

# ROHM Stepper Motor Driver Evaluation and Applications

with STEPMO\_EVK\_20x – EVK designed as Arduino / Genuino Shield

## Table of Contents

1.	Introduction.....	2
2.	Junction temperature measurement.....	2
2.1	Hardware modifications.....	2
2.2	Junction temperature calibration.....	3
	Multi-point Calibration (recommended).....	3
	One-point Calibration (less accurate).....	3
3.	Measurement Results.....	4
3.1	Decay Setting.....	5
3.2	Current per Phase.....	6
3.3	Stepping Mode.....	7
3.4	Supply Voltage.....	8
4.	Thermal resistance (junction to ambient).....	9
5.	EMC Measurements.....	10
5.1	Conducted Emission.....	10
5.1	Radiated Emission.....	11
6.	Conclusion.....	11

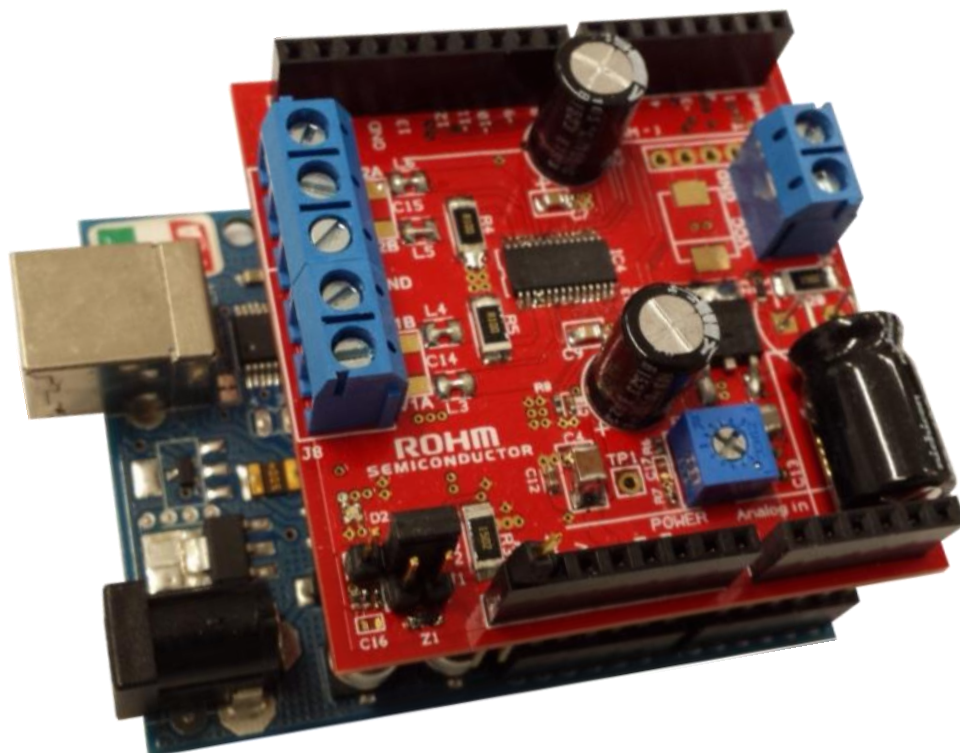


Figure 1: ROHM's stepper motor driver EVK (STEPMO\_EVK\_20x) stacked on Arduino microcontroller

## 1. Introduction

This application note demonstrates some applications with ROHM's stepper motor driver EKV STEPMO\_EVK\_20x. For general operating instructions please refer to the EVK manual at (<http://www.rohm.com/web/eu/arduino-stepper-motor-shield>). Also additional information such as hardware schematics, BOM, Gerber files, software libraries and example programs can be obtained from that site.

In general this document refers to any EVK model version; however for the applications shown in this document the model STEPMO\_EVK\_202 has been used.

## 2. Junction temperature measurement

Every electrical component which consumes power will convert this power into heat.

As explained in their datasheets the motor driver ICs used in the EVK allow indirect measurement of the junction temperature. It is highly recommended to check the junction temperature in the final application because it will strongly depend on the motor current, PCB and IC configuration. In operation the junction temperature should have margin to its absolute maximum rating of +150°C otherwise thermal shutdown might be activated and the motor operation will stop.

In this chapter it will be explained how the junction temperature can be measured, calibrated and how the temperature is affected by IC configuration.

### 2.1 Hardware modifications

Pin 17 of the motor driver IC is a test pin which must be pulled to GND in final application. However, during evaluation phase this pin can be used for indirect junction temperature measurement. For preparation of this test the following hardware modification is suggested to the EVK's PCB. Resistor R21 which pulls down pin 17 to GND must be de-soldered. Instead a wire should be connected from R21's solder point to an unused header pin as indicated with the "red wire" in Figure 2.

Now a current source with voltage monitoring capability can be connected between this pin and GND as shown in Figure 3a. This current source is used to sink a 50µA current out of pin 17 to GND. The current will create a voltage drop across the integrated diode which can be monitored by the current source. This diode voltage has a linear dependency on temperature and thus can be used to accurately measure the junction temperature of the IC if the voltage to temperature mapping is known. Please see chapter 2.2 on how to determine this mapping.

For the sake of clearness it shall be pointed out that the current source must sink the 50µA current which means that if the measurement instrument is connected between pin 17 of the IC and GND the sign of the current value entered in the instrument is negative so actually -50µA. Also since the anode of the measurement diode is connected to GND the cathode voltage to be measured has actually a negative sign. As indicated in Figure 3b the sign is typically omitted and the absolute voltage value is used to represent the junction temperature.

