Application Brief

AMC0386 Output Histograms in HEV/EV Traction Inverter Voltage Sensing Application

Jiri Panacek

Introduction

The AMC038x is a family of galvanically-isolated amplifiers and modulators designed for high-voltage sensing applications. Different from traditional isolated amplifiers and modulators, such as the AMC1311 and AMC1336, these devices feature a high-impedance, integrated resistive divider that connects directly to a high-voltage signal source. The integrated divider exhibits excellent DC accuracy, low temperature drift, and high life-time stability. AMC038x devices achieve better than 1% accuracy over a lifetime and temperature range without system-level calibration.

In a typical application, the integrated high-impedance resistive divider replaces a discrete resistive divider with much lower impedance. For comparison, the AMC0386M10 has a divider impedance of 12.5MΩ. Typical discrete implementations are in the range of 2-5MΩ due to concerns over coupling noise into a high-impedance sense point. This application brief summarizes measurement results under real-life operating conditions in a high-power application. Results show that the integrated high-impedance resistive divider is not affected by switching noise in the system.

Table 1. AMC038x Family Device Comparison

Device	Type	R1 (1)	R2 (1)	DIVIDER RATIO	LINEAR INPUT RANGE	CLIPPING VOLTAGE	ABS MAX INPUT VOLTAGE
AMC0381D06-Q1	Isolated amplifier	10MΩ	16.7kΩ	601:1	600V	769V	900V
AMC0381D10-Q1	Isolated amplifier	12.5MΩ	12.5kΩ	1001:1	1000V	1281V	1500V
AMC0381D16-Q1	Isolated amplifier	33.5MΩ	21kΩ	1601:1	1600V	2049V	2000V
AMC0380D04-Q1	Isolated amplifier	8.3MΩ	20kΩ	401:1	±400V	±513V	±600V
AMC0386M06-Q1	Isolated modulator	10MΩ	16.6kΩ	601:1	±600V	±751V	±900V
AMC0386M10-Q1	Isolated modulator	12.5MΩ	12.5kΩ	1001:1	±1000V	±1251V	±1500V

1. R1 and R2 are approximated resistor values and do not accurately reflect divider ratio.

The latest revision of the TIDA-02014, high-power, high-performance automotive SIC traction inverter reference design, integrates AMC0381M10 device for DC-link voltage sensing. Figure 1 shows the implementation on the PCB. For the circuit diagram, see the reference design folder on ti.com.

