STDES-AKI003V1 test report

Introduction

An overview of the ISOSD61 performance using the STDES-AKI003V1 reference design is herein described.

The STDES-AKI003V1 provides accurate current sensing for high-end industrial motor control applications based on three-phase inverter topology. It is tailored for high-end servo drives.

The board features three ISOSD61 16-bit isolated sigma-delta modulators (with low voltage differential signaling (LVDS) and single-ended (TTL/CMOS) options) and six power metal strip shunt resistors (two in parallel for each phase) of 5 mΩ 7 W for current sensing placed inline with the motor phases.

Two types of tests have been performed: a low-current test running a motor in closed loop to verify the quality of the current measurement and a nominal current test.

The tests have been carried out using:

- an STEVAL-CTM009V1 5 kW low voltage high current inverter for industrial motor control applications composed of:
  - a power stage
  - a capacitor board
  - a driver board
  - and a current sensing board which has not been used for the tests as it has been replaced by the STDES-AKI003V1
- an STM32H7B3I-EVAL evaluation board with STM32H7B3LI MCU
- an STDES-AKI003V1 sigma-delta current sensing board
- DC power supplies: 24 V,48 V (V_{BUS}), 12 V (Aux), 5 V (STDES-AKI003V1 power supply)

The STSW-AKI003, a customized version of X-CUBE-MCSDK motor control software development kit, has been used to perform the tests. In particular, the current sensing related functions have been customized to acquire the measurements of the motor phase currents from the sigma-delta modulated inputs using the STM32H7B3LI microcontroller sigma-delta filtering peripheral.

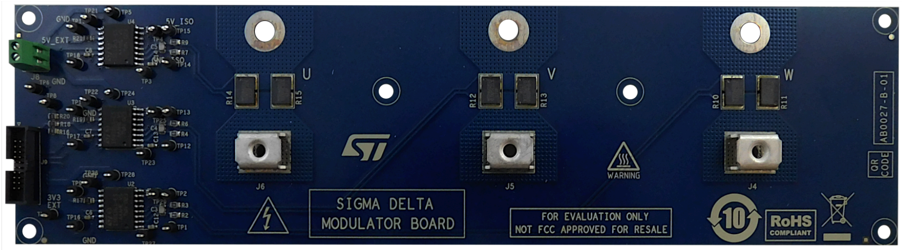
The STDES-AKI003V1 three-phase sigma-delta current sensing board is a fully assembled board developed for performance evaluation only, not available for sale.

1 Overview

The STDES-AKI003V1 features:

- Accurate current sensing for high-end industrial motor control applications based on ISOSD61
- 6 kV galvanic isolation, 16 bit Sigma-Delta modulator, up to 25 MSps (Mega Sample per second)
- Fast and dynamic response to load variations
- Compatible with field-oriented control for PMSM motors
- Triple simultaneous current sampling via shunt resistors placed in line with the motor phases
- Fully compatible with the STM32H7B3LI DFSDM peripheral
- Tailored for high-end servo drives

Figure 1. **STDES-AKI003V1 reference design**



Fully assembled board developed for performance evaluation only, **not available for sale**

2 Specifications

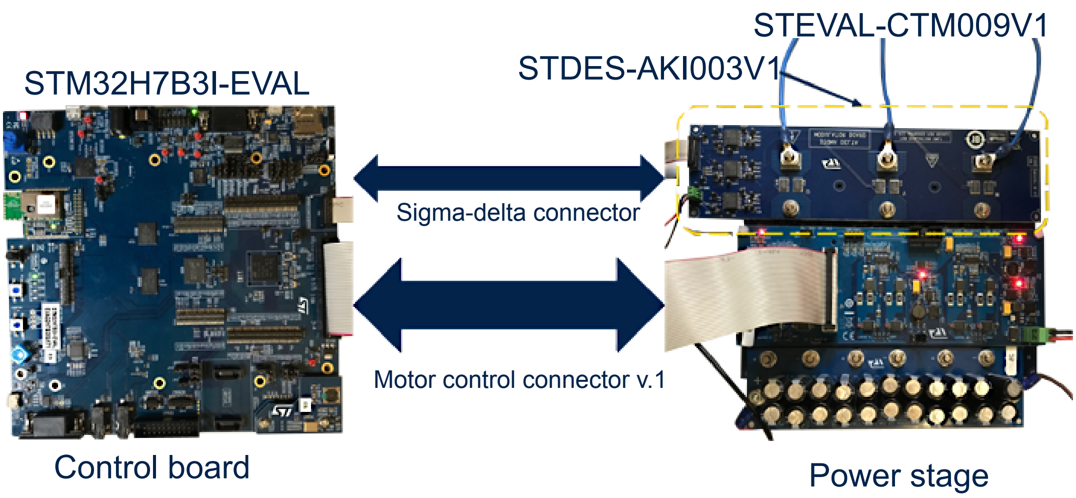
- 72 A motor phase peak current
- 6 kV galvanic isolation
- Up to 25 MHz sigma-delta clock
- 5 V V_{in} supply voltage

3 Test setup

3.1 Test conditions and equipment

- an STEVAL-CTM009V1 5 kW low voltage high current inverter for industrial motor control applications composed of:
  - a power stage
  - a capacitor board
  - a driver board
  - and a current sensing board which has not been used for the tests as it has been replaced by the STDES-AKI003V1
- an STM32H7B3I-EVAL evaluation board with STM32H7B3LI MCU
- an STDES-AKI003V1 sigma-delta current sensing board with no heat-sink

Figure 2. **Board assembly and connections**



- a heat-sink by ABL Components (order code: 159AB2000B, Rth: 0.36 °C/W, dimensions: 200x160x40 mm) mounted on the power board bottom side
- DC power supplies: 24 V,48 V (V_{BUS}), 12 V (Aux), 5 V (STDES-AKI003V1 power supply)
- the STSW-AKI003, customized version of X-CUBE-MCSDK
- a 30 A Teledyne Lecroy current probe
- an MDA810 Teledyne Lecroy oscilloscope
- a thermal camera by Fluke
- for the nominal current test, a 55 kW three-phase permanent magnet motor connected to a dynamo-meter bench not loaded

For further details on how to configure the above boards, refer to:

- UM2662: "Evaluation board with STM32H7B3LI MCU" (Section 8.8 Enabling the motor control functionality)
- UM2458: "5 kW low voltage high current inverter for industrial motor control applications"

3.2 STM32H7B3I-EVAL modifications

To enable motor control you need to configure the STM32H7B3I-EVAL as per the table below.