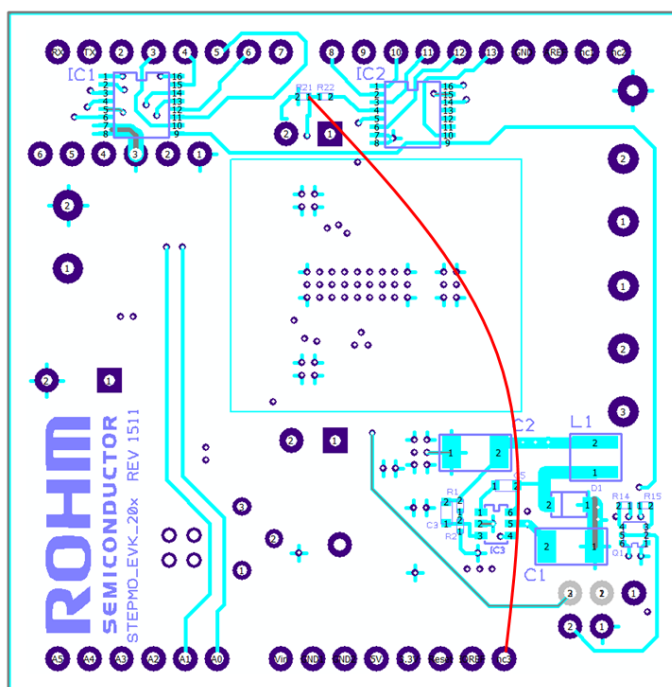


Figure 2: Wiring the IC test terminal to an unused header pin on PCB bottom

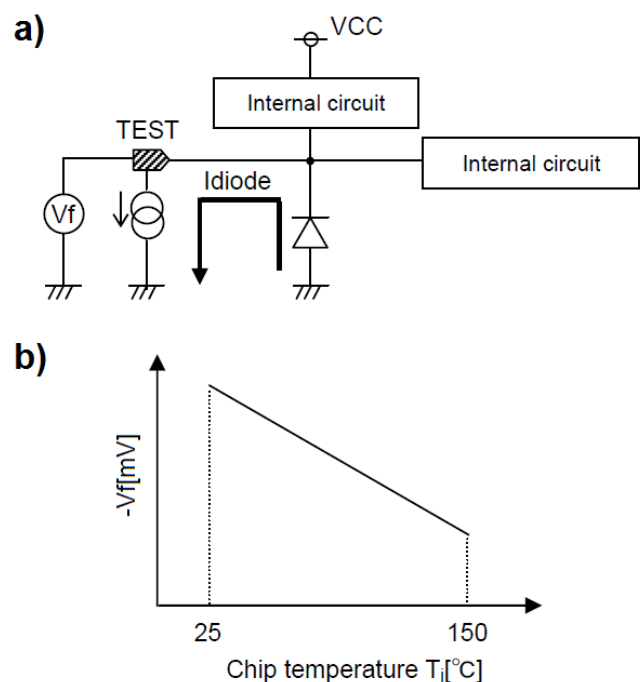


Figure 3: Principle of diode voltage measurement

## 2.2 Junction temperature calibration

### ● Multi-point Calibration (recommended)

To determine the voltage to temperature mapping please connect the -50μA current source as explained in chapter 2.1 and put the EVK hardware must in a temperature chamber or under a thermal streamer to expose it to known ambient temperatures. It should not be connected to the Arduino motherboard and in any case it must not be powered for this calibration. With only the small diode current the power consumption of the IC is so low that the IC junction temperature can be approximated to be the same as the ambient temperature. The diode voltage should now be measured at different temperatures, in this example it was measured from -20°C to +80°C in 10°C steps. The measured diode voltages and the resulting linear mapping are shown in Table 1 and Figure 4 respectively.

With linear regression the formula to calculate any temperature from a measured diode voltage can be obtained. In this example the formula is

$$Tj = -0.4819 \frac{^{\circ}\text{C}}{\text{mV}} \cdot |Vf| + 325.24^{\circ}\text{C} \quad \text{where } Vf \text{ is measured in mV and } Tj \text{ is obtained in } ^{\circ}\text{C}.$$

For confirmation the reciprocal value of the slope should yield the well-known temperature coefficient of approximately -2.1mV/°C for any silicon diode voltage. It will be quite constant for any batch of fabricated ICs. However, the offset the line may vary so it is highly recommended to perform this calibration on each individual EVK to be measured. As an example

The coefficient of determination ( $R^2$ ) obtained by linear regression is 1.0000 which proves the diode voltage scales absolutely linear with temperature and also temperatures higher than +85°C degrees can be extrapolated with the obtained formula.

$Tj / ^{\circ}\text{C}$	$ Vf  / \text{mV}$
-20	715.5
-10	695.5
0	675.0
10	654.6
20	634.2
30	612.8
40	592.0
50	571.1
60	550.2
70	529.3
80	508.7

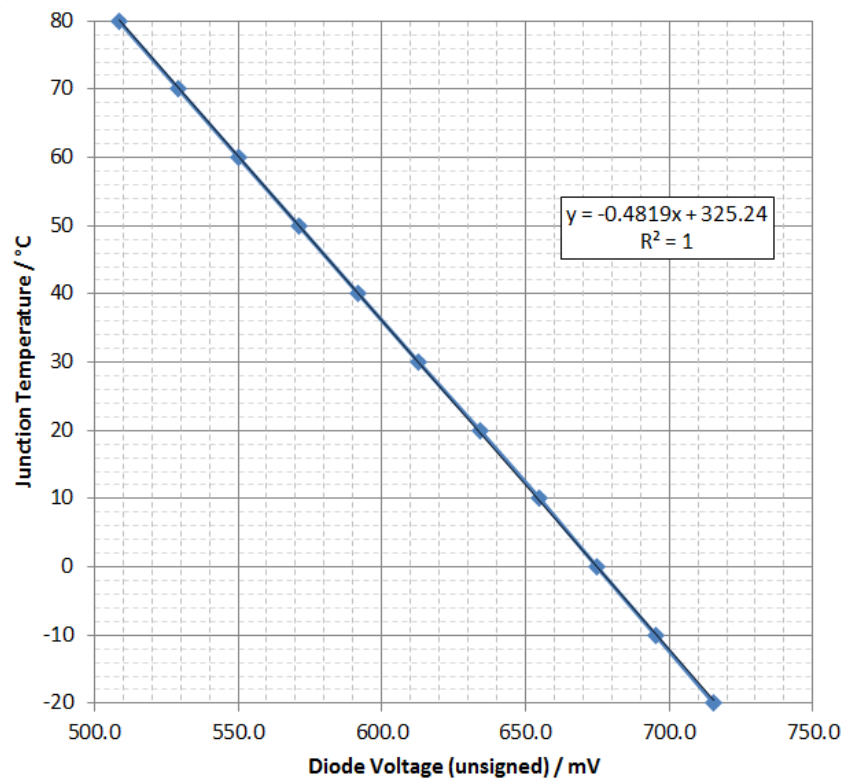


Table 1: Measured diode voltage at different temperatures

Figure 4: Graphical mapping of diode voltage to junction temperature

#### Note:

Do not go outside the rated ambient temperature range of -20°C to +85°C. Temperatures higher than +85°C must be extrapolated from the known slope and offset. Also, always wait until the diode voltage (junction temperature) has been settled. The thermal time constant can be long, at least 10 minutes.

### ● One-point Calibration (less accurate)

If a temperature chamber is not available at least a 1-point calibration at a known temperature (typically room temperature) needs to be done to calibrate the offset of the curve. Of course this 1-point calibration is not as accurate as the proposed scheme because it relies on the slope to be known.

