

# AMIS-30543

## Micro-Stepping Motor Driver

### Introduction

The AMIS-30543 is a micro-stepping stepper motor driver for bipolar stepper motors. The chip is connected through I/O pins and an SPI interface with an external microcontroller. It has an on-chip voltage regulator, reset-output and watchdog reset, able to supply peripheral devices. AMIS-30543 contains a current-translation table and takes the next micro-step depending on the clock signal on the “NXT” input pin and the status of the “DIR” (=direction) register or input pin. The chip provides a so-called “speed and load angle” output. This allows the creation of stall detection algorithms and control loops based on load-angle to adjust torque and speed. It is using a proprietary PWM algorithm for reliable current control.

The AMIS-30543 is implemented in I2T100 technology, enabling both high-voltage analog circuitry and digital functionality on the same chip. The chip is fully compatible with the automotive voltage requirements.

The AMIS-30543 is ideally suited for general-purpose stepper motor applications in the automotive, industrial, medical, and marine environment. With the on-chip voltage regulator it further reduces the BOM for mechatronic stepper applications.

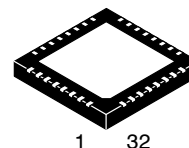
### Key Features

- Dual H-Bridge for 2-Phase Stepper Motors
- Programmable Peak-Current Up to 3 A
- On-Chip Current Translator
- SPI Interface
- Speed and Load Angle Output
- Eleven Step Modes from Full Step Up to 128 Micro-Steps
- Fully Integrated Current-Sense
- PWM Current Control with Automatic Selection of Fast and Slow Decay
- Low EMC PWM with Selectable Voltage Slopes
- Active Fly-Back Diodes
- Full Output Protection and Diagnosis
- Thermal Warning and Shutdown
- Compatible with 5 V and 3.3 V Microcontrollers
- Integrated 5 V Regulator to Supply External Microcontroller
- Integrated Reset Function to Reset External Microcontroller
- Integrated Watchdog Function
- These Devices are Pb-Free and are RoHS Compliant



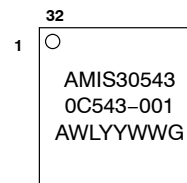
**ON Semiconductor®**

[www.onsemi.com](http://www.onsemi.com)



**QFN32  
CASE 485J**

### MARKING DIAGRAM



A = Assembly Location  
WL = Wafer Lot  
YY = Year  
WW = Work Week  
G = Pb-Free Package

### ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 37 of this data sheet.

# AMIS-30543

## BLOCK DIAGRAM

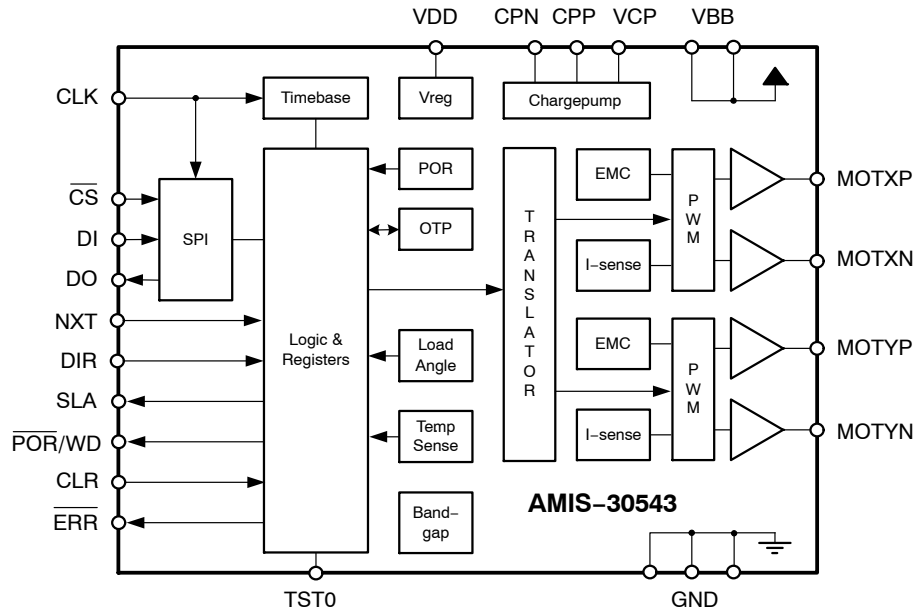


Figure 1. Block Diagram AMIS-30543

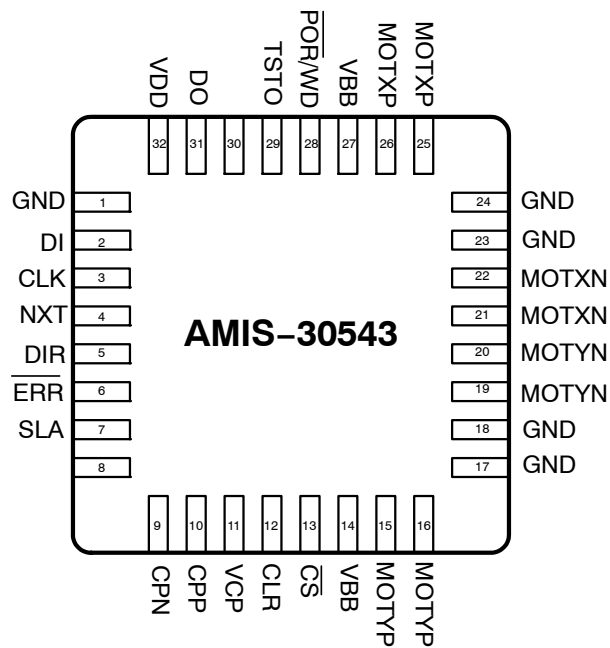


Figure 2. Pin Out AMIS-30543

**Table 1. PIN LIST AND DESCRIPTION**

| Name   | Pin    | Description                                               | Type           | Equivalent Schematic |
|--------|--------|-----------------------------------------------------------|----------------|----------------------|
| GND    | 1      | Ground                                                    | Supply         |                      |
| DI     | 2      | SPI Data In                                               | Digital Input  | Type 2               |
| CLK    | 3      | SPI Clock Input                                           | Digital Input  | Type 2               |
| NXT    | 4      | Next micro-step input                                     | Digital Input  | Type 2               |
| DIR    | 5      | Direction input                                           | Digital Input  | Type 2               |
| ERR    | 6      | Error output (open drain)                                 | Digital Output | Type 4               |
| SLA    | 7      | Speed load angle output                                   | Analog Output  | Type 5               |
| /      | 8      | No function (to be left open in normal operation)         |                |                      |
| CPN    | 9      | Negative connection of charge pump capacitor              | High Voltage   |                      |
| CPP    | 10     | Positive connection of charge pump capacitor              | High Voltage   |                      |
| VCP    | 11     | Charge pump filter-capacitor                              | High Voltage   |                      |
| CLR    | 12     | "Clear" = chip reset input                                | Digital Input  | Type 1               |
| CS     | 13     | SPI chip select input                                     | Digital Input  | Type 2               |
| VBB    | 14     | High voltage supply Input                                 | Supply         | Type 3               |
| MOTYP  | 15, 16 | Negative end of phase Y coil output                       | Driver Output  |                      |
| GND    | 17, 18 | Ground, heat sink                                         | Supply         |                      |
| MOTYN  | 19, 20 | Positive end of phase Y coil output                       | Driver Output  |                      |
| MOTXN  | 21, 22 | Positive end of phase X coil output                       | Driver Output  |                      |
| GND    | 23, 24 | Ground, heat sink                                         | Supply         |                      |
| MOTXP  | 25, 26 | Negative end of phase X coil output                       | Driver Output  |                      |
| VBB    | 27     | High voltage supply input                                 | Supply         | Type 3               |
| POR/WD | 28     | Power-on-reset and watchdog reset output (open drain)     | Digital Output | Type 4               |
| TST0   | 29     | Test pin input (to be tied to ground in normal operation) | Digital Input  |                      |
| /      | 30     | No function (to be left open in normal operation)         |                |                      |
| DO     | 31     | SPI data output (open drain)                              | Digital Output | Type 4               |
| VDD    | 32     | Logic supply output (needs external decoupling capacitor) | Supply         | Type 3               |

**Table 2. ABSOLUTE MAXIMUM RATINGS**

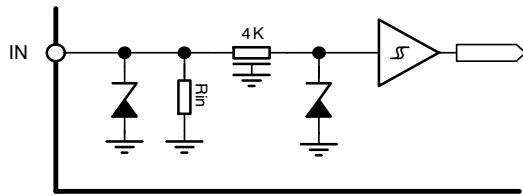
| Symbol           | Parameter                                                      | Min  | Max  | Unit |
|------------------|----------------------------------------------------------------|------|------|------|
| V <sub>BB</sub>  | Analog DC supply voltage (Note 1)                              | -0.3 | +40  | V    |
| T <sub>ST</sub>  | Storage temperature                                            | -55  | +160 | °C   |
| T <sub>J</sub>   | Junction Temperature under bias (Note 2)                       | -50  | +175 | °C   |
| V <sub>ESD</sub> | Electrostatic discharges on component level, All pins (Note 3) | -2   | +2   | kV   |
| V <sub>ESD</sub> | Electrostatic discharges on component level, HiV pins (Note 4) | -8   | +8   | kV   |

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

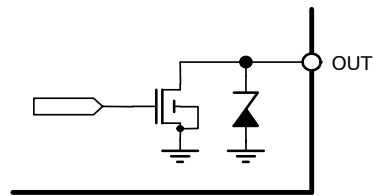
1. For limited time < 0.5 s.
2. Circuit functionality not guaranteed.
3. Human body model (100 pF via 1.5 kΩ, according to JEDEC EIA-JESD22-A114-B).
4. HiV = High Voltage Pins MOTxx, V<sub>BB</sub>, GND; (100 pF via 1.5 kΩ, according to JEDEC EIA-JESD22-A114-B).

## EQUIVALENT SCHEMATICS

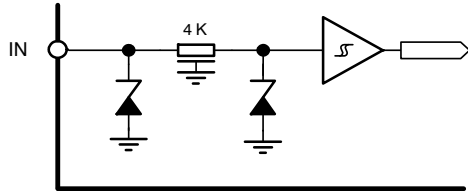
Following figure gives the equivalent schematics of the user relevant inputs and outputs. The diagrams are simplified representations of the circuits used.



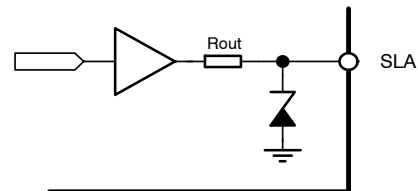
TYPE 1: CLR input



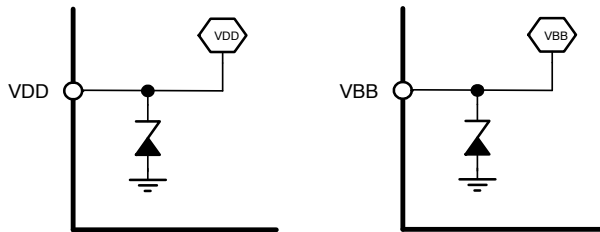
TYPE 4: DO, ERRB and PORB/WD open drain outputs



TYPE 2: CLK, DI, CSB, NXT, DIR inputs



TYPE 5: SLA analog output



TYPE 3: VDD and VBB power supply inputs

**Figure 3. In- and Output Equivalent Diagrams**

## PACKAGE THERMAL CHARACTERISTICS

The AMIS-30543 is available in a NQFP32 package. For cooling optimizations, the NQFP has an exposed thermal pad which has to be soldered to the PCB ground plane. The ground plane needs thermal vias to conduct the heat to the bottom layer. Figure 4 gives an example for good power distribution solutions.

For precise thermal cooling calculations the major thermal resistances of the device are given in Table 5. The thermal media to which the power of the devices has to be given are:

- Static environmental air (via the case)
- PCB board copper area (via the exposed pad)

The major thermal resistances of the device are the  $R_{thja}$  from the junction to the ambient and the overall  $R_{th}$  from the junction to exposed pad ( $R_{thjp}$ ). In Table 4 below one can find the values for the  $R_{thja}$  and  $R_{thjp}$ , simulated according to JESD-51.

The  $R_{thja}$  for 2S2P is simulated conform JEDEC JESD-51 as follows:

- A 4-layer printed circuit board with inner power planes and outer (top and bottom) signal layers is used
- Board thickness is 1.46 mm (FR4 PCB material)
- The 2 signal layers: 70  $\mu\text{m}$  thick copper with an area of 5500  $\text{mm}^2$  copper and 20% conductivity
- The 2 power internal planes: 36  $\mu\text{m}$  thick copper with an area of 5500  $\text{mm}^2$  copper and 90% conductivity

The  $R_{thja}$  for 1S0P is simulated conform to JEDEC JESD-51 as follows:

- A 1-layer printed circuit board with only 1 layer
- Board thickness is 1.46 mm (FR4 PCB material)
- The layer has a thickness of 70  $\mu\text{m}$  copper with an area of 5500  $\text{mm}^2$  copper and 20% conductivity

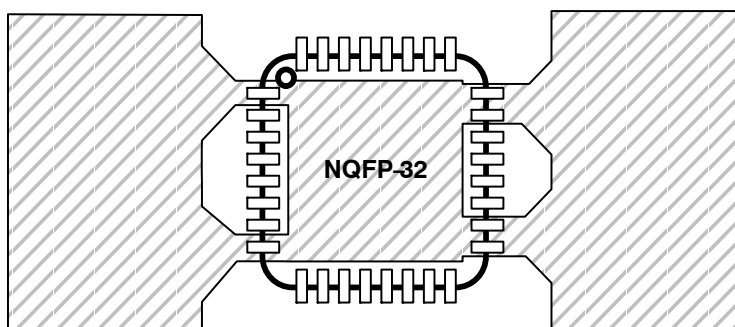


Figure 4. Example of NQFP-32 PCB Ground Plane Layout in Top View (Preferred Layout at Top and Bottom)

## ELECTRICAL SPECIFICATION

### Recommend Operation Conditions

Operating ranges define the limits for functional operation and parametric characteristics of the device. Note that the functionality of the chip outside these operating

ranges is not guaranteed. Operating outside the recommended operating ranges for extended periods of time may affect device reliability.

Table 3. OPERATING RANGES

| Symbol   | Parameter                     | Min | Max  | Unit               |
|----------|-------------------------------|-----|------|--------------------|
| $V_{BB}$ | Analog DC Supply              | +6  | +30  | V                  |
| $T_J$    | Junction Temperature (Note 5) | -40 | +172 | $^{\circ}\text{C}$ |

5. No more than 100 cumulative hours in life time above  $T_{tw}$ .

**Table 4. DC PARAMETERS** (The DC parameters are given for  $V_{BB}$  and temperature in their operating ranges unless otherwise specified) Convention: currents flowing in the circuit are defined as positive.

| Symbol | Pin(s) | Parameter | Remark/Test Conditions | Min | Typ | Max | Unit |
|--------|--------|-----------|------------------------|-----|-----|-----|------|
|--------|--------|-----------|------------------------|-----|-----|-----|------|

**SUPPLY AND VOLTAGE REGULATORS**

|                 |          |                                             |                                                                                    |          |     |     |               |
|-----------------|----------|---------------------------------------------|------------------------------------------------------------------------------------|----------|-----|-----|---------------|
| $V_{BB}$        | $V_{BB}$ | Nominal operating supply range              |                                                                                    | 6        |     | 30  | V             |
| $I_{BB}$        |          | Total internal current consumption (Note 6) | Unloaded outputs                                                                   |          |     | 12  | mA            |
| $V_{DD}$        | $V_{DD}$ | Regulated Output Voltage                    | $I_{LOAD}$ within limits                                                           | 4.5      | 5   | 5.5 | V             |
| $V_{DD\_SLP}$   |          | Regulated Output Voltage in Sleep Mode      | $-1\text{ mA} \leq I_{LOAD} \leq 0\text{ mA}$<br>$V_{BB} > 9\text{ V}$             | 4        |     | 5.5 | V             |
| $I_{INT}$       |          | Internal load current (Note 6)              | Unloaded outputs                                                                   |          |     | 8   | mA            |
| $I_{LOAD}$      |          | Max Output Current                          | $6\text{ V} \leq V_{BB} < 8\text{ V}$<br>$8\text{ V} \leq V_{BB} \leq 30\text{ V}$ | 15<br>40 |     |     |               |
| $I_{DDLIM}$     |          | Current limitation                          | Pin shorted to ground                                                              |          |     | 200 | mA            |
| $I_{LOAD\_SLP}$ |          | Current Consumption when in Sleep Mode      | $V_{BB} > 9\text{ V}$                                                              |          | 230 |     | $\mu\text{A}$ |

**POWER-ON-RESET (POR)**

|             |          |                                    |                  |     |      |     |   |
|-------------|----------|------------------------------------|------------------|-----|------|-----|---|
| $V_{DDH}$   | $V_{DD}$ | Internal POR comparator threshold  | $V_{DD}$ rising  | 3.9 | 4.2  | 4.4 | V |
| $V_{DDL}$   |          | Internal POR comparator threshold  | $V_{DD}$ falling |     | 3.86 |     | V |
| $V_{DDHYS}$ |          | Internal POR comparator hysteresis |                  |     | 0.35 |     | V |

**MOTORDRIVER**

|                  |                                  |                                                              |                           |  |      |      |          |
|------------------|----------------------------------|--------------------------------------------------------------|---------------------------|--|------|------|----------|
| $I_{MDmax,Peak}$ | MOTXP<br>MOTXN<br>MOTYP<br>MOTYN | Max current through motor coil in normal operation           | $T_J = 130^\circ\text{C}$ |  | 3000 |      | mA       |
| $R_{HS}$         |                                  | On-resistance high-side driver, $CUR[4:0] = 0...31$ (Note 7) | $T_J = 160^\circ\text{C}$ |  | 0.15 | 0.4  | $\Omega$ |
| $R_{LS3}$        |                                  | On-resistance low-side driver, $CUR[4:0] = 16...25$ (Note 7) | $T_J = 160^\circ\text{C}$ |  | 0.1  | 0.4  | $\Omega$ |
| $R_{LS2}$        |                                  | On-resistance low-side driver, $CUR[4:0] = 10...15$ (Note 7) | $T_J = 160^\circ\text{C}$ |  | 0.2  | 0.7  | $\Omega$ |
| $R_{LS1}$        |                                  | On-resistance low-side driver, $CUR[4:0] = 3...9$ (Note 7)   | $T_J = 160^\circ\text{C}$ |  | 0.4  | 1.1  | $\Omega$ |
| $R_{LS0}$        |                                  | On-resistance low-side driver, $CUR[4:0] = 0...2$ (Note 7)   | $T_J = 160^\circ\text{C}$ |  | 0.8  | 2.2  | $\Omega$ |
|                  |                                  |                                                              | $T_J = 160^\circ\text{C}$ |  |      | 2.50 | $\Omega$ |

**DIGITAL INPUTS**

|               |                                |                            |                           |      |     |          |               |
|---------------|--------------------------------|----------------------------|---------------------------|------|-----|----------|---------------|
| $I_{leak}$    | DI, CLK<br>NXT, DIR<br>CLR, CS | Input Leakage (Note 8)     | $T_J = 160^\circ\text{C}$ |      |     | 1        | $\mu\text{A}$ |
| $V_{IL}$      |                                | Logic Low Threshold        |                           | 0    |     | 0.65     | V             |
| $V_{IH}$      |                                | Logic High Threshold       |                           | 2.35 |     | $V_{DD}$ | V             |
| $R_{pd\_CLR}$ | CLR                            | Internal Pulldown Resistor |                           | 120  | 200 | 300      | k $\Omega$    |
| $R_{pd\_TST}$ | TST0                           | Internal Pulldown Resistor |                           | 3    |     | 9        | k $\Omega$    |

6. Current with oscillator running, all analogue cells active, SPI communication and NXT pulses applied. No floating inputs. Parameter guaranteed by design.

