Driving Stepper Motor Using AVR® EB

TB3362

Introduction

Authors: Bogdan Mariniuc. Microchip Technology Inc.

This application note describes how to drive a stepper motor. An electric motor is a machine that converts electrical energy into mechanical energy. Most electric motors operate through the interaction between the motor's magnetic field and electric current in a wire winding and generate a force in the form of torque applied on the motor's shaft.

A stepper motor is a DC motor that works in discrete steps. It is synchronous, brushless, and can accurately control position and speed by digitally controlling step points.

Stepper motors have several advantages:

- Precision: Stepper motors move in discrete steps, allowing for precise positioning and repeatability of movement
- High Torque at low speeds: Unlike other motors, stepper motors can deliver high torque at low speeds, making them ideal for applications that require precise speed and position control
- Open-Loop Control: Stepper motors can be controlled without a feedback sensor because they move in predictable steps
- Low-Cost: Stepper motors are generally less expensive than servo motors of the same power rating
- Simple to Use: Stepper motors are easier to use and program than other types of motors
- Reliable: Because of their simplicity, stepper motors are very reliable and have a long life span

This application note presents a controller with four demonstration application codes capable of controlling acceleration, deceleration, position, and speed.

Click to view code examples on MPLAB® DISCOVER

Table of Contents

1. Overview

1.1 Overview - AVR® EB Family of Microcontrollers

The AVR® EB family integrates real-time control and drive functionality into the AVR's functionality. Featuring the latest Core Independent Peripherals (CIPs), these microcontrollers (MCUs) excel as stand-alone processors that will be valuable additions to any modern embedded design.

Features:

- Functional Safety:
  - Appliances Safety - IEC 60730 (Class B)
  - Industrial Safety – IEC 61508 (SIL)
  - Automotive Safety – ISO 26262 (ASIL)
- High-Performance AVR RISC CPU with Hardware Multiplier:
  - Running at up to 20 MHz
  - Flash with true Read-While-Write (RWW) operation
  - Single Cycle I/O Access
  - Two-level Interrupt Controller
  - Sleep modes: Idle, Standby, Power-down
  - Six channels Event System (EVSYS)
  - Configurable Custom Logic (CCL)
  - Single-pin Unified Program and Debug Interface (UPDI)
- Analog Features:
  - 12-bit Diff ADC with Programmable Gain Amplifier (PGA)
  - 2x Analog Comparator with internal DAC reference
- Timer/Counters:
  - 2x 16-bit Timer/Counter type B (TCB)
  - 1x 16-bit Timer/Counter type E (TCE) with Waveform Extension (WEX)
  - 1x 24-bit Timer/Counter F for Frequency Generation
  - 1x 16-bit Real Time Counter (RTC) with Periodic Interrupt Controller (PIT)
- Built-in Safety Functions:
  - Power-On Reset (POR)
  - Brown-Out-Detection (BOD)
  - Voltage Level Monitor (VLM)
  - Clock Failure Detection (CFD)
  - Cyclic Redundancy Check (CRC) Scan
  - Window Watchdog Timer (WWDT)
- Communication:
- Serial communication interfaces: 3x USART, SPI, I^{2}C

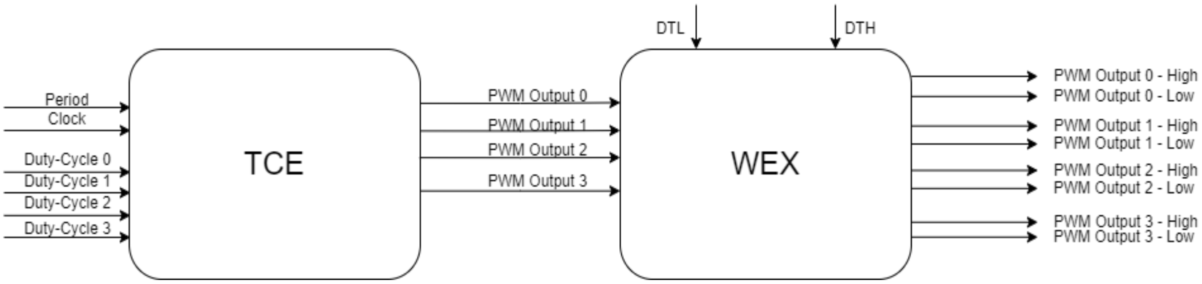
For more information, visit the official website:

www.microchip.com/en-us/product/AVR16EB32

1.2 Overview – TCE and WEX

In AVR EB, the TCE works with the WEX to insert dead times and generate four independent and complementary PWM channels.

Figure 1-1. TCE and WEX - 8 Output PWM Channels



1.2.1 TCE - 16-Bit Timer/Counter Type E

The flexible 16-bit PWM provides accurate program execution timing, frequency and waveform generation, and command execution. The Timer/Counter consists of a base counter and compare channels. You may use the base counter to count clock cycles or events or to allow events to dictate clock cycle counting. The counting direction and period setting control are used for accurate timing. You may use the compare channels with the base counter for compare match control, frequency generation, and PWM.

A timer/counter can be clocked and timed from the peripheral clock, with optional prescaling, or from the Event System (EVSYS). The EVSYS can also be used to control direction or synchronize operations.

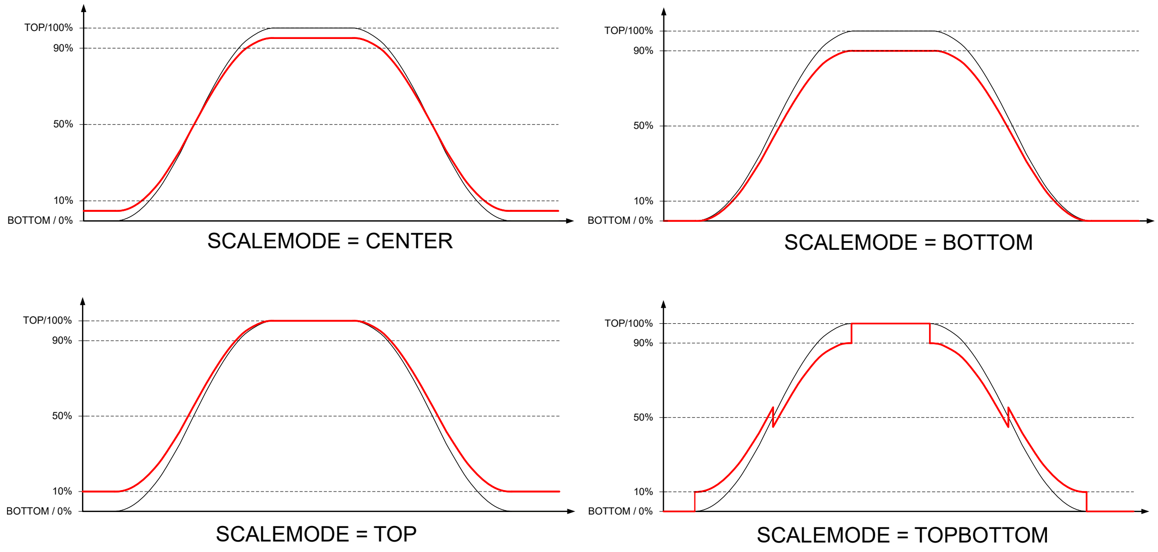
The counter register (TCEn.CNT), period registers with buffer (TCEn.PER and TCEn.PERBUF), and compare registers with buffers (TCEn.CMPn and TCEn.CMPBUFn) are 16-bit registers. All buffer registers use a buffer valid (BV) flag that indicates when the buffer contains a new value.

During ordinary operation, the counter value is compared continuously to zero and the Period (PER) value to determine whether the counter has reached TOP or BOTTOM.

The counter includes a high-resolution option that can increase the duty cycle resolution by up to eight times the input clock. The counter value is also compared to the TCEn.CMPn registers. These comparisons can generate interrupt requests. The waveform generator modes use these comparisons to set the waveform period or pulse width.

When the scaled write is enabled, the values written to the CMPn/CMPnBUF are between 0 and 1.99, giving a duty-cycle range between 0% and 100% of the PWM period, as shown below.

Figure 1-2. Scale Mode



BLACK line – Normal full-scale CMP write.

RED line – CMP values when AMP is 90%.

1.2.2 WEX – for the 16-Bit TCE

The WEX provides extra functions to the timer/counter in Waveform Generation (WG) modes. It is intended primarily for use in different types of motor control and other power control applications. The WEX consists of five independent and successive units.

The Dead-Time Insertion (DTI) unit generates OFF time where the non-inverted low side (LS) and inverted high side (HS) of the Waveform Output (WO) are low. This OFF time is called dead time, and the Dead-Time Insertion unit ensures that the LS and HS never switch simultaneously.

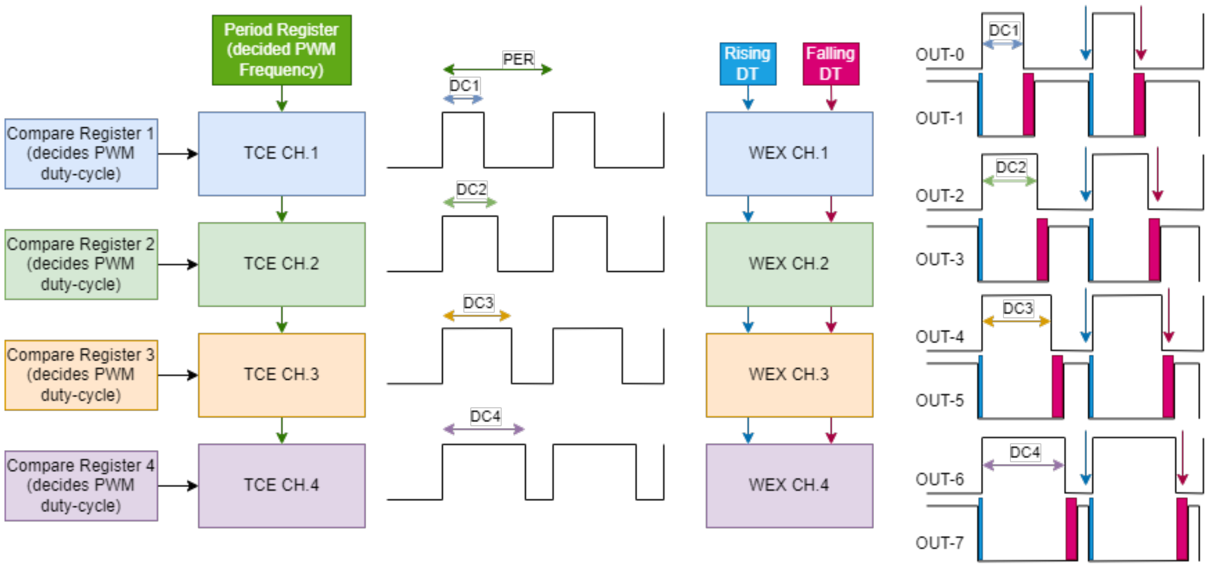
All channels have a mutual register that controls the dead time. The high and low sides have independent dead-time settings, and the dead-time registers are double-buffered.

