AMIS-3052x/NCV7052x Stepper Motor Driver Failure Diagnostics and Protection

Prepared by: Johannes Vorenholt and Christiam Gasparini
ON Semiconductor

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APPLICATION NOTE

Introduction

The AMIS-3052x/NCV7052x are micro-stepping motor drivers for bipolar stepper motors. These devices have a serial peripheral interface (SPI) and a dedicated error output pin, which can be connected to an external microcontroller. Advanced features for error diagnostics such as: *open coil detection*, *short circuit protection* and *over temperature protection* are embedded into the 52x. By using proper diagnostics routines, 100% of the single case open/shorts can be detected and handled.

This application note gives an overview of the failure modes that can occur in a stepper motor application and describes the coverage of the 52x for their detection. For specific error conditions, algorithms are described.

Open Coil Detection

The 52x has the capability to detect open coils, as well as loss of connection to the motor. The detection for open load is based on a 100% duty cycle of the internal PWM controller. This principle allows proper detection in most situations, providing the total resistive path in series with the motor coils is compatible with the applied supply voltage and the requested drive-current.

The instantaneous current value for the motor coils is derived from a current translator table. The real current to the motor is regulated by the PWM controller. Depending on the required current value, the PWM controller applies the battery voltage for shorter or longer time to the motor coils. Figure 1 gives an overview of the PWM regulated current.

Let us suppose there is an open coil existing at the motor driver. In this case, the PWM controller will try to achieve the requested current level by applying 100% battery voltage to the coil, because (due to the open) no current will be measured. The internal logic of the 52x will state that the current can not be attained and will activate an internal timer, with a timeout value of 32 milliseconds. If the duty cycle of the PWM controller stays at 100% for the entire 32 ms time window, then the device will interpret this to be an open coil situation. Two different flags of the status register, OPENX and OPENY indicate whether the X or Y coil are affected. At the same time, the ERRB output is pulled low to indicate to the microcontroller that there is potentially a failure.

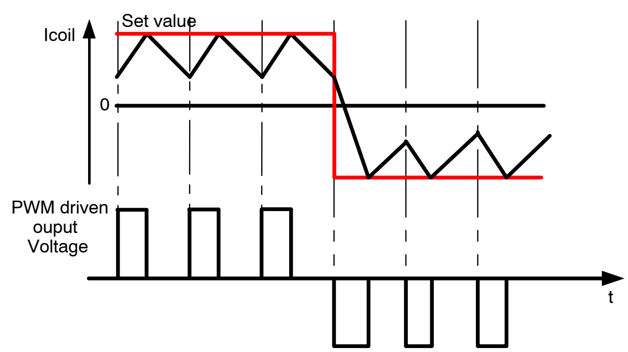


Figure 1. PWM Controlled Current Regulation

Open coil detection is only possible when a current is required in a certain coil. Therefore, in order to detect the issue, the coil in question must be activated. Due to the timeout value of 32 ms, the open coil detection is dependant on the motor speed. In more detail, there is a maximum speed at which it can be done: Table 1 specifies these maxima for the different step modes. For practical reasons, all values are given in full steps per second.

Table 1. Maximum Velocities for Open Coil Detection

Step Mode	Speed [FS /s]
Full	62.5
1/2	46.9
1/4	54.7
1/8	58.6
1/16	60.5
1/32	61.5

TIP 1: Open Coil Diagnostics

It is advised to perform open coil diagnostics before operating the motor and/or during *hold* condition or at *hold current*. The use of low motor currents during open coil diagnostics helps avoiding dummy open coil detection (“current not reached”, see **TIP 2**).

TIP 2: Alternative Use “current not reached” (Courtesy Flag)

When the resistance of a motor coil is very large and the battery voltage is low, it can happen that the motor driver is not able to deliver the requested current to the motor. Under these conditions, the PWM controller duty cycle will be 100% and after 32 ms, the error pin will flag this situation (motor current is kept alive). This feature can be used to test if the operating conditions (supply voltage, motor coil resistance, etc...), really allow to reach the requested coil-current, otherwise it should be reduced accordingly.

Overcurrent Detection

The AMIS-3052x/NCV7052x motor drivers are protected against short circuits. For this purpose, two types of detection stages are implemented.

The first stage is acting on the Top MOSFETS of the output H-Bridges. It is using a positive feedback circuit which limits the driver current to a fixed maximum of around 4.8 A. When an over current takes place, the output driver is disabled and an appropriate bit in the status registers of the device is set. In addition, the error output pin is driven low. For all Top MOSFETS there are 4 bits assigned: OVCXPT, OVCXNT, OVCYPT and OVCYNT.