7. Characterization Data Only

8. Not valid for pins with internal Pulldown resistor

**Table 4. DC PARAMETERS** (The DC parameters are given for  $V_{BB}$  and temperature in their operating ranges unless otherwise specified) Convention: currents flowing in the circuit are defined as positive.

| Symbol | Pin(s) | Parameter | Remark/Test Conditions | Min | Typ | Max | Unit |
|--------|--------|-----------|------------------------|-----|-----|-----|------|
|--------|--------|-----------|------------------------|-----|-----|-----|------|

**DIGITAL OUTPUTS**

|          |                 |                            |                         |  |  |     |   |
|----------|-----------------|----------------------------|-------------------------|--|--|-----|---|
| $V_{OL}$ | DO, ERR, POR/WD | Logic Low level open drain | $I_{OL} = 5 \text{ mA}$ |  |  | 0.5 | V |
|----------|-----------------|----------------------------|-------------------------|--|--|-----|---|

**THERMAL WARNING AND SHUTDOWN**

|           |  |                                   |  |     |               |     |    |
|-----------|--|-----------------------------------|--|-----|---------------|-----|----|
| $T_{tw}$  |  | Thermal Warning                   |  | 150 | 160           | 170 | °C |
| $T_{tsd}$ |  | Thermal shutdown (Notes 9 and 10) |  |     | $T_{tw} + 20$ |     | °C |

**CHARGE PUMP**

|              |         |                           |                                        |              |                  |               |    |
|--------------|---------|---------------------------|----------------------------------------|--------------|------------------|---------------|----|
| $V_{cp}$     | VCP     | Output voltage            | $6 \text{ V} < V_{BB} < 15 \text{ V}$  |              | $2 * V_{BB} - 2$ |               | V  |
|              |         |                           | $15 \text{ V} < V_{BB} < 30 \text{ V}$ | $V_{BB} + 9$ | $V_{BB} + 12.5$  | $V_{BB} + 16$ | V  |
| $C_{buffer}$ |         | External buffer capacitor |                                        | 180          | 220              | 470           | nF |
| $C_{pump}$   | CPP CPN | External pump capacitor   |                                        | 180          | 220              | 470           | nF |

**PACKAGE THERMAL RESISTANCE VALUE**

|            |      |                                            |                                       |  |      |  |     |
|------------|------|--------------------------------------------|---------------------------------------|--|------|--|-----|
| $R_{thja}$ | NQFP | Thermal Resistance Junction-to-Ambient     | Simulated Conform JEDEC JESD-51, 2S2P |  | 30   |  | K/W |
|            |      |                                            | Simulated Conform JEDEC JESD-51, 1S0P |  | 60   |  | K/W |
| $R_{thjp}$ | NQFP | Thermal Resistance Junction-to-Exposed Pad |                                       |  | 0.95 |  | K/W |

**SPEED AND LOAD ANGLE OUTPUT**

|                  |     |                                                         |          |     |      |                       |    |
|------------------|-----|---------------------------------------------------------|----------|-----|------|-----------------------|----|
| V <sub>out</sub> | SLA | Output Voltage Range                                    |          | 0.2 |      | V <sub>DD</sub> – 0.2 | V  |
| V <sub>off</sub> |     | Output Offset SLA pin                                   |          | –50 |      | 50                    | mV |
| G <sub>sla</sub> |     | Gain of SLA Pin = V <sub>BEMF</sub> / V <sub>COIL</sub> | SLAG = 0 |     | 0.5  |                       |    |
|                  |     |                                                         | SLAG = 1 |     | 0.25 |                       |    |
| R <sub>out</sub> |     | Output Resistance SLA pin                               |          |     |      |                       | 1  |

9. No more than 100 cumulated hours in life time above  $T_{tw}$ .

10. Thermal shutdown is derived from thermal warning. Characterization Data Only.

**Table 5. AC PARAMETERS** (The AC parameters are given for  $V_{BB}$  and temperature in their operating ranges)

| Symbol                         | Pin(s)  | Parameter                                                  | Remark/Test Conditions                                                        | Min  | Typ  | Max  | Unit |
|--------------------------------|---------|------------------------------------------------------------|-------------------------------------------------------------------------------|------|------|------|------|
| INTERNAL OSCILLATOR            |         |                                                            |                                                                               |      |      |      |      |
| f <sub>osc</sub>               |         | Frequency of internal oscillator                           |                                                                               | 3.6  | 4    | 4.4  | MHz  |
| MOTOR DRIVER                   |         |                                                            |                                                                               |      |      |      |      |
| f <sub>PWM</sub>               | MOTxx   | PWM frequency                                              | Frequency depends only on internal oscillator                                 | 20.5 | 22.8 | 25.1 | kHz  |
|                                |         | Double PWM frequency                                       |                                                                               | 41.0 | 45.6 | 50.2 | kHz  |
| t <sub>b</sub> <sub>rise</sub> | MOTxx   | Turn-on voltage slope, 10% to 90%                          | EMC[1:0] = 00                                                                 |      | 200  |      | V/μs |
|                                |         |                                                            | EMC[1:0] = 01                                                                 |      | 140  |      | V/μs |
|                                |         |                                                            | EMC[1:0] = 10                                                                 |      | 70   |      | V/μs |
|                                |         |                                                            | EMC[1:0] = 11                                                                 |      | 35   |      | V/μs |
| t <sub>b</sub> <sub>fall</sub> | MOTxx   | Turn-off voltage slope, 90% to 10%                         | EMC[1:0] = 00                                                                 |      | 200  |      | V/μs |
|                                |         |                                                            | EMC[1:0] = 01                                                                 |      | 140  |      | V/μs |
|                                |         |                                                            | EMC[1:0] = 10                                                                 |      | 70   |      | V/μs |
|                                |         |                                                            | EMC[1:0] = 11                                                                 |      | 35   |      | V/μs |
| DIGITAL OUTPUTS                |         |                                                            |                                                                               |      |      |      |      |
| t <sub>H2L</sub>               | DO ERR  | Output fall-time from V <sub>inH</sub> to V <sub>inL</sub> | Capacitive load 400 pF and pullup resistor of 1.5 kΩ                          |      |      | 50   | ns   |
| CHARGE PUMP                    |         |                                                            |                                                                               |      |      |      |      |
| f <sub>CP</sub>                | CPN CPP | Charge pump frequency                                      |                                                                               |      | 250  |      | kHz  |
| t <sub>CPU</sub>               | MOTxx   | Startup time of charge pump (Note 11)                      | Spec external components                                                      |      |      | 5    | ms   |
| CLR FUNCTION                   |         |                                                            |                                                                               |      |      |      |      |
| t <sub>CLR</sub>               | CLR     | Hard reset duration time                                   |                                                                               | 100  |      |      | μs   |
| POWER-UP                       |         |                                                            |                                                                               |      |      |      |      |
| t <sub>PU</sub>                | POR/WD  | Powerup time                                               | V <sub>BB</sub> = 12 V, I <sub>LOAD</sub> = 50 mA, C <sub>LOAD</sub> = 220 nF |      | 100  |      | μs   |
| t <sub>POR</sub>               |         | Reset duration                                             | See Figure 16                                                                 |      | 100  |      | ms   |
| t <sub>RF</sub>                |         | Reset filter time                                          | See Figure 16                                                                 |      | 0.5  |      | μs   |
| WATCHDOG                       |         |                                                            |                                                                               |      |      |      |      |
| t <sub>WDTO</sub>              | POR/WD  | Watchdog time out interval                                 |                                                                               | 32   |      | 512  | ms   |
| t <sub>WDPR</sub>              |         | Prohibited watchdog acknowledge delay                      |                                                                               |      | 2    |      | ms   |
| NXT FUNCTION                   |         |                                                            |                                                                               |      |      |      |      |
| t <sub>NXT_HI</sub>            | NXT     | NXT Minimum, High Pulse Width                              | See Figure 5                                                                  | 2    |      |      | μs   |
| t <sub>NXT_LO</sub>            |         | NXT Minimum, Low Pulse Width                               | See Figure 5                                                                  | 2    |      |      | μs   |
| t <sub>DIR_SET</sub>           |         | NXT Hold Time, Following Change of DIR                     | See Figure 5                                                                  | 0.5  |      |      | μs   |
| t <sub>DIR_HOLD</sub>          |         | NXT Hold Time, Before Change of DIR                        | See Figure 5                                                                  | 0.5  |      |      | μs   |

11. Guaranteed by design

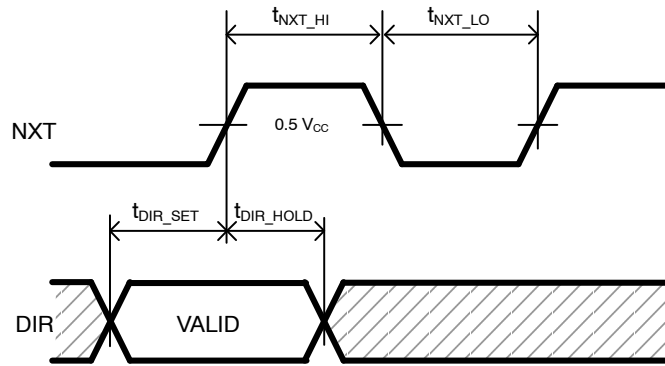


Figure 5. NXT-Input Timing Diagram

Table 6. SPI TIMING PARAMETERS

| Symbol          | Parameter                                                                  | Min | Typ | Max | Unit    |
|-----------------|----------------------------------------------------------------------------|-----|-----|-----|---------|
| $t_{CLK}$       | SPI Clock Period                                                           | 1   |     |     | $\mu s$ |
| $t_{CLK\_HIGH}$ | SPI Clock High Time                                                        | 100 |     |     | ns      |
| $t_{CLK\_LOW}$  | SPI Clock Low Time                                                         | 100 |     |     | ns      |
| $t_{SET\_DI}$   | DI Set Up Time, Valid Data Before Rising Edge of CLK                       | 50  |     |     | ns      |
| $t_{HOLD\_DI}$  | DI Hold Time, Hold Data After Rising Edge of CLK                           | 50  |     |     | ns      |
| $t_{CSB\_HIGH}$ | $\overline{CS}$ High Time                                                  | 2.5 |     |     | $\mu s$ |
| $t_{SET\_CSB}$  | $\overline{CS}$ Set Up Time, $\overline{CS}$ Low Before Rising Edge of CLK | 100 |     |     | ns      |
| $t_{SET\_CLK}$  | CLK Set Up Time, CLK Low Before Rising Edge of $\overline{CS}$             | 100 |     |     | ns      |

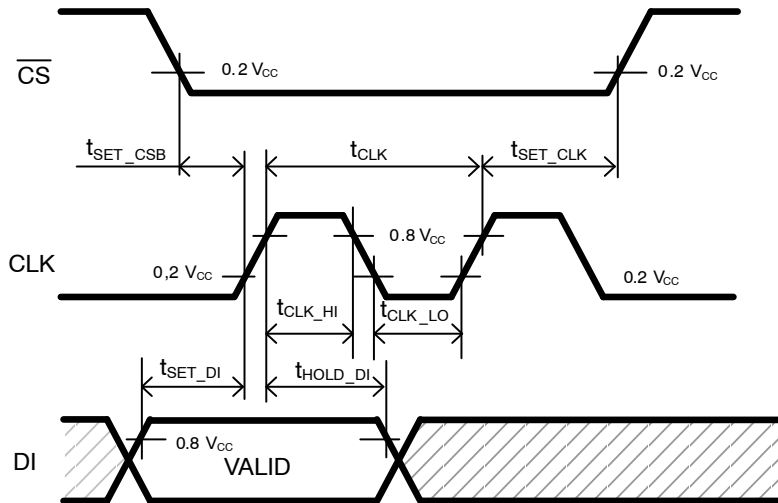


Figure 6. SPI Timing

# AMIS-30543

## TYPICAL APPLICATION SCHEMATIC

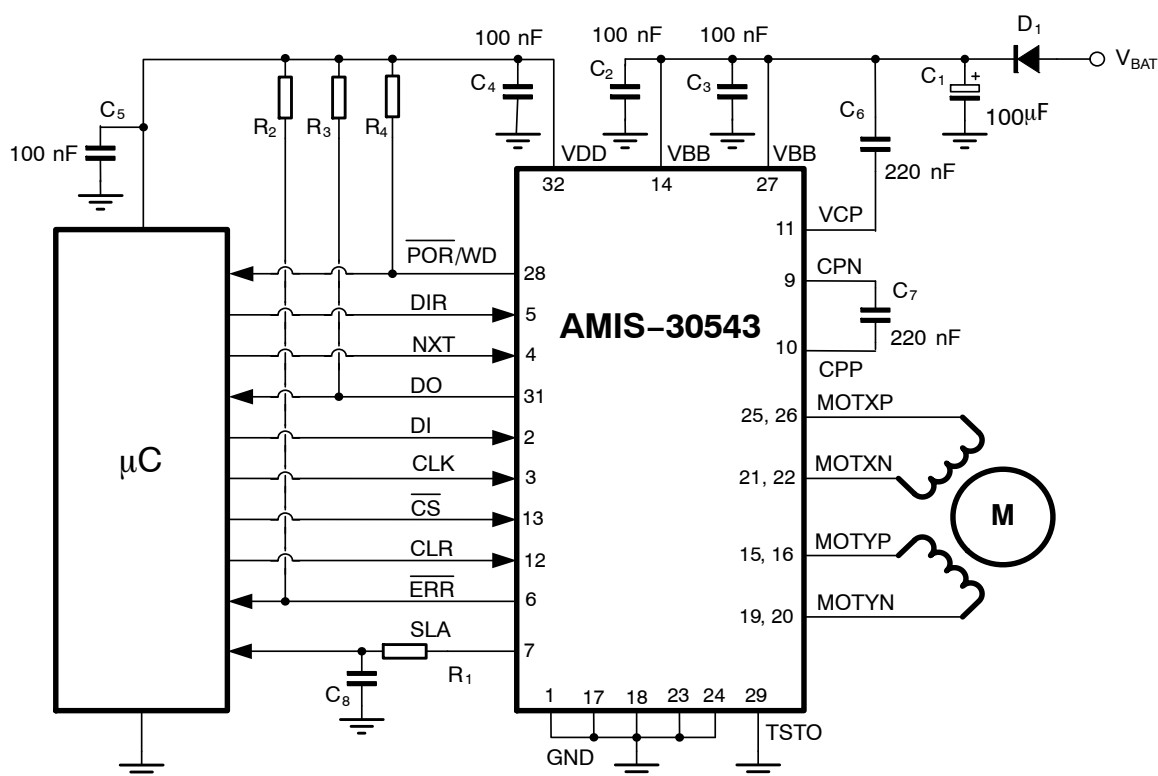


Figure 7. Typical Application Schematic AMIS-30543

Table 7. EXTERNAL COMPONENTS LIST AND DESCRIPTION

| Component                                        | Function                                             | Typ Value | Tolerance | Unit |
|--------------------------------------------------|------------------------------------------------------|-----------|-----------|------|
| C <sub>1</sub>                                   | V <sub>BB</sub> Buffer Capacitor (Note 12)           | 100       | -20 +80%  | μF   |
| C <sub>2</sub> , C <sub>3</sub>                  | V <sub>BB</sub> Decoupling Block Capacitor (Note 13) | 100       | -20 +80%  | nF   |
| C <sub>4</sub>                                   | V <sub>DD</sub> Buffer Capacitor                     | 100       | ± 20%     | nF   |
| C <sub>5</sub>                                   | V <sub>DD</sub> Buffer Capacitor                     | 100       | ± 20%     | nF   |
| C <sub>6</sub>                                   | Charge Pump Buffer Capacitor                         | 220       | ± 20%     | nF   |
| C <sub>7</sub>                                   | Charge Pump Pumping Capacitor                        | 220       | ± 20%     | nF   |
| C <sub>8</sub>                                   | Low Pass Filter SLA                                  | 1         | ± 20%     | nF   |
| R <sub>1</sub>                                   | Low Pass Filter SLA                                  | 5.6       | ± 1%      | kΩ   |
| R <sub>2</sub> , R <sub>3</sub> , R <sub>4</sub> | Pullup Resistor Open Drain Output                    | 4.7       | ± 1%      | kΩ   |
| D <sub>1</sub>                                   | Optional Reverse Protection Diode                    | MURD530   |           |      |

12. ESR < 1 Ω.

13. ESR < 50 mΩ.

## FUNCTIONAL DESCRIPTION

### H-Bridge Drivers

A full H-bridge is integrated for each of the two stator windings. Each H-bridge consists of two low-side and two high-side N-type MOSFET switches. Writing logic '0' in bit <MOTEN> disables all drivers (high-impedance). Writing logic '1' in this bit enables both bridges and current can flow in the motor stator windings.

In order to avoid large currents through the H-bridge switches, it is guaranteed that the top- and bottom-switches of the same half-bridge are never conductive simultaneously (interlock delay).

A two-stage protection against shorts on motor lines is implemented. In a first stage, the current in the driver is limited. Secondly, when excessive voltage is sensed across the transistor, the transistor is switched off.

In order to reduce the radiated/conducted emission, voltage slope control is implemented in the output switches. The output slope is defined by the gate-drain capacitance of output transistor and the (limited) current that drives the gate. There are two trimming bits for slope control (see Table 12 SPI Control Parameter Overview EMC[1:0]).

The power transistors are equipped with so-called “active diodes”: when a current is forced through the transistor switch in the reverse direction, i.e. from source to drain, then the transistor is switched on. This ensures that most of the current flows through the channel of the transistor instead of through the inherent parasitic drain-bulk diode of the transistor.

Depending on the desired current range and the micro-step position at hand, the  $R_{DS(on)}$  of the low-side

transistors will be adapted such that excellent current-sense accuracy is maintained. The  $R_{DS(on)}$  of the high-side transistors remain unchanged; see Table 4 DC Parameters for more details.

### PWM Current Control

A PWM comparator compares continuously the actual winding current with the requested current and feeds back the information to a digital regulation loop. This loop then generates a PWM signal, which turns on/off the H-bridge switches. The switching points of the PWM duty-cycle are synchronized to the on-chip PWM clock. The frequency of the PWM controller can be doubled and an artificial jitter can be added (see Table 12 SPI Control Parameter Overview PWMJ). The PWM frequency will not vary with changes in the supply voltage. Also variations in motor-speed or load-conditions of the motor have no effect. There are no external components required to adjust the PWM frequency.