Table 1. **STM32H7B3I-EVAL modifications**

Pin name	Fitted	Not fitted	MCU function	Motor-control function
PF12	R72	R326	ADC1_INP6	BUS VOLTAGE

Pin name	Fitted	Not fitted	MCU function	Motor-control function
PC0	R253	R255	ADC12_INP10	PHASE A CURRENT
PC1	R210	R216	ADC12_INP11	PHASE B CURRENT
PC4	R277	R281	ADC12_INP4	PFC INDUCTOR CURRENT
PA7	R67	R322	ADC12_INP7	PHASE C CURRENT
PC5	R282	R286	ADC12_INP8	PFC VAC
PC3_C	R219		ADC2_INP1	HEATSINK TEMPERATURE
MFX_GPO6	SB33 / R130	R129	GPIO1	ICL SHUT OUT
MFX_GPO7	SB30 / R99	R100	GPIO2	DISSIPATIVE BREAK
PD4	R367	R368	INT_JOY_DOWN	JOYSTICK DOWN
PA4	-	JP7		
PD5	R363	R364	INT_JOY_LEFT	JOYSTICK LEFT
PI0	R386	R128	INT_JOY_RIGHT	JOYSTICK RIGHT
PI9	R360	R351	INT_JOY_SEL	JOYSTICK SEL
PH13	R389	R131	INT_JOY_UP	JOYSTICK UP
PA8	R301	R308	TIM1_CH1	PWM_1H
PE8	R81	R96	TIM1_CH1N	PWM_1L
PA9	R294	R60	TIM1_CH2	PWM_2H
PB14	R304	R307	TIM1_CH2N	PWM_2L
PA10	R288	R58	TIM1_CH3	PWM_3H
PB15	R309	R311	TIM1_CH3N	PWM_3L
PD2	R278	R49	TIM15_BKIN	PFC SHUTDOWN
PE6	R330	JP27 / R78 / R334	TIM15_CH2	PFC PWM
PA0	R213	R229 / C30	TIM2_CH1	ENCODER A
PA1	R235	R236	TIM2_CH2	ENCODER B
PA2	R239	R240	TIM2_CH3	ENCODER C
PA6	R349	JP6	TIM1_BKIN	EMERGENCY STOP
PE5	R323	R69 / R71 / JP28	TIM15_CH1	PFC SYNC
PA3	R258	R236	LCD_BL_CTRL BACK-UP	LCD_BL_CTRL BACK-UP
PC0	R253	R255	DFSDM_1_CKIN0	MOTOR_DFSDM_1_CKIN0
PC1	R210	R216	DFSDM_1_DATIN0	MOTOR_DFSDM_1_DATIN0
PC4	R277	R281	DFSDM1_CKIN2	MOTOR_DFSDM1_CKIN2
PC5	R282	R286	DFSDM_1_DATIN2	MOTOR_DFSDM_1_DATIN2
PB13	R314	R316	DFSDM1_CKIN1_DFSDM2_CKIN1	MOTOR_DFSDM1_CKIN1_DFSDM2_CKIN1
PD8	R123	R384	DFSDM1_CKIN3	MOTOR_DFSDM1_CKIN3
PD6	R284	R285	DFSDM1_CKIN4	MOTOR_DFSDM1_CKIN4
PB7	R238	R29	DFSDM1_CKIN5	MOTOR_DFSDM1_CKIN5

Pin name	Fitted	Not fitted	MCU function	Motor-control function
PB8	-	-	DFSDM1_CKIN7	MOTOR_DFSDM1_CKIN7
PB12	JP19 [1-2]	-	DFSDM1_DATIN1	MOTOR_DFSDM1_DATIN1
PC7	JP35 [2-3]	-	DFSDM1_DATIN3	MOTOR_DFSDM1_DATIN3
PE10	R95	R341	DFSDM1_DATIN4	MOTOR_DFSDM1_DATIN4
PB6	-	-	DFSDM1_DATIN5	MOTOR_DFSDM1_DATIN5
PB9	R233	-	DFSDM1_DATIN7	MOTOR_DFSDM1_DATIN7
PD4	R367	R368	INT_JOY_DOWN	JOYSTICK DOWN
PA4		JP7		
PD5	R363	R364	INT_JOY_LEFT	JOYSTICK LEFT
PI0	R386	R128	INT_JOY_RIGHT	JOYSTICK RIGHT
PI9	R360	R351	INT_JOY_SEL	JOYSTICK SEL
PH13	R389	R131	INT_JOY_UP	JOYSTICK UP
PA3	R258	R236	LCD_BL_CTRL BACK-UP	LCD_BL_CTRL BACK-UP

Note:
- *R282 must be open*
- *R55 must be closed*
- *JP10 must be open*

3.3 Procedure

To validate the solution, two types of tests can be performed: a low-current test running a motor in closed loop to verify the quality of the current measurements in such conditions and a nominal current test.

Step 1. For the low current test, use a 100 W three-phase permanent magnet motor and a V_{BUS} of 24 V_{DC} up to the speed of 9000 rpm.

Figure 3. Testing motor

Table 2. Testing motor parameters

Parameter	Value
Pole pairs	2
Max. speed	9000 rpm
Nominal current	3 Apk
Stator resistance	0.8 Ω
Stator inductance	0.16 mH
Bemf constant	2.5 Vllrms/kprm

Step 2. For the nominal current test, verify if the currents are correctly regulated and which is the final temperature of the components of the STDES-AKI003V1 board sustaining the final values of currents.

To perform this test, you have to generate three sinusoidal currents shifted in time by 120°. Each current should have an amplitude that follows a predefined ramp (a motor phase peak current of 50 A or 72 A in the performed tests).

The chosen ramp allows the motor to follow the imposed acceleration and, at the end of the acceleration phase, to rotate at a constant speed of 50 rpm.

Figure 4. Testing ramp up to 50 A

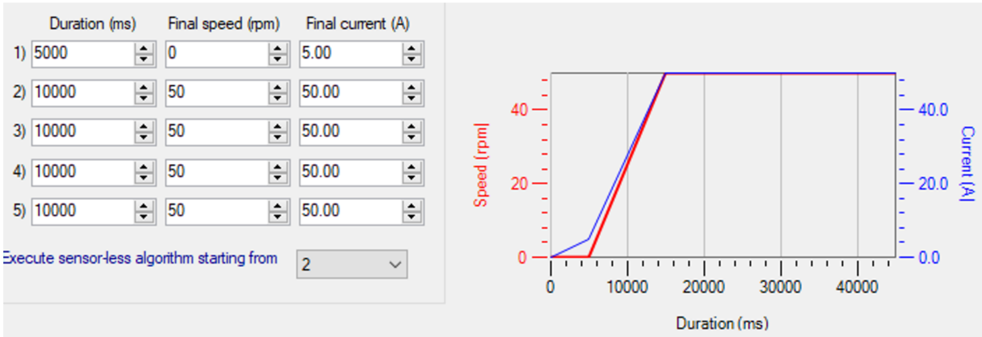
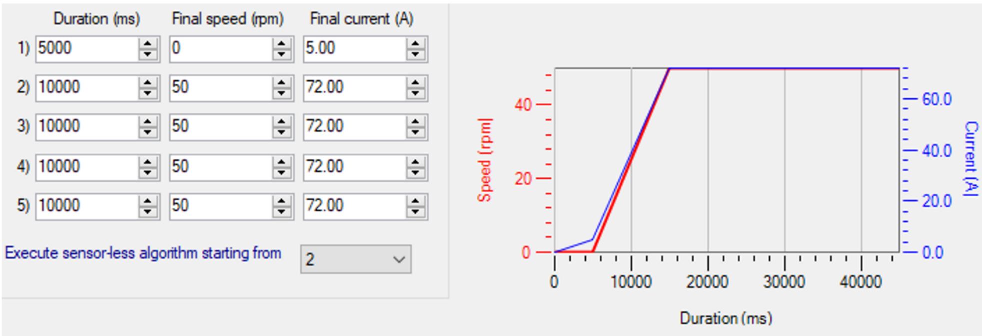