The second stage of the over current protection acts on the Bottom MOSFETS. These circuitries are using the PWM regulator feedback amplifier to achieve a more accurate over current limitation. The current is measured in terms of voltage drop over the MOSFETS’ Rdson . The limit values are related to the selected current range of the AMIS-3052x/NCV7052x (refer to the datasheet and application notes). Table 2 shows an overview of the over current limit values. As soon as the current value becomes higher than the current limit threshold, the output drivers are disabled and the appropriate bit in the status register is set. Furthermore, the ERRB pin is driven low. There are in total four bits responsible for this kind of error in the SPI registers: OVCXPB, OVCXNB, OVCYPB and OVCYNB.

Table 2. Current Limit Values

Current Range Group	MOSFET (position)	Current Range [mA]	Typical Rdson [Ω] @ 27°C	Typical Current Limit Value [A]
0	Bottom	33 .. 166	3.60	0.8
1	Bottom	190 .. 325	1.80	1.5
2	Bottom	365 .. 630	0.90	2.6
3	Bottom	750 .. 1480	0.45	4.7
All	Top	33 .. 1480	0.45	4.8

Figure 2 presents a diagram of the motor driver output stages with the different failure modes. Only single fault conditions are presented and discussed.

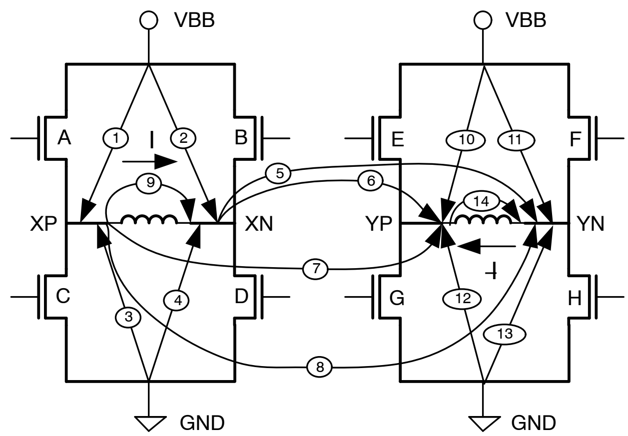
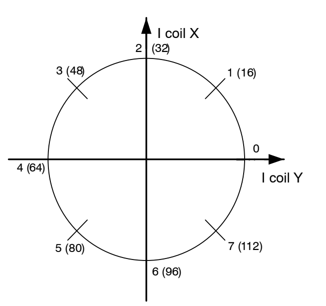


Figure 2. Short Circuit Failure Modes

The detection of over currents depends on the phase of the motor current. Figure 3 presents the currents for half step mode. For each position within the electrical period, a combination of current values is driven to the X and Y coils of the motor. The overcurrent condition in any coil can be detected only when a current is applied.



Pos.	Coil X	Coil Y
0	0	Imax
1	0,7 Imax	0,7 Imax
2	Imax	0
3	0,7 Imax	−0,7 Imax
4	0	−Imax
5	−0,7 Imax	−0,7 Imax
6	-Imax	0
7	−0,7 Imax	0,7 Imax

Figure 3. Motor Current for Half Step Mode

The failure modes from Figure 2 are examined for all positions of Figure 3 and discussed in Table 3.