### Automatic Forward and Slow-Fast Decay

The PWM generation is in steady-state using a combination of forward and slow-decay. The absence of fast-decay in this mode, guarantees the lowest possible current-ripple “by design”. For transients to lower current levels, fast-decay is automatically activated to allow high-speed response. The selection of fast or slow decay is completely transparent for the user and no additional parameters are required for operation.

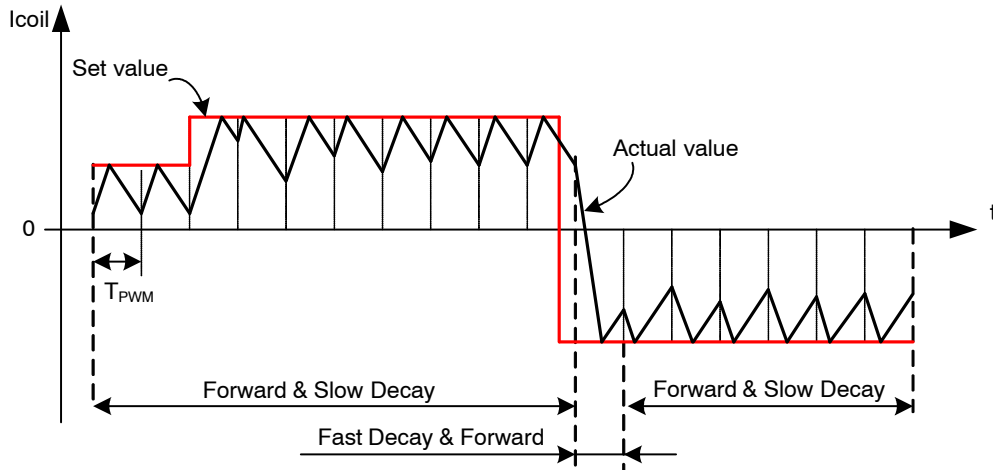


Figure 8. Forward and Slow/Fast Decay PWM

### Automatic Duty Cycle Adaptation

In case the supply voltage is lower than  $2 \cdot B_{emf}$ , then the duty cycle of the PWM is adapted automatically to  $> 50\%$  to maintain the requested average current in the coils. This

process is completely automatic and requires no additional parameters for operation. The over-all current-ripple is divided by two if PWM frequency is doubled (see Table 12 SPI Control Parameter Overview PWMF)

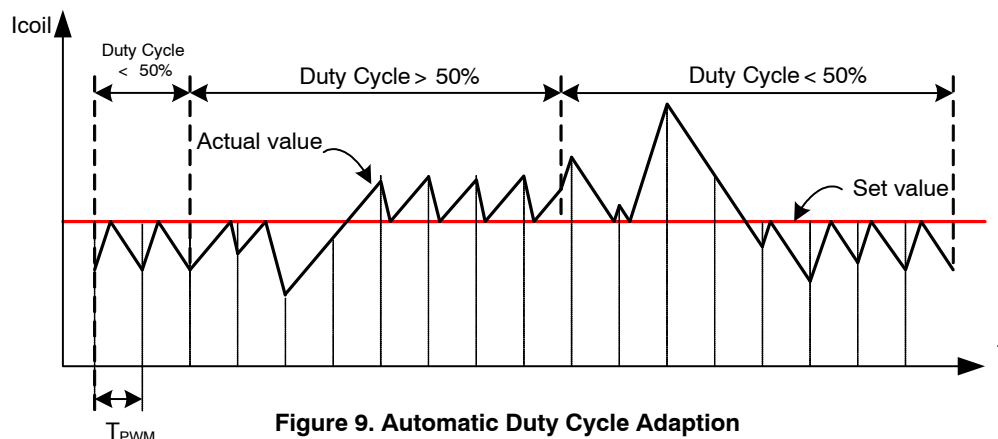


Figure 9. Automatic Duty Cycle Adaption

### Step Translator and Step Mode

The step translator provides the control of the motor by means of SM[2:0], ESM[2:0], SPI register DIRCTRL and input pins DIR and NXT. It is translating consecutive steps in corresponding currents in both motor coils for a given step mode.

One out of eleven possible stepping modes can be selected through SPI-bits SM[2:0] and ESM[2:0] (see Table 12 SPI Control Parameter Overview). After power-on or hard reset, the coil-current translator is set to the default 1/32 micro-stepping at position '0'. When remaining in the same

step mode, subsequent translator positions are all in the same column and increased or decreased with 1. Table 9 lists the output current vs. the translator position.

As shown in Figure 10 the output current-pairs can be projected approximately on a circle in the  $(I_x, I_y)$  plane. There are, however, two exceptions: uncompensated half step and uncompensated full step. In these step modes the currents are not regulated to a fraction of  $I_{max}$  but are in all intermediate steps regulated at 100%. In the  $(I_x, I_y)$  plane the current-pairs are projected on a square. Table 8 lists the output current vs. the translator position for these cases.

Table 8. SQUARE TRANSLATOR TABLE FOR UNCOMPENSATED FULL STEP AND UNCOMPENSATED HALF STEP

| MSP[8:0]    | Stepmode ( SM[2:0] )    |                         | % of $I_{max}$ |        |
|-------------|-------------------------|-------------------------|----------------|--------|
|             | 101                     | 110                     | Coil x         | Coil y |
|             | Uncompensated Half Step | Uncompensated Full Step |                |        |
| 0 0000 0000 | 0                       | –                       | 0              | 100    |
| 0 0100 0000 | 1                       | 1                       | 100            | 100    |
| 0 1000 0000 | 2                       | –                       | 100            | 0      |
| 0 1100 0000 | 3                       | 2                       | 100            | –100   |
| 1 0000 0000 | 4                       | –                       | 0              | –100   |
| 1 0100 0000 | 5                       | 3                       | –100           | –100   |
| 1 1000 0000 | 6                       | –                       | –100           | 0      |
| 1 1100 0000 | 7                       | 0                       | –100           | 100    |