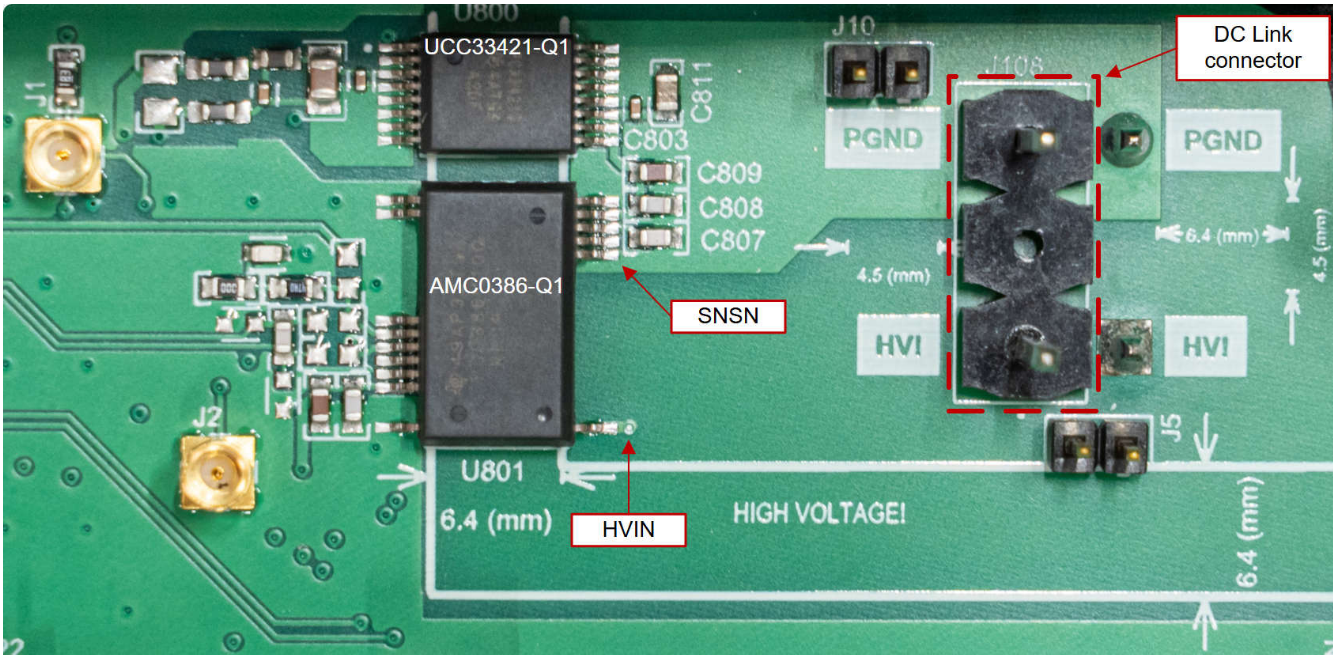

Figure 1. TIDM-02014 DC Link Voltage Sensing Subsystem with AMC0381M10

The AMC0386M10 is an isolated modulator with 10MHz external clock. The digital output connects to the sigma-delta filter module (SDFM) of the F29H859TU-Q1 microcontroller (MCU). The SDFM converts the 10MHz single-bit data stream from the modulator into a 16-bit word at a sample rate of 10MHz/OSR. A 16b data in 2's complement format can store integer from -32768 to +32767. However, the SDFM module in 16b result configuration outputs data in the range from -16384 to +16384. For this reason, the LSB size is double the expected value. Table 2 lists the system configuration.

Table 2. TIDA-02014 System Configuration

Modulator Clock	Filter	Over-Sampling Ratio (OSR)	Output Data Format	Differential Clipping Voltage	LSB Size
10MHz	Sinc3	256Ω	16b 2's complement	±1251V	76.35mV

The reference design was tested in a motor laboratory under various operating conditions. During the tests, the microcontroller stores voltage readings in the internal debug memory. 1000 voltage readings were collected for each operating condition and plot histograms. The histogram width and distribution help engineers identify how the real-life conditions affect the voltage measurement subsystem. The motor runs at 100RPM during all tests. This mechanical speed corresponds to an electrical frequency of 6.66Hz for a four-pole electric motor.

Figure 2 shows histograms of the voltage readings at a nominal 400V DC-link voltage, and phase peak currents of 0A, 50A, 100A, and 150A. The histogram bin width corresponds to the least significant bit (LSB) size. The histograms illustrate that the noise floor, represented by the width of the distribution, slightly increases with the phase current, as expected. However, no outliers in the data are observed. Table 3 summarizes the test results. Root mean square (RMS) noise, signal-to-noise ratio (SNR) and effective number of bits (ENOB) parameters are approximations that assume Gauss distribution of the noise.

Equation 1 calculates the RMS noise in volts:

$$\mathrm{RMSnoise} = \sigma \times \mathrm{LSB} \tag{1}$$

where

- σ is standard deviation of the SDFM output data
- LSB is the size of the least significant bit in volts (refer to Table 2)

Equation 2 calculates SNR in decibels:

$$SNR = 20 \times \log\left(\frac{V_{IN}}{RMSnoise}\right) \tag{2}$$

where

- V_{IN} is the linear input voltage range of the AMC0386M10 device (2000V)
- RMS noise is the value from Equation 1

Equation 3 calculates ENOB in bits:

$$ENOB = \frac{SNR - 1.76}{6.02} \tag{3}$$

where

- SNR is signal-to-noise ratio in decibels

Table 3. Test Results Summary for Phase Current Sweep at 400V

Phase Current	DC Link Voltage Readout (MIN)	DC Link Voltage Readout (AVG)	DC Link Voltage Readout (MAX)	DC Link Voltage RMS Noise	DC Link Voltage SNR	DC Link Voltage ENOB
0A	399.170V	399.626V	400.085V	$0.154V_{RMS}$	82.3dB	13.4b
50A	399.018V	399.599V	400.237V	$0.203V_{RMS}$	79.9dB	13b
100A	398.789V	399.650V	400.618V	$0.349V_{RMS}$	75.2dB	12.2b
150A	398.408V	399.548V	401.000V	$0.382V_{RMS}$	74.4dB	12.1b

