# Achieving smooth and fast startup of a sensorless BLDC motor using a microcontroller for sensorless initial position detection

Brushless DC motors featuring low noise and high durability are extensively used in many fields, including industrial applications, automobiles, and household appliances. This paper describes a method for initial rotor position detection that is realized by using a microcontroller for motor control and is highly useful for the control of such motors. This method solves various problems that tend to occur with sensorless motors, making it possible to realize a highly efficient system with smooth and fast high-torque startup.

When using a brushless DC motor, the designer has the option of choosing between several control principles. If the cost is to remain low, sensors to detect the rotor position will normally be omitted (sensorless principle), and another method will be adopted instead, such as estimating the position from the back electromotive force of the motor. However, this does not provide information about rotor position when the motor is stopped. Controlling the motor at startup, according to the rotor position, is therefore not possible and can lead to reduced efficiency, for example, due to unnecessary reverse rotation at startup. Such problems can be solved by incorporating an initial position detection function (Figure 1).

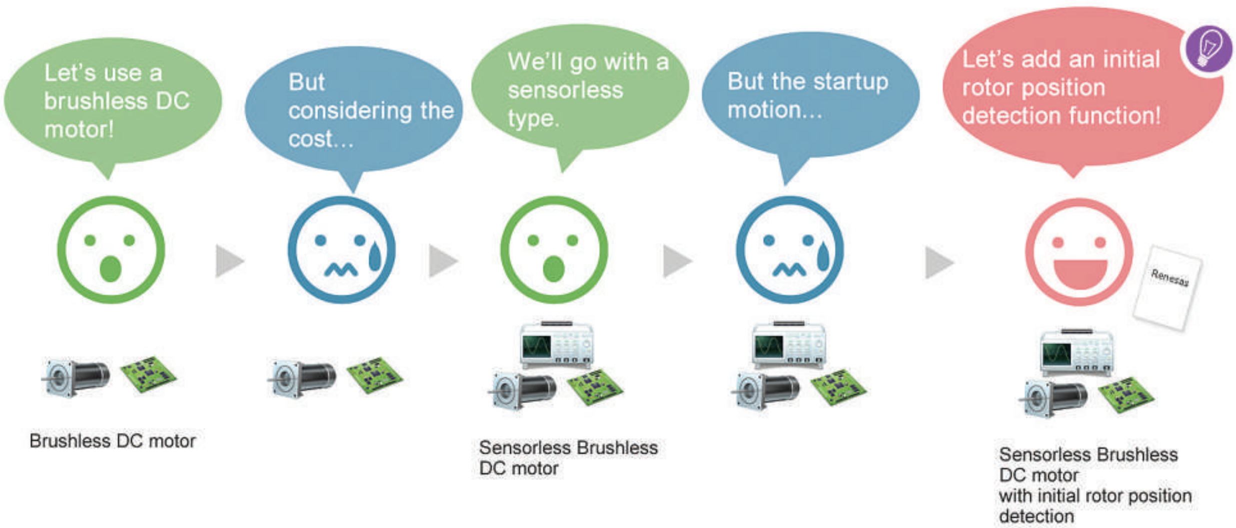



Figure 1: Considering sensorless brushless DC motors

In this paper, initial rotor position detection, which is effective for controlling a sensorless brushless DC motor, is explained. This initial position detection can be realized by using a microcontroller that controls the motor. By applying the method described here, it is possible to achieve sensorless and smooth, fast and high torque startup. This technology is effective for the development of electric tools, machine tools, conveying equipments, robots, pumps, blowers, and more.

## Solving startup problems that tend to occur with sensorless motors

Figure 2 illustrates the positioning of the initial rotor position detection in brushless DC motor control technology. Control of three-phase brushless DC motors can be implemented, for example, with the 120-degree conduction method (trapezoidal control) or the vector method (sinusoidal control). The 120-degree conduction method switches the three-phase energization pattern every 60 degrees, generating torque between the coil's magnetic flux and the permanent magnet of the rotor. This method is quite simple to implement and is, therefore, widely used. The vector method, on the other hand, divides the current value of the motor into a torque component and a magnetic field component, which are finely controlled. This enables high efficiency over a broad range of low to high speeds, but it requires complex arithmetic processing that increases the load to be handled by the CPU.