Figure 5. Testing ramp up to 72 A



The STSW-AKI003, customized version of the X-CUBE-MCSDK motor control software development kit current sensing functions, is provided to acquire the measurements of the motor phase currents from the sigma-delta modulated inputs using the STM32H7B3LI microcontroller sigma-delta filtering peripheral.

In the main.c file of X-CUBE-MCSDK standard project, the functions below have already been modified:

– `GetPhaseCurrents`
– `WriteTIMRegisters`
– `CurrentReadingPolarization`

A new data structure (SD_t) is thus defined in main.c to store the sigma-delta related variable.

Table 3. SD_t sigma-delta data structure

Field name	Description	Type
`currAs16`	Measured current of phase A expressed in s16A	int16_t
`currBs16`	Measured current of phase B expressed in s16A	int16_t
`currCs16`	Measured current of phase C expressed in s16A	int16_t
`currentPolarizatonOngoing`	True if current polarization measurement is ongoing	bool

Field name	Description	Type
`offCurrA`	Measured value of current polarization of phase A as raw value coming from sigma-delta filter output	int32_t
`offCurrB`	Measured value of current polarization of phase B as raw value coming from sigma-delta filter output	int32_t
`offCurrC`	Measured value of current polarization of phase C as raw value coming from sigma-delta filter output	int32_t
`nbConversions`	Number of samples used to perform the current polarization measurements	int32_t
`gain`	Gain used to compute the value of currents in amperes from the raw data coming from the sigma-delta filer	int32_t
`Imax`	Max. readable current set in the ST Motor Control Workbench project (shunt and operational amplifier gain set in the ST Motor Control Workbench are only dummy values)	float

For further details on how the current measurement is expressed in the firmware as s16A, refer to UM2392: "STM32 motor control SDK".

Step 3. Optional step: even if the firmware is ready to be used with the tested motors, you can choose to use another testing motor and modify the parameters shown in the figures below by using the provided STM32H7B3LI-EVAL_CTM009V1.stmcx ST Motor Control Workbench file.