Table 3. Failure Mode Description and Detection Coverage

Failure Mode		Conditional Description	Coverage at Positions	Bit Activation
1	Short from motor pin XP to V_{BB}	For positive current through the coil a short is detected via FET D or FET C (*)	For positions: 1,2 and 3 (*)	OVCXNB or OVCXPB
		For negative current through the coil a short is detected via FET C	For position: 5,6 and 7	OVCXPB
2	Short from motor pin XN to V_{BB}	For positive current through the coil a short is detected via FET D	For positions: 1,2and 3	OVCXNB
		For negative current through the coil a short is detected via FET C or FET D (*)	For position: 5,6 and 7(*)	OVCXPB or OVCXNB
3	Short from motor pin XP to GND	For positive current through the coil a short is detected via FET A	For positions: 1,2 and 3	OVCXPT
		For negative current through the coil a short is detected via FET B or FET A (**)	For position: 5,6 and 7(**)	OVCXNT or OVCXPT
4	Short from motor pin XN to GND	For positive current through the coil a short is detected via FET A or FET B (**)	For positions: 1,2 and 3 (**)	OVCXPT or OVCXNT
		For negative current through the coil a short is detected via FET B	For position: 5,6 and 7	OVCXNT
5	Short between CoilXN and CoilYN	For positive current through CoilX and negative current through CoilY	For position: 3	OVCYNT or OVCXNB
		For negative current through CoilX and positive current through coil Y	For position: 7	OVCXNT or OVCYNB
6	Short between CoilXN and CoilYP	For positive current through CoilX and positive current through CoilY	For position: 1	OVCXNB or OVCYPT
		For negative current through CoilX and negative current through CoilY	For position: 5	OVCXNT or OVCYPB
7	Short between CoilXP and CoilYP	For positive current through CoilX and negative current through coil Y	For position: 3	OVCXPT or OVCYPB
		For negative current through CoilX and positive current through coil Y	For position: 7	OVCXPB or OVCYPT
8	Short between CoilXP and CoilYN	For positive current through CoilX and positive current through coil Y	For position: 1	OVCXPT or OVCYNB
		For negative current through CoilX and negative current through CoilY	For position: 5	OVCXPB or OVCYNT
9	Short of CoilX	For positive current through CoilX	For positions: 1,2 and 3	OVCXNB
		For negative current through CoilX	For position: 5,6 and 7	OVCXPB
10	Short from motor pin YP to V_{BB}	For positive current through the coil a short is detected via FET H or FET G (*)	For positions: 0,1 and 7 (*)	OVCYNB or OVCYPB
		For negative current through the coil a short is detected via FET G	For position: 3,4 and 5	OVCYPB
11	Short from motor pin YN to V_{BB}	For positive current through the coil a short is detected via FET H	For positions: 0,1 and 7	OVCYNB
		For negative current through the coil a short is detected via FET G or FET H (*)	For position: 3,4 and 5 (*)	OVCYPB or OVCYNB
12	Short from motor pin YP to GND	For positive current through the coil a short is detected via FET E	For positions: 0,1 and 7	OVCYPT
		For negative current through the coil a short is detected via FET F or FET E (**)	For position: 3,4 and 5 (**)	OVCYNT or OVCYPT
13	Short from motor pin YN to GND	For positive current through the coil a short is detected via FET E or FET F (**)	For positions: 0,1 and 7(**)	OVCYPT or OVCYNT
		For negative current through the coil a short is detected via FET F	For position: 3,4 and 5	OVCYNT
14	Short of CoilY	For positive current through CoilY	For positions: 0,1 and 7	OVCYNB
		For negative current through CoilY	For positions: 3,4 and 5	OVCYPB

(*) only if V_{BB} / Rcoil > I_limit_lowside (**) only if V_{BB} / Rcoil > I_limit _highside

In certain circumstances the over current is only detectable if the ratio Vbat/Rcoil is larger than the over current limit value of the High side MOSFET. However, this is not a limitation for the error diagnostics. Supposing the low side MOSFET is shorted to ground, the current measurement over the Rdson of the MOSFET will give a current representative voltage drop of 0 V to the PWM regulator. As a reaction, the PWM regulator tries to achieve the target current by applying the full battery voltage to the motor (100% duty cycle). Therefore, at low speeds, the overcurrent situation is catched by an “open load detected”. Further diagnostics permit to classify the short circuit correctly.

The flowchart in Figure 4 gives a solution to cover all (single fault) short circuit conditions during operation.