In Pattern Generation mode (PGM), the Dead-Time buffers are unavailable. The dead-time can still be implemented using only the data registers, as when PGM is enabled only on some outputs, and Complementary PWM with dead-time is needed on other outputs.

Four half-bridge channels are required to drive a bipolar stepper motor. Each half-bridge channel is controlled with two PWM signals in counter-time, alternated and inverted.

The following figure depicts the TCE and WEX working together.

Figure 1-3. TCE and WEX Control Flow



For application examples, check the link below:

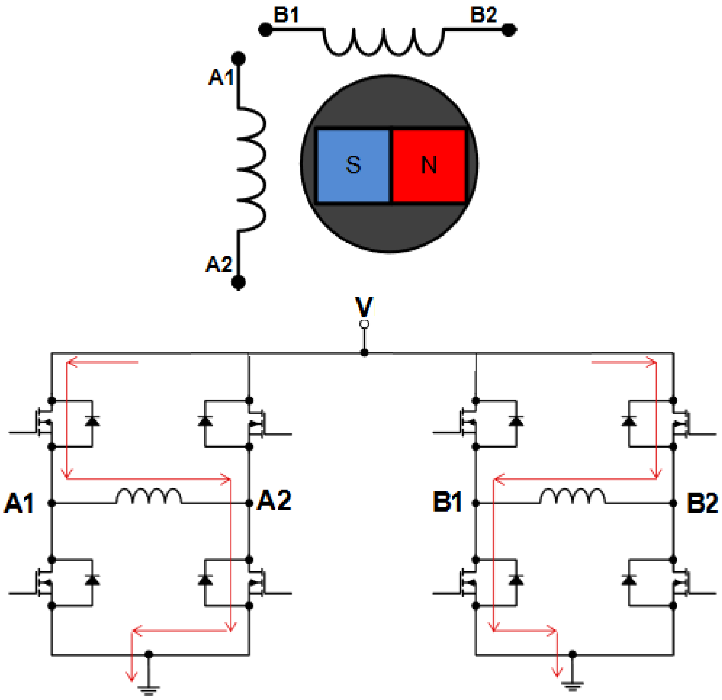
onlinedocs.microchip.com/oxy/GUID-8FB8D192-E8C9-4748-B991-D4D842E01591-en-US-1/index.html

1.3 Overview – Bipolar Stepper Motor

The motor consists of a rotor, typically a bunch of permanent magnets, and a stator, made of coil pairs wound around a ferromagnetic core. The operation of a bipolar stepper motor is based on the attraction and repulsion between magnetic fields. When applying current to the stator coils, a magnetic field generates and magnetically interacts with the rotor, excreting a force on it.

Idealized and simplified schematic of a stepper motor:

Figure 1-4. Bipolar Stepper Motor with Two Half-Bridges



If the stator is being driven by a variable magnetic field, a variable moving magnetic field creates and determines the rotor to follow the varying magnetic field, resulting in mechanical movement. Changing the command angle will reverse the rotation direction.

Figure 1-5. The Four Stepper Motor Quadrants

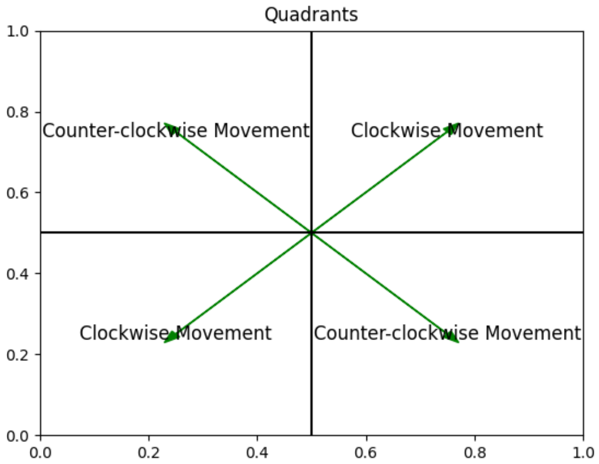


Figure 1-6. Quadrant 1

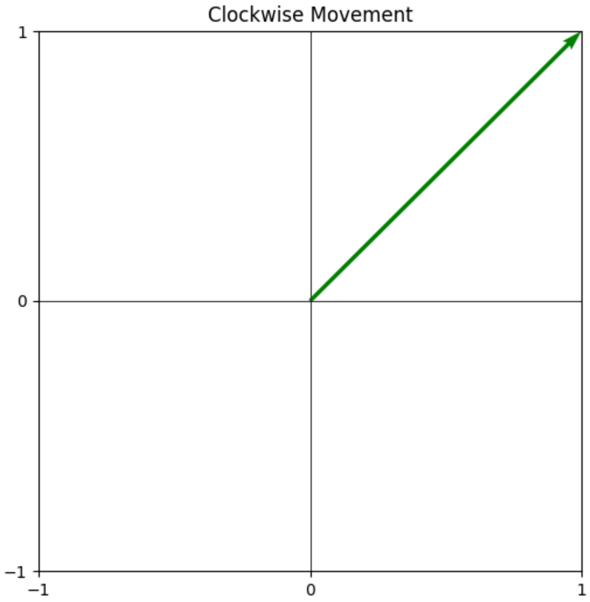


Figure 1-7. Current Sequence Through Coils that Allows the Clockwise Rotation from Quadrant 1

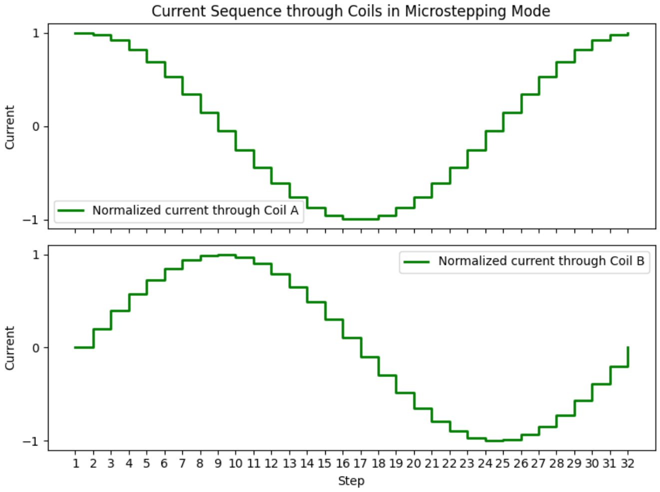


Figure 1-8. Quadrant 2

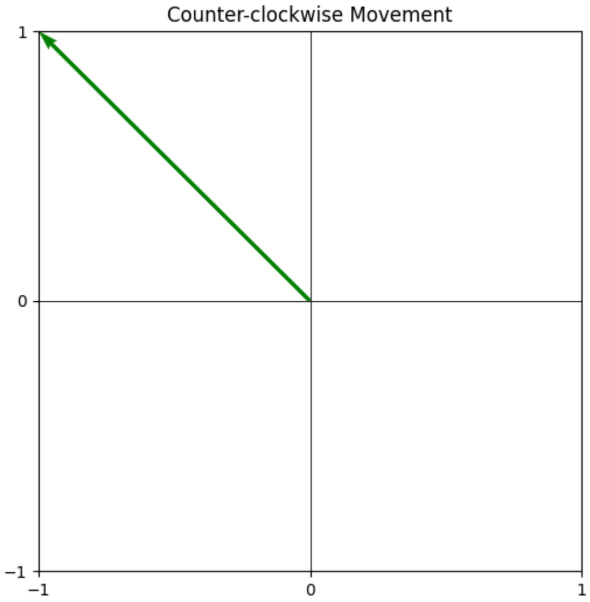


Figure 1-9. Current Sequence Through Coils that Allows the Conter-Clockwise Rotation from Quadrant 2

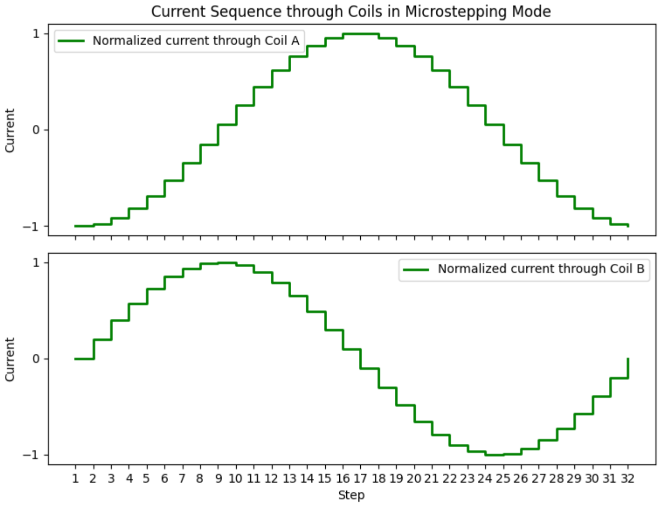


Figure 1-10. Quadrant 3

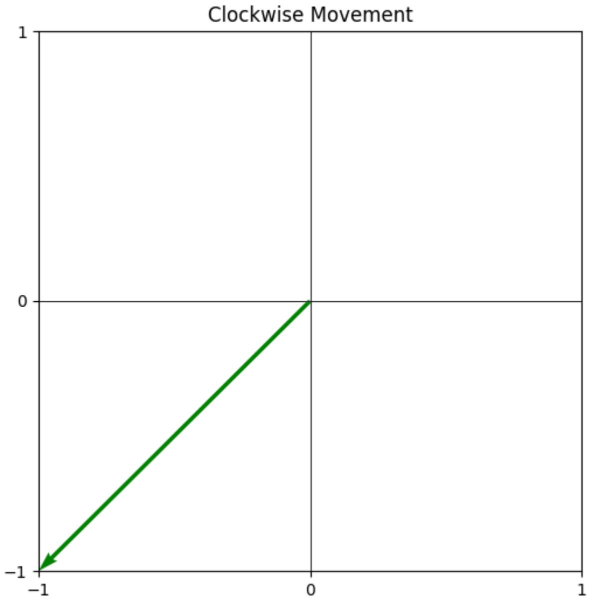


Figure 1-11. Current Sequence Through Coils that Allows the Conter-Clockwise Rotation from Quadrant 3

