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ABSTRACT

Industrial applications such as motor drives, photo voltaic inverters, and uninterruptible power supplies (UPS) and automotive applications such as onboard chargers (OBCs), traction inverters, and DC/DC converters operate at high voltage and current levels to optimize overall efficiency and power throughput. These systems are subjected to hostile environments such as electrical noise, vibration, mechanical shock, extreme temperatures, ingress of contaminants, and so forth. Such systems demand robust, reliable, galvanic isolation to isolate high voltages from low-voltage circuits. The feedback signals measured on these high voltages are galvanically isolated from the low-voltage controllers by isolated amplifiers or isolated modulators.

This document compares isolated amplifiers and isolated-modulator-based designs and explains some unique advantages of isolated-modulator-based designs.

Table of Contents

1 Introduction to Isolated Amplifiers	2
2 Introduction to Isolated Modulators	2
3 Performance Comparison Between Isolated Amplifiers and Isolated Modulators	3
4 Isolated Modulators in Traction Inverters	4
5 Isolated Amplifier and Modulator Recommendations	5
6 Conclusion	5
7 Revision History	6

List of Figures

Figure 1-1. Isolated Amplifier Implementation.....	2
Figure 2-1. Isolated Modulator Implementation.....	2
Figure 3-1. Implementation of Two Digital Filter in Parallel.....	4
Figure 4-1. Current Measurement Using an Isolated Modulator.....	4

List of Tables

Table 3-1. Performance Comparison Between Isolated Amplifiers and Isolated Modulators.....	3
Table 3-2. Performance Trade-Off Between ENOB and Settling, Latency or Bandwidth for the AMC1306 at CLKIN = 20 MHz Using a Sinc ³ Filter.....	3
Table 5-1. Recommended Devices.....	5

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1 Introduction to Isolated Amplifiers

Figure 1-1 shows the implementation of an isolated-amplifier-based measurement design.

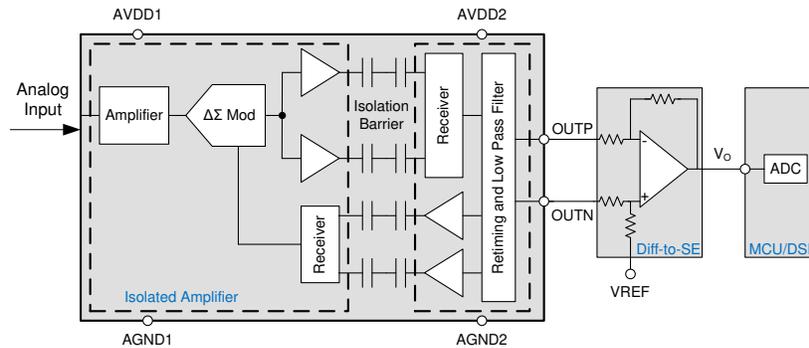


Figure 1-1. Isolated Amplifier Implementation

The input stage of an isolated amplifier consists of an input amplifier that drives a delta-sigma ($\Delta\Sigma$) modulator. The gain of the input amplifier is fixed and set by internal precision resistors. The $\Delta\Sigma$ modulator uses the internal reference voltage and clock generator to convert the analog input signal to a digital bit stream. The drivers transfer the output of the modulator across an isolation barrier that separates the high and low voltage domains. The received bitstream and clock are synchronized and processed by an analog low-pass filter on the low voltage side and presented as an analog output signal.

The differential output of the isolated amplifier is often converted to a single-ended analog output with an op-amp-based circuit. This op-amp-based circuit can also implement a low-pass filter to further reduce the signal bandwidth to a bandwidth of interest and thereby improve the system noise performance.

The analog-to-digital converter (ADC), either external or internal to the microcontroller (MCU) or digital signal processor (DSP), receives this feedback analog output and converts this output back to the digital domain.

2 Introduction to Isolated Modulators

Figure 2-1 shows the implementation of an isolated-modulator-based measurement design.

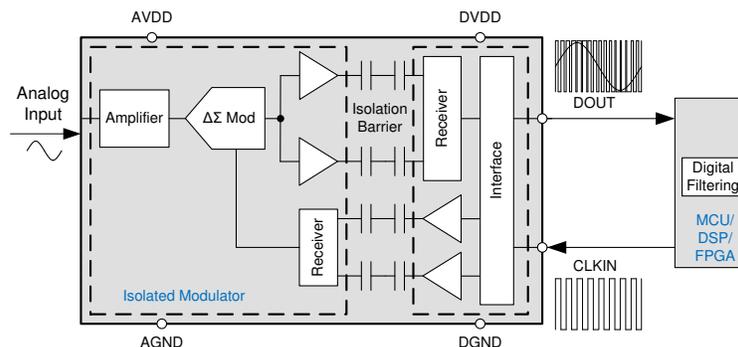


Figure 2-1. Isolated Modulator Implementation

The input stage of an isolated modulator is similar to that of an isolated amplifier. The drivers transfer the modulator output across the isolation barrier. The isolated data output DOUT provides a digital bit stream of 1's and 0's at a much higher frequency (up to 20 MHz). The time average of this bit stream output is proportional to the analog input voltage. The measured signal is reconstructed with a digital filter inside the microcontroller families such as the [TMS320F2807x](#) and [TMS320F2837x](#), a DSP, or a field programmable gate array (FPGA).

