Webinar

Quick and Easy Guide to Motor Driver Technology — Intermediate Level ~Key Considerations for Implementing Sensorless Control of Brushless DC Motors~

TOSHIBA

Toshiba Electronic Devices & Storage Corporation

Industrial Consumer Application Engineering Group I, Industrial Consumer Application Engineering Department, Semiconductor Application Engineering Center, Semiconductor Division

Toshiba Electronic Device Solutions Corporation

Field Application Engineering Group 4, Field Application Engineering Department, Field Application Engineering

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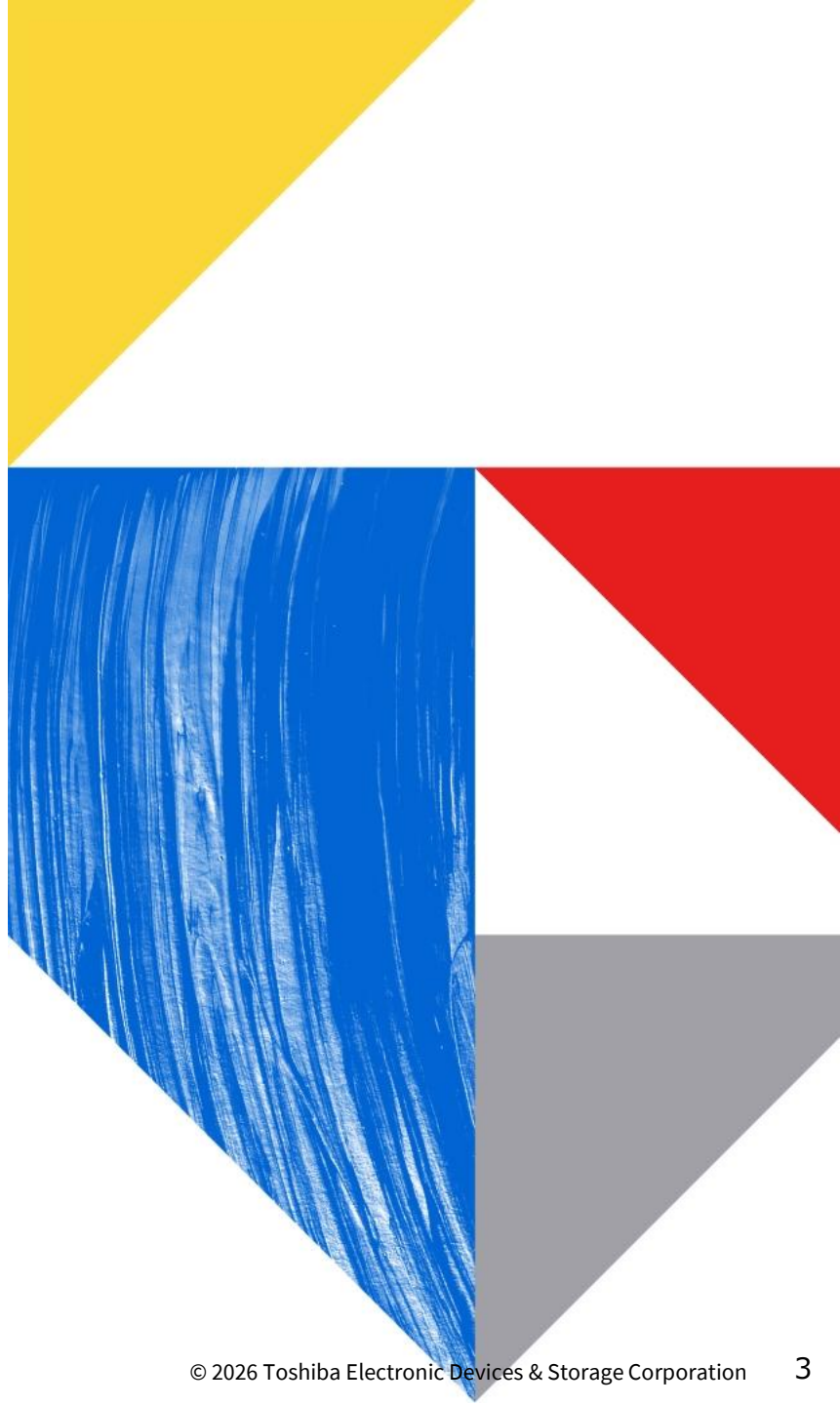
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01

Overview of brushless DC motors



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What is a BLDC motor?

A BLDC motor is a DC motor without brushes or mechanical contacts.

DC motors are broadly categorized into two main types: brushed and brushless DC motors.

Both types of motors rotate by switching the direction of current flowing through the coils (i.e., the direction of magnetic force) at the appropriate times. They use different methods to switch the direction of the current.

- **Brushed DC motors**
  The direction of the current reverses as the brushes make mechanical contact with the commutator inside the motor.
  (**Mechanical contacts are used.**)

- **Brushless DC (BLDC) motors**
  The direction of the current is switched electronically without using brushes.
  (**No mechanical contacts are used.**)

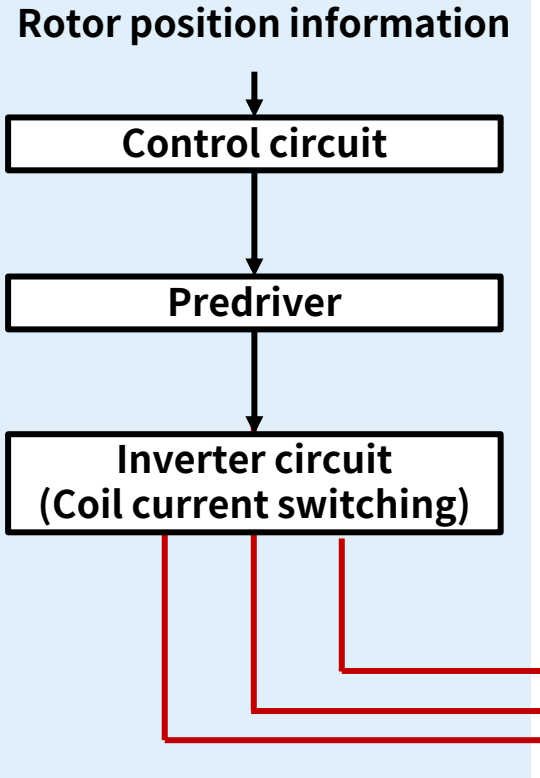
Motor covered in this webinar

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What is a BLDC motor?

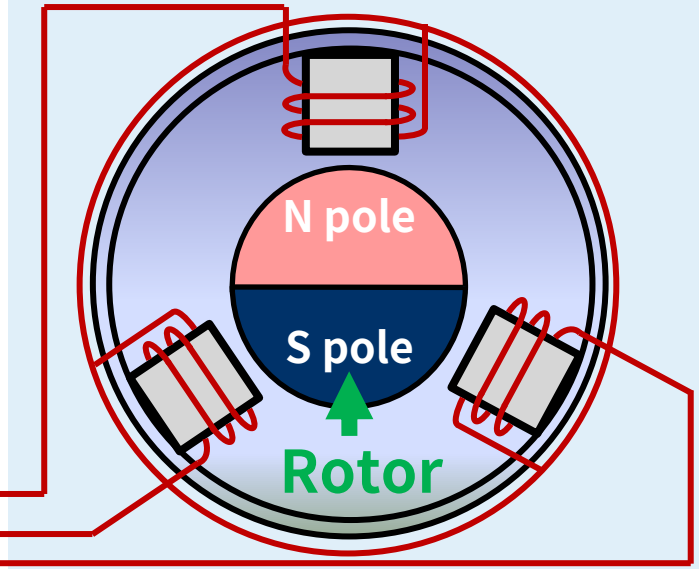
A BLDC motor is driven by switching the direction of the current flowing through its coils using an electronic circuit.

Electronic circuit blocks



3-phase BLDC motor

Structure of a 2-pole, 3-slot BLDC motor



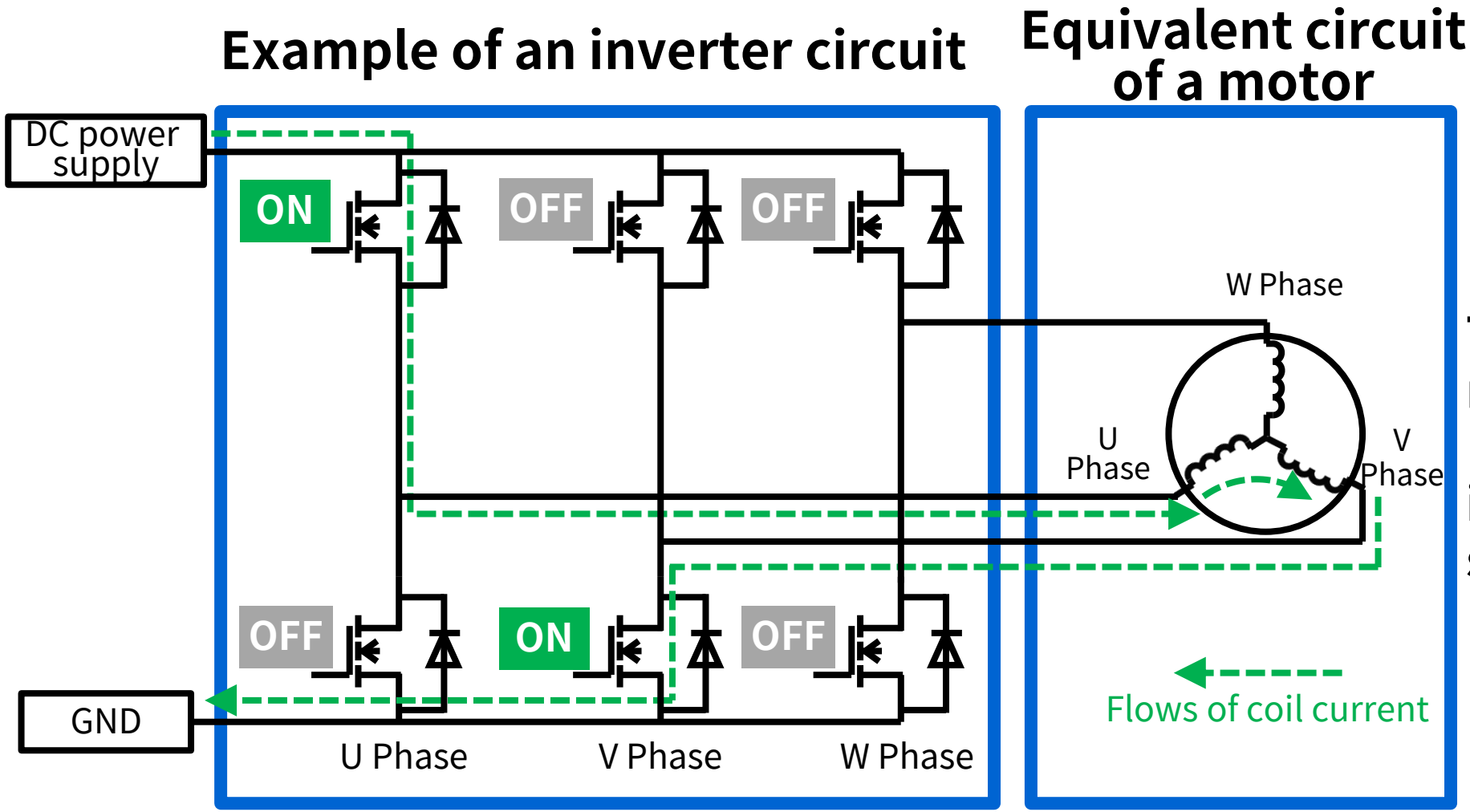
To rotate a BLDC motor, an electronic circuit switches the direction of current flowing through its coils (i.e., the direction of the magnetic force) based on information about the rotor position.

(*) The block diagram and motor structure above are simplified for illustrative purposes.

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Example of an inverter circuit for a 3-phase BLDC motor

An inverter circuit is used to switch the direction of the motor coil current.



The motor coil current reverses as the six MOSFETs in the inverter circuit are switched on and off.

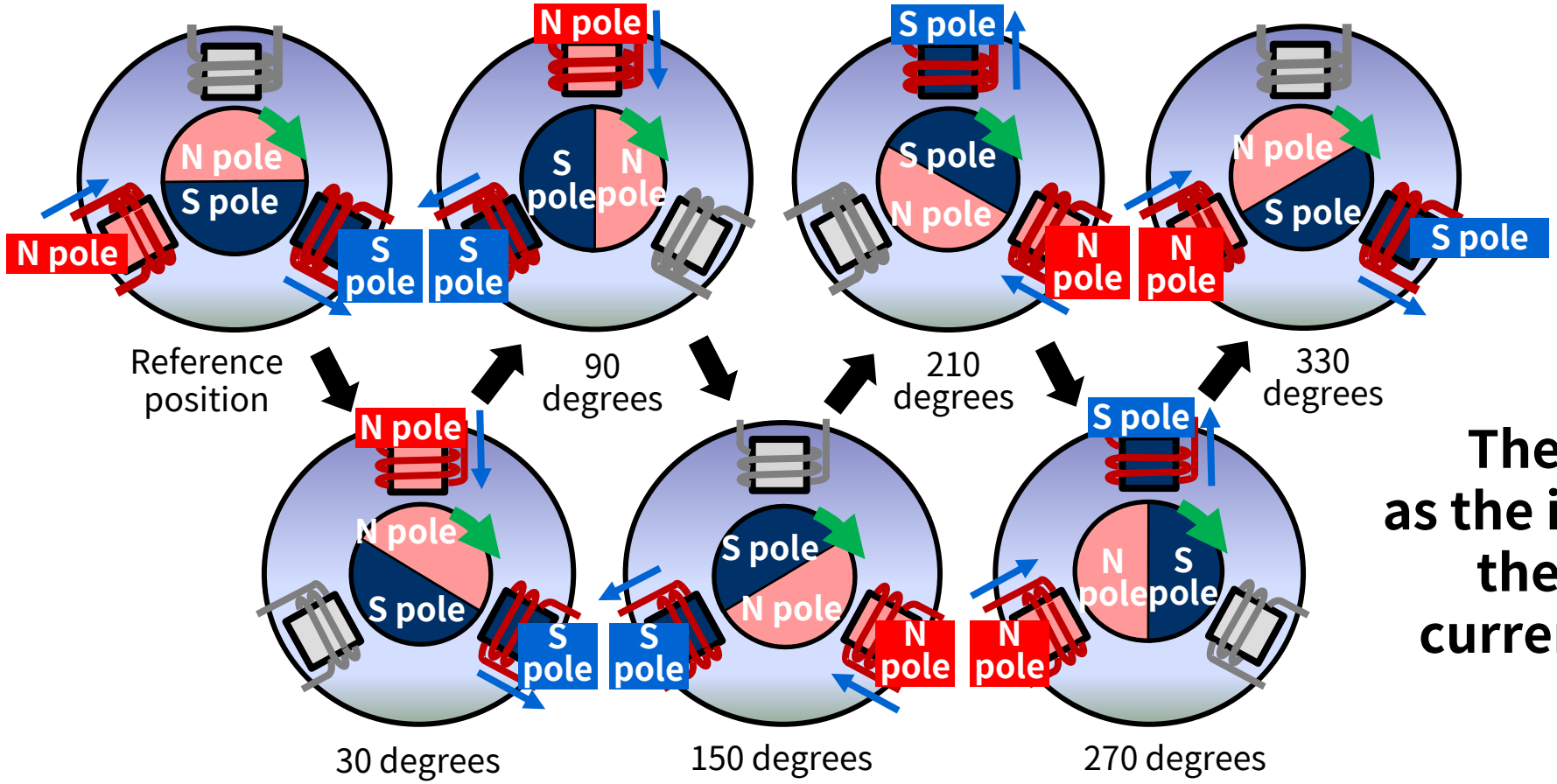
(*) The above circuit diagram is simplified for illustrative purposes.

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Sequence for switching the direction of the coil current

Switching the direction of the coil current at the optimal time causes the BLDC motor to rotate.

Example of a square-wave commutation sequence for a 3-phase, 2-pole, 3-slot BLDC motor



The BLDC motor rotates as the inverter circuit switches the direction of the coil current at the optimal time.

(*) The above motor structure is simplified for illustrative purposes.

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Characteristics of BLDC motors

The key advantages of BLDC motors are their long service life and high-speed operation. Although BLDC motors require a complex electronic control system, dedicated motor driver ICs can help overcome this disadvantage.

Advantages:

Without mechanical contacts, BLDC motors offer **a longer service life** and **higher maximum speeds** than brushed DC motors.

Disadvantages:

BLDC motors require a **complex electronic control system** to switch the direction of the current, making them more challenging to drive.

Overcoming the disadvantage:

Dedicated **motor driver ICs** simplify this process by accurately detecting the rotor position and controlling the inverter circuit.

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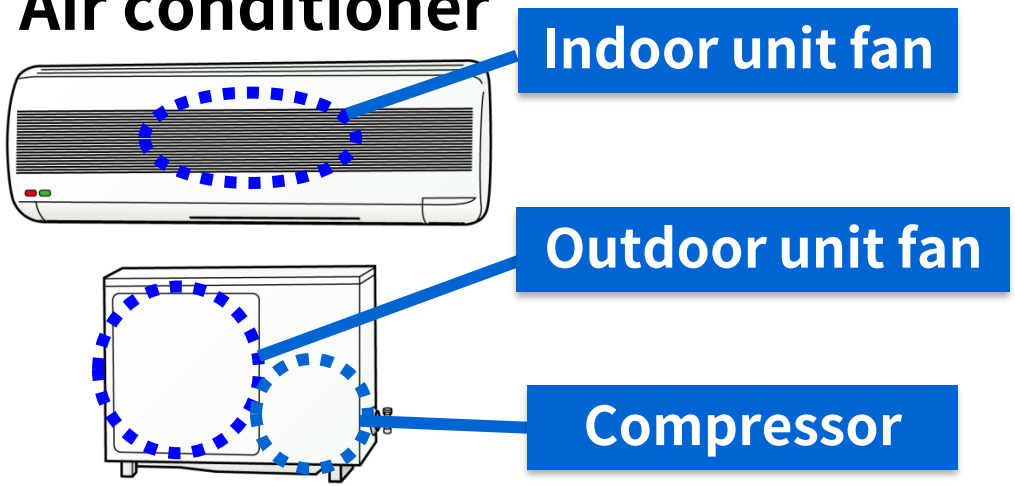
Examples of BLDC motor applications (1)

BLDC motors are widely used in home appliances because of their high-speed operation and long service life.