In this example the diode voltage  $Vf_{\text{room}} = 629.2\text{mV}$  is measured at a room temperature  $T_{\text{room}} = 22^{\circ}\text{C}$  the formula to calculate the junction temperature results in

$$Tj = (|Vf| - 629.2\text{mV}) / (-2.1 \frac{\text{mV}}{^{\circ}\text{C}}) + 22^{\circ}\text{C} \quad \text{where } Vf \text{ is measured in mV and } Tj \text{ is obtained in } ^{\circ}\text{C}.$$

### 3. Measurement Results

For the following measurement results the calibrated STEPMO\_EVK\_202 Shield was plugged into an Arduino Uno R3 board and a motor with the specifications as summarized in Table 2 was connected to the outputs. The current waveform was measured with an oscilloscope and a current probe. Unless otherwise noticed the test conditions as denoted in Table 3 were applied during the measurements.

The purpose of these measurements is to show the influence of IC configuration and software setup on current waveform and temperature. Please note that these results and values are just meant as some general guidance. Please double check the behavior in the real application.

Step Angle	1.8°	Phase Resistance	1.4Ω
Step Accuracy	5%	Rated Voltage	2.8V
Holding Torque	59Ncm	Phase Inductance	3.0mH ±20%
Rated Current/phase	2.0A	Type	Bipolar 4 wire

Table 2: Specifications of stepper motor used for the tests

Stepping Mode	Full Step	Speed	144rpm
Decay Mode	Slow	Current	1A/phase
Operation	Continuous	Supply Voltage	24V
Ambient Temp.	22°C	Heat sink on PCB	none

Table 3: Typical test conditions

### 3.1 Decay Setting

In the following 4 figures the current waveform of one motor phase is plotted in different decay modes. The current limit has been tuned with potentiometer R19 to 0.5A/phase amplitude value.

It can be seen that in slow decay mode (MTH voltage = 0V) the current peaks above the set limit (Figure 5). This may lead to undesired behavior or in the worst case reliability problems or even motor destruction. The peaking can be compensated by changing the decay mode to “fast” (Figure 6) but this causes a lot of noise in the current waveform because the chopping frequency filtering is lower. Also the junction temperature rises significantly. An optimum value is found in mixed decay mode (here with MTH voltage = 0.4V) where the current peaking is gone and temperature rise is moderate (Figure 8).

**Figure 5 to Figure 8: Full step mode, continuous spin with 144 rpm, 0.5A / phase, 24V supply**

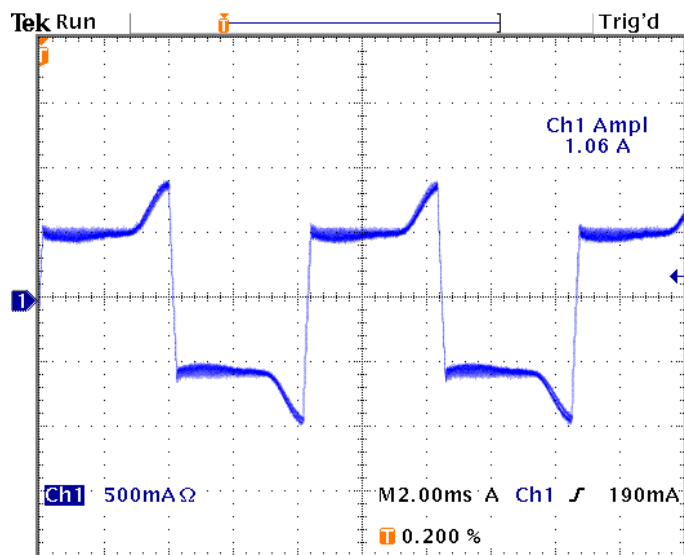


Figure 5: slow decay (V\_MTH = 0.0V), T<sub>j</sub> = 45°C

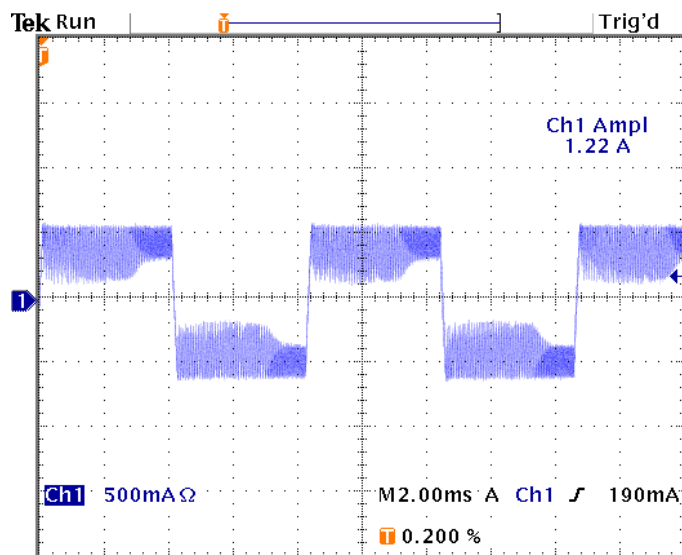


Figure 6: fast decay (V\_MTH = 2.5V), T<sub>j</sub> = 61°C

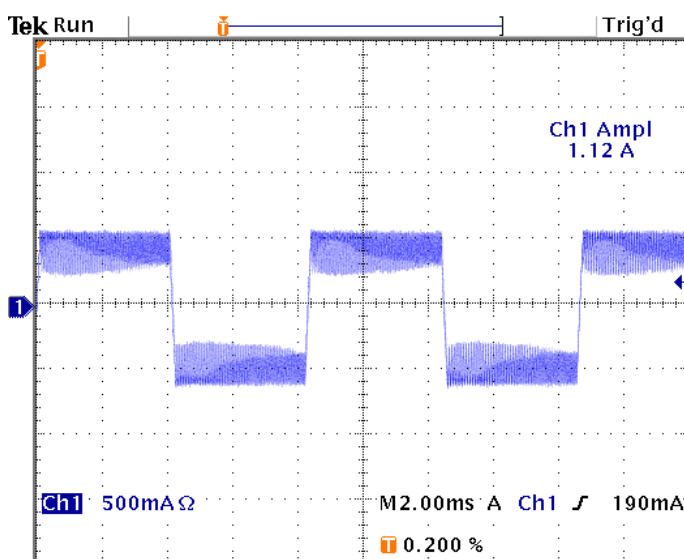


Figure 7: pre-defined mixed decay (V\_MTH = 0.7V), T<sub>j</sub> = 67°C

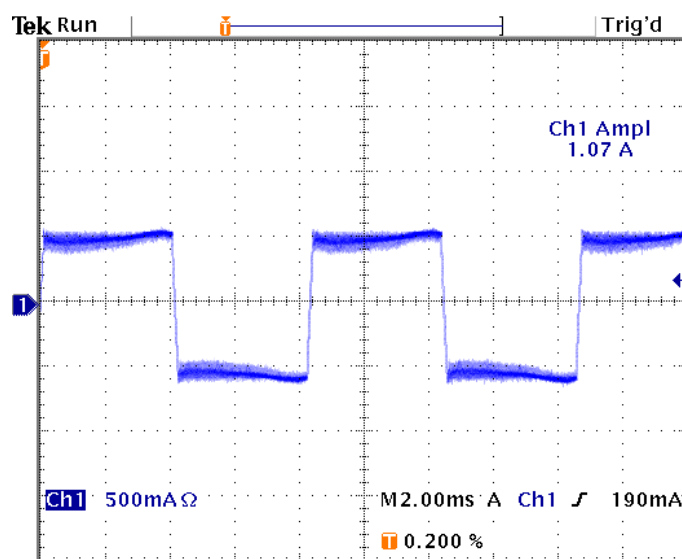


Figure 8: optimum mixed decay (V\_MTH = 0.4V), T<sub>j</sub> = 53°C

#### Note:

Typically always start evaluation in slow decay mode because of the lower junction temperature.