3 Performance Comparison Between Isolated Amplifiers and Isolated Modulators

Table 3-1 shows the basic difference in performance between isolated amplifiers and isolated modulators.

Table 3-1. Performance Comparison Between Isolated Amplifiers and Isolated Modulators

CATEGORY	ISOLATED AMPLIFIER	ISOLATED MODULATOR
Sample resolution	11 bits (bandwidth = 100 kHz)	> 14 bits achievable, trade-off between resolution and bandwidth or latency
Latency	2 μ s to 3 μ s (fixed)	< 1 μ s achievable, trade-off between resolution and bandwidth or latency
Bandwidth	up to 300 kHz	> 1 MHz achievable, trade-off between resolution and bandwidth or latency
Accuracy and drift performance	High	Very high
No. of components needed	More	Less

In an *isolated-amplifier-based design*, the measured analog signal undergoes several analog-to-digital and digital-to-analog conversions. The stages within the isolated amplifier, the differential-to-single-ended stage, and the ADC either external or internal to the MCU or DSP reduce overall accuracy and noise performance and increase latency. The fixed low-pass filter implementation in the output stage of the isolated amplifier limits the signal bandwidth. An external op-amp-based circuit used for differential-to-single-ended conversions can be used to create an active low-pass filter to further limit the signal bandwidth and thereby improve noise performance. The isolated amplifier has a fixed latency. Isolated-amplifier-based designs are widely used because of familiarity and relative ease of implementation.

As shown in Figure 2-1, the measured analog signal in an *isolated-modulator-based design* undergoes only one analog-to-digital conversion. This design eliminates the need for a differential-to-single-ended stage, thereby reducing the number of components and design size. The ADC used in an isolated-amplifier-based design, which in many situations limits the maximum achievable sample resolution and accuracy, is not needed anymore. This isolated-modulator-based approach has improved signal noise performance, overall accuracy, and can achieve higher signal bandwidth and lower latency than an isolated-amplifier-based design. Isolated modulators provide a much faster digital bitstream output, typically up to 20 MHz. The sigma-delta filter module (SDFM) module inside the microcontroller families (such as the TMS320F2807x and TMS320F2837x) provides an easy way to tune the noise performance and signal bandwidth or latency. As shown in Table 3-2, a higher oversampling ratio (OSR) implementation leads to better accuracy and higher sample resolution but less signal bandwidth and higher latency. Similarly, lowering OSR reduces accuracy and sample resolution but increases bandwidth and reduces latency. A similar DSP or an FPGA can also implement such a digital filter.

Table 3-2. Performance Trade-Off Between ENOB and Settling, Latency or Bandwidth for the AMC1306 at CLKIN = 20 MHz Using a Sinc³ Filter

OSR	ENOB (Bits)	SETTLING (μ s)	LATENCY (μ s)	BANDWIDTH (kHz)
8	4.65	1.2	0.6	1250
16	7.57	2.4	1.2	625
32	10.02	4.8	2.4	312.5
64	12.3	9.6	4.8	156.25
128	13.51	19.2	9.6	78.13
256	14.11	38.4	19.2	39.06
512	14.39	76.8	38.4	19.53

Additionally, as shown in Figure 3-1, multiple digital filters can be implemented in parallel to achieve higher sample resolution, lower latency, and higher bandwidth, all at the same time. One of the digital filters can implement a high OSR digital filter for better noise performance and another one can implement a low-latency digital filter.

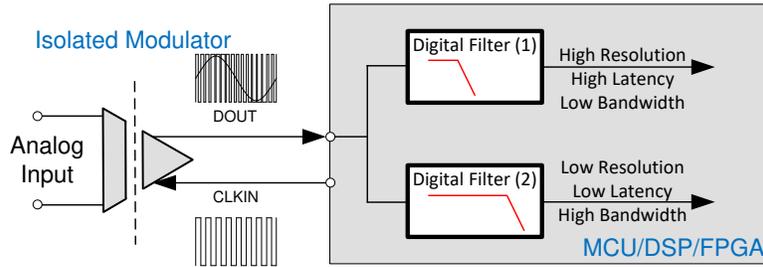


Figure 3-1. Implementation of Two Digital Filter in Parallel

With the system advantages offered by an isolated-modulator-based design, there is a resulting trend to move to an isolated-modulator-based design in high-performance systems.