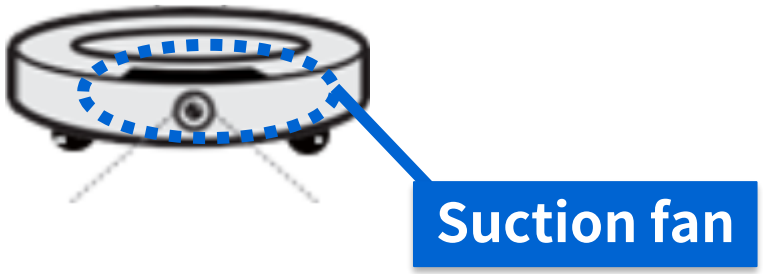
Dishwasher



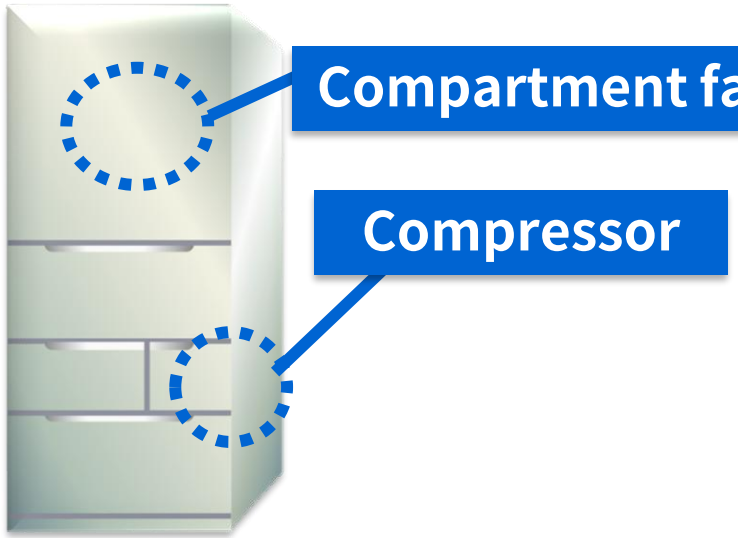
Air conditioner



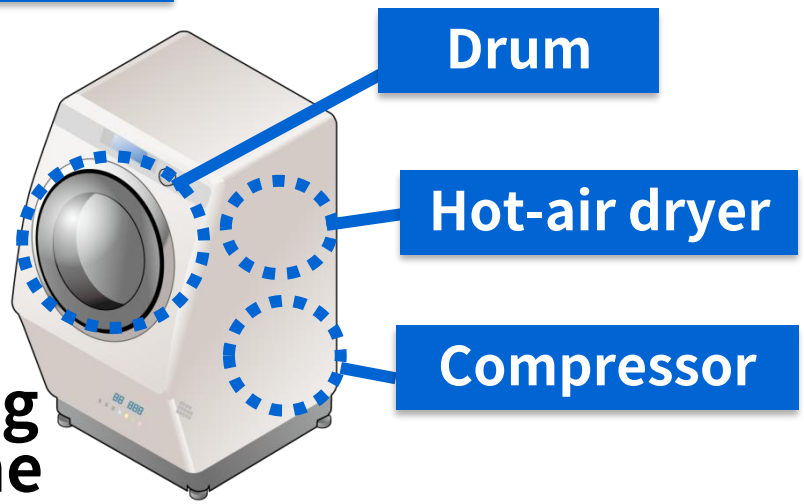
Robotic vacuum cleaner



Refrigerator



Washing machine



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Examples of BLDC motor applications (2)

BLDC motors are widely used in office equipment because of their high-speed operation and long service life.

Fan

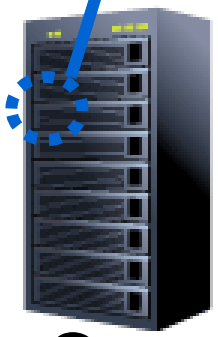


Cooling fan

PC



Server



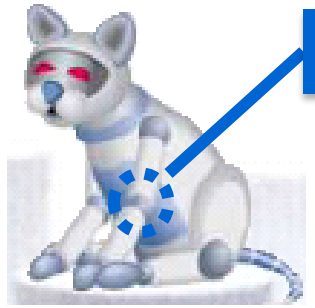
Multifunction printer (MFP)



Paper transport

Image forming unit (Polygon mirror, drum)

Robot



Joint

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Reference: Comparison with other types of motors

Different types of motors have different characteristics.

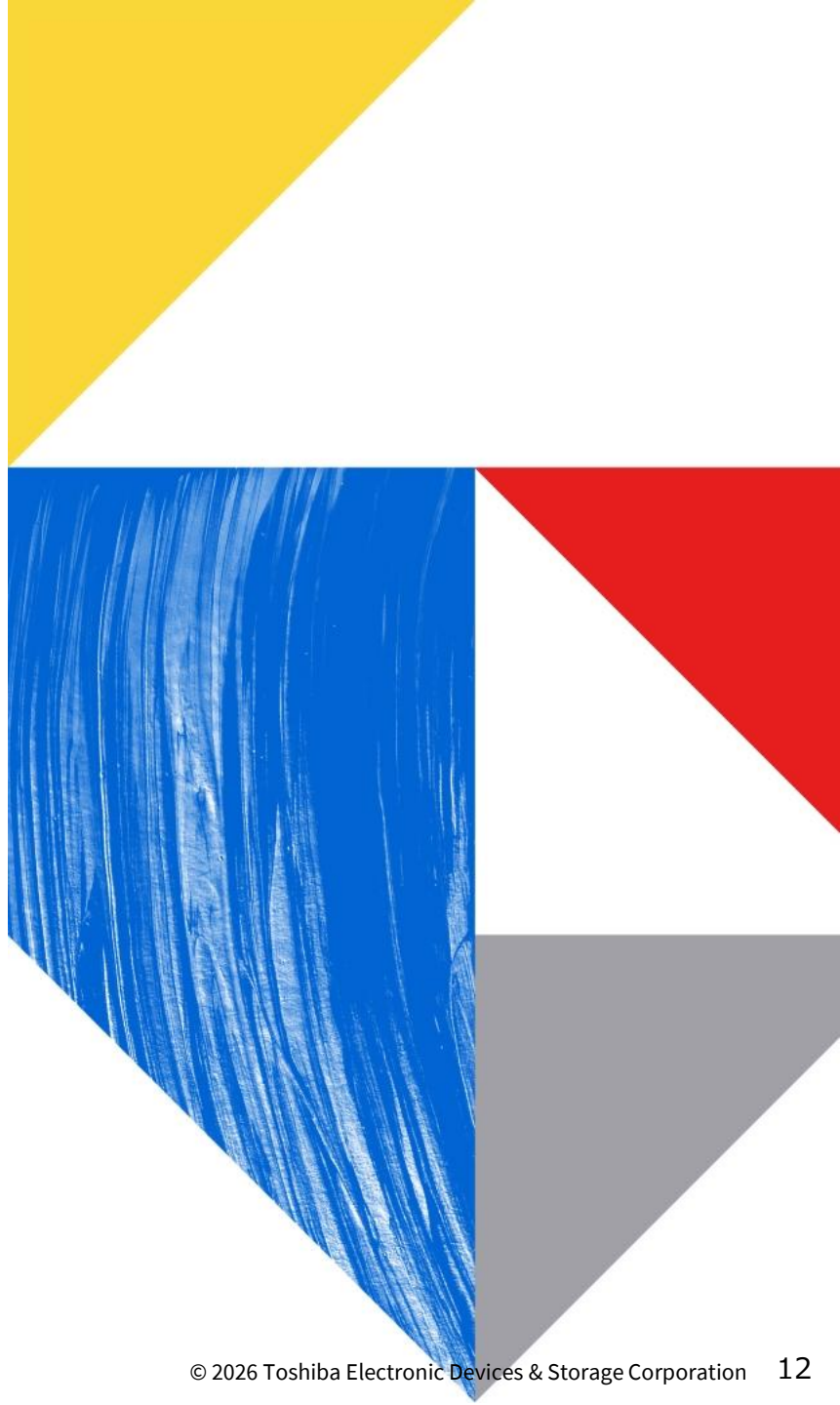
Motor covered in this webinar

Types of Motor	Brushed DC Motors	BLDC Motors	Stepping Motors
Rotation method	A brushed DC motor rotates as the direction of the coil current is reversed through mechanical contact between the brushes and commutator.	A BLDC motor rotates as an electronic circuit (consisting of position sensors and an inverter circuit) switches the coil current on and off in a predefined sequence. The electronic circuit performs the same function as the brushes and commutator.	A stepping motor rotates as an electronic circuit (an H-bridge) switches the coil current on and off in a predefined sequence.
Electronic circuit	**Not required for simple rotation**	Required	Required
Rotation speed	Proportional to the voltage applied	Proportional to the voltage applied	Proportional to the input pulse frequency
High-speed rotation	Several thousand rpm	Several thousand to tens of thousands of rpm **High-speed rotation**	Unsuitable
Service life	Several hundred to several thousand hours (Depends on the wear of brushes)	Tens of thousands to hundreds of thousands of hours **Long life**	Tens of thousands of hours
Position control	Unsuitable	Unsuitable	**Precise position control**
Price	**Low**	High	High

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02

Control circuits and commutation methods



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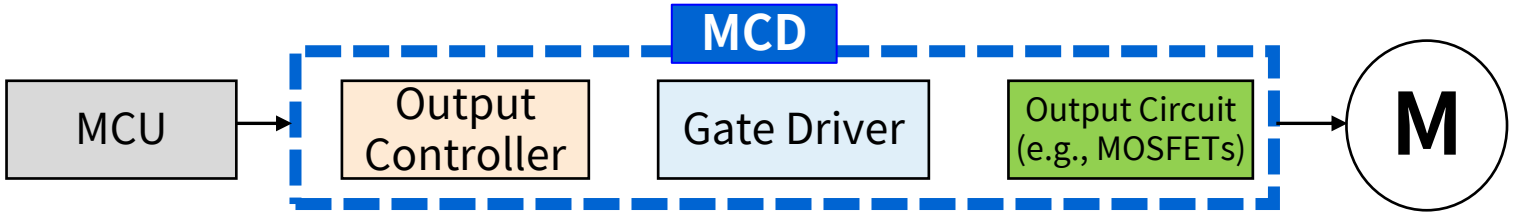
Examples of control circuit configurations for BLDC motors

MCD: Motor control driver

Toshiba offers a range of MCDs, allowing you to select the one that best suits your requirements.

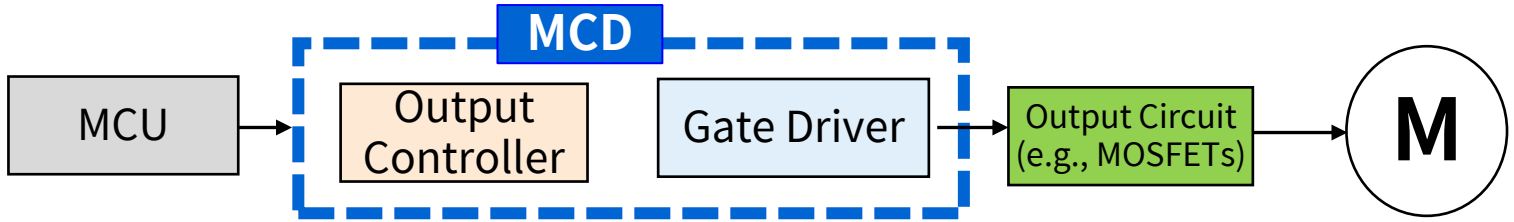
1. Driver-type MCD

This type of MCD integrates all the circuits necessary to drive a BLDC motor, including a control circuit, gate driver, and output circuit.
It helps reduce the number of components.



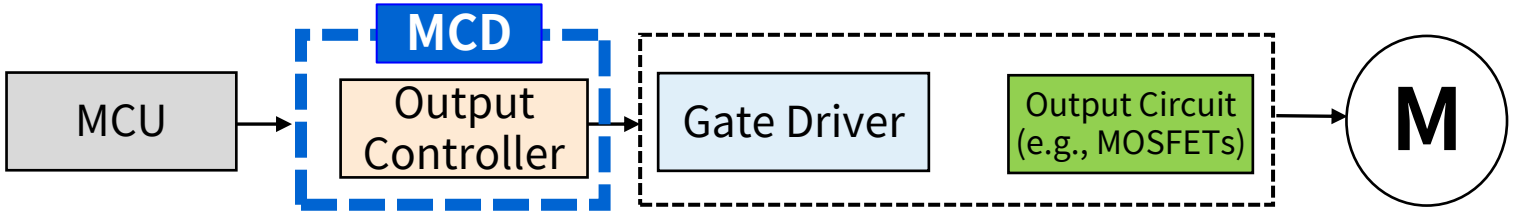
2. Predriver-type MCD

This type of MCD requires an external output circuit. For **high-current motor applications**, this MCD can be combined with an external output circuit with high current-handling capability.



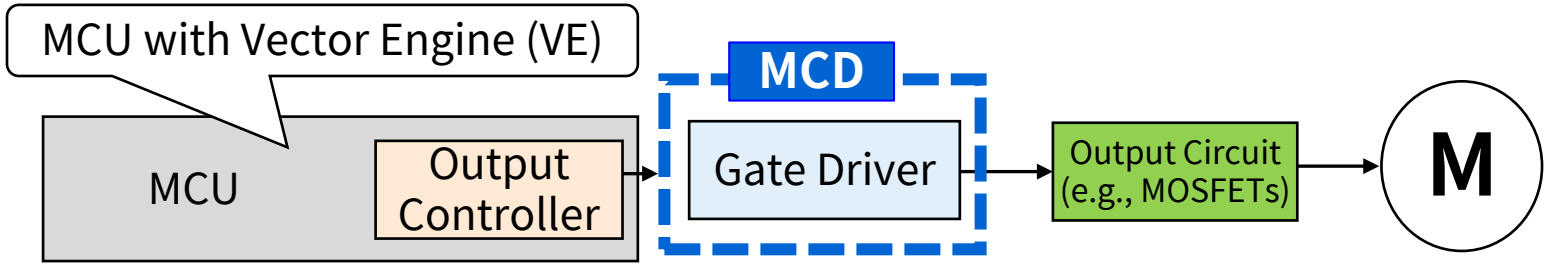
3. Controller-type MCD

This type of MCD is used in combination with a driver consisting of a gate driver and an output circuit.
This configuration is commonly used to drive motors with high supply voltage.



4. Gate-driver-type MCD

When an MCU controls the motor output, a gate driver is required to increase the current drive capability because the MCU cannot drive the output circuit directly.



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Examples of control circuit configurations for BLDC motors

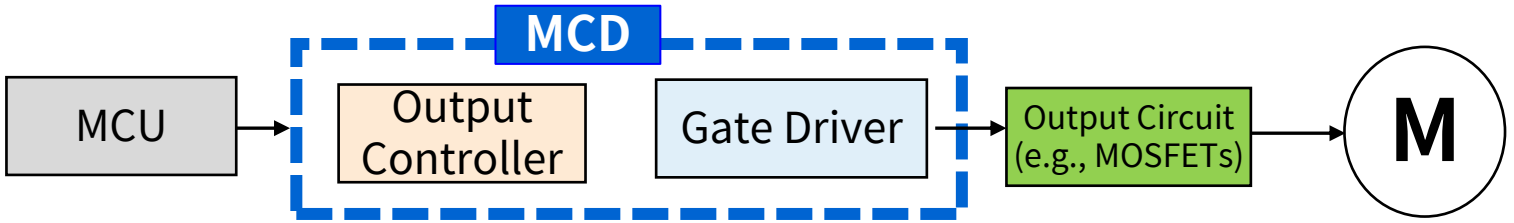
MCD: Motor control driver

An actual motor control circuit will be discussed in Section 4, using a predriver-type MCD as an example.

Control circuit configuration for this webinar

2. Predriver-type MCD

This type of MCD requires an external output circuit.
For **high-current motor applications**, this MCD can be combined with an external output circuit with high current-handling capability.



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Methods for rotor position detection

The rotor position is detected using position sensors or estimated from the back EMF induced in the motor coils.

To switch the inverter circuit at the optimal time, it is essential to accurately detect the rotor position.
There are three primary methods for detecting the rotor position.

Method 1: Using position sensors

Advantage: Simplifies motor control
Disadvantage: Hall sensors for rotor position detection increase component cost and wiring complexity.

→ This method is widely used in various applications because it simplifies motor control.

Method 2: Sensorless rotor position detection based on back EM

Advantages: Smaller motor size, higher reliability due to the elimination of physical sensors, and lower cost
Disadvantages: More challenging motor control due to a slower transient response and motor-to-motor variations

→ This method is commonly used for fans that require only continuous rotation, compact size, and high reliability.

Method 3: Sensorless rotor position detection based on vector control

Advantage: High efficiency over the medium- to high-speed range.
Disadvantage: Requires software development

→ This method is used for applications requiring sophisticated motor control.

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Methods for rotor position detection

Actual design techniques will be discussed in Section 4, using an MCD designed for Method 2 as an example.

Method covered in this webinar

Method 2: Sensorless rotor position detection based on back EM

Advantages: Smaller motor size, higher reliability due to the elimination of physical sensors, and lower cost

Disadvantages: More challenging motor control due to a slower transient response and motor-to-motor variations

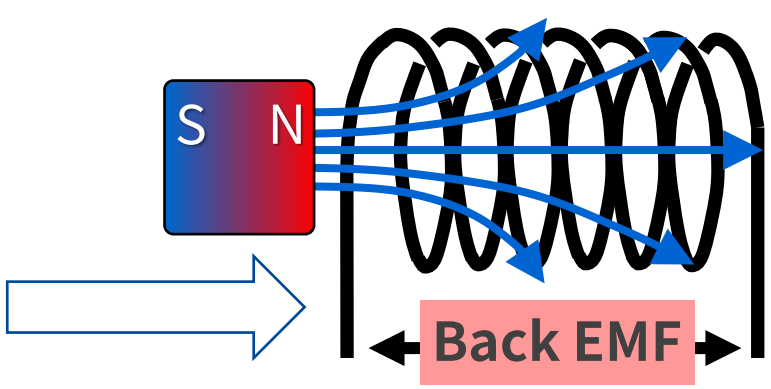
This method is commonly used for fans that require only continuous rotation, compact size, and high reliability.

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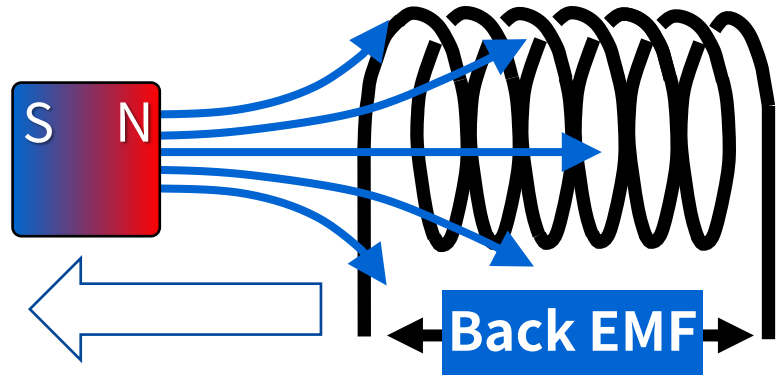
What is back EMF?

Back EMF is the voltage induced by changes in the magnetic flux passing through a coil.

As the N pole **approaches** the coil, the magnetic flux passing through the coil increases, generating **a positive back EMF**.



As the N pole **moves away** from the coil, the magnetic flux passing through the coil decreases, generating **a negative back EMF**.



Back EMF is directly proportional to the rate of change of magnetic flux.

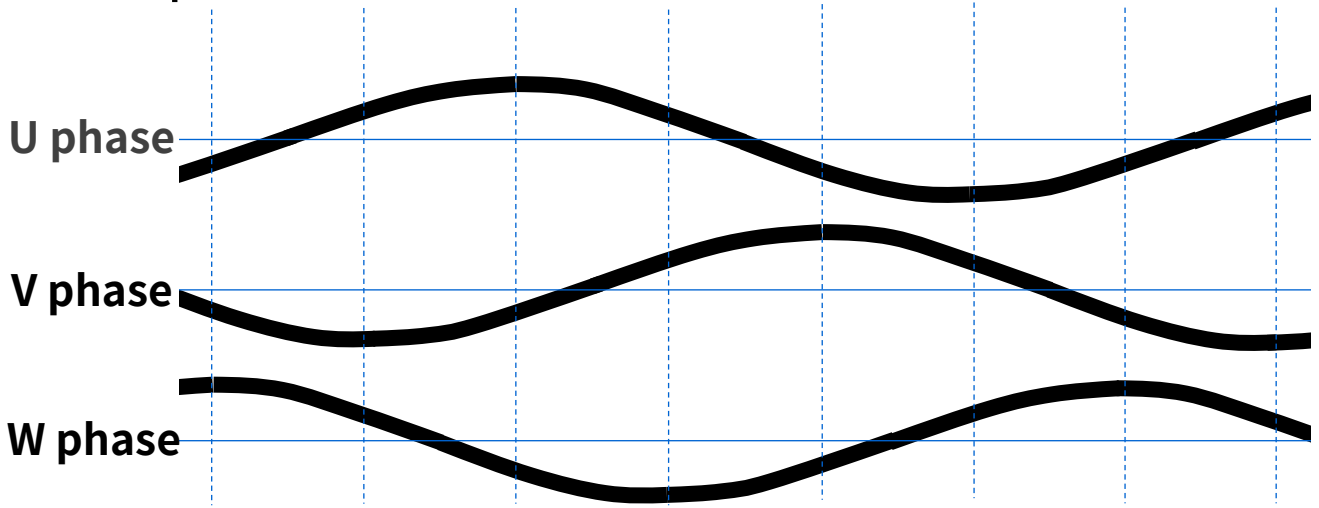
(*) The above figures are simplified for illustrative purposes.