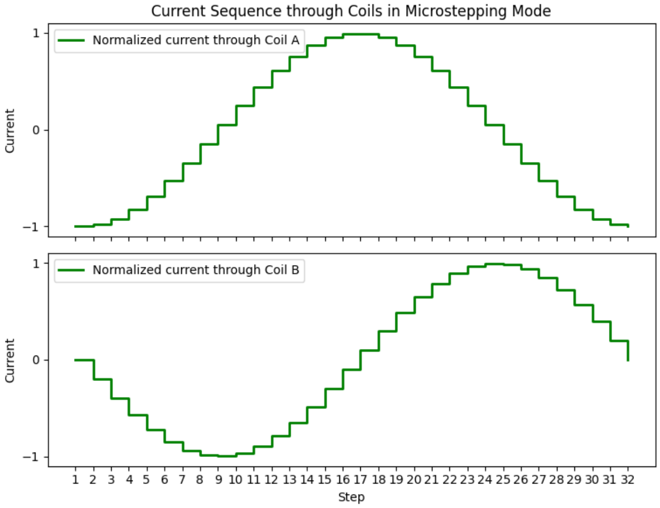


Figure 1-12. Quadrant 4

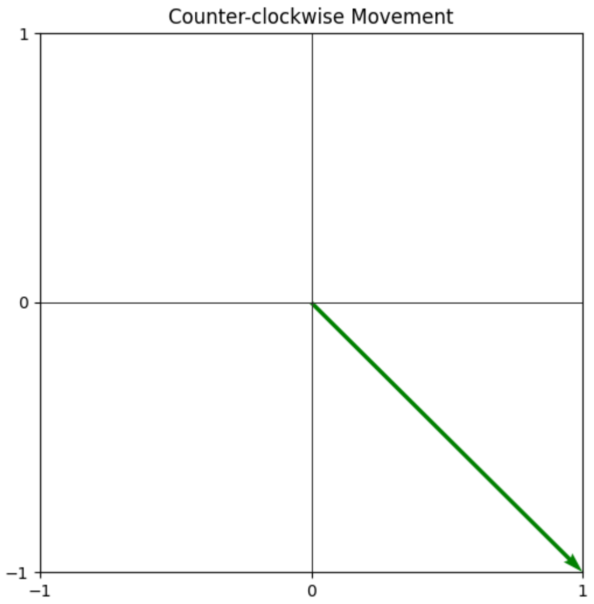
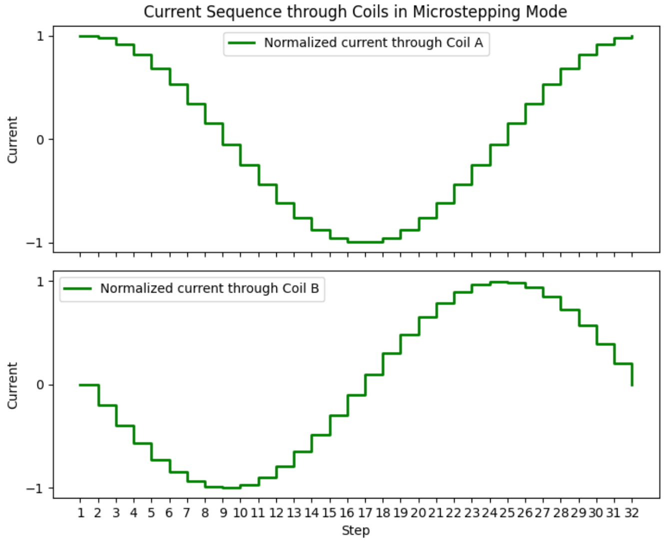


Figure 1-13. Current Sequence Through Coils that Allows the Conter-Clockwise Rotation from Quadrant 4



The motor's torque or rotational force is affected by several factors:

- The amount of current supplied to the stator coils directly impacts the strength of the magnetic field and torque
- The number of stator coils also plays a role, with more coils potentially generating a stronger magnetic field and more torque
- The design and material of the rotor can also affect the torque, with a rotor having more poles or made of a material with high magnetic permeability potentially providing more torque

The selected motor for this demo is the 17HS4401 bipolar stepper motor, which has a 1.8° step angle (200 steps/revolution) with 40 Ncm (56 oz-in) holding torque.

The 17HS4401 stepper motor has the following specifications:

- Step Angle: 1.8°
- Holding Torque: 40 Ncm (56 oz-in)
- Rated Current/phase: 1.7A
- Phase Resistance: 1.5Ω ± 10%
- Insulation Resistance: 100 MΩ¸ Min, 500 VDC
- Insulation Strength: 500 VAC for one minute

Here are some key equations related to bipolar stepper motors:

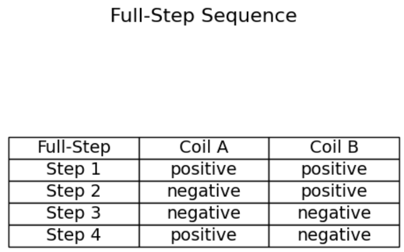
- I (coil current) = Torque (T) x Kt (torque constant). The torque is directly proportional to the current and the torque constant (Kt).
- Steps per Revolution (SPR) = 360°/Step Angle. This equation calculates the total number of full steps a bipolar stepper motor will take to make one complete 360° rotation. The step angle is the angle turned by the motor for each step. The stepper motor used in the applications has an SPR of 1.8°, giving 200 steps per revolution (360/1.8).
- Speed (RPM) = (Step Frequency x 60)/Steps per Revolution. This equation calculates the speed of the motor in Revolutions per Minute (RPM). The step frequency is the rate at which the control signals change, and steps per revolution is the number of steps the motor takes to complete one full rotation. This equation converts the step frequency into a more commonly used speed metric, RPM.
- Coil Current (I) = Driving Voltage (V)/Coil Resistance (R)

1.4 Overview – Stepper Run Modes

Full-Step

In Full-Step mode, the motor rotates complete mechanical steps at once - for a standard 200 full-steps/revolution stepper motor, this would be 1.8° for a single step. The motor's two coils are powered sequentially in four full steps. The sequence determines the stepper motor's direction of rotation. Full-Step mode is simple to control, but can cause vibration and noise due to the large step angle. Another drawback of using this mode is that the stepper motor's current consumption is at the highest level, having the lowest efficiency. This mode is often used in applications where the drive algorithm simplicity is more important than the smoothness of operation or precision.

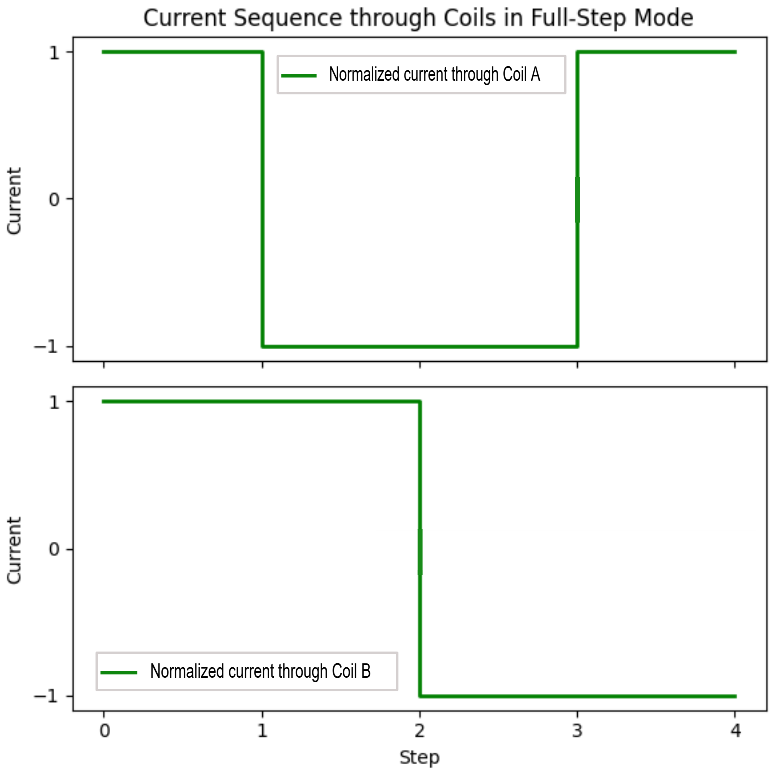
Figure 1-14. Full-Step Sequence



Full-Step Sequence

Full-Step	Coil A	Coil B
Step 1	positive	positive
Step 2	negative	positive
Step 3	negative	negative
Step 4	positive	negative

Figure 1-15. Current Sequence through Coils in Full-Step Mode

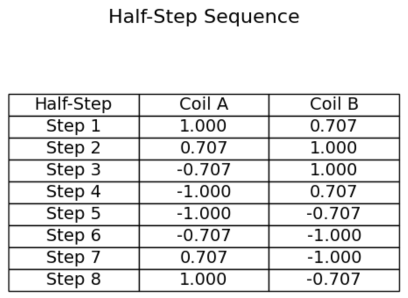


Remember: Green represents the current through coil A and B.

Half-Step

In Half-Step mode, four extra steps are inserted between the four initial full steps, making the stepper motor rotate by half its full-step angle, effectively doubling the number of mechanical steps per revolution - for a standard 200 full-steps/revolution stepper motor, this would be 0.9° for a complete step, resulting in a smoother operation and less vibration than the Full-Step mode. The benefits of having a balance between simplicity, efficiency, smoothness of operation, and lower current consumption outweigh the increased complexity of the control algorithm needed for this mode. It also provides double resolution of the Full-Step mode.