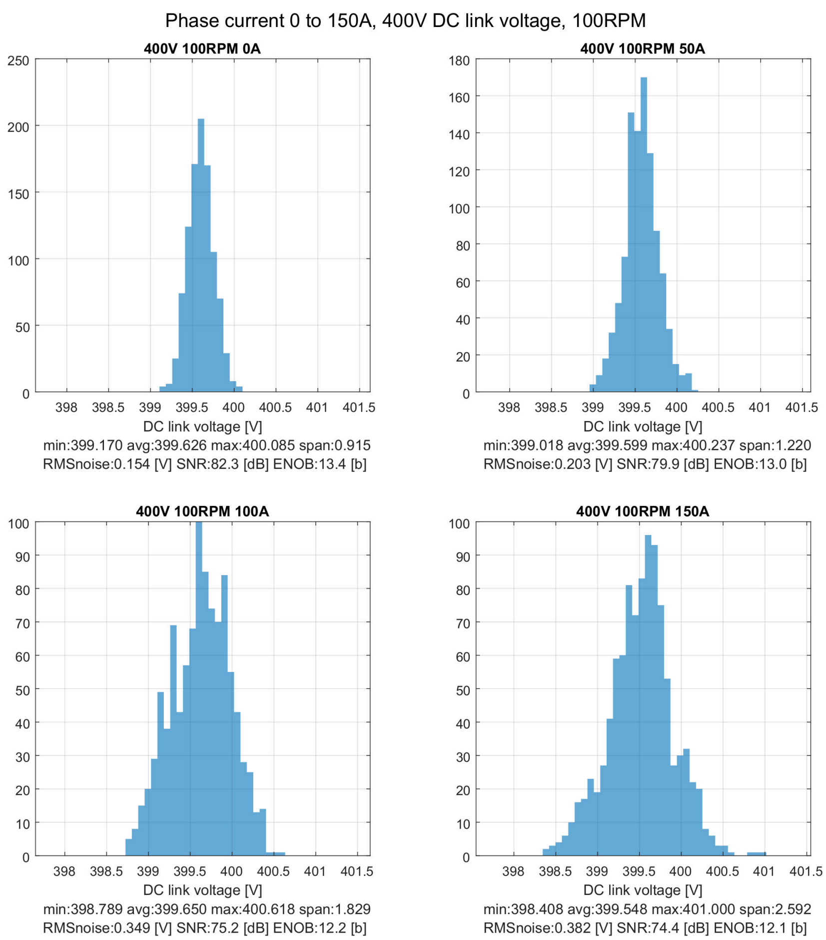

Figure 2. Phase Current Sweep at Fixed DC-link Voltage of 400V

Figure 3 displays histograms of the voltage readings at nominal 100V, 200V, and 400V DC-link voltage at a fixed 50A phase peak current. The histogram plots show that the noise decreases as the input voltage increases. Expect this behavior because the input current increases when the input voltage decreases. Additionally, reducing the input voltage affects the SNR calculation. Table 4 summarizes the results.

Table 4. Test Results Summary for DC Link Voltage Sweep at Phase Current of 50A

DC Link Voltage	DC Link Voltage Readout (MIN)	DC Link Voltage Readout (AVG)	DC Link Voltage Readout (MAX)	DC Link Voltage RMS Noise	DC Link Voltage SNR	AMC0386 SNR (Spec)
100V	98.630V	99.968V	101.450V	$0.473V_{RMS}$	72.5dB	11.8b
200V	198.861V	199.787V	200.690V	$0.291V_{RMS}$	76.8dB	12.5b
400V	399.018V	399.599V	400.237V	$0.203V_{RMS}$	79.9dB	13.0b

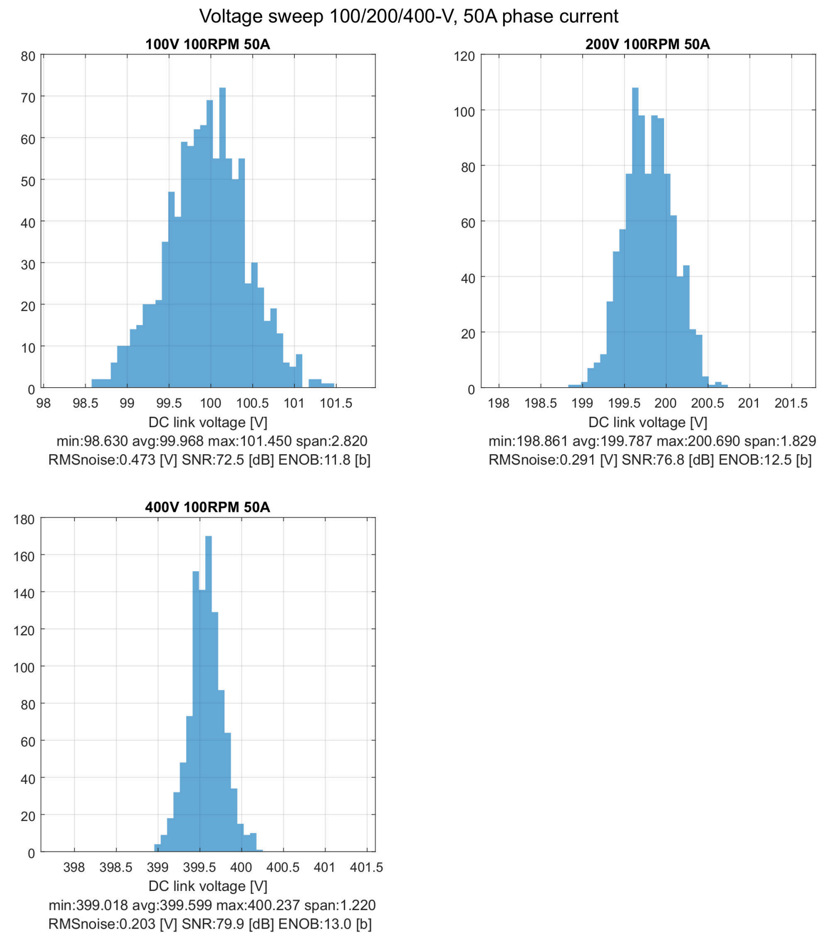

Figure 3. DC Link Voltage Sweep for 50A Phase Current

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