

# Application Note

## Stepper Motor Driver

AN-CM-295

### Abstract

*This application note describes HVPAK IC configured as stepper motor driver with current mode control.*

*The application note comes complete with design files which can be found in the Reference section.*

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## Contents

|   |           |
|---|-----------|
| <b>Abstract</b> .....                               | <b>1</b>  |
| <b>Contents</b> .....                               | <b>2</b>  |
| <b>Figures</b> .....                                | <b>3</b>  |
| <b>Tables</b> .....                                 | <b>3</b>  |
| <b>1 Terms and Definitions</b> .....                | <b>4</b>  |
| <b>2 References</b> .....                           | <b>4</b>  |
| <b>3 Introduction</b> .....                         | <b>5</b>  |
| <b>4 Construction and Operation Principle</b> ..... | <b>6</b>  |
| <b>5 GreenPAK Design</b> .....                      | <b>8</b>  |
| 5.1 PWM Frequency and Blanking Time .....           | 8         |
| 5.2 RegFile Usage .....                             | 9         |
| 5.3 Changing Rotation Direction .....               | 10        |
| 5.4 Current Measurement .....                       | 11        |
| 5.5 Step/Microstep Modes .....                      | 13        |
| 5.5.1 Full Step Mode.....                           | 14        |
| 5.5.2 Microstep Mode .....                          | 15        |
| <b>6 Waveforms</b> .....                            | <b>18</b> |
| 6.1 Full Step .....                                 | 18        |
| 6.1.1 Changing Rotation Direction.....              | 19        |
| 6.1.2 Motor Turn-On in Full Step Mode .....         | 19        |
| 6.2 Microstep.....                                  | 20        |
| 6.2.1 Changing Rotation Direction.....              | 20        |
| 6.2.2 Motor Turn-On in Microstep Mode.....          | 21        |
| 6.2.3 Microstep Decay Modes .....                   | 21        |
| 6.3 Changing Modes Dynamically .....                | 23        |
| <b>7 Conclusion</b> .....                           | <b>24</b> |
| <b>Revision History</b> .....                       | <b>25</b> |

## Stepper Motor Driver

### Figures

|   |    |
|---|----|
| Figure 1. Stepper Motor.....  | 5  |
| Figure 2. Block Diagram.....  | 6  |
| Figure 3. Typical Application Circuit.....  | 7  |
| Figure 4. Evaluation Board Motor Connection.....                                  | 8  |
| Figure 5. Design View.....  | 8  |
| Figure 6. Block for Blanking Time Generation.....                                 | 9  |
| Figure 7. CNT1/DLY1 Timings.....  | 9  |
| Figure 8. Reg File Data.....  | 10 |
| Figure 9: Windings Current Form.....  | 10 |
| Figure 10. Changing Direction.....  | 10 |
| Figure 11: Current Measurement Circuit.....                                       | 11 |
| Figure 12. Resistor Connection.....   | 11 |
| Figure 13: Increasing Current Limit.....  | 12 |
| Figure 14. Decreasing Current Limit.....  | 12 |
| Figure 15. Step Operation: a) Full Step Operation, b) 16 Microstep Operation..... | 13 |
| Figure 16. Step/Microstep Mode Control Block.....                                 | 13 |
| Figure 17: Step Mode Timing Diagram.....  | 14 |
| Figure 18: Square Current Shape.....  | 15 |
| Figure 19: Microstep Mode Timing Diagram.....                                     | 16 |
| Figure 20: Sine Wave Current Shape.....   | 17 |
| Figure 21. Full Step Current Waveforms.....                                       | 18 |
| Figure 22. Changing Rotation Direction in Full Step Mode.....                     | 19 |
| Figure 23. Motor Start in Full Step Mode.....                                     | 19 |
| Figure 24. Microstep Mode Current Waveforms.....                                  | 20 |
| Figure 25. Changing Rotation Direction in Microstep Mode.....                     | 20 |
| Figure 26. Motor Start in Microstep Mode.....                                     | 21 |
| Figure 27. Decay Mode Input.....  | 21 |
| Figure 28. Fast Decay Mode.....   | 22 |
| Figure 29. Slow Decay Mode.....   | 22 |
| Figure 30. Changing Mode from Full Step to Microstep.....                         | 23 |
| Figure 31. Changing Mode from Microstep to Full Step Mode.....                    | 23 |

### Tables

|                                |   |
|--------------------------------|---|
| Table 1. Motor Parameters..... | 7 |
|--------------------------------|---|

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## Stepper Motor Driver

### 1 Terms and Definitions

|     |                        |
|-----|------------------------|
| PWM | Pulse width modulation |
| DC  | Direct current         |
| CMP | Comparator             |
| MCU | Microcontroller unit   |
| HV  | High voltage           |
| GPO | General purpose output |
| LUT | Look up table          |

### 2 References

For related documents and software, please visit:

[GreenPAK™ Programmable Mixed-Signal Products | Renesas](#)

Download our free [GreenPAK™ Designer](#) software [1] to open the .gp files [2] and view the proposed circuit design. Use the [GreenPAK development tools](#) [3] to freeze the design into your own customized IC in a matter of minutes. Find out more in complete library of application notes [4] featuring design examples as well as explanations of features and blocks within the GreenPAK IC.

- [1] [Go Configure™ Software Hub | Renesas](#), Software Download and User Guide
- [2] [AN-CM-295 Stepper Motor Driver.gp](#), [GreenPAK Design File](#)
- [3] [GreenPAK Development Tools](#), [GreenPAK Development Tools Webpage](#)
- [4] [GreenPAK Application Notes](#), [GreenPAK Application Notes Webpage](#)
- [5] [SLG47105 Datasheet](#)

Author: Petro Zhuk

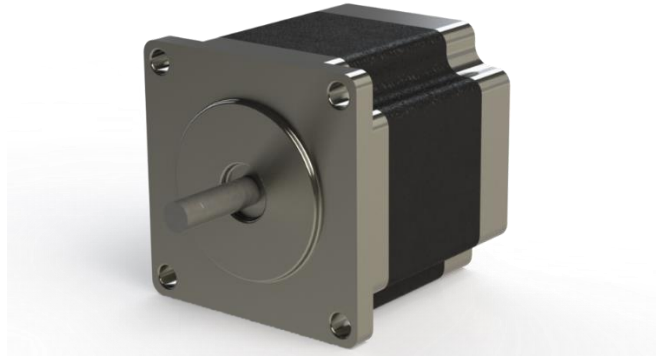
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**Stepper Motor Driver**

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### 3 Introduction

A stepper motor is a brushless DC electric motor that divides every revolution into a number of equal steps. The motor's position can be then commanded to move and hold at one of these steps without any position sensor for feedback (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed.



**Figure 1. Stepper Motor**

A typical stepper motor can be used in three modes: full step, half-stepping, and microstepping. The microstep mode allows rotating the rotor on a smaller angle than full step mode and makes rotation smoother. The SLG47105 IC supports all of these modes.

Stepper motors can be divided into two classes according to the type of winding - bipolar and unipolar steppers.

Unipolar stepper motors have one winding with the center tap per phase. Each section of windings is switched on for each direction of magnetic field. Because in this arrangement a magnetic pole can be reversed without switching the direction of current, the commutation circuit can be made very simple for each winding. Usually, given a phase, the center tap of each winding is made common, giving three leads per phase and six leads for a typical two-phase motor. These two-phase commons are often connected internally, so the motor has only five external leads.

Bipolar stepper motors have a single winding per phase. To reverse a magnetic pole, the current in a winding needs to be reversed. Therefore, the control circuit must be more complicated. There are two leads per phase, and none is common.

## Stepper Motor Driver

### 4 Construction and Operation Principle

In this application note an example of SLG47105 usage is shown for the bipolar stepper motor. Since current flows across entire coil, bipolar motors have greater torque than in the unipolar motor case. In brief, the SLG47105 is used as a driver for the stepper motor. The MCU controls the driver. In this design example, the driver has two modes: full step and 1/16 step.

The internal design structure can be divided into several parts:

- Step/Microstep block that controls step and microstep modes. In step mode, one pulse on 'Step' input corresponds to one step for the stepper motor. In microstep mode 16 pulses on 'Step' input correspond to one step for the stepper motor, so one step in this mode is divided to 16 microsteps that increases rotation accuracy;
- Within the SLG47105, a 'Blanking time' block determines the PWM frequency and minimum time for HIGH level of PWM.
- Current CMPs, DAC\_PWMs, RegFile, and PWM choppers control the current in two windings with the help of external resistors and set the sine current waveform. RegFile holds 16 DAC\_PWM period values that correspond to  $\frac{1}{4}$  of sine wave. DAC\_PWM block selects the value from RegFile and sets this value as Current CMP reference. When the current is greater than the required value, the PWM chopper will chop output voltage to decrease output current.
- PIN logic and HV GPOs toggle the current sine polarity and rotation direction (depending on 'Rotary Direction' input pin state).

The main block diagram is shown in [Figure 2](#).

