

TOSHIBA BiCD Integrated Circuit Silicon Monolithic

# TB6613FTG

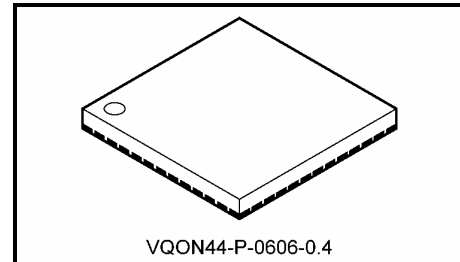
## DC and Stepping Motor Driver

The TB6613FTG is a DC motor driver IC using LDMOS output transistors with low ON-resistance.

The TB6613FTG incorporates five PWM constant-current H-bridge drivers, of which four drivers can be used for microstepping motor drives of up to two stepping motors.

The TB6613FTG is best suited to control various lens actuators in digital still cameras.

The three-wire serial interface provides control over the drivers, thus reducing the number of lines required for interfacing with the control IC.



Weight: 0.05 g (typ.)

## Features

- Motor power supply voltage:  $V_M \leq 6\text{ V}$  (max)
- Control power supply voltage:  $V_{CC} = 3\text{ V}$  to  $6\text{ V}$
- Output current:  $I_{OUT} \leq 0.8\text{ A}$  (max)
- Complementary P- and N-channel LDMOS output transistors
- Output ON-resistance:  $R_{ON}$  (upper and lower sum) =  $1.5\ \Omega$  (@ $V_M = V_{CC} = 5\text{ V}$  typ.)

### Channels A, B, C and D

- Four H-bridge drivers capable of PWM constant-current control  
Supports up to two two-phase bipolar stepping motors (STMs) or up to four actuators.
- Each channel is individually configurable for either H-Bridge mode or STM  $\mu$ Step mode via the serial interface.
- In STM  $\mu$ Step mode, the microstepping resolution is selectable from 6 bits (256 steps per full cycle) or 1 bit (8 steps per full cycle).

### Channel E

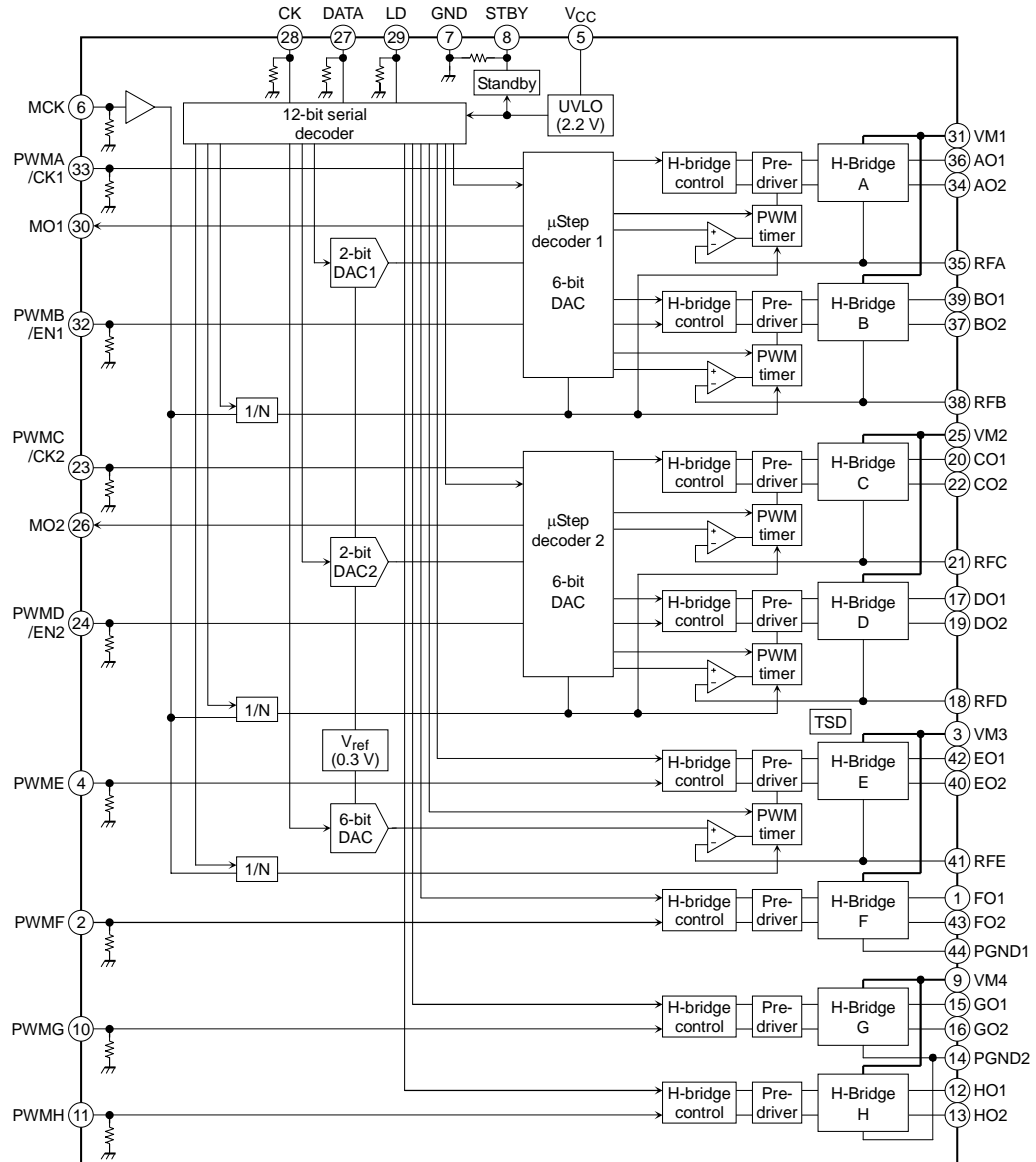
- One PWM constant-current driver
- The constant-current reference voltage ( $V_{ref}$ ) is programmable via the internal 6-bit DAC.

### Other Features

- Each channel has a DAC for setting constant-current values (Channels A to D = 2 bits in H-Bridge mode and 2 bits  $\times$  6 bits in  $\mu$ Step mode; Channel E = 6 bits)
- Dedicated standby (power-save) pin
- Thermal shutdown (TSD)
- Undervoltage lockout (UVLO): Resets and disables the internal circuitry when  $V_{CC}$  falls below  $2.2\text{ V}$  (typ.).
- Small VQON44 package (0.4-mm lead pitch)
- Compatible with lead-free reflow soldering

Note: This product has a MOS structure and is sensitive to electrostatic discharge. When handling this product, ensure that the environment is protected against electrostatic discharge by using an earth strap, a conductive mat and an ionizer. Ensure also that the ambient temperature and relative humidity are maintained at reasonable levels.

Block Diagram



**Pin Function**

| No. | Pin Name        | I/O | Function  |
|-----|-----------------|-----|---|
| 1   | FO1             | O   | Channel-F output 1  |
| 2   | PWMF            | I   | PWM signal input (Channel F)  |
| 3   | VM3             | —   | Motor power supply 3 (Channels E and F)   |
| 4   | PWME            | I   | PWM signal input (Channel E)  |
| 5   | V <sub>CC</sub> | —   | Power supply  |
| 6   | MCK             | I   | Clock input for constant-current control  |
| 7   | GND             | —   | Ground  |
| 8   | STBY            | I   | Standby (power-save) control  |
| 9   | VM4             | —   | Motor power supply 4 (Channels G and H)   |
| 10  | PWMG            | I   | PWM signal input (Channel G)  |
| 11  | PWMH            | I   | PWM signal input (Channel H)  |
| 12  | HO1             | O   | Channel-H output 1  |
| 13  | HO2             | O   | Channel-H output 2  |
| 14  | PGND2           | —   | Motor ground 2 (Channels G and H)   |
| 15  | GO1             | O   | Channel-G output 1  |
| 16  | GO2             | O   | Channel-G output 2  |
| 17  | DO1             | O   | Channel-D output 1  |
| 18  | RFD             | —   | Connection pin for a current-sensing resistor (Channel D)                             |
| 19  | DO2             | O   | Channel-D output 2  |
| 20  | CO1             | O   | Channel-C output 1  |
| 21  | RFC             | —   | Connection pin for a current-sensing resistor (Channel C)                             |
| 22  | CO2             | O   | Channel-C output 2  |
| 23  | PWMC/CK2        | I   | PWM signal input (Channel C)/ $\mu$ Step clock input 2                                |
| 24  | PWMD/EN2        | I   | PWM signal input (Channel D)/STM enable input 2                                       |
| 25  | VM2             | —   | Motor power supply 2 (Channels C and D)   |
| 26  | MO2             | O   | STM electrical degree monitor output 2, Open-drain output, need ext. pull-up resistor |
| 27  | DATA            | I   | Serial data input   |
| 28  | CK              | I   | Serial clock input  |
| 29  | LD              | I   | Serial load enable  |
| 30  | MO1             | O   | STM electrical degree monitor output 1, Open-drain output, need ext. pull-up resistor |
| 31  | VM1             | —   | Motor power supply 1  |
| 32  | PWMB/EN1        | I   | PWM signal input (Channel B)/STM enable input 1                                       |
| 33  | PWMA/CK1        | I   | PWM signal input (Channel A)/ $\mu$ Step clock input 1                                |
| 34  | AO2             | O   | Channel-A output 2  |
| 35  | RFA             | —   | Connection pin for a current-sensing resistor (Channel A)                             |
| 36  | AO1             | O   | Channel-A output 1  |
| 37  | BO2             | O   | Channel-B output 2  |
| 38  | RFB             | —   | Connection pin for a current-sensing resistor (Channel B)                             |
| 39  | BO1             | O   | Channel-B output 1  |
| 40  | EO2             | O   | Channel-E output 1  |
| 41  | RFE             | —   | Connection pin for a current-sensing resistor (Channel E)                             |
| 42  | EO1             | O   | Channel-E output 1  |
| 43  | FO2             | O   | Channel-F output 2  |
| 44  | PGND1           | —   | Motor ground 1 (Channel F)  |

