Application Note

How to Drive Unipolar Stepper Motors with DRV8xxx

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ABSTRACT

Even though less popular than their bipolar counterparts, unipolar stepper motors are still used in a wide variety of industrial applications. There are several ways to drive unipolar stepper motors - such as by using four low-side MOSFETs; by using bipolar stepper drivers and converting the unipolar stepper motor into a bipolar stepper motor; and by using four-channel half-bridge drivers. The goal of this application report is to show how different DRV8xxx drivers from Texas Instruments can drive unipolar stepper drivers.

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1 Introduction

Stepper motors come in many different varieties, but there are two main winding configurations for permanent magnet and hybrid stepper motors: unipolar and bipolar. Bipolar motors are currently more widely used, and some legacy systems are slowly phasing out unipolar stepper motors in favor of bipolar steppers. Nevertheless, unipolar stepper motors are still used in several applications such as textile machines, printers, Pachinko, and slot machines.

The DRV8xxx stepper drivers from Texas Instruments are primarily meant to drive bipolar stepper motors. But some of them can drive unipolar stepper motors as well. The following sections describe how various DRV8xxx drivers can be adapted to drive unipolar stepper motors.

2 Principle of Operation

2.1 Unipolar Stepper Motors

Unipolar stepper motors have two windings per phase. The common wiring configuration for unipolar motors is four wires connected to the motor windings (A+, A-, B+ and B-) and a center tap on each phase. The center taps can be electrically isolated; or they can be shorted electrically. The center taps are generally connected to the motor voltage supply, VM.

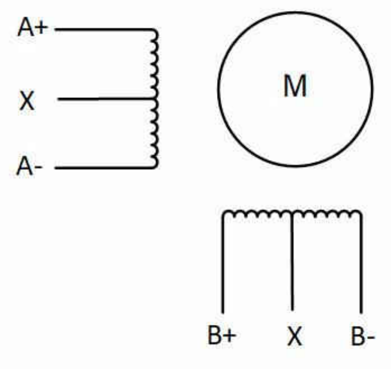

Figure 2-1. Unipolar Stepper Motor

Current flows from VM supply to only one half of a winding at any given time. The center tap allows the magnetic field to be reversed without having to reverse the direction of current in a winding. The tradeoff is that because only half of each winding is used at a given time, unipolar steppers result in lower torque and efficiency.

However, as current flows only in a single direction, the driver electronics for unipolar stepper motors can be simpler compared to bipolar stepper motors. Only four low-side MOSFETs and circulating diodes are sufficient to drive a unipolar stepper motor.

2.2 Bipolar Stepper Motors

Bipolar stepper motors have only a single winding per phase. Four wires are connected to the motor windings, and there is no center tap to VM.

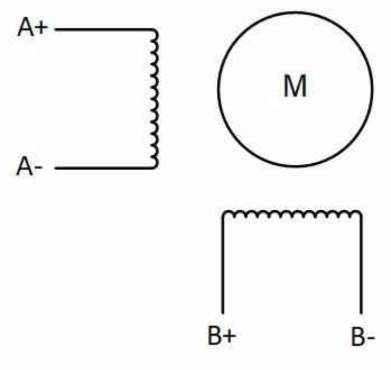

Figure 2-2. Bipolar Stepper Motor

Bipolar steppers require more complicated driver electronics (typically an H-bridge for each phase) to be able to reverse the current in the winding. However, bipolar drivers use the full amount of copper windings, so the motor delivers more torque.

3 How to Drive Unipolar Stepper Motors with DRV8xxx Drivers

The following sections describe how various DRV8xxx drivers can drive unipolar stepper motors.

3.1 Driving Unipolar Motor with Four-channel Low-side Driver

To drive a unipolar stepper motor with a single supply connection, only four low side MOSFETs and circulating diodes are needed. The schematic with such a low-side MOSFET driver is shown in Figure 3-1.