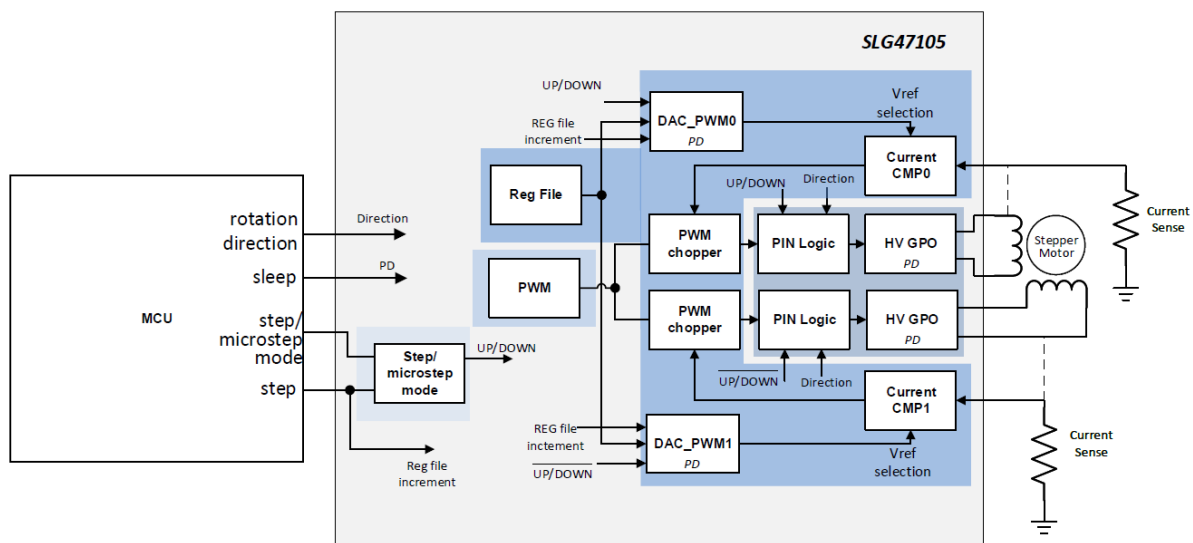
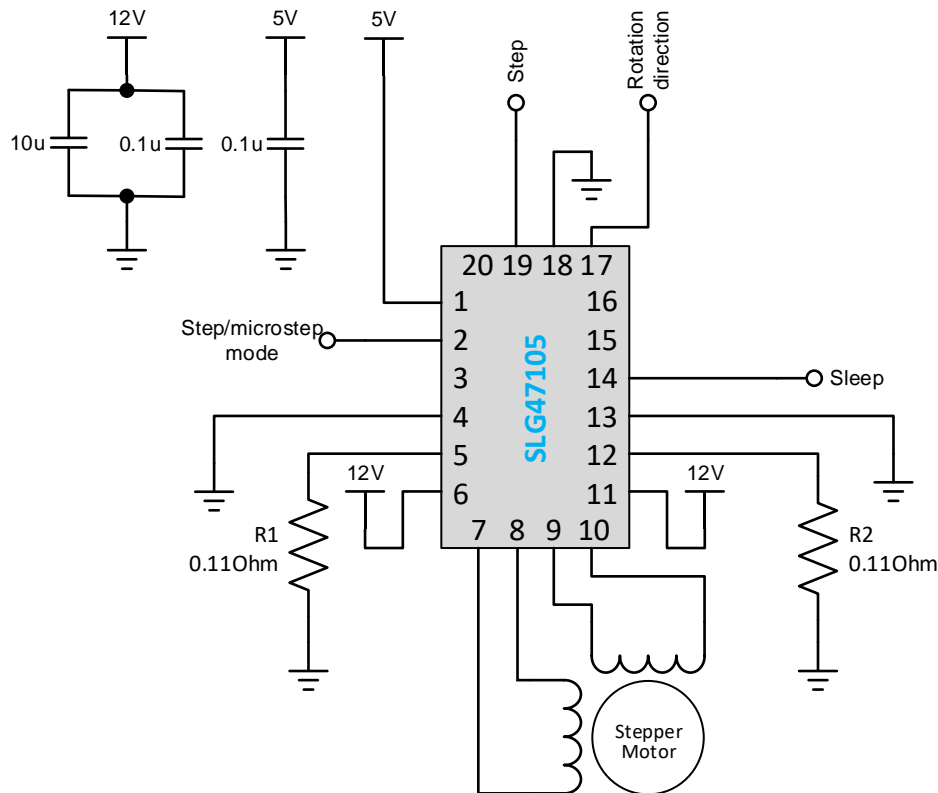


Figure 2. Block Diagram

## Stepper Motor Driver

Typical application circuit requires only two external resistors for current sensing, see [Figure 3](#).



**Figure 3. Typical Application Circuit**

The design has four inputs for motor control:

1. PIN#2 Step/Microstep mode – to select the stepper motor operation mode. HIGH signal level = full step operation, LOW signal level = 1/16 step operation.
2. PIN#14 Sleep – to disable the driver. HIGH signal level = sleep, LOW signal level = active mode.
3. PIN#17 Rotation Direction – to change the direction of motor rotation. HIGH = forward, LOW = reverse.
4. PIN#19 Step – motor rotates by one step or 1/16 step every rising edge using this input.

Design Parameters:

- Motor max current: 1 A/Phase
- Motor Voltage: 12 V
- PWM frequency: 125 kHz

Used motor: NEMA17 42HS40-1206.

**Table 1. Motor Parameters**

| Step Angle<br>deg | Current/Phase<br>A | Resistance /Phase<br>Ohm | Inductance /Phase<br>mH | Holding Torque<br>kg*cm | Detent Torque<br>g*cm | Rotor Inertia<br>g*cm | Mass<br>kg |
|-------------------|--------------------|--------------------------|-------------------------|-------------------------|-----------------------|-----------------------|------------|
| 1.8               | 1.2                | 3.3                      | 3.2                     | 2.8                     | 150                   | 54                    | 0.28       |

Stepper Motor Driver

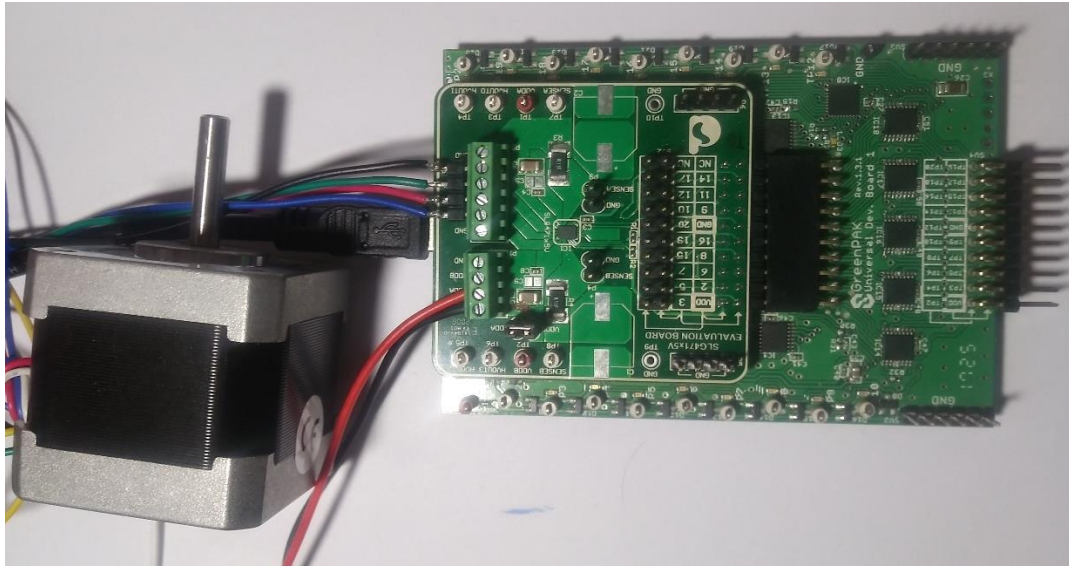


Figure 4. Evaluation Board Motor Connection

## 5 GreenPAK Design

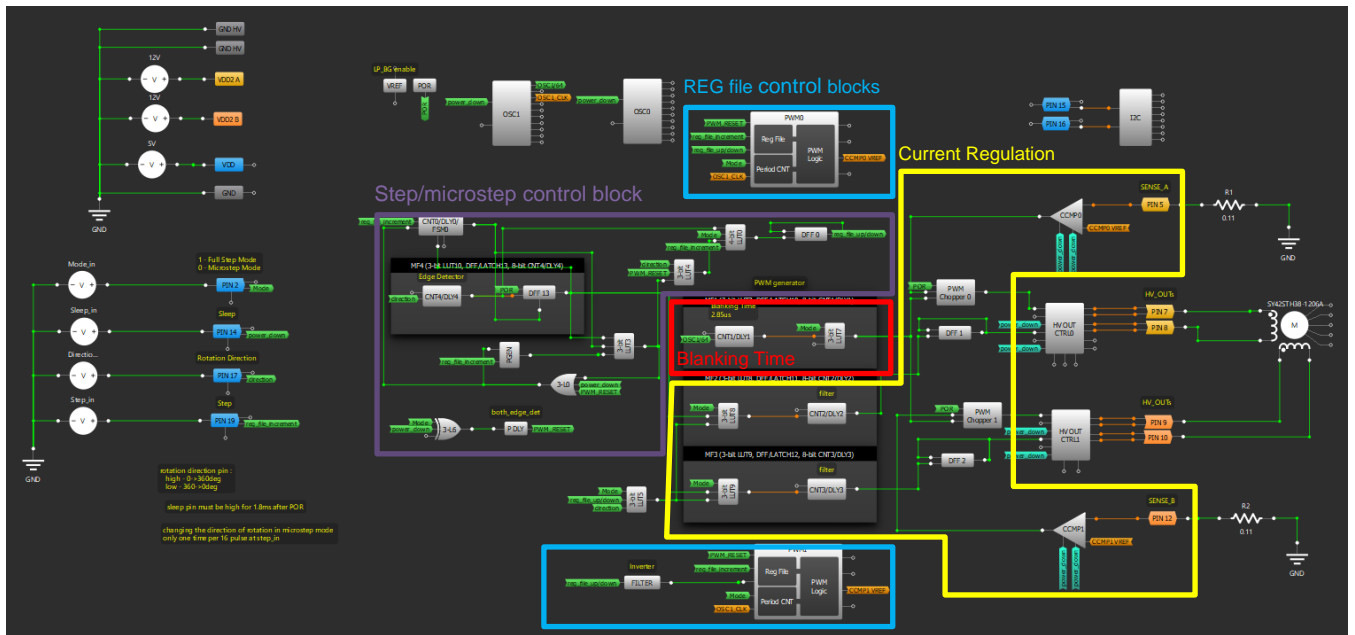


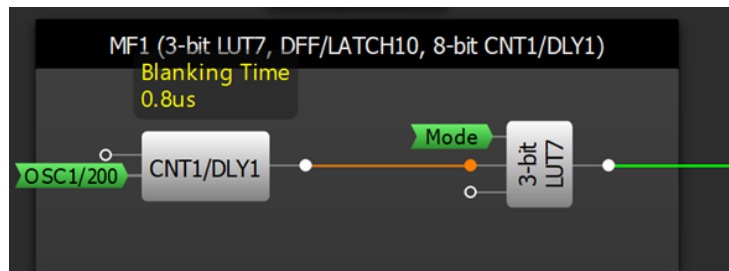
Figure 5. Design View

### 5.1 PWM Frequency and Blanking Time

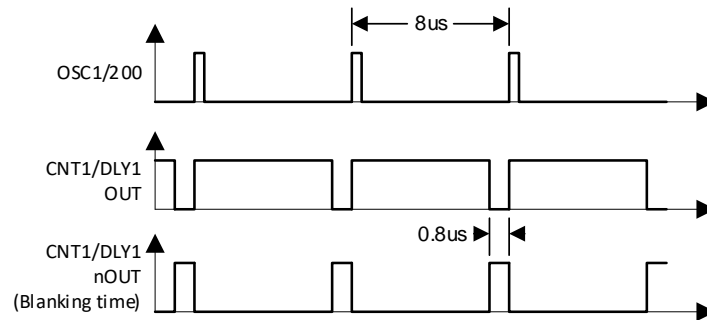
DLY1 block is used for blanking time generation and determining PWM frequency.