## Absolute Maximum Ratings (Ta = 25°C)

| Characteristics       | Symbol           | Rating          | Unit | Remarks                |
|-----------------------|------------------|-----------------|------|------------------------|
| Supply voltage        | V <sub>CC</sub>  | 6               | V    | V <sub>CC</sub>        |
| Motor supply voltage  | V <sub>M</sub>   | 6               | V    | V <sub>M</sub>         |
| Output voltage        | V <sub>OUT</sub> | -0.2 to 6       | V    | Channels A to G        |
|                       | V <sub>MO</sub>  | V <sub>CC</sub> | V    | MO1, MO2 (Open-drain)  |
| Output current        | I <sub>OUT</sub> | 0.8             | A    | Sum of channels A to G |
|                       | I <sub>MO</sub>  | 1               | mA   | MO1, MO2 (Open-drain)  |
| Input voltage         | V <sub>IN</sub>  | -0.2 to 6       | V    | Control input pins     |
| Power dissipation     | P <sub>D</sub>   | 4.17            | W    | Note                   |
| Operating temperature | T <sub>opr</sub> | -20 to 85       | °C   |                        |
| Storage temperature   | T <sub>stg</sub> | -55 to 150      | °C   |                        |

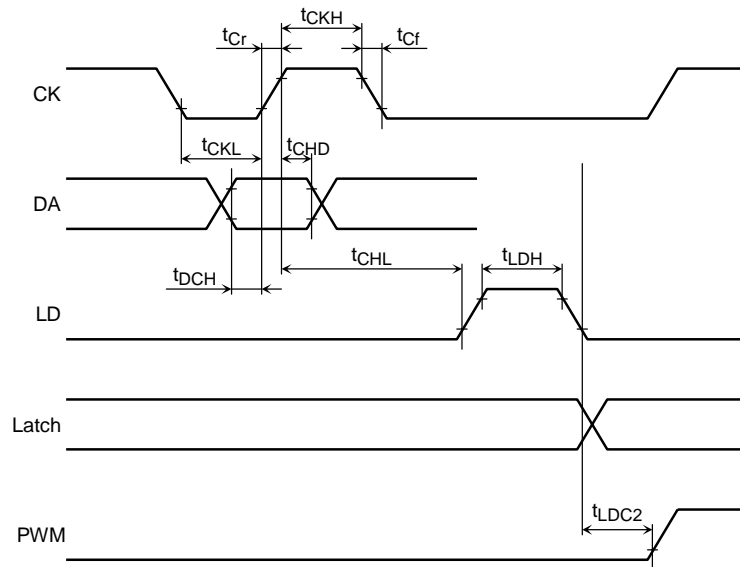
Note: When mounted on a single-side glass epoxy PCB (size: 76.4 mm × 114.3 mm × 1.6 mm) with a 40% dissipating copper surface.

## Operating Ranges (Ta = -20 to 85°C)

| Characteristics                           | Symbol           | Rating |      |     | Unit | Remarks                      |
|---|------------------|--------|------|-----|------|------------------------------|
|   |                  | Min    | Typ. | Max |      |                              |
| Supply voltage for small-signal circuitry | V <sub>CC</sub>  | 3      | 3.3  | 5.5 | V    |                              |
| Motor supply voltage                      | V <sub>M</sub>   | 2.5    | —    | 5.5 | V    |                              |
| Output current                            | I <sub>OUT</sub> | —      | —    | 600 | mA   | V <sub>M</sub> = 3 to 5.5 V  |
|   |                  | —      | —    | 250 |      | 2.2 V ≤ V <sub>M</sub> ≤ 3 V |
| PWM frequency                             | f <sub>PWM</sub> | —      | —    | 100 | kHz  |                              |
| Master clock frequency                    | f <sub>MCK</sub> | —      | 1    | 5   | MHz  |                              |

## Operating Ranges: Serial Data Controller (Ta = -20°C to 85°C)

| Characteristics        | Symbol     | Rating |     | Unit    |
|------------------------|------------|--------|-----|---------|
|                        |            | Min    | Max |         |
| Clock pulse width Low  | $t_{CKL}$  | 200    | —   | ns      |
| Clock pulse width High | $t_{CKH}$  | 200    | —   | ns      |
| Clock rise time        | $t_{Cr}$   | —      | 50  | ns      |
| Clock fall time        | $t_{Cf}$   | —      | 50  | ns      |
| Data setup time        | $t_{DCH}$  | 30     | —   | ns      |
| Data hold time         | $t_{CHD}$  | 60     | —   | ns      |
| CK to LD rising edge   | $t_{CHL}$  | 200    | —   | ns      |
| LD to PWM delay        | $t_{LDC2}$ | 100    | —   | ns      |
| Load pulse width High  | $t_{LDH}$  | 2      | —   | $\mu$ s |
| CK frequency           | $f_{CLK}$  | —      | 2.5 | MHz     |



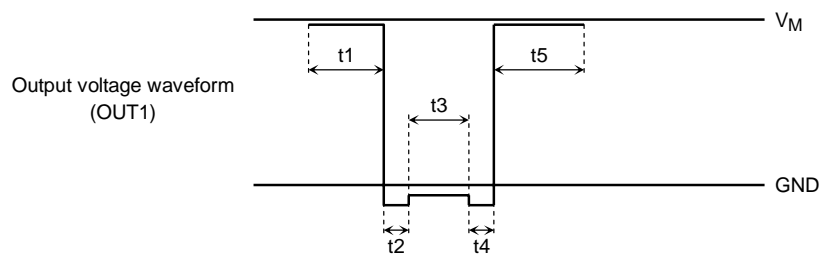
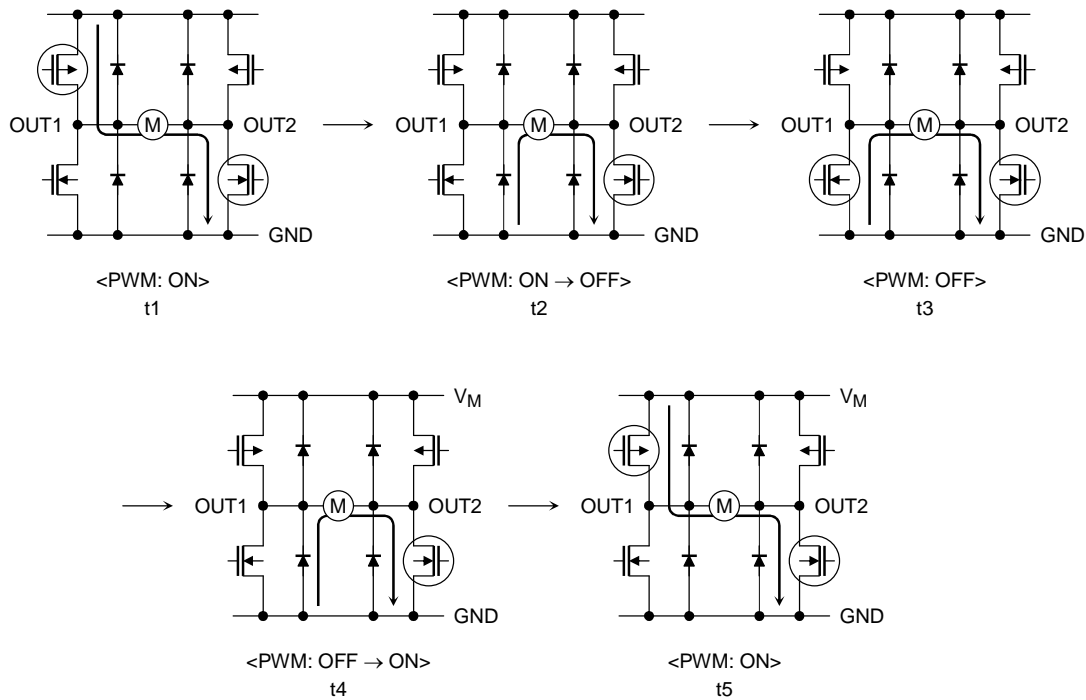
## Principle of Operation

### Bridge Outputs: Channels A through H

#### PWM Control

In PWM constant-current mode, the PWM chopper circuit alternates between on ( $t_1$ ,  $t_5$ ) and short brake ( $t_3$ ).

(To eliminate shoot-through current, a dead time ( $t_2$ ,  $t_4$ ) of 50 ns (design target only) is inserted when the PWM is turned on and off.)



**Constant-Current H-Bridge Drivers: PWM Constant-Current Choppers with a Constant Turn-Off Period**

The TB6613FTG has PWM choppers with a constant turn-off period.

The turn-off period is measured by counting the number of rising edges of an internal clock signal, which is generated by dividing the external MCK signal. The turn-off period can be adjusted by changing either the MCK frequency or the number of its rising edges counted (2, 4, 6 or 8 counts).