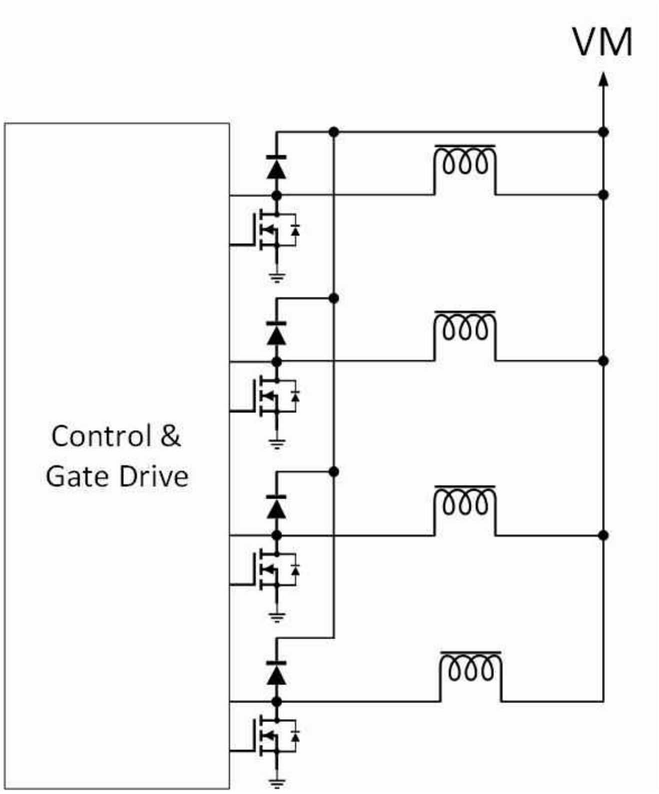

Figure 3-1. Driving Unipolar Stepper with Low-side Driver

DRV8803, DRV8804, DRV8805 and DRV8806 from Texas Instruments are examples of such drivers meant to drive unipolar motors. These drivers are rated up to 60 V supply voltage, available in PWM, STEP/DIR or serial interfaces, and can deliver up to 2 A per channel.

Table 3-1 summarizes the major features of these four drivers.

Table 3-1. Comparison among DRV880x Low-side Drivers

Driver	DRV8803	DRV8804	DRV8805	DRV8806
Maximum Supply Voltage	60 V	60 V	60 V	40 V
MOSFET $R_{DS\ (ON)}$	0.5 Ω	0.5 Ω	0.5 Ω	0.5 Ω
Input Interface	PWM (EN/INx)	Serial Interface	STEP/DIR with full-step, half-step and wave drive	Serial Interface
Package Options	SOIC-20, HTSSOP-16	SOIC-20, HTSSOP-16	SOIC-20, HTSSOP-16	HTSSOP-16
Maximum Continuous Output Current	1.5 A (SOIC), 2 A (HTSSOP)	1.5 A (SOIC), 2 A (HTSSOP)	1.5 A (SOIC), 2 A (HTSSOP)	2 A
Integrated Clamp Diodes	Yes	Yes	Yes	Yes
Protection Features	Overcurrent, Short circuit, Undervoltage, Overtemperature	Overcurrent, Short circuit, Undervoltage, Overtemperature	Overcurrent, Short circuit, Undervoltage, Overtemperature	Overcurrent, Short circuit, Undervoltage, Overtemperature, Open load detection

A typical application schematic with the DRV8803 is shown in Figure 3-2.

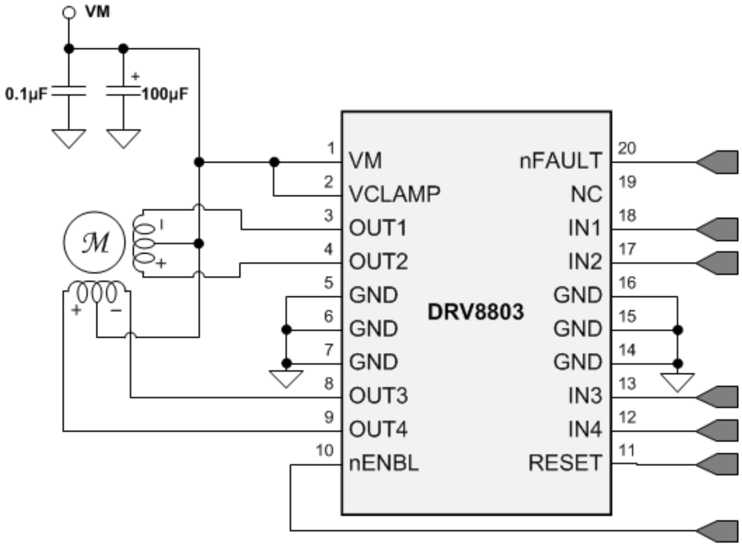

Figure 3-2. Unipolar Stepper Schematic with DRV8803

3.2 Driving a Unipolar Motor with a Bipolar Driver

This approach has been described in detail in this blog post. One can effectively convert a unipolar stepper motor into a bipolar stepper motor and use a conventional bipolar stepper motor driver such as the DRV8424, DRV8426, DRV8428 and DRV8434 to drive it. This can be done in two ways.