## Stepper Motor Driver



**Figure 6. Block for Blanking Time Generation**



**Figure 7. CNT1/DLY1 Timings**

Blanking time signal is generated by DLY1, as shown in [Figure 6](#). The output frequency is 125 kHz (8us). Blanking time (minimum HIGH-level duration) is 0.8us (10% of PWM period).

PWM Chopper function is used to chop PWM Duty Cycle by Current Comparator signal. PWM chopper ignores Current CMP signal during blanking time. Any active signal from Current CMP after Blanking time causes PWM Duty Cycle chopping end the current Period.

In this use case the PWM period is equal to blanking time signal frequency, and PWM duty cycle depends on a signal from Current CMP, but not less than blanking time.

## 5.2 RegFile Usage

The driver has a 16-byte RegFile, which allows creating an arbitrary current waveform. The driver has 64 values of Vref in the range from 0.032 V to 2.016 V with 0.032 V step, which can be used to fill 16 points of RegFile. They are used for creating a 1/4 of sine, as shown on [Figure 8](#). Another sine part is created by moving through RegFile up and down and by operating with H-Bridge logic, see [Figure 9](#). It is possible to write a half period or full period of the signal, but in this case, the signal will not be so smooth.

Max Vref value for sine depends on the sense resistor value:

$$V_{ref\_max} = I_{MAX} * GAIN_{CCMP} * R_{sense} = 1 \text{ A} * 8 * 0.11 \text{ Ohm} = 0.88 \text{ V}$$

where:

$I_{MAX}$  – maximum current per motor phase.

$GAIN_{CCMP}$  – gain of current CMP. Should be set in [GreenPAK](#) designer in CCMP block.

$R_{SENSE}$  – value of external resistor for current measuring.

Stepper Motor Driver

| Reg File Data: <a href="#">[?]</a> |       |            |        |
|------------------------------------|-------|------------|--------|
| Byte #                             | Value | Duty Cycle | Vref   |
| 0                                  | 1     | 0.39 %     | 64 mV  |
| 1                                  | 2     | 0.78 %     | 96 mV  |
| 2                                  | 4     | 1.57 %     | 160 mV |
| 3                                  | 7     | 2.75 %     | 256 mV |
| 4                                  | 10    | 3.92 %     | 352 mV |
| 5                                  | 12    | 4.71 %     | 416 mV |
| 6                                  | 14    | 5.49 %     | 480 mV |
| 7                                  | 16    | 6.27 %     | 544 mV |
| 8                                  | 18    | 7.06 %     | 608 mV |
| 9                                  | 20    | 7.84 %     | 672 mV |
| 10                                 | 22    | 8.63 %     | 736 mV |
| 11                                 | 23    | 9.02 %     | 768 mV |
| 12                                 | 24    | 9.41 %     | 800 mV |
| 13                                 | 25    | 9.80 %     | 832 mV |
| 14                                 | 26    | 10.20 %    | 864 mV |
| 15                                 | 27    | 10.59 %    | 896 mV |

Figure 8. Reg File Data

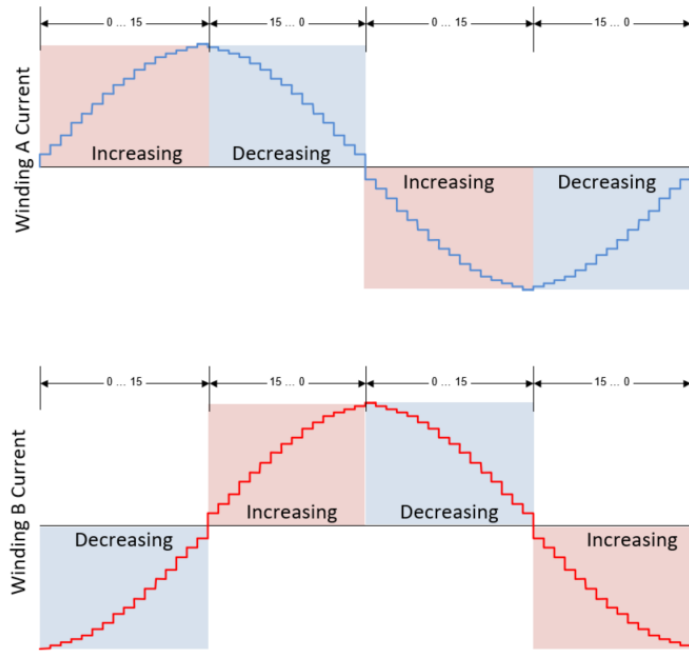


Figure 9: Windings Current Form

Four signals are used to generate two shifted sine waves. Two signals (“reg\_file\_up/down” and inverted) are used to select the direction of moving through RegFile (Up or Down) for each sine wave and another two signals (DFF1 OUT and DFF2 OUT) are used to select the polarity of generated sine wave (positive or negative).

5.3 Changing Rotation Direction

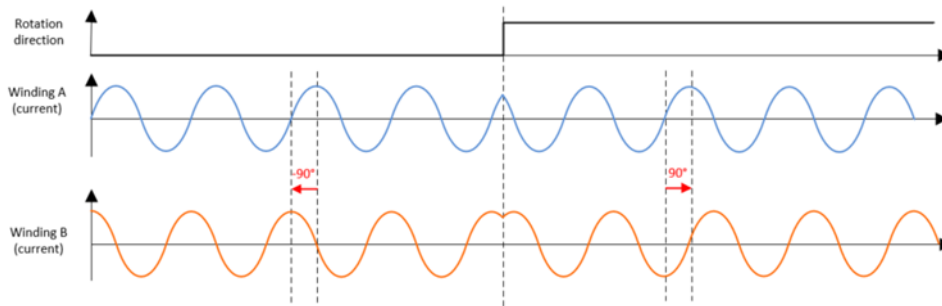


Figure 10. Changing Direction

The direction of rotation depends on what sine wave lags.

$$\phi(A) - \phi(B) = 90 \text{ deg}$$

corresponds to clockwise rotation.

$$\phi(B) - \phi(A) = 90 \text{ deg}$$

corresponds to counterclockwise rotation.

When the ‘Rotary Direction’ input (GPIO4) level is changed, for example from LOW to HIGH, the sine current phase will be changed by 180 degrees (from -90 to 90 degrees), see Figure 10. If the signal is changed from HIGH to LOW level, the sine current phase on the windings will be changed to -90 degrees.

## Stepper Motor Driver

### 5.4 Current Measurement

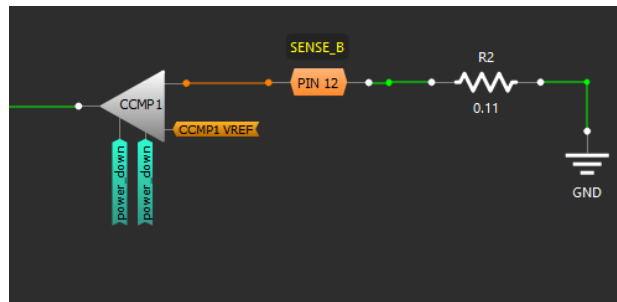


Figure 11: Current Measurement Circuit

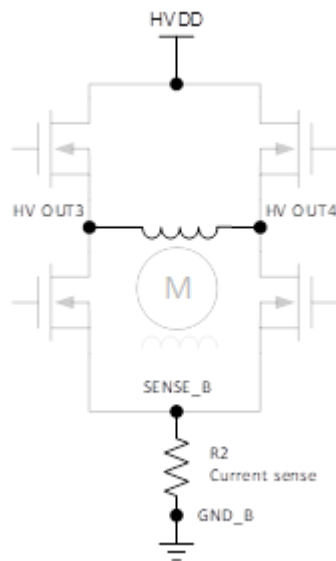


Figure 12. Resistor Connection

The signal from the current sense resistor in [Figure 11](#) is connected through 8x gain to the positive input of Current CMP. RegFile Data from DAC\_PWM is connected to MUX, which switches one of Vref values (one point of sine) to negative input of Current CMP. When the voltage drop on sense resistor after 8x gain is higher than current Vref value from RegFile, the PWM starts cutting, see [Figure 13](#).