### 3.2 Current per Phase

In the following 4 figures the current waveform of one motor phase is plotted with different current limitation values (set by potentiometer R19). It is clear that with higher output currents the internal losses in the IC get higher and the junction temperature rises. At about 1.7A/phase the junction temperature was measured to be +127°C which is still below the absolute maximum rating of +150°C with some margin. It is not recommended to operate too close to the absolute maximum rating.

It can be seen that for high motor current the slow decay setting yields an optimum current waveform without peaking whereas for low current settings the optimum decay mode was mixed (MTH = 0.4V, see Figure 8).

**Figure 9 to Figure 12: Full step mode, continuous spin with 144 rpm, 24V supply, slow decay**

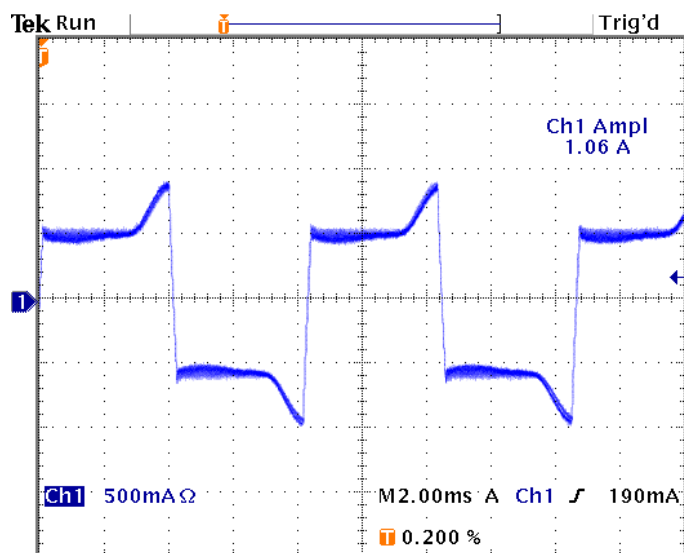


Figure 9: 0.5A/phase,  $T_j = 45^\circ\text{C}$

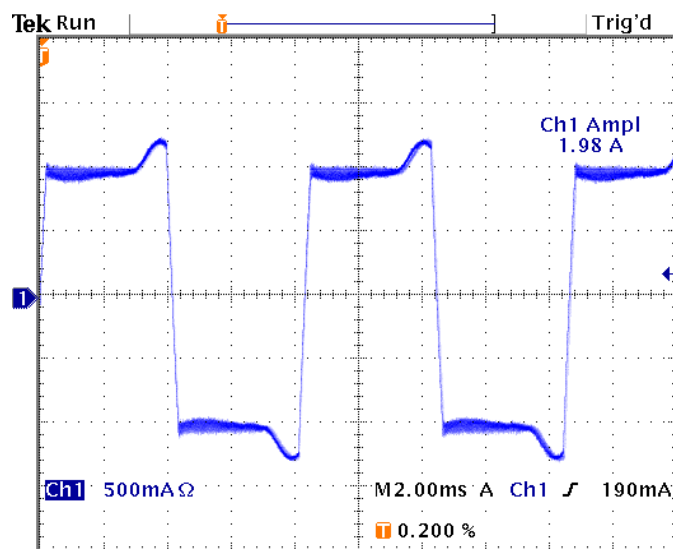


Figure 10: 1A/phase,  $T_j = 65^\circ\text{C}$

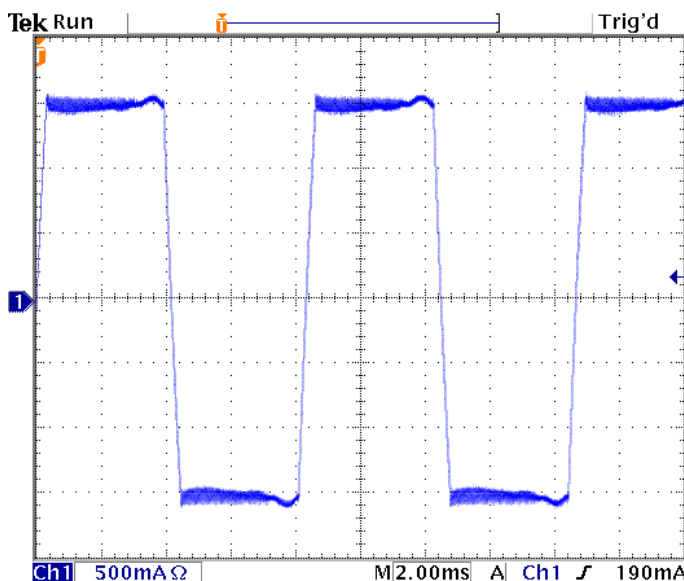


Figure 11: 1.5A/phase,  $T_j = 100^\circ\text{C}$

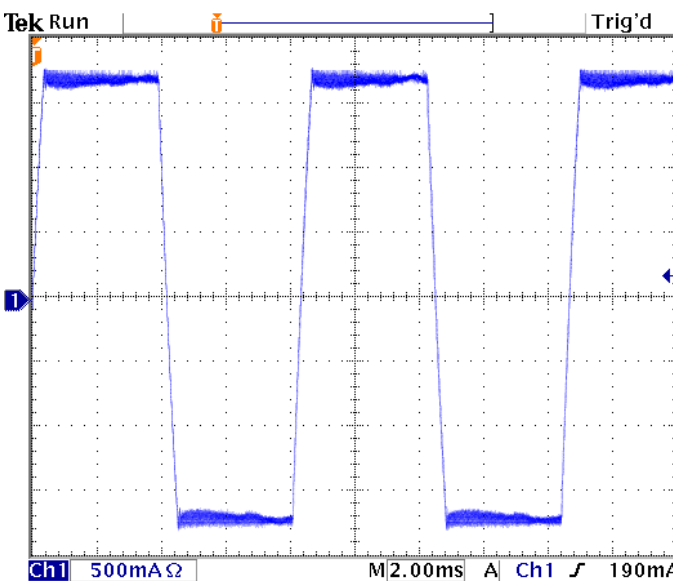


Figure 12: 1.7A/phase,  $T_j = 127^\circ\text{C}$

#### Note:

Please always confirm the IC's junction temperature in the real application in particular when using high output currents.