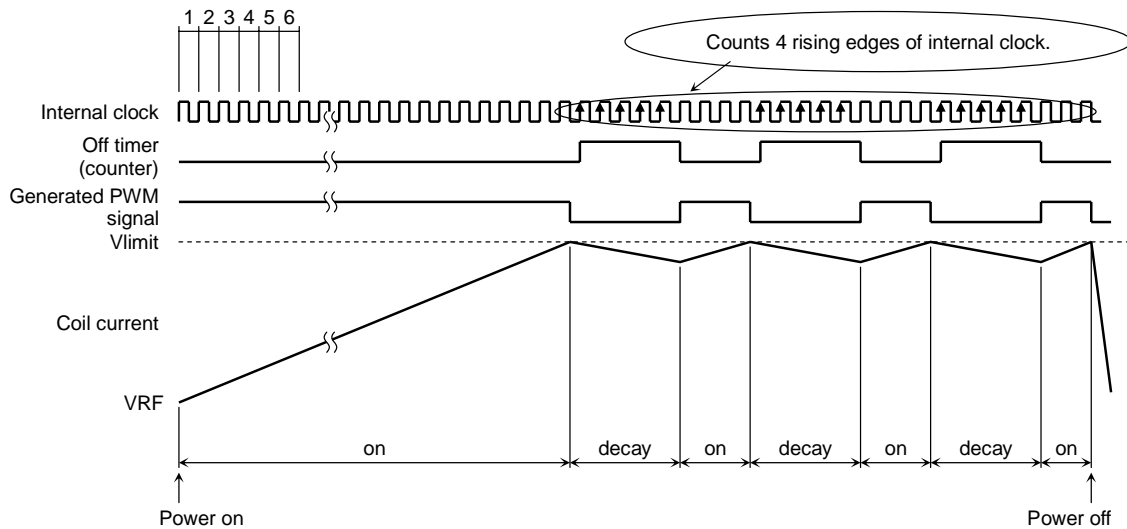
Example: Turn-off period of four clock cycles

Turning on the power supply causes a current to flow into the motor coils. The peak current through the winding is sensed via an external current-sensing resistor. As the current increases, a voltage (VRF) develops across the resistor, which is fed back to the internal comparator. At the predetermined reference voltage (Vlimit), the comparator turns off (chops) the power supply.

When high-side output transistors are turned off, the TB6613FTG, by default, counts four rising edges of the internal clock signal as a turn-off period. (The counter resets at the fifth rising edge of the clock.)

Based on this turn-off period, the TB6613FTG generates a PWM signal that turns on and off the output transistors.

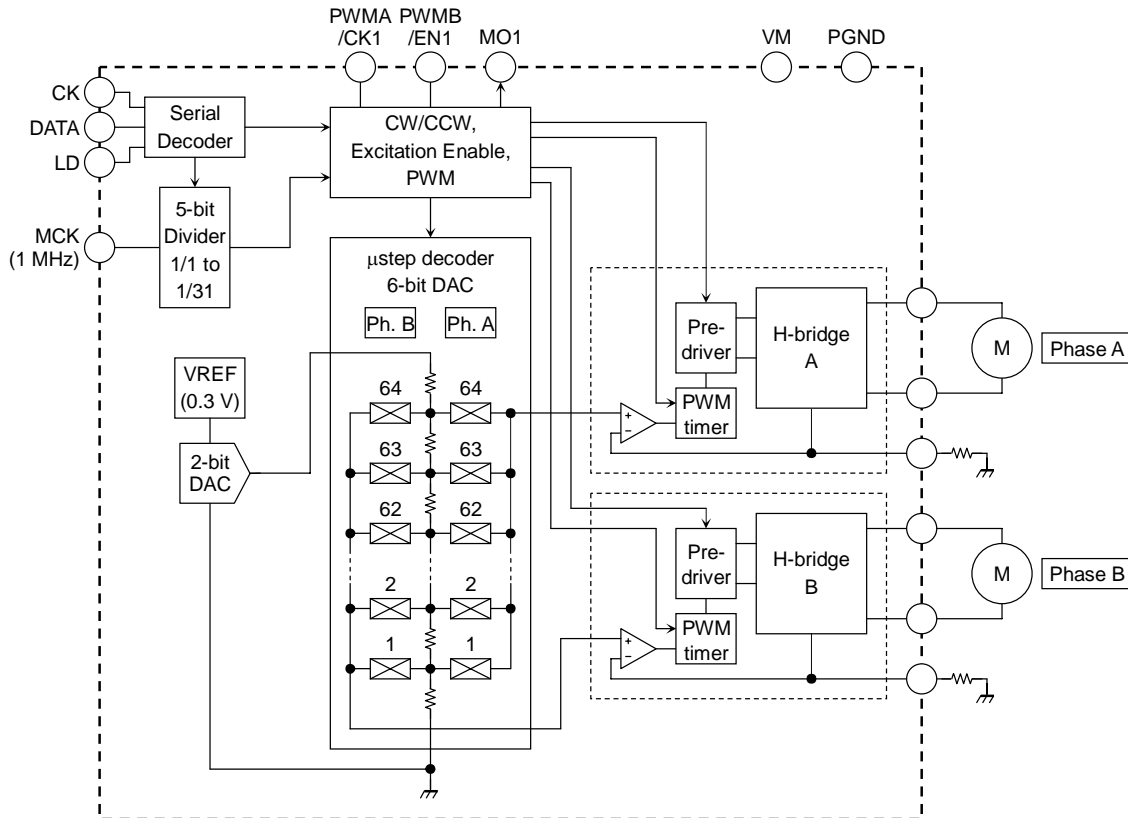
**Timing Diagram of the PWM Constant-Current Chopper Circuit with a Turn-Off Period of Four Clock Cycles**



(The upper limit of the coil current (IO peak) can be calculated as:  $IO = Vlimit/RNF$ .)

## Microstep Control: Channels A, B, C and D

In PWM constant-current mode, when the TB6613FTG generates a PWM signal, it measures a constant turn-off period by counting the number of rising edges of the internal clock signal (divided clock of MCK).



- Pulse clock control: The TB6613FTG steps up the current at each rising edge of the clock input to the PWMA/CK1 (for channels A and B) or PWMC/CK2 (for channels C and D) pin. (Current step-ups actually occur synchronous to the internal clock signal derived from MCK.)
- μStep modes: Selectable from the following two modes:
  - 1-bit mode: 8 steps per full cycle
  - 6-bit mode: resolution = 256 steps per full cycle
- Enable control: Setting PWMB/EN1 (for channels A and B) or PWMD/EN2 (for channels C and D) High and Low enables and disables motor excitation.
  - ENn = 1: Excitation enabled; ENn = 0: Excitation disabled
- Current decay modes: In STM μStep mode, the motor current recirculates back to the power supply in Fast-Decay mode when the Vref level changes during current step-down. The current decay rate is selectable from four modes.
- Electrical degree monitor: As the output current increases or decreases in steps with the CK input, a negative pulse is generated from the MO1 (or MO2) pin at every 90 or 360 electrical degrees.
- PWM chopping frequency: The PWM signal is generated by dividing the external MCK signal by up to 31, as programmed in a 5-bit register.
- Turn-off period: The turn-off period is selectable from 2, 4, 6 and 8 cycles of the internal clock signal, which is generated by dividing MCK internally.



- Constant-current setting: The maximum Vref voltage can be selected from 0.3 V, 0.225 V, 0.15 V and 0.075 V with a 2-bit DAC based on the 0.3-V on-chip reference voltage. This DAC output is divided by the 6-bit DAC under control of the microstep decoder to establish Vref for constant-current control.

**Current Decay Mode: Only Applicable for Step-Down Control in STM  $\mu$ Step Mode**

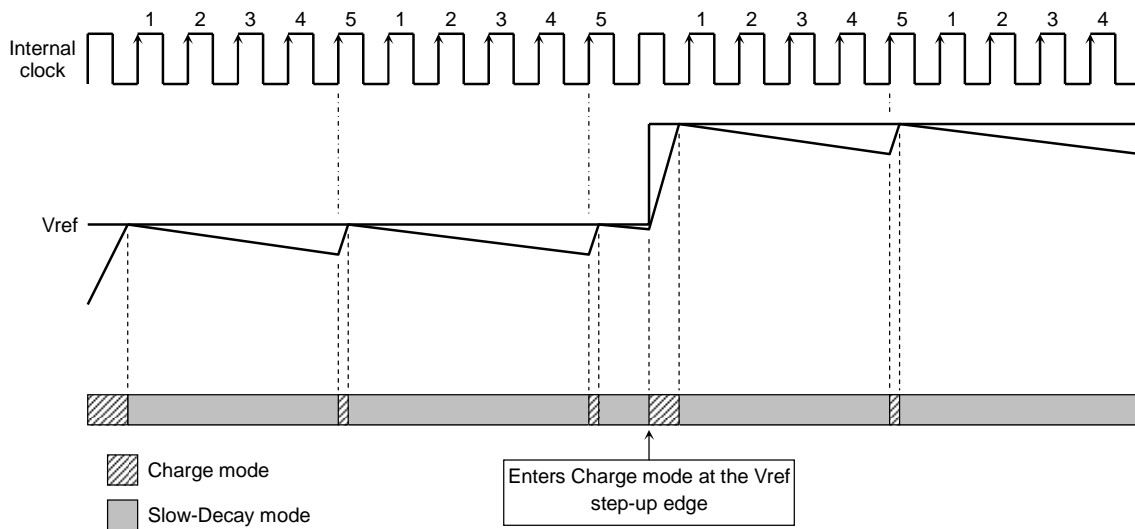
In STM  $\mu$ Step mode, the output current step-down slope may not match the changes of the target current level specified by Vref depending on the time constant of a motor coil, thus leading to a big distortion from the desired output current waveform.

To improve the matching between the output current and the target current level, the TB6613FTG enters Fast-Decay mode very briefly immediately after each Vref step-down. In this mode, the output current recirculates back to the power supply.