Stepper Motor Driver

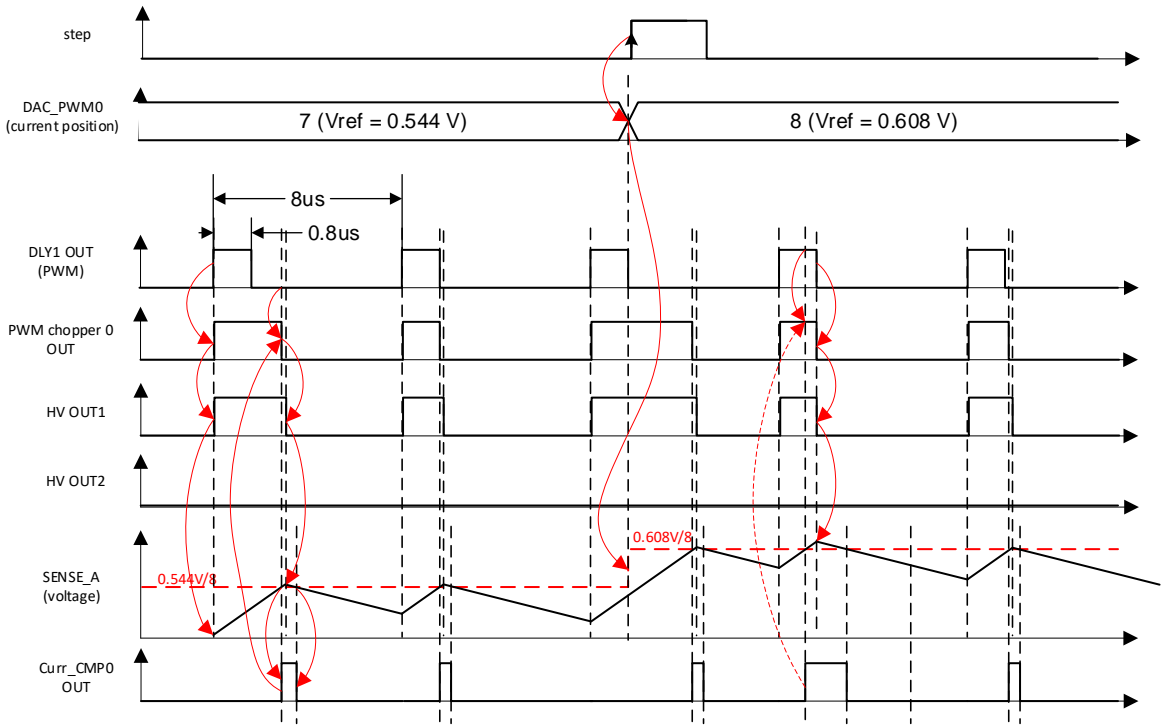


Figure 13: Increasing Current Limit

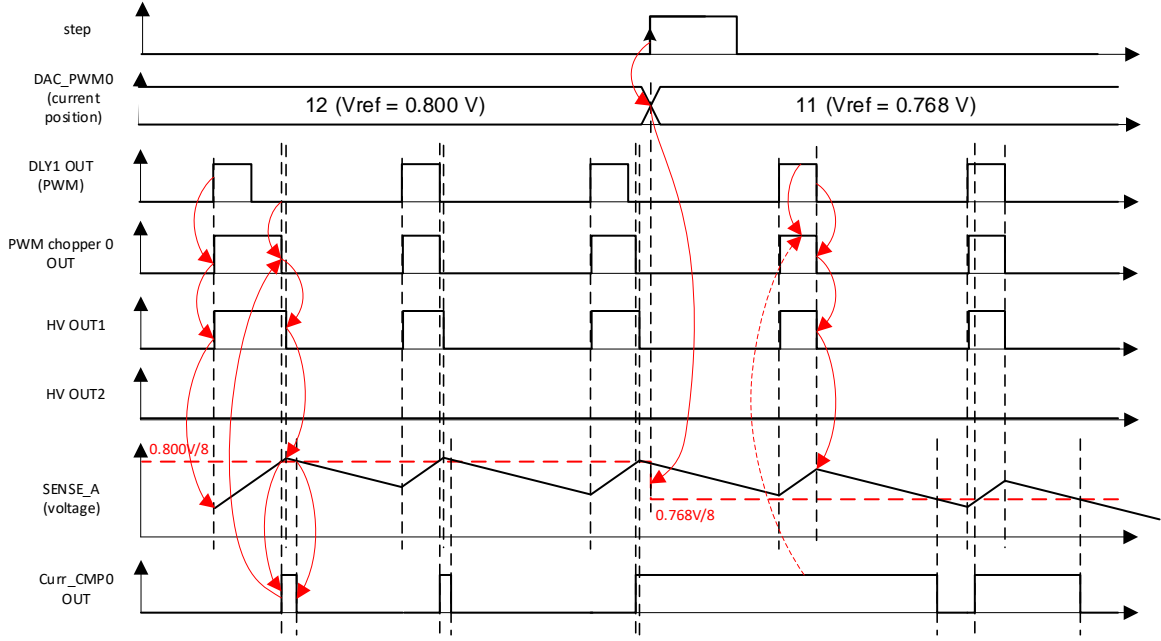


Figure 14: Decreasing Current Limit

## Stepper Motor Driver

### 5.5 Step/Microstep Modes

There are two modes used – full step and 1/16 step (microstep). This allows to switch between normal, and precise rotation modes that is useful for Camera Lens and others.

When driving a stepper motor with full step, the output of the stepper motor driver looks like a square signal and produces rough movements, see [Figure 15.a](#). When driving a stepper motor with microstep, the output looks like a sine signal and moves more smoothly, see [Figure 15.b](#).

Figure 15 shows timing diagrams for full step operation, and for 16 microsteps per step operation.

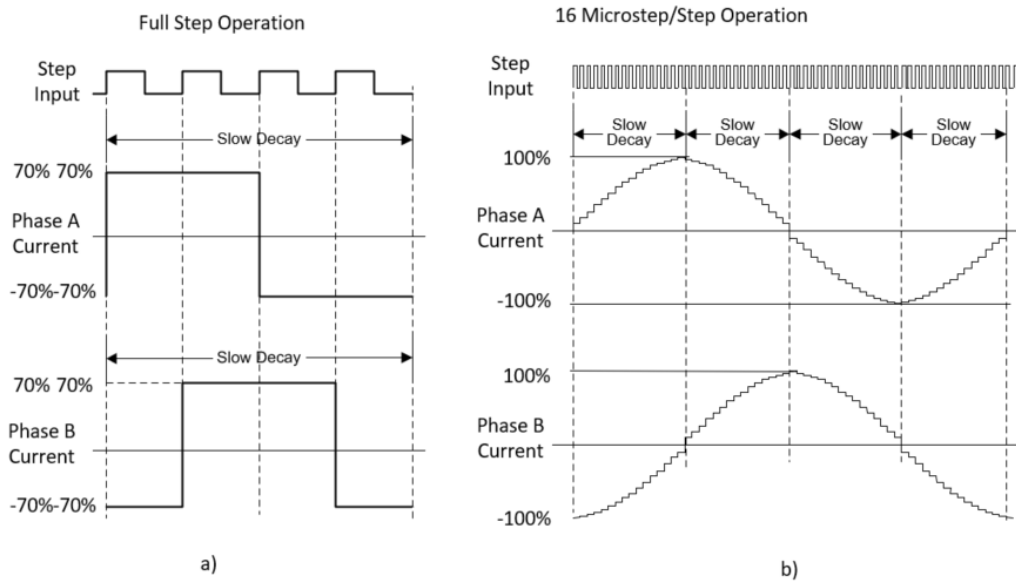


Figure 15. Step Operation: a) Full Step Operation, b) 16 Microstep Operation

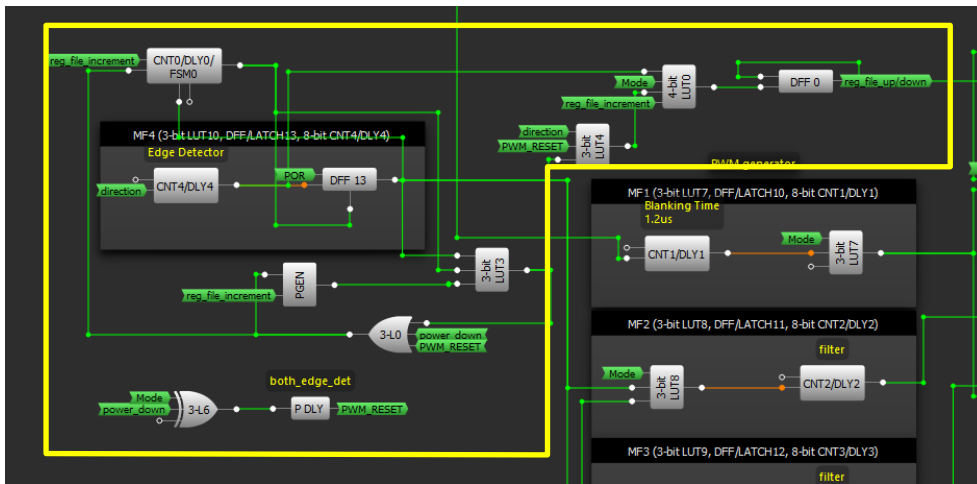


Figure 16. Step/Microstep Mode Control Block

Stepper Motor Driver

5.5.1 Full Step Mode

When step mode is selected, “keep” signal of DAC\_PWM block is logic HIGH. This does not allow the switching between RegFile Values. LUT4\_0 transfers signal from “step” input to DFF0, and each rising edge at “step” input changes the DFF0 out level. DFF0 output is connected to UP/DOWN signal. See Figure 16 and Figure 17.

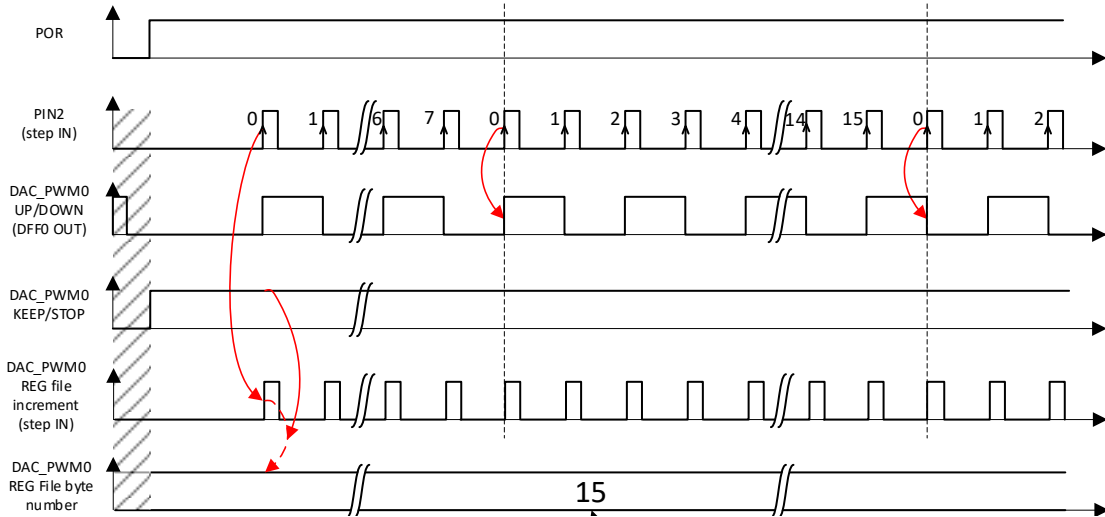


Figure 17: Step Mode Timing Diagram

The UP/DOWN signal is not inverted for Winding A and is inverted for Winding B. Rising edge on DFF0 output toggles DFF1, which toggles PWM signal between HV OUTs. If DFF1 OUT is HIGH, then the PWM block output signal is connected to HV OUT1. If DFF1 OUT is LOW, then to HV OUT2. The current in the windings will have a square shape, see Figure 18. The Winding B functions just like Winding A with 90 degrees phase shift.

In full step mode current regulation isn't used, and when current is higher than 1.2 A, OCP protection will turn off OUTs for a short time. This happens when motor rotation speed is too slow.