- **Ignore the center tap on each winding** – The motor effectively looks as shown in Figure 2-2. This configuration energizes the full winding, thus achieving higher torque at lower speeds compared to the corresponding unipolar stepper motor. However the resulting higher inductance causes the torque to drop at a faster rate than that of a unipolar stepper motor - thereby limiting the maximum speed of operation. A typical application schematic with the DRV8424 is shown in Figure 3-3.

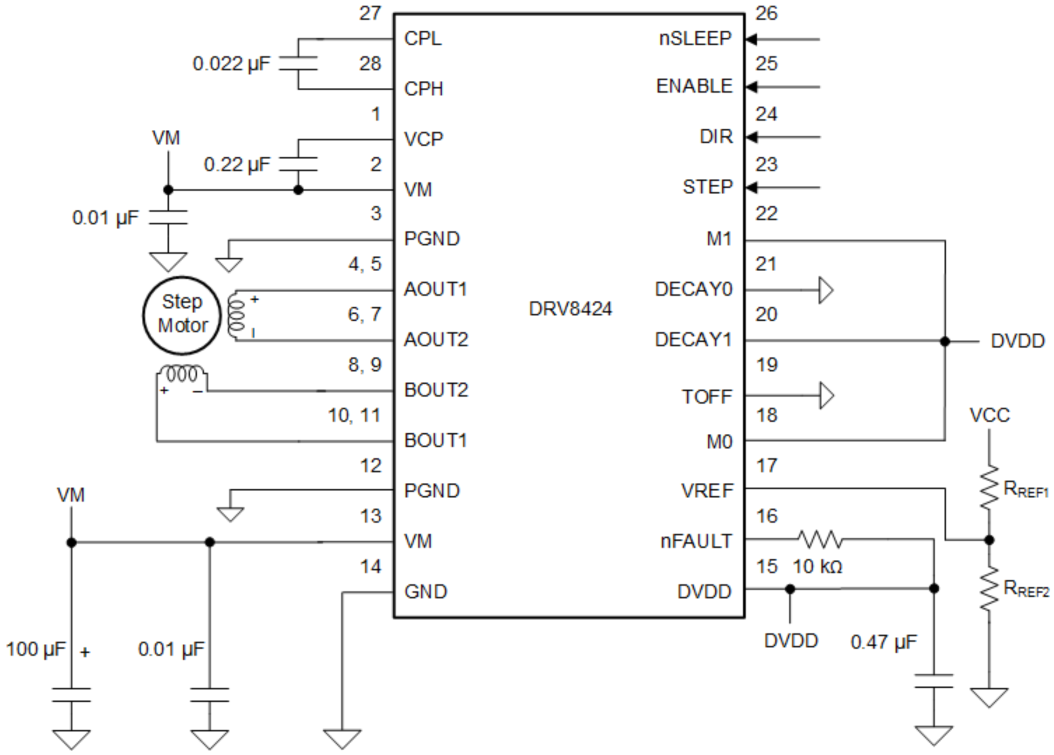

Figure 3-3. Unipolar Stepper Schematic with DRV8424

- **Use half of each winding** – If the center taps of an unipolar stepper are electrically isolated, as shown in Figure 2-1, one can use one of the half windings per phase, as shown in Figure 3-4.

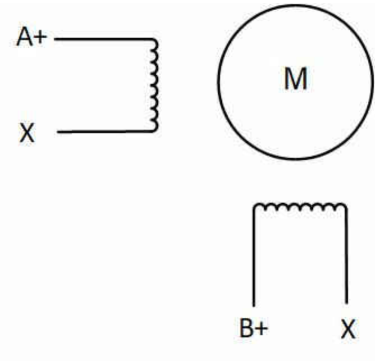

Figure 3-4. Unipolar Motor with Half Windings per Phase

There are few pros and cons for both of these methods.

- Compared to using the full winding, the half-winding configuration reduces the coil inductance. Therefore using only half winding results in lower torque at lower speed, but at the same time results in higher available torque at high speeds.
- For the torque for both configurations to be the same, half winding approach needs to drive with 2x the current compared to full winding driving. This however results in worse thermal performance - (I^2*R for full winding compared to (($2I)^2$*R/2 = $2I^2$R) for half winding driving.
- Additionally, using only half of a winding results in noisier voltage and current waveforms.