Table 9. CIRCULAR TRANSLATOR TABLE

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |        |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph | Coil X                | Coil Y |
| 000000000 | 0        | 0    | 0    | 0    | 0   | 0   | 0        |               | 0             | 0                     | 100    |
| 000000001 | 1        |      |      |      |     |     |          |               |               | 1                     | 100    |
| 000000010 | 2        | 1    |      |      |     |     |          |               |               | 2                     | 100    |
| 000000011 | 3        |      |      |      |     |     |          |               |               | 4                     | 100    |
| 000000100 | 4        | 2    | 1    |      |     |     |          |               |               | 5                     | 100    |
| 000000101 | 5        |      |      |      |     |     |          |               |               | 6                     | 100    |
| 000000110 | 6        | 3    |      |      |     |     |          |               |               | 7                     | 100    |
| 000000111 | 7        |      |      |      |     |     |          |               |               | 9                     | 100    |
| 000001000 | 8        | 4    | 2    | 1    |     |     |          |               |               | 10                    | 100    |
| 000001001 | 9        |      |      |      |     |     |          |               |               | 11                    | 99     |
| 000001010 | 10       | 5    |      |      |     |     |          |               |               | 12                    | 99     |
| 000001011 | 11       |      |      |      |     |     |          |               |               | 13                    | 99     |
| 000001100 | 12       | 6    | 3    |      |     |     |          |               |               | 15                    | 99     |
| 000001101 | 13       |      |      |      |     |     |          |               |               | 16                    | 99     |
| 000001110 | 14       | 7    |      |      |     |     |          |               |               | 17                    | 99     |
| 000001111 | 15       |      |      |      |     |     |          |               |               | 18                    | 98     |
| 000010000 | 16       | 8    | 4    | 2    | 1   |     |          |               |               | 20                    | 98     |
| 000010001 | 17       |      |      |      |     |     |          |               |               | 21                    | 98     |
| 000010010 | 18       | 9    |      |      |     |     |          |               |               | 22                    | 98     |
| 000010011 | 19       |      |      |      |     |     |          |               |               | 23                    | 97     |
| 000010100 | 20       | 10   | 5    |      |     |     |          |               |               | 24                    | 97     |
| 000010101 | 21       |      |      |      |     |     |          |               |               | 25                    | 97     |
| 000010110 | 22       | 11   |      |      |     |     |          |               |               | 27                    | 96     |
| 000010111 | 23       |      |      |      |     |     |          |               |               | 28                    | 96     |
| 000011000 | 24       | 12   | 6    | 3    |     |     |          |               |               | 29                    | 96     |
| 000011001 | 25       |      |      |      |     |     |          |               |               | 30                    | 95     |
| 000011010 | 26       | 13   |      |      |     |     |          |               |               | 31                    | 95     |
| 000011011 | 27       |      |      |      |     |     |          |               |               | 33                    | 95     |
| 000011100 | 28       | 14   | 7    |      |     |     |          |               |               | 34                    | 94     |
| 000011101 | 29       |      |      |      |     |     |          |               |               | 35                    | 94     |
| 000011110 | 30       | 15   |      |      |     |     |          |               |               | 36                    | 93     |
| 000011111 | 31       |      |      |      |     |     |          |               |               | 37                    | 93     |
| 000100000 | 32       | 16   | 8    | 4    | 2   | 1   |          |               |               | 38                    | 92     |
| 000100001 | 33       |      |      |      |     |     |          |               |               | 39                    | 92     |
| 000100010 | 34       | 17   |      |      |     |     |          |               |               | 41                    | 91     |
| 000100011 | 35       |      |      |      |     |     |          |               |               | 42                    | 91     |
| 000100100 | 36       | 18   | 9    |      |     |     |          |               |               | 43                    | 90     |
| 000100101 | 37       |      |      |      |     |     |          |               |               | 44                    | 90     |
| 000100110 | 38       | 19   |      |      |     |     |          |               |               | 45                    | 89     |
| 000100111 | 39       |      |      |      |     |     |          |               |               | 46                    | 89     |
| 000101000 | 40       | 20   | 10   | 5    |     |     |          |               |               | 47                    | 88     |
| 000101001 | 41       |      |      |      |     |     |          |               |               | 48                    | 88     |
| 000101010 | 42       | 21   |      |      |     |     |          |               |               | 49                    | 87     |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |        |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph | Coil X                | Coil Y |
| 000101011 | 43       |      |      |      |     |     |          |               |               | 50                    | 86     |
| 000101100 | 44       | 22   | 11   |      |     |     |          |               |               | 51                    | 86     |
| 000101101 | 45       |      |      |      |     |     |          |               |               | 52                    | 85     |
| 000101110 | 46       | 23   |      |      |     |     |          |               |               | 53                    | 84     |
| 000101111 | 47       |      |      |      |     |     |          |               |               | 55                    | 84     |
| 000110000 | 48       | 24   | 12   | 6    | 3   |     |          |               |               | 56                    | 83     |
| 000110001 | 49       |      |      |      |     |     |          |               |               | 57                    | 82     |
| 000110010 | 50       | 25   |      |      |     |     |          |               |               | 58                    | 82     |
| 000110011 | 51       |      |      |      |     |     |          |               |               | 59                    | 81     |
| 000110100 | 52       | 26   | 13   |      |     |     |          |               |               | 60                    | 80     |
| 000110101 | 53       |      |      |      |     |     |          |               |               | 61                    | 80     |
| 000110110 | 54       | 27   |      |      |     |     |          |               |               | 62                    | 79     |
| 000110111 | 55       |      |      |      |     |     |          |               |               | 62                    | 78     |
| 000111000 | 56       | 28   | 14   | 7    |     |     |          |               |               | 63                    | 77     |
| 000111001 | 57       |      |      |      |     |     |          |               |               | 64                    | 77     |
| 000111010 | 58       | 29   |      |      |     |     |          |               |               | 65                    | 76     |
| 000111011 | 59       |      |      |      |     |     |          |               |               | 66                    | 75     |
| 000111100 | 60       | 30   | 15   |      |     |     |          |               |               | 67                    | 74     |
| 000111101 | 61       |      |      |      |     |     |          |               |               | 68                    | 73     |
| 000111110 | 62       | 31   |      |      |     |     |          |               |               | 69                    | 72     |
| 000111111 | 63       |      |      |      |     |     |          |               |               | 70                    | 72     |
| 001000000 | 64       | 32   | 16   | 8    | 4   | 2   | 1        | 0             |               | 71                    | 71     |
| 001000001 | 65       |      |      |      |     |     |          |               |               | 72                    | 70     |
| 001000010 | 66       | 33   |      |      |     |     |          |               |               | 72                    | 69     |
| 001000011 | 67       |      |      |      |     |     |          |               |               | 73                    | 68     |
| 001000100 | 68       | 34   | 17   |      |     |     |          |               |               | 74                    | 67     |
| 001000101 | 69       |      |      |      |     |     |          |               |               | 75                    | 66     |
| 001000110 | 70       | 35   |      |      |     |     |          |               |               | 76                    | 65     |
| 001000111 | 71       |      |      |      |     |     |          |               |               | 77                    | 64     |
| 001001000 | 72       | 36   | 18   | 9    |     |     |          |               |               | 77                    | 63     |
| 001001001 | 73       |      |      |      |     |     |          |               |               | 78                    | 62     |
| 001001010 | 74       | 37   |      |      |     |     |          |               |               | 79                    | 62     |
| 001001011 | 75       |      |      |      |     |     |          |               |               | 80                    | 61     |
| 001001100 | 76       | 38   | 19   |      |     |     |          |               |               | 80                    | 60     |
| 001001101 | 77       |      |      |      |     |     |          |               |               | 81                    | 59     |
| 001001110 | 78       | 39   |      |      |     |     |          |               |               | 82                    | 58     |
| 001001111 | 79       |      |      |      |     |     |          |               |               | 82                    | 57     |
| 001010000 | 80       | 40   | 20   | 10   | 5   |     |          |               |               | 83                    | 56     |
| 001010001 | 81       |      |      |      |     |     |          |               |               | 84                    | 55     |
| 001010010 | 82       | 41   |      |      |     |     |          |               |               | 84                    | 53     |
| 001010011 | 83       |      |      |      |     |     |          |               |               | 85                    | 52     |
| 001010100 | 84       | 42   | 21   |      |     |     |          |               |               | 86                    | 51     |
| 001010101 | 85       |      |      |      |     |     |          |               |               | 86                    | 50     |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |             |                     |                     | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|-------------|---------------------|---------------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100         | xxx                 | xxx                 |                       |        |
|           | ESM[2:0] |      |      |      |     |     |             |                     |                     |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000         | 011                 | 100                 |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp<br>1/2 | Comp<br>full<br>2ph | Comp<br>full<br>1ph | Coil X                | Coil Y |
| 001010110 | 86       | 43   |      |      |     |     |             |                     |                     | 87                    | 49     |
| 001010111 | 87       |      |      |      |     |     |             |                     |                     | 88                    | 48     |
| 001011000 | 88       | 44   | 22   | 11   |     |     |             |                     |                     | 88                    | 47     |
| 001011001 | 89       |      |      |      |     |     |             |                     |                     | 89                    | 46     |
| 001011010 | 90       | 45   |      |      |     |     |             |                     |                     | 89                    | 45     |
| 001011011 | 91       |      |      |      |     |     |             |                     |                     | 90                    | 44     |
| 001011100 | 92       | 46   | 23   |      |     |     |             |                     |                     | 90                    | 43     |
| 001011101 | 93       |      |      |      |     |     |             |                     |                     | 91                    | 42     |
| 001011110 | 94       | 47   |      |      |     |     |             |                     |                     | 91                    | 41     |
| 001011111 | 95       |      |      |      |     |     |             |                     |                     | 92                    | 39     |
| 001100000 | 96       | 48   | 24   | 12   | 6   | 3   |             |                     |                     | 92                    | 38     |
| 001100001 | 97       |      |      |      |     |     |             |                     |                     | 93                    | 37     |
| 001100010 | 98       | 49   |      |      |     |     |             |                     |                     | 93                    | 36     |
| 001100011 | 99       |      |      |      |     |     |             |                     |                     | 94                    | 35     |
| 001100100 | 100      | 50   | 25   |      |     |     |             |                     |                     | 94                    | 34     |
| 001100101 | 101      |      |      |      |     |     |             |                     |                     | 95                    | 33     |
| 001100110 | 102      | 51   |      |      |     |     |             |                     |                     | 95                    | 31     |
| 001100111 | 103      |      |      |      |     |     |             |                     |                     | 95                    | 30     |
| 001101000 | 104      | 52   | 26   | 13   |     |     |             |                     |                     | 96                    | 29     |
| 001101001 | 105      |      |      |      |     |     |             |                     |                     | 96                    | 28     |
| 001101010 | 106      | 53   |      |      |     |     |             |                     |                     | 96                    | 27     |
| 001101011 | 107      |      |      |      |     |     |             |                     |                     | 97                    | 25     |
| 001101100 | 108      | 54   | 27   |      |     |     |             |                     |                     | 97                    | 24     |
| 001101101 | 109      |      |      |      |     |     |             |                     |                     | 97                    | 23     |
| 001101110 | 110      | 55   |      |      |     |     |             |                     |                     | 98                    | 22     |
| 001101111 | 111      |      |      |      |     |     |             |                     |                     | 98                    | 21     |
| 001110000 | 112      | 56   | 28   | 14   | 7   |     |             |                     |                     | 98                    | 20     |
| 001110001 | 113      |      |      |      |     |     |             |                     |                     | 98                    | 18     |
| 001110010 | 114      | 57   |      |      |     |     |             |                     |                     | 99                    | 17     |
| 001110011 | 115      |      |      |      |     |     |             |                     |                     | 99                    | 16     |
| 001110100 | 116      | 58   | 29   |      |     |     |             |                     |                     | 99                    | 15     |
| 001110101 | 117      |      |      |      |     |     |             |                     |                     | 99                    | 13     |
| 001110110 | 118      | 59   |      |      |     |     |             |                     |                     | 99                    | 12     |
| 001110111 | 119      |      |      |      |     |     |             |                     |                     | 99                    | 11     |
| 001111000 | 120      | 60   | 30   | 15   |     |     |             |                     |                     | 100                   | 10     |
| 001111001 | 121      |      |      |      |     |     |             |                     |                     | 100                   | 9      |
| 001111010 | 122      | 61   |      |      |     |     |             |                     |                     | 100                   | 7      |
| 001111011 | 123      |      |      |      |     |     |             |                     |                     | 100                   | 6      |
| 001111100 | 124      | 62   | 31   |      |     |     |             |                     |                     | 100                   | 5      |
| 001111101 | 125      |      |      |      |     |     |             |                     |                     | 100                   | 4      |
| 001111110 | 126      | 63   |      |      |     |     |             |                     |                     | 100                   | 2      |
| 001111111 | 127      |      |      |      |     |     |             |                     |                     | 100                   | 1      |
| 010000000 | 128      | 64   | 32   | 16   | 8   | 4   | 2           |                     | 1                   | 100                   | 0      |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |        |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph | Coil X                | Coil Y |
| 010000001 | 129      |      |      |      |     |     |          |               |               | 100                   | -1     |
| 010000010 | 130      | 65   |      |      |     |     |          |               |               | 100                   | -2     |
| 010000011 | 131      |      |      |      |     |     |          |               |               | 100                   | -4     |
| 010000100 | 132      | 66   | 33   |      |     |     |          |               |               | 100                   | -5     |
| 010000101 | 133      |      |      |      |     |     |          |               |               | 100                   | -6     |
| 010000110 | 134      | 67   |      |      |     |     |          |               |               | 100                   | -7     |
| 010000111 | 135      |      |      |      |     |     |          |               |               | 100                   | -9     |
| 010001000 | 136      | 68   | 34   | 17   |     |     |          |               |               | 100                   | -10    |
| 010001001 | 137      |      |      |      |     |     |          |               |               | 99                    | -11    |
| 010001010 | 138      | 69   |      |      |     |     |          |               |               | 99                    | -12    |
| 010001011 | 139      |      |      |      |     |     |          |               |               | 99                    | -13    |
| 010001100 | 140      | 70   | 35   |      |     |     |          |               |               | 99                    | -15    |
| 010001101 | 141      |      |      |      |     |     |          |               |               | 99                    | -16    |
| 010001110 | 142      | 71   |      |      |     |     |          |               |               | 99                    | -17    |
| 010001111 | 143      |      |      |      |     |     |          |               |               | 98                    | -18    |
| 010010000 | 144      | 72   | 36   | 18   | 9   |     |          |               |               | 98                    | -20    |
| 010010001 | 145      |      |      |      |     |     |          |               |               | 98                    | -21    |
| 010010010 | 146      | 73   |      |      |     |     |          |               |               | 98                    | -22    |
| 010010011 | 147      |      |      |      |     |     |          |               |               | 97                    | -23    |
| 010010100 | 148      | 74   | 37   |      |     |     |          |               |               | 97                    | -24    |
| 010010101 | 149      |      |      |      |     |     |          |               |               | 97                    | -25    |
| 010010110 | 150      | 75   |      |      |     |     |          |               |               | 96                    | -27    |
| 010010111 | 151      |      |      |      |     |     |          |               |               | 96                    | -28    |
| 010011000 | 152      | 76   | 38   | 19   |     |     |          |               |               | 96                    | -29    |
| 010011001 | 153      |      |      |      |     |     |          |               |               | 95                    | -30    |
| 010011010 | 154      | 77   |      |      |     |     |          |               |               | 95                    | -31    |
| 010011011 | 155      |      |      |      |     |     |          |               |               | 95                    | -33    |
| 010011100 | 156      | 78   | 39   |      |     |     |          |               |               | 94                    | -34    |
| 010011101 | 157      |      |      |      |     |     |          |               |               | 94                    | -35    |
| 010011110 | 158      | 79   |      |      |     |     |          |               |               | 93                    | -36    |
| 010011111 | 159      |      |      |      |     |     |          |               |               | 93                    | -37    |
| 010100000 | 160      | 80   | 40   | 20   | 10  | 5   |          |               |               | 92                    | -38    |
| 010100001 | 161      |      |      |      |     |     |          |               |               | 92                    | -39    |
| 010100010 | 162      | 81   |      |      |     |     |          |               |               | 91                    | -41    |
| 010100011 | 163      |      |      |      |     |     |          |               |               | 91                    | -42    |
| 010100100 | 164      | 82   | 41   |      |     |     |          |               |               | 90                    | -43    |
| 010100101 | 165      |      |      |      |     |     |          |               |               | 90                    | -44    |
| 010100110 | 166      | 83   |      |      |     |     |          |               |               | 89                    | -45    |
| 010100111 | 167      |      |      |      |     |     |          |               |               | 89                    | -46    |
| 010101000 | 168      | 84   | 42   | 21   |     |     |          |               |               | 88                    | -47    |
| 010101001 | 169      |      |      |      |     |     |          |               |               | 88                    | -48    |
| 010101010 | 170      | 85   |      |      |     |     |          |               |               | 87                    | -49    |
| 010101011 | 171      |      |      |      |     |     |          |               |               | 86                    | -50    |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |             |                     |                     | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|-------------|---------------------|---------------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100         | xxx                 | xxx                 |                       |        |
|           | ESM[2:0] |      |      |      |     |     |             |                     |                     |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000         | 011                 | 100                 |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp<br>1/2 | Comp<br>full<br>2ph | Comp<br>full<br>1ph | Coil X                | Coil Y |
| 010101100 | 172      | 86   | 43   |      |     |     |             |                     |                     | 86                    | -51    |
| 010101101 | 173      |      |      |      |     |     |             |                     |                     | 85                    | -52    |
| 010101110 | 174      | 87   |      |      |     |     |             |                     |                     | 84                    | -53    |
| 010101111 | 175      |      |      |      |     |     |             |                     |                     | 84                    | -55    |
| 010110000 | 176      | 88   | 44   | 22   | 11  |     |             |                     |                     | 83                    | -56    |
| 010110001 | 177      |      |      |      |     |     |             |                     |                     | 82                    | -57    |
| 010110010 | 178      | 89   |      |      |     |     |             |                     |                     | 82                    | -58    |
| 010110011 | 179      |      |      |      |     |     |             |                     |                     | 81                    | -59    |
| 010110100 | 180      | 90   | 45   |      |     |     |             |                     |                     | 80                    | -60    |
| 010110101 | 181      |      |      |      |     |     |             |                     |                     | 80                    | -61    |
| 010110110 | 182      | 91   |      |      |     |     |             |                     |                     | 79                    | -62    |
| 010110111 | 183      |      |      |      |     |     |             |                     |                     | 78                    | -62    |
| 010111000 | 184      | 92   | 46   | 23   |     |     |             |                     |                     | 77                    | -63    |
| 010111001 | 185      |      |      |      |     |     |             |                     |                     | 77                    | -64    |
| 010111010 | 186      | 93   |      |      |     |     |             |                     |                     | 76                    | -65    |
| 010111011 | 187      |      |      |      |     |     |             |                     |                     | 75                    | -66    |
| 010111100 | 188      | 94   | 47   |      |     |     |             |                     |                     | 74                    | -67    |
| 010111101 | 189      |      |      |      |     |     |             |                     |                     | 73                    | -68    |
| 010111110 | 190      | 95   |      |      |     |     |             |                     |                     | 72                    | -69    |
| 010111111 | 191      |      |      |      |     |     |             |                     |                     | 72                    | -70    |
| 011000000 | 192      | 96   | 48   | 24   | 12  | 6   | 3           | 1                   |                     | 71                    | -71    |
| 011000001 | 193      |      |      |      |     |     |             |                     |                     | 70                    | -72    |
| 011000010 | 194      | 97   |      |      |     |     |             |                     |                     | 69                    | -72    |
| 011000011 | 195      |      |      |      |     |     |             |                     |                     | 68                    | -73    |
| 011000100 | 196      | 98   | 49   |      |     |     |             |                     |                     | 67                    | -74    |
| 011000101 | 197      |      |      |      |     |     |             |                     |                     | 66                    | -75    |
| 011000110 | 198      | 99   |      |      |     |     |             |                     |                     | 65                    | -76    |
| 011000111 | 199      |      |      |      |     |     |             |                     |                     | 64                    | -77    |
| 011001000 | 200      | 100  | 50   | 25   |     |     |             |                     |                     | 63                    | -77    |
| 011001001 | 201      |      |      |      |     |     |             |                     |                     | 62                    | -78    |
| 011001010 | 202      | 101  |      |      |     |     |             |                     |                     | 62                    | -79    |
| 011001011 | 203      |      |      |      |     |     |             |                     |                     | 61                    | -80    |
| 011001100 | 204      | 102  | 51   |      |     |     |             |                     |                     | 60                    | -80    |
| 011001101 | 205      |      |      |      |     |     |             |                     |                     | 59                    | -81    |
| 011001110 | 206      | 103  |      |      |     |     |             |                     |                     | 58                    | -82    |
| 011001111 | 207      |      |      |      |     |     |             |                     |                     | 57                    | -82    |
| 011010000 | 208      | 104  | 52   | 26   | 13  |     |             |                     |                     | 56                    | -83    |
| 011010001 | 209      |      |      |      |     |     |             |                     |                     | 55                    | -84    |
| 011010010 | 210      | 105  |      |      |     |     |             |                     |                     | 53                    | -84    |
| 011010011 | 211      |      |      |      |     |     |             |                     |                     | 52                    | -85    |
| 011010100 | 212      | 106  | 53   |      |     |     |             |                     |                     | 51                    | -86    |
| 011010101 | 213      |      |      |      |     |     |             |                     |                     | 50                    | -86    |
| 011010110 | 214      | 107  |      |      |     |     |             |                     |                     | 49                    | -87    |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |        |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph | Coil X                | Coil Y |
| 011010111 | 215      |      |      |      |     |     |          |               |               | 48                    | -88    |
| 011011000 | 216      | 108  | 54   | 27   |     |     |          |               |               | 47                    | -88    |
| 011011001 | 217      |      |      |      |     |     |          |               |               | 46                    | -89    |
| 011011010 | 218      | 109  |      |      |     |     |          |               |               | 45                    | -89    |
| 011011011 | 219      |      |      |      |     |     |          |               |               | 44                    | -90    |
| 011011100 | 220      | 110  | 55   |      |     |     |          |               |               | 43                    | -90    |
| 011011101 | 221      |      |      |      |     |     |          |               |               | 42                    | -91    |
| 011011110 | 222      | 111  |      |      |     |     |          |               |               | 41                    | -91    |
| 011011111 | 223      |      |      |      |     |     |          |               |               | 39                    | -92    |
| 011100000 | 224      | 112  | 56   | 28   | 14  | 7   |          |               |               | 38                    | -92    |
| 011100001 | 225      |      |      |      |     |     |          |               |               | 37                    | -93    |
| 011100010 | 226      | 113  |      |      |     |     |          |               |               | 36                    | -93    |
| 011100011 | 227      |      |      |      |     |     |          |               |               | 35                    | -94    |
| 011100100 | 228      | 114  | 57   |      |     |     |          |               |               | 34                    | -94    |
| 011100101 | 229      |      |      |      |     |     |          |               |               | 33                    | -95    |
| 011100110 | 230      | 115  |      |      |     |     |          |               |               | 31                    | -95    |
| 011100111 | 231      |      |      |      |     |     |          |               |               | 30                    | -95    |
| 011101000 | 232      | 116  | 58   | 29   |     |     |          |               |               | 29                    | -96    |
| 011101001 | 233      |      |      |      |     |     |          |               |               | 28                    | -96    |
| 011101010 | 234      | 117  |      |      |     |     |          |               |               | 27                    | -96    |
| 011101011 | 235      |      |      |      |     |     |          |               |               | 25                    | -97    |
| 011101100 | 236      | 118  | 59   |      |     |     |          |               |               | 24                    | -97    |
| 011101101 | 237      |      |      |      |     |     |          |               |               | 23                    | -97    |
| 011101110 | 238      | 119  |      |      |     |     |          |               |               | 22                    | -98    |
| 011101111 | 239      |      |      |      |     |     |          |               |               | 21                    | -98    |
| 011110000 | 240      | 120  | 60   | 30   | 15  |     |          |               |               | 20                    | -98    |
| 011110001 | 241      |      |      |      |     |     |          |               |               | 18                    | -98    |
| 011110010 | 242      | 121  |      |      |     |     |          |               |               | 17                    | -99    |
| 011110011 | 243      |      |      |      |     |     |          |               |               | 16                    | -99    |
| 011110100 | 244      | 122  | 61   |      |     |     |          |               |               | 15                    | -99    |
| 011110101 | 245      |      |      |      |     |     |          |               |               | 13                    | -99    |
| 011110110 | 246      | 123  |      |      |     |     |          |               |               | 12                    | -99    |
| 011110111 | 247      |      |      |      |     |     |          |               |               | 11                    | -99    |
| 011111000 | 248      | 124  | 62   | 31   |     |     |          |               |               | 10                    | -100   |
| 011111001 | 249      |      |      |      |     |     |          |               |               | 9                     | -100   |
| 011111010 | 250      | 125  |      |      |     |     |          |               |               | 7                     | -100   |
| 011111011 | 251      |      |      |      |     |     |          |               |               | 6                     | -100   |
| 011111100 | 252      | 126  | 63   |      |     |     |          |               |               | 5                     | -100   |
| 011111101 | 253      |      |      |      |     |     |          |               |               | 4                     | -100   |
| 011111110 | 254      | 127  |      |      |     |     |          |               |               | 2                     | -100   |
| 011111111 | 255      |      |      |      |     |     |          |               |               | 1                     | -100   |
| 100000000 | 256      | 128  | 64   | 32   | 16  | 8   | 4        |               | 2             | 0                     | -100   |
| 100000001 | 257      |      |      |      |     |     |          |               |               | -1                    | -100   |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |        |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph | Coil X                | Coil Y |
| 100000010 | 258      | 129  |      |      |     |     |          |               |               | -2                    | -100   |
| 100000011 | 259      |      |      |      |     |     |          |               |               | -4                    | -100   |
| 100000100 | 260      | 130  | 65   |      |     |     |          |               |               | -5                    | -100   |
| 100000101 | 261      |      |      |      |     |     |          |               |               | -6                    | -100   |
| 100000110 | 262      | 131  |      |      |     |     |          |               |               | -7                    | -100   |
| 100000111 | 263      |      |      |      |     |     |          |               |               | -9                    | -100   |
| 100001000 | 264      | 132  | 66   | 33   |     |     |          |               |               | -10                   | -100   |
| 100001001 | 265      |      |      |      |     |     |          |               |               | -11                   | -99    |
| 100001010 | 266      | 133  |      |      |     |     |          |               |               | -12                   | -99    |
| 100001011 | 267      |      |      |      |     |     |          |               |               | -13                   | -99    |
| 100001100 | 268      | 134  | 67   |      |     |     |          |               |               | -15                   | -99    |
| 100001101 | 269      |      |      |      |     |     |          |               |               | -16                   | -99    |
| 100001110 | 270      | 135  |      |      |     |     |          |               |               | -17                   | -99    |
| 100001111 | 271      |      |      |      |     |     |          |               |               | -18                   | -98    |
| 100010000 | 272      | 136  | 68   | 34   | 17  |     |          |               |               | -20                   | -98    |
| 100010001 | 273      |      |      |      |     |     |          |               |               | -21                   | -98    |
| 100010010 | 274      | 137  |      |      |     |     |          |               |               | -22                   | -98    |
| 100010011 | 275      |      |      |      |     |     |          |               |               | -23                   | -97    |
| 100010100 | 276      | 138  | 69   |      |     |     |          |               |               | -24                   | -97    |
| 100010101 | 277      |      |      |      |     |     |          |               |               | -25                   | -97    |
| 100010110 | 278      | 139  |      |      |     |     |          |               |               | -27                   | -96    |
| 100010111 | 279      |      |      |      |     |     |          |               |               | -28                   | -96    |
| 100011000 | 280      | 140  | 70   | 35   |     |     |          |               |               | -29                   | -96    |
| 100011001 | 281      |      |      |      |     |     |          |               |               | -30                   | -95    |
| 100011010 | 282      | 141  |      |      |     |     |          |               |               | -31                   | -95    |
| 100011011 | 283      |      |      |      |     |     |          |               |               | -33                   | -95    |
| 100011100 | 284      | 142  | 71   |      |     |     |          |               |               | -34                   | -94    |
| 100011101 | 285      |      |      |      |     |     |          |               |               | -35                   | -94    |
| 100011110 | 286      | 143  |      |      |     |     |          |               |               | -36                   | -93    |
| 100011111 | 287      |      |      |      |     |     |          |               |               | -37                   | -93    |
| 100100000 | 288      | 144  | 72   | 36   | 18  | 9   |          |               |               | -38                   | -92    |
| 100100001 | 289      |      |      |      |     |     |          |               |               | -39                   | -92    |
| 100100010 | 290      | 145  |      |      |     |     |          |               |               | -41                   | -91    |
| 100100011 | 291      |      |      |      |     |     |          |               |               | -42                   | -91    |
| 100100100 | 292      | 146  | 73   |      |     |     |          |               |               | -43                   | -90    |
| 100100101 | 293      |      |      |      |     |     |          |               |               | -44                   | -90    |
| 100100110 | 294      | 147  |      |      |     |     |          |               |               | -45                   | -89    |
| 100100111 | 295      |      |      |      |     |     |          |               |               | -46                   | -89    |
| 100101000 | 296      | 148  | 74   | 37   |     |     |          |               |               | -47                   | -88    |
| 100101001 | 297      |      |      |      |     |     |          |               |               | -48                   | -88    |
| 100101010 | 298      | 149  |      |      |     |     |          |               |               | -49                   | -87    |
| 100101011 | 299      |      |      |      |     |     |          |               |               | -50                   | -86    |
| 100101100 | 300      | 150  | 75   |      |     |     |          |               |               | -51                   | -86    |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |             |                     |                     | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|-------------|---------------------|---------------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100         | xxx                 | xxx                 |                       |        |
|           | ESM[2:0] |      |      |      |     |     |             |                     |                     |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000         | 011                 | 100                 |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp<br>1/2 | Comp<br>full<br>2ph | Comp<br>full<br>1ph | Coil X                | Coil Y |
| 100101101 | 301      |      |      |      |     |     |             |                     |                     | -52                   | -85    |
| 100101110 | 302      | 151  |      |      |     |     |             |                     |                     | -53                   | -84    |
| 100101111 | 303      |      |      |      |     |     |             |                     |                     | -55                   | -84    |
| 100110000 | 304      | 152  | 76   | 38   | 19  |     |             |                     |                     | -56                   | -83    |
| 100110001 | 305      |      |      |      |     |     |             |                     |                     | -57                   | -82    |
| 100110010 | 306      | 153  |      |      |     |     |             |                     |                     | -58                   | -82    |
| 100110011 | 307      |      |      |      |     |     |             |                     |                     | -59                   | -81    |
| 100110100 | 308      | 154  | 77   |      |     |     |             |                     |                     | -60                   | -80    |
| 100110101 | 309      |      |      |      |     |     |             |                     |                     | -61                   | -80    |
| 100110110 | 310      | 155  |      |      |     |     |             |                     |                     | -62                   | -79    |
| 100110111 | 311      |      |      |      |     |     |             |                     |                     | -62                   | -78    |
| 100111000 | 312      | 156  | 78   | 39   |     |     |             |                     |                     | -63                   | -77    |
| 100111001 | 313      |      |      |      |     |     |             |                     |                     | -64                   | -77    |
| 100111010 | 314      | 157  |      |      |     |     |             |                     |                     | -65                   | -76    |
| 100111011 | 315      |      |      |      |     |     |             |                     |                     | -66                   | -75    |
| 100111100 | 316      | 158  | 79   |      |     |     |             |                     |                     | -67                   | -74    |
| 100111101 | 317      |      |      |      |     |     |             |                     |                     | -68                   | -73    |
| 100111110 | 318      | 159  |      |      |     |     |             |                     |                     | -69                   | -72    |
| 100111111 | 319      |      |      |      |     |     |             |                     |                     | -70                   | -72    |
| 101000000 | 320      | 160  | 80   | 40   | 20  | 10  | 5           | 2                   |                     | -71                   | -71    |
| 101000001 | 321      |      |      |      |     |     |             |                     |                     | -72                   | -70    |
| 101000010 | 322      | 161  |      |      |     |     |             |                     |                     | -72                   | -69    |
| 101000011 | 323      |      |      |      |     |     |             |                     |                     | -73                   | -68    |
| 101000100 | 324      | 162  | 81   |      |     |     |             |                     |                     | -74                   | -67    |
| 101000101 | 325      |      |      |      |     |     |             |                     |                     | -75                   | -66    |
| 101000110 | 326      | 163  |      |      |     |     |             |                     |                     | -76                   | -65    |
| 101000111 | 327      |      |      |      |     |     |             |                     |                     | -77                   | -64    |
| 101001000 | 328      | 164  | 82   | 41   |     |     |             |                     |                     | -77                   | -63    |
| 101001001 | 329      |      |      |      |     |     |             |                     |                     | -78                   | -62    |
| 101001010 | 330      | 165  |      |      |     |     |             |                     |                     | -79                   | -62    |
| 101001011 | 331      |      |      |      |     |     |             |                     |                     | -80                   | -61    |
| 101001100 | 332      | 166  | 83   |      |     |     |             |                     |                     | -80                   | -60    |
| 101001101 | 333      |      |      |      |     |     |             |                     |                     | -81                   | -59    |
| 101001110 | 334      | 167  |      |      |     |     |             |                     |                     | -82                   | -58    |
| 101001111 | 335      |      |      |      |     |     |             |                     |                     | -82                   | -57    |
| 101010000 | 336      | 168  | 84   | 42   | 21  |     |             |                     |                     | -83                   | -56    |
| 101010001 | 337      |      |      |      |     |     |             |                     |                     | -84                   | -55    |
| 101010010 | 338      | 169  |      |      |     |     |             |                     |                     | -84                   | -53    |
| 101010011 | 339      |      |      |      |     |     |             |                     |                     | -85                   | -52    |
| 101010100 | 340      | 170  | 85   |      |     |     |             |                     |                     | -86                   | -51    |
| 101010101 | 341      |      |      |      |     |     |             |                     |                     | -86                   | -50    |
| 101010110 | 342      | 171  |      |      |     |     |             |                     |                     | -87                   | -49    |
| 101010111 | 343      |      |      |      |     |     |             |                     |                     | -88                   | -48    |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |     |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|-----|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |     |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |     |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |     |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph |                       |     |
| 101011000 | 344      | 172  | 86   | 43   |     |     |          |               |               | -88                   | -47 |
| 101011001 | 345      |      |      |      |     |     |          |               |               | -89                   | -46 |
| 101011010 | 346      | 173  |      |      |     |     |          |               |               | -89                   | -45 |
| 101011011 | 347      |      |      |      |     |     |          |               |               | -90                   | -44 |
| 101011100 | 348      | 174  | 87   |      |     |     |          |               |               | -90                   | -43 |
| 101011101 | 349      |      |      |      |     |     |          |               |               | -91                   | -42 |
| 101011110 | 350      | 175  |      |      |     |     |          |               |               | -91                   | -41 |
| 101011111 | 351      |      |      |      |     |     |          |               |               | -92                   | -39 |
| 101100000 | 352      | 176  | 88   | 44   | 22  | 11  |          |               |               | -92                   | -38 |
| 101100001 | 353      |      |      |      |     |     |          |               |               | -93                   | -37 |
| 101100010 | 354      | 177  |      |      |     |     |          |               |               | -93                   | -36 |
| 101100011 | 355      |      |      |      |     |     |          |               |               | -94                   | -35 |
| 101100100 | 356      | 178  | 89   |      |     |     |          |               |               | -94                   | -34 |
| 101100101 | 357      |      |      |      |     |     |          |               |               | -95                   | -33 |
| 101100110 | 358      | 179  |      |      |     |     |          |               |               | -95                   | -31 |
| 101100111 | 359      |      |      |      |     |     |          |               |               | -95                   | -30 |
| 101101000 | 360      | 180  | 90   | 45   |     |     |          |               |               | -96                   | -29 |
| 101101001 | 361      |      |      |      |     |     |          |               |               | -96                   | -28 |
| 101101010 | 362      | 181  |      |      |     |     |          |               |               | -96                   | -27 |
| 101101011 | 363      |      |      |      |     |     |          |               |               | -97                   | -25 |
| 101101100 | 364      | 182  | 91   |      |     |     |          |               |               | -97                   | -24 |
| 101101101 | 365      |      |      |      |     |     |          |               |               | -97                   | -23 |
| 101101110 | 366      | 183  |      |      |     |     |          |               |               | -98                   | -22 |
| 101101111 | 367      |      |      |      |     |     |          |               |               | -98                   | -21 |
| 101110000 | 368      | 184  | 92   | 46   | 23  |     |          |               |               | -98                   | -20 |
| 101110001 | 369      |      |      |      |     |     |          |               |               | -98                   | -18 |
| 101110010 | 370      | 185  |      |      |     |     |          |               |               | -99                   | -17 |
| 101110011 | 371      |      |      |      |     |     |          |               |               | -99                   | -16 |
| 101110100 | 372      | 186  | 93   |      |     |     |          |               |               | -99                   | -15 |
| 101110101 | 373      |      |      |      |     |     |          |               |               | -99                   | -13 |
| 101110110 | 374      | 187  |      |      |     |     |          |               |               | -99                   | -12 |
| 101110111 | 375      |      |      |      |     |     |          |               |               | -99                   | -11 |
| 101111000 | 376      | 188  | 94   | 47   |     |     |          |               |               | -100                  | -10 |
| 101111001 | 377      |      |      |      |     |     |          |               |               | -100                  | -9  |
| 101111010 | 378      | 189  |      |      |     |     |          |               |               | -100                  | -7  |
| 101111011 | 379      |      |      |      |     |     |          |               |               | -100                  | -6  |
| 101111100 | 380      | 190  | 95   |      |     |     |          |               |               | -100                  | -5  |
| 101111101 | 381      |      |      |      |     |     |          |               |               | -100                  | -4  |
| 101111110 | 382      | 191  |      |      |     |     |          |               |               | -100                  | -2  |
| 101111111 | 383      |      |      |      |     |     |          |               |               | -100                  | -1  |
| 110000000 | 384      | 192  | 96   | 48   | 24  | 12  | 6        |               | 3             | -100                  | 0   |
| 110000001 | 385      |      |      |      |     |     |          |               |               | -100                  | 1   |
| 110000010 | 386      | 193  |      |      |     |     |          |               |               | -100                  | 2   |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |        |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph | Coil X                | Coil Y |
| 110000011 | 387      |      |      |      |     |     |          |               |               | -100                  | 4      |
| 110000100 | 388      | 194  | 97   |      |     |     |          |               |               | -100                  | 5      |
| 110000101 | 389      |      |      |      |     |     |          |               |               | -100                  | 6      |
| 110000110 | 390      | 195  |      |      |     |     |          |               |               | -100                  | 7      |
| 110000111 | 391      |      |      |      |     |     |          |               |               | -100                  | 9      |
| 110001000 | 392      | 196  | 98   | 49   |     |     |          |               |               | -100                  | 10     |
| 110001001 | 393      |      |      |      |     |     |          |               |               | -99                   | 11     |
| 110001010 | 394      | 197  |      |      |     |     |          |               |               | -99                   | 12     |
| 110001011 | 395      |      |      |      |     |     |          |               |               | -99                   | 13     |
| 110001100 | 396      | 198  | 99   |      |     |     |          |               |               | -99                   | 15     |
| 110001101 | 397      |      |      |      |     |     |          |               |               | -99                   | 16     |
| 110001110 | 398      | 199  |      |      |     |     |          |               |               | -99                   | 17     |
| 110001111 | 399      |      |      |      |     |     |          |               |               | -98                   | 18     |
| 110010000 | 400      | 200  | 100  | 50   | 25  |     |          |               |               | -98                   | 20     |
| 110010001 | 401      |      |      |      |     |     |          |               |               | -98                   | 21     |
| 110010010 | 402      | 201  |      |      |     |     |          |               |               | -98                   | 22     |
| 110010011 | 403      |      |      |      |     |     |          |               |               | -97                   | 23     |
| 110010100 | 404      | 202  | 101  |      |     |     |          |               |               | -97                   | 24     |
| 110010101 | 405      |      |      |      |     |     |          |               |               | -97                   | 25     |
| 110010110 | 406      | 203  |      |      |     |     |          |               |               | -96                   | 27     |
| 110010111 | 407      |      |      |      |     |     |          |               |               | -96                   | 28     |
| 110011000 | 408      | 204  | 102  | 51   |     |     |          |               |               | -96                   | 29     |
| 110011001 | 409      |      |      |      |     |     |          |               |               | -95                   | 30     |
| 110011010 | 410      | 205  |      |      |     |     |          |               |               | -95                   | 31     |
| 110011011 | 411      |      |      |      |     |     |          |               |               | -95                   | 33     |
| 110011100 | 412      | 206  | 103  |      |     |     |          |               |               | -94                   | 34     |
| 110011101 | 413      |      |      |      |     |     |          |               |               | -94                   | 35     |
| 110011110 | 414      | 207  |      |      |     |     |          |               |               | -93                   | 36     |
| 110011111 | 415      |      |      |      |     |     |          |               |               | -93                   | 37     |
| 110100000 | 416      | 208  | 104  | 52   | 26  | 13  |          |               |               | -92                   | 38     |
| 110100001 | 417      |      |      |      |     |     |          |               |               | -92                   | 39     |
| 110100010 | 418      | 209  |      |      |     |     |          |               |               | -91                   | 41     |
| 110100011 | 419      |      |      |      |     |     |          |               |               | -91                   | 42     |
| 110100100 | 420      | 210  | 105  |      |     |     |          |               |               | -90                   | 43     |
| 110100101 | 421      |      |      |      |     |     |          |               |               | -90                   | 44     |
| 110100110 | 422      | 211  |      |      |     |     |          |               |               | -89                   | 45     |
| 110100111 | 423      |      |      |      |     |     |          |               |               | -89                   | 46     |
| 110101000 | 424      | 212  | 106  | 53   |     |     |          |               |               | -88                   | 47     |
| 110101001 | 425      |      |      |      |     |     |          |               |               | -88                   | 48     |
| 110101010 | 426      | 213  |      |      |     |     |          |               |               | -87                   | 49     |
| 110101011 | 427      |      |      |      |     |     |          |               |               | -86                   | 50     |
| 110101100 | 428      | 214  | 107  |      |     |     |          |               |               | -86                   | 51     |
| 110101101 | 429      |      |      |      |     |     |          |               |               | -85                   | 52     |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |          |               |               | % of I <sub>max</sub> |        |
|-----------|----------|------|------|------|-----|-----|----------|---------------|---------------|-----------------------|--------|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100      | xxx           | xxx           |                       |        |
|           | ESM[2:0] |      |      |      |     |     |          |               |               |                       |        |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000      | 011           | 100           |                       |        |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp 1/2 | Comp full 2ph | Comp full 1ph | Coil X                | Coil Y |
| 110101110 | 430      | 215  |      |      |     |     |          |               |               | -84                   | 53     |
| 110101111 | 431      |      |      |      |     |     |          |               |               | -84                   | 55     |
| 110110000 | 432      | 216  | 108  | 54   | 27  |     |          |               |               | -83                   | 56     |
| 110110001 | 433      |      |      |      |     |     |          |               |               | -82                   | 57     |
| 110110010 | 434      | 217  |      |      |     |     |          |               |               | -82                   | 58     |
| 110110011 | 435      |      |      |      |     |     |          |               |               | -81                   | 59     |
| 110110100 | 436      | 218  | 109  |      |     |     |          |               |               | -80                   | 60     |
| 110110101 | 437      |      |      |      |     |     |          |               |               | -80                   | 61     |
| 110110110 | 438      | 219  |      |      |     |     |          |               |               | -79                   | 62     |
| 110110111 | 439      |      |      |      |     |     |          |               |               | -78                   | 62     |
| 110111000 | 440      | 220  | 110  | 55   |     |     |          |               |               | -77                   | 63     |
| 110111001 | 441      |      |      |      |     |     |          |               |               | -77                   | 64     |
| 110111010 | 442      | 221  |      |      |     |     |          |               |               | -76                   | 65     |
| 110111011 | 443      |      |      |      |     |     |          |               |               | -75                   | 66     |
| 110111100 | 444      | 222  | 111  |      |     |     |          |               |               | -74                   | 67     |
| 110111101 | 445      |      |      |      |     |     |          |               |               | -73                   | 68     |
| 110111110 | 446      | 223  |      |      |     |     |          |               |               | -72                   | 69     |
| 110111111 | 447      |      |      |      |     |     |          |               |               | -72                   | 70     |
| 111000000 | 448      | 224  | 112  | 56   | 28  | 14  | 7        | 3             |               | -71                   | 71     |
| 111000001 | 449      |      |      |      |     |     |          |               |               | -70                   | 72     |
| 111000010 | 450      | 225  |      |      |     |     |          |               |               | -69                   | 72     |
| 111000011 | 451      |      |      |      |     |     |          |               |               | -68                   | 73     |
| 111000100 | 452      | 226  | 113  |      |     |     |          |               |               | -67                   | 74     |
| 111000101 | 453      |      |      |      |     |     |          |               |               | -66                   | 75     |
| 111000110 | 454      | 227  |      |      |     |     |          |               |               | -65                   | 76     |
| 111000111 | 455      |      |      |      |     |     |          |               |               | -64                   | 77     |
| 111001000 | 456      | 228  | 114  | 57   |     |     |          |               |               | -63                   | 77     |
| 111001001 | 457      |      |      |      |     |     |          |               |               | -62                   | 78     |
| 111001010 | 458      | 229  |      |      |     |     |          |               |               | -62                   | 79     |
| 111001011 | 459      |      |      |      |     |     |          |               |               | -61                   | 80     |
| 111001100 | 460      | 230  | 115  |      |     |     |          |               |               | -60                   | 80     |
| 111001101 | 461      |      |      |      |     |     |          |               |               | -59                   | 81     |
| 111001110 | 462      | 231  |      |      |     |     |          |               |               | -58                   | 82     |
| 111001111 | 463      |      |      |      |     |     |          |               |               | -57                   | 82     |
| 111010000 | 464      | 232  | 116  | 58   | 29  |     |          |               |               | -56                   | 83     |
| 111010001 | 465      |      |      |      |     |     |          |               |               | -55                   | 84     |
| 111010010 | 466      | 233  |      |      |     |     |          |               |               | -53                   | 84     |
| 111010011 | 467      |      |      |      |     |     |          |               |               | -52                   | 85     |
| 111010100 | 468      | 234  | 117  |      |     |     |          |               |               | -51                   | 86     |
| 111010101 | 469      |      |      |      |     |     |          |               |               | -50                   | 86     |
| 111010110 | 470      | 235  |      |      |     |     |          |               |               | -49                   | 87     |
| 111010111 | 471      |      |      |      |     |     |          |               |               | -48                   | 88     |
| 111011000 | 472      | 236  | 118  | 59   |     |     |          |               |               | -47                   | 88     |