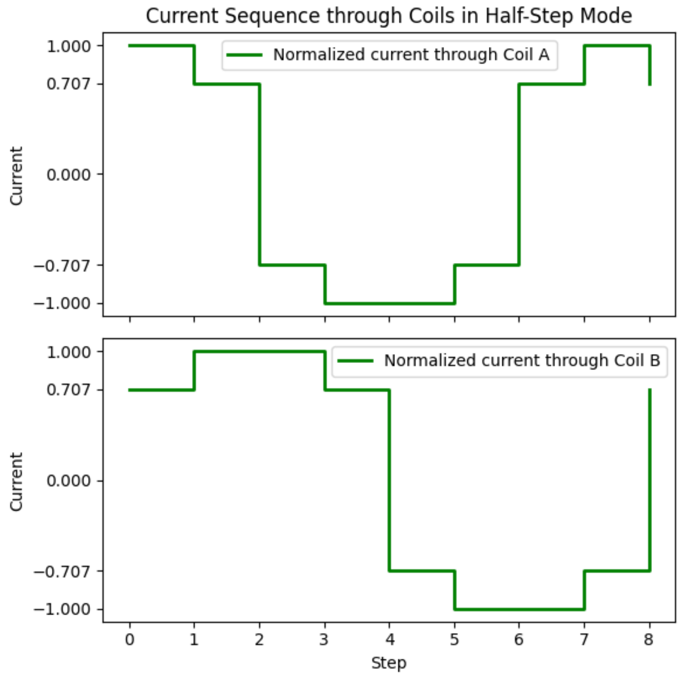
Figure 1-16. Half-Step Sequence



Half-Step Sequence

Half-Step	Coil A	Coil B
Step 1	1.000	0.707
Step 2	0.707	1.000
Step 3	-0.707	1.000
Step 4	-1.000	0.707
Step 5	-1.000	-0.707
Step 6	-0.707	-1.000
Step 7	0.707	-1.000
Step 8	1.000	-0.707

Figure 1-17. Current Sequence Through Coils in Half-Step Mode



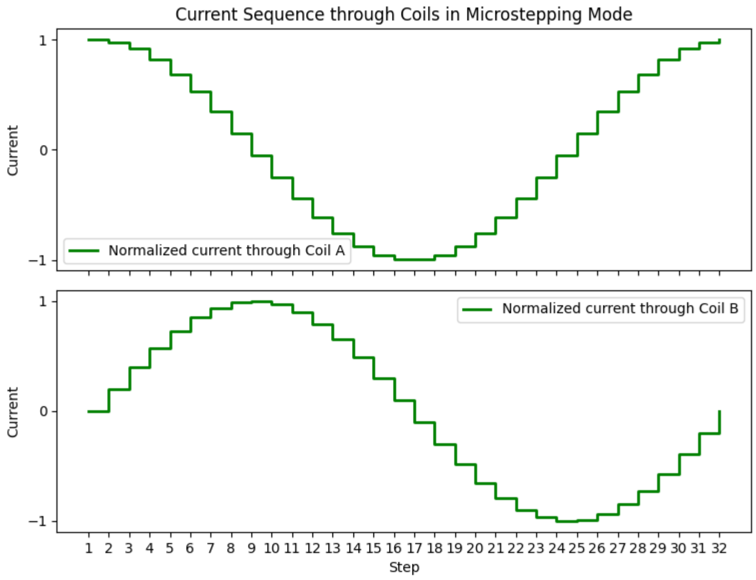
NOTICE 0.707 represents sin (45°) or cos (45°).
The green represents the current through coils A and B.

Micro-Step

The Micro-step mode divides the full-step angle into smaller steps, providing even smoother operation and higher precision. The number of micro-steps per full-step can vary, but the typical values are 8, 16, 32, or even 256 micro steps per full-step. Even though this mode requires the most complex control algorithms, the current consumption is lower than in Full-Step and Half-Step modes, providing the highest precision, the lowest vibration, and less noise. Micro-Step mode is often used in applications where accuracy and smoothness of operation are paramount, such as in CNC machines.

In the current implementation, 32 micro-steps are used for every 90° of the wave, equivalent to 32 micro-steps per full step.

Figure 1-18. Current Sequence Through Coils in Micro-Step Mode



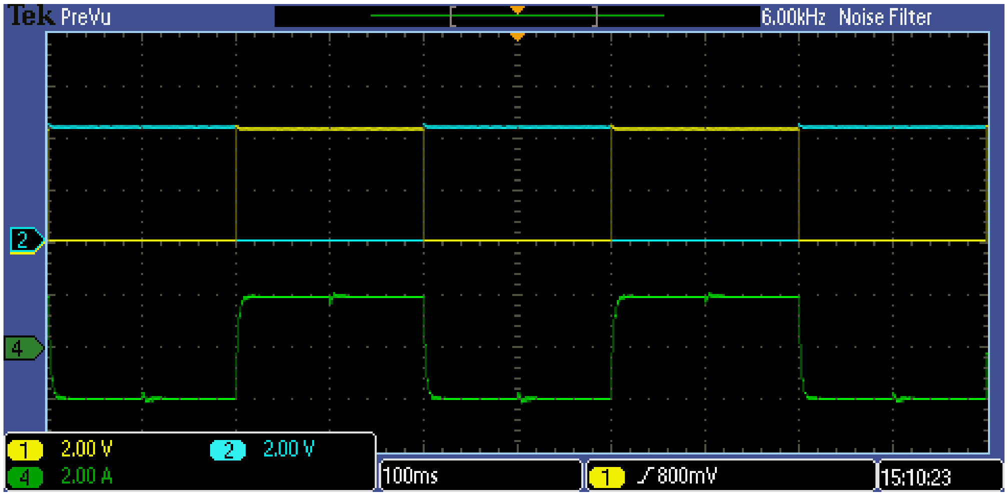
Remember:
Green represents the current through coils A and B.

2. Drive Modes

2.1 Full-Step

In Full-Step mode, the motor rotates complete mechanical steps at once - for a standard 200 full-steps/revolution stepper motor, this would be 1.8° for a sub-step. The motor's two coils are powered sequentially in four full-steps. The sequence determines the stepper motor's direction of rotation.

Figure 2-1. Oscilloscope Capture for Full-Step Mode

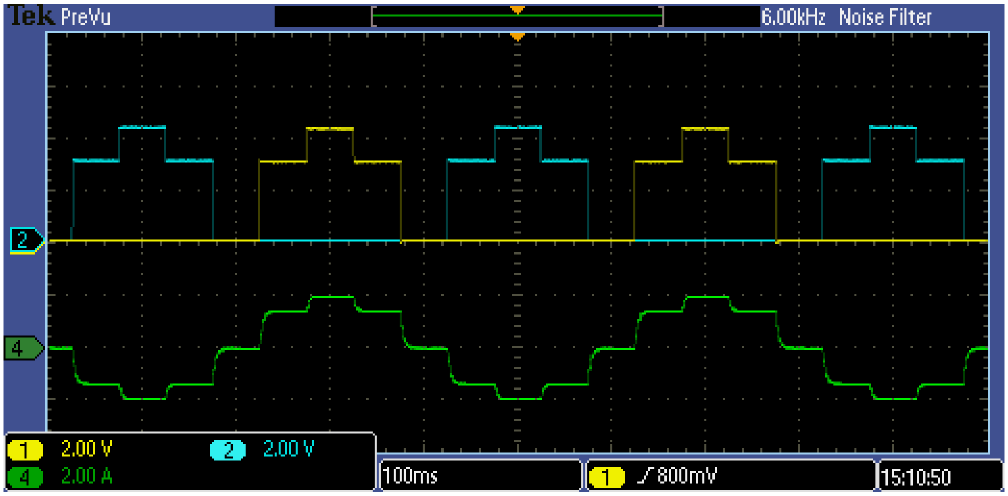


Note:
Yellow and blue represent the voltages at the two ends of coil A. Green indicates the current through coil A. A low-pass filtering from the oscilloscope applies, removing the PWM artifacts and making the short-time average values visible on all three traces.

2.2 Half-Step

In Half-Step mode, four extra steps are inserted between the four initial full-steps, which makes the stepper motor rotate by half of its full-step angle. This effectively doubles the number of mechanical steps per revolution - for a standard 200 full-steps/revolution stepper motor, this would be 0.9° for a complete step, resulting in a smoother operation and less vibration compared to the Full-Step mode. The benefits of having a balance between simplicity, efficiency, smoothness of operation and a lower current consumption outweigh the increased complexity of the control algorithm needed for this mode. It also provides double resolution of the Full-Step mode.

Figure 2-2. Oscilloscope Capture for Half-Step Mode



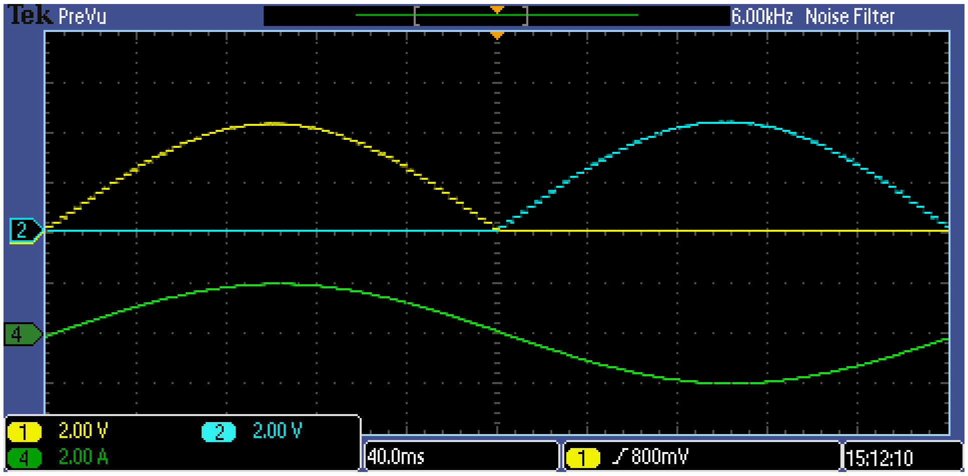
Note:
Yellow and blue represent the voltages at the two ends of coil A. Green represents the current through coil A. On all three traces a low pass filtering from the oscilloscope is applied. This removes the PWM artifacts and makes visible the short time average values.

2.3 Micro-Step

The Micro-Step mode divides the full step angle into smaller steps, providing even smoother operation and higher precision. The number of micro-steps per full step can vary. But in this demo it is implemented with 32 micro-steps per full step. Even though this mode requires the most complex control algorithms, the current consumption is lower than in full step and Half-Step modes, providing the highest accuracy, the lowest vibration, and less noise. Micro-Step mode is often used in applications where accuracy and smoothness of operation are paramount, such as in CNC machines.

The TCE peripheral has two primary functions. It generates the PWM signal and modulates the signal amplitude. The function generates the PWM signal according to the LUT array of 32 positions, scaled form 0 to 99%.