All of these points should be carefully considered at the time of selecting a topology to drive an unipolar stepper motor with a bipolar motor driver. If the application requires the motor to run at low to moderate speeds, then ignoring the centre taps and using the full coil for driving is the recommended approach.

Both half windings cannot be paralleled because the mutual inductance will cancel out the respective phase.

Table 3-2 summarizes the major features of these four bipolar stepper drivers.

Table 3-2. Comparison Among DRV84xx Bipolar Stepper Drivers

Driver	DRV8424	DRV8426	DRV8428	DRV8434
Maximum Supply Voltage	33 V	33 V	33 V	48 V
MOSFET RDS(ON) (HS +LS)	0.33 Ω	0.9 Ω	1.5 Ω	0.33 Ω
Input Interface	STEP/DIR with up to1/256 microstepping	STEP/DIR with up to1/256 microstepping	STEP/DIR with up to1/256 microstepping	STEP/DIR with up to 1/256microstepping, DRV8434S with SPI interface
Package Options	HTSSOP-28, QFN-24	HTSSOP-28,QFN-24	HTSSOP-16,QFN-16	HTSSOP-28,QFN-24
Maximum Continuous Output Current	2.5 A	1.5 A	1 A	2.5 A
Protection Features	Overcurrent, Short circuit, Undervoltage, Overtemperature	Overcurrent, Short circuit, Undervoltage, Overtemperature	Overcurrent, Short circuit, Undervoltage, Overtemperature	Overcurrent, Short circuit, Undervoltage, Overtemperature, Open load detection, DRV8434A/S with stall detection

3.3 Driving Unipolar Motor with Four-channel Half-Bridge Driver

Another way to drive a unipolar motor is to use four-channel half-bridge drivers, such as the DRV8932, DRV8935, DRV8955, DRV8844, DRV8847, and DRV8412. These drivers all feature PWM input interface, and therefore can be operated such that an external controller turns on low-side MOSFETs in succession to drive a unipolar stepper motor. Table 3-3 summarizes the major features of these half-bridge drivers.

Table 3-3. Comparison among DRV8xxx Half-bridge Drivers

Driver	DRV8847	DRV8932	DRV8935	DRV8955	DRV8412	DRV8844
Maximum Supply Voltage	18 V	33 V	33 V	48 V	52 V	60 V
LS MOSFETRDS(ON)	0.45 Ω	0.45 Ω	0.165 Ω	0.165 Ω	0.11 Ω	0.24 Ω
Independent Half-bridge	Yes	No	No	Yes	Yes	Yes
Package Options	HTSSOP-16, QFN-16	HTSSOP-28, QFN-24	HTSSOP-28, QFN-24	HTSSOP-28, QFN-24	HTSSOP-44	HTSSOP-28
Maximum Continuous Output Current	1 A	1.5 A	2.5 A	2.5 A	3 A	2.5 A
Protection Features	Overcurrent,Short circuit, Undervoltage, Overtemperature	Overcurrent,Short circuit, Undervoltage, Overtemperature	Overcurrent,Short circuit, Undervoltage, Overtemperature	Overcurrent,Short circuit, Undervoltage, Overtemperature	Overcurrent,Short circuit, Undervoltage, Overtemperature	Overcurrent,Short circuit, Undervoltage, Overtemperature

In the following section, this approach is described in detail by showing how unipolar stepper motors can be driven by the DRV8935. A typical application schematic with the DRV8935 is shown in Figure 3-5.