Stepper Motor Driver

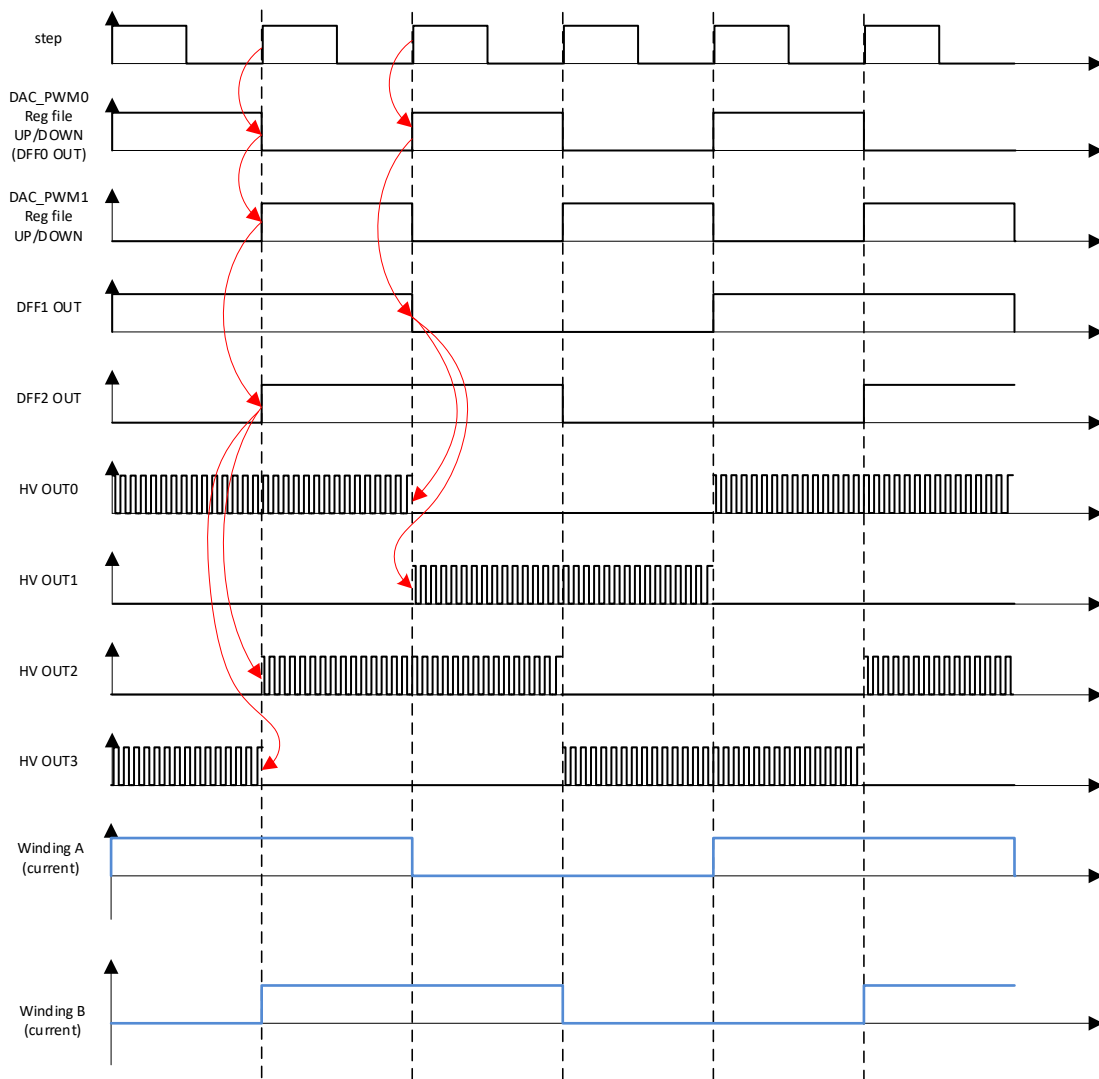


Figure 18: Square Current Shape

5.5.2 Microstep Mode

If microstep mode is active, the default RegFile address is the 15<sup>th</sup> Value for DAC\_PWM0 and 0<sup>th</sup> Value for DAC\_PWM1. After rising edge at “Step” input, DAC\_PWM0 counts up and DAC\_PWM1 counts down. CNT2 counts 15 values to reach the bottom position of RegFile for DAC\_PWM0, and top position for DAC\_PWM1.

DFF0 changes sine output polarity every rising edge at its CLK input.

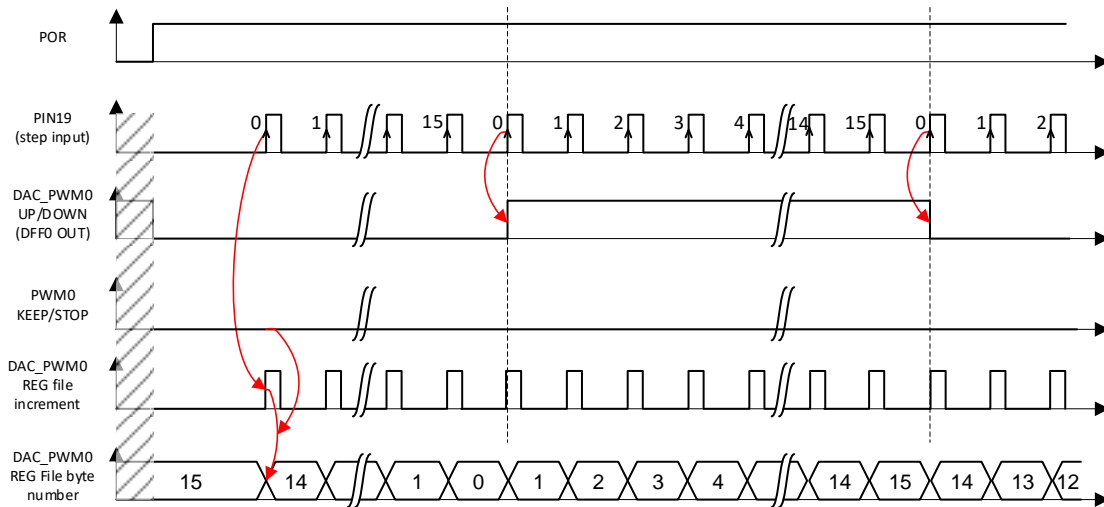
RegFile adress changes for DAC\_PWM0:

15<sup>th</sup> → 14<sup>th</sup> → 13<sup>th</sup> → 12<sup>th</sup> → 11<sup>th</sup> → ... 2<sup>th</sup> → 1<sup>th</sup> → 0<sup>th</sup> → 1<sup>th</sup> → 2<sup>th</sup> → ...

RegFile adress changes for DAC\_PWM1:

0<sup>th</sup> → 1<sup>th</sup> → 2<sup>th</sup> → 3<sup>th</sup> → ... 13<sup>th</sup> → 14<sup>th</sup> → 15<sup>th</sup> → 14<sup>th</sup> → 13<sup>th</sup> → ...

Stepper Motor Driver



**Figure 19: Microstep Mode Timing Diagram**

The outputs switch like in full step mode, but 1/4 of a sine wave now has 16 values. The resulting current in windings have a sine wave shape, as shown on [Figure 20](#).

[Figure 20](#) shows a timing diagram for microstep mode.