### 3.3 Stepping Mode

In the following 4 figures the current waveform of one motor phase is plotted vs. the stepping mode. The current limit had been tuned with potentiometer R19 to 1A/phase at full step mode. For the other plots the potentiometer was not changed. Nevertheless the peak value in half/quarter/sixteenth step modes is automatically adjusted by factor 1.41 as explained in the datasheet of the IC used in this EVK version (BD632520EFV). This feature is not present in all model versions; please check the according IC datasheet.

The purpose of this feature is to keep the RMS current approximately constant in all stepping modes. This is confirmed by measurement of the junction temperature which is nearly the same in all modes.

The plot in Figure 17 confirms again that in this application the MTH voltage = 0.4V is an optimum value because it removes the current distortion seen in Figure 16 and yields in better sine wave approximation again with the trade-off with higher temperature.

**Figure 13 to Figure 17: Continuous spin with 144 rpm, 24V supply, slow decay mode**

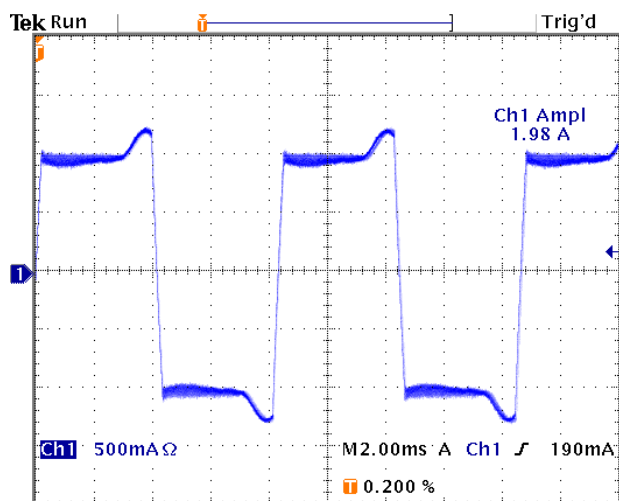


Figure 13: Full Step Mode,  $T_j = 65^\circ\text{C}$

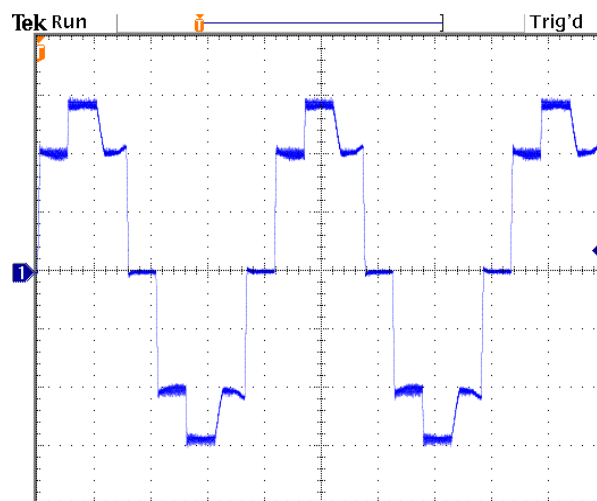


Figure 14: Half Step Mode,  $T_j = 65^\circ\text{C}$

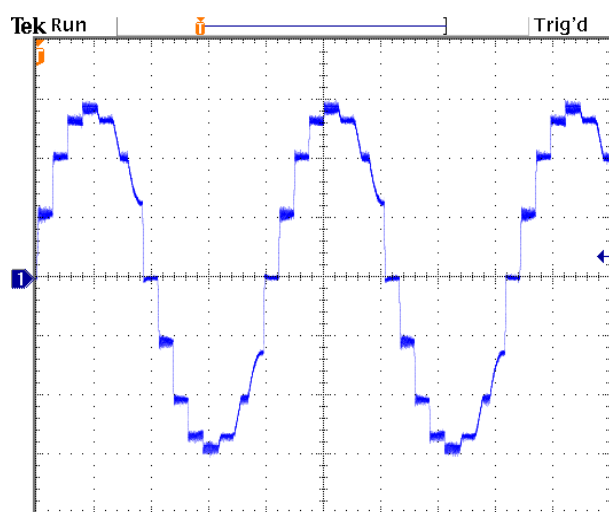


Figure 15: Quarter Step Mode,  $T_j = 65^\circ\text{C}$

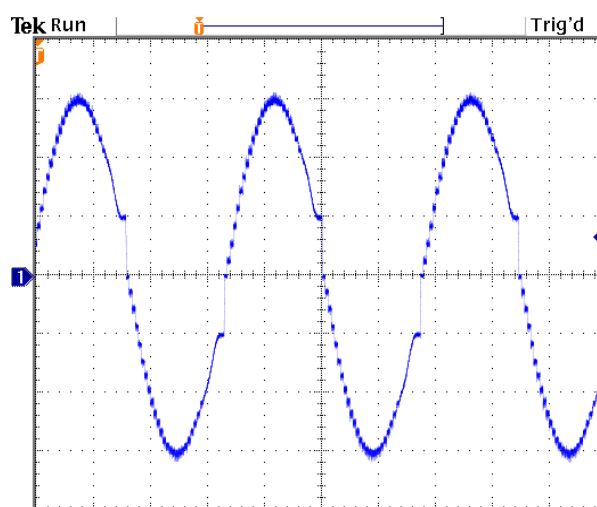


Figure 16: Sixteenth Step mode,  $T_j = 68^\circ\text{C}$

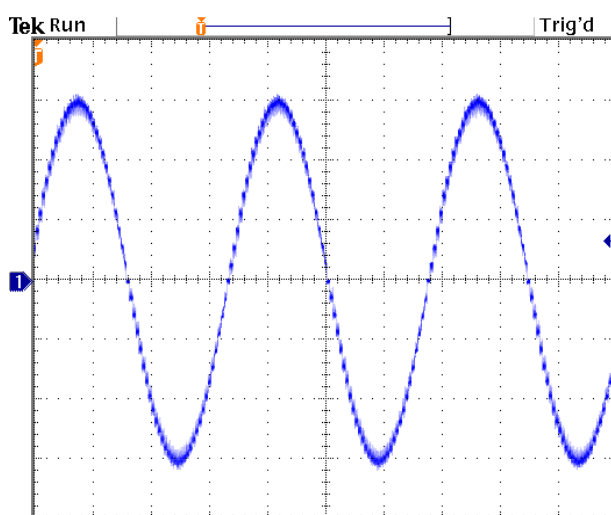


Figure 17: Sixteenth Step mode, mixed decay ( $V_{MTH} = 0.4\text{V}$ ),  $T_j = 86^\circ\text{C}$

### 3.4 Supply Voltage

In the following 4 figures the current waveform of one motor phase is plotted vs. the IC and motor supply voltage. The mixed decay mode with MTH voltage of 0.4V has been used to achieve the optimum current waveform. For the measurement as shown in Figure 18 the supply voltage was only 8V. Here it can be clearly seen that due to the motor phase inductance the current rise and fall times are limited. Note that without the current limit feature of ROHM's stepper motor driver IC the motor voltage would be limited to 2.8V only. With that low voltage the motor speed and torque could never be as high as demonstrated here. The following figures show the current waveforms with 12V, 18V and 24 supply voltage and the improvement of rise/fall time which corresponds to higher motor torque.