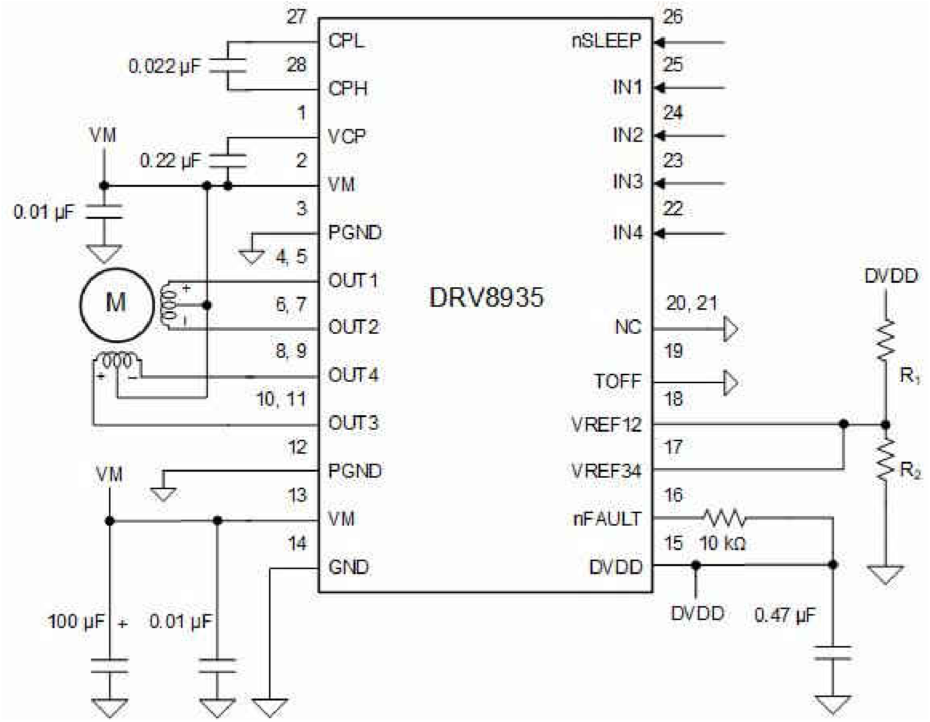

Figure 3-5. Unipolar Stepper Schematic with DRV8935

The PWM inputs can be controlled to drive a unipolar stepper motor in full-step or half-step modes, as described in the following subsections.

3.3.1 Driving in Full-step Mode

Driving in full-step mode can be with one phase ON or two phases ON together.

3.3.1.1 Full-step Mode with One Phase ON

In this mode of operation, only one low-side MOSFET is turned on at a time, therefore the driving method is the simplest. The truth table and timing diagram for this mode of operation are shown in Table 3-4.

Figure 3-6 and Figure 3-7 show the input and output waveforms when driving a unipolar stepper motor in one phase ON mode with the DRV8935.