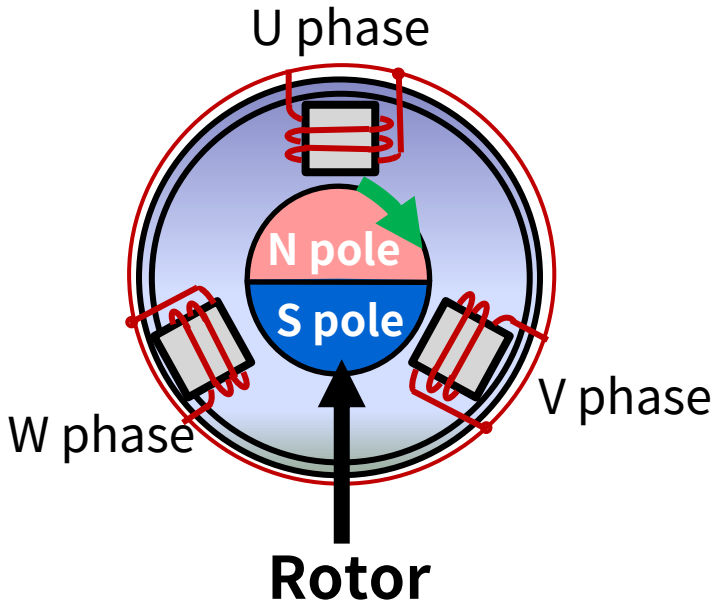
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Back EMF induced in a three-phase BLDC motor

Back-EMF waveforms are used to estimate the rotor position.

Example of Back-EMF Waveforms for Each Coil





As the rotor rotates, the distance between the rotor and each coil changes, causing the back EMF induced in each coil to change.

(*) The above timing chart is simplified for illustrative purposes.

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03

TC78B011FTG motor driver for sensorless sine-wave drive

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Roles of a motor driver IC

A motor driver IC provides the features necessary to control a motor, simplifying the design of the motor drive circuit.

BLDC motors cannot be operated simply by applying a supply voltage.

They require an IC capable of controlling the electronic commutation sequence.

Examples of motor driver IC benefits

1. **Commutation sequence control** of the **inverter circuit**
2. **Motor speed** control
3. **Sine-wave drive** to **reduce motor vibration and acoustic noise**
4. **Lead angle** control to improve **power efficiency**
5. **Safety enhancement** through **fault detection**

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TC78B011FTG three-phase BLDC motor predriver

Today, I'll explain the key considerations for designing a motor drive circuit using this product.

Features

1. Sensorless Sine-wave drive

→ Reduces motor vibration and acoustic noise

2. Closed-loop motor speed control and integrated nonvolatile memory

→ Stabilizes motor speed against voltage and load fluctuations without an external MCU

→ Stores various motor settings in internal nonvolatile memory

3. Adjustable external MOSFET gate drive current

→ Enables gate drive current adjustment to match the selected external MOSFETs



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TC78B011FTG three-phase BLDC motor predriver

Today, I'll explain the key considerations for designing a motor drive circuit using this product.

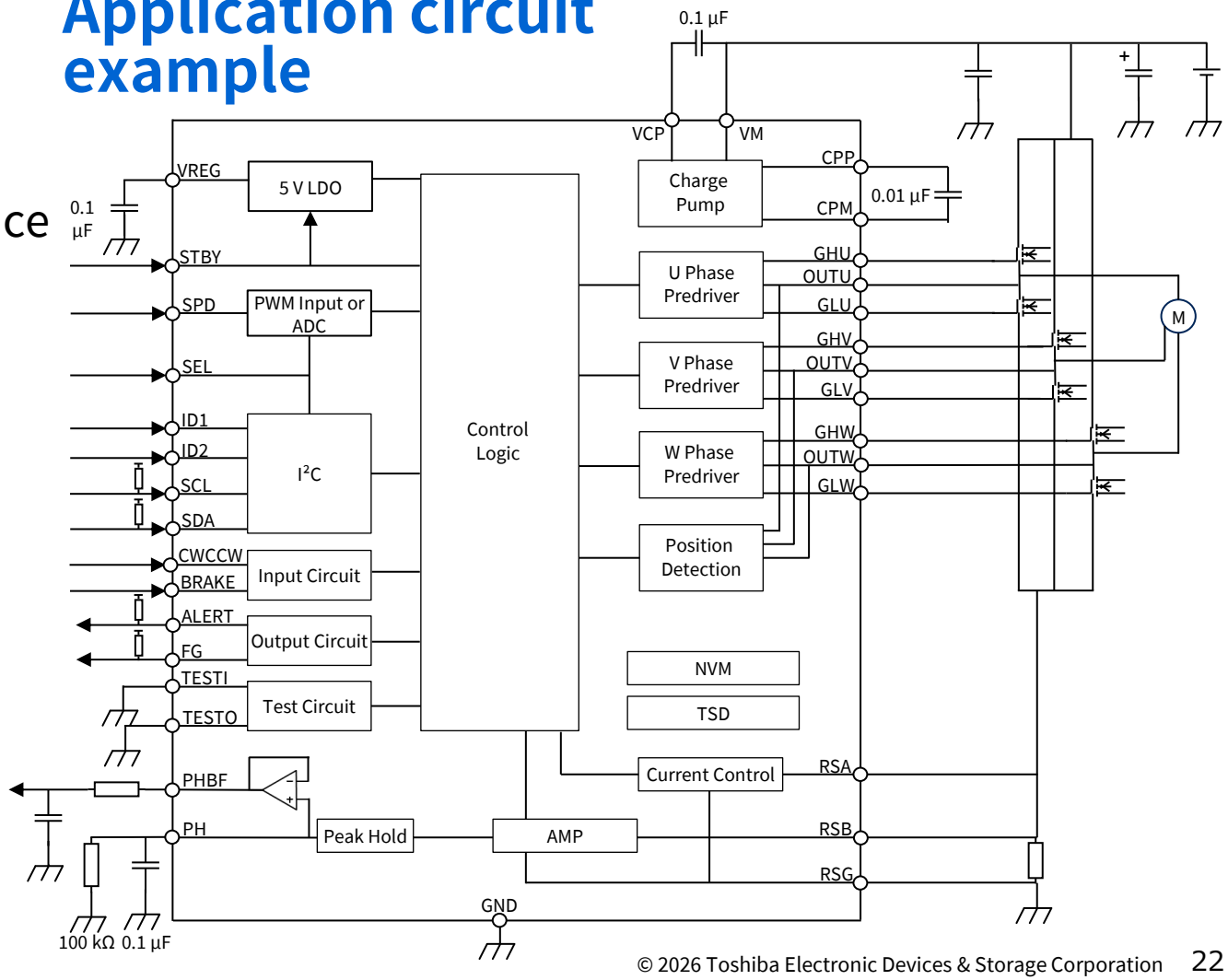
Specifications

- **Operating supply voltage range**
  5.5 V to 27 V
- **Speed control commands**
  PWM signal, analog voltage input, and I²C interface
- **Fault detection features**
  Fault flag output, thermal shutdown (TSD), undervoltage lockout (UVLO), charge pump low-voltage detection, output current limit, output overcurrent detection, and motor lock protection
- **Package**
  Compact QFN36 (5×5 mm)

Target applications

- Server fans
- Suction motors for cordless vacuum cleaners
- Suction motors for robotic vacuum cleaners
- Pumps
- Blowers

Application circuit example



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Feature 1: Sensorless Sine-wave drive

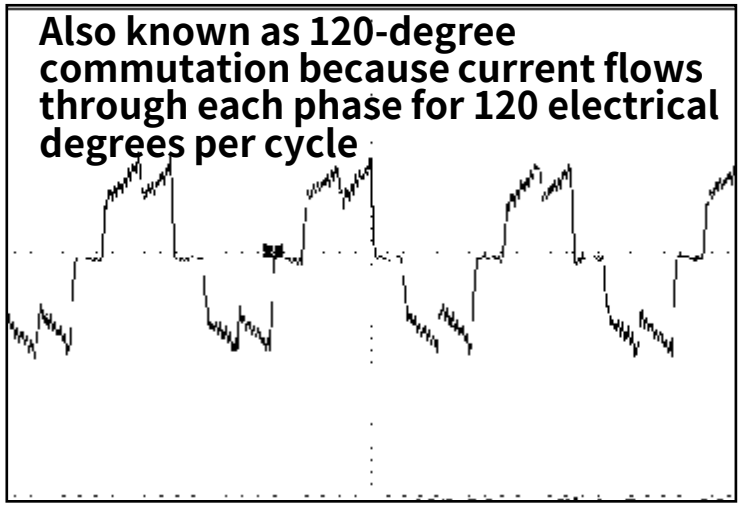
The TC78B011FTG supports Sine-wave drive, which reduces motor vibration and acoustic noise.

Square-wave commutation

Advantage: **Easy motor control**

Disadvantage: Higher acoustic noise and mechanical vibration

Motor current waveform

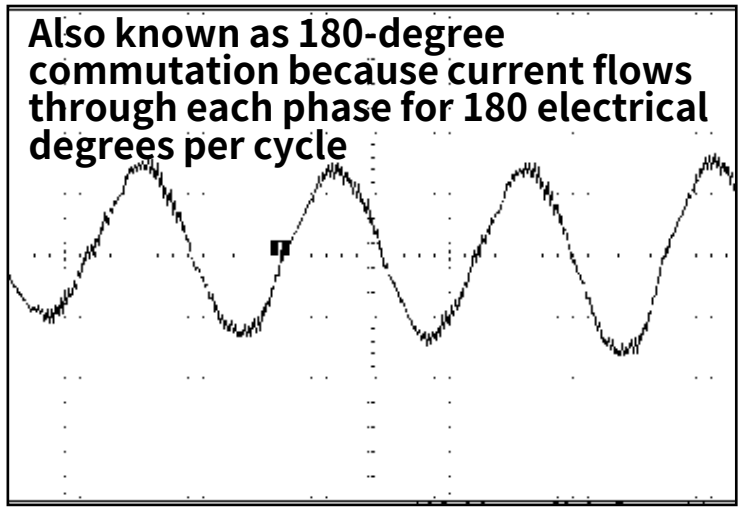


Sine-wave drive

Advantage: **Lower acoustic noise and mechanical vibration**

Disadvantage: More complicated control

Motor current waveform



The TC78B011FTG incorporates a sine-wave control function that automates this complicated control process.

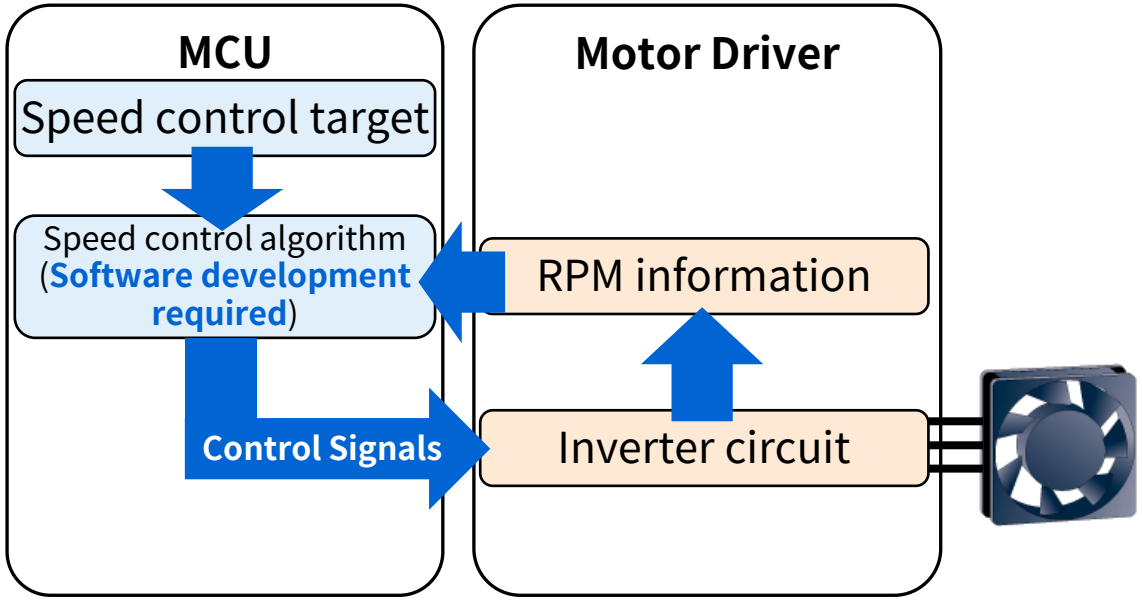
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Feature 2: Closed-loop motor speed control

With the TC78B011FTG, a simple speed control system can be configured without an MCU.

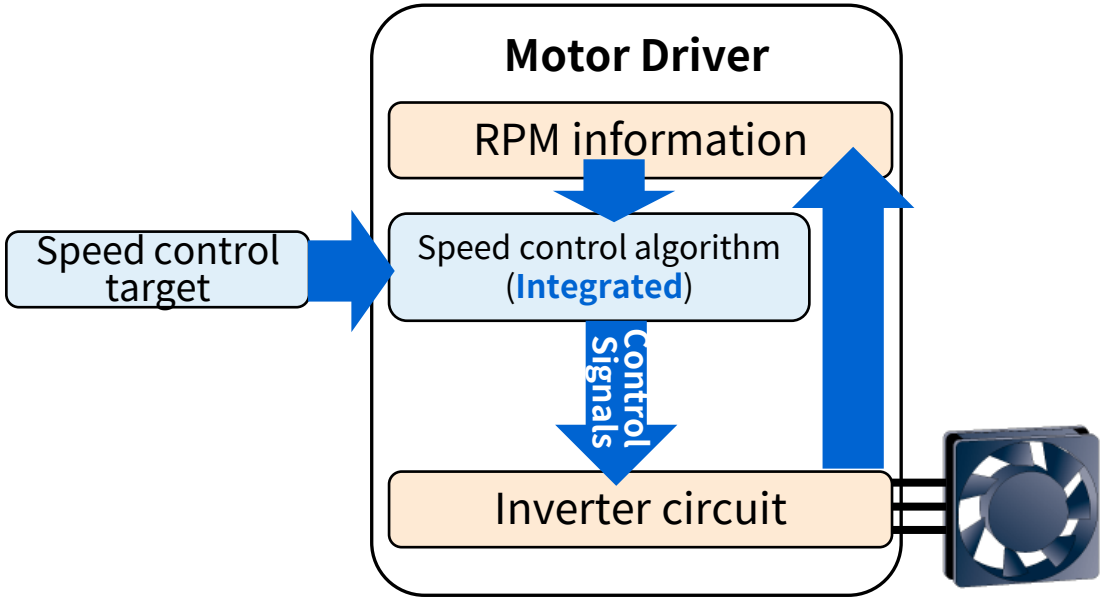
Conventional configuration

An MCU and a motor driver IC form a closed loop for speed control.



Configuration using the TC78B011FTG

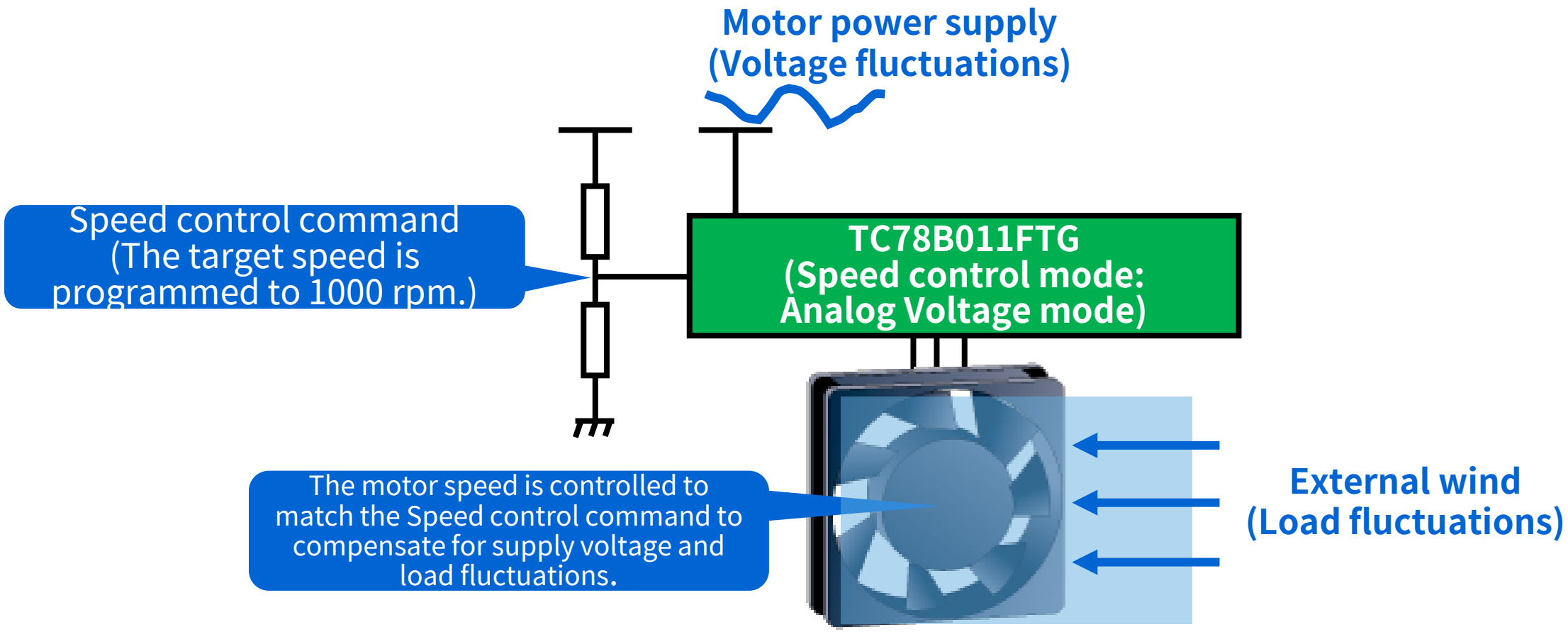
Only a motor driver IC is required to form a closed loop for speed control.



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Closed-loop motor speed control: Application Example 1

The TC78B011FTG reduces motor speed variations caused by supply voltage and load fluctuations without an MCU.