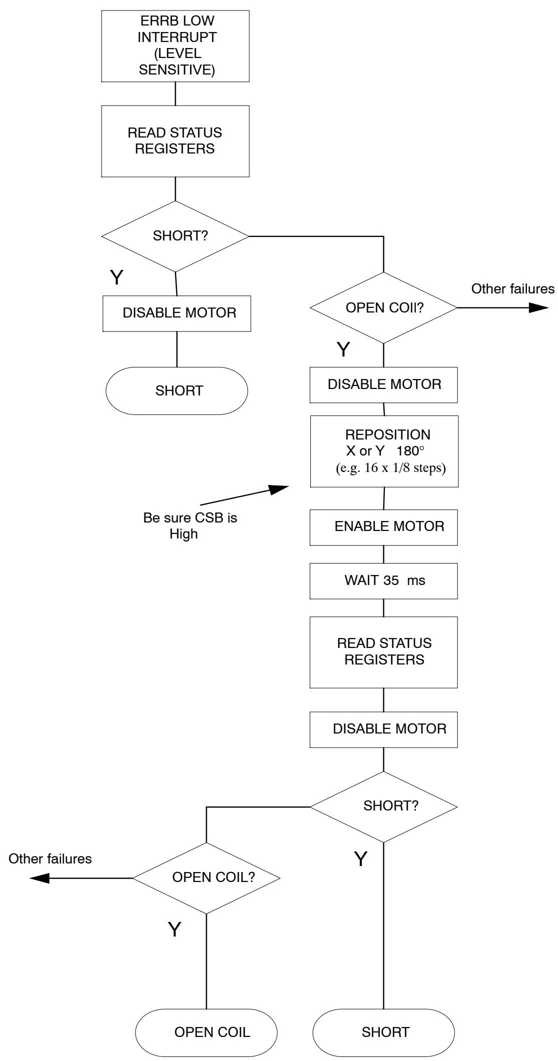


Figure 4. 100% Coverage Short Detection to GND

Important Notification

If a short (and/or thermal shutdown) condition happens, the application has to handle it in a proper way. For safety reasons (risk to burn the device), it is not allowed to clear the error bits by reading via SPI and enabling the motor driver in a repetitive way.

REMARK: Weak Shorts

In case the existing short circuit conditions are weak (hence with a significant series resistance) the short detection is not always guaranteed. On the other hand, the *thermal warning* and the *thermal protection* of the 52x driver will become active after a certain delay due to the heating time. Because of the high currents that can flow during this interval, care has to be taken not to burn the motor windings. Please also refer to the next section.

Advice on use: Power−up Diagnostics

Due to the fact the overload/short circuit currents is not displayed for coils that are not driven by a current, a good practice is to perform power-up diagnostics. The idea is to verify every possible open and short situation immediately after power−up, by means of a special algorithm.

A proposal for the algorithm follows. Please refer to Figure 3.

First, position the motor at a 45° electrical angle (E.G. in half step mode to position 1), then read the short and open flags of the 52x. Secondly, shift the motor by an additional electrical angle of 90° (position 3) and check again for errors. Again, reposition to 90° (to position 5) and check for errors. As a last step, move to position 7 and verify error state once more. By following this scheme and the information provided in Table 3, all error types can be deducted from the status register bits.

Thermal Warning and Overtemperature Detection

The AMIS3052x/NCV7052x are equipped with an internal temperature sensor and over temperature protection circuitry. When due to high driver currents and insufficient cooling, the junction temperature of the motor driver rises above a given threshold (thermal warning level), the *thermal warning flag* <TW> in the status registers is set and the ERRB pin is pulled low. During this warning condition, the motor can still be operated, but the application has to reduce the power consumption with the aim to bring the temperature back to safe levels. If the temperature after the warning is still rising above a second threshold, (thermal shutdown), the output drivers are put in high impedance state and the thermal shutdown <TSD> bit in the status registers is set. After a thermal shutdown situation, the motor can be enabled only if the junction temperature is lower then the temperature warning level.

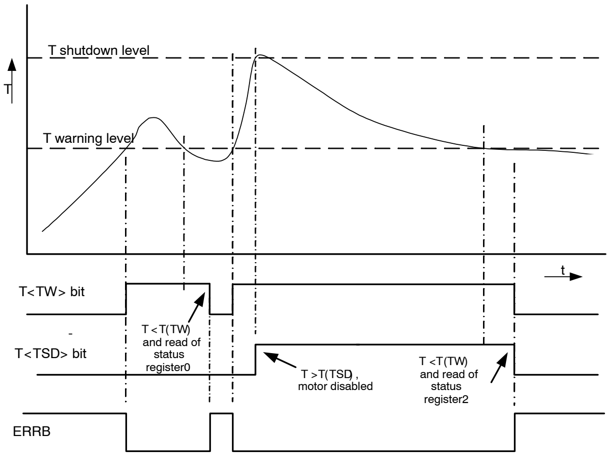


Figure 5. Thermal Management Scheme of 52x

Charge Pump Failure

The internal drivers of the AMIS-3052x/NCV7052x need for the top MOSFETs a voltage which is higher than the battery supply voltage. To provide this voltage, a charge pump generator is implemented inside the device.

When the battery voltage is reduced to around 6,7 V, the charge pump cannot deliver enough voltage and potentially, the top MOSFET resistance increases, meaning that full functional operation is not guaranteed anymore: a “charge pump failure flag” (CPFail) in the status register of the motor driver displays this alert. During the charge pump failure condition, the ERRB pin is pulled low. However, the motor driver remains active.

References

1. Datasheet AMIS-30521/NCV70521 & AMIS-30522/NCV70522 products, http://www.onsemi.com
2. Application note AND8732/D “Current Range Switching Using the 52x”, http://www.onsemi.com

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