Figure 6. Changing motor parameters

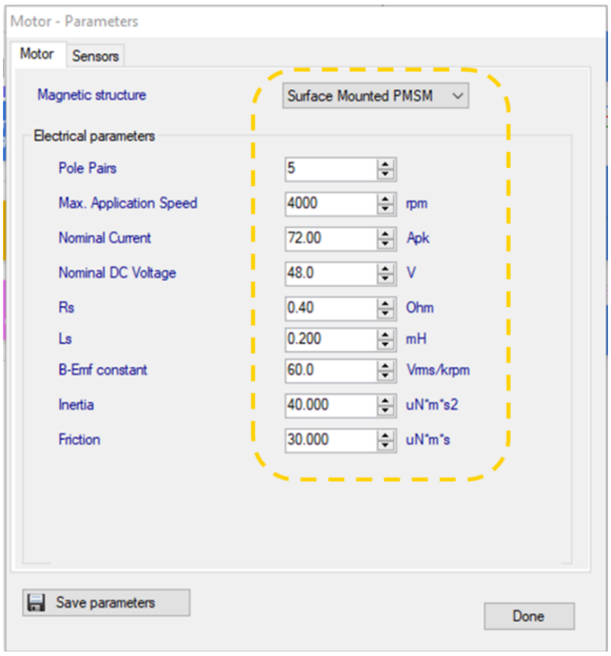


Figure 7. Changing drive settings

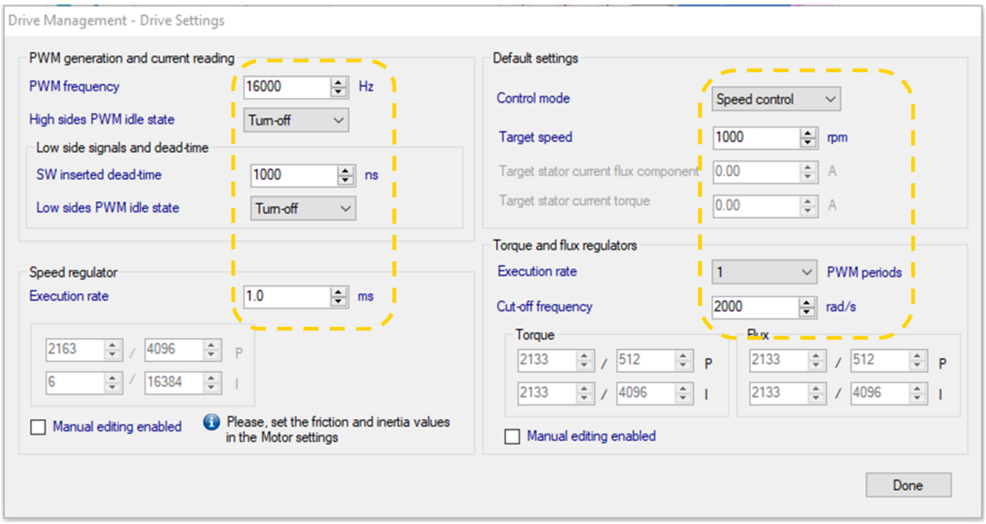
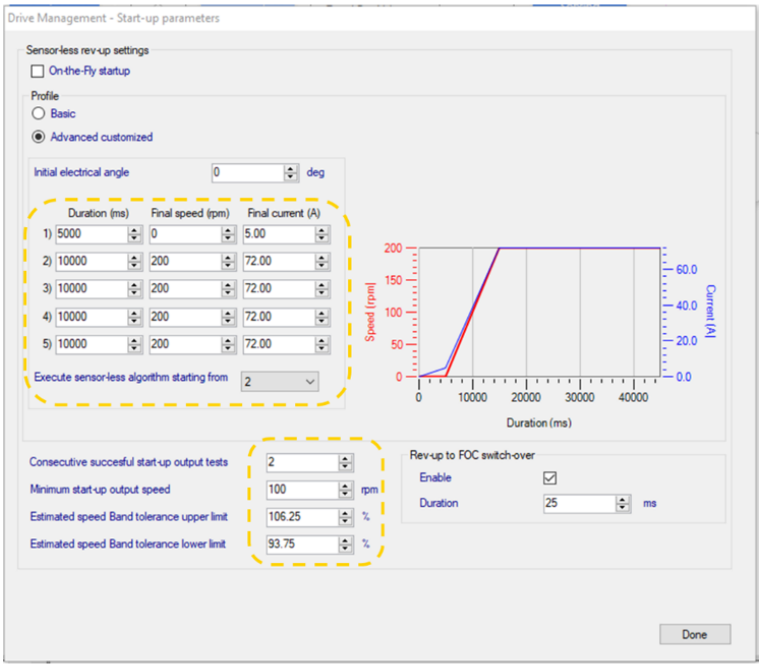
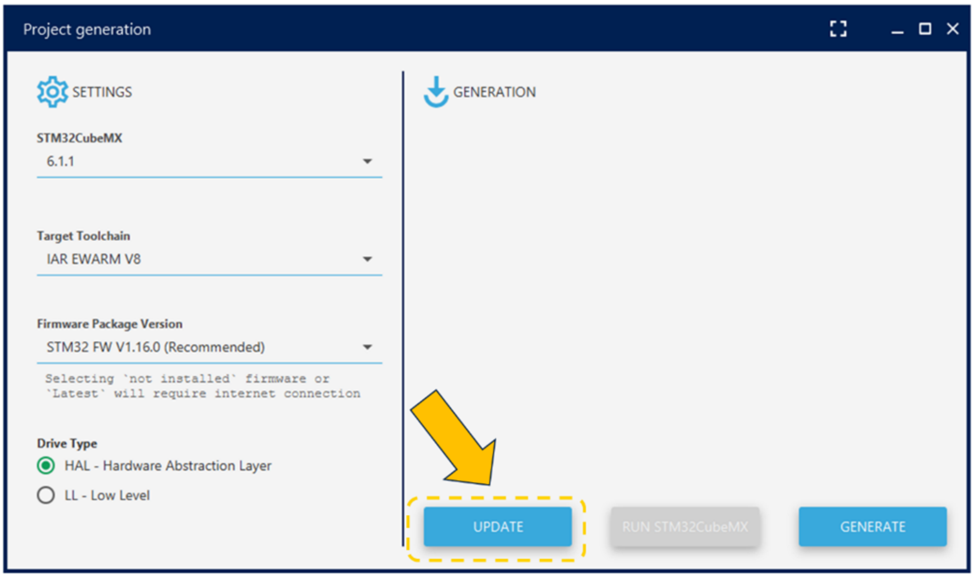


Figure 8. **Changing start-up parameters**



In order not to lose the sigma-delta current sensing customizations in the firmware, click on the update button to apply the modifications done in the ST Motor Control Workbench as shown below.

Figure 9. **Project generation**

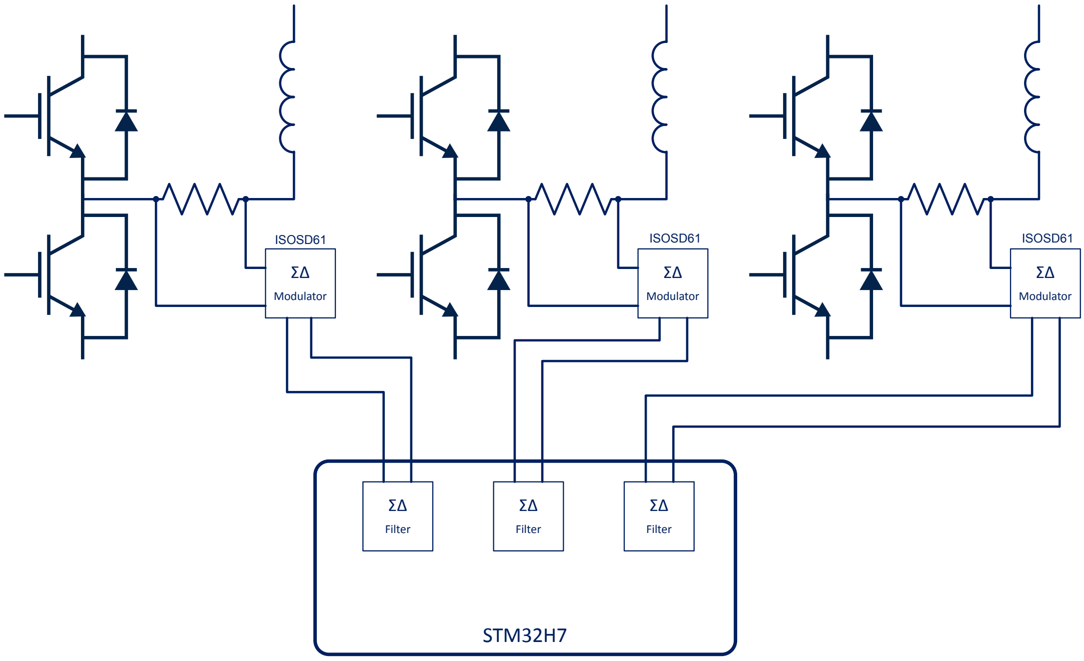


4 Technical details

The STDES-AKI003V1 reads the three phase currents from the three embedded ISOSD61 available on the board.

The firmware uses only two currents (phase A (U) and phase B (V)) thanks to the optimization of the Clark transformation.

Figure 10. Current sensing block diagram



The table below shows the clock frequencies set in the project.

Table 4. Clock frequencies

Parameter	Value
STM32H7B3 core frequency	280 MHz
DFSDM clock frequency	140 MHz
DFSDM clock divider	7
ΣΔ clock frequency	20 MHz

The table below shows the settings used for the sigma-delta filtering. In particular, the Duration parameter indicates the duration of the sigma-delta filtering and the Rate is the maximum current acquisition frequency.

Table 5. Sigma-delta filter settings

Parameter	Value	Unit
ΣΔ clock frequency	20	MHz
Filter mode	$Sinc^3$	
f_{osr}	128	
I_{osr}	1	

Parameter	Value	Unit
F_{ord}	3	
Rate	51.5	kHz
Duration	19.4	µs

The MaxCount is the maximum raw value that can be converted by the sigma-delta filtering and this value, according to the microcontroller datasheet (see the table below) and the selected value is expressed in Equation 1.