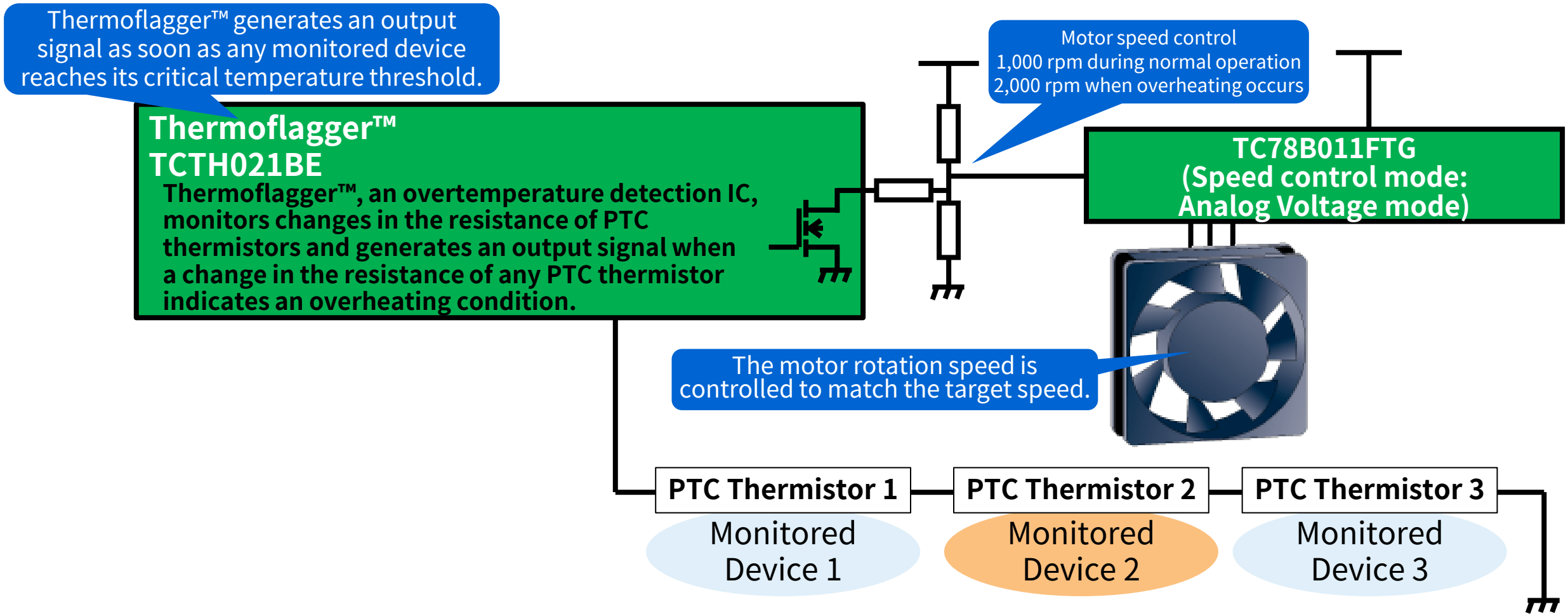


(*) The above circuit diagram is simplified for illustrative purposes.

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Closed-loop motor speed control: Application Example 2

Combining the TC78B011FTG with Thermoflagger™, Toshiba's overtemperature detection IC, enables fan airflow control based on the temperature of target devices—without requiring an MCU.



(*) The above circuit diagram is simplified for illustrative purposes.

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Feature 3: Adjustable external MOSFET gate drive current

The TC78B011FTG includes built-in features that make it easy to create an optimal motor application design.

The IC allows you to adjust the gate drive current in eight steps to match the characteristics of your external MOSFETs.

Benefit 1: Reduced noise and power loss

Allows you to easily balance the trade-off between noise reduction (slower switching) and power efficiency (faster switching).

Benefit 2: No board modifications required

Allows you to adjust the MOSFET switching speed using software register settings—no component changes are required

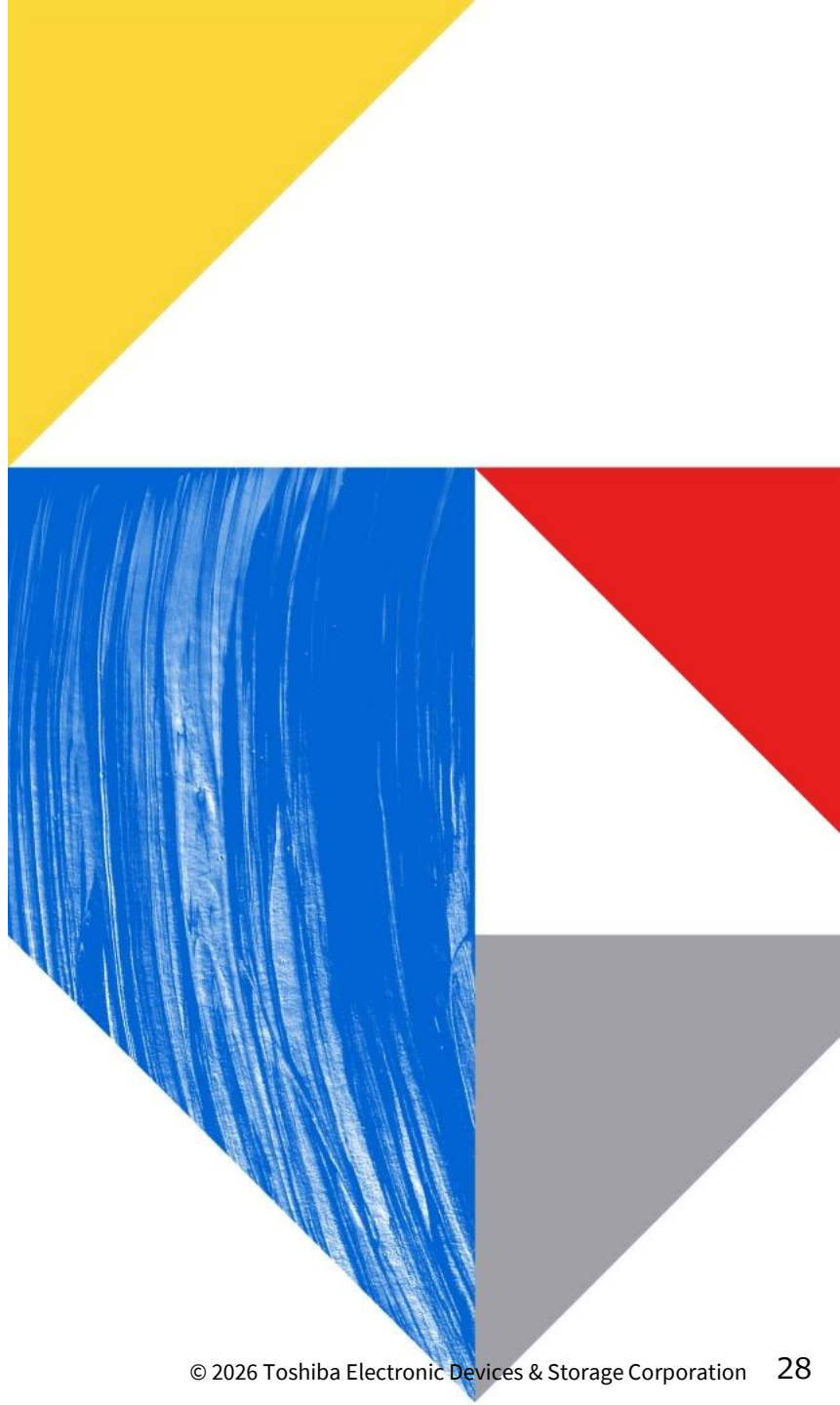
Benefit 3: Lower component count

Reduces the number of external gate resistors and diodes, minimizing the board space required for the control circuit

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04

Design considerations



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Five key topics for designing a sensorless motor drive circuit using the TC78B011FTG:

1. Drive circuit design

A reference design available on our website to help you get started quickly

2. Inverter circuit settings

Configuring dead time, gate drive current, and related parameters

3. Speed control settings

Selecting the motor speed control mode and setting the speed curve parameters

4. Startup control settings

Settings related to motor startup from an idle state,
plus tips for troubleshooting startup failures

5. Lead angle control settings

Settings necessary to improve motor drive efficiency

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1. Drive circuit design

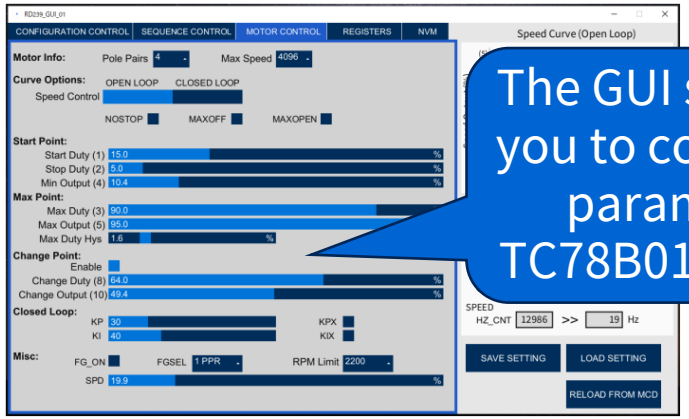
The Reference Design Center page on our website provides reference design information to help you get started quickly with system design.

TC78B011FT Evaluation Board Photo



The Arduino Nano Every can be connected to the evaluation board.

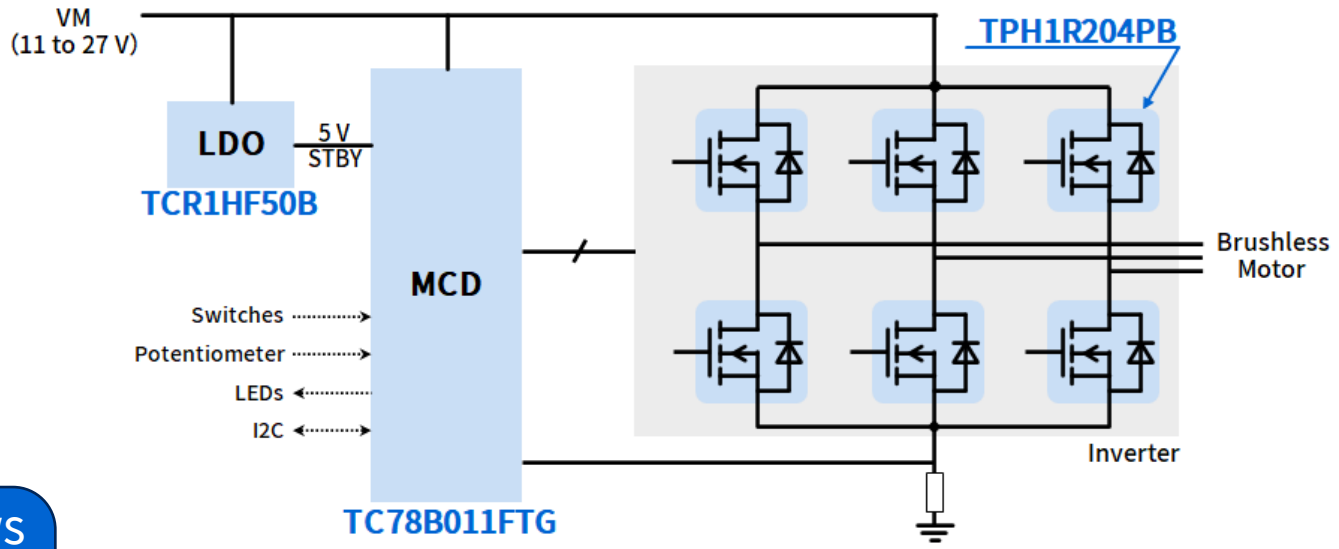
GUI Software for the TC78B011FT



The GUI software allows you to configure various parameters of the TC78B011FT using a PC.

(*) The above block diagram is simplified for illustrative purposes.

TC78B011FT Evaluation Board Block Diagram



(*) The following web page provides not only circuit diagrams, but also board layout data, Gerber data, sample software, and other related data.
https://toshiba.semicon-storage.com/ap-en/semiconductor/design-development/referencedesign/detail.RD239.html

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Reference: Toshiba's MOSFET lineup

The reference design uses MOSFETs with a V_{DSS} rating of 40 V. For applications with a 24 V motor power supply, we recommend using MOSFETs with a V_{DSS} rating of 60 V.

Package	Part No.	I_D (A)	$R_{DS(ON)}$ (mΩ)				Gate Charge (typ.)			Q_{oss} (typ.) (nC)	Q_{rr} (typ.) (nC)	rg (typ.) (Ω)	Gen.
			V_{GS} = 10V		V_{GS} = 4.5V		Q_g (nC)		Q_{sw} (nC)				
			Typ.	Max	Typ.	Max	V_{GS} = 10 V	V_{GS} = 4.5 V					
DSOP Advance	TPW1R306PL	100	0.95	1.29	1.5	2.3	91	44	22	77.5	48	0.5	U-MOSIX-H
SOP Advance(E)	TPM1R006PL	341	0.74	1	1.4	2.3	106	54	35	99	68	0.7	U-MOSIX-H LS
SOP Advance(N)	TPH1R306PL1	100	1	1.34	1.5	2.3	91	44	22	77.5	48	0.5	U-MOSIX-H
	TPH1R306PL	100	1	1.34	1.5	2.3	91	44	22	77.5	48	0.5	U-MOSIX-H
	TPH1R906PU	207	1.41	1.91	2.7	5.4	57	29	19	50	42	1.3	U-MOSIX-H LS
	TPH2R306NH1	136	1.9	2.3	-	-	72	-	26	92	72	1.1	U-MOSVIII-H
	TPH2R306PL1	100	1.7	2.3	2.6	4.2	60	32	19	51	57	0.6	U-MOSIX-H
SOP Advance	TPH1R306P1	100	0.96	1.28	1.5	2.3	91	44	22	77.5	39	2.2	U-MOSIX-H LS
	TPH3R506PL	94	2.6	3.5	3.9	6.7	55	27	16	39	36	0.8	U-MOSIX-H
	TPH4R606NH	32	3.8	4.6	-	-	49	-	19		46	1	U-MOSVIII-H
	TPH5R906NH	28	4.8	5.9	-	-	38	-	18	42.9	40	1	U-MOSVIII-H
	TPH7R006PL	60	5.4	7	8.9	13.5	22	11	6.2	20	28	0.8	U-MOSIX-H
	TPH7R506NH	22	6.1	7.5	-	-	31	-	14	34.2	28	1	U-MOSVIII-H
	TPH9R506PL	34	7.3	9.5	10.2	15	21	11	7.4	18	20	0.7	U-MOSIX-H
	TPH11006NL	17	9.6	11.4	12.8	17	23	11.2	6.4	21	-	0.6	U-MOSVIII-H
	TPH14006NH	14	11	14	-	-	16	-	6.3	18.3	20	2	U-MOSVIII-H
TSON Advance	TPN4R806PL	72	3.5	4.8	6.2	9.1	29	14	11	24	26	0.8	U-MOSIX-H
	TPN7R006PL	54	5.4	7	9.2	13.5	20	9.8	6.8	20	22	0.8	U-MOSIX-H
	TPN7R506NH	26	6	7.5	-	-	22	-	9.2	28.3	26	0.7	U-MOSVIII-H
	TPN11006NL	17	9.6	11.4	12.8	17	23	11.2	6.4	21		0.6	U-MOSVIII-H
	TPN11006PL	26	8.8	11.4	12.3	18.1	17	9	5.8	14.4	18	0.65	U-MOSIX-H
	TPN14006NH	13	11	14	-	-	15	-	5.5	34.2	20	2	U-MOSVIII-H
	TPN22006NH	9	18	22	-	-	12	-	4.5	12.5	18	1	U-MOSVIII-H

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(*) Company names, product names, and service names mentioned herein may be trademarks of respective companies.

Reference: Obtaining an evaluation board

You can purchase third-party evaluation boards made by MIKROE.

Clicking the blue text takes you to a web page with detailed information.
You can purchase evaluation boards from DigiKey and Mouser Electronics.

Brushed DC motors

MIKROEBOARD	TOSHIBA PART
DC Motor 6 Click	TB67H451AFNG
DC Motor 7 Click	TB67H400AFTG
DC Motor 13 Click	TB67H481FNG
DC Motor 14 Click	TB67H450AFNG
DC Motor 17 Click	TC78H660FTG
DC Motor 19 Click	TC78H653FTG
DC Motor 20 Click	TC78H651AFNG
DC Motor 23 Click	TB67H480FNG
DC Motor 28 Click (FNG/FTG)	TB67H453 (FNG/FTG)
DC Motor 31 Click	TB67H482FNG

BLDC motors

MIKROEBOARD	TOSHIBA PART
Brushless 7 Click	TC78B009FTG
Brushless 8 Click	TC78B042FTG
Brushless 9 Click	TC78B027FTG
Brushless 10 Click	TC78B016FTG
Brushless 14 Click	TB67B001FTG
Brushless 23 Click	TC78B011FTG
Brushless 31 Click	TB6605FTG
Inverter Shield 2	TB67Z833SFTG

Stepping motors

MIKROEBOARD	TOSHIBA PART
Stepper 4 Click	TB67S269FTG
Stepper 8 Click	TC78H670FTG
Stepper 9 Click	TB67S581FNG
Stepper 10 Click	TB67S128FTG
Stepper 12 Click	TB67S549FTG
Stepper 17 Click	TB67S539FTG
Stepper 20 Click	TB67S580FNG
Stepper 23 Click	TB67S569FTG
Stepper 24 Click	TB67S589FTG
Stepper 28 Click	TB67S559FTG
Stepper 29 Click	TB67S579FTG
Multi Stepper Click	For 9 MCDs (TB67S109A/TB67S102A/TB67S101A/TB67S269/TB67S261/TB67S209/TB62269/TB62262/TB62261)

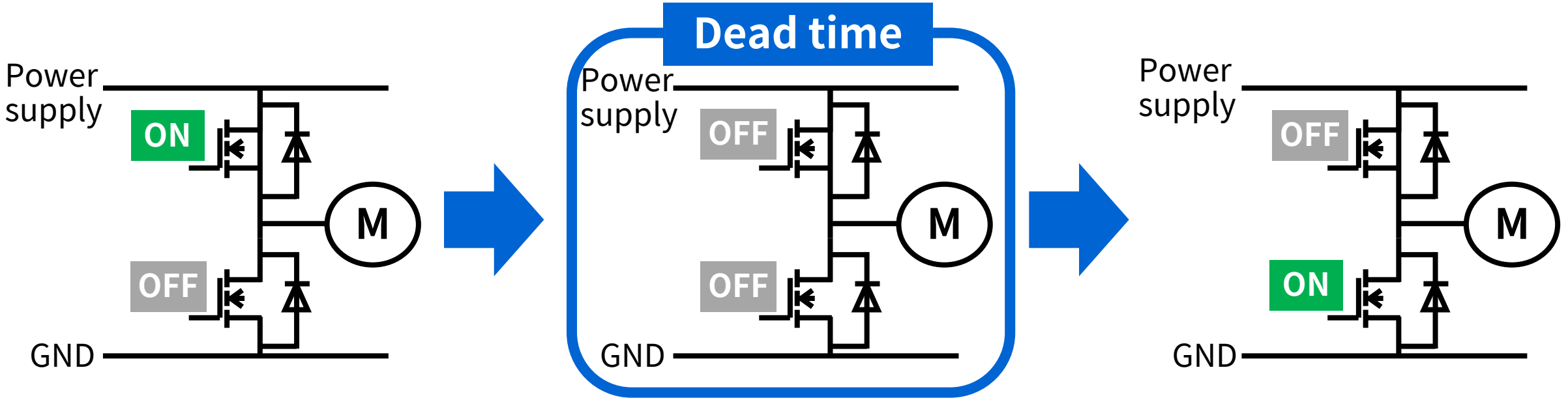
(*) The TC78B011FTG evaluation board shown above differs from the one available on the Reference Design Center page.

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2. Inverter circuit settings: Dead time

Setting the optimum dead time is crucial.

Dead time is a short blanking period where **both the high-side and low-side MOSFETs** in a half-bridge circuit **are turned off simultaneously**. This prevents shoot-through, a destructive condition where both MOSFETs conduct at the same time.



During dead time, current flows through the MOSFET body diodes, resulting in higher conduction losses than during normal MOSFET operation.
Therefore, **setting an excessively long dead time unnecessarily increases power loss.**

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2. Inverter circuit settings: Dead time

The TC78B011FTG features Auto Dead Time Control.

The TC78B011FTG controls external MOSFETs using an I²C-programmable dead time. Auto Dead Time Control prevents shoot-through current by monitoring the V_{GS} voltages of the external MOSFETs and delaying turn-on of either the high-side or low-side MOSFET until the other MOSFET has completely turned off.