4 Isolated Modulators in Traction Inverters

Figure 4-1 shows an implementation of an isolated-modulator-based design in automotive traction inverters.

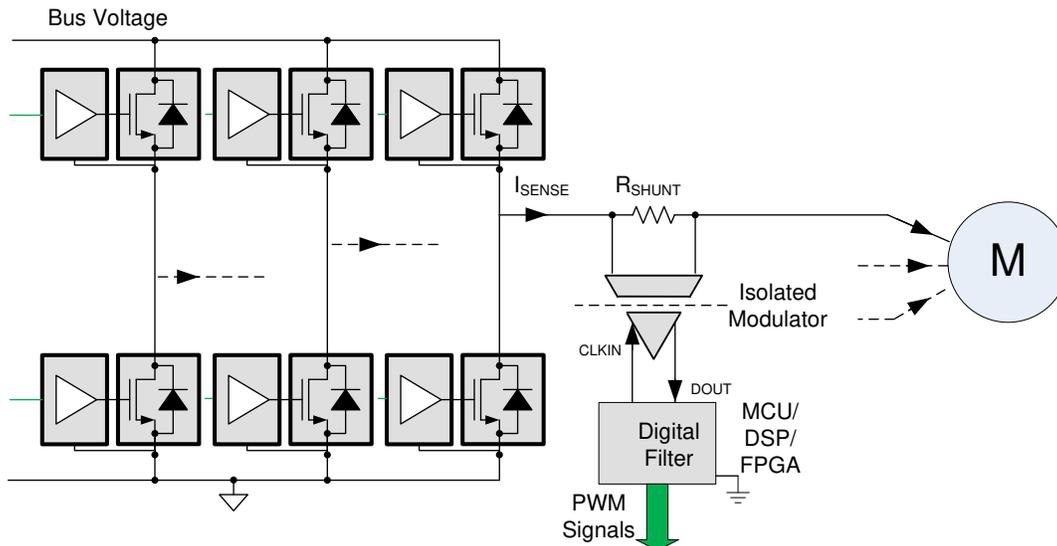


Figure 4-1. Current Measurement Using an Isolated Modulator

Traction inverters have a direct influence on the driving experience and require precise control of speed and torque of the traction motor. A shunt coupled with an isolated delta-sigma modulator provides the highest-quality feedback signals to the controller to establish the pulse-width modulation (PWM) pattern for bridge transistors. The digital filter implementation allows the engineer to tune the quality of traction motor controls.

As shown in Figure 3-1, the FPGA, MCU, and DSP can have multiple digital filters running in parallel. One of the digital filters can be a high-performance digital filter that provides accurate feedback signals to control the bridge transistors. Another digital filter can be a low-latency digital filter for detecting overload or overcurrent conditions. A third-order (sinc^3) filter with a different OSR can be used for both digital filters.

5 Isolated Amplifier and Modulator Recommendations

Table 5-1 lists the recommended devices for use with the isolated amplifier and modulator.

Table 5-1. Recommended Devices

DEVICE	ISOLATION	DESCRIPTION
AMC1306	Reinforced	±50-mV, ±250-mV small isolated modulators
AMC1305 , AMC1305-Q1	Reinforced	±50-mV, ±250-mV isolated modulators
AMC1301 , AMC1301-Q1	Reinforced	±250-mV isolated amplifiers
AMC1302 , AMC1302-Q1	Reinforced	±50-mV isolated amplifiers
AMC1311 , AMC1311-Q1	Reinforced	0-V to 2-V isolated amplifiers

6 Conclusion

Isolated modulators offer higher sample resolution and accuracy compared to isolated amplifiers. With the combination of isolated modulators and custom digital filters, the engineer can trade system latency and bandwidth with sample resolution. Isolated-modulator-based designs require fewer components and enable a smaller design size at a reasonable cost. Isolated modulators are strongly recommended in isolated measurement applications wherein high sample resolution or low latency is required.

7 Revision History

Changes from Revision A (February 2019) to Revision B (June 2024) Page

- Updated the numbering format for tables, figures, and cross-references throughout the document 1
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Changes from Revision * (February 2019) to Revision A (February 2019) Page

- Updated digital bitstream output from *up to 20 MHz* to *typically up to 20 MHz*3
 - Updated *Performance Trade-Off Between ENOB and Settling, Latency or Bandwidth* table.....3
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