Figure 2-3. Oscilloscope Capture for Micro-Step Mode



In the current implementation, 32 micro-steps are used for every 90° of the wave, equivalent to 32 micro-steps per full step.

Note:
The colors used in the figure are yellow and blue, symbolizing the voltages at the two ends of coil A. Green symbolizes the current through coil A. Applying low pass filtering from the oscilloscope will remove the PWM artifacts and make the short-time average values visible on all three traces.

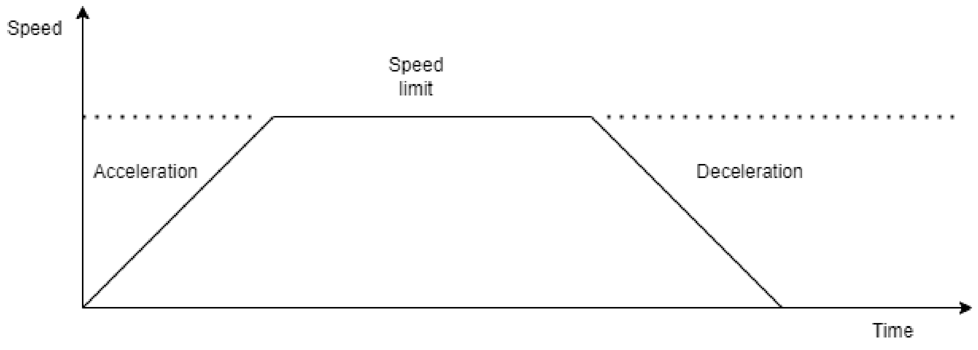
3. Implementation

3.1 Ramps

The application implements acceleration and deceleration ramps for stepper motor control.

Depending on the number of steps requested and the acceleration/deceleration values, the motor may get the desired speed limit (Fig. 3.1) or not (Fig. 3.2). If the distance to reach the speed is too short, the motor will accelerate and then start decelerating without reaching the limit speed.

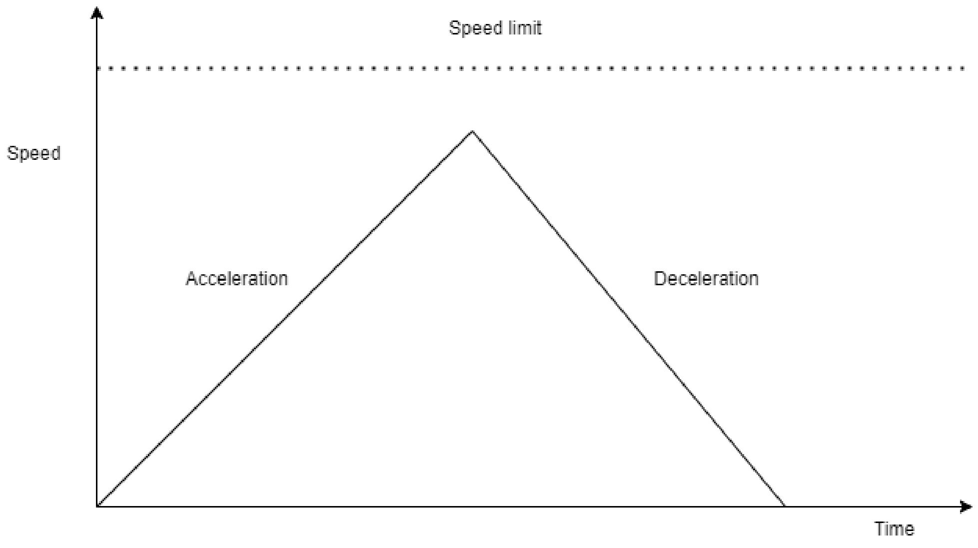
Figure 3-1. Acceleration Followed by Constant Speed and Deceleration



The stepper motor has time to accelerate, reach and cruise at the speed limit, followed by the deceleration period.

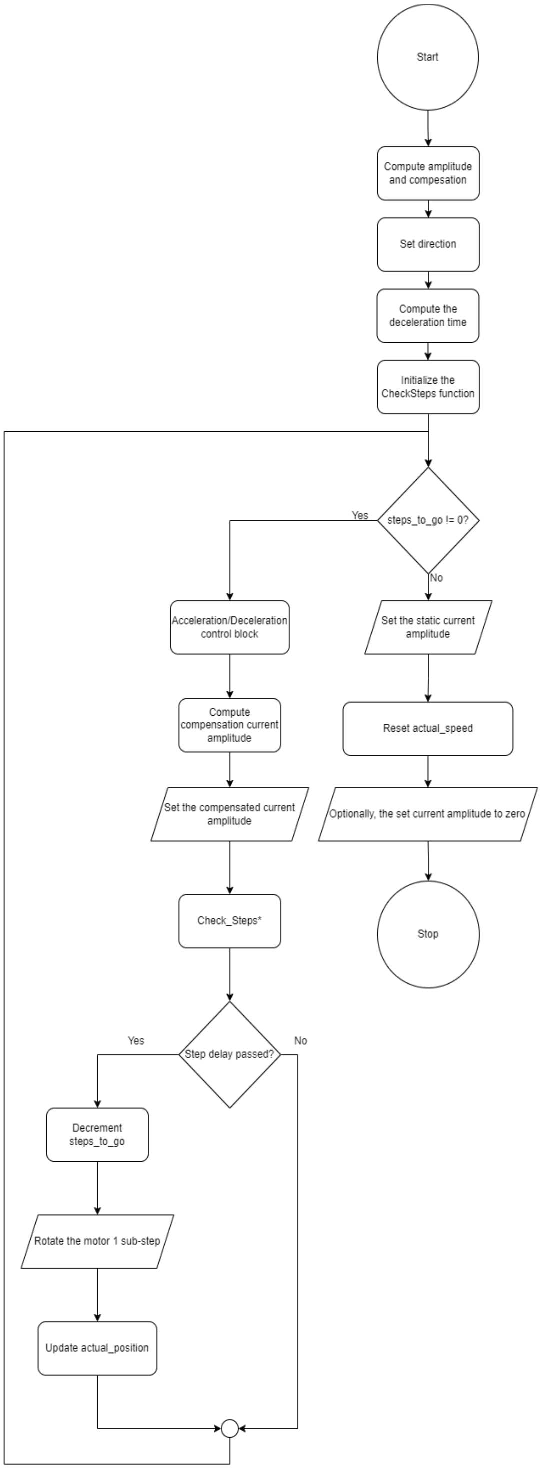
The distance to reach the speed is too small. The stepper motor will accelerate and then start decelerating without reaching the limit speed, as shown in the figure below.

Figure 3-2. Acceleration Followed by Deceleration



The application calls the Stepper_Move function periodically with the parameters. Initial position, steps (to go), acceleration, deceleration, speed and V_{BUS} (BUS voltage). In this implementation, the application automatically adjusts the drive amplitude according to the power supply voltage, trying to keep the current constant through the coils. The function precalculates the acceleration and deceleration time based on the speed and the number of steps the end user wants the motor to move. After finishing the computation, the StepAdvance function is called, which controls the movement of the motor. The StepAdvance function regulates the stepper drive schema, which generates a wave of 90 electrical degrees shifted.

Figure 3-3. Stepper Move Flowchart



3.2 Feed Forward Current Regulation

In this implementation, the application automatically adjusts the drive amplitude according to the power supply voltage, trying to keep the current constant through the coils.

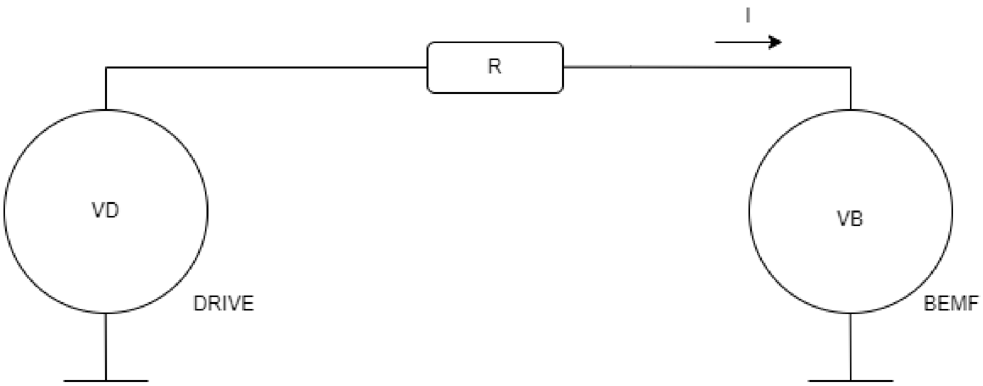
The duty cycle (amplitude) is adjusted so that the current through the two coils is ideally independent of the power supply voltage and cvasi-constant.

The BEMF is directly proportional to the speed of the rotor.

This method has limitations. There may be cases when the power supply voltage may be too small to produce the desired current through the coils. For example, the power supply voltage is 6V, the windings resistance is 10Ω, and the desired current through the coils is 1A; the current consumption in this case would be less than 1A.

The application adjusts the amplitude according to the speed of the stepper (BEMF).

Figure 3-4. Drive Amplitude in Relation with BEMF



V_{BEMF} (Back Electromotive Force) = Kv * Speed

As (Static Amplitude)= I * R/V_{BUS}

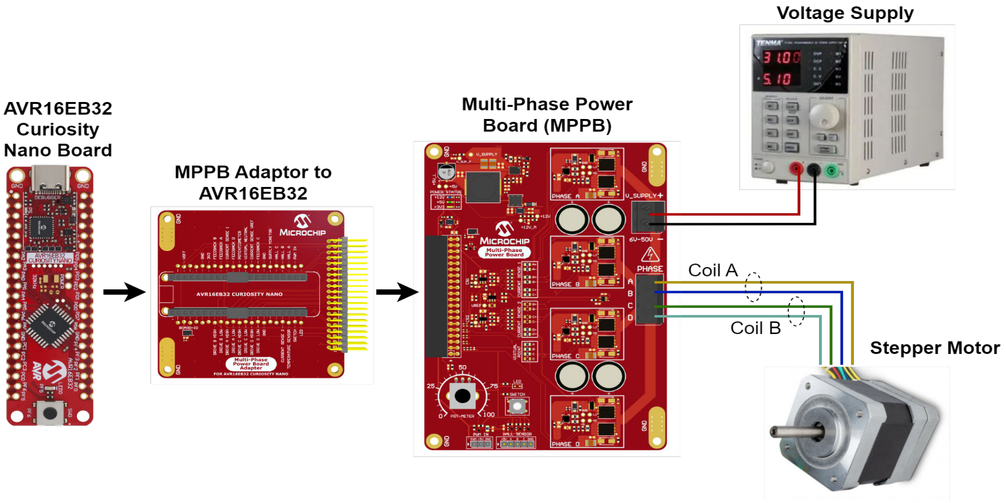
Ad (Dynamic Amplitude)=Kv * Speed/V_{BUS}

Drive Amplituude = (As +Ad) * V_{BUS}

3.3 Demo

This example presents how to drive a bipolar stepper motor using an AVR microcontroller, including the power stage.