Table 6. MaxCount values according to I_{OSR} and filter type

I_{OSR}	$Sinc^1$	$Sinc^2$	FastSinc	$Sinc^3$	$Sinc^4$	$Sinc^5$
X	± FOSR. x	± $FOSR^2$. x	±2.$FOSR^2$. x	± $FOSR^3$. x	± $FOSR^4$. x	± $FOSR^5$. x

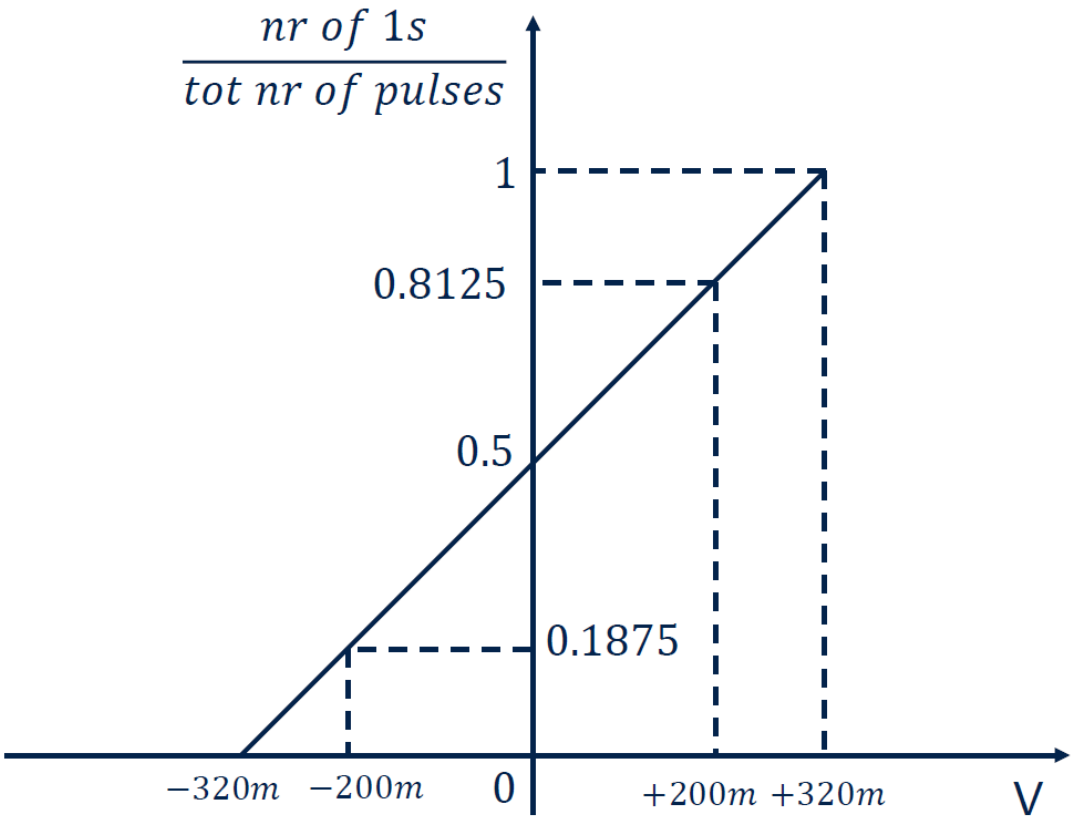
$$MaxCount = FOSR^3 \cdot I_{OSR} \quad (1)$$

The gain parameter represents the converted value corresponding to a motor phase current of 1 A and is used for the conversion between the filtered value and the current measured in the firmware (s16Current). It can be computed by Equation 2.

$$gain = \frac{MaxCount \cdot R_{shunt}}{2 \cdot V_{SDMax}} \quad (2)$$

V_{SDMax} is the value of the voltage drop in the shunt for which the sigma-delta modulator returns only 1 and it can be calculated as shown below.

Figure 11. ISOSD61 sigma-delta converter transfer function



Considering the R_{shunt} = 0.005, from Equation 2 the computed gain is 16384.

5 Measurements/waveforms/test data

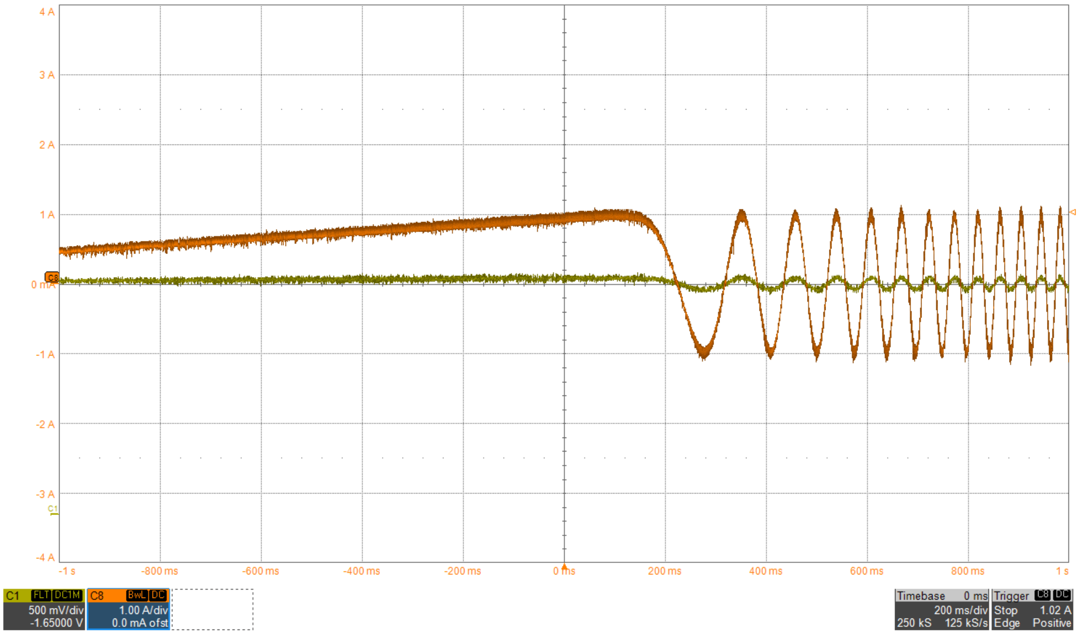
5.1 Low current test

The STDES-AKI003V1 can drive the testing motor shown in Figure 3 in closed loop up to 9000 rpm and with phase currents up to 2 Apk.

The figure below shows the programmed start-up sequence.