**Figure 18 to Figure 21: Full step mode, continuous spin with 144 rpm, 1A/phase, mixed decay (0.4V)**

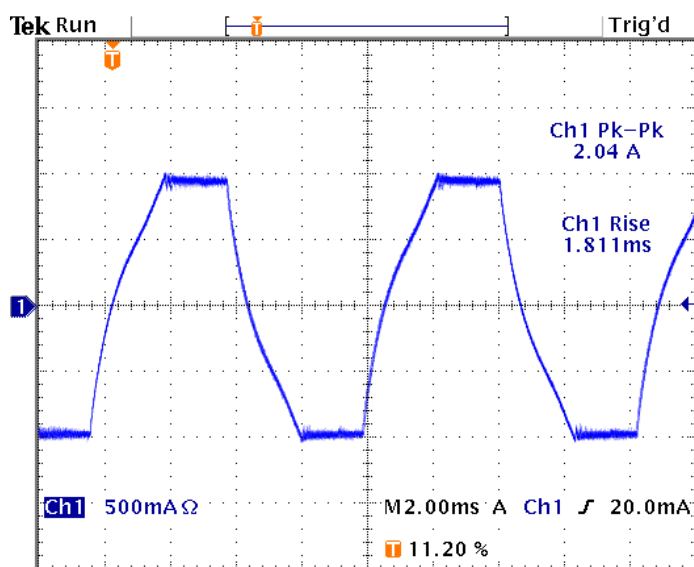


Figure 18: 8V supply, 1.8ms rise/fall time

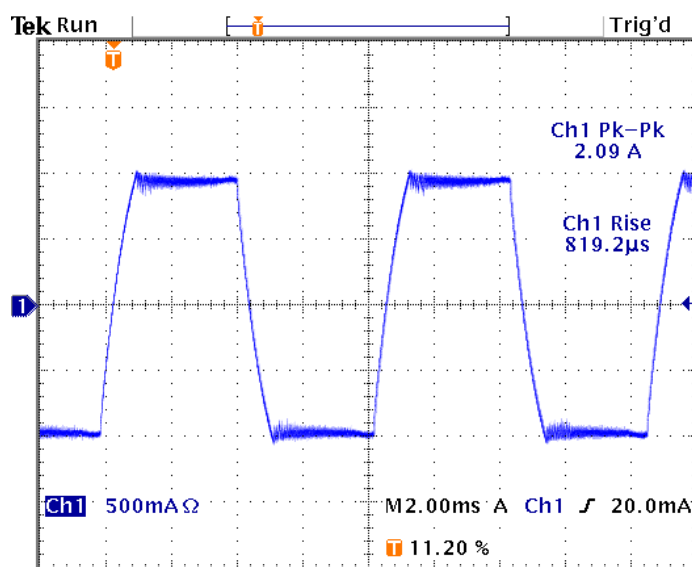


Figure 19: 12V supply, 0.8ms rise/fall time

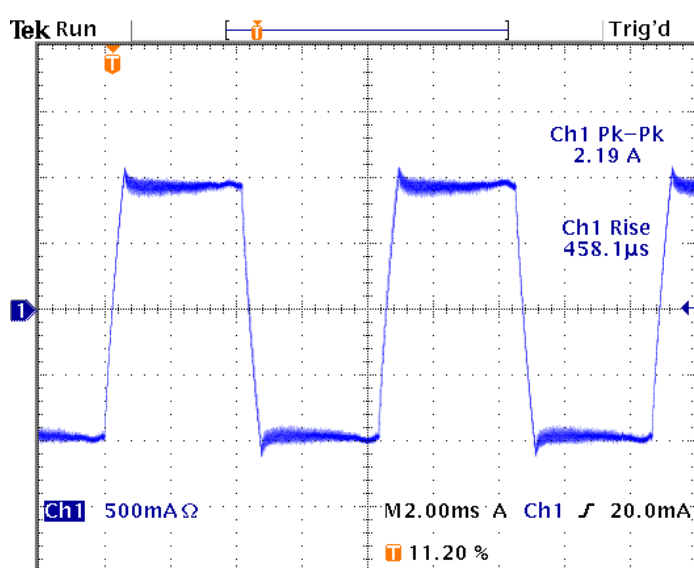


Figure 20: 18V supply, 0.45ms rise/fall time

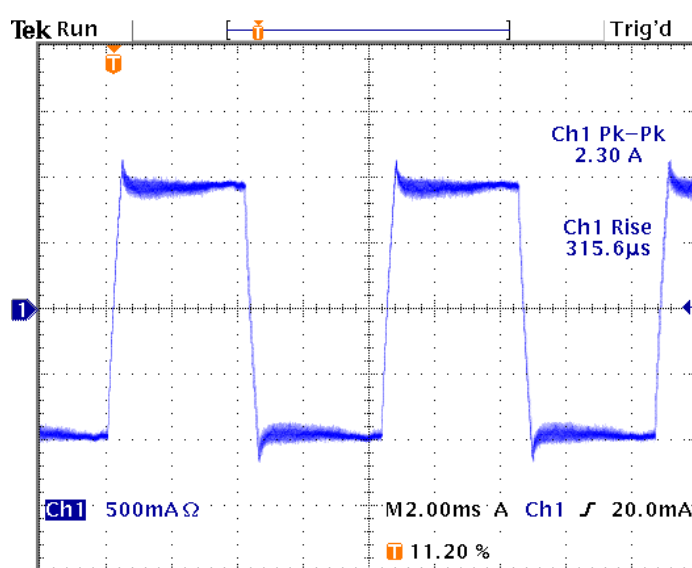


Figure 21: 24V supply, 0.32ms rise/fall time



#### 4. Thermal resistance (junction to ambient)

The EVK PCB is a 4-layer board with dimensions of 54 x 54 mm<sup>2</sup> and 1.6mm thickness. The layer stack is Signal-GND-Power-Signal with a copper thickness is 35µm for all layers. All unused areas of all layers are poured with copper connected to GND to minimize the thermal resistance of the board. For more details please check the Gerber files of the PCB.