Table 9. CIRCULAR TRANSLATOR TABLE (continued)

| MSP[8:0]  | SM[2:0]  |      |      |      |     |     |             |                     |                     | % of I <sub>max</sub> |     |
|-----------|----------|------|------|------|-----|-----|-------------|---------------------|---------------------|-----------------------|-----|
|           | xxx      | xxx  | 000  | 001  | 010 | 011 | 100         | xxx                 | xxx                 |                       |     |
|           | ESM[2:0] |      |      |      |     |     |             |                     |                     |                       |     |
|           | 001      | 010  | 000  | 000  | 000 | 000 | 000         | 011                 | 100                 |                       |     |
|           | 1/128    | 1/64 | 1/32 | 1/16 | 1/8 | 1/4 | Comp<br>1/2 | Comp<br>full<br>2ph | Comp<br>full<br>1ph |                       |     |
| 111011001 | 473      |      |      |      |     |     |             |                     |                     | -46                   | 89  |
| 111011010 | 474      | 237  |      |      |     |     |             |                     |                     | -45                   | 89  |
| 111011011 | 475      |      |      |      |     |     |             |                     |                     | -44                   | 90  |
| 111011100 | 476      | 238  | 119  |      |     |     |             |                     |                     | -43                   | 90  |
| 111011101 | 477      |      |      |      |     |     |             |                     |                     | -42                   | 91  |
| 111011110 | 478      | 239  |      |      |     |     |             |                     |                     | -41                   | 91  |
| 111011111 | 479      |      |      |      |     |     |             |                     |                     | -39                   | 92  |
| 111100000 | 480      | 240  | 120  | 60   | 30  | 15  |             |                     |                     | -38                   | 92  |
| 111100001 | 481      |      |      |      |     |     |             |                     |                     | -37                   | 93  |
| 111100010 | 482      | 241  |      |      |     |     |             |                     |                     | -36                   | 93  |
| 111100011 | 483      |      |      |      |     |     |             |                     |                     | -35                   | 94  |
| 111100100 | 484      | 242  | 121  |      |     |     |             |                     |                     | -34                   | 94  |
| 111100101 | 485      |      |      |      |     |     |             |                     |                     | -33                   | 95  |
| 111100110 | 486      | 243  |      |      |     |     |             |                     |                     | -31                   | 95  |
| 111100111 | 487      |      |      |      |     |     |             |                     |                     | -30                   | 95  |
| 111101000 | 488      | 244  | 122  | 61   |     |     |             |                     |                     | -29                   | 96  |
| 111101001 | 489      |      |      |      |     |     |             |                     |                     | -28                   | 96  |
| 111101010 | 490      | 245  |      |      |     |     |             |                     |                     | -27                   | 96  |
| 111101011 | 491      |      |      |      |     |     |             |                     |                     | -25                   | 97  |
| 111101100 | 492      | 246  | 123  |      |     |     |             |                     |                     | -24                   | 97  |
| 111101101 | 493      |      |      |      |     |     |             |                     |                     | -23                   | 97  |
| 111101110 | 494      | 247  |      |      |     |     |             |                     |                     | -22                   | 98  |
| 111101111 | 495      |      |      |      |     |     |             |                     |                     | -21                   | 98  |
| 111110000 | 496      | 248  | 124  | 62   | 31  |     |             |                     |                     | -20                   | 98  |
| 111110001 | 497      |      |      |      |     |     |             |                     |                     | -18                   | 98  |
| 111110010 | 498      | 249  |      |      |     |     |             |                     |                     | -17                   | 99  |
| 111110011 | 499      |      |      |      |     |     |             |                     |                     | -16                   | 99  |
| 111110100 | 500      | 250  | 125  |      |     |     |             |                     |                     | -15                   | 99  |
| 111110101 | 501      |      |      |      |     |     |             |                     |                     | -13                   | 99  |
| 111110110 | 502      | 251  |      |      |     |     |             |                     |                     | -12                   | 99  |
| 111110111 | 503      |      |      |      |     |     |             |                     |                     | -11                   | 99  |
| 111111000 | 504      | 252  | 126  | 63   |     |     |             |                     |                     | -10                   | 100 |
| 111111001 | 505      |      |      |      |     |     |             |                     |                     | -9                    | 100 |
| 111111010 | 506      | 253  |      |      |     |     |             |                     |                     | -7                    | 100 |
| 111111011 | 507      |      |      |      |     |     |             |                     |                     | -6                    | 100 |
| 111111100 | 508      | 254  | 127  |      |     |     |             |                     |                     | -5                    | 100 |
| 111111101 | 509      |      |      |      |     |     |             |                     |                     | -4                    | 100 |
| 111111110 | 510      | 255  |      |      |     |     |             |                     |                     | -2                    | 100 |
| 111111111 | 511      |      |      |      |     |     |             |                     |                     | -1                    | 100 |