Figure 12. Phase A start-up current

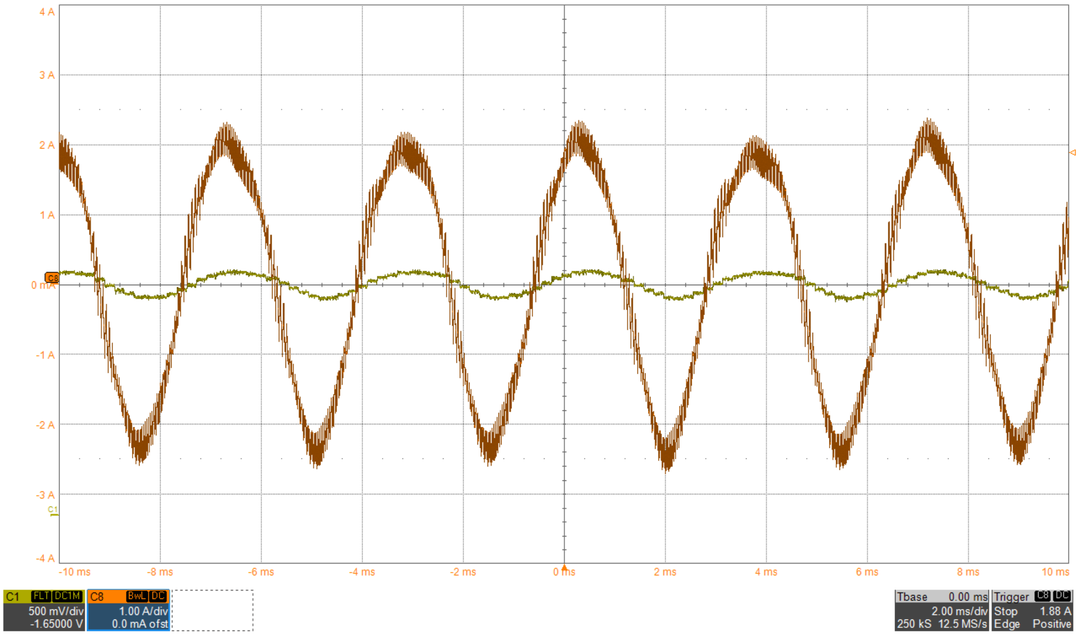
- C8 (orange) - motor phase A current measured with a 30 A Teledyne Lecroy current probe on MDA810 Lecroy oscilloscope
- C1 - decoded current measurement traced through the microcontroller DAC



The figure below shows the current measurement and regulation done running the motor at 9000 rpm with phase currents of 2 Apk.

Figure 13. Phase A current in run state

- C8 (orange) - motor phase A current measured with a 30 A Teledyne Lecroy current probe on MDA810 Lecroy oscilloscope
- C1 - decoded current measurement traced through the microcontroller DAC

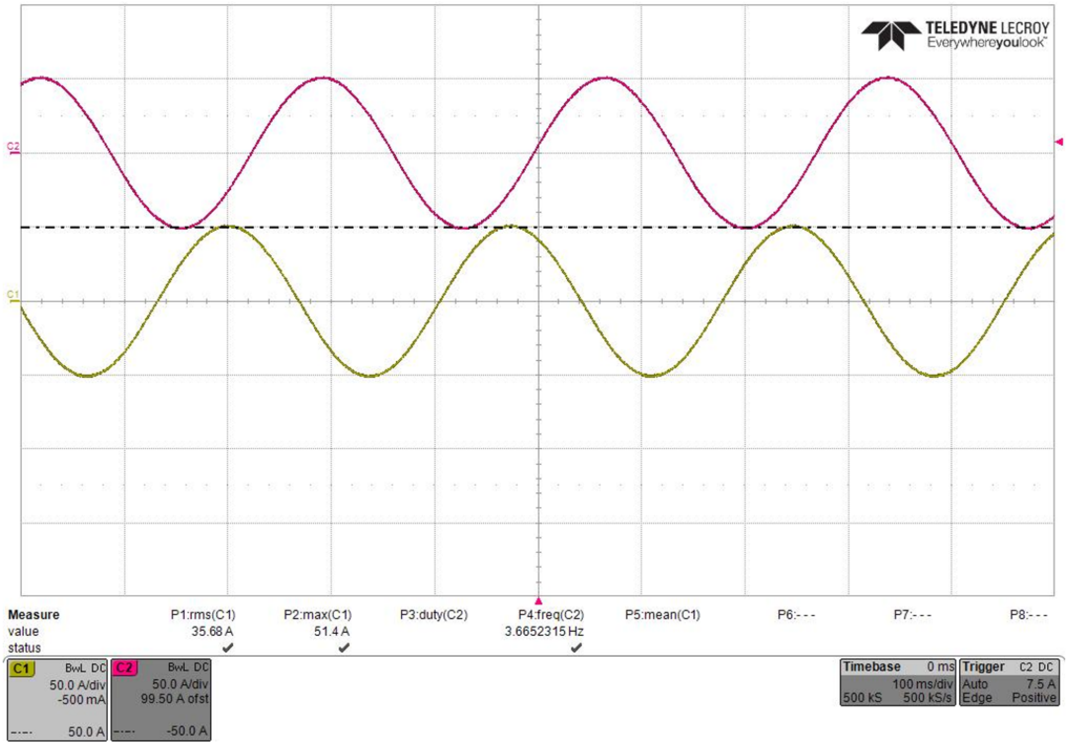


5.2 Nominal current test

Current ramp of a motor phase peak current up to 50 A with a steady state of 50 A at 50 rpm

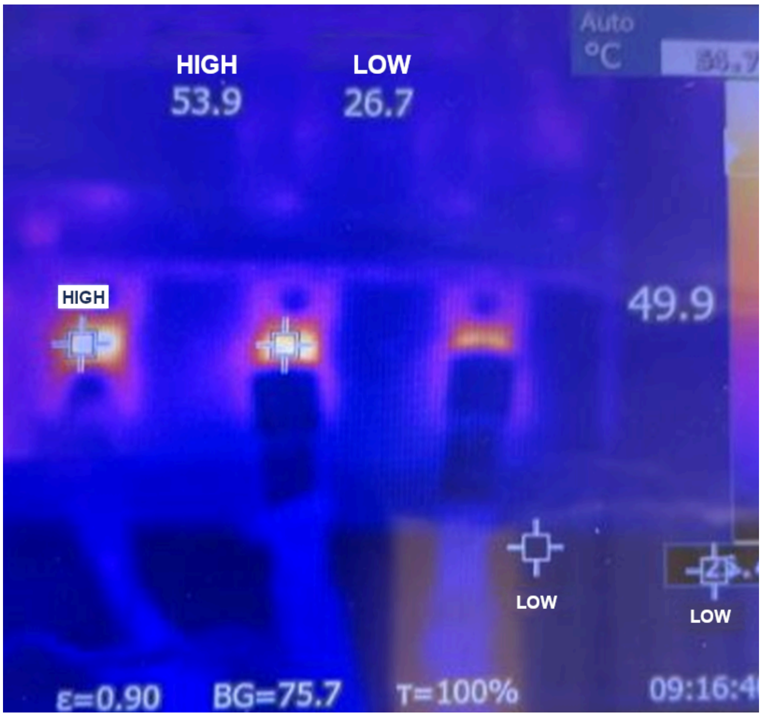
The figure below shows the capture of the current A (CH1 yellow) and B (CH2 red) measured with a 500 A current probe at the end of the programmed start-up procedure. This operating point is then maintained indefinitely to analyze the thermal behavior of the STDES-AKI003V1 shunt resistors.