Table 3-4. Truth Table and Timing Diagram

INDEX	IN1	IN2	IN3	IN4
1	0	1	1	1
2	1	0	1	1
3	1	1	0	1
4	1	1	1	0

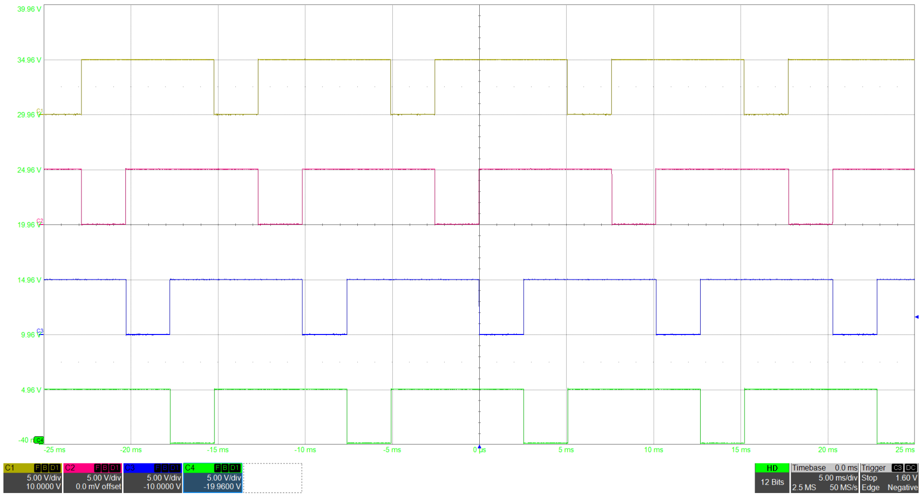

Figure 3-6. Input PWM Signal

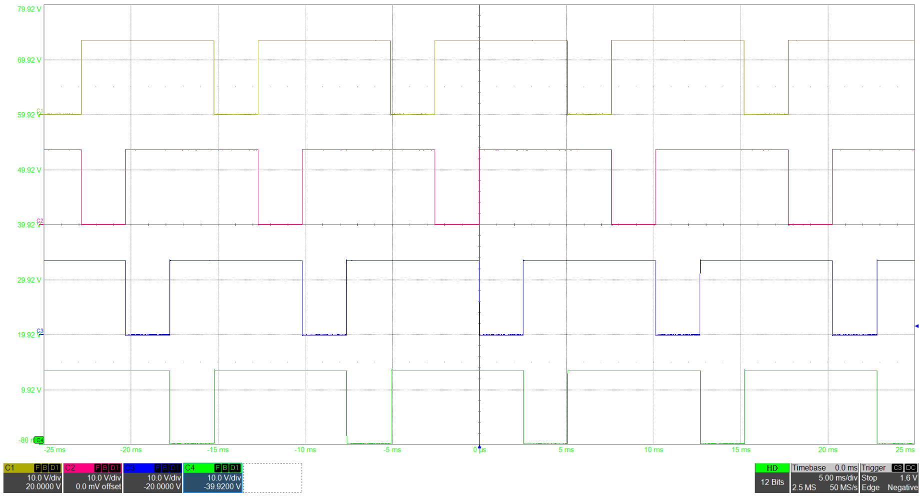

Figure 3-7. Output node waveforms of DRV8935

3.3.1.2 Two Phases ON

In this mode of operation, two low-side MOSFETs are turned on together. This mode results in higher torque than the case when single phase is ON. The truth table and timing diagram for this mode of operation are shown in Table 3-5.

Figure 3-8 and Figure 3-9 show the input and output waveforms when driving a unipolar stepper motor in two phases ON mode with the DRV8935.

Table 3-5. Input and Output Waveforms

INDEX	IN1	IN2	IN3	IN4
1	0	0	1	1
2	1	0	0	1
3	1	1	0	0
4	0	1	1	0

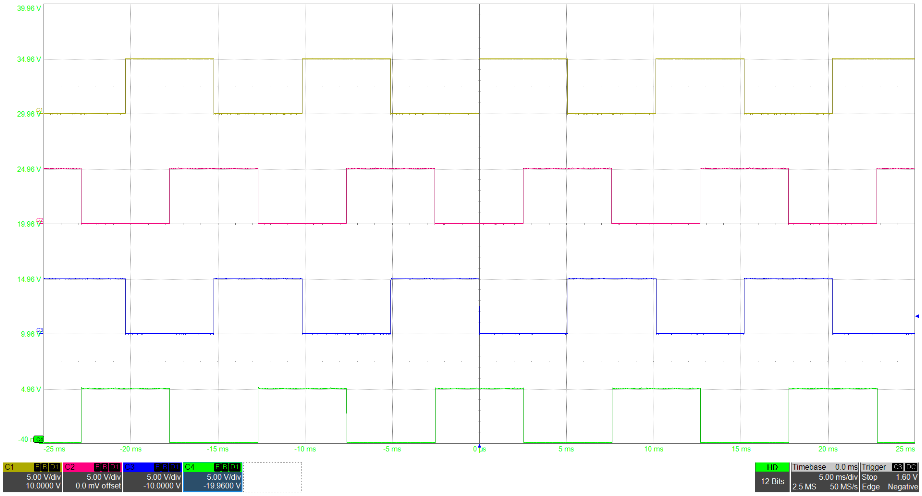

Figure 3-8. Input PWM signal of DRV8935

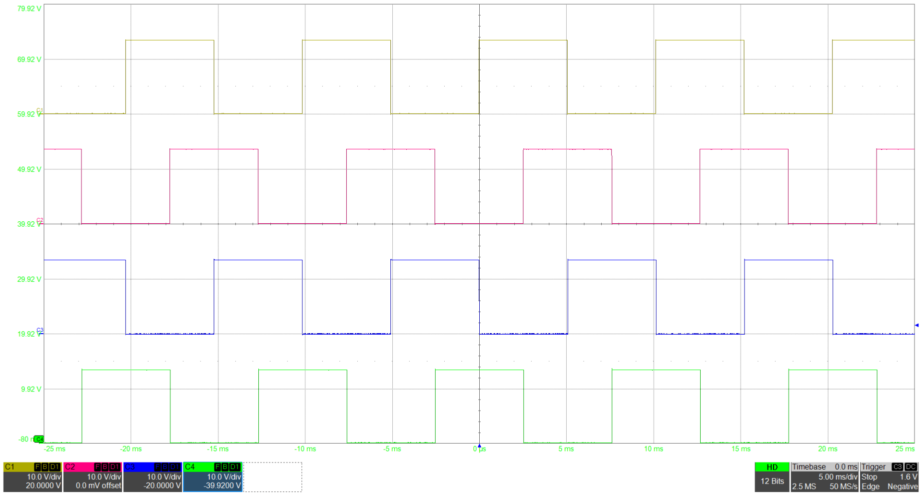

Figure 3-9. Output node waveforms of DRV8935

3.3.2 Driving in Half-step Mode

The truth table for this mode of operation is shown in Table 3-6.