Figure 3-5. Setup



Application Scenarios:

A basic example showing the stepper motor in Full-Step and Half-Step modes.

Adding the micro-stepping feature for precision increase.

Adding ramps (acceleration and deceleration) for better dynamic response.

3.3.1 Multi-Phase Power Board (MPPB)

The Multi-Phase Power Board has four half-bridges, each controlled by a MIC4605 MOSFET driver. Each MIC4605 controls two power MOSFET transistors.

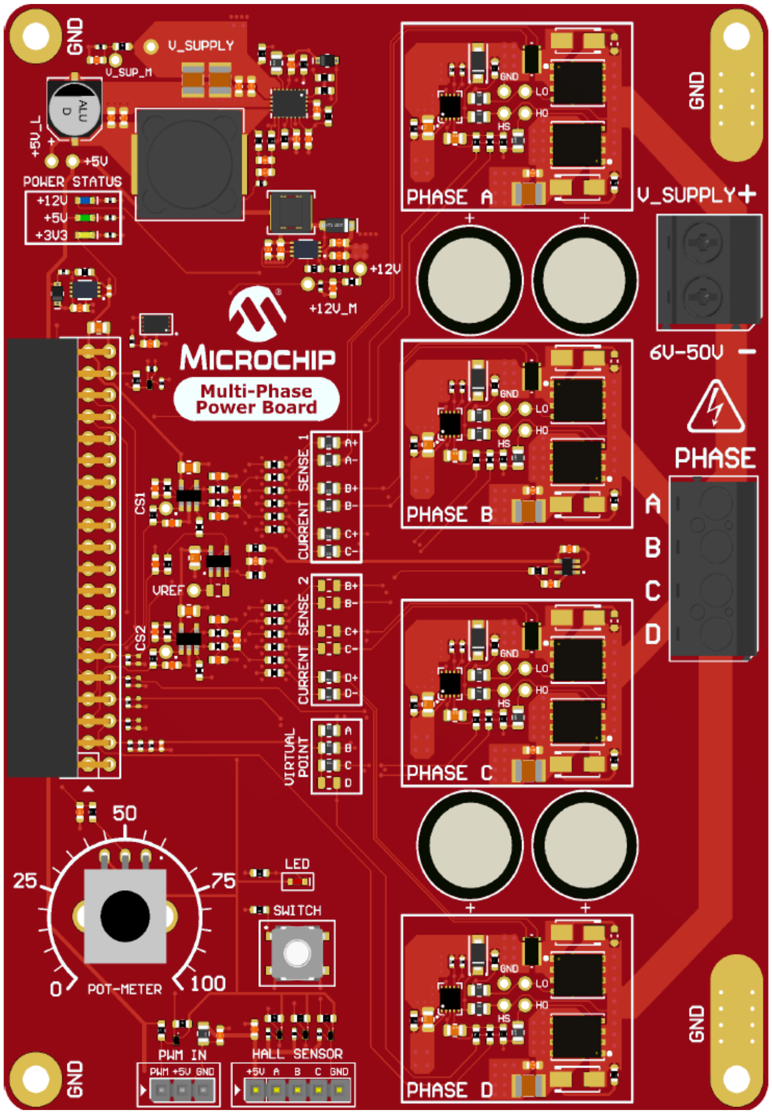
Two configurable current sense amplifiers can be configured in several ways.

An on-board power supply to take the motor voltage down to logic levels.

Generally, a wide input voltage range (6-50V).

Some peripherals on board (switch/LED/potentiometer/temperature sensor).

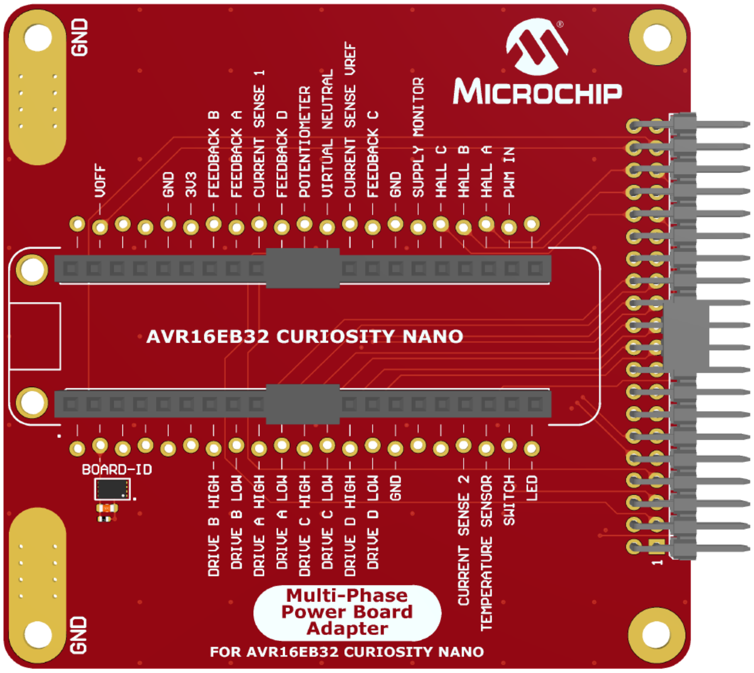
Figure 3-6. MPPB



More comprehensive information on MPPB can be found here: Multi-Phase Power Board Hardware User Guide

3.3.2 Demo-MPPB Adaptor

Figure 3-7. MPPB Adaptor



The MPPB board is not targeted only for AVR EB. It can be coupled with AVR® DA, for example.

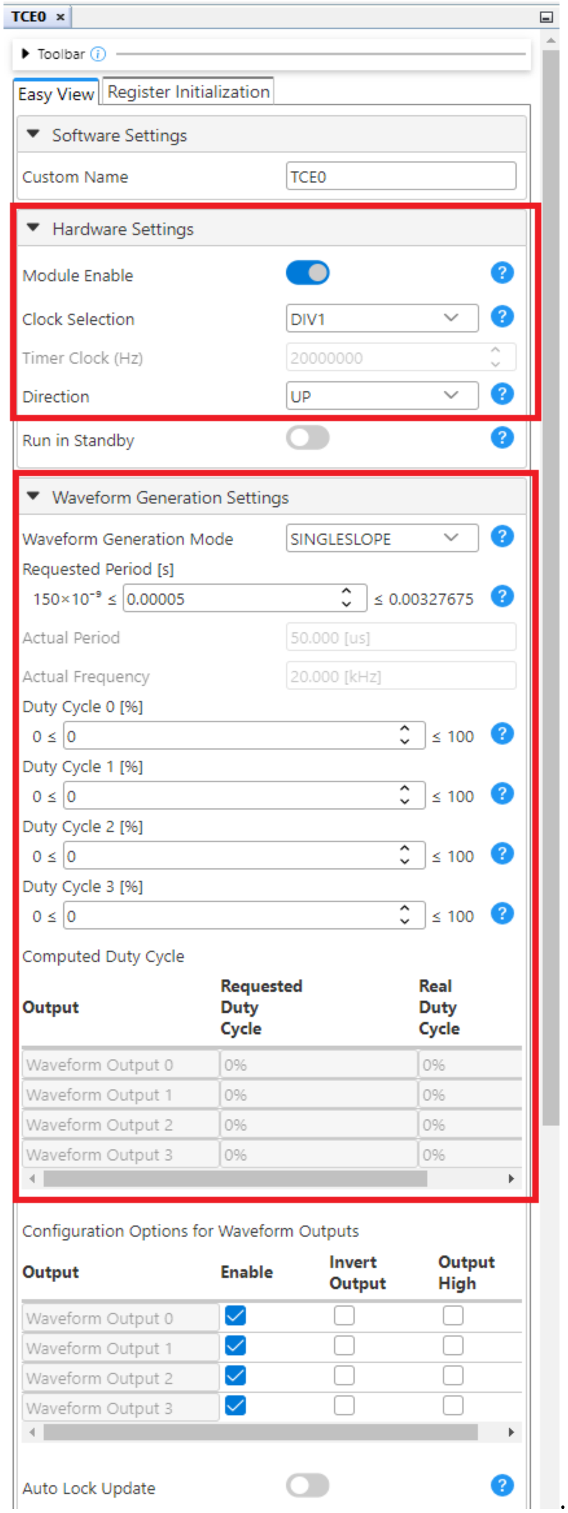
The adapter's role is to connect the AVR EB with the MPPB electrically.