Figure 14. **Motor phase A and B - 50 A steady state**



The figure below shows the result of the thermal steady state acquisition by a Fluke thermal camera.

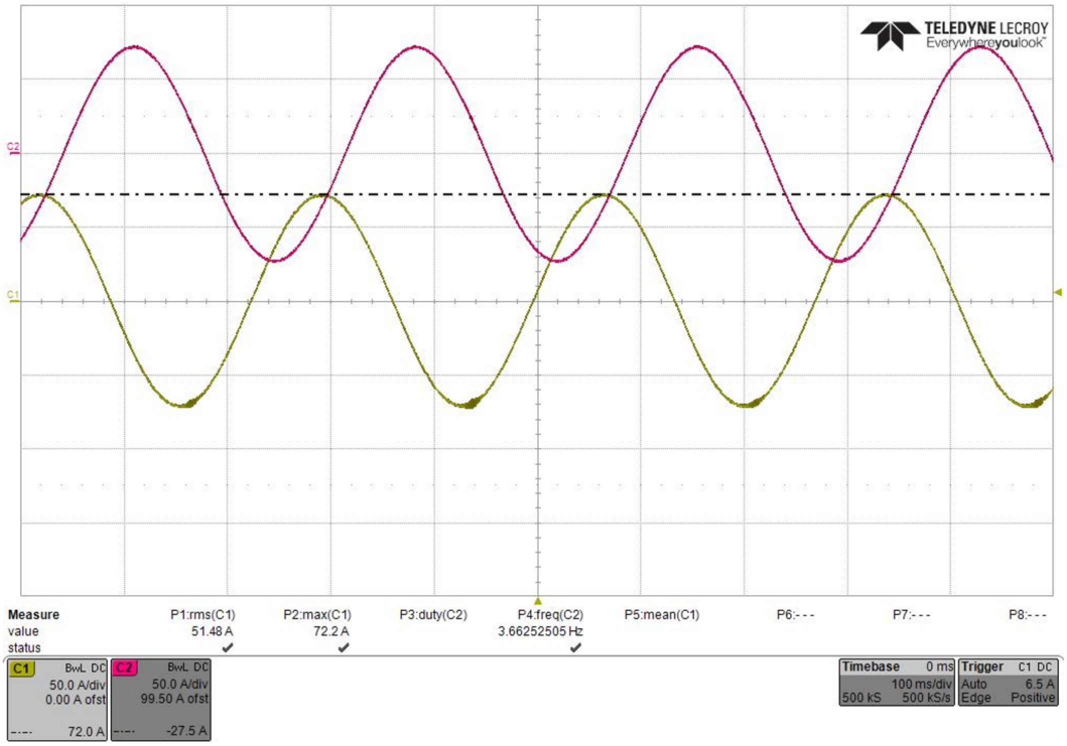
Figure 15. **Thermal acquisition at 50 A**



Current ramp of a motor phase peak current up to 72 A with a steady state of 72 A at 50 rpm

The figure below shows the capture of the currents measured with two 500 A current probes at the end of the programmed start-up procedure. This operating point is then maintained indefinitely to analyze the thermal behavior of the STDES-AKI003V1 shunt resistors.

Figure 16. Motor phase A and B - 72 A steady state



The figure below shows the result of the thermal steady state acquisition by a Fluke thermal camera.

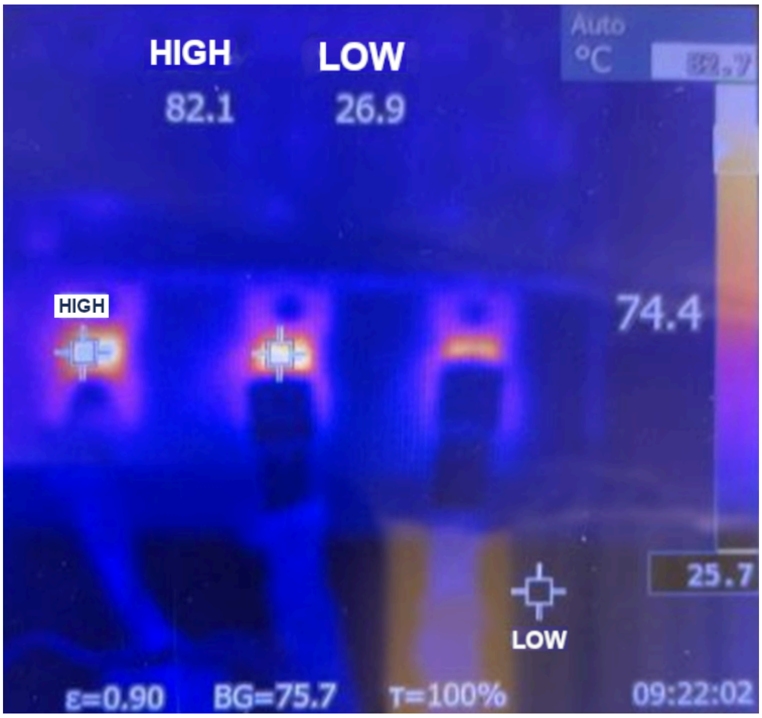
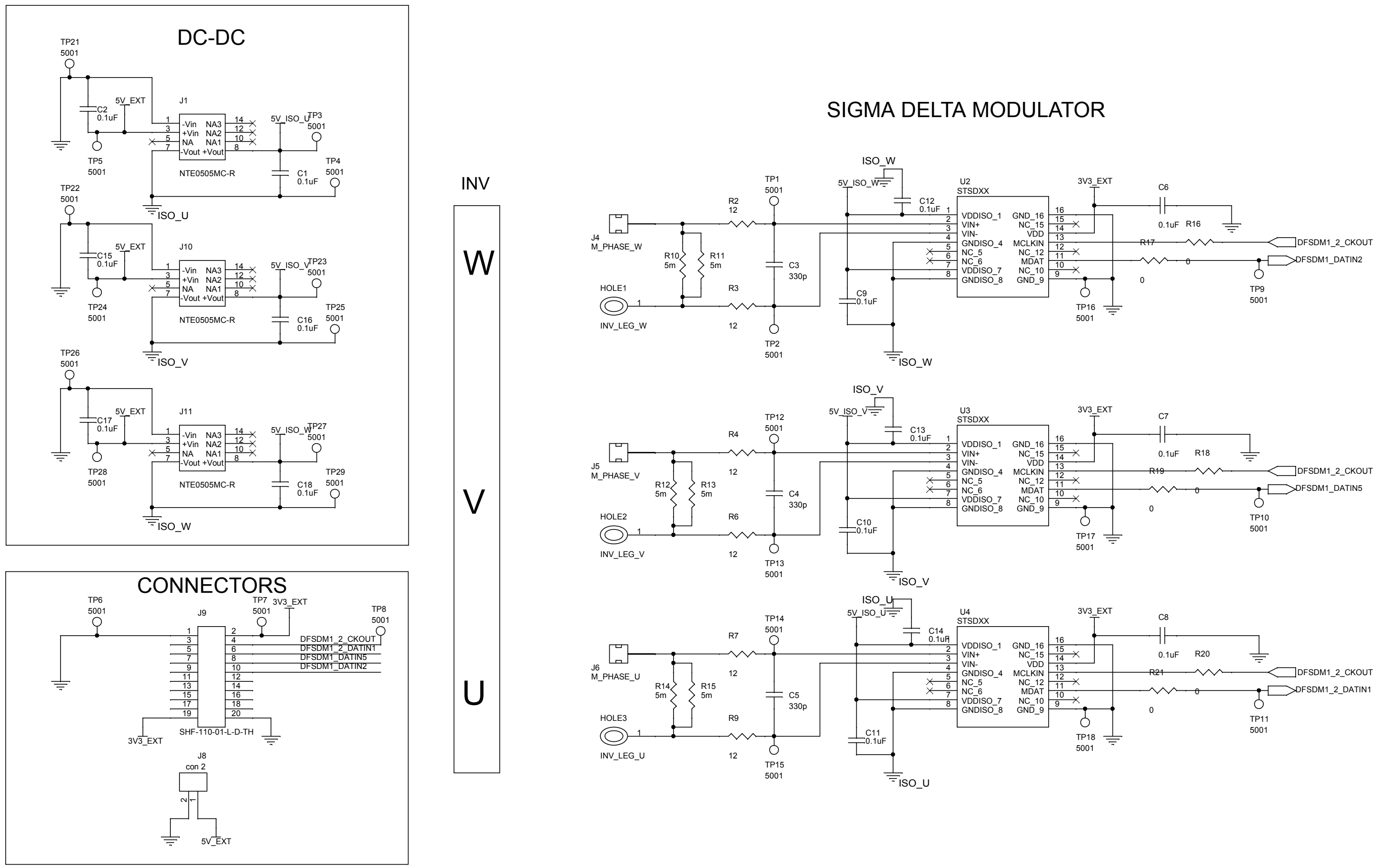