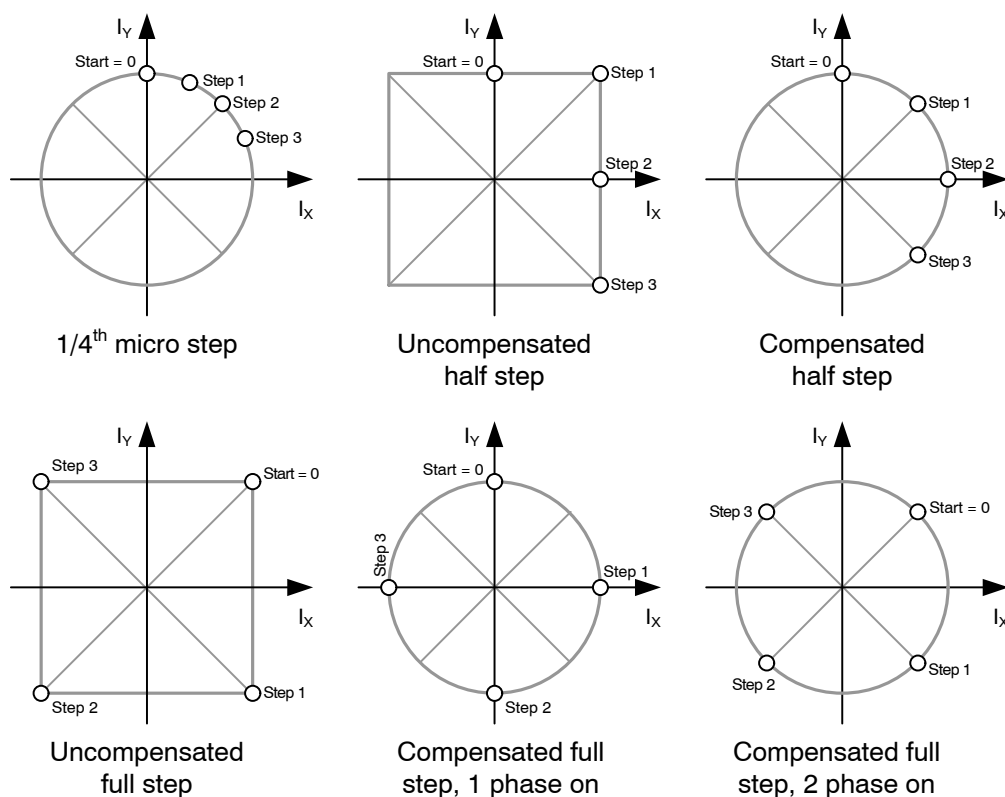


Figure 10. Translator Table: Circular and Square

### Direction

The direction of rotation is selected by means of following combination of the DIR input pin and the SPI-controlled direction bit <DIRCTRL>. (see Table 12 SPI Control Parameter Overview)

### NXT Input

Changes on the NXT input will move the motor current one step up/down in the translator table (even when the motor is disabled: <MOTEN> = 0). Depending on the NXT-polarity bit <NXTP> (see Table 12 SPI Control

Parameter Overview), the next step is initiated either on the rising edge or the falling edge of the NXT input.

### Translator Position

The translator position MSP[8:0] can be read in SPI Status Register 3 and Status Register 4 (See Table 14 SR3 and SR4). This is a 9-bit number equivalent to the 1/128<sup>th</sup> micro-step (see Table 9 “Circular Translator Table”). The translator position is updated immediately following a NXT trigger.

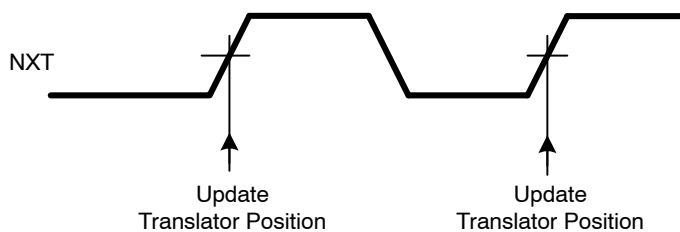


Figure 11. Translator Position Timing Diagram

### Synchronization of Step Mode and NXT Input

When step mode is re-programmed to another resolution (Figure 12), then this is put in effect immediately upon the first arriving “NXT” input. If the micro-stepping resolution is increased, the coil currents will be regulated to the nearest micro-step, according to the fixed grid of the increased resolution. If however the micro-stepping resolution is decreased, then it is possible to introduce an offset (or phase shift) in the micro-step translator table.

If the step resolution is decreased at a translator table position that is shared both by the old and new resolution setting, then the offset is zero and micro-stepping is proceeds according to the translator table.

If the translator position is **not** shared both by the old and new resolution setting, then the micro-stepping proceeds with an offset relative to the translator table (See Figure 12 right hand side).

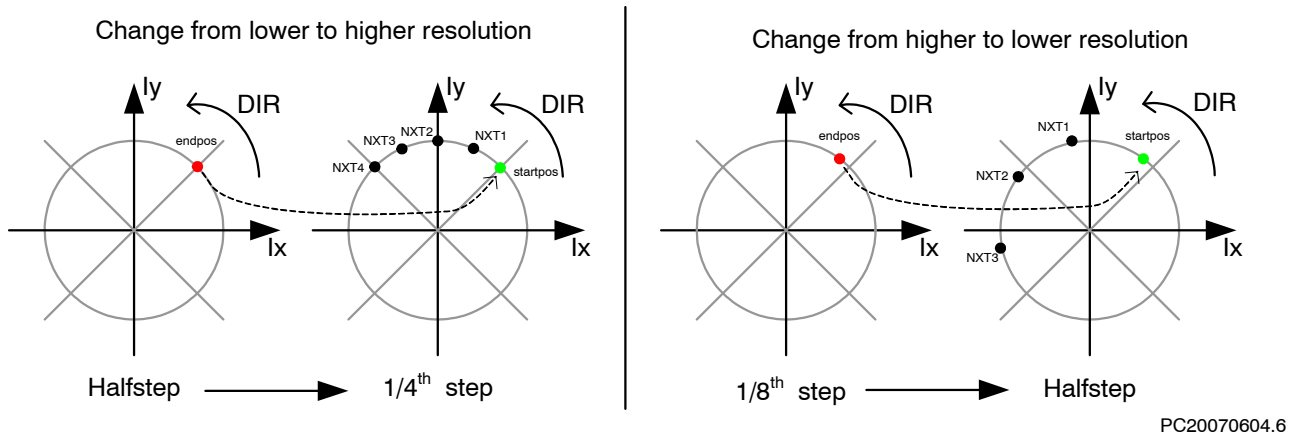


Figure 12. NXT-Step Mode Synchronization

**Left:** Change from lower to higher resolution. The left-hand side depicts the ending half-step position during which a new step mode resolution was programmed. The right-hand side diagram shows the effect of subsequent NXT commands on the micro-step position.

**Right:** Change from higher to lower resolution. The left-hand side depicts the ending micro-step position during which a new step mode resolution was programmed. The right-hand side diagram shows the effect of subsequent NXT commands on the half-step position.

**Note:** It is advised to reduce the micro-stepping resolution only at micro-step positions that overlap with desired micro-step positions of the new resolution.

### Programmable Peak-Current

The amplitude of the current waveform in the motor coils (coil peak current =  $I_{max}$ ) is adjusted by means of an SPI parameter “CUR[4:0]” (see Table 12 SPI Control Parameter

Overview). Whenever this parameter is changed, the coil-currents will be updated immediately at the next PWM period. Figure 13 presents the Peak-Current and Current Ratings in conjunction to the Current setting CUR[4:0].

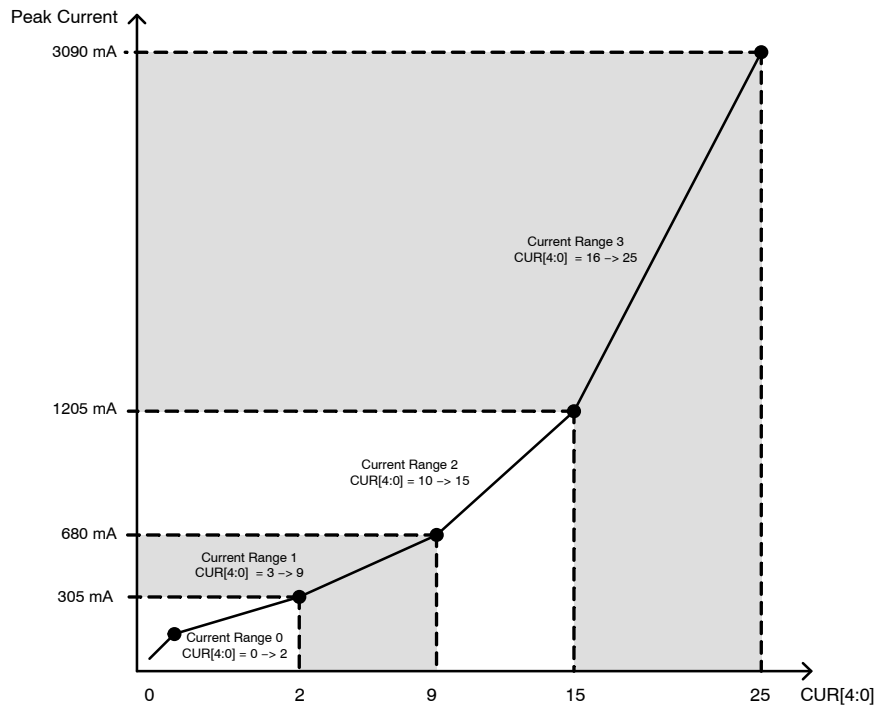


Figure 13. Programmable Peak-Current Overview

## Speed and Load Angle Output

The SLA-pin provides an output voltage that indicates the level of the Back-e.m.f. voltage of the motor. This Back-e.m.f. voltage is sampled during every so-called "coil

current zero crossings". Per coil, two zero-current positions exist per electrical period, yielding in total four zero-current observation points per electrical period.

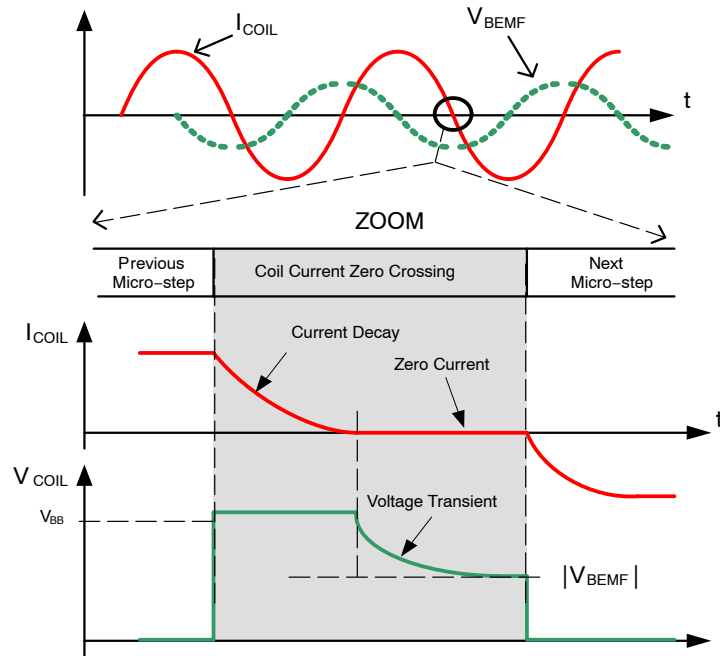


Figure 14. Principle of BEMF Measurement

Because of the relatively high recirculation currents in the coil during current decay, the coil voltage  $V_{COIL}$  shows a transient behavior. As this transient is not always desired in application software, two operating modes can be selected by means of the bit <SLAT> (see "SLA-transparency" in Table 12 SPI Control Parameter Overview). The SLA pin shows in "transparent mode" full visibility of the voltage transient behavior. This allows a sanity-check of the speed-setting versus motor operation and characteristics and supply voltage levels. If the bit "SLAT" is cleared, then only the voltage samples at the end of each coil current zero crossing are visible on the SLA-pin. Because the transient

behavior of the coil voltage is not visible anymore, this mode generates smoother Back e.m.f. input for post-processing, e.g. by software.

In order to bring the sampled Back e.m.f. to a descent output level (0 V to 5 V), the sampled coil voltage  $V_{COIL}$  is divided by 2 or by 4. This divider is set through an SPI bit <SLAG>. (see Table 12 SPI Control Parameter Overview)

The following drawing illustrates the operation of the SLA-pin and the transparency-bit. "PWMsh" and " $I_{COIL} = 0$ " are internal signals that define together with SLAT the sampling and hold moments of the coil voltage.

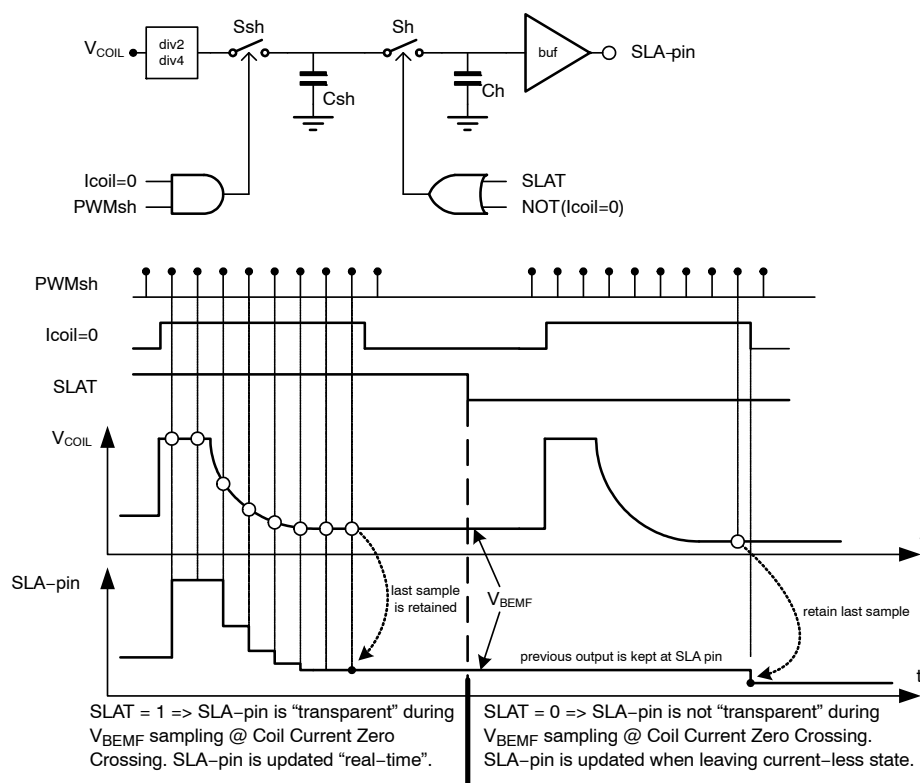


Figure 15. Timing Diagram of SLA-Pin

## Warning, Error Detection and Diagnostics Feedback

### Thermal Warning and Shutdown

When junction temperature rises above  $T_{TW}$ , the thermal warning bit <TW> is set (Table 14 SPI Status registers Address SR0). If junction temperature increases above thermal shutdown level, then the circuit goes in "Thermal Shutdown" mode (<TSD>) and all driver transistors are disabled (high impedance) (see Table 14 SPI Status registers Address SR2). The conditions to reset flag <TSD> is to be at a temperature lower than  $T_{TW}$  and to clear the <TSD> flag by reading it using any SPI read command.

### Overcurrent Detection

The overcurrent detection circuit monitors the load current in each activated output stage. If the load current exceeds the over-current detection threshold, then the overcurrent flag is set and the drivers are switched off to reduce the power dissipation and to protect the integrated circuit. Each driver transistor has an individual detection bit (see Table 14 SPI Status Registers Address SR1 and SR2: <OVCIj> and <OVCIj>). Error condition is latched and the microcontroller needs to clean the status bits to reactivate the drivers.

**Note:** Successive reading the SPI Status Registers 1 and 2 in case of a short circuit condition, may lead to damage to the drivers.

### Open Coil/Current Not Reached Detection

Open coil detection is based on the observation of 100% duty cycle of the PWM regulator. If in a coil 100% duty cycle is detected for longer than 200 ms then the related driver transistors are disabled (high-impedance) and an appropriate bit in the SPI status register is set (<OPENX> or <OPENY>). (Table 14)

When the resistance of a motor coil is very large and the supply 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 200 ms the error pin and <OPENX>, <OPENY> 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) still allow reaching the requested coil-current or else the coil current should be reduced.

### Charge Pump Failure

The charge pump is an important circuit that guarantees low  $R_{DS(on)}$  for all drivers, especially for low supply voltages. If supply voltage is too low or external components are not properly connected to guarantee  $R_{DS(on)}$  of the drivers, then the bit <CPFAIL> is set (Table 14). Also after POR the charge pump voltage will need some time to exceed the required threshold. During that time <CPFAIL> will be set to "1".

## Error Output

This is a digital output to flag a problem to the external microcontroller. The signal on this output is active low and the logic combination of:

$\text{NOT}(\text{ERRB}) = \langle \text{TW} \rangle \text{ OR } \langle \text{TSD} \rangle \text{ OR } \langle \text{OVCXi}j \rangle \text{ OR } \langle \text{OVCI}j \rangle \text{ OR } \langle \text{OPENi} \rangle \text{ OR } \langle \text{CPFAIL} \rangle$

## Logic Supply Regulator

AMIS-30543 has an on-chip 5 V low-drop regulator with external capacitor to supply the digital part of the chip, some low-voltage analog blocks and external circuitry. The voltage level is derived from an internal bandgap reference. To calculate the available drive-current for external

circuitry, the specified  $I_{\text{load}}$  should be reduced with the consumption of internal circuitry (unloaded outputs) and the loads connected to logic outputs. See Table 4. DC parameters

## Power-On Reset (POR) Function

The open drain output pin  $\overline{\text{POR}}/\text{WD}$  provides an “active low” reset for external purposes. At powerup of AMIS-30543, this pin will be kept low for some time to reset for example an external microcontroller. A small analogue filter avoids resetting due to spikes or noise on the  $V_{\text{DD}}$  supply.