3.3.3 Setup

These are the settings for the TCE and WEX peripherals made with MCC:

- Module Enable: Must be enabled by default. If not, toggle the button (it turns blue if enabled)
- Clock Selection: System clock (by default, the divider must be 1 - System clock)
- Counter Direction: UP
- Waveform Generation Mode: Single-Slope PWM mode with overflow on TOP
- Requested Period [s]: 0.00005
- Duty Cycle 0 [%]: 0
- Duty Cycle 1 [%]: 0
- Duty Cycle 2 [%]: 0
- Duty Cycle 3 [%]: 0
- Waveform Output n: Check the boxes from the Enable column for Waveform Output 0, 1, 2, 3
- Scale mode: CMP values are scaled from the Bottom, 50% DC (duty cycle)
- Scaled Writing to registers: Normal
- Amplitude Control Enable: Toggle the button (it turns blue if enabled)
- Generate ISR: Toggle the button (it turns blue if enabled)
- Overflow Interrupt Enable: Toggle the button (it turns blue if enabled)

Figure 3-8. TCE Initialization



Software Settings

Custom Name: TCE0

Hardware Settings

Module Enable: On

Clock Selection: DIV1

Timer Clock (Hz): 20000000

Direction: UP

Run in Standby: Off

Waveform Generation Settings

Waveform Generation Mode: SINGLESLOPE

Requested Period [s]

$150\times10^{-9} \le$ 0.00005 $\le$ 0.00327675

Actual Period: 50.000 [us]

Actual Frequency: 20.000 [kHz]

Duty Cycle 0 [%]: 0 ≤ 0 ≤ 100

Duty Cycle 1 [%]: 0 ≤ 0 ≤ 100

Duty Cycle 2 [%]: 0 ≤ 0 ≤ 100

Duty Cycle 3 [%]: 0 ≤ 0 ≤ 100

Computed Duty Cycle

Output	**Requested Duty Cycle**	**Real Duty Cycle**
Waveform Output 0	0%	0%
Waveform Output 1	0%	0%
Waveform Output 2	0%	0%
Waveform Output 3	0%	0%

Configuration Options for Waveform Outputs

Output	**Enable**	**Invert Output**	**Output High**
Waveform Output 0	☑	☐	☐
Waveform Output 1	☑	☐	☐
Waveform Output 2	☑	☐	☐
Waveform Output 3	☑	☐	☐

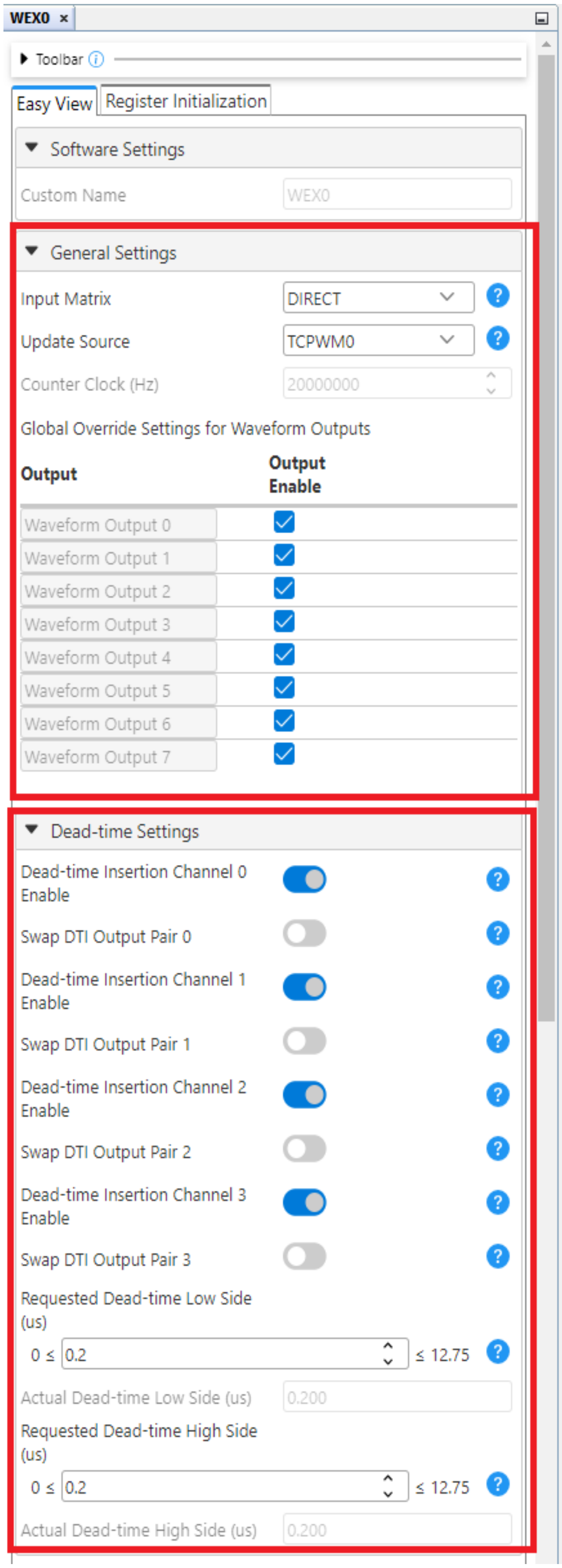
Auto Lock Update: Off

WEX configurations:

- Input Matrix: Direct
- Update Source: TCE (the update condition for the output signals will be dictated by TCE)

- Override Settings: Check all the boxes from the Output Enable column for the Waveform Output [0-7]
- Dead-time Insertion Channel 0 Enable: Toggle the button (it turns blue if enabled)
- Dead-time Insertion Channel 1 Enable: Toggle the button (it turns blue if enabled)
- Dead-time Insertion Channel 2 Enable: Toggle the button (it turns blue if enabled)
- Dead-time Insertion Channel 3 Enable: Toggle the button (it turns blue if enabled)
- Requested Dead-time Low Side (µs): 0.2
- Requested Dead-time High Side (µs): 0.2

Figure 3-9. WEX Initialization



Software Settings

Custom Name: WEX0

General Settings

Input Matrix: DIRECT

Update Source: TCPWM0

Counter Clock (Hz): 20000000

Global Override Settings for Waveform Outputs

Output	**Output Enable**
Waveform Output 0	☑
Waveform Output 1	☑
Waveform Output 2	☑
Waveform Output 3	☑
Waveform Output 4	☑
Waveform Output 5	☑
Waveform Output 6	☑
Waveform Output 7	☑

Dead-time Settings

Dead-time Insertion Channel 0 Enable	●
Swap DTI Output Pair 0	○
Dead-time Insertion Channel 1 Enable	●
Swap DTI Output Pair 1	○
Dead-time Insertion Channel 2 Enable	●
Swap DTI Output Pair 2	○
Dead-time Insertion Channel 3 Enable	●
Swap DTI Output Pair 3	○

Requested Dead-time Low Side (us): 0 ≤ 0.2 ≤ 12.75

Actual Dead-time Low Side (us): 0.200

Requested Dead-time High Side (us): 0 ≤ 0.2 ≤ 12.75

Actual Dead-time High Side (us): 0.200

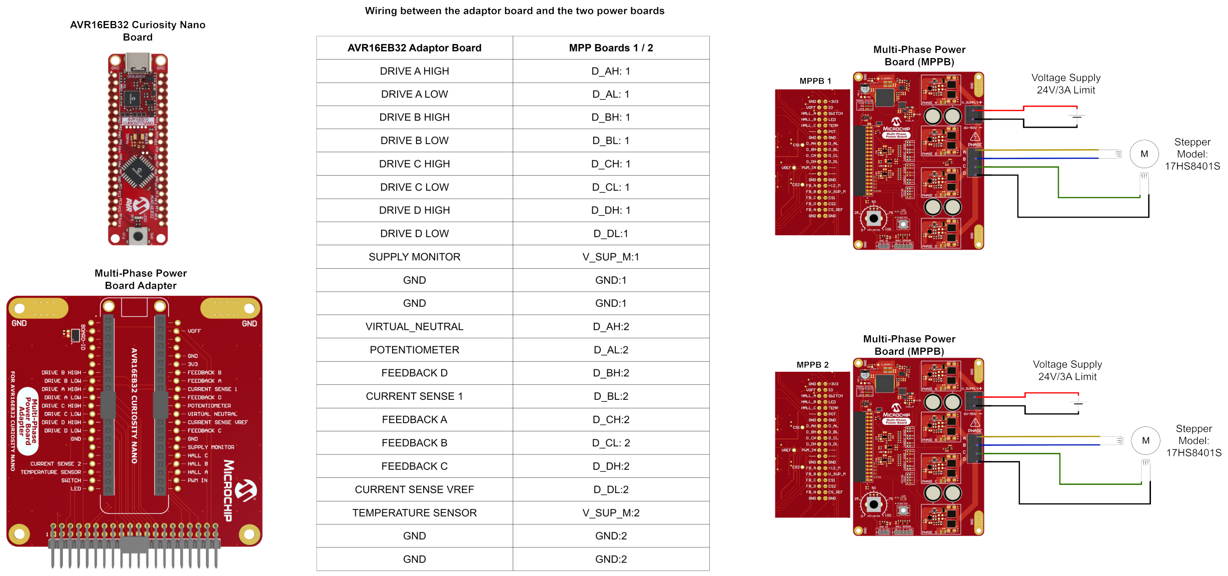
After the MCC libraries are generated, the code is only sufficient for peripheral initialization, to spin the motor the demo files must be added. The "`stepper.c`" and "`stepper.h`" files must be added and the "`main.c`" file must be edited to call the dedicated APIs.

3.4 Further Use Cases: Two Bipolar Stepper Motors

This illustration presents a method for alternately operating two bipolar stepper motors with a solitary AVR microcontroller paired with dual power boards. The inclusion of a second motor serves to exemplify the capabilities of the PORTMUX peripheral. In this setup, the motors are engaged sequentially, not simultaneously.

The hardware used includes the AVR16EB32 Curiosity Nano Development board, in conjunction with the MPPB, the AVR EB CNANO to MPPB Adapter Board, a pair of stepper motors, and a power source. The configuration allows a single or dual power supply to energize both MPPBs.

Figure 3-10. Two Stepper Motors Configuration



Wiring between the adaptor board and the two power boards

AVR16EB32 Adaptor Board	MPP Boards 1 / 2
DRIVE A HIGH	D_AH: 1
DRIVE A LOW	D_AL: 1
DRIVE B HIGH	D_BH: 1
DRIVE B LOW	D_BL: 1
DRIVE C HIGH	D_CH: 1
DRIVE C LOW	D_CL: 1
DRIVE D HIGH	D_DH: 1
DRIVE D LOW	D_DL:1
SUPPLY MONITOR	V_SUP_M:1
GND	GND:1
GND	GND:1
VIRTUAL_NEUTRAL	D_AH:2
POTENTIOMETER	D_AL:2
FEEDBACK D	D_BH:2
CURRENT SENSE 1	D_BL:2
FEEDBACK A	D_CH:2
FEEDBACK B	D_CL: 2
FEEDBACK C	D_DH:2
CURRENT SENSE VREF	D_DL:2
TEMPERATURE SENSOR	V_SUP_M:2
GND	GND:2
GND	GND:2

4. Conclusions

This application note presented a stepper motor drive solution using the AVR EB family of microcontrollers. The new TCE and WEX peripherals can generate the necessary drive PWMs with internal configurations to reduce code complexity. Microchip provides new hardware supporting the connection and demonstration of a stepper motor, comprising the AVR EB Curiosity Nano, Multi-phase Power Board, and an AVR EB CNANO to MPPB adapter, which can be ordered from the Microchip website.