Stepper Motor Driver

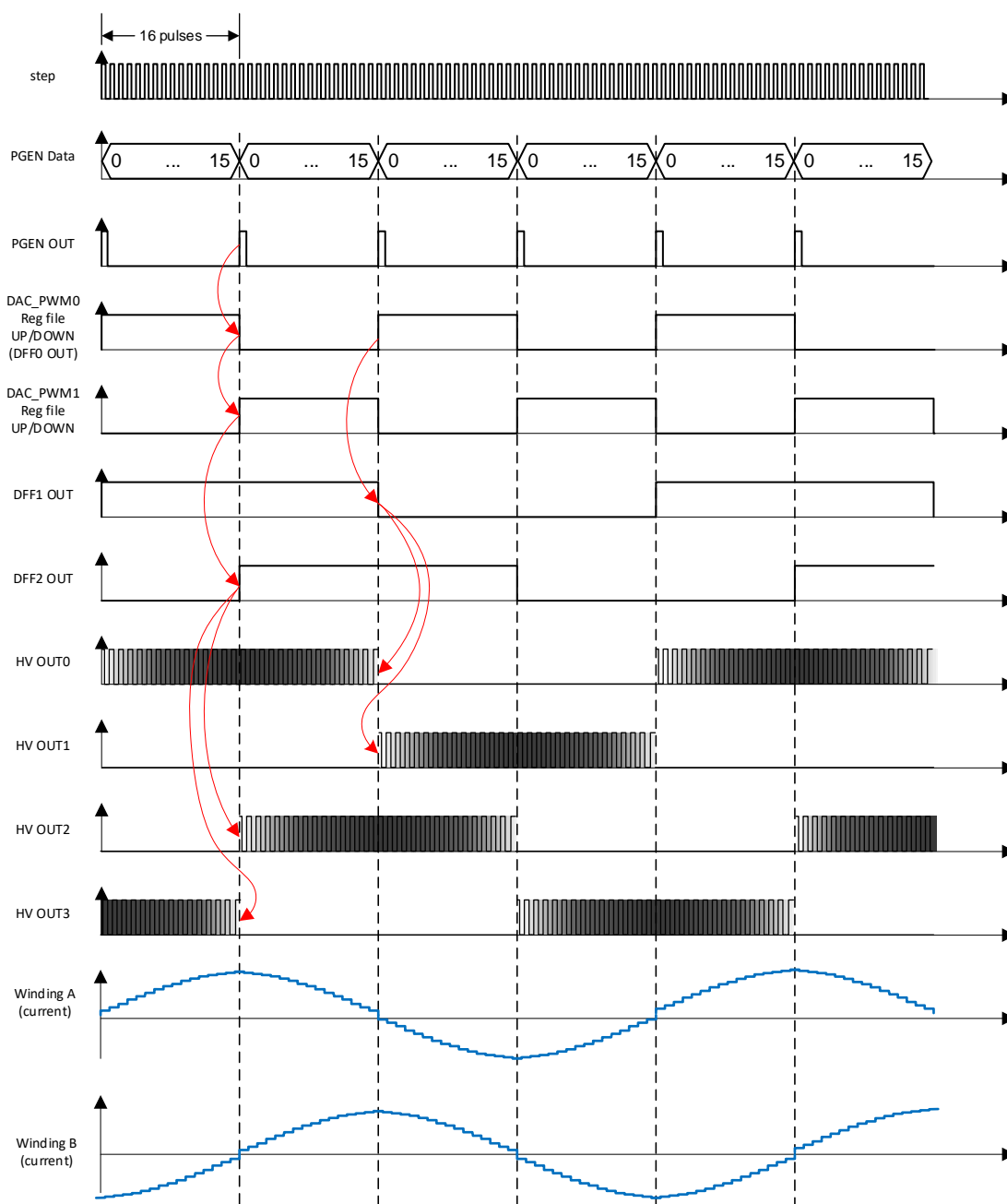


Figure 20: Sine Wave Current Shape

Stepper Motor Driver

## 6 Waveforms

### 6.1 Full Step

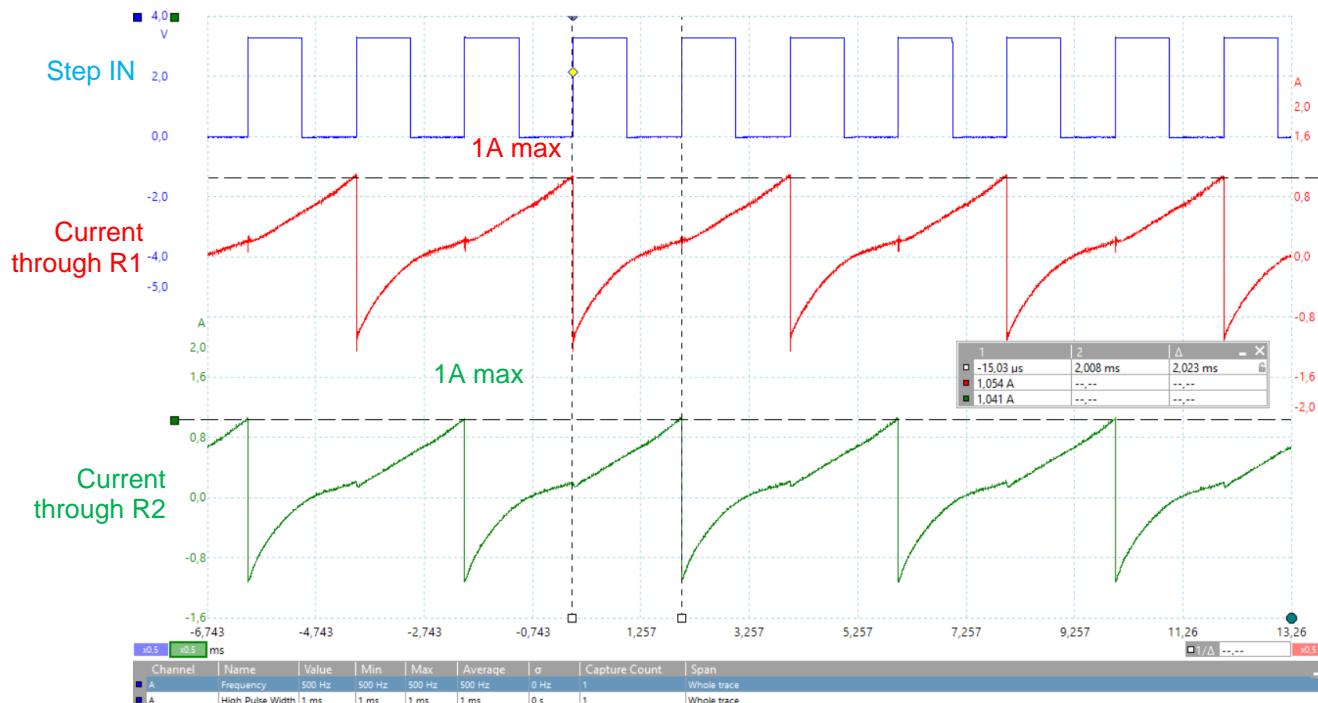


Figure 21. Full Step Current Waveforms

Stepper Motor Driver

6.1.1 Changing Rotation Direction

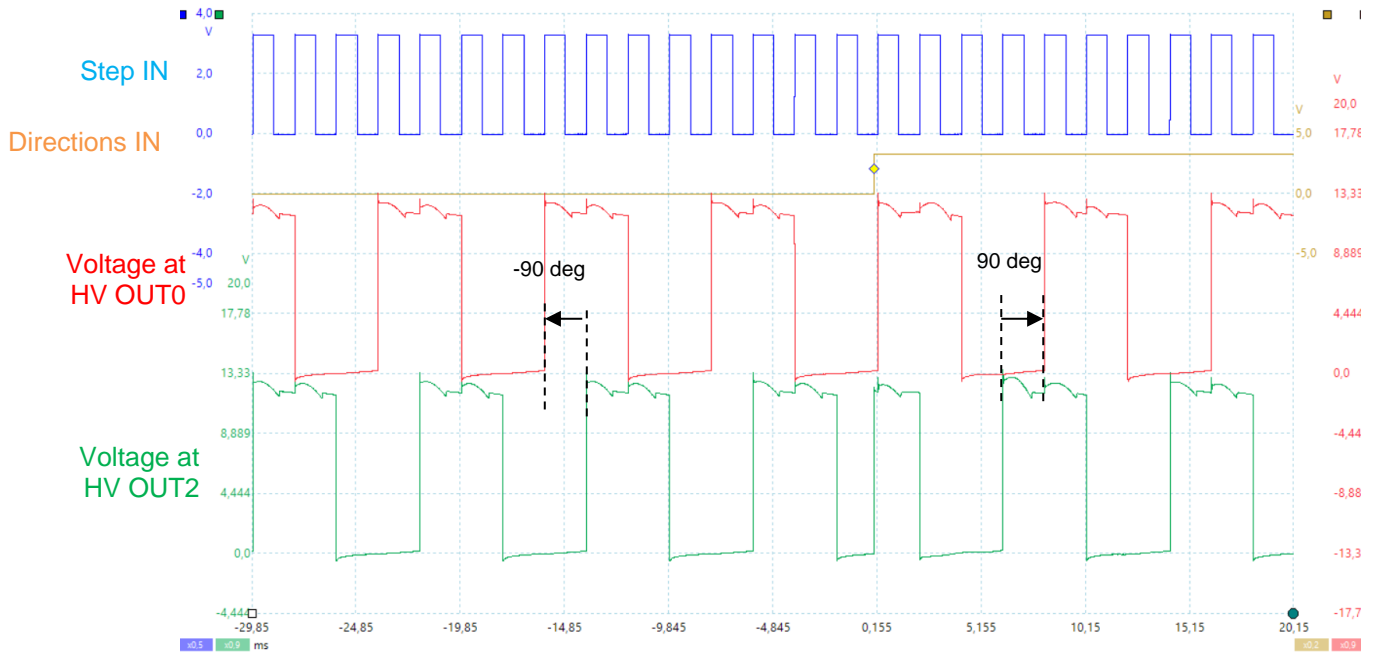


Figure 22. Changing Rotation Direction in Full Step Mode

6.1.2 Motor Turn-On in Full Step Mode

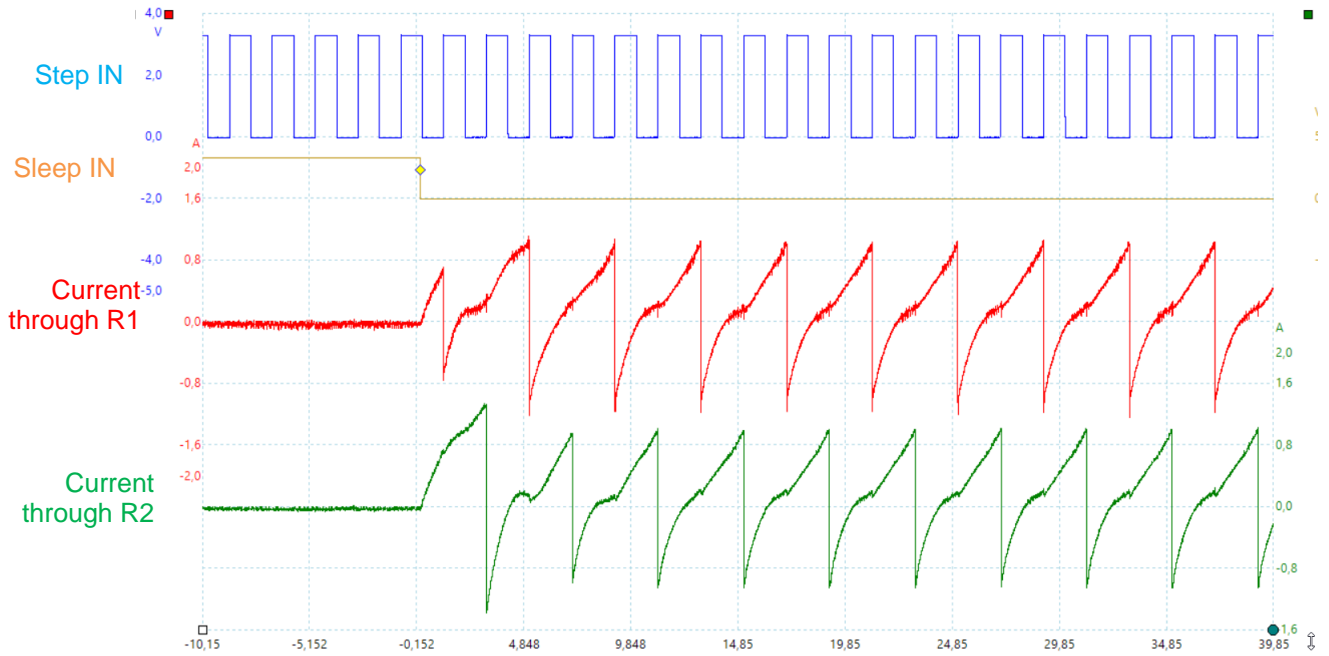


Figure 23. Motor Start in Full Step Mode

Stepper Motor Driver

6.2 Microstep

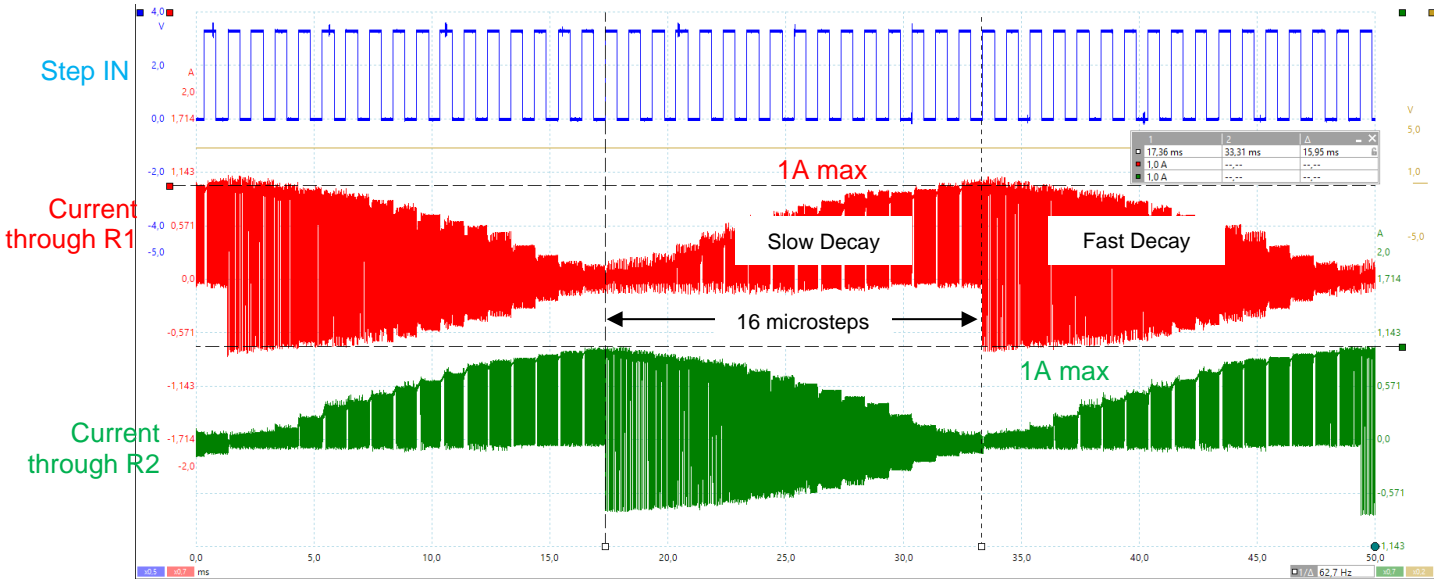


Figure 24. Microstep Mode Current Waveforms