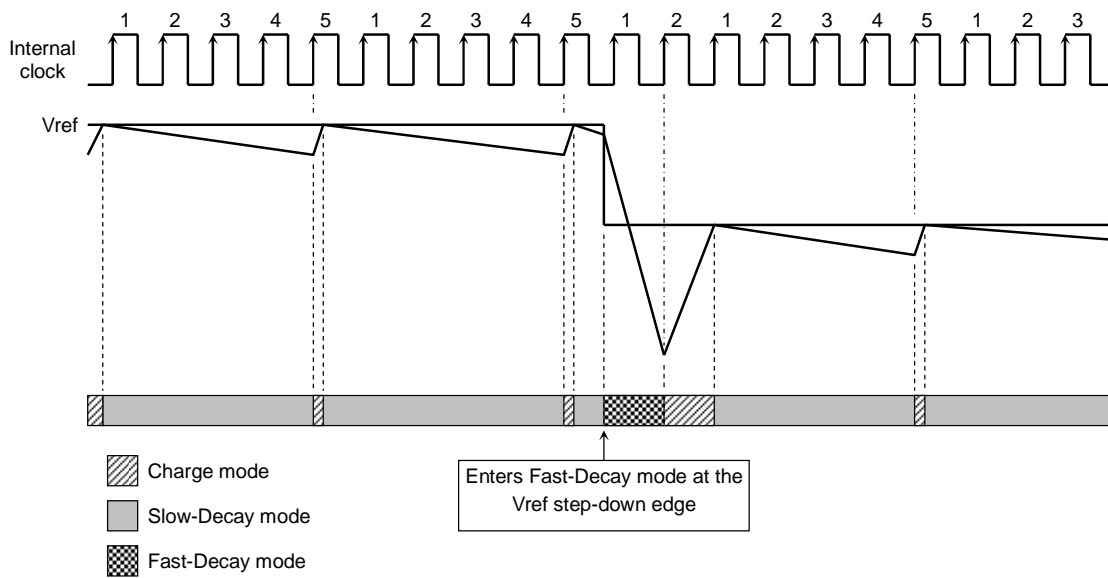
The Fast-Decay time is generated by counting the internal clock signal and selectable from the four modes listed below:

| Fast-Decay Mode | Number of Internal Clock Cycle | Decay Rate |
|-----------------|--------------------------------|------------|
| Fast0           | 0                              | No         |
| Fast1           | 1                              | Small      |
| Fast2           | 2                              | Medium     |
| Fast3           | 3                              | Large      |

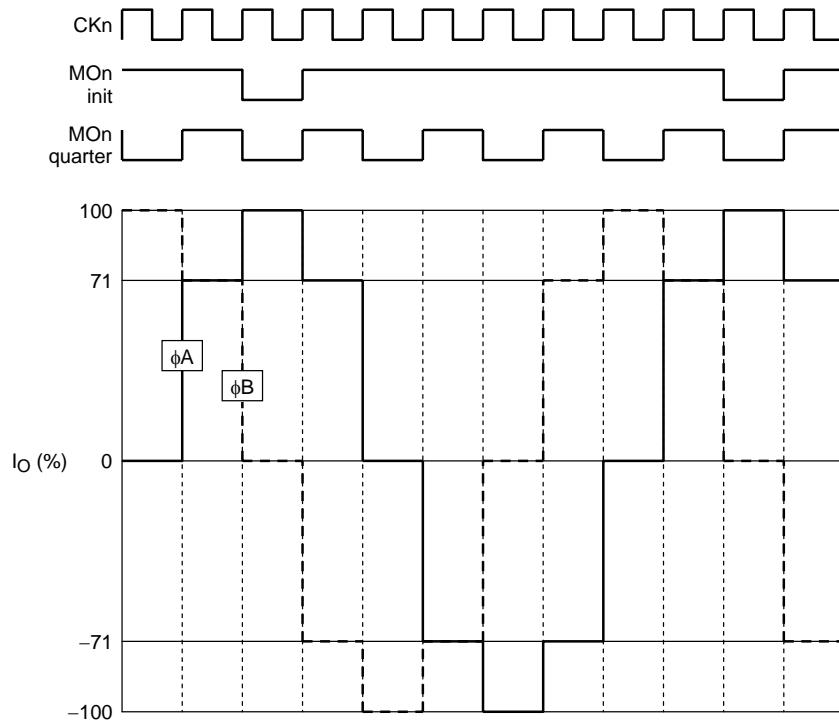
## Current Step-Up Slope



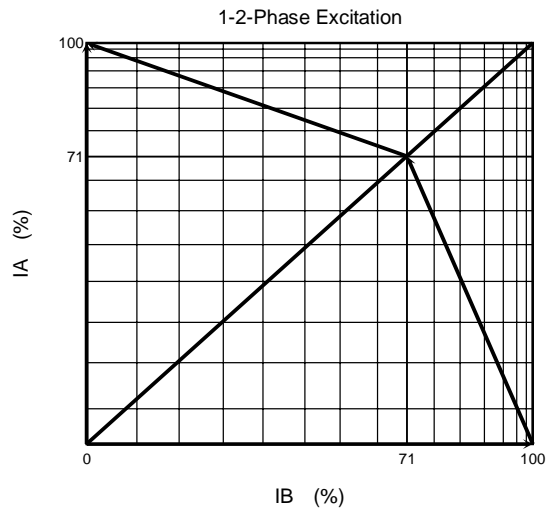
## Current Step-Down Slope (when in Fast1 mode)



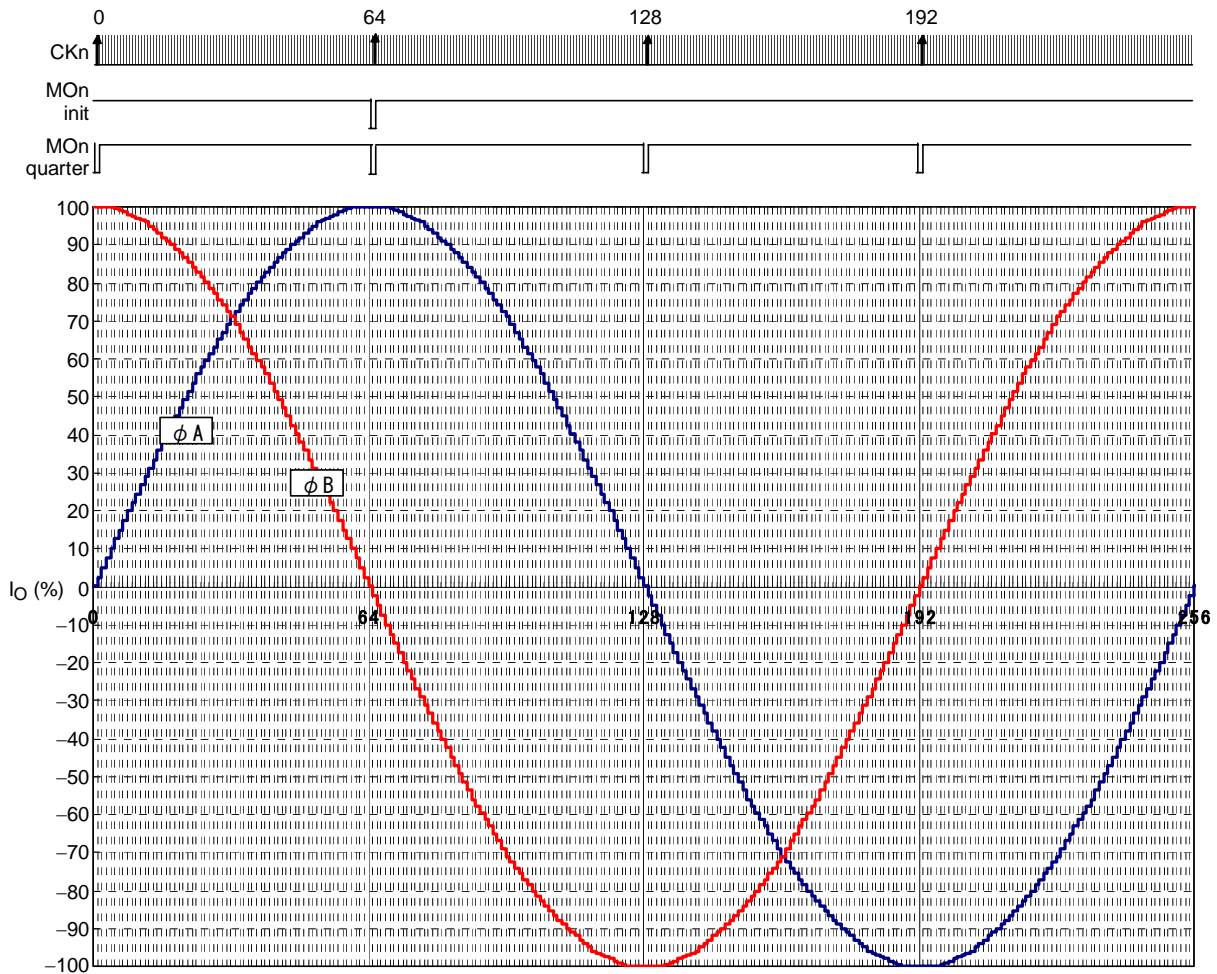
**Timing Diagram of Microstep Operation with 1-Bit Resolution (8 steps per full cycle)**



**Output Current Vector**

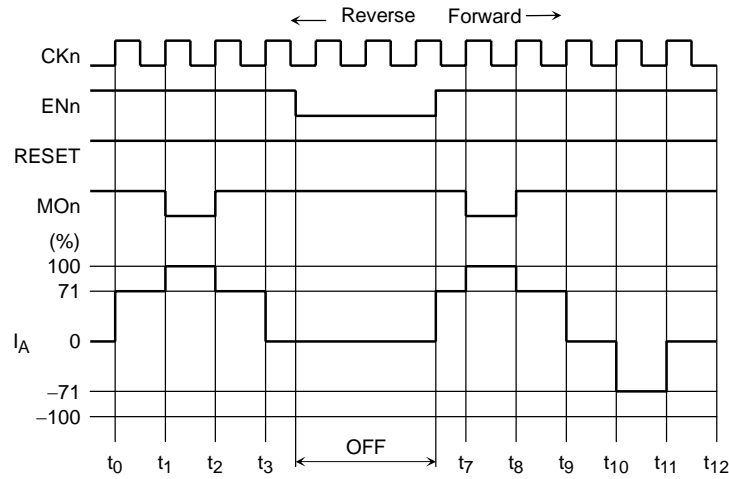


Timing Diagram of Microstep Operation with 6-Bit Resolution (256 steps per full cycle)



**Relationship between the Enable and RESET Inputs and Output Signals**

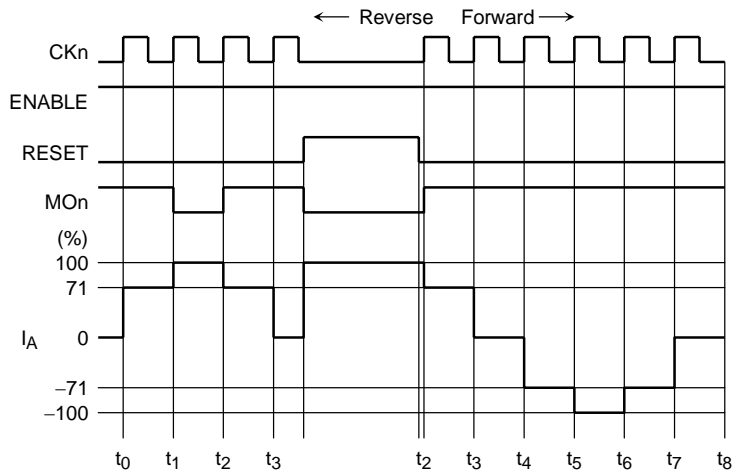
**Enable (ENn Pin)**



Setting the ENn signal Low disables only the output block, and the internal circuitry continues to operate in accordance with the CKn input. Therefore, when the ENn signal is set High again, the output current restarts as if phases had proceeded with the CKn signal.