The application drives the stepper motor in three modes: Full-Step, Half-Step and, Micro-Step, with acceleration and deceleration ramps and dynamic current management. A further use case application has been created to drive two stepper motors sequentially.

Possible enhancements:

Implementing functional safety for stepper motors by constantly measuring voltage, current, and temperature is a proactive approach to ensure the system operates within safe parameters. Functional safety refers to a part of the overall safety that depends on a system or equipment operating correctly in response to its inputs, including the safe management of likely operator errors, hardware failures, and environmental changes.

A method of controlling the acceleration and deceleration of stepper motors to create a smooth motion profile is known as an S-curve acceleration profile, an S-shaped ramp.

To implement an S-shaped ramp, the stepper motor controller needs to be capable of generating the complex motion profile and adjusting the current to the motor coils accordingly, which typically requires more advanced control algorithms and may involve the use of micro-stepping to achieve the desired level of motion smoothness.

5. References

AVR16EB32 CURIOSITY NANO EVALUATION KIT

AVR16EB32-CNANO MPPB-Adapter

Clock Failure Detect (CFD)

Getting Started with Timer/Counter type E (TCE) and Waveform Extension (WEX)

IEC 60730 Home Appliance Functional Safety for 8-bit MCUs

Industrial Functional Safety for 8-bit MCUs

ISO 26262 Automotive Functional Safety for 8-bit MCUs

Multi-Phase Power Board

6. Revision History

Document Revision	Date	Comments
A	09/2024	Initial document release

Microchip Information

The Microchip Website

Microchip provides online support via our website at www.microchip.com/. This website is used to make files and information easily available to customers. Some of the content available includes:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip design partner program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

Product Change Notification Service

Microchip's product change notification service helps keep customers current on Microchip products. Subscribers will receive email notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, go to www.microchip.com/pcn and follow the registration instructions.

Customer Support

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Embedded Solutions Engineer (ESE)
- Technical Support

Customers should contact their distributor, representative or ESE for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in this document.

Technical support is available through the website at: www.microchip.com/support

Microchip Devices Code Protection Feature

Note the following details of the code protection feature on Microchip products:

- Microchip products meet the specifications contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is secure when used in the intended manner, within operating specifications, and under normal conditions.
- Microchip values and aggressively protects its intellectual property rights. Attempts to breach the code protection features of Microchip product is strictly prohibited and may violate the Digital Millennium Copyright Act.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of its code. Code protection does not mean that we are guaranteeing the product is "unbreakable". Code protection is constantly evolving. Microchip is committed to continuously improving the code protection features of our products.

Legal Notice

This publication and the information herein may be used only with Microchip products, including to design, test, and integrate Microchip products with your application. Use of this information in any other manner violates these terms. Information regarding device applications is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure

Trademarks

The Microchip name and logo, the Microchip logo, Adaptec, AVR, AVR logo, AVR Freaks, BesTime, BitCloud, CryptoMemory, CryptoRF, dsPIC, flexPWR, HELDO, IGLOO, JukeBlox, KeeLoq, Kleer, LANCheck, LinkMD, maXStylus, maXTouch, MediaLB, megaAVR, Microsemi, Microsemi logo, MOST, MOST logo, MPLAB, OptoLyzer, PIC, picoPower, PICSTART, PIC32 logo, PolarFire, Prochip Designer, QTouch, SAM-BA, SenGenuity, SpyNIC, SST, SST Logo, SuperFlash, Symmetricom, SyncServer, Tachyon, TimeSource, tinyAVR, UNI/O, Vectron, and XMEGA are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

AgileSwitch, ClockWorks, The Embedded Control Solutions Company, EtherSynch, Flashtec, Hyper Speed Control, HyperLight Load, Libero, motorBench, mTouch, Powermite 3, Precision Edge, ProASIC, ProASIC Plus, ProASIC Plus logo, Quiet-Wire, SmartFusion, SyncWorld, TimeCesium, TimeHub, TimePictra, TimeProvider, and ZL are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Adjacent Key Suppression, AKS, Analog-for-the-Digital Age, Any Capacitor, AnyIn, AnyOut, Augmented Switching, BlueSky, BodyCom, Clockstudio, CodeGuard, CryptoAuthentication, CryptoAutomotive, CryptoCompanion, CryptoController, dsPICDEM, dsPICDEM.net, Dynamic Average Matching, DAM, ECAN, Espresso T1S, EtherGREEN, EyeOpen, GridTime, IdealBridge, IGaT, In-Circuit Serial Programming, ICSP, INICnet, Intelligent Paralleling, IntelliMOS, Inter-Chip Connectivity, JitterBlocker, Knob-on-Display, MarginLink, maxCrypto, maxView, memBrain, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, mSiC, MultiTRAK, NetDetach, Omniscient Code Generation, PICDEM, PICDEM.net, PICkit, PICtail, Power MOS IV, Power MOS 7, PowerSmart, PureSilicon, QMatrix, REAL ICE, Ripple Blocker, RTAX, RTG4, SAM-ICE, Serial Quad I/O, simpleMAP, SimpliPHY, SmartBuffer, SmartHLS, SMART-I.S., storClad, SQI, SuperSwitcher, SuperSwitcher II, Switchtec, SynchroPHY, Total Endurance, Trusted Time, TSHARC, Turing, USBCheck, VariSense, VectorBlox, VeriPHY, ViewSpan, WiperLock, XpressConnect, and ZENA are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

The Adaptec logo, Frequency on Demand, Silicon Storage Technology, and Symmcom are registered trademarks of Microchip Technology Inc. in other countries.

GestIC is a registered trademark of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

ISBN: 978-1-6683-0205-7

Quality Management System

For information regarding Microchip’s Quality Management Systems, please visit www.microchip.com/quality.

Worldwide Sales and Service

AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200
Fax: 480-792-7277
Technical Support:
www.microchip.com/support
Web Address:
www.microchip.com
Atlanta
Duluth, GA
Tel: 678-957-9614
Fax: 678-957-1455
Austin, TX
Tel: 512-257-3370
Boston
Westborough, MA
Tel: 774-760-0087
Fax: 774-760-0088
Chicago
Itasca, IL
Tel: 630-285-0071
Fax: 630-285-0075
Dallas
Addison, TX
Tel: 972-818-7423
Fax: 972-818-2924
Detroit
Novi, MI
Tel: 248-848-4000
Houston, TX
Tel: 281-894-5983
Indianapolis
Noblesville, IN
Tel: 317-773-8323
Fax: 317-773-5453
Tel: 317-536-2380
Los Angeles
Mission Viejo, CA
Tel: 949-462-9523
Fax: 949-462-9608
Tel: 951-273-7800
Raleigh, NC
Tel: 919-844-7510
New York, NY
Tel: 631-435-6000
San Jose, CA
Tel: 408-735-9110
Tel: 408-436-4270
Canada - Toronto
Tel: 905-695-1980
Fax: 905-695-2078

ASIA/PACIFIC

Australia - Sydney
Tel: 61-2-9868-6733
China - Beijing
Tel: 86-10-8569-7000
China - Chengdu
Tel: 86-28-8665-5511
China - Chongqing
Tel: 86-23-8980-9588
China - Dongguan
Tel: 86-769-8702-9880
China - Guangzhou
Tel: 86-20-8755-8029
China - Hangzhou
Tel: 86-571-8792-8115
China - Hong Kong SAR
Tel: 852-2943-5100
China - Nanjing
Tel: 86-25-8473-2460
China - Qingdao
Tel: 86-532-8502-7355
China - Shanghai
Tel: 86-21-3326-8000
China - Shenyang
Tel: 86-24-2334-2829
China - Shenzhen
Tel: 86-755-8864-2200
China - Suzhou
Tel: 86-186-6233-1526
China - Wuhan
Tel: 86-27-5980-5300
China - Xian
Tel: 86-29-8833-7252
China - Xiamen
Tel: 86-592-2388138
China - Zhuhai
Tel: 86-756-3210040

ASIA/PACIFIC

India - Bangalore
Tel: 91-80-3090-4444
India - New Delhi
Tel: 91-11-4160-8631
India - Pune
Tel: 91-20-4121-0141
Japan - Osaka
Tel: 81-6-6152-7160
Japan - Tokyo
Tel: 81-3-6880- 3770
Korea - Daegu
Tel: 82-53-744-4301
Korea - Seoul
Tel: 82-2-554-7200
Malaysia - Kuala Lumpur
Tel: 60-3-7651-7906
Malaysia - Penang
Tel: 60-4-227-8870
Philippines - Manila
Tel: 63-2-634-9065
Singapore
Tel: 65-6334-8870
Taiwan - Hsin Chu
Tel: 886-3-577-8366
Taiwan - Kaohsiung
Tel: 886-7-213-7830
Taiwan - Taipei
Tel: 886-2-2508-8600
Thailand - Bangkok
Tel: 66-2-694-1351
Vietnam - Ho Chi Minh
Tel: 84-28-5448-2100

EUROPE

Austria - Wels
Tel: 43-7242-2244-39
Fax: 43-7242-2244-393
Denmark - Copenhagen
Tel: 45-4485-5910
Fax: 45-4485-2829
Finland - Espoo
Tel: 358-9-4520-820
France - Paris
Tel: 33-1-69-53-63-20
Fax: 33-1-69-30-90-79
Germany - Garching
Tel: 49-8931-9700
Germany - Haan
Tel: 49-2129-3766400
Germany - Heilbronn
Tel: 49-7131-72400
Germany - Karlsruhe
Tel: 49-721-625370
Germany - Munich
Tel: 49-89-627-144-0
Fax: 49-89-627-144-44
Germany - Rosenheim
Tel: 49-8031-354-560
Israel - Ra’anana
Tel: 972-9-744-7705
Italy - Milan
Tel: 39-0331-742611
Fax: 39-0331-466781
Italy - Padova
Tel: 39-049-7625286
Netherlands - Drunen
Tel: 31-416-690399
Fax: 31-416-690340
Norway - Trondheim
Tel: 47-72884388
Poland - Warsaw
Tel: 48-22-3325737
Romania - Bucharest
Tel: 40-21-407-87-50
Spain - Madrid
Tel: 34-91-708-08-90
Fax: 34-91-708-08-91
Sweden - Gothenberg
Tel: 46-31-704-60-40
Sweden - Stockholm
Tel: 46-8-5090-4654
UK - Wokingham
Tel: 44-118-921-5800
Fax: 44-118-921-5820