Register setting 22[1:0] DEADTIME	Dead time
00	250ns (3clk)
01	500ns (6clk)
10	1000ns (12clk)
11	1500ns (18clk)

Register setting 18[0] ANTITHROUGH	Auto Dead time control
0	Enable
1	Disable

Recommended settings:
Enable Auto Dead Time Control and program the minimum necessary dead time via I²C. This allows the TC78B011FTG to automatically provide the minimum necessary dead time.

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2. Inverter circuit settings: Gate drive current

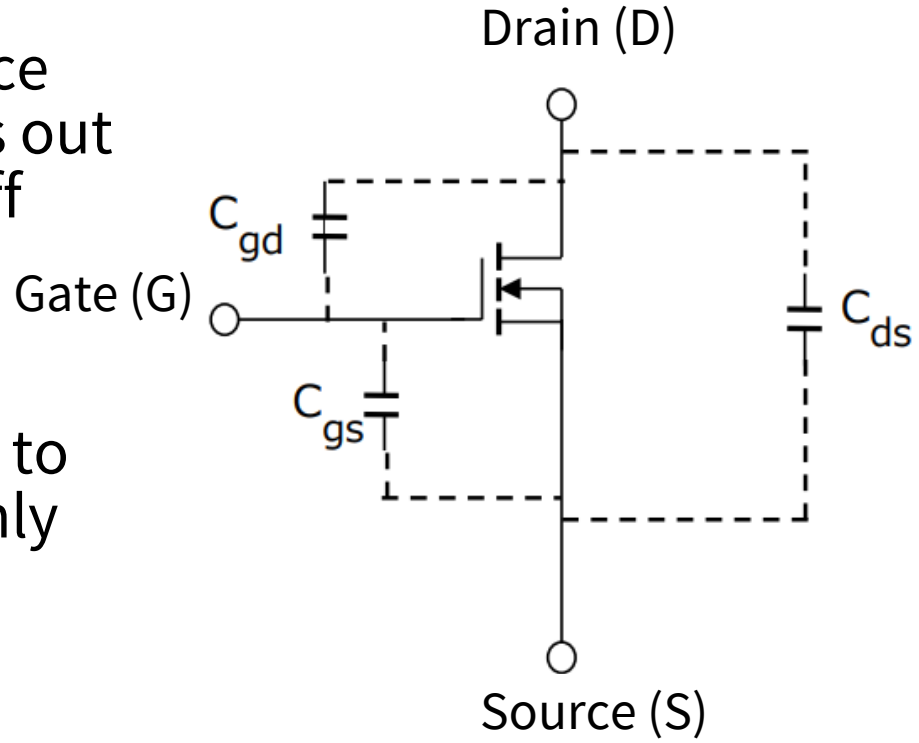
To switch a MOSFET properly, sufficient gate drive current is required.

Because a MOSFET's gate acts like a capacitor, its internal capacitance must be charged or discharged to change the gate voltage.

Gate current flows into the gate to charge the capacitance during turn-on (source current), while gate current flows out of the gate to discharge the stored charge during turn-off (sink current).

The switching time of a MOSFET is determined by the relationship between the total gate charge (Q_g) required to drive the gate and the gate current (I_g), and can be roughly expressed as $t \approx Q_g / I_g$.

A MOSFET with a larger total gate charge takes longer to switch, but the switching time can be reduced by increasing the gate drive current.



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2. Inverter circuit settings: Gate drive current

The TC78B011FTG allows the gate drive current to be programmed via I^2C.

Gate sourcing and sinking currents must be configured according to the total gate charge (Q_g) of the external MOSFETs. While this adjustment is conventionally made using external gate resistors, the TC78B011FTG enables direct adjustment through software.

Register setting 23[5:3] SOURCE	Source current setting for high side and low side FET (mA)
000	10.0
001	13.9
010	19.3
011	26.8
100	37.3
101	51.8
110	72.0
111	100.0

Register setting 23[2:0] SINK	Sink current setting for high side and low side FET (mA)
000	20.0
001	27.8
010	38.6
011	53.7
100	74.6
101	103.6
110	143.9
111	200.0

Increasing the gate drive current speeds up MOSFET switching and reduces switching losses, thereby lowering heat generation. However, it also increases electromagnetic interference (EMI).

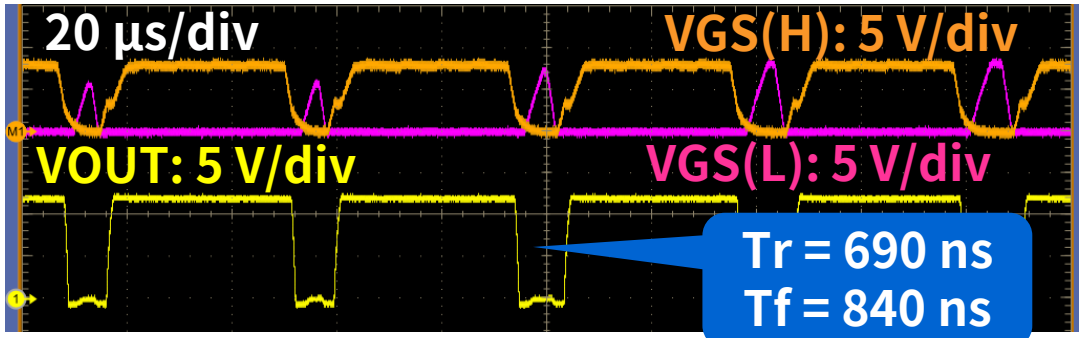
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2. Inverter circuit settings: Gate drive current

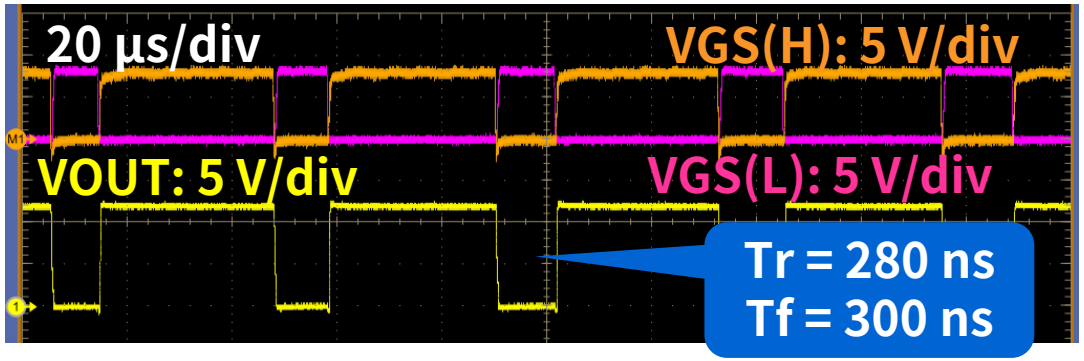
Let’s take a look at how changing the gate drive current affects the output waveforms.

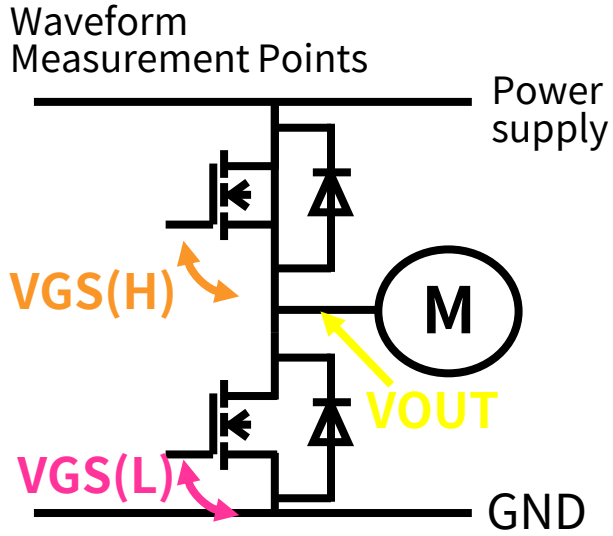
Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C

Condition 1:
Source current = 10 mA, sink current = 20 mA



Condition 2:
Source current 100 mA, sink current 200 mA





Increasing the gate drive current increases the MOSFET switching speed (i.e., reduces Tr and Tf of the VOUT waveform).

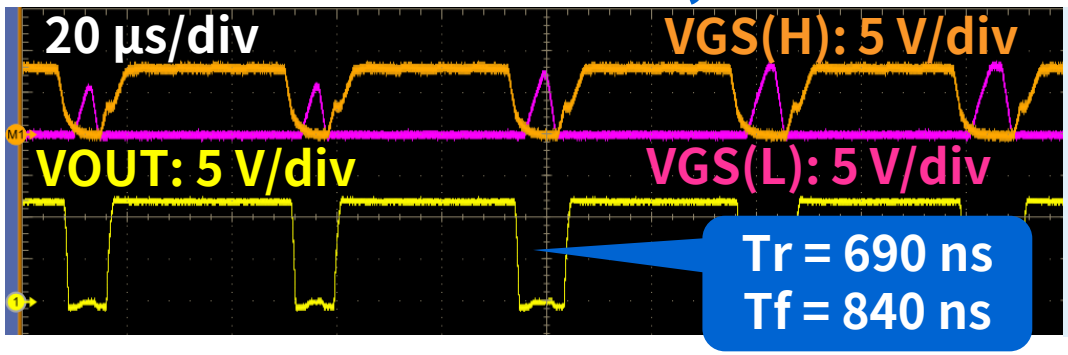
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2. Inverter circuit settings: Gate drive current

Let's take a look at how changing the gate drive current affects the output waveforms.

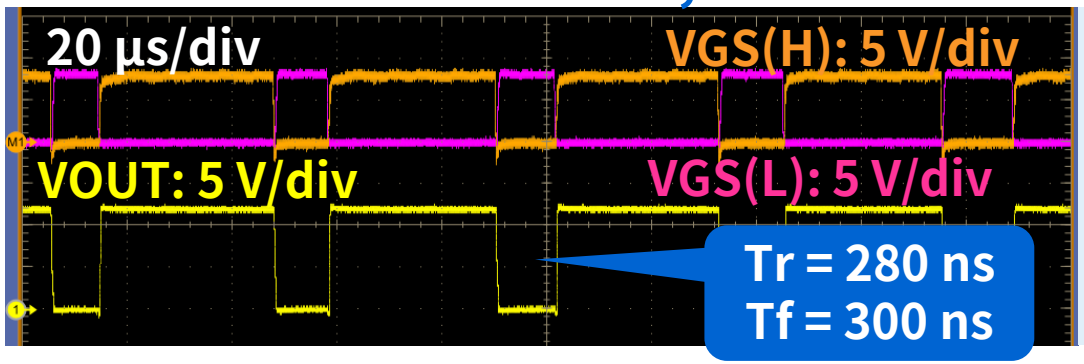
Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C

Condition 1:
Source current = 10 mA, sink current = 20 mA



Because the gate drive current is too low, the MOSFET switches to the next state before the gate voltage reaches its full bias level (V_{GS} ≈ 8 V). Therefore, the gate current needs to be increased.

Condition 2:
Source current 100 mA, sink current 200 mA



Excessively fast switching can cause gate voltage overshoot.
However, Condition 2 produces no overshoot and is therefore acceptable.

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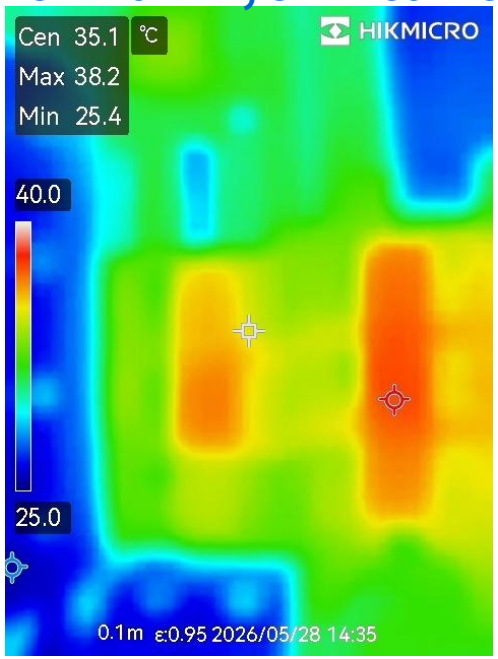
2. Inverter circuit settings: Gate drive current

Let's take a look at how changing the gate drive current affects the surface temperature of the external MOSFETs.

Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C

Condition 1:
Source current = 10 mA, sink current = 20 mA

Max. temperature ≈ 38°C



Temperature distribution in the MOSFET section of the evaluation board

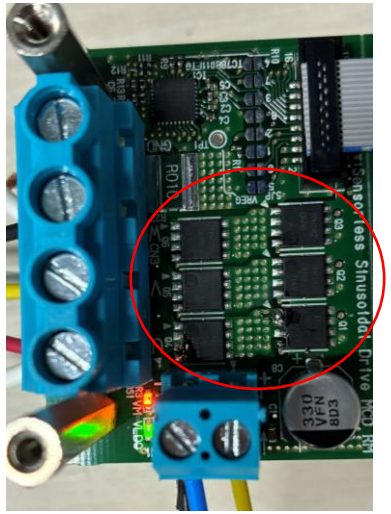
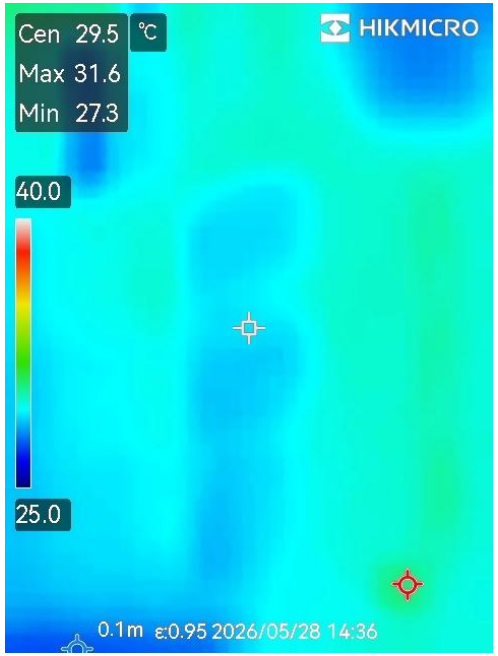


Photo of the MOSFET section of the evaluation board

Condition 2:
Source current 100 mA, sink current 200 mA

Max. temperature ≈ 32°C



Temperature distribution in the MOSFET section of the evaluation board

Increasing the sink and source gate currents reduces heat generation in the MOSFETs.

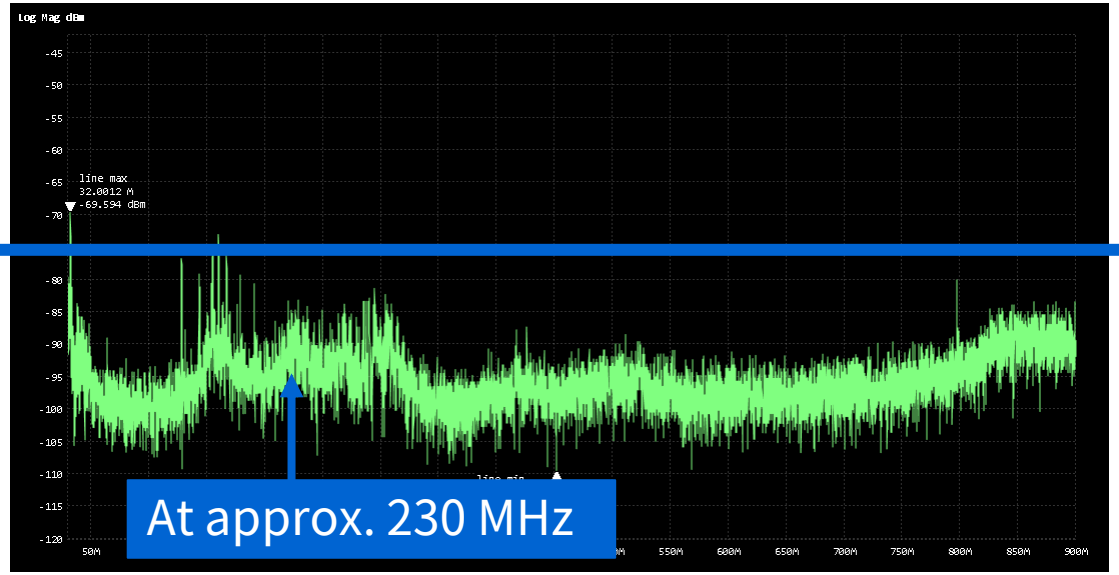
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2. Inverter circuit settings: Gate drive current

Let’s take a look at how changing the gate drive current affects the EMI noise levels.

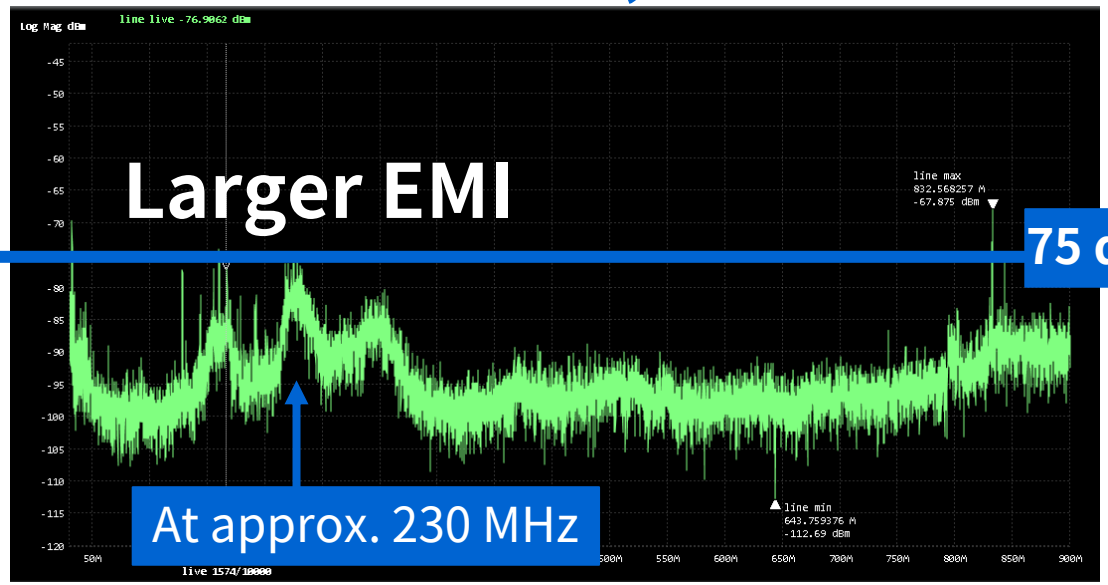
Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C

Condition 1:
Source current = 10 mA, sink current = 20 mA



EMI noise around the motor wiring measured using a spectrum analyzer and a near-field probe

Condition 2:
Source current 100 mA, sink current 200 mA



EMI noise around the motor wiring measured using a spectrum analyzer and a near-field probe

Increasing the sink and source gate currents tends to increase the EMI noise level.

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3. Speed control settings: Speed control signal

The TC78B011FTG provides three selectable motor speed control modes.

The desired mode is selected via register field 15[4:3] or the SEL pin:

● Direct I^2C programming

Motor speed is set directly via register fields 27[7:0] and 28[7:6].

● Analog voltage control

Motor speed is determined by the analog voltage applied to the SPD pin (1.5 V to 4.0 V typical).
Speed is controlled with 9-bit resolution, scaling linearly from 0% at 1.5 V typical to 100% at 4.0 V typical.