When ENn = Low, the output signals are disabled regardless of the state of the RESET signal. Setting the RESET signal Low while ENn = Low resets the counter.

**RESET (Serial Command)**

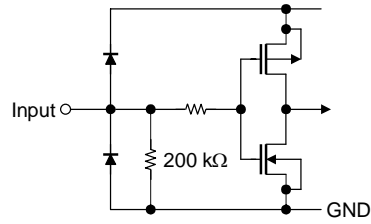


Setting the RESET signal High causes the outputs to be put in the Initial state and the MOn output to be driven Low.

When the RESET signal goes is set Low again, the output current generation restarts from the Initial state at the next rising edge of CKn.

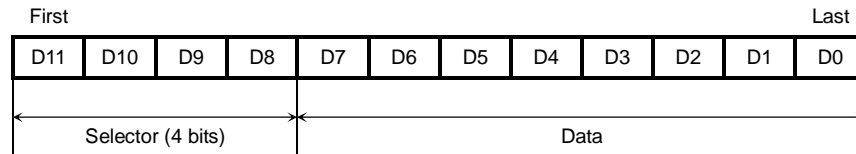
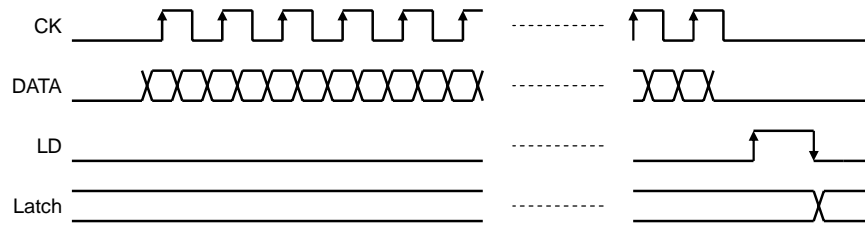
**Input Pins**

All input pins (CK, DATA, LD, PWMA/CK1, PWMB/EN1, PWMC/CK2, PWMD/EN2, PWME, PWMF, PWMG, PWMH, STBY, MCK) have a pull-down resistor of about 200 k $\Omega$ .



## Serial Data Format

### 12-Bit Serial Data



## Register Organizations

| D11 | D10 | D9 | D8 | D7         | D6   | D5        | D4           | D3   | D2   | D1 | D0 | Address |    |
|-----|-----|----|----|------------|------|-----------|--------------|------|------|----|----|---------|----|
| 0   | 0   | 0  | 0  | mod1       | stm1 | if1       | ick1: 5 bits |      |      |    |    | 0       |    |
| 0   | 0   | 0  | 1  | 2-bit DAC1 |      | mdr1      | rst1         | mo1  | off1 |    | —  | 1       |    |
| 0   | 0   | 1  | 0  | p1a        | p1b  | sdfst1    |              | scw1 | —    | —  | —  | 2       |    |
| 0   | 0   | 1  | 1  | mod2       | p2a  | p2b       | if2          | off2 |      | —  | —  | 3       |    |
| 0   | 1   | 0  | 0  | mod3       | stm3 | if3       | ick3: 5 bits |      |      |    |    | 4       |    |
| 0   | 1   | 0  | 1  | 2-bit DAC2 |      | mdr3      | rst3         | mo3  | off3 |    | —  | 5       |    |
| 0   | 1   | 1  | 0  | p3a        | p3b  | Sdfst3    |              | scw3 | —    | —  | —  | 6       |    |
| 0   | 1   | 1  | 1  | mod4       | p4a  | p4b       | if4          | off4 |      | —  | —  | 7       |    |
| 1   | 0   | 0  | 0  | mod5       | if5  | 6-bit DAC |              |      |      |    | 8  |         |    |
| 1   | 0   | 0  | 1  | off5       |      | —         | ick5: 5 bits |      |      |    |    | 9       |    |
| 1   | 0   | 1  | 0  | p5a        | p5b  | —         | —            | —    | —    | —  | —  | 10      |    |
| 1   | 0   | 1  | 1  | mod6       | p6a  | p6b       | —            | —    | —    | —  | —  | 11      |    |
| 1   | 1   | 0  | 0  | mod7       | p7a  | p7b       | —            | —    | —    | —  | —  | 12      |    |
| 1   | 1   | 0  | 1  | mod8       | p8a  | p8b       | —            | —    | —    | —  | —  | 13      |    |
| 1   | 1   | 1  | 0  | Don't care |      |           |              |      |      |    |    |         | 14 |
| 1   | 1   | 1  | 1  |            |      |           |              |      |      |    |    |         | 15 |

- modx : H-bridge control  
0 = Direct PWM mode (Table 1)  
1 = Control mode of Table 2 (All channels)
- stmx : STM mode select  
0 = H-Bridge mode  
1 = STM  $\mu$ Step mode (\*)
- ifx : Constant-current control  
0 = Constant-current control disabled  
1 = Constant-current control enabled (Channels A, B, C, D and E)  
\* Valid only in H-Bridge mode (stmx = 0). Constant-current control is always enabled in STM  $\mu$ Step mode.
- 2-bit DACx: 2-bit DAC setting  
0 = 0.075 V; 1 = 0.15 V; 2 = 0.225 V; 3 = 0.3 V  
4 levels in 0.075-V steps (\*)
- ickx : Divide ratio for internal clock\*  
Divides the external MCK by 1 to 31. (\*, channel E)
- mdrx : STM excitation mode  
0 =  $\mu$ Step mode with 6-bit resolution  
1 = 1-2-phase excitation mode (\*)

|           |                                 |   |
|-----------|---------------------------------|---|
| sdfstx    | : Fast-Decay mode               | Specifies the Fast-Decay time in number of internal clock cycles: 0 = No Fast-Decay cycle; 1 = 1 cycle; 2 = 2 cycles; 3 = 3 cycles (*)      |
| scwx      | : STM rotation direction select | 0 = Forward; 1 = Reverse (*)  |
| rstx      | : STM step counter reset        | 0 = Count mode; 1 = Reset (*)   |
| mox       | : Monitor signal interval       | 0 = Every 360 electrical degree<br>1 = Every 90 electrical degree (*)   |
| offx      | : PWM turn-off period           | Specifies the PWM turn-off period in number of internal clock cycles: 0 = 2 cycles; 1 = 4 cycles; 2 = 6 cycles; 3 = 8 cycles (*, channel E) |
| pxa       | : H-bridge control input a      | See Tables 1 and 2 on next page (All channels)  |
| pxb       | : H-bridge control input b      | See Tables 1 and 2 on next page (All channels)  |
| 6-bit DAC | : Channel-E 6-bit DAC setting*  | MSB = 0.3 V (6 bits) (Channel E)  |

Note: Two registers at addresses 3 and 7 are only valid in H-Bridge mode (stm<sub>x</sub> = 0).

\*: Detailed descriptions of register settings are provided in the tables on the following pages.



## Supplemental Register Descriptions

### 1. Each channel or microstep pair is separately addressed.

| Address    | Corresponding Channels                              |
|------------|---|
| 0, 1, 2, 3 | Channels A and B (stm1 = 1: microstep pair 1 (A&B)) |
| 4, 5, 6, 7 | Channels C and D (stm3 = 1: microstep pair 2 (C&D)) |
| 8, 9, 10   | Channel E   |
| 11         | Channel F   |
| 12         | Channel G   |
| 13         | Channel H   |

Note: Two registers at addresses 3 (channel-B setting) and 7 (channel-D setting) are only valid in H-Bridge mode (stm<sub>x</sub> = 0).