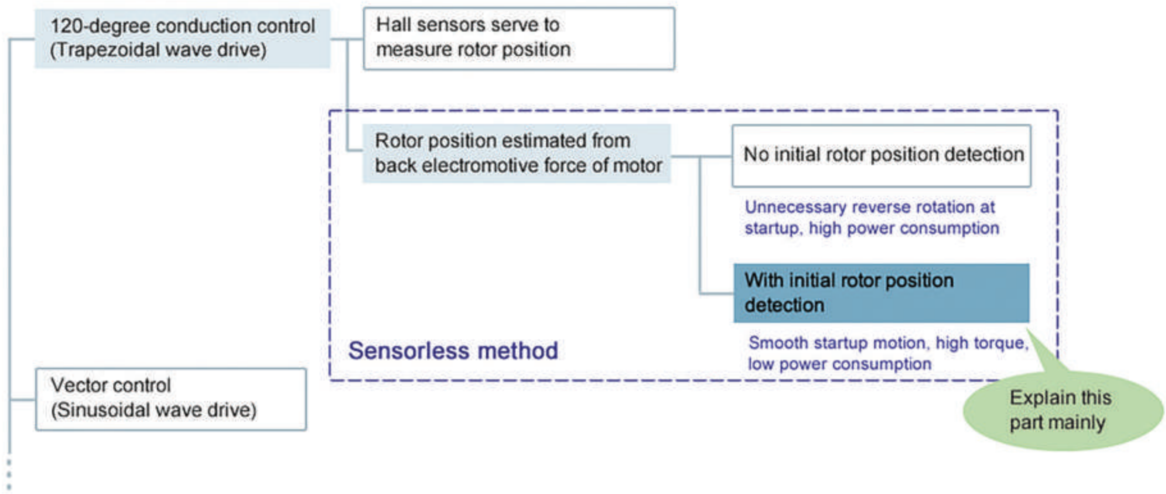



Figure 2: Technologies applied to brushless DC motors

For both the 120-degree conduction and vector methods, there are sensored and sensorless solutions for rotor position detection. This paper focuses on the 120-degree conduction method only. Hall sensors (magnetic sensors) are often used for sensored systems using the 120-degree conduction method. However, this increases the system cost, and Hall sensors also have the drawback of not being very heat resistant.

Sensorless systems, on the other hand, rely on various phenomena linked to motor rotation, such as the generated back electromotive force, to estimate the rotor position. But this precludes rotor position detection when the motor is stopped. At motor startup, proper control according to the rotor position can therefore not be performed.

In applications where the behavior at startup is not an issue, it is possible to ignore the rotor position and perform a forcible start, but this is not appropriate in cases such as the following:

- Unnecessary reverse rotation during startup is to be avoided
- Rapid and smooth start is desired
- Current consumption at startup is to be kept low

In such cases, it is necessary to detect the initial rotor position in order to enable suitable control.

## Integrating all functions required for sensorless motor control

Before going into detail about the sensorless initial rotor position detection implementation, some details about the Renesas RL78/G1F microcontroller (subsequently called "G1F"), which is a microcontroller designed for motor control, will be outlined in this paper. This product is part of the RL78 family of low-end microcontrollers from Renesas Electronics (see Figure 3). Within this family, the G1F belongs to the "general purpose" subgroup (G1x) and is comprised of a specialized feature set that makes the RL78/G1F suitable for motor control applications. Some of the features of the RL78/G1F related to motor control applications include:

- Timers arranged for motor control, supporting a 64 MHz on-chip oscillator clock,
- High-speed comparators with DAC for reference voltage,
- High-slew rate programmable gain amplifier (PGA),
- A/D converters, etc.