Figure 17. Thermal acquisition at 72 A

6 Schematic diagrams

Figure 18. STDES-AKI003V1 circuit schematic



7 Bill of materials

Table 7. **STDES-AKI003V1 bill of materials**

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	15	C1 C2 C6 C7 C8 C9 C10 C11 C12 C13 C14 C15 C16 C17 C18	0.1 µF, 0603 (1608 Metric), 50 V,±10%, X7R	Ceramic capacitors	KEMET	C0603C104K5RACTU
2	3	C3 C4 C5	330 p, 0805 (2012 Metric), 10 V	Ceramic capacitors	Any	
3	3	J1 J10 J11	NTE0505MC-R, 0.50" L x 0.30" W x 0.26" H (12.7 mm x 7.6 mm x 6.6 mm)	DC-DC SM	Murata Power Solutions Inc.	NTE0505MC-R
4	1	J4	M_PHASE_W	Solder screw	ERNI	214786
5	1	J5	M_PHASE_V	Solder screw	ERNI	214786
6	1	J6	M_PHASE_U	Solder screw	ERNI	214786
7	1	J8	con 2	Terminal block	Würth Elektronik	691210910002
8	1	J9	SHF-110-01-L-D-TH	Connector header	Samtec Inc.	SHF-110-01-L-D-TH
9	6	R2 R3 R4 R6 R7 R9	12,0805 (2012 Metric), 0.125 W, 1/8 W,±1%	Chip resistors	Any	
10	6	R10 R11 R12 R13 R14 R15	5m, 2818, 7 W, ±1%	Current sense resistors	Vishay / Dale	WSHM28185L000FEB
11	6	R16 R17 R18 R19 R20 R21	0805 (2012 Metric), 0.125 W, 1/8 W, ±1%	Chip resistors	Any	Any
12	27	TP1 TP2 TP3 TP4 TP5 TP6 TP7 TP8 TP9 TP10 TP11 TP12 TP13 TP14 TP15 TP16 TP17 TP18 TP21 TP22 TP23 TP24 TP25 TP26 TP27 TP28 TP29	5001, 0.100" Diam. x 0.180" L (2.54 mm x 4.57 mm)	Test points	Keystone Electronics	5001
13	3	U2 U3 U4	STSDXX 16-SOIC (0.295", 7.50 mm Width)	16-bit isolated sigma-delta modulator with single-ended and LVDS options	ST	ISOSD61
14	1	cable supply for J8	2-pin, about 30 cm	Connector 1.25	Hirose	DF13-2S-1.25C
				Crimp contact	Hirose	DF13-2630SCF

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
14	1	cable supply for J8	2-pin, about 30 cm	AWG 26 cable-length 30cm twisted red and black	-	-
15	1	cable supply for J9	20-pin, about 20 cm	Plug to J9 connector	Samtec Inc.	FFMD-10-T-06.00-01-N-SR
16	1	PCB	FR4 TG180, 222.5x60x2.4 mm	PCB	-	-

8 Conclusions

The STDES-AKI003V1 sigma-delta current sensing board shows a good noise rejection working in the range of 1-2 A of motor phase peak current (1.3% of nominal current) and can sustain up to 72 A of motor phase current as nominal current.

Appendix A Reference design warnings, restrictions and disclaimer

Important:
The reference design is not a complete product. It is intended exclusively for evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical/mechanical components, systems and subsystems.

Danger:
Exceeding the specified reference design ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings, contact an STMicroelectronics field representative prior to connecting interface electronics, including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the reference design and/or interface electronics. During normal operation, some circuit components may reach very high temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified in the reference design schematic diagrams.

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You further acknowledge and agree that the reference designs may not be used in or in connection with any legal or administrative proceeding in any court, arbitration, agency, commission or other tribunal or in connection with any action, cause of action, litigation, claim, allegation, demand or dispute of any kind.

Revision history

Table 8. Document revision history

Date	Revision	Changes
01-Sep-2021	1	Initial release.

Contents

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