● PWM duty cycle control

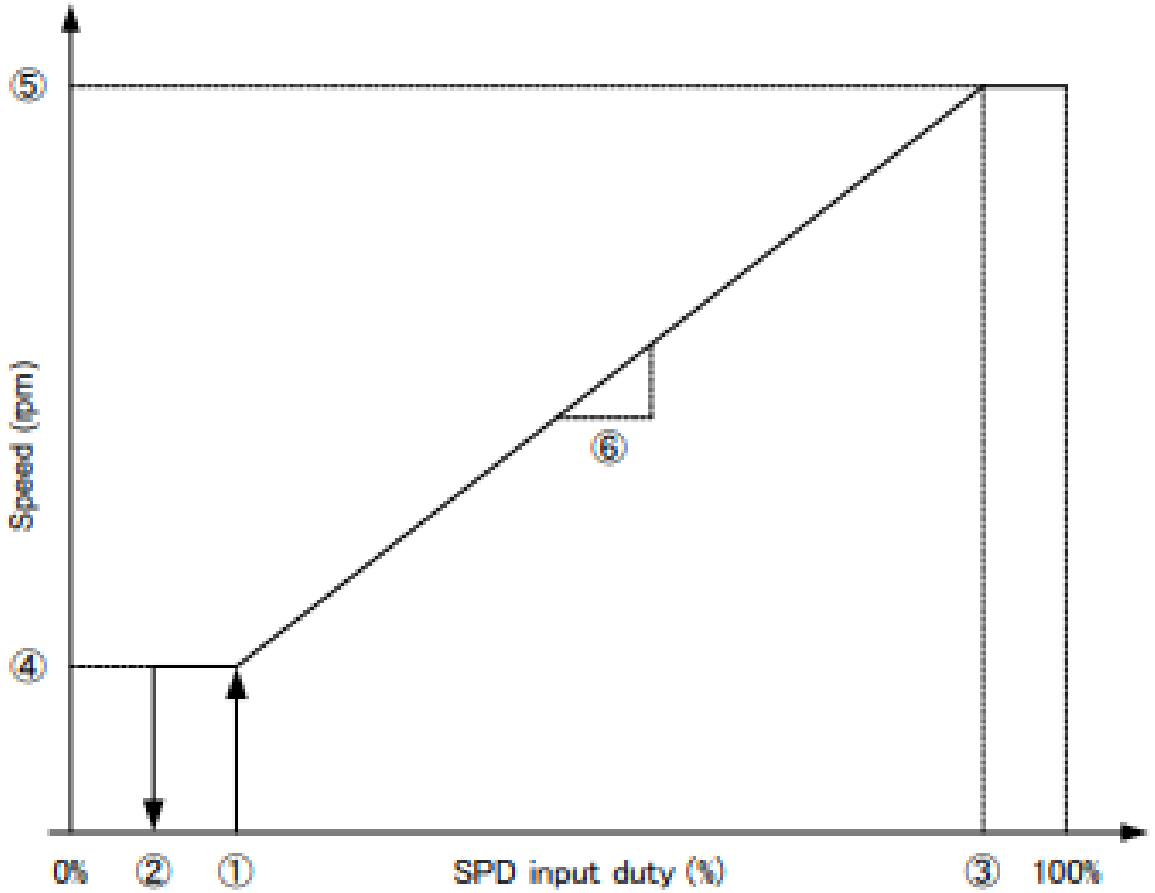
Motor speed is determined by the duty cycle of a PWM signal applied to the SPD pin.
For input frequencies between 1 kHz and 20 kHz, speed is controlled with 9-bit resolution, scaling linearly from 0% at 0% duty cycle to 100% at 100% duty cycle.

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3. Speed control settings: Speed curve

The TC78B011FTG allows you to fully program the closed-loop motor speed curve.

As shown below, the curve defines the relationship between the duty cycle of the signal applied to the SPD pin and the motor speed.



Six key parameters are programmable via registers:

1. Start duty cycle: Register field 3[7:0]
The SPD duty cycle threshold at which the motor begins rotating

2. Stop duty cycle: Register field 2[6:0]
The SPD duty cycle threshold at which the motor stops

3. Maximum duty cycle: Register field 5[7:0]
The SPD duty cycle threshold at which the motor reaches maximum speed

4. Startup speed: Register fields 6[7:0] and 7[7:4]
The target motor speed when the input reaches the start duty cycle.

5. Maximum rotation speed
The target motor speed when the input reaches the maximum duty cycle

6. Speed slope: Register fields 8[7:0] and 9[7:2]
The rate at which the target motor speed increases with the SPD duty cycle

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Start a BLDC motor in the following sequence:
DC excitation → forced commutation → sensorless control.

Starting a sensorless BLDC motor from a standstill

⇒ At a standstill, no back EMF is induced in the motor, making it **impossible to detect the initial rotor position**.

Therefore, a specific startup sequence is required to transition to sensorless control. This sequence is also used for the TC78B011FTG featured in this webinar.



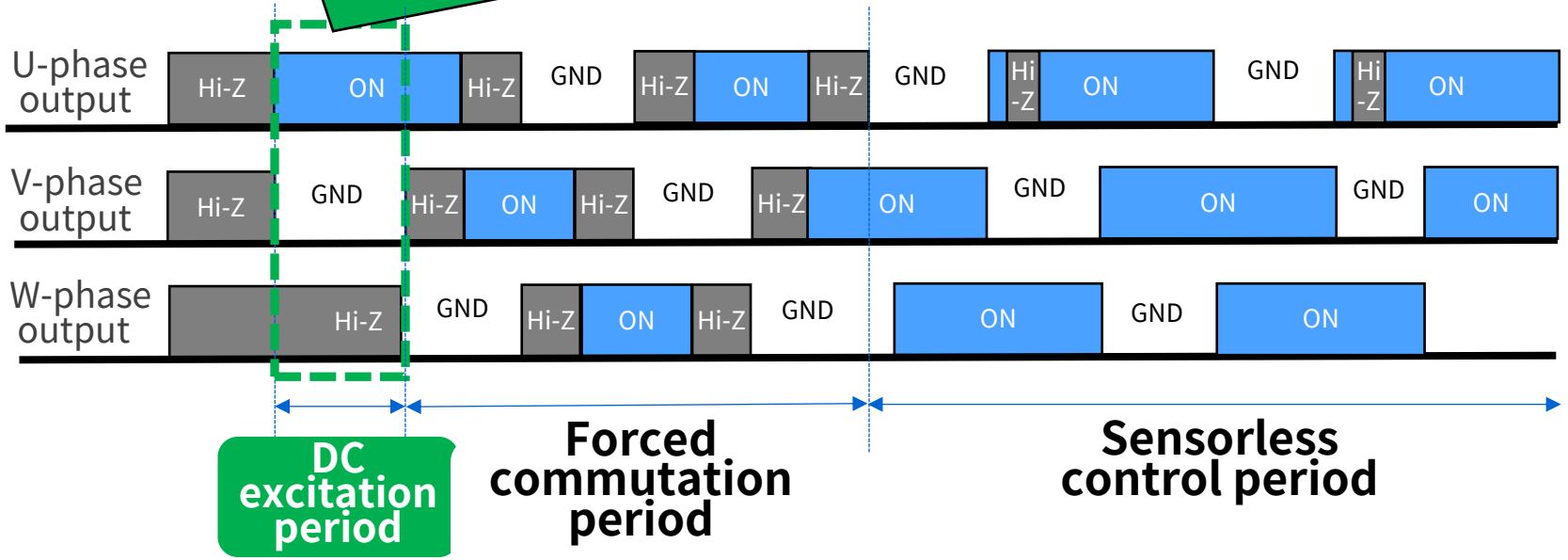
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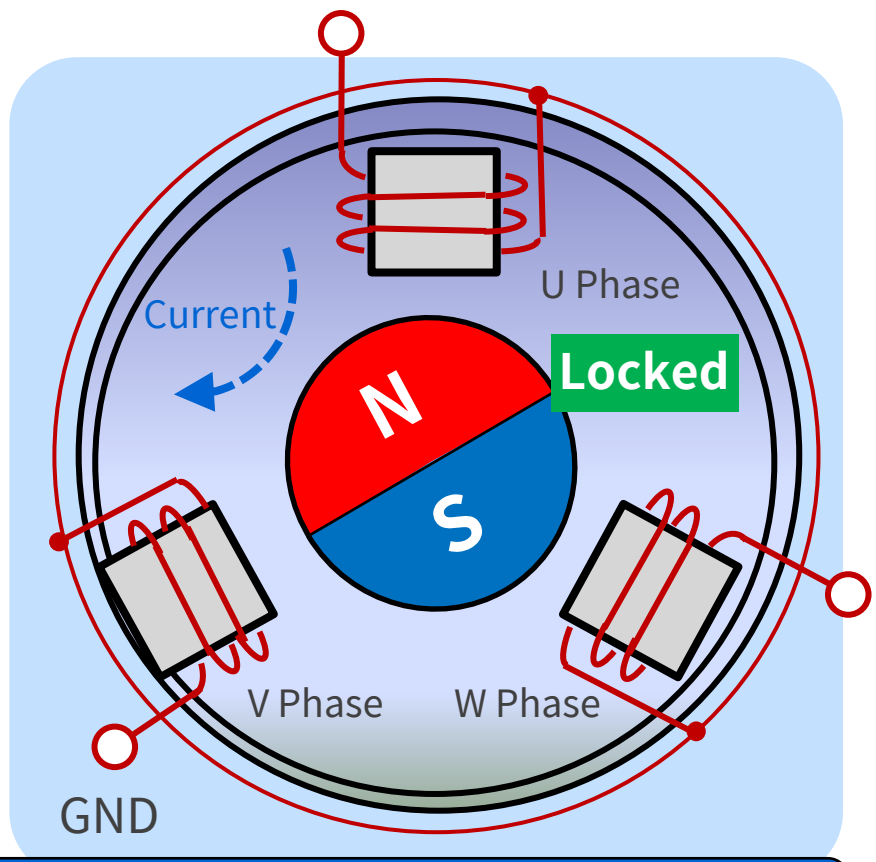
4. Startup control settings: DC excitation

In this step, current is applied from the U phase to the V phase to lock the rotor into a predetermined position.

Overview of the DC Excitation Sequence

Unknown rotor position ⇒ Lock the rotor at a known reference position. (For the TC78B011FTG, this is achieved by driving current from the U phase to the V phase.)





You need to configure the output PWM duty cycle and DC excitation duration in the motor driver IC to ensure that the rotor locks into a known position, regardless of its initial position.

Additionally, the TC78B011FTG allows you to set an output current limit during startup, ensuring reliable operation even when the supply voltage fluctuates.

(*) The above timing chart is simplified for illustrative purposes.

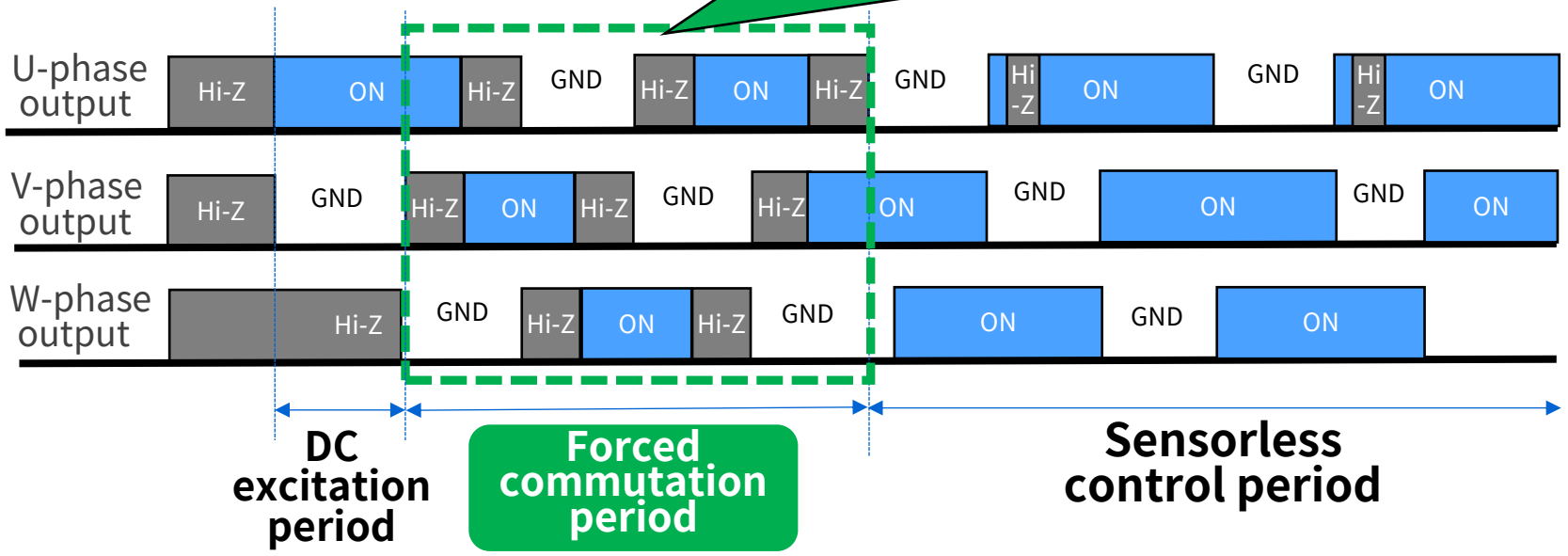
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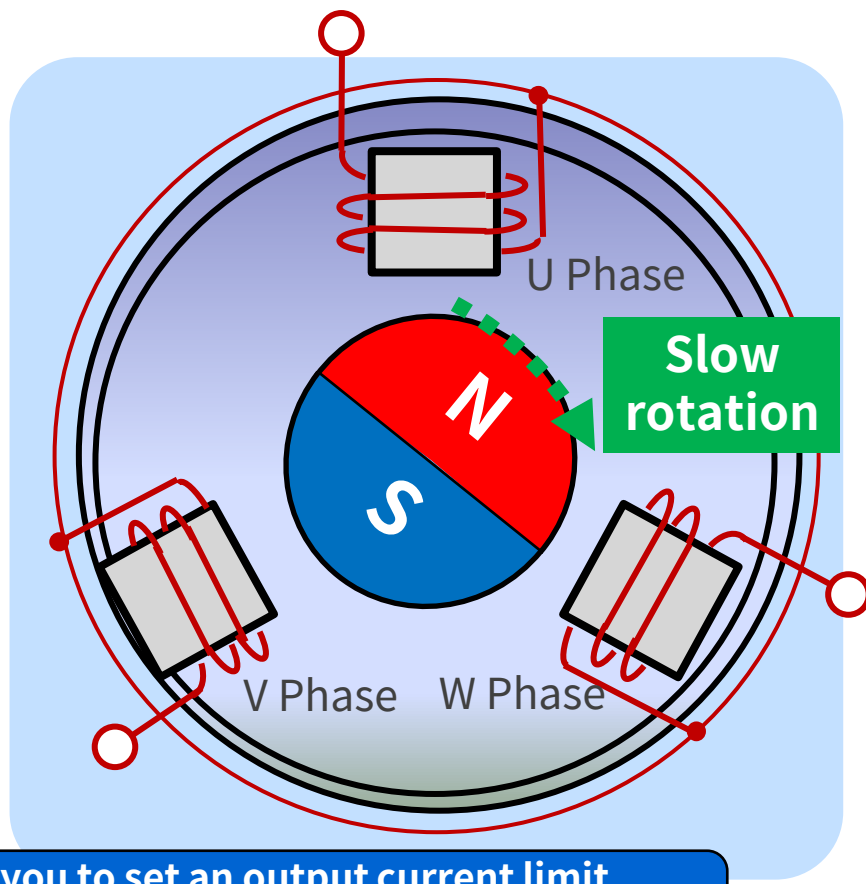
4. Startup control settings: Forced commutation

In this step, the rotor is forced to rotate until it reaches a speed at which back EMF can be detected.

Overview of the Forced Commutation Sequence

The motor is forced to rotate in open-loop mode using 120-degree commutation until sufficient back EMF is generated for detection.





You need to configure the output PWM duty cycle and commutation frequency in the motor driver IC to ensure that the rotor follows the rotating magnetic field.

Additionally, the TC78B011FTG allows you to set an output current limit during startup, ensuring reliable operation even when the supply voltage fluctuates.

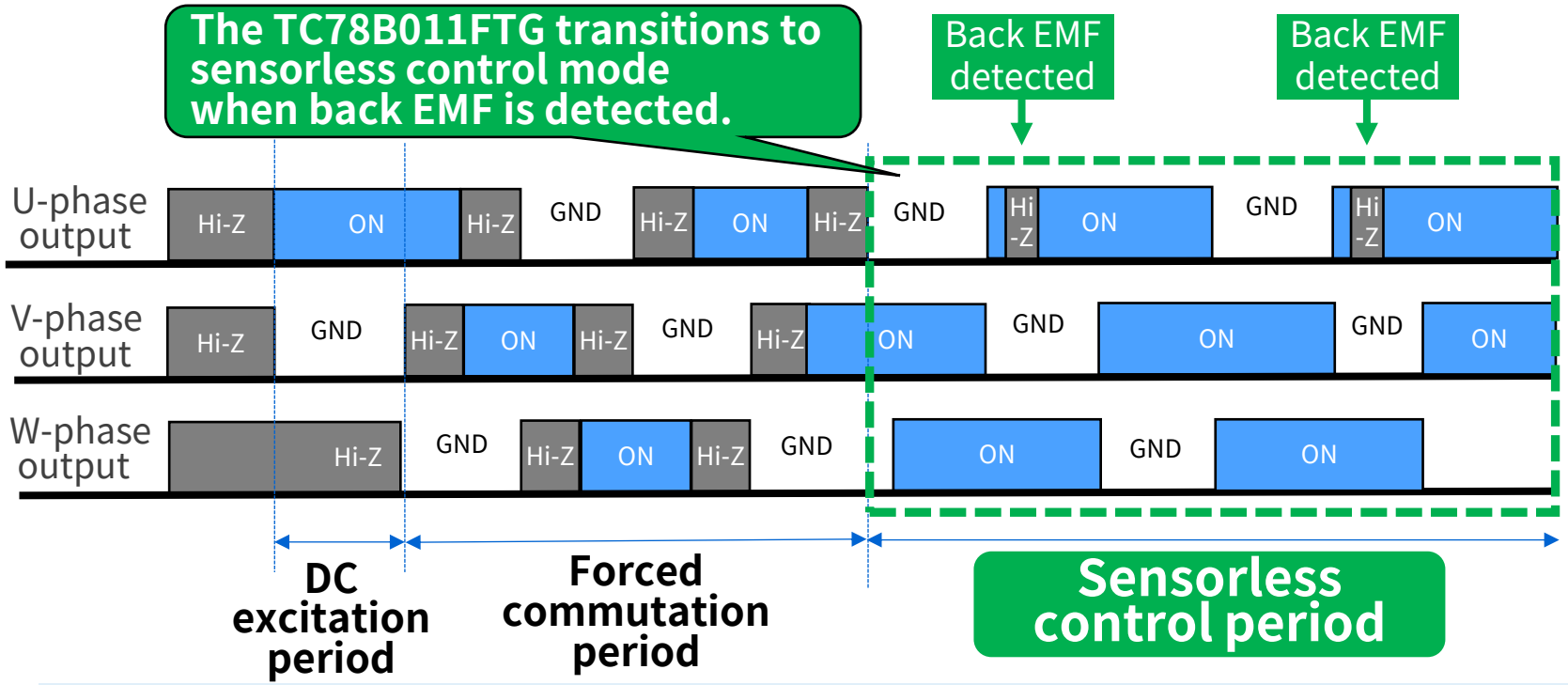
(*) The above timing chart is simplified for illustrative purposes.