To calculate the thermal resistance from junction to ambient not only the junction temperature but also the power consumption of the IC needs to be known which can be calculated as the difference between input power and output power. The input power is simply the product of supply voltage (VCC) with the difference of supply current in operation (ICC) and supply current in power save mode (IPS). VCC and ICC are typically directly taken from the laboratory supply used to power the board. For IPS the IC should be programmed to power save mode to get the current consumption of the other components on the board.

$$P_{in} = VCC \cdot (ICC - I_{PS})$$

The output power can easily be calculated if the current waveform is measured as shown in the previous chapters. With measurement functions the oscilloscope allows to calculate the RMS current from the waveform. The output power is twice the product of the squared output RMS current (IRMS) and the motor phase resistance (Rm).

$$P_{out} = 2 \cdot I_{RMS}^2 \cdot R_m$$

The thermal resistance is calculated as the difference between junction (Tj) and ambient temperature (Ta) divided by the difference between input (Pin) and output power (Pout).

$$R_{thja} = \frac{T_j - T_a}{P_{in} - P_{out}}$$

In Table 4 the measured thermal resistance from IC junction to ambient is shown. As the board design allows the heat to be spread among the copper layers and radiated at the bottom a low thermal resistance of 20K/W is achieved. Nevertheless, some investigations have been made to improve the thermal resistance by adding discrete heat sinks to the IC or board.

In the first investigation the heat sink ICK68L by Fischer has been attached with thermally conducting tape to the IC case (see Figure 22). Since the heat sink is fairly small and the main heat path is through the bottom of the IC the effect of this heat sink is very small. As second investigation the larger heat sink ICK SMD B 19 MI also by Fischer has been soldered to the exposed GND area of the PCB bottom (see Figure 23). This could reduce the thermal resistance from 20K/W to approximately 16 K/W.

Heat Sink Type	Specified Rth by heat sink only	Effective total Rth junction to ambient including heat sink
none	N/A	20 K/W
ICK68L	83 K/W	19 K/W
ICK SMD B 19 MI	22 K/W	16 K/W

Table 4: Improvement of thermal resistance from junction to ambient by adding discrete heat sinks

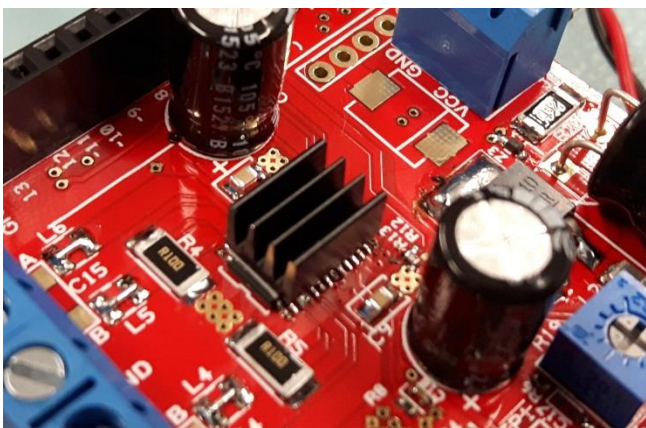


Figure 22: Fischer heat sink ICK68L added on top of IC case

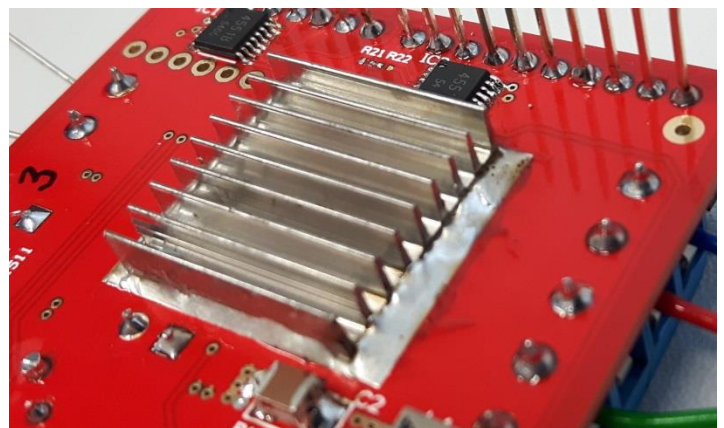


Figure 23: Fischer heat sink ICK SMD B 19 MI added on exposed GND area of PCB bottom

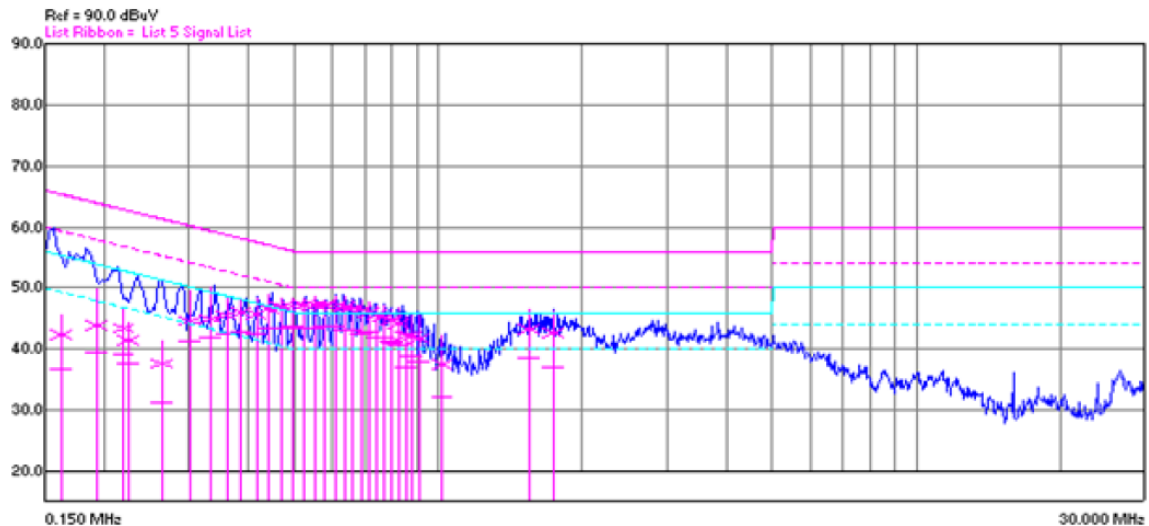
## 5. EMC Measurements

The EVK has been measured for electromagnetic compatibility (EMC) compliance in the accredited test laboratory of IMST GmbH, Germany. With the reference design provided by this EVK the stepper motor driver circuit has passed the requirements for immunity according to DIN EN 61000-6-2 (industrial environments) and emission to DIN EN 61000-6-3 (residential, commercial and light-industrial environments).

The plots in the following sub-chapters are taken from test report "ROHM\_1532".

### 5.1 Conducted Emission

The measurement result in Figure 24 shows that the EVK fulfills the requirements of EN55011:2007 class B for conducted emissions.