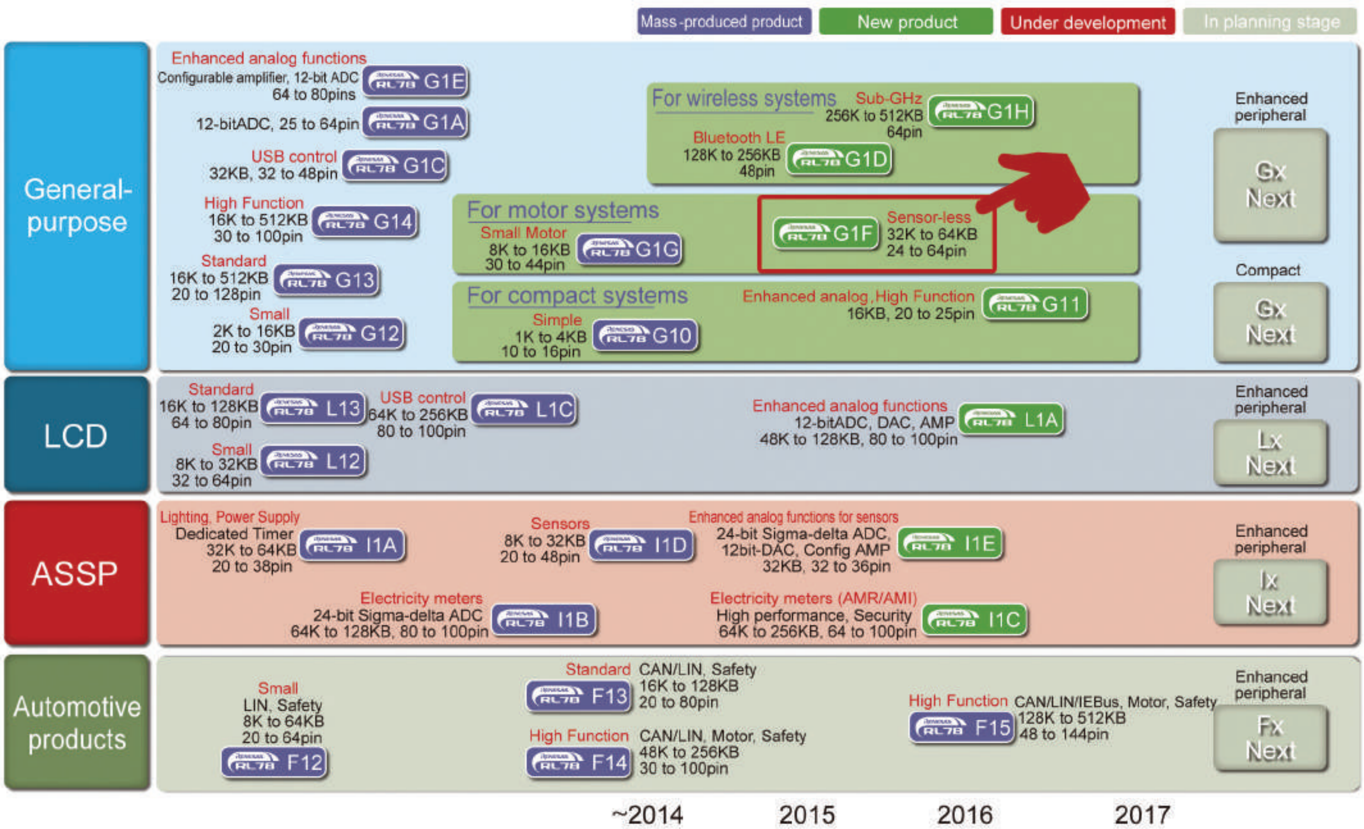



Figure 3: RL78 family roadmap

The circuit configuration for implementing sensorless 120-degree conduction control by using the peripheral functions of the G1F is shown in Figure 4. The 16-bit timer (Timer RD) generates the three-phase compensation PWM signal required for inverter control. For safety, the programmable gain amp (PGA) and comparator (CMP0) are used to detect over-current, allowing forced shutdown of the PWM signal without CPU intervention.