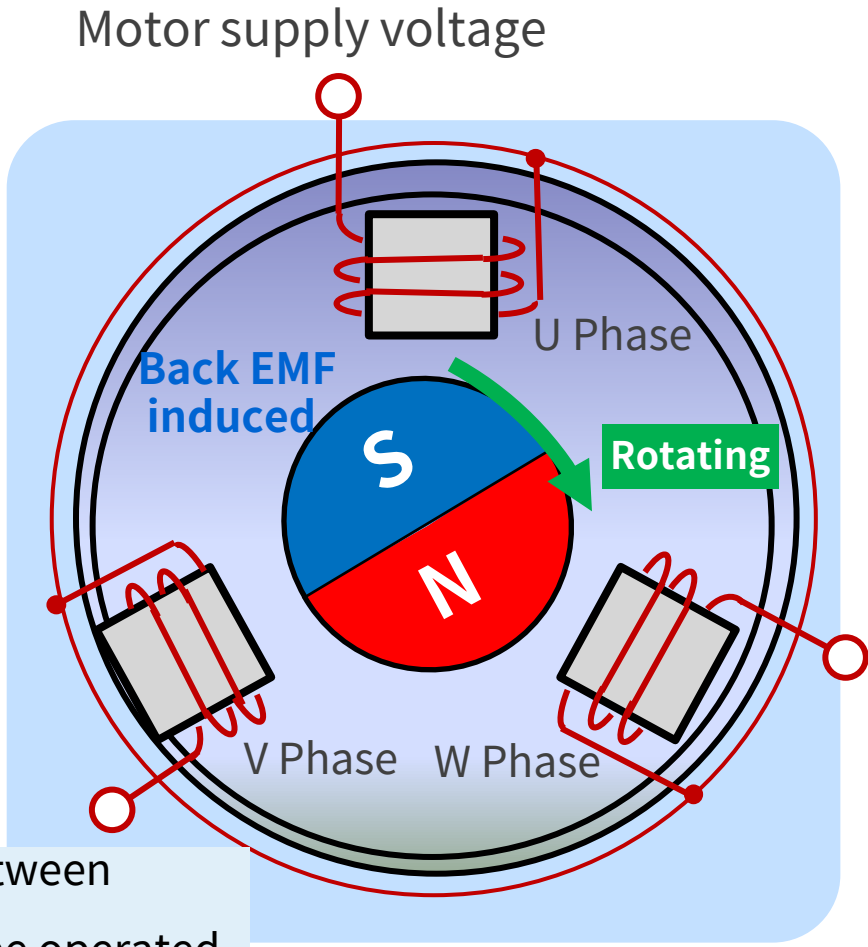
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4. Startup control settings: Sensorless control

The TC78B011FTG transitions to sensorless control mode when the motor speed reaches a level at which back EMF can be detected.

Overview of the Sensorless Control Sequence





Back EMF is sampled while the U-phase output is in the Hi-Z state, specifically between electrical angles of 3° and 30°.
Since back-EMF sampling occurs at the PWM frequency, the TC78B011FTG must be operated at a PWM frequency that is at least 100 times higher than the rotational frequency to ensure accurate rotor position detection.

(*) The above timing chart is simplified for illustrative purposes.

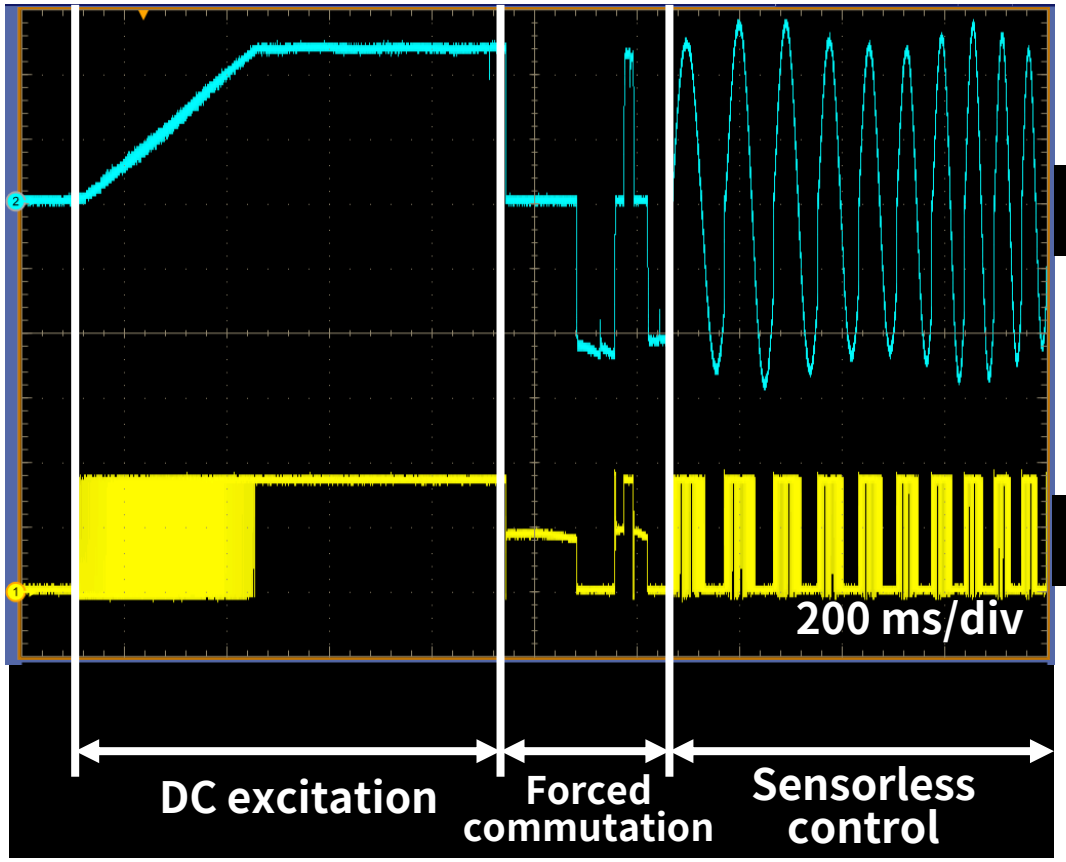
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4. Startup control settings: Startup waveform example

Start a motor in the sequence shown below.

Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C

Reference



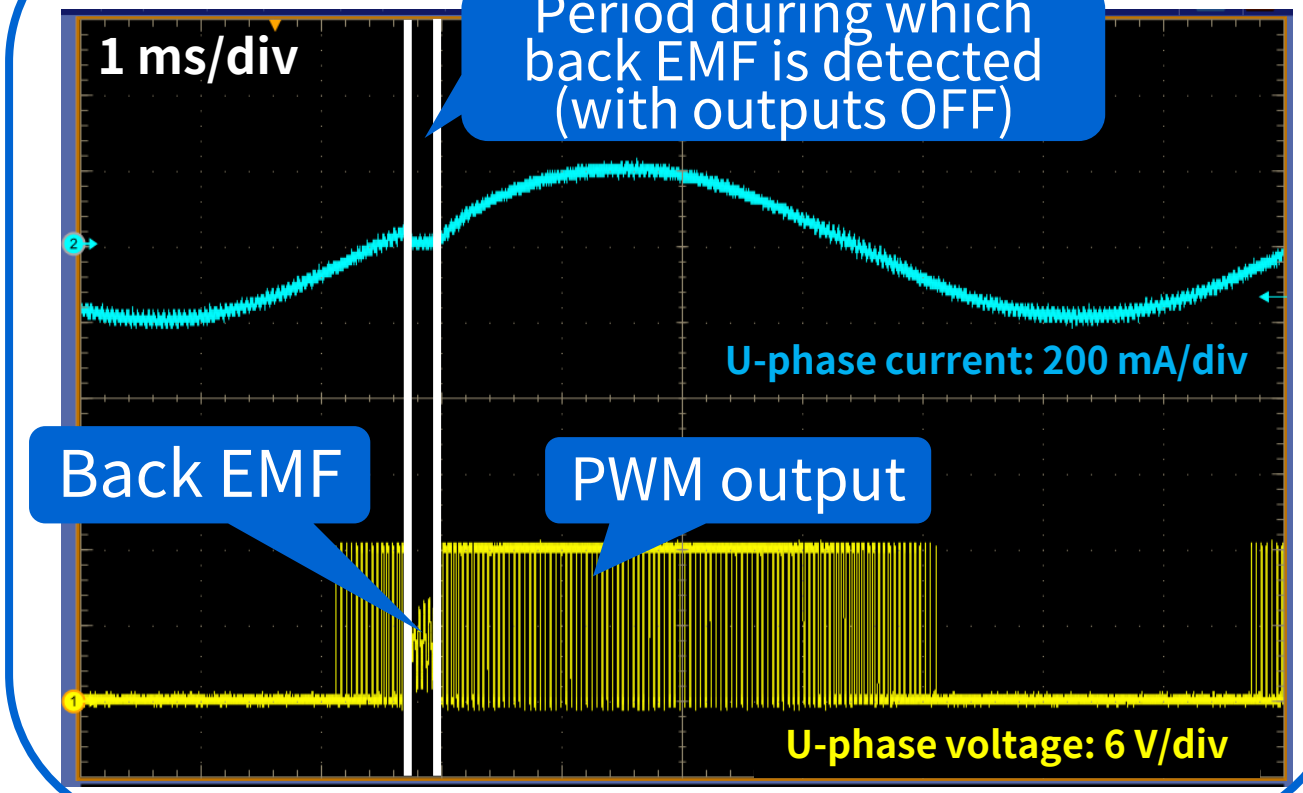
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4. Startup control settings: Startup waveform example

Shown below is an example of the motor current and voltage waveforms during sensorless control.

Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C, rotational speed: 2,000 rpm

Reference



The TC78B011FTG uses PWM to control the output voltage and generate a sinusoidal motor current waveform.

Because the back EMF generated during rotation cannot be measured while the drive voltage is applied, the TC78B011FTG provides an output-OFF period to detect back EMF.

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4. Startup control settings: Troubleshooting startup failures

First, check which fault detection function has been triggered.

When the motor fails to start

↓

Check the fault detection results stored in register field 0[5:0].

↓

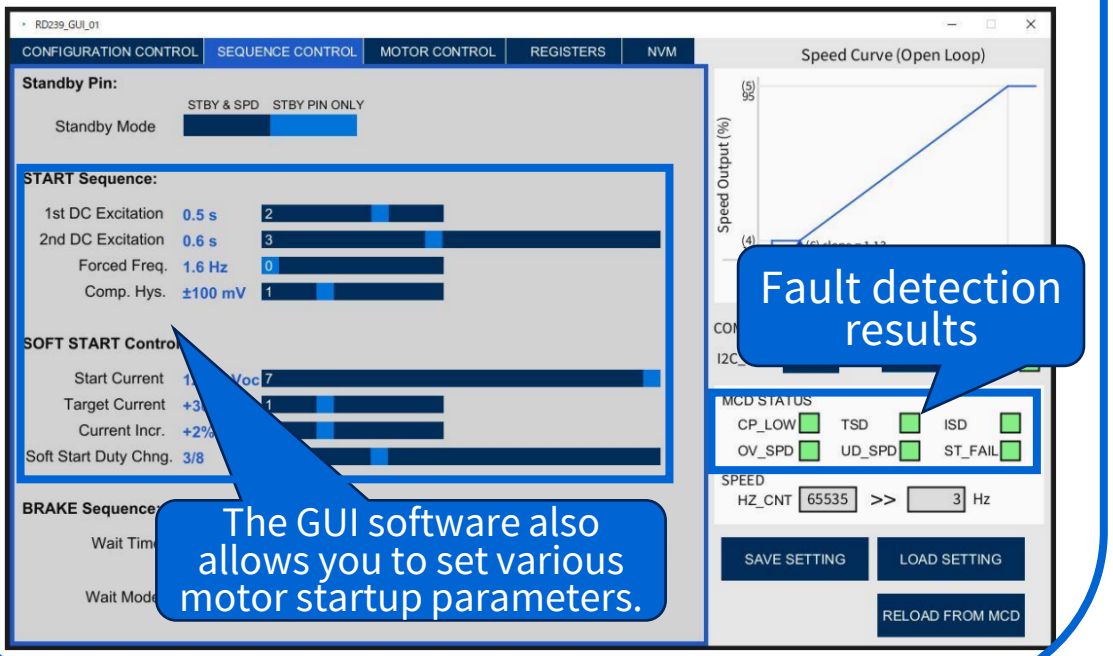
Typically, one of the following fault detection features is triggered:

- Output overcurrent detection (ISD)
- Startup failure detection (ST_FAIL)

Reference

The GUI software, downloadable from the Reference Design Center page, displays the fault detection status.

GUI software for the TC78B011FTG



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4. Startup control settings: Troubleshooting startup failures

Adjust the startup parameters as necessary.

When the GUI software flags an output overcurrent detection (ISD)

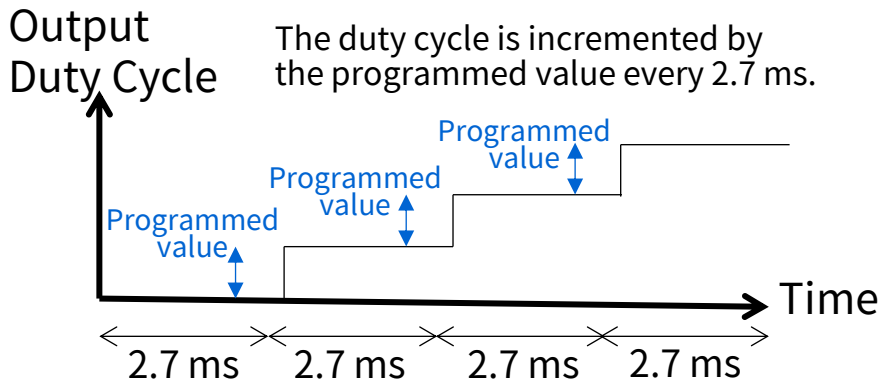
The overcurrent detection may have been triggered by inrush current during motor startup.

Use **the soft-start feature** to **reduce** the duty cycle increment and suppress the starting current.

Soft-start feature

The soft-start feature suppresses inrush current by gradually increasing the output PWM duty cycle.
The duty cycle increment can be configured as follows.

Soft start duty change limit Register setting 17[3:1] SS_DUTYCHGLIMIT	Duty change for every 2.7ms (Δ/512)	Speed control time (s) 0% to 100%
000	64/8	0.17
001	2/8	5.53
010	3/8	3.69
011	4/8	2.76
100	6/8	1.84
101	10/8	1.11
110	20/8	0.55
111	56/8	0.20



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4. Startup control settings: Troubleshooting startup failures

Adjust the startup parameters as necessary.

When the GUI software flags a startup failure (ST_FAIL)

If the starting current is reduced excessively, the motor may not generate sufficient torque to start rotating.

In this case, **increase** the current limit setting using **the output startup current limit feature**.

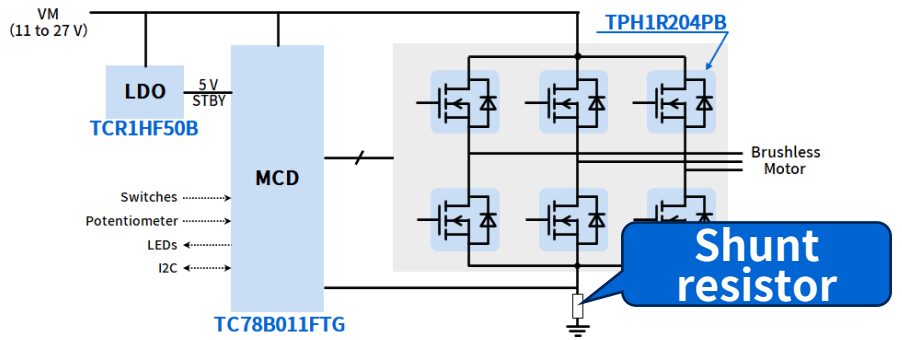
If the motor still fails to start, proceed to the next page.

Output startup current limit

This feature limits the output current during motor startup.
Use the following equation to calculate the programmed value:
Output current limit (A) = V_{OC} / shunt resistor value
The V_{OC} value can be configured as follows.

Register setting 16[3:1] STARTCURRENT	Startup current VOC Voltage (V)
000	VOC
001	VOC×87.5%
010	VOC×75.0%
011	VOC×62.5%
100	VOC×50.0%
101	VOC×37.5%
110	VOC×25.0%
111	VOC×12.5%

(*) V_{OC} is selectable from 0.25 V and 0.125 V.



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4. Startup control settings: Troubleshooting startup failures

Adjust the startup parameters as necessary.

When the GUI software flags a startup failure (ST_FAIL)

If the starting current is reduced excessively, the motor may not generate sufficient torque to start rotating.

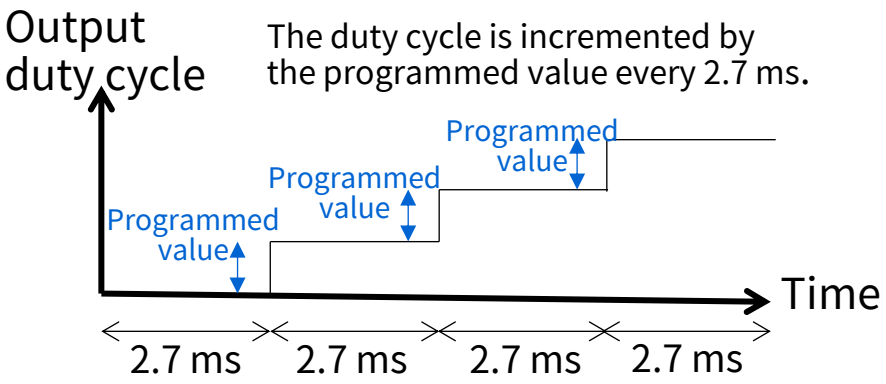
In this case, you need to **increase** the duty cycle increment using **the soft-start feature**.

If the motor still fails to start, proceed to the next page.

Soft-start feature

The soft-start feature suppresses inrush current by gradually increasing the output PWM duty cycle. The duty cycle increment can be configured as follows.

Soft start duty change limit Register setting 17[3:1] SS_DUTYCHGLIMIT	Duty change for every 2.7ms (Δ/512)	Speed control time (s) 0% to 100%
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110	20/8	0.55
111	56/8	0.20



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4. Startup control settings: Troubleshooting startup failures

Adjust the startup parameters as necessary.

When the GUI software flags a startup failure (ST_FAIL)

The initial rotor positioning may be insufficient.

In this case, **increase the DC excitation period** to ensure reliable motor startup regardless of the initial rotor position.

If the motor still fails to start, proceed to the next page.

The DC excitation period can be configured as follows.

Two DC excitation periods are available. Normally, only the second DC excitation period is used. However, if a dead zone or a specific physical alignment prevents proper rotor positioning during the second period, the first DC excitation period is used to move the rotor away from that position, ensuring reliable positioning during the second period.

First DC excitation

Register setting 20[4:3] PreTIP	Period of 1st DC excitation (s)
00	0
01	0.2
10	0.5
11	1.0

Second DC excitation

Register setting 20[2:0] TIP	Period of 2nd DC excitation (s)
000	0.1
001	0.2
010	0.4
011	0.6
100	0.8
101	1
110	1.5
111	2

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4. Startup control settings: Troubleshooting startup failures

Adjust the startup parameters as necessary.

When the GUI software flags a startup failure (ST_FAIL)

If the rotor loses synchronization during forced commutation, **decrease the forced commutation frequency.**

Conversely, if the rotor maintains synchronization but fails to transition to sensorless control, **increase the forced commutation frequency** to ensure stable back-EMF detection.

The forced commutation frequency can be configured as follows.