### 2. The character x in register names represents a channel number.

| x     | Corresponding Channels   |
|-------|--|
| x = 1 | Channel A (The settings of stm <sub>x</sub> , ick <sub>x</sub> , 2-bit DAC <sub>x</sub> , mdr <sub>x</sub> , rst <sub>x</sub> , mox, sdfst <sub>x</sub> and scw <sub>x</sub> are shared between channels A and B.) |
| x = 2 | Channel B  |
| x = 3 | Channel C (The settings of stm <sub>x</sub> , ick <sub>x</sub> , 2-bit DAC <sub>x</sub> , mdr <sub>x</sub> , rst <sub>x</sub> , mox, sdfst <sub>x</sub> and scw <sub>x</sub> are shared between channels C and D.) |
| x = 4 | Channel D  |
| x = 5 | Channel E  |
| x = 6 | Channel F  |
| x = 7 | Channel G  |
| x = 8 | Channel H  |

**3. ickx: Setting the divide ratio for the external MCK used to generate the internal clock**

The external MCK is divided to generate an internal clock, as specified for each channel (microstep pair) by D4, D3, D2, D1 and D0 at addresses 0 (for channels A and B), 4 (for channels C and D) and 8 (for channel E).

| Decimal | Binary | Address 0, 4 or 8 |    |    |    |    | Divide Ratio for Internal Clock |
|---------|--------|-------------------|----|----|----|----|---------------------------------|
|         |        | D4                | D3 | D2 | D1 | D0 |                                 |
| 1       | 00001  | 0                 | 0  | 0  | 0  | 1  | 1/1                             |
| 2       | 00010  | 0                 | 0  | 0  | 1  | 0  | 1/2                             |
| 3       | 00011  | 0                 | 0  | 0  | 1  | 1  | 1/3                             |
| 4       | 00100  | 0                 | 0  | 1  | 0  | 0  | 1/4                             |
| 5       | 00101  | 0                 | 0  | 1  | 0  | 1  | 1/5                             |
| 6       | 00110  | 0                 | 0  | 1  | 1  | 0  | 1/6                             |
| 7       | 00111  | 0                 | 0  | 1  | 1  | 1  | 1/7                             |
| 8       | 01000  | 0                 | 1  | 0  | 0  | 0  | 1/8                             |
| 9       | 01001  | 0                 | 1  | 0  | 0  | 1  | 1/9                             |
| 10      | 01010  | 0                 | 1  | 0  | 1  | 0  | 1/10                            |
| 11      | 01011  | 0                 | 1  | 0  | 1  | 1  | 1/11                            |
| 12      | 01100  | 0                 | 1  | 1  | 0  | 0  | 1/12                            |
| 13      | 01101  | 0                 | 1  | 1  | 0  | 1  | 1/13                            |
| 14      | 01110  | 0                 | 1  | 1  | 1  | 0  | 1/14                            |
| 15      | 01111  | 0                 | 1  | 1  | 1  | 1  | 1/15                            |
| 16      | 10000  | 1                 | 0  | 0  | 0  | 0  | 1/16                            |
| 17      | 10001  | 1                 | 0  | 0  | 0  | 1  | 1/17                            |
| 18      | 10010  | 1                 | 0  | 0  | 1  | 0  | 1/18                            |
| 19      | 10011  | 1                 | 0  | 0  | 1  | 1  | 1/19                            |
| 20      | 10100  | 1                 | 0  | 1  | 0  | 0  | 1/20                            |
| 21      | 10101  | 1                 | 0  | 1  | 0  | 1  | 1/21                            |
| 22      | 10110  | 1                 | 0  | 1  | 1  | 0  | 1/22                            |
| 23      | 10111  | 1                 | 0  | 1  | 1  | 1  | 1/23                            |
| 24      | 11000  | 1                 | 1  | 0  | 0  | 0  | 1/24                            |
| 25      | 11001  | 1                 | 1  | 0  | 0  | 1  | 1/25                            |
| 26      | 11010  | 1                 | 1  | 0  | 1  | 0  | 1/26                            |
| 27      | 11011  | 1                 | 1  | 0  | 1  | 1  | 1/27                            |
| 28      | 11100  | 1                 | 1  | 1  | 0  | 0  | 1/28                            |
| 29      | 11101  | 1                 | 1  | 1  | 0  | 1  | 1/29                            |
| 30      | 11110  | 1                 | 1  | 1  | 1  | 0  | 1/30                            |
| 31      | 11111  | 1                 | 1  | 1  | 1  | 1  | 1/31                            |

#### 4. 6-bit DAC: Setting the 6-bit DAC for channel E

The Vref voltage that determines the target current level for constant-current control of channel E can be specified by D5, D4, D3, D2, D1 and D0 at address 8.

The target current level is determined by this voltage level and the external current sensing resistor.

| Decimal | Binary | Address 8 |    |    |    |    |    | Voltage (mV) |
|---------|--------|-----------|----|----|----|----|----|--------------|
|         |        | D5        | D4 | D3 | D2 | D1 | D0 |              |
| 0       | 000000 | 0         | 0  | 0  | 0  | 0  | 0  | 0.0          |
| 1       | 000001 | 0         | 0  | 0  | 0  | 0  | 1  | 4.8          |
| 2       | 000010 | 0         | 0  | 0  | 0  | 1  | 0  | 9.5          |
| 3       | 000011 | 0         | 0  | 0  | 0  | 1  | 1  | 14.3         |
| 4       | 000100 | 0         | 0  | 0  | 1  | 0  | 0  | 19.0         |
| 5       | 000101 | 0         | 0  | 0  | 1  | 0  | 1  | 23.8         |
| 6       | 000110 | 0         | 0  | 0  | 1  | 1  | 0  | 28.6         |
| 7       | 000111 | 0         | 0  | 0  | 1  | 1  | 1  | 33.3         |
| 8       | 001000 | 0         | 0  | 1  | 0  | 0  | 0  | 38.1         |
| 9       | 001001 | 0         | 0  | 1  | 0  | 0  | 1  | 42.9         |
| 10      | 001010 | 0         | 0  | 1  | 0  | 1  | 0  | 47.6         |
| 11      | 001011 | 0         | 0  | 1  | 0  | 1  | 1  | 52.4         |
| 12      | 001100 | 0         | 0  | 1  | 1  | 0  | 0  | 57.1         |
| 13      | 001101 | 0         | 0  | 1  | 1  | 0  | 1  | 61.9         |
| 14      | 001110 | 0         | 0  | 1  | 1  | 1  | 0  | 66.7         |
| 15      | 001111 | 0         | 0  | 1  | 1  | 1  | 1  | 71.4         |
| 16      | 010000 | 0         | 1  | 0  | 0  | 0  | 0  | 76.2         |
| 17      | 010001 | 0         | 1  | 0  | 0  | 0  | 1  | 81.0         |
| 18      | 010010 | 0         | 1  | 0  | 0  | 1  | 0  | 85.7         |
| 19      | 010011 | 0         | 1  | 0  | 0  | 1  | 1  | 90.5         |
| 20      | 010100 | 0         | 1  | 0  | 1  | 0  | 0  | 95.2         |
| 21      | 010101 | 0         | 1  | 0  | 1  | 0  | 1  | 100.0        |
| 22      | 010110 | 0         | 1  | 0  | 1  | 1  | 0  | 104.8        |
| 23      | 010111 | 0         | 1  | 0  | 1  | 1  | 1  | 109.5        |
| 24      | 011000 | 0         | 1  | 1  | 0  | 0  | 0  | 114.3        |
| 25      | 011001 | 0         | 1  | 1  | 0  | 0  | 1  | 119.0        |
| 26      | 011010 | 0         | 1  | 1  | 0  | 1  | 0  | 123.8        |
| 27      | 011011 | 0         | 1  | 1  | 0  | 1  | 1  | 128.6        |
| 28      | 011100 | 0         | 1  | 1  | 1  | 0  | 0  | 133.3        |
| 29      | 011101 | 0         | 1  | 1  | 1  | 0  | 1  | 138.1        |
| 30      | 011110 | 0         | 1  | 1  | 1  | 1  | 0  | 142.9        |
| 31      | 011111 | 0         | 1  | 1  | 1  | 1  | 1  | 147.6        |
| 32      | 100000 | 1         | 0  | 0  | 0  | 0  | 0  | 152.4        |
| 33      | 100001 | 1         | 0  | 0  | 0  | 0  | 1  | 157.1        |
| 34      | 100010 | 1         | 0  | 0  | 0  | 1  | 0  | 161.9        |
| 35      | 100011 | 1         | 0  | 0  | 0  | 1  | 1  | 166.7        |
| 36      | 100100 | 1         | 0  | 0  | 1  | 0  | 0  | 171.4        |
| 37      | 100101 | 1         | 0  | 0  | 1  | 0  | 1  | 176.2        |
| 38      | 100110 | 1         | 0  | 0  | 1  | 1  | 0  | 181.0        |

| Decimal | Binary | Address 8 |    |    |    |    |    | Voltage (mV) |
|---------|--------|-----------|----|----|----|----|----|--------------|
|         |        | D5        | D4 | D3 | D2 | D1 | D0 |              |
| 39      | 100111 | 1         | 0  | 0  | 1  | 1  | 1  | 185.7        |
| 40      | 101000 | 1         | 0  | 1  | 0  | 0  | 0  | 190.5        |
| 41      | 101001 | 1         | 0  | 1  | 0  | 0  | 1  | 195.2        |
| 42      | 101010 | 1         | 0  | 1  | 0  | 1  | 0  | 200.0        |
| 43      | 101011 | 1         | 0  | 1  | 0  | 1  | 1  | 204.8        |
| 44      | 101100 | 1         | 0  | 1  | 1  | 0  | 0  | 209.5        |
| 45      | 101101 | 1         | 0  | 1  | 1  | 0  | 1  | 214.3        |
| 46      | 101110 | 1         | 0  | 1  | 1  | 1  | 0  | 219.0        |
| 47      | 101111 | 1         | 0  | 1  | 1  | 1  | 1  | 223.8        |
| 48      | 110000 | 1         | 1  | 0  | 0  | 0  | 0  | 228.6        |
| 49      | 110001 | 1         | 1  | 0  | 0  | 0  | 1  | 233.3        |
| 50      | 110010 | 1         | 1  | 0  | 0  | 1  | 0  | 238.1        |
| 51      | 110011 | 1         | 1  | 0  | 0  | 1  | 1  | 242.9        |
| 52      | 110100 | 1         | 1  | 0  | 1  | 0  | 0  | 247.6        |
| 53      | 110101 | 1         | 1  | 0  | 1  | 0  | 1  | 252.4        |
| 54      | 110110 | 1         | 1  | 0  | 1  | 1  | 0  | 257.1        |
| 55      | 110111 | 1         | 1  | 0  | 1  | 1  | 1  | 261.9        |
| 56      | 111000 | 1         | 1  | 1  | 0  | 0  | 0  | 266.7        |
| 57      | 111001 | 1         | 1  | 1  | 0  | 0  | 1  | 271.4        |
| 58      | 111010 | 1         | 1  | 1  | 0  | 1  | 0  | 276.2        |
| 59      | 111011 | 1         | 1  | 1  | 0  | 1  | 1  | 281.0        |
| 60      | 111100 | 1         | 1  | 1  | 1  | 0  | 0  | 285.7        |
| 61      | 111101 | 1         | 1  | 1  | 1  | 0  | 1  | 290.5        |
| 62      | 111110 | 1         | 1  | 1  | 1  | 1  | 0  | 295.2        |
| 63      | 111111 | 1         | 1  | 1  | 1  | 1  | 1  | 300.0        |

Note: The voltage values are typical values.