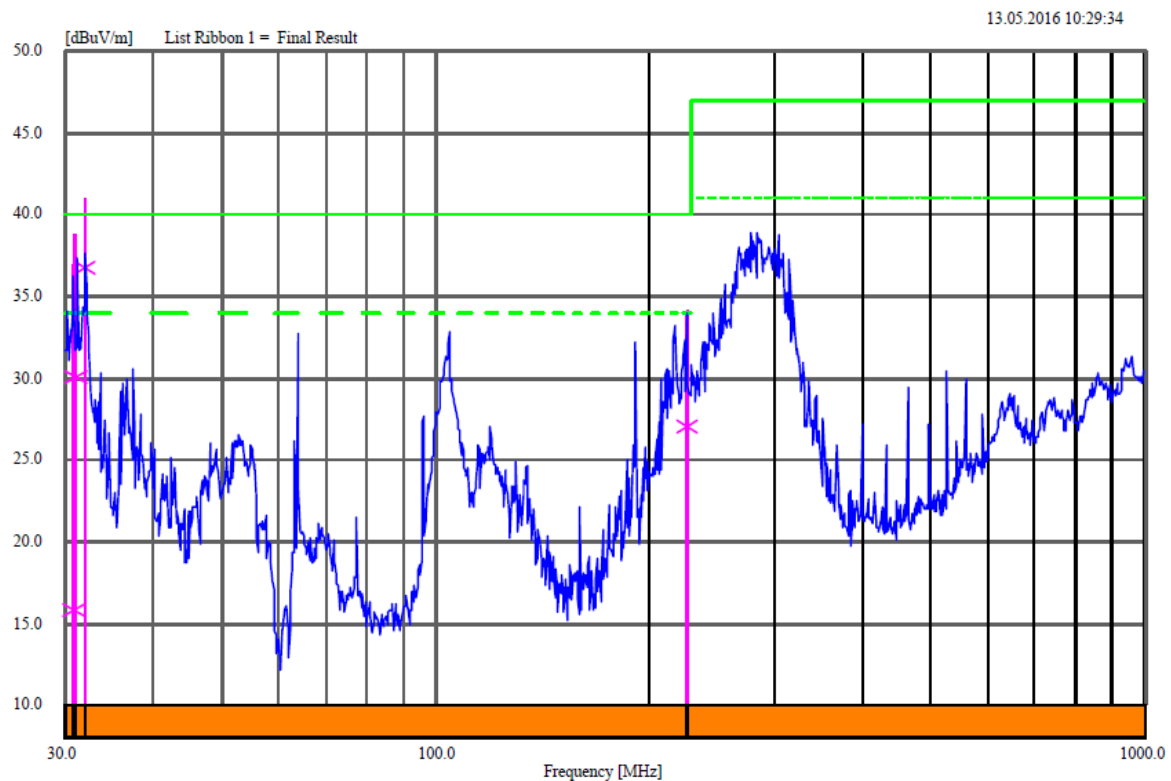
Limits:

- Quasi peak limit in dB $\mu$ V class B, DIN EN 55011: 2007
- - - Margin 6 dB below the quasi peak limit
- Average limit in dB $\mu$ V class B, DIN EN 55011: 2007
- - - Margin 6 dB below the average limit
- × Quasi Peak
- Average

Figure 24: Conducted emissions according to EN55011:2007

## 5.1 Radiated Emission

The measurement result in Figure 25 shows that the EVK fulfills the requirements of EN55011:2007 class B for radiated emissions.



Limits:

- Quasi peak limit in dB $\mu$ V class B, distance 3 m, DIN EN 55011: 2007
- - - Margin 6 dB below the quasi peak limit
- × Quasi peak

Figure 25: Radiated emissions according to EN55011:2007

## 6. Conclusion

This application note explains how to accurately measure the junction temperature of the stepper motor driver IC with the Arduino based EVK. The influence of various operating conditions on junction temperature has been shown. The results of EMC measurements prove that the reference design fulfills the requirements of immunity according to DIN EN 61000-6-2 (industrial environments) and emission to DIN EN 61000-6-3 (residential, commercial and light-industrial environments).

## Notes

1. The information contained herein is subject to change without notice.
2. Before you use our Products, please contact our sales representative and verify the latest specifications :
3. Although ROHM is continuously working to improve product reliability and quality, semiconductors can break down and malfunction due to various factors. Therefore, in order to prevent personal injury or fire arising from failure, please take safety measures such as complying with the derating characteristics, implementing redundant and fire prevention designs, and utilizing backups and fail-safe procedures. ROHM shall have no responsibility for any damages arising out of the use of our Products beyond the rating specified by ROHM.
4. Examples of application circuits, circuit constants and any other information contained herein are provided only to illustrate the standard usage and operations of the Products. The peripheral conditions must be taken into account when designing circuits for mass production.
5. The technical information specified herein is intended only to show the typical functions of and examples of application circuits for the Products. ROHM does not grant you, explicitly or implicitly, any license to use or exercise intellectual property or other rights held by ROHM or any other parties. ROHM shall have no responsibility whatsoever for any dispute arising out of the use of such technical information.
6. The Products are intended for use in general electronic equipment (i.e. AV/OA devices, communication, consumer systems, gaming/entertainment sets) as well as the applications indicated in this document.
7. The Products specified in this document are not designed to be radiation tolerant.
8. For use of our Products in applications requiring a high degree of reliability (as exemplified below), please contact and consult with a ROHM representative: transportation equipment (i.e. cars, ships, trains), primary communication equipment, traffic lights, fire/crime prevention, safety equipment, medical systems, servers, solar cells, and power transmission systems.
9. Do not use our Products in applications requiring extremely high reliability, such as aerospace equipment, nuclear power control systems, and submarine repeaters.
10. ROHM shall have no responsibility for any damages or injury arising from non-compliance with the recommended usage conditions and specifications contained herein.
11. ROHM has used reasonable care to ensure the accuracy of the information contained in this document. However, ROHM does not warrants that such information is error-free, and ROHM shall have no responsibility for any damages arising from any inaccuracy or misprint of such information.
12. Please use the Products in accordance with any applicable environmental laws and regulations, such as the RoHS Directive. For more details, including RoHS compatibility, please contact a ROHM sales office. ROHM shall have no responsibility for any damages or losses resulting non-compliance with any applicable laws or regulations.
13. When providing our Products and technologies contained in this document to other countries, you must abide by the procedures and provisions stipulated in all applicable export laws and regulations, including without limitation the US Export Administration Regulations and the Foreign Exchange and Foreign Trade Act.
14. This document, in part or in whole, may not be reprinted or reproduced without prior consent of ROHM.



Thank you for your accessing to ROHM product information.  
More detailed product information and catalogs are available, please contact us.

## ROHM Customer Support System

<http://www.rohm.com/contact/>