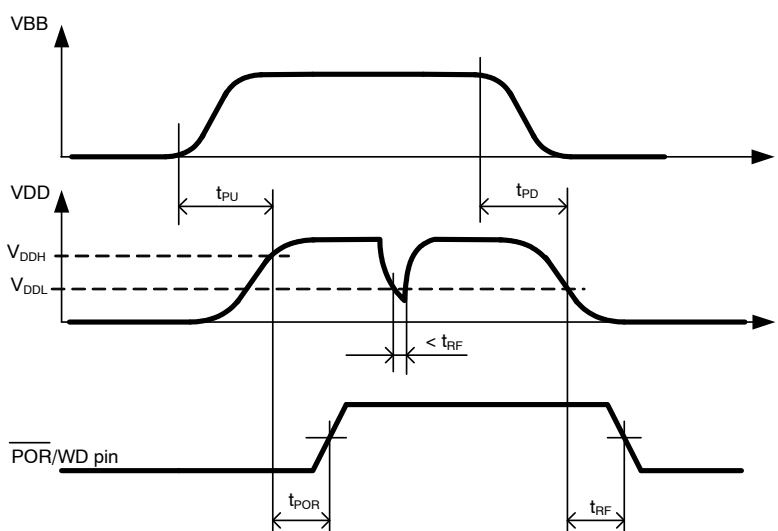


Figure 16. Power-on-Reset Timing Diagram

## Watchdog Function

The watchdog function is enabled/disabled through  $\langle \text{WDEN} \rangle$  bit (Table 11: SPI CONTROL REGISTERS). Once this bit has been set to “1” (watchdog enable), the microcontroller needs to re-write this bit to clear an internal timer before the watchdog timeout interval expires. In case the timer is activated and WDEN is acknowledged too early (before  $t_{\text{WDPR}}$ ) or not within the interval (after  $t_{\text{WDTO}}$ ), then a reset of the microcontroller will occur through  $\overline{\text{POR}}/\text{WD}$  pin. In addition, a warm/cold boot bit  $\langle \text{WD} \rangle$  is available (see Tables 14 and 15) for further processing when the external microcontroller is alive again.

## CLR pin (=Hard Reset)

Logic 0 on CLR pin allows normal operation of the chip. To reset the complete digital inside AMIS-30543, the input CLR needs to be pulled to logic 1 during minimum time given by  $t_{\text{CLR}}$  (Table 5 AC Parameters). This reset function clears all internal registers without the need of a power-cycle, except in sleep mode. Logic 0 on CLR pin resumes normal operation again.

The voltage regulator and charge pump remains functional during and after the reset and the  $\overline{\text{POR}}/\text{WD}$  pin is not activated. Watchdog function is reset completely.

## Sleep Mode

The bit  $\langle \text{SLP} \rangle$  in SPI Control Register 2 (See Table 10) is provided to enter a so-called “sleep mode”. This mode allows reduction of current-consumption when the motor is not in operation. The effect of sleep mode is as follows:

- The drivers are put in HiZ
- All analog circuits are disabled and in low-power mode
- All internal registers are maintaining their logic content
- NXT and DIR inputs are forbidden
- SPI communication remains possible (slight current increase during SPI communication)
- Oscillator and digital clocks are silent, except during SPI communication
- Registers cannot be cleared by using the CLR pin

$V_{\text{BB}}$  should be minimum 9 V to be able to enter Sleep Mode.

The voltage regulator remains active but with reduced current-output capability ( $I_{LOADSLP}$ ). The watchdog timer stops running and its value is kept in the counter. Upon leaving sleep mode, this timer continues from the value it had before entering sleep mode.

Normal operation is resumed after writing logic '0' to bit <SLP>. A startup time is needed for the charge pump to stabilize. After this time, NXT commands can be issued.

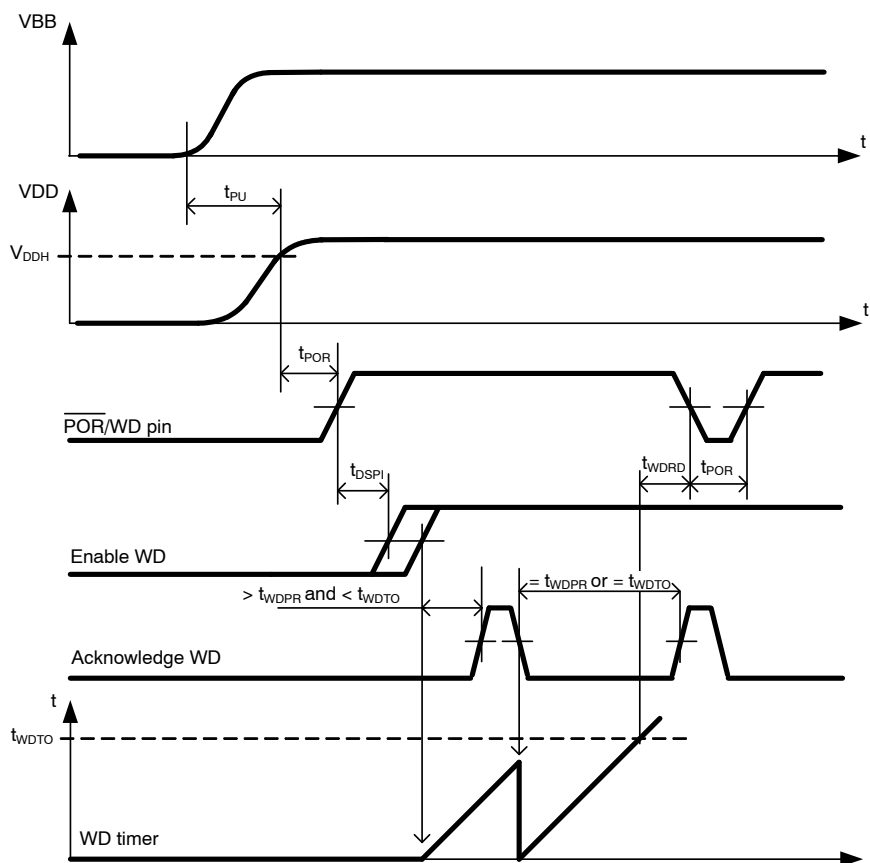


Figure 17. Watchdog Timing Diagram

NOTE:  $t_{DSPi}$  is the time needed by the external microcontroller to shift-in the <WDEN> bit after a powerup.

The duration of the watchdog timeout interval is programmable through the WDT[3:0] bits (See also Table 11: SPI CONTROL REGISTERS. The timing is given in Table 10 below.

Table 10. WATCHDOG TIMEOUT INTERVAL AS FUNCTION OF WDT[3:0]

| Index WDT[3:0] |      | $t_{WDTO}$ (ms) | Index WDT[3:0] |      | $t_{WDTO}$ (ms) |
|----------------|------|-----------------|----------------|------|-----------------|
| 0              | 0000 | 32              | 8              | 1000 | 288             |
| 1              | 0001 | 64              | 9              | 1001 | 320             |
| 2              | 0010 | 96              | 10             | 1010 | 352             |
| 3              | 0011 | 128             | 11             | 1011 | 384             |
| 4              | 0100 | 160             | 12             | 1100 | 416             |
| 5              | 0101 | 192             | 13             | 1101 | 448             |
| 6              | 0110 | 224             | 14             | 1110 | 480             |
| 7              | 0111 | 256             | 15             | 1111 | 512             |

## SPI INTERFACE

The serial peripheral interface (SPI) allows an external microcontroller (Master) to communicate with AMIS-30543. The implemented SPI block is designed to interface directly with numerous micro-controllers from several manufacturers. AMIS-30543 acts always as a Slave and can't initiate any transmission. The operation of the device is configured and controlled by means of SPI registers which are observable for read and/or write from the Master.

### SPI Transfer Format and Pin Signals

During a SPI transfer, data is simultaneously transmitted (shifted out serially) and received (shifted in serially). A serial clock line (CLK) synchronizes shifting and sampling of the information on the two serial data lines (DO and DI).

DO signal is the output from the Slave (AMIS-30543), and DI signal is the output from the Master. A chip select line ( $\overline{CS}$ ) allows individual selection of a Slave SPI device in a multiple-slave system. The  $\overline{CS}$  line is active low. If AMIS-30543 is not selected, DO is pulled up with the external pull up resistor. Since AMIS-30543 operates as a Slave in MODE 0 (CPOL = 0; CPHA = 0) it always clocks data out on the falling edge of clock and samples data in on rising edge of clock. The Master SPI port must be configured in MODE 0 too, to match this operation. The SPI clock idles low between the transferred bytes.

The diagram below is both a Master and a Slave timing diagram since CLK, DO and DI pins are directly connected between the Master and the Slave.

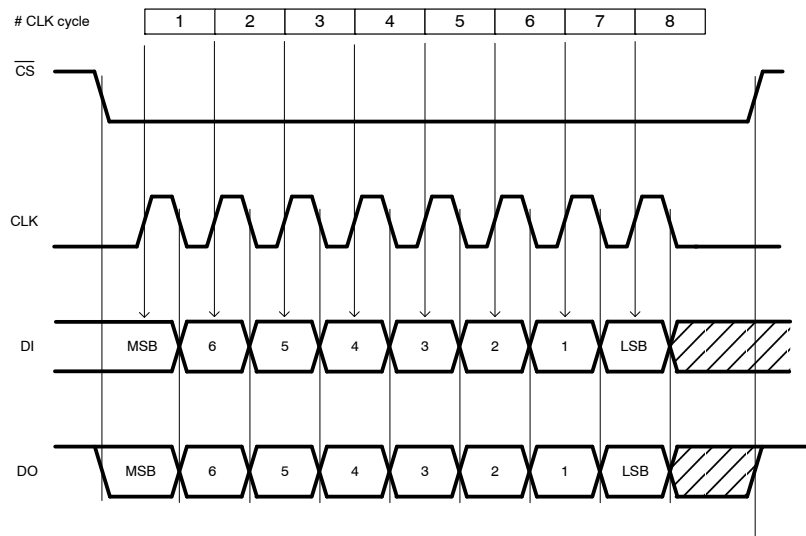


Figure 18. Timing Diagram of a SPI Transfer

NOTE: At the falling edge of the eight clock pulse the data-out shift register is updated with the content of the addressed internal SPI register. The internal SPI registers are updated at the first rising edge of the AMIS-30543 system clock when  $\overline{CS}$  = High

### Transfer Packet:

Serial data transfer is assumed to follow MSB first rule. The transfer packet contains one or more bytes.

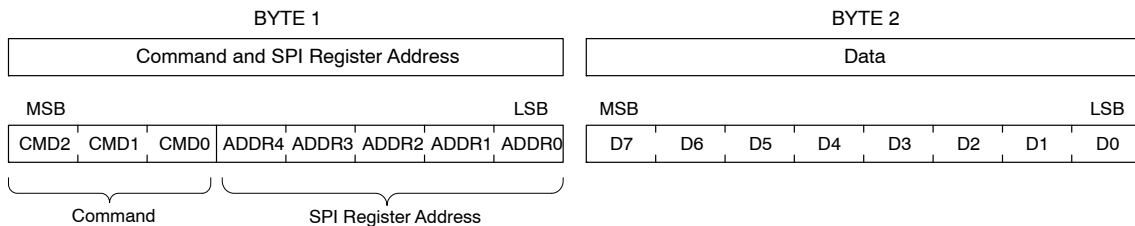


Figure 19. SPI Transfer Packet

Byte 1 contains the Command and the SPI Register Address and indicates to AMIS-30543 the chosen type of operation and addressed register. Byte 2 contains data, or

sent from the Master in a WRITE operation, or received from AMIS-30543 in a READ operation.

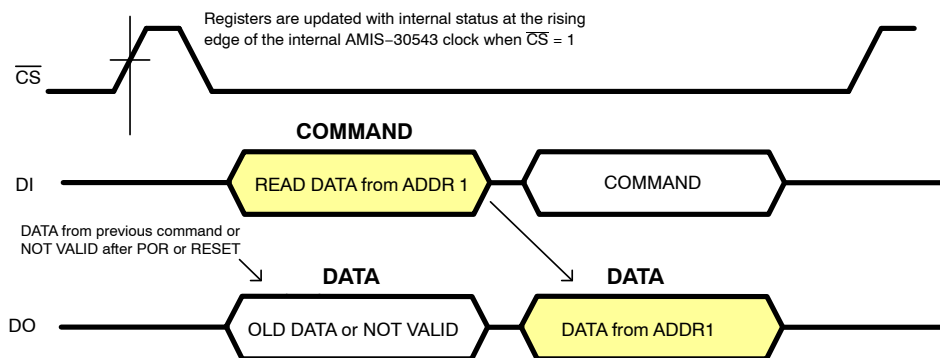
Two command types can be distinguished in the communication between master and AMIS-30543:

- **READ from SPI Register** with address ADDR[4:0]:  
CMD2 = "0"
- **WRITE to SPI Register** with address ADDR[4:0]:  
CMD2 = "1"

## READ Operation

If the Master wants to read data from Status or Control Registers, it initiates the communication by sending a

READ command. This READ command contains the address of the SPI register to be read out. At the falling edge of the eight clock pulse the data-out shift register is updated with the content of the corresponding internal SPI register. In the next 8-bit clock pulse train this data is shifted out via DO pin. At the same time the data shifted in from DI (Master) should be interpreted as the following successive command or the same command.



**Figure 20. Single READ Operation where DATA from SPI Register with Address 1 is Read by the Master**

All 4 Status Registers (see SPI Registers) contain 7 data bits and a parity check bit. The most significant bit (D7) represents a parity of D[6:0]. If the number of logical ones in D[6:0] is odd, the parity bit D7 equals "1". If the number of logical ones in D[6:0] is even then the parity bit D7 equals "0". This simple mechanism protects against noise and increases the consistency of the transmitted data. If a parity check error occurs it is recommended to initiate an additional READ command to obtain the status again.

Also the Control Registers can be read out following the same routine. Control Registers don't have a parity check.

The  $\overline{CS}$  line is active low and may remain low between successive READ commands as illustrated in Figure 22. There is however one exception. In case an error condition is latched in one of Status Registers (see SPI Registers) the  $\overline{ERR}$  pin is activated (See Section Error Output). This signal flags a problem to the external microcontroller. By reading the Status Registers information about the root cause of the problem can be determined. After this READ operation the Status Registers are cleared. Because the Status Registers and  $\overline{ERR}$  pin (see SPI Registers) are only updated by the internal system clock when the  $\overline{CS}$  line is high, the Master

should force  $\overline{CS}$  high immediately after the READ operation. For the same reason it is recommended to keep the  $\overline{CS}$  line high always when the SPI bus is idle.

## WRITE Operation

If the Master wants to write data to a Control Register it initiates the communication by sending a WRITE command. This contains the address of the SPI register to write to. The command is followed with a data byte. This incoming data will be stored in the corresponding Control Register after  $\overline{CS}$  goes from low to high! AMIS-30543 responds on every incoming byte by shifting out via DO the data stored in the last received address.

It is important that the writing action (command – address and data) to the Control Register is exactly 16 bits long. If more or less bits are transmitted the complete transfer packet is ignored.

A WRITE command executed for a read-only register (e.g. Status Registers) will not affect the addressed register and the device operation.

Because after a power-on-reset the initial address is unknown the data shifted out via DO is not valid.

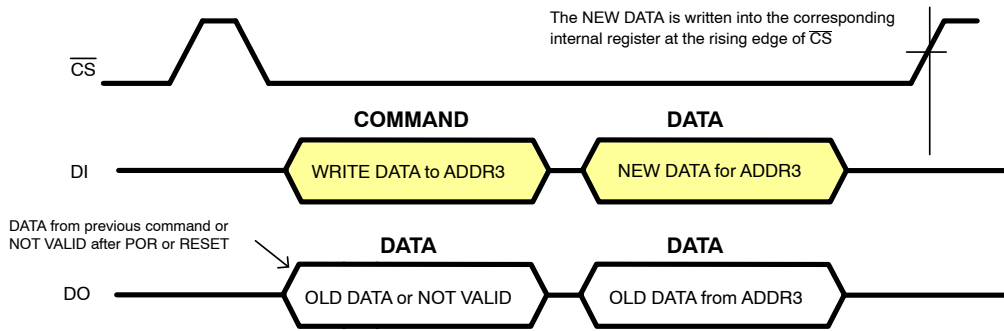


Figure 21. Single WRITE Operation Where DATA from the Master is Written in SPI Register with Address 3

### Examples of combined READ and WRITE Operations

In the following examples successive READ and WRITE operations are combined. In Figure 22 the Master first reads the status from Register at ADDR4 and at ADDR5 followed

by writing a control byte in Control Register at ADDR2. Note that during the write command the old data of the pointed register is returned at the moment the new data is shifted in

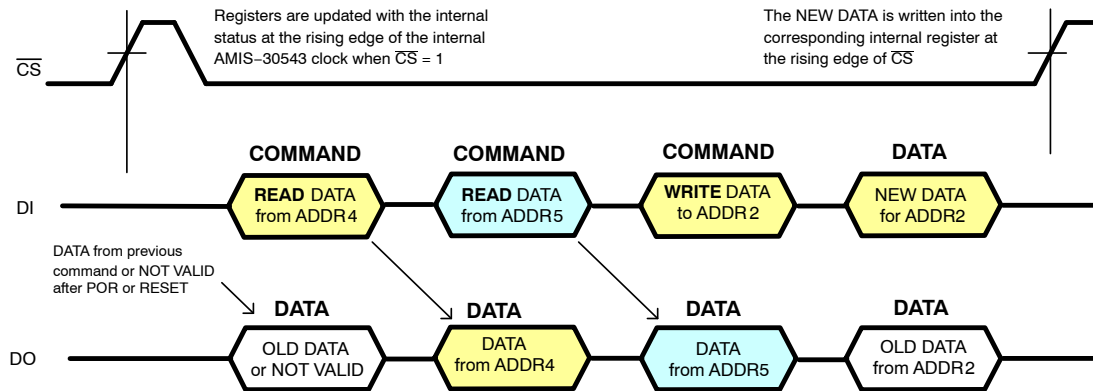
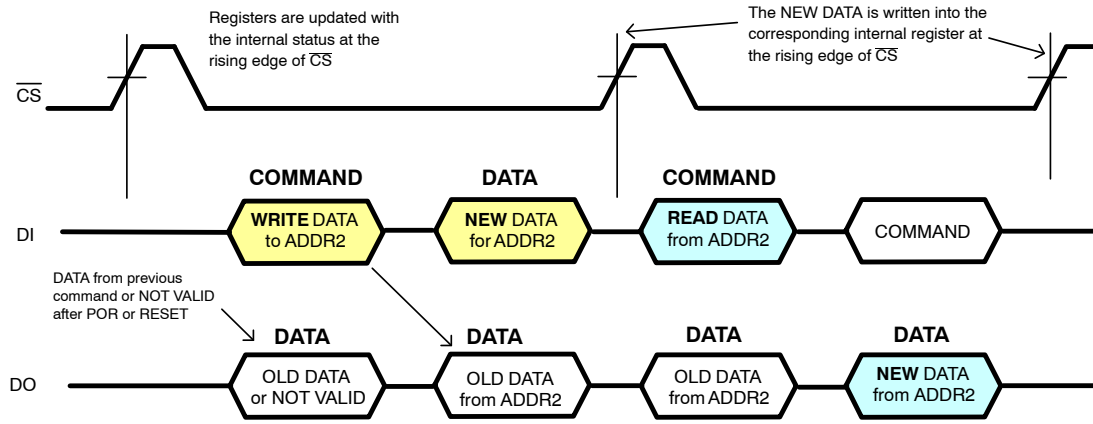


Figure 22. 2 Successive READ Commands Followed by a WRITE Command

After the write operation the Master could initiate a read back command in order to verify the data correctly written as illustrated in Figure 23. During reception of the READ command the old data is returned for a second time. Only after receiving the READ command the new data is

transmitted. This rule also applies when the master device wants to initiate an SPI transfer to read the Status Registers. Because the internal system clock updates the Status Registers only when  $\overline{CS}$  line is high, the first read out byte might represent old status information.



