design based on data sheet parameters. Therefore, some measured specifications can be higher or lower than data sheet values. In addition, all Digital Power Monitors used to compare against relative EZShunt™ devices were chosen on the basis of similar price point, accuracy, and functionality.

When considering a current range up to 15A over temperature, we used our INA700 capable of supporting 15A at 25°C against the INA234 with Resistor A, B, and C. The data retrieved from all three resistor groups provides clear and compelling evidence that EZShunt™ technology provides significantly higher accuracy, and less error across current at 25°C and 125°C.

In the current range up to 25A over temperature, we used our INA745A and INA740A capable of supporting 35A at 25°C and 40V/85V of common mode voltage respectively against the INA236 with Resistor D, E, and F. The data helps us understand EZShunt™ technology can have higher accuracy across current from approximately 0.7A to 25A at 125°C. Meanwhile, the discrete design can be more accurate and posses less error at 25°C depending on the measured accuracy of the resistor. However, if a design is based on data sheet typical parameters of 1% tolerance and 50ppm, EZShunt™ can provide higher precision and less total error than the discrete design.

In the current range up to 50A over temperature, we used our INA780A capable of supporting 75A at 25°C against the INA238 with Resistor G, H, and I. The data shows the discrete design can perform better with higher accuracy and less total error with shunt resistors providing tolerance below 0.5% and drift of 50ppm. However, if a design is based on data sheet typical parameters of 1% tolerance and 50ppm, EZShunt™ technology can have higher precision and lower total error from 1A to 50A at both 25°C and 125°C compared to the discrete design.

5 References

- Texas Instruments, *INA700: Current Sensing With EZShunt™ Technology*, product overview.

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