Table 3-6. Truth Table

INDEX	IN1	IN2	IN3	IN4
1	0	1	1	1
2	0	0	1	1
3	1	0	1	1
4	1	0	0	1
5	1	1	0	1
6	1	1	0	0
7	1	1	1	0
8	0	1	1	0
9	0	1	1	1
10	0	0	1	1
11	1	0	1	1
12	1	0	0	1
13	1	1	0	1
14	1	1	0	0
15	1	1	1	0
16	0	1	1	0

Figure 3-10 and Figure 3-11 show the input and output waveforms when driving a unipolar stepper motor in half step mode with the DRV8935.

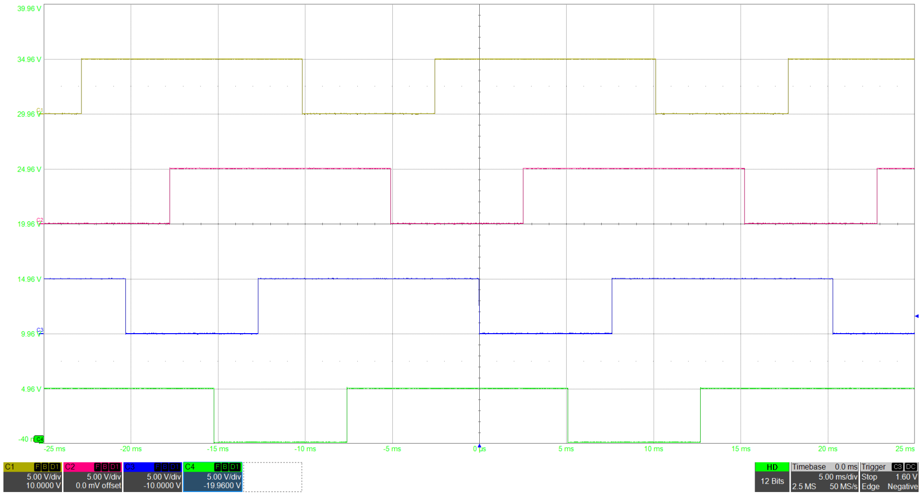

Figure 3-10. Input PWM signal of DRV8935

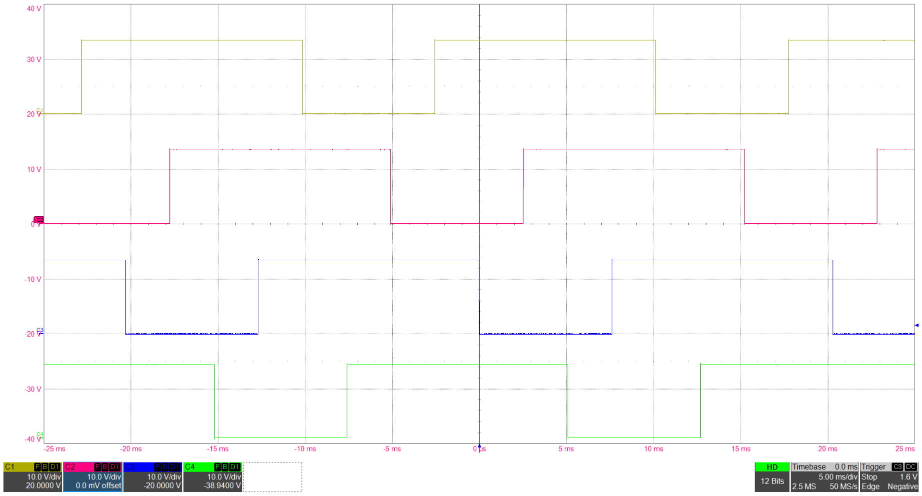

Figure 3-11. Output node waveforms of DRV8935

3.3.3 Example Pseudocode

Here are example pseudocodes to drive unipolar motors with the DRV8932, DRV8935 or DRV8955 drivers.