6.2.1 Changing Rotation Direction

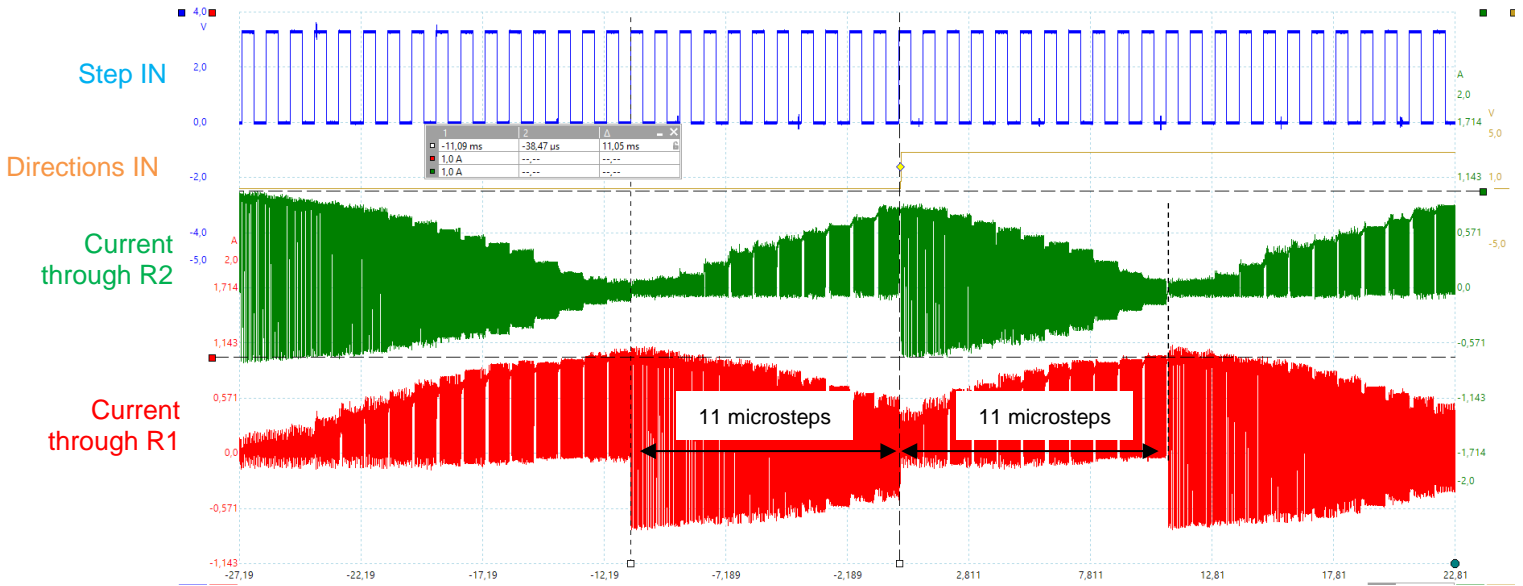


Figure 25. Changing Rotation Direction in Microstep Mode

Stepper Motor Driver

6.2.2 Motor Turn-On in Microstep Mode

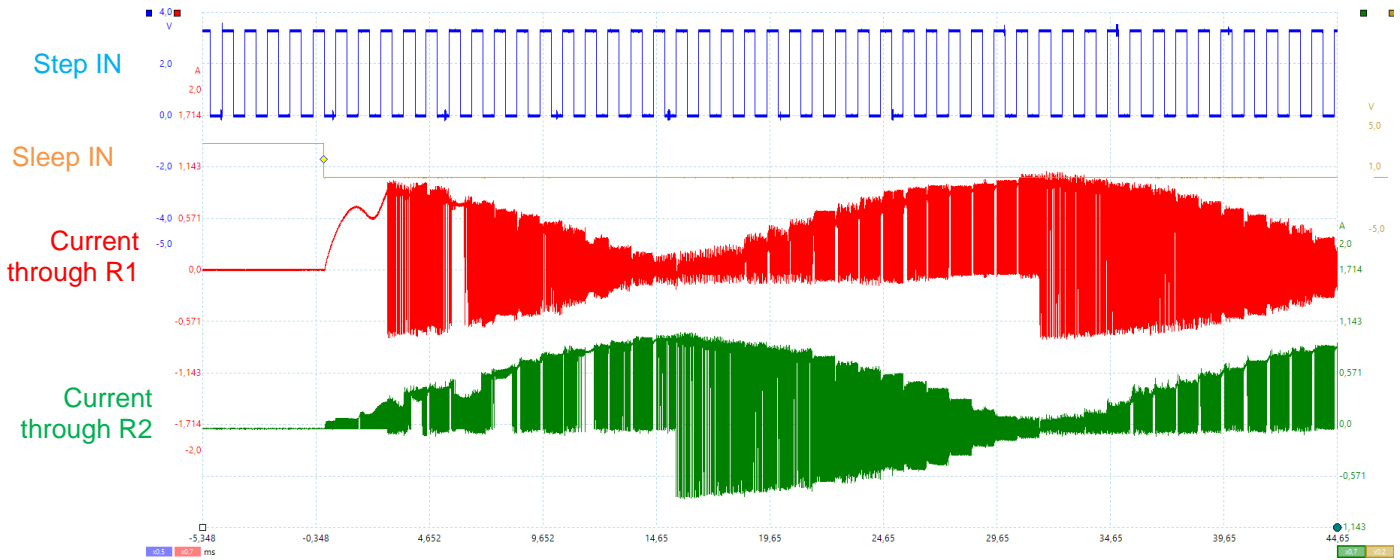


Figure 26. Motor Start in Microstep Mode

6.2.3 Microstep Decay Modes

Decay Mode of HV OUTs can be changed by “Decay” input of HV OUT CTRL0/HV OUT CTRL1 blocks. When this pin is connected to  $V_{DD}$  = slow decay mode, when to GND = fast decay. “Decay” input is connected to “reg file up/down” signal. When current increases than is used slow decay, when decrease – fast decay.