**Figure 23. A WRITE Operation Where DATA from the Master is Written in SPI Register with Address 2 Followed by a READ Back Operation to Confirm a Correct WRITE Operation**

**NOTE:** The internal data-out shift buffer of AMIS-30543 is updated with the content of the selected SPI register only at the last (every eight) falling edge of the CLK signal (see SPI Transfer Format and Pin Signals). As a result, new data for transmission cannot be written to the shift buffer at the beginning of the transfer packet and the first byte shifted out might represent old data.

**Table 11. SPI CONTROL REGISTERS** (All SPI control registers have Read/Write Access and default to “0” after power-on or hard reset)

| Address   | Content | Structure |          |       |          |       |          |          |       |
|-----------|---------|-----------|----------|-------|----------|-------|----------|----------|-------|
|           |         | Bit 7     | Bit 6    | Bit 5 | Bit 4    | Bit 3 | Bit 2    | Bit 1    | Bit 0 |
|           | Access  | R/W       | R/W      | R/W   | R/W      | R/W   | R/W      | R/W      | R/W   |
|           | Reset   | 0         | 0        | 0     | 0        | 0     | 0        | 0        | 0     |
| WR (00h)  | Data    | WDEN      | WDT[3:0] |       |          |       | –        | –        | –     |
| CR0 (01h) | Data    | SM[2:0]   |          |       | CUR[4:0] |       |          |          |       |
| CR1 (02h) | Data    | DIRCTRL   | NXTP     | –     | –        | PWMF  | PWMJ     | EMC[1:0] |       |
| CR2 (03h) | Data    | MOTEN     | SLP      | SLAG  | SLAT     | –     | –        | –        | –     |
| CR3 (09h) | Data    | –         | –        | –     | –        | –     | ESM[2:0] |          |       |

Where:

R/W Read and Write access

Reset: Status after power-On or hard reset

Table 12. SPI CONTROL PARAMETER OVERVIEW

| Symbol   | Description                                                                       | Status      |                                   | Value                |
|----------|-----------------------------------------------------------------------------------|-------------|-----------------------------------|----------------------|
| DIRCTRL  | Controls the direction of rotation (in combination with logic level on input DIR) | <DIR> = 0   | <DIRCTRL> = 0                     | CW motion (Note 15)  |
|          |                                                                                   |             | <DIRCTRL> = 1                     | CCW motion (Note 15) |
|          |                                                                                   | <DIR> = 1   | <DIRCTRL> = 0                     | CCW motion (Note 15) |
|          |                                                                                   |             | <DIRCTRL> = 1                     | CW motion (Note 15)  |
| NXTP     | Selects if NXT triggers on rising or falling edge                                 | <NXTP> = 0  | Trigger on rising edge            |                      |
|          |                                                                                   | <NXTP> = 1  | Trigger on falling edge           |                      |
| EMC[1:0] | Turn On – Turn-off Slopes of motor driver (Note 14)                               | 00          | Very Fast                         |                      |
|          |                                                                                   | 01          | Fast                              |                      |
|          |                                                                                   | 10          | Slow                              |                      |
|          |                                                                                   | 11          | Very Slow                         |                      |
| SLAT     | Speed load angle transparency bit                                                 | <SLAT> = 0  | SLA is not transparent            |                      |
|          |                                                                                   | <SLAT> = 1  | SLA is transparent                |                      |
| SLAG     | Speed load angle gain setting                                                     | <SLAG> = 0  | Gain = 0.5                        |                      |
|          |                                                                                   | <SLAG> = 1  | Gain = 0.25                       |                      |
| PWMF     | Enables doubling of the PWM frequency (Note 14)                                   | <PWMF> = 0  | Default Frequency                 |                      |
|          |                                                                                   | <PWMF> = 1  | Double Frequency                  |                      |
| PWMJ     | Enables jittery PWM                                                               | <PWMJ> = 0  | Jitter disabled                   |                      |
|          |                                                                                   | <PWMJ> = 1  | Jitter enabled                    |                      |
| SM[2:0]  | Stepmode (only valid if ESM[2:0] = 000)                                           | 000         | 1/32 Micro – Step                 |                      |
|          |                                                                                   | 001         | 1/16 Micro – Step                 |                      |
|          |                                                                                   | 010         | 1/8 Micro – Step                  |                      |
|          |                                                                                   | 011         | 1/4 Micro – Step                  |                      |
|          |                                                                                   | 100         | Compensated Half Step             |                      |
|          |                                                                                   | 101         | Uncompensated Half Step           |                      |
|          |                                                                                   | 110         | Uncompensated full step           |                      |
|          |                                                                                   | 111         | Uncompensated full step           |                      |
| ESM[2:0] | Stepmode                                                                          | 001         | 1/128 Micro–Step                  |                      |
|          |                                                                                   | 010         | 1/64 Micro–Step                   |                      |
|          |                                                                                   | 011         | Compensated full step, 2 phase on |                      |
|          |                                                                                   | 100         | Compensated full step, 1 phase on |                      |
|          |                                                                                   | Other       | Stepping mode defined by SM[2:0]  |                      |
| SLP      | Enables sleep mode (if $V_{BB} > 9\text{ V}$ )                                    | <SLP> = 0   | Active mode                       |                      |
|          |                                                                                   | <SLP> = 1   | Sleep mode                        |                      |
| MOTEN    | Activates the motor driver outputs                                                | <MOTEN> = 0 | Drivers disabled                  |                      |
|          |                                                                                   | <MOTEN> = 1 | Drivers enabled                   |                      |

14. The typical values can be found in Table 4: DC Parameters and in Table 5: AC parameters

15. Depending on the wiring of the motor connections

**CUR[4:0]** Selects IMCmax peak. This is the peak or amplitude of the regulated current waveform in the motor coils.

**Table 13. SPI CONTROL PARAMETER OVERVIEW CUR[4:0]**

| Current Range<br>(Note 17) | Index CUR[4:0] |       | Current (mA)<br>(Note 16) | Current Range<br>(Note 17) | Index CUR[4:0] |       | Current (mA)<br>(Note 16) |
|----------------------------|----------------|-------|---------------------------|----------------------------|----------------|-------|---------------------------|
| 0                          | 0              | 00000 | 132                       | 3                          | 16             | 10000 | 1405                      |
|                            | 1              | 00001 | 245                       |                            | 17             | 10001 | 1520                      |
|                            | 2              | 00010 | 355                       |                            | 18             | 10010 | 1695                      |
| 1                          | 3              | 00011 | 395                       |                            | 19             | 10011 | 1850                      |
|                            | 4              | 00100 | 445                       |                            | 20             | 10100 | 2070                      |
|                            | 5              | 00101 | 485                       |                            | 21             | 10101 | 2240                      |
|                            | 6              | 00110 | 540                       |                            | 22             | 10110 | 2440                      |
|                            | 7              | 00111 | 585                       |                            | 23             | 10111 | 2700                      |
|                            | 8              | 01000 | 640                       |                            | 24             | 11000 | 2845                      |
|                            | 9              | 01001 | 715                       |                            | 25             | 11001 | 3000                      |
| 2                          | 10             | 01010 | 780                       |                            | 26             | 11010 | 3000                      |
|                            | 11             | 01011 | 870                       |                            | 27             | 11011 | 3000                      |
|                            | 12             | 01100 | 955                       |                            | 28             | 11100 | 3000                      |
|                            | 13             | 01101 | 1060                      |                            | 29             | 11101 | 3000                      |
|                            | 14             | 01110 | 1150                      |                            | 30             | 11110 | 3000                      |
|                            | 15             | 01111 | 1260                      |                            | 31             | 11111 | 3000                      |

16. Typical current amplitude at  $T_J = 125$

17. Reducing the current over different current ranges might trigger overcurrent detection. See dedicated application note for solutions

### SPI Status Register Description

All 5 SPI status registers have Read Access and are default to “0” after power-on or hard reset.

**Table 14. SPI STATUS REGISTERS**

| Address   | Content             | Structure |          |        |        |        |       |       |       |
|-----------|---------------------|-----------|----------|--------|--------|--------|-------|-------|-------|
|           |                     | Bit 7     | Bit 6    | Bit 5  | Bit 4  | Bit 3  | Bit 2 | Bit 1 | Bit 0 |
|           | Access              | R         | R        | R      | R      | R      | R     | R     | R     |
| Address   | Reset               | 0         | 0        | 0      | 0      | 0      | 0     | 0     | 0     |
| SR0 (04h) | Data is not latched | PAR       | TW       | CPFAIL | WD     | OPENX  | OPENY | –     | –     |
| SR1 (05h) | Data is latched     | PAR       | OVCXPT   | OVCXPB | OVCXNT | OVCXNB | –     | –     | –     |
| SR2 (06h) | Data is latched     | PAR       | OVCYPT   | OVCYPB | OVCYNT | OVCYNB | TSD   | –     | –     |
| SR3 (07h) | Data is not latched | PAR       | MSP[8:2] |        |        |        |       |       |       |
| SR4 (0Ah) | Data is not latched | PAR       | MSP[6:0] |        |        |        |       |       |       |

Where:

R Read only mode access  
Reset Status after power-on or hard reset  
PAR Parity check

Table 15. SPI STATUS FLAGS OVERVIEW

| Mnemonic | Flag                                                                                             | Length (bit) | Related SPI Register                           | Comment                                                                                                             | Reset State |
|----------|--------------------------------------------------------------------------------------------------|--------------|------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-------------|
| CPFail   | Charge pump failure                                                                              | 1            | <u>Status Register 0</u>                       | '0' = no failure<br>'1' = failure: indicates that the charge pump does not reach the required voltage level. Note 1 | '0'         |
| MSP[8:0] | Micro-step position                                                                              | 9            | <u>Status Register 3 and Status Register 4</u> | Translator micro step position                                                                                      | '000000000' |
| OPENX    | OPEN Coil X                                                                                      | 1            | <u>Status Register 0</u>                       | '1' = Open coil detected                                                                                            | '0'         |
| OPENY    | OPEN Coil Y                                                                                      | 1            | <u>Status Register 0</u>                       | '1' = Open coil detected                                                                                            | '0'         |
| OVCXNB   | <b>O</b> Ver <b>C</b> urrent on X H-bridge; <b>MOT</b> <b>XN</b> terminal; <b>B</b> ottom tran.  | 1            | <u>Status Register 1</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at bottom transistor XN-terminal         | '0'         |
| OVCXNT   | <b>O</b> Ver <b>C</b> urrent on X H-bridge; <b>MOT</b> <b>XN</b> terminal; <b>T</b> op transist. | 1            | <u>Status Register 1</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at top transistor XN-terminal            | '0'         |
| OVCXPB   | <b>O</b> Ver <b>C</b> urrent on X H-bridge; <b>MOT</b> <b>XP</b> terminal; <b>B</b> ottom tran.  | 1            | <u>Status Register 1</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at bottom transistor XP-terminal         | '0'         |
| OVCXPT   | <b>O</b> Ver <b>C</b> urrent on X H-bridge; <b>MOT</b> <b>XP</b> terminal; <b>T</b> op transist. | 1            | <u>Status Register 1</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at top transistor XP-terminal            | '0'         |
| OVCYNB   | <b>O</b> Ver <b>C</b> urrent on Y H-bridge; <b>MOT</b> <b>YN</b> terminal; <b>B</b> ottom tran.  | 1            | <u>Status Register 2</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at bottom transistor YN-terminal         | '0'         |
| OVCYNT   | <b>O</b> Ver <b>C</b> urrent on Y H-bridge; <b>MOT</b> <b>YN</b> terminal; <b>T</b> op transist. | 1            | <u>Status Register 2</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at top transistor YN-terminal            | '0'         |
| OVCYPB   | <b>O</b> Ver <b>C</b> urrent on Y H-bridge; <b>MOT</b> <b>YP</b> terminal; <b>B</b> ottom tran.  | 1            | <u>Status Register 2</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at bottom transistor YP-terminal         | '0'         |
| OVCYPT   | <b>O</b> Ver <b>C</b> urrent on Y H-bridge; <b>MOT</b> <b>YP</b> terminal; <b>T</b> op transist. | 1            | <u>Status Register 2</u>                       | '0' = no failure<br>'1' = failure: indicates that over current is detected at top transistor YP-terminal            | '0'         |
| TSD      | Thermal shutdown                                                                                 | 1            | <u>Status Register 2</u>                       |                                                                                                                     | '0'         |
| TW       | Thermal warning                                                                                  | 1            | <u>Status Register 0</u>                       |                                                                                                                     | '0'         |
| WD       | Watchdog event                                                                                   | 1            | <u>Status Register 0</u>                       | '1' = watchdog reset after time-out                                                                                 | '0'         |

NOTE: WD – This bit indicates that the watchdog timer has not been cleared properly. If the master reads that WD is set to “1” after reset, it means that a watchdog reset occurred (warm boot) instead of POR (cold boot). WD bit will be cleared only when the master writes “0” to WDEN bit.

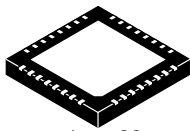
Table 16. ORDERING INFORMATION

| Part No.         | Peak Current | Temperature Range | Package                         | Shipping†     |
|------------------|--------------|-------------------|---------------------------------|---------------|
| AMIS30543C5431G  | 3000 mA      | –40°C to 125°C    | NQFP-32 (7 x 7 mm)<br>(Pb-Free) | Units / Tubes |
| AMIS30543C5431RG | 3000 mA      | –40°C to 125°C    | NQFP-32 (7 x 7 mm)<br>(Pb-Free) | Tape & Reel   |

†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.

**QFN32 7x7, 0.65P**  
**CASE 485J-02**  
**ISSUE E**

DATE 30 JAN 2013


**SCALE 2:1**

PIN 1  
INDICATOR

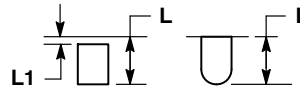
2X 0.15 C

2X 0.15 C

0.10 C

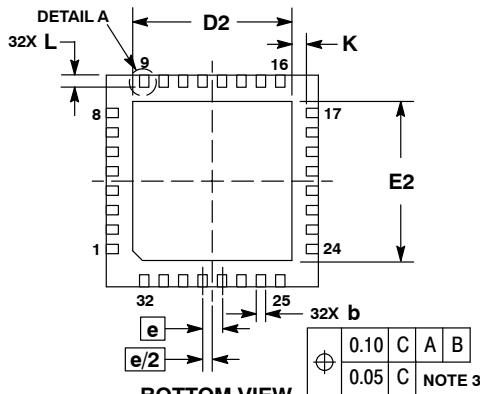
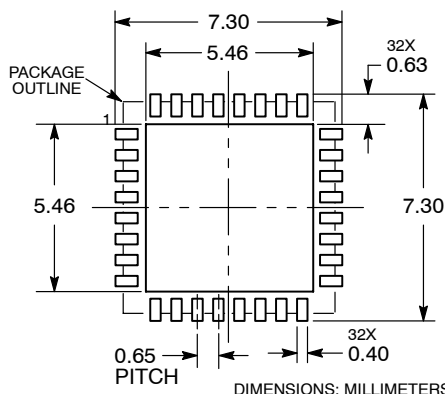
0.08 C

NOTE 4

**TOP VIEW**
**DETAIL B**
**SIDE VIEW**

**DETAIL A**  
**ALTERNATE TERMINAL**  
**CONSTRUCTIONS**

EXPOSED Cu MOLD CMPD

**DETAIL B**  
**ALTERNATE**  
**CONSTRUCTION**

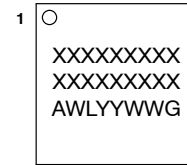
SEATING  
PLANE

**BOTTOM VIEW**
**RECOMMENDED**  
**MOUNTING FOOTPRINT**


DIMENSIONS: MILLIMETERS

**NOTES:**

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: MILLIMETERS.
3. DIMENSION b APPLIES TO PLATED TERMINAL AND IS MEASURED BETWEEN 0.15 AND 0.25MM FROM THE TERMINAL TIP.
4. COPLANARITY APPLIES TO THE EXPOSED PAD AS WELL AS THE TERMINALS.

| MILLIMETERS |      |      |
|-------------|------|------|
| DIM         | MIN  | MAX  |
| A           | 0.80 | 1.00 |
| A1          | 0.00 | 0.05 |
| A3          | 0.20 | REF  |
| b           | 0.25 | 0.35 |
| D           | 7.00 | BSC  |
| D2          | 5.16 | 5.36 |
| E           | 7.00 | BSC  |
| E2          | 5.16 | 5.36 |
| e           | 0.65 | BSC  |
| K           | 0.20 | ---  |
| L           | 0.30 | 0.50 |
| L1          | 0.00 | 0.15 |

**GENERIC**  
**MARKING DIAGRAM\***

A = Assembly Location  
WL = Wafer Lot  
YY = Year  
WW = Work Week  
G = Pb-Free Package

\*This information is generic. Please refer to device data sheet for actual part marking.  
Pb-Free indicator, "G" or microdot "▪", may or may not be present.

**DOCUMENT NUMBER:** 98AON11451D

Electronic versions are uncontrolled except when accessed directly from the Document Repository.  
Printed versions are uncontrolled except when stamped "CONTROLLED COPY" in red.

**DESCRIPTION:** QFN32 7X7, 0.65MM PITCH

**PAGE 1 OF 1**

onsemi and onsemi are trademarks of Semiconductor Components Industries, LLC dba onsemi or its subsidiaries in the United States and/or other countries. onsemi reserves the right to make changes without further notice to any products herein. onsemi makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does onsemi assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. onsemi does not convey any license under its patent rights nor the rights of others.

**onsemi**, **Onsemi**, and other names, marks, and brands are registered and/or common law trademarks of Semiconductor Components Industries, LLC dba "**onsemi**" or its affiliates and/or subsidiaries in the United States and/or other countries. **onsemi** owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of **onsemi**'s product/patent coverage may be accessed at [www.onsemi.com/site/pdf/Patent-Marking.pdf](http://www.onsemi.com/site/pdf/Patent-Marking.pdf). **onsemi** reserves the right to make changes at any time to any products or information herein, without notice. The information herein is provided "as-is" and **onsemi** makes no warranty, representation or guarantee regarding the accuracy of the information, product features, availability, functionality, or suitability of its products for any particular purpose, nor does **onsemi** assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using **onsemi** products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by **onsemi**. "Typical" parameters which may be provided in **onsemi** data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. **onsemi** does not convey any license under any of its intellectual property rights nor the rights of others. **onsemi** products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use **onsemi** products for any such unintended or unauthorized application, Buyer shall indemnify and hold **onsemi** and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that **onsemi** was negligent regarding the design or manufacture of the part. **onsemi** is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.

## ADDITIONAL INFORMATION

### TECHNICAL PUBLICATIONS:

Technical Library: [www.onsemi.com/design/resources/technical-documentation](http://www.onsemi.com/design/resources/technical-documentation)  
onsemi Website: [www.onsemi.com](http://www.onsemi.com)

### ONLINE SUPPORT: [www.onsemi.com/support](http://www.onsemi.com/support)

For additional information, please contact your local Sales Representative at  
[www.onsemi.com/support/sales](http://www.onsemi.com/support/sales)