Register setting 21[1:0] FST	Electrical angle frequency	Idling detection time (electrical angle frequency)
00	1.6Hz	200ms (5Hz)
01	3.2Hz	100ms (10Hz)
10	6.4Hz	50ms (20Hz)
11	12.8Hz	25ms (40Hz)

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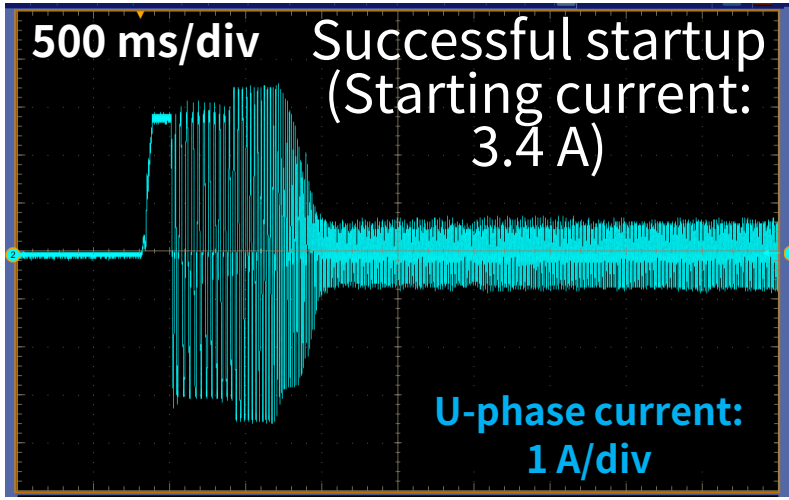
4. Startup control settings: Troubleshooting startup failures

Shown below are the starting current waveforms obtained with different soft-start settings.

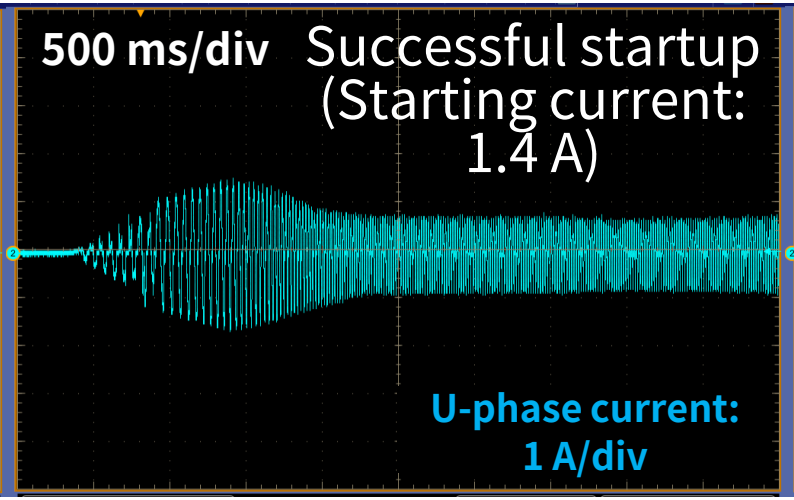
Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C

Reference

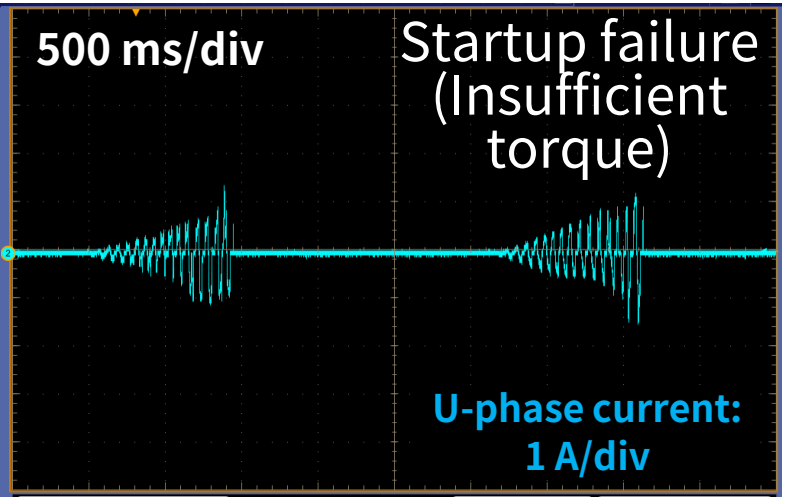
Duty cycle increment during soft start: **64/8**



Duty cycle increment during soft start: **20/8**



Duty cycle increment during soft start: **2/8**

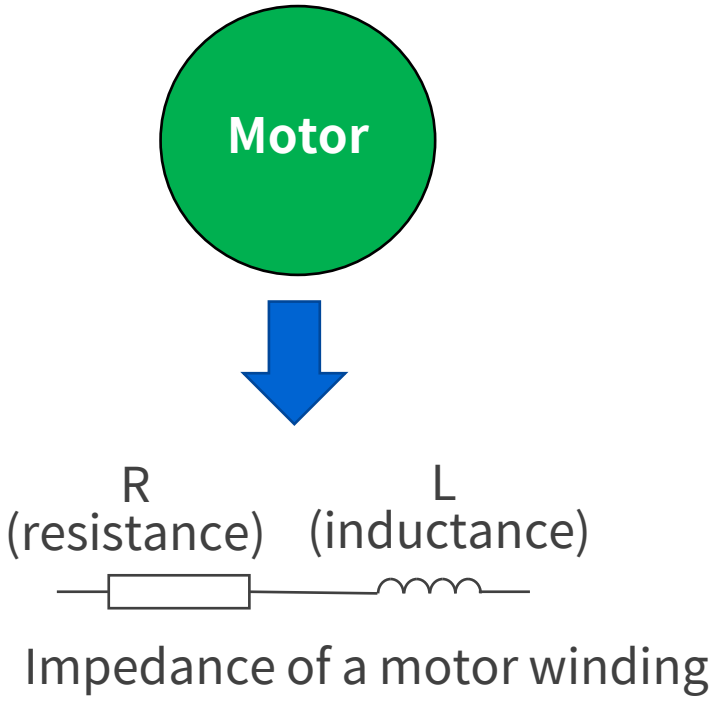


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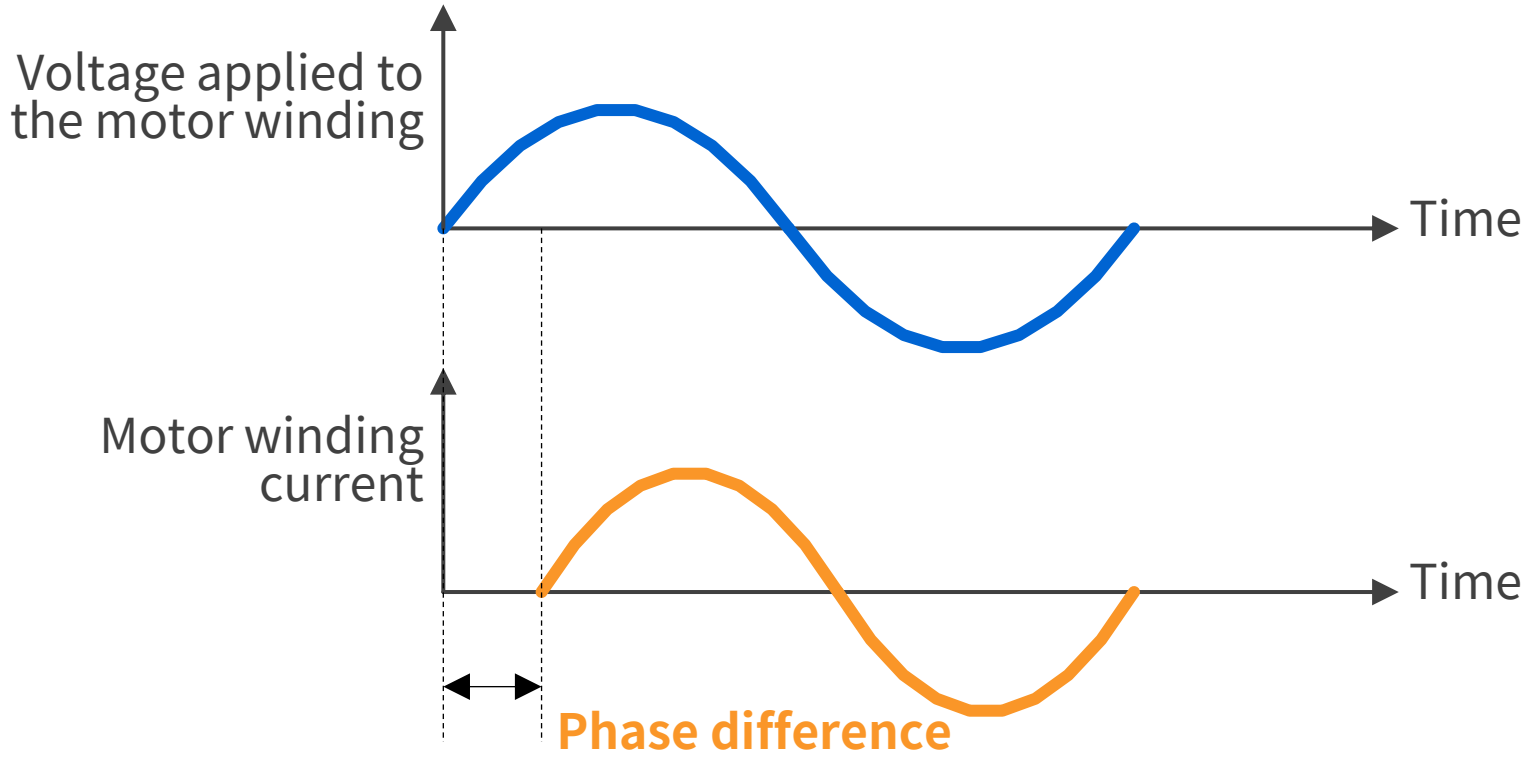
In a coil, current lags voltage because of its inductance.

Characteristics of a motor winding

Due to winding **inductance**, **current does not flow immediately** upon application of voltage. As **the motor rotation speed increases**, **the phase difference** between the **voltage** and **current grows**.



Impedance of a motor winding



(*) The above timing chart is simplified for illustrative purposes.

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5. Lead angle control settings

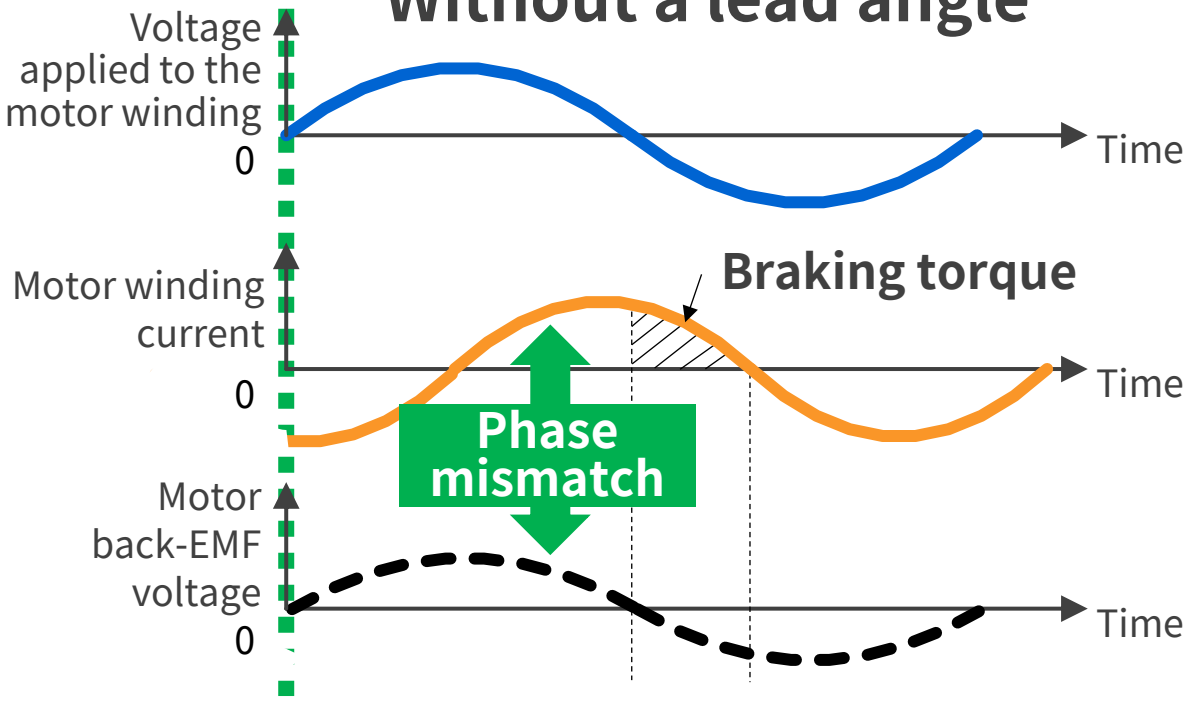
Motor efficiency can be improved by aligning the phase of the back EMF in the winding with that of the winding current.

How to run a motor efficiently

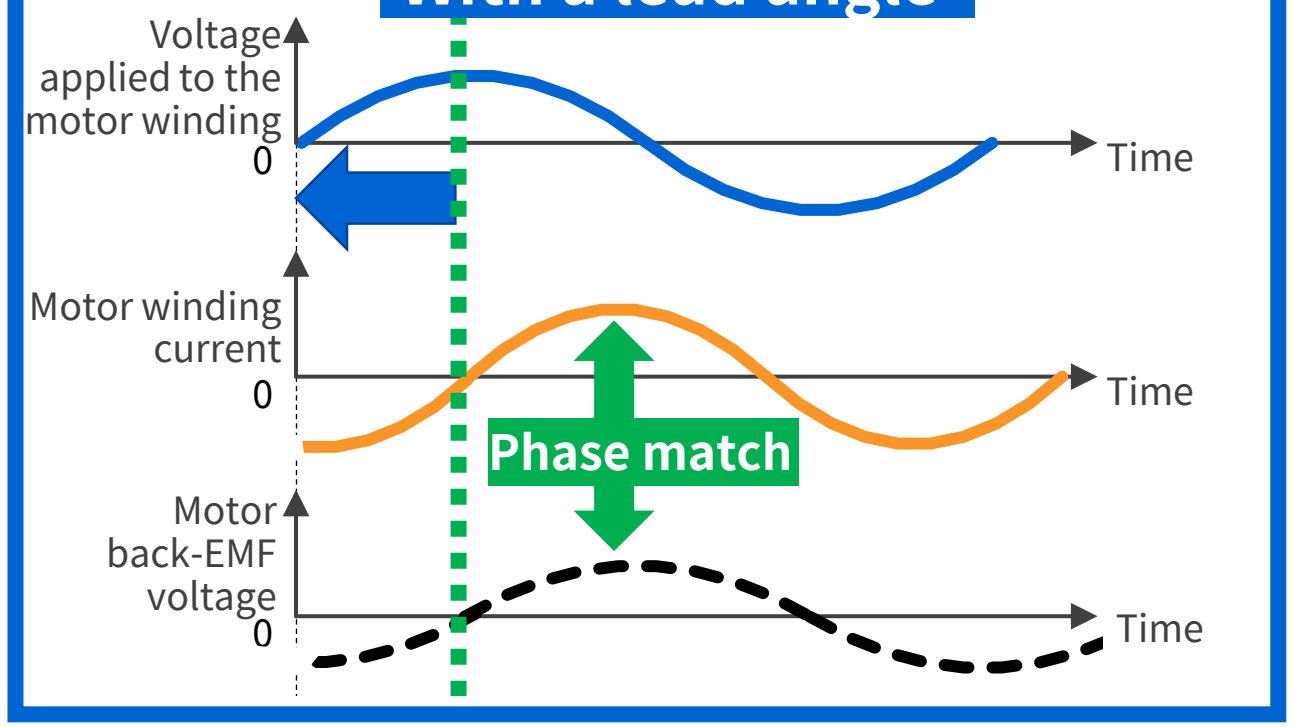
It is effective to align **the phase of the back EMF** in the coil with **that of the winding current**.

Lead angle control advances the phase of the voltage applied to the motor windings.

Without a lead angle



With a lead angle



(*) The above timing chart is simplified for illustrative purposes.

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5. Lead angle control settings

Determine the lead angle that yields the highest efficiency at the target motor speed, and program that value.

Evaluation board shown on the Reference Design Center web page, V_M = 12 V, PWM frequency = 23.4 kHz (typ.), T_a = 25°C, rotational speed: 1,000 rpm

The lead angle can be configured as follows.

Register setting 21[7:4] LA	Register setting 21[1:0] FST		Rotation speed (electrical angle)					
	00	Speed up	0Hz < f ≤ 100Hz	100Hz < f ≤ 200Hz	200Hz < f ≤ 300Hz	300Hz < f ≤ 400Hz	400Hz < f ≤ 500Hz	500Hz < f
		Speed down	0Hz < f ≤50Hz	50Hz < f ≤ 150Hz	150 Hz < f ≤ 250Hz	250 Hz < f ≤ 350Hz	350 Hz < f ≤ 450Hz	450Hz < f
	01 10 11	Speed up	0Hz < f ≤200Hz	200Hz < f ≤ 400Hz	400 Hz < f ≤ 600Hz	600 Hz < f ≤ 800Hz	800 Hz < f ≤ 1kHz	1kHz < f
		Speed down	0Hz < f ≤100Hz	100Hz < f ≤ 300Hz	300 Hz < f ≤ 500Hz	500 Hz < f ≤ 700Hz	700 Hz < f ≤ 900Hz	900Hz < f
0000	0		0°					
0001	1		3.75°					
0010	2		7.5°					
0011	3		11.25°					
0100	4		15°					
0101	5		18.75°					
0110	6		22.5°					
0111	7		26.25°					
1000	8		30°					
1001	9		7.5°	15°	15°	15°	18.75°	22.5°
1010	10		7.5°	7.5°	15°	15°	18.75°	22.5°
1011	11		0°	3.75°	7.5°	11.25°	15°	18.75°
1100	12		3.75°	7.5°	11.25°	15°	18.75°	22.5°
1101	13		7.5°	11.25°	15°	18.75°	22.5°	26.25°
1110	14		11.25°	15°	18.75°	22.5°	26.25°	30°
1111	15		3.75°	11.25°	18.75°	26.25°	30°	30°

Reference

Motor current measured with different lead angle settings

Lead Angle Setting	Motor Current
0°	240 mA
3.75°	236 mA
7.5°	234 mA
11.25°	231 mA
15°	237 mA
18.75°	240 mA
22.5°	246 mA
26.25°	252 mA

Under the evaluation conditions, a lead-angle setting of 11.25° resulted in the lowest motor current and optimal efficiency.

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Three-phase BLDC motor drivers

In addition to the product presented today, Toshiba offers a broad portfolio of BLDC motor drivers designed to meet diverse application requirements. We invite you to consider Toshiba motor drivers for your next design.

Controller type

TC78B043
Low acoustic noise

Operating supply voltage: 6 to 23 V | Hall sensors | High-precision sine wave | Sine-wave drive

TC78B042/B041
High efficiency

Operating supply voltage: 6 to 16.5 V | Hall sensors | Sine wave | Auto lead angle control InPAC

Predriver type

TC78B011
Product covered in this webinar

Operating supply voltage: 5.5 to 27 V | Sensor-less | Sine wave | Closed loop

TC78B009

Operating supply voltage: 5.5 to 27 V | Sensor-less | Square wave | Closed loop

TB6605

Operating supply voltage: 9 to 28 V | Hall sensors | Sine wave

Driver type

TB67B001
3 A

Operating supply voltage: 4 to 22 V | Sensor-less | Square wave

TC78B016
3 A

Operating supply voltage: 6 to 30 V | Hall sensors | Sine wave | Auto lead angle control InPAC

TC78B025
4 A

Operating supply voltage: 4.5 to 16 V | Hall sensors | Sine wave | Closed loop

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Support information:
Technical inquiries about Toshiba's motor driver ICs

Submit technical inquiries through our website.

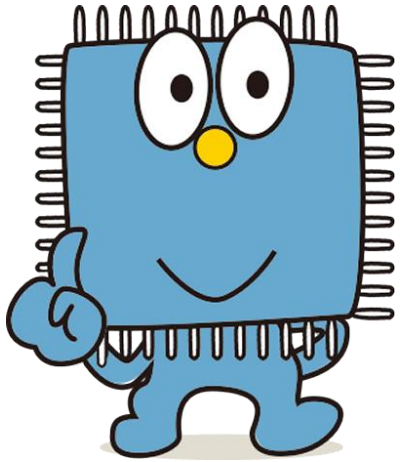
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