3.3.3.1 Code for Full-step with One Phase ON

```
/// 0111 1011 1101 1110 // input format for full step one phase ON

int in1 = 8;
int in2 = 9;
int in3 = 10;
int in4 = 11;

int i = 0;
int freq = 200;
       unsigned long t_half =0.5*(1000000/freq);

       void setup()
       { pinMode(in1, OUTPUT);
         pinMode(in2, OUTPUT);
         pinMode(in3, OUTPUT);
         pinMode(in4, OUTPUT);
       }

       void loop() {
         delayMicroseconds(t_half);
         i=i+1;
         if (i >=4) {i=0;}
        switch(i)
        {
          case 0:
            digitalWrite(in1,LOW);
            digitalWrite(in3,HIGH);
            digitalWrite(in2,HIGH);
            digitalWrite(in4,HIGH);
          break;
          case 1:
            digitalWrite(in1,HIGH);
            digitalWrite(in3,LOW);
            digitalWrite(in2,HIGH);
            digitalWrite(in4,HIGH);
          break;
          case 2:
            digitalWrite(in1,HIGH);
            digitalWrite(in3,HIGH);
            digitalWrite(in2,LOW);
            digitalWrite(in4,HIGH);
       break;
       case 3:
            digitalWrite(in1,HIGH);
            digitalWrite(in3,HIGH);
            digitalWrite(in2,HIGH);
            digitalWrite(in4,LOW);
       break;
       }
      }
```

3.3.3.2 Code for Full-step with Two Phase ON

```
/// 0011 1001 1100 0110 // input format for full step one phase ON

int in1 = 8;
int in2 = 9;
int in3 = 10;
int in4 = 11;

int i = 0;
int freq = 200;
unsigned long t_half =0.5*(1000000/freq);

void setup()
{ pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  pinMode(in3, OUTPUT);
  pinMode(in4, OUTPUT);
}

void loop() {
  delayMicroseconds(t_half);
  i=i+1;
  if (i >=4) {i=0;}
 switch(i)
 {
   case 0:
     digitalWrite(in1,LOW);
     digitalWrite(in3,LOW);
     digitalWrite(in2,HIGH);
     digitalWrite(in4,HIGH);
   break;
   case 1:
     digitalWrite(in1,HIGH);
     digitalWrite(in3,LOW);
     digitalWrite(in2,LOW);
     digitalWrite(in4,HIGH);
   break;
   case 2:
     digitalWrite(in1,HIGH);
     digitalWrite(in3,HIGH);
     digitalWrite(in2,LOW);
     digitalWrite(in4,LOW);
break;
case 3:
     digitalWrite(in1,LOW);
     digitalWrite(in3,HIGH);
     digitalWrite(in2,HIGH);
     digitalWrite(in4,LOW);
break;
}
}
```

3.3.3.3 Code for Half-step

```
/// 0111 0011 1011 1001 1101 1100 1110 0110 // input format

int in1 = 8;
int in2 = 9;
int in3 = 10;
int in4 = 11;

int i = 0;
int freq = 200;
unsigned long t_half =0.5*(1000000/freq);


void setup()
{
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  pinMode(in3, OUTPUT);
  pinMode(in4, OUTPUT);
}

void loop() {
  delayMicroseconds(t_half);
  i=i+1;
  if (i >=8)  {i=0;}
 switch(i)
 {
  case 0:
    digitalWrite(in1,LOW);
    digitalWrite(in3,HIGH);
    digitalWrite(in2,HIGH);
    digitalWrite(in4,HIGH);
  break;
  case 1:
    digitalWrite(in1,LOW);
    digitalWrite(in3,LOW);
    digitalWrite(in2,HIGH);
    digitalWrite(in4,HIGH);
  break;
  case 2:
    digitalWrite(in1,HIGH);
    digitalWrite(in3,LOW);
    digitalWrite(in2,HIGH);
    digitalWrite(in4,HIGH);
  break;
  case 3:
    digitalWrite(in1,HIGH);
    digitalWrite(in3,LOW);
    digitalWrite(in2,LOW);
    digitalWrite(in4,HIGH);
  break;
  case 4:
    digitalWrite(in1,HIGH);
    digitalWrite(in3,HIGH);
    digitalWrite(in2,LOW);
    digitalWrite(in4,HIGH);
  break;
  case 5:
    digitalWrite(in1,HIGH);
    digitalWrite(in3,HIGH);
    digitalWrite(in2,LOW);
    digitalWrite(in4,LOW);
  break;
  case 6:
    digitalWrite(in1,HIGH);
    digitalWrite(in3,HIGH);
    digitalWrite(in2,HIGH);
    digitalWrite(in4,LOW);
  break;
  case 7:
    digitalWrite(in1,LOW);
    digitalWrite(in3,HIGH);
    digitalWrite(in2,HIGH);
    digitalWrite(in4,LOW);
  break;
  }
}
```

4 References

- Texas Instruments, Drive Unipolar Stepper Motors as Bipolar Stepper Motors with a Simple Wiring Reconfiguration, Dalton Ortega, TI e2e Blog, April 2020

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