## Function Tables

The drive method in H-Bridge mode (stm<sub>x</sub> = 0) can be selected from Tables 1 and 2, via the mod<sub>x</sub> bit.  
(Channels E, F, G and H are always in H-Bridge mode regardless of the stm<sub>x</sub> setting.)

**Table 1**

**mod<sub>x</sub> = 0, stm<sub>x</sub> = 0**

| pxa | pxb | PWM <sub>x</sub> | OUT <sub>x</sub> A | OUT <sub>x</sub> B | Drive Mode  |
|-----|-----|------------------|--------------------|--------------------|-------------|
| 0   | 0   | X                | Z                  | Z                  | Stop        |
| 0   | 1   | L                | L                  | L                  | Short brake |
| 0   | 1   | H                | L                  | H                  | Reverse     |
| 1   | 0   | L                | L                  | L                  | Short brake |
| 1   | 0   | H                | H                  | L                  | Forward     |
| 1   | 1   | X                | L                  | L                  | Short brake |

**Table 2**

**mod<sub>x</sub> = 1, stm<sub>x</sub> = 0**

| pxa | pxb | PWM <sub>x</sub> | OUT <sub>x</sub> A | OUT <sub>x</sub> B | Drive Mode  |
|-----|-----|------------------|--------------------|--------------------|-------------|
| 0   | X   | X                | Z                  | Z                  | Stop        |
| 1   | 0   | L                | H                  | L                  | Forward     |
| 1   | 0   | H                | L                  | H                  | Reverse     |
| 1   | 1   | X                | L                  | L                  | Short brake |

**Function Table: STBY pin, UVLO and TSD circuitry, rstx bit (internal register)**

| Function          | STBY (Note 1) | UVLO       | TSD          | rstx   |
|-------------------|---------------|------------|--------------|--|
| Internal Register | Cleared       | Cleared    | Not affected | Not affected   |
| Driver            | Turned off    | Turned off | Turned off   | Turned on<br>(controlled by the EN <sub>n</sub> pin) |

Note 1: STBY: L = Standby (power-save) mode; H = Normal operation mode

Note 2: All registers are cleared to zero.

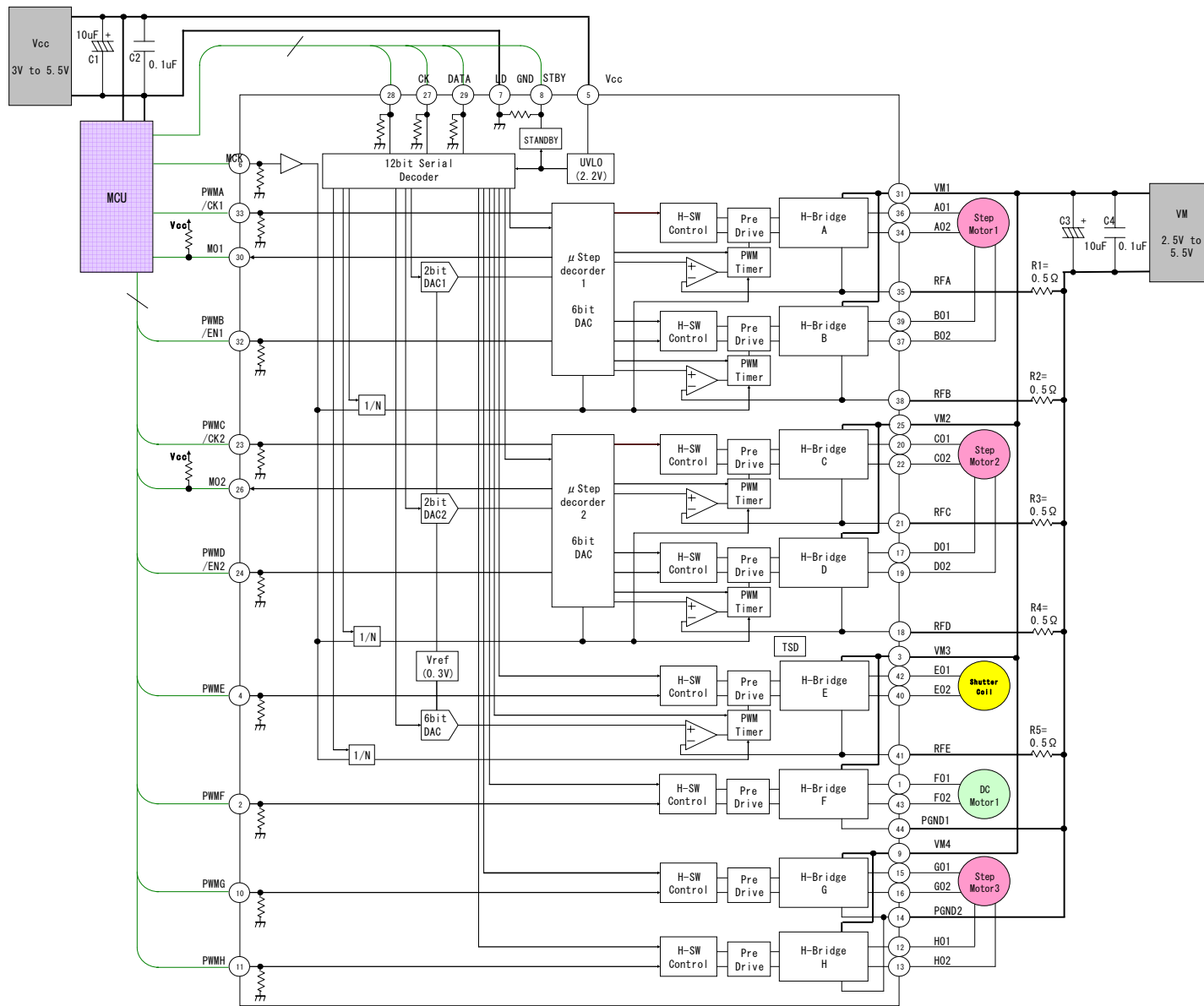
**Electrical Characteristics ( $V_{CC} = 3.3\text{ V}$ ,  $V_M = 5\text{ V}$ ,  $T_a = 25^\circ\text{C}$ , unless otherwise specified.)**

| Characteristics  |                              | Symbol                                | Test Condition   | Min                 | Typ. | Max                 | Unit             |
|--|------------------------------|---------------------------------------|--|---------------------|------|---------------------|------------------|
| Supply current   |                              | $I_{CC}$                              | All 8 channels in Forward mode   | —                   | 2    | 4                   | mA               |
|  |                              | $I_{CC}(\text{STB})$                  | Standby mode (STBY = 0 V)  | —                   | 0.1  | 10                  | $\mu\text{A}$    |
|  |                              | $I_M(\text{STB})$                     |  | —                   | 0    | 1                   |                  |
| Serial, STBY, PWM and CLK inputs                       | Input voltage                | $V_{\text{INH}}$                      |  | $V_{CC} \times 0.7$ | —    | $V_{CC} + 0.2$      | V                |
|  |                              | $V_{\text{INL}}$                      |  | -0.2                | —    | $V_{CC} \times 0.3$ |                  |
|  | Input current                | $I_{\text{INH}}$                      | $V_{\text{IH}} = 3\text{ V}$   | 5                   | 15   | 25                  | $\mu\text{A}$    |
|  |                              | $I_{\text{INL}}$                      | $V_{\text{IL}} = 0\text{ V}$   | —                   | —    | 1                   |                  |
| Output saturation voltage (Channels A to H)            |                              | $V_{\text{sat}}(\text{U} + \text{L})$ | $I_O = 0.2\text{ A}$ , $V_{CC} = 5\text{ V}$                             | —                   | 0.3  | 0.4                 | V                |
|  |                              |                                       | $I_O = 0.6\text{ A}$ , $V_{CC} = 5\text{ V}$                             | —                   | 0.9  | 1.2                 |                  |
| Output leakage current (Channels A to H)               |                              | $I_L(\text{U})$                       | $V_M = 6\text{ V}$   | —                   | —    | 1                   | $\mu\text{A}$    |
|  |                              | $I_L(\text{L})$                       |  | —                   | —    | 1                   |                  |
| Output diode forward voltage                           |                              | $V_F(\text{U})$                       | $I_F = 0.6\text{ A}$ (Design target only)                                | —                   | 1    | —                   | V                |
|  |                              | $V_F(\text{L})$                       |  | —                   | 1    | —                   |                  |
| Voltage comparator offset for constant-current control |                              | Comp ofs                              | $R_F = 0.5\ \Omega$ ,<br>$V_{\text{ref}} = 0.1\text{ V}$ (including DAC) | -10                 | —    | 10                  | mV               |
| 6-bit DAC  | Nonlinearity                 | LB                                    | Channel E  | -3                  | —    | 3                   | LSB              |
|  | Differential linearity error | DLB                                   |  | -2                  | —    | 2                   |                  |
| Microstep reference level                              | 6-bit mode                   | $\theta$                              | See Appendix on next page.   | —                   | —    | —                   | %                |
|  | 1-bit mode                   | Half step                             | (Design target only)   | —                   | 71   | —                   |                  |
| $V_{CC}$ undervoltage lockout (UVLO)                   | UVLO trip threshold          | UVLD                                  | (Design target value)  | —                   | 2.0  | —                   | V                |
|  | UVLO recovery                | UVLC                                  |  | —                   | 2.2  | —                   |                  |
| Thermal shutdown threshold                             |                              | TSD                                   | (Design target only)   | —                   | 170  | —                   | $^\circ\text{C}$ |
| Thermal shutdown hysteresis                            |                              | $\Delta\text{TSD}$                    |  | —                   | 20   | —                   |                  |