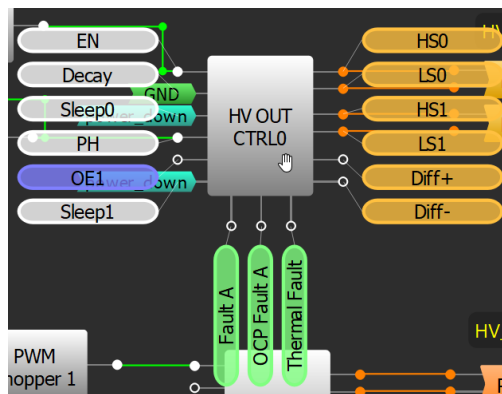


Figure 27. Decay Mode Input

Stepper Motor Driver

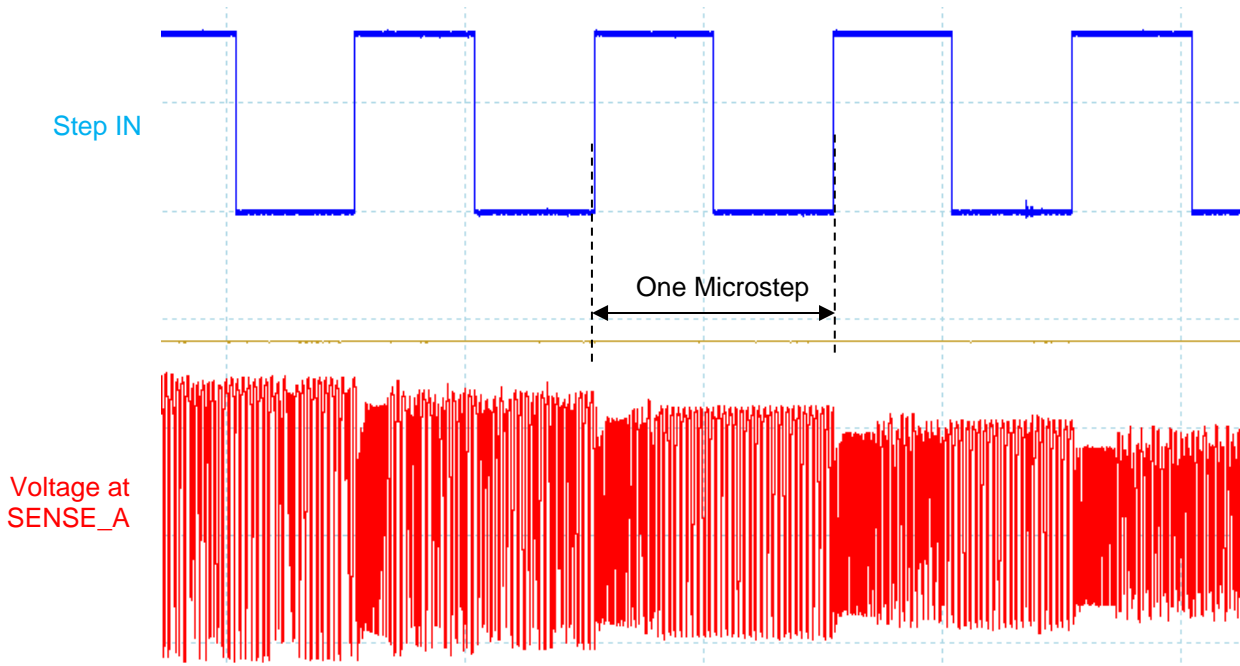


Figure 28. Fast Decay Mode

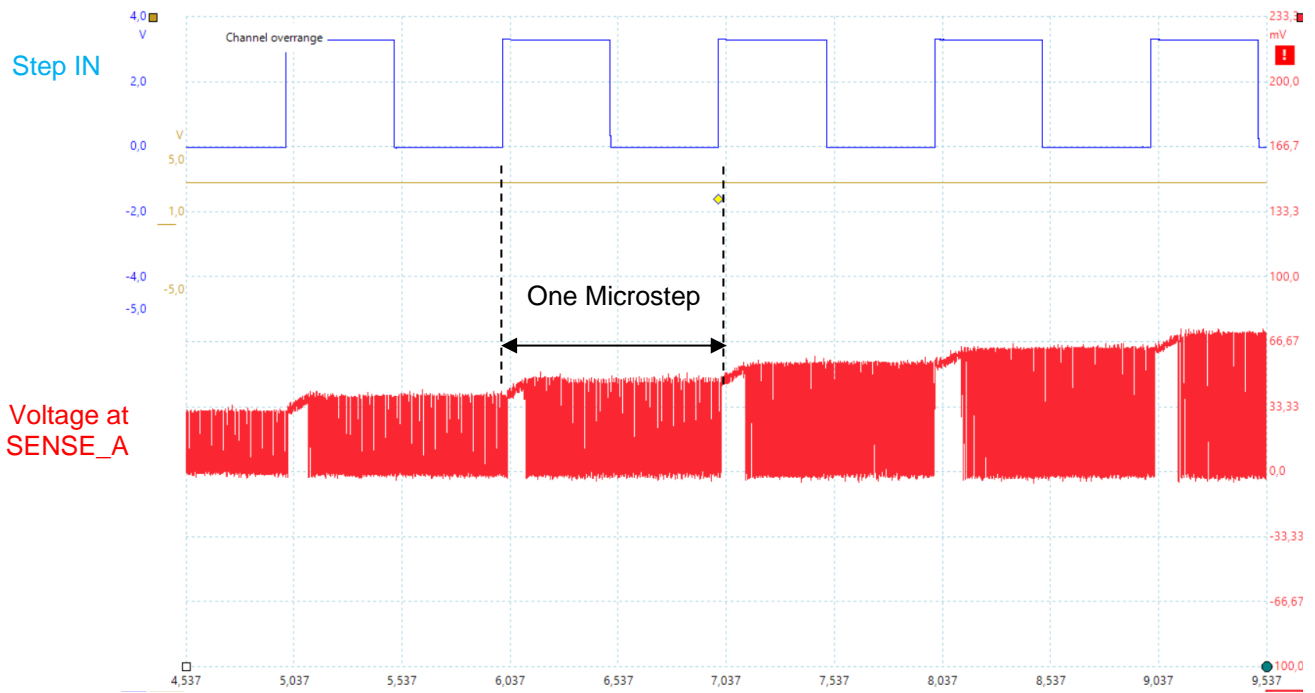


Figure 29. Slow Decay Mode

Stepper Motor Driver

6.3 Changing Modes Dynamically

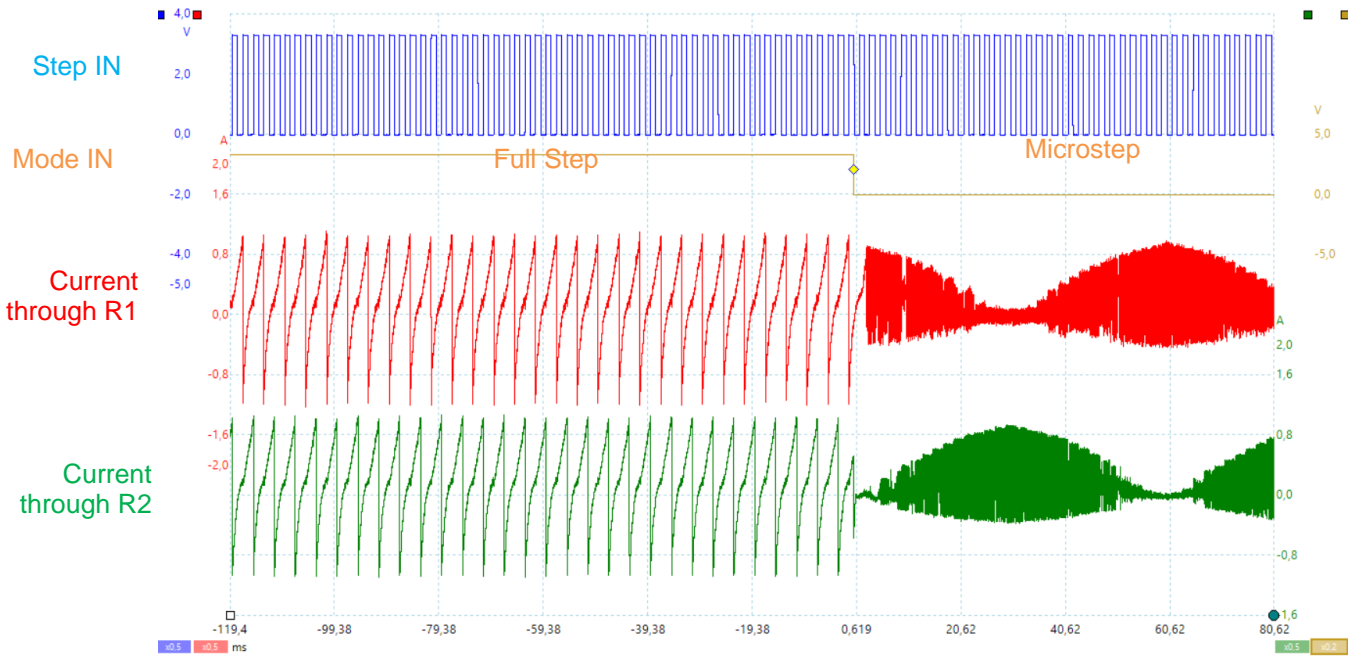


Figure 30. Changing Mode from Full Step to Microstep

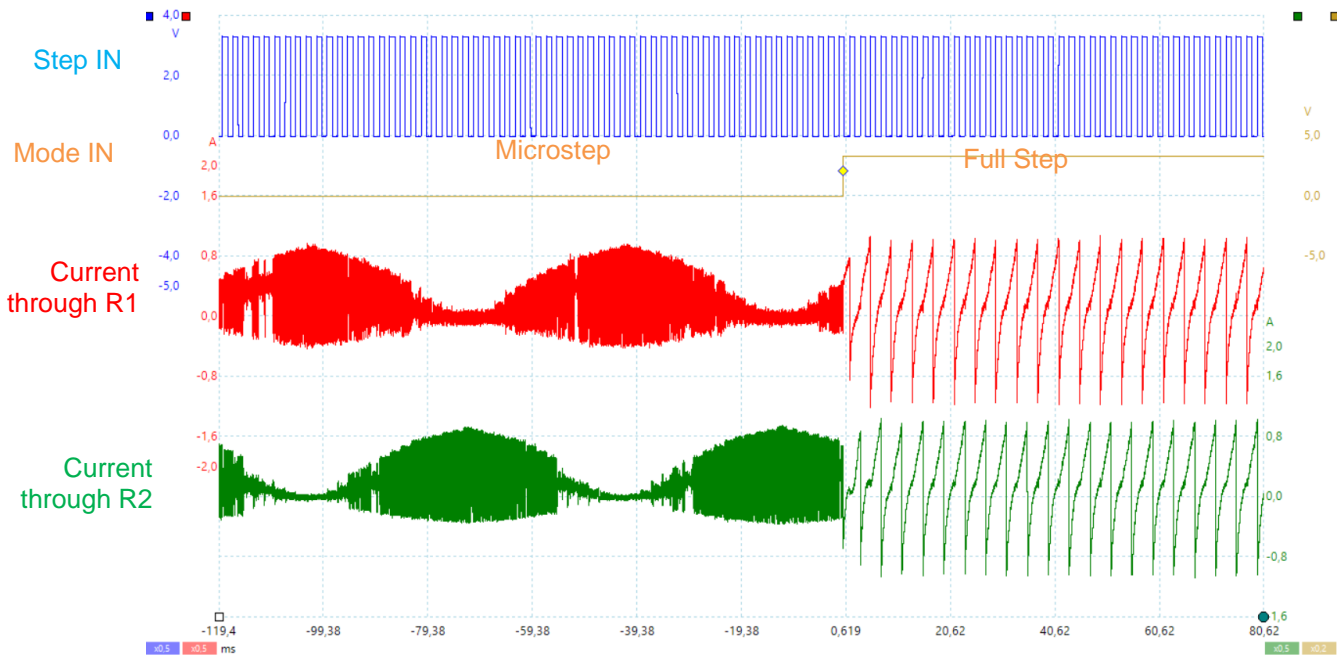


Figure 31. Changing Mode from Microstep to Full Step Mode

## 7 Conclusion

The application note described how to configure HVPAK for a bipolar stepper motor controller. In this usage case, motor rotation is controlled using current control for each Coil. Motor torque depends on current going through the motor's coils, and it results in motor rotation with constant torque.

Many parameters are configured. For example, PWM frequency, min PWM duty cycle value, number of control pins, and motor current which can be adjusted for a particular motor with up to 1A current per phase. Also, there is a possibility to add logic to automatically rotate the stepper motor with one or more defined speeds, etc.

By integrating the high voltage blocks into HVPAK, one can see that the design and layout becomes very compact, convenient, reconfigurable, and low cost. Additionally, having extra circuitry still available within HVPAK allows for additional customization or integrating other functions.



## Stepper Motor Driver

## Revision History

| Revision | Date        | Description   |
|----------|-------------|---|
| 1.0      | 24-Mar-2020 | Initial Version   |
| 1.1      | 14-Aug-2020 | <ul style="list-style-type: none"><li>- Changed PWM frequency from 164kHz to 125kHz</li><li>- Changed blanking time from 1.2us to 0.8us</li><li>- Added slow decay mode for sine rising and slow decay for sine falling</li><li>- Fixed number of steps in microstep mode from 15 to 16</li></ul> |