**Appendix: Microstep Reference Level with 6-Bit Resolution (Design target only)**

| $\theta$ | Min | Typ.  | Max | Unit | $\theta$ | Min | Typ.  | Max | Unit |
|----------|-----|-------|-----|------|----------|-----|-------|-----|------|
| 063      | —   | 100   | —   | %    | 031      | —   | 71    | —   | %    |
| 062      | —   | 100   | —   |      | 030      | —   | 69    | —   |      |
| 061      | —   | 100   | —   |      | 029      | —   | 67    | —   |      |
| 060      | —   | 100   | —   |      | 028      | —   | 65    | —   |      |
| 059      | —   | 100   | —   |      | 027      | —   | 63    | —   |      |
| 058      | —   | 99.5  | —   |      | 026      | —   | 61.25 | —   |      |
| 057      | —   | 99    | —   |      | 025      | —   | 59.5  | —   |      |
| 056      | —   | 98.5  | —   |      | 024      | —   | 57.75 | —   |      |
| 055      | —   | 98    | —   |      | 023      | —   | 56    | —   |      |
| 054      | —   | 97.5  | —   |      | 022      | —   | 53.75 | —   |      |
| 053      | —   | 97    | —   |      | 021      | —   | 51.5  | —   |      |
| 052      | —   | 96.5  | —   |      | 020      | —   | 49.25 | —   |      |
| 051      | —   | 96    | —   |      | 019      | —   | 47    | —   |      |
| 050      | —   | 95    | —   |      | 018      | —   | 44.75 | —   |      |
| 049      | —   | 94    | —   |      | 017      | —   | 42.5  | —   |      |
| 048      | —   | 93    | —   |      | 016      | —   | 40.25 | —   |      |
| 047      | —   | 92    | —   |      | 015      | —   | 38    | —   |      |
| 046      | —   | 91    | —   |      | 014      | —   | 35.75 | —   |      |
| 045      | —   | 90    | —   |      | 013      | —   | 33.5  | —   |      |
| 044      | —   | 89    | —   |      | 012      | —   | 31.25 | —   |      |
| 043      | —   | 88    | —   |      | 011      | —   | 29    | —   |      |
| 042      | —   | 86.75 | —   |      | 010      | —   | 26.75 | —   |      |
| 041      | —   | 85.5  | —   |      | 09       | —   | 24.5  | —   |      |
| 040      | —   | 84.25 | —   |      | 08       | —   | 22.25 | —   |      |
| 039      | —   | 83    | —   |      | 07       | —   | 20    | —   |      |
| 038      | —   | 81.5  | —   |      | 06       | —   | 17.5  | —   |      |
| 037      | —   | 80    | —   |      | 05       | —   | 15    | —   |      |
| 036      | —   | 78.5  | —   |      | 04       | —   | 12.5  | —   |      |
| 035      | —   | 77    | —   |      | 03       | —   | 10    | —   |      |
| 034      | —   | 75.5  | —   |      | 02       | —   | 7.5   | —   |      |
| 033      | —   | 74    | —   |      | 01       | —   | 5     | —   |      |
| 032      | —   | 72.5  | —   |      | 00       | —   | 2.5   | —   |      |

Application Circuit Example

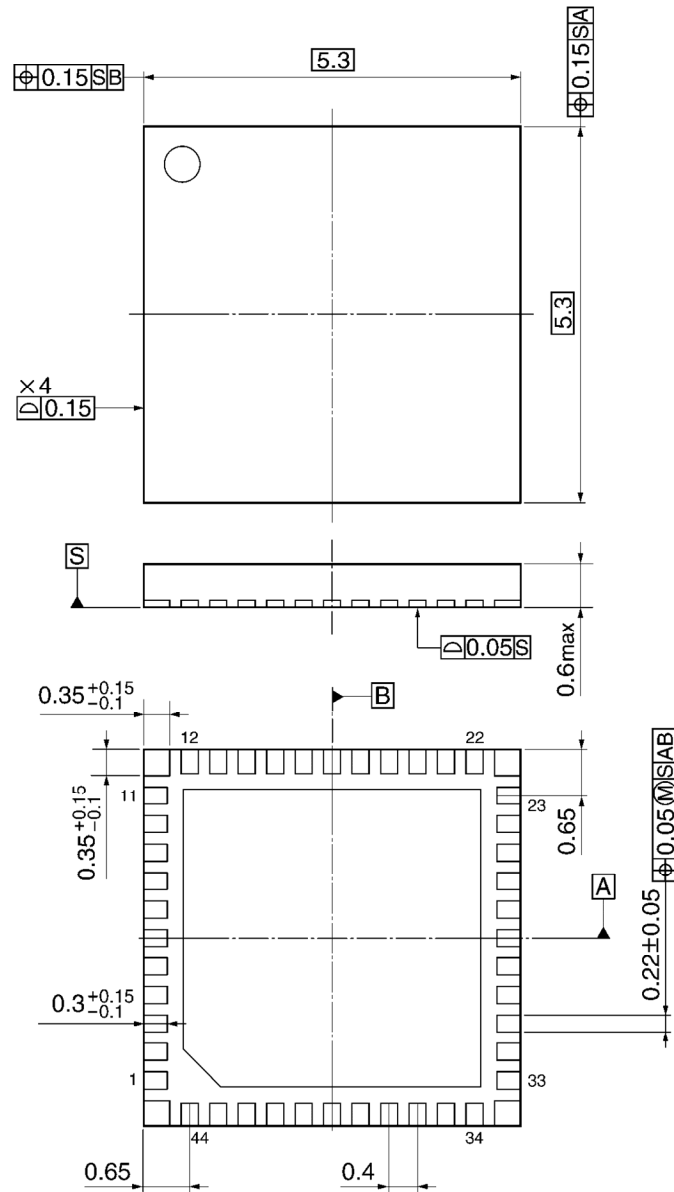




## Package Dimensions

VQON44-P-0606-0.4

Unit: mm



Weight: 0.05 g (typ.)

## Notes on Contents

### 1. Block Diagrams

Some of the functional blocks, circuits, or constants in the block diagram may be omitted or simplified for explanatory purposes.

### 2. Equivalent Circuits

The equivalent circuit diagrams may be simplified or some parts of them may be omitted for explanatory purposes.

### 3. Timing Charts

Timing charts may be simplified for explanatory purposes.

### 4. Application Circuits

The application circuits shown in this document are provided for reference purposes only. Thorough evaluation is required, especially at the mass production design stage.

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### 5. Test Circuits

Components in the test circuits are used only to obtain and confirm the device characteristics. These components and circuits are not guaranteed to prevent malfunction or failure from occurring in the application equipment.

## IC Usage Considerations

### Notes on Handling of ICs

- (1) The absolute maximum ratings of a semiconductor device are a set of ratings that must not be exceeded, even for a moment. Do not exceed any of these ratings.  
Exceeding the rating(s) may cause the device breakdown, damage or deterioration, and may result in injury by explosion or combustion.
- (2) Use an appropriate power supply fuse to ensure that a large current does not continuously flow in case of over current and/or IC failure. The IC will fully break down when used under conditions that exceed its absolute maximum ratings, when the wiring is routed improperly or when an abnormal pulse noise occurs from the wiring or load, causing a large current to continuously flow and the breakdown can lead to smoke or ignition. To minimize the effects of the flow of a large current in case of breakdown, appropriate settings, such as fuse capacity, fusing time and insertion circuit location, are required.
- (3) If your design includes an inductive load such as a motor coil, incorporate a protection circuit into the design to prevent device malfunction or breakdown caused by the current resulting from the inrush current at power ON or the negative current resulting from the back electromotive force at power OFF. IC breakdown may cause injury, smoke or ignition.  
Use a stable power supply with ICs with built-in protection functions. If the power supply is unstable, the protection function may not operate, causing IC breakdown. IC breakdown may cause injury, smoke or ignition.
- (4) Do not insert devices in the wrong orientation or incorrectly.  
Make sure that the positive and negative terminals of power supplies are connected properly. Otherwise, the current or power consumption may exceed the absolute maximum rating, and exceeding the rating(s) may cause the device breakdown, damage or deterioration, and may result in injury by explosion or combustion.  
In addition, do not use any device that is applied the current with inserting in the wrong orientation or incorrectly even just one time.

**Points to Remember on Handling of ICs**

## (1) Over current Protection Circuit

Over current protection circuits (referred to as current limiter circuits) do not necessarily protect ICs under all circumstances. If the Over current protection circuits operate against the over current, clear the over current status immediately.

Depending on the method of use and usage conditions, such as exceeding absolute maximum ratings can cause the over current protection circuit to not operate properly or IC breakdown before operation. In addition, depending on the method of use and usage conditions, if over current continues to flow for a long time after operation, the IC may generate heat resulting in breakdown.

## (2) Heat Radiation Design

In using an IC with large current flow such as power amp, regulator or driver, please design the device so that heat is appropriately radiated, not to exceed the specified junction temperature ( $T_j$ ) at any time and condition. These ICs generate heat even during normal use. An inadequate IC heat radiation design can lead to decrease in IC life, deterioration of IC characteristics or IC breakdown. In addition, please design the device taking into consideration the effect of IC heat radiation with peripheral components.

## (3) Back-EMF

When a motor rotates in the reverse direction, stops or slows down abruptly, a current flow back to the motor's power supply due to the effect of back-EMF. If the current sink capability of the power supply is small, the device's motor power supply and output pins might be exposed to conditions beyond maximum ratings. To avoid this problem, take the effect of back-EMF into consideration in system design.

About solderability, following conditions were confirmed

- Solderability
  - (1) Use of Sn-37Pb solder Bath
    - solder bath temperature = 230°C
    - dipping time = 5 seconds
    - the number of times = once
    - use of R-type flux
  - (2) Use of Sn-3.0Ag-0.5Cu solder Bath
    - solder bath temperature = 245°C
    - dipping time = 5 seconds
    - the number of times = once
    - use of R-type flux

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