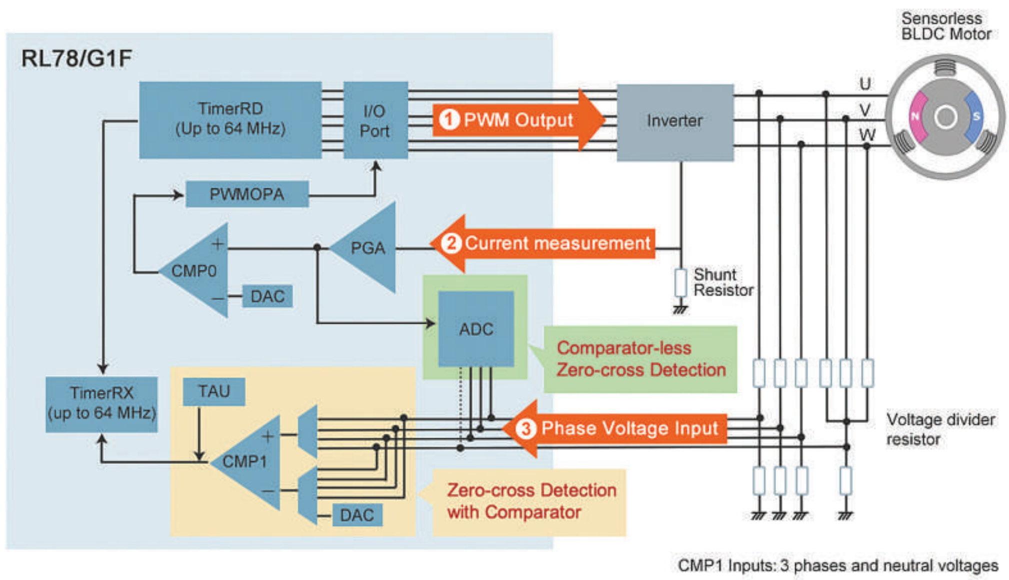



Figure 4: Circuit configuration for sensorless 120-degree conduction control

The initial rotor position is detected using the selectable 4-input comparator (CMP1) and the timer with input capture function (Timer RX). After rotation starts and back electromotive force becomes available, zero-cross detection can be utilized to determine the rotor position. Using the three-phase neutral input as reference, the comparator performs zero-cross detection. Alternatively, it is also possible to use the 10-bit A/D converter (ADC) to get the values and perform zero-cross detection. The first method using the comparator is suitable for high-accuracy and high-speed operations. The second method using the A/D converter (comparator-less) is preferable for medium- and low-speed applications.

## Combining two processing steps to reduce detection time

The sensorless initial rotor position detection consists of the following two processing steps.

Step 1: Position detection within 180 degrees

Step 2: Polarity detection

Step 1 is based on the fact that the inductance between the terminals of a three-phase motor differs depending on the position of the rotor (Refer Fig. 8). The inductance difference influences the voltage rise behavior at the downstream terminals, which is used as a basis for detection. This step determines the orientation of the magnet along one of the three phases (U, V, and W). However, the poles (North or South) of the magnet are not yet defined, as the same change is repeated in two cycles over the full range of 360 electrical angle degrees.

Step 2 then uses the fact that the influence of the magnetic flux created by the permanent magnet of the motor and the magnetic flux generated by the current flowing through the coil cause magnetic saturation in the core material, which makes the current flow more easily. As a result, the orientation of the magnetic poles of the permanent magnet are identified. Together with the results from Steps 1 and 2, the rotor position can therefore be detected within the entire 360-degree range.

There are certain differences depending on the type of motor, but the target current in processing Step 1 is extremely small, and the measurement time required is only on the order of a few microseconds. By contrast, processing Step 2 deals with much higher currents, and the measurement time is also longer by about two orders of magnitude.

Actually, even by only executing processing Step 2 for the three phases (three times), the initial position of the rotor can be detected with a resolution of 60 degrees. However, this involves a longer processing time and the necessity to deal with higher currents. The solution described here, therefore, aims for higher efficiency by integrating processing Steps 1 and 2.

Processing Step 1: Evaluation by comparing voltage rise behavior between phases

The process for position detection within 180 degrees is explained below. The usage configuration of G1F peripheral functions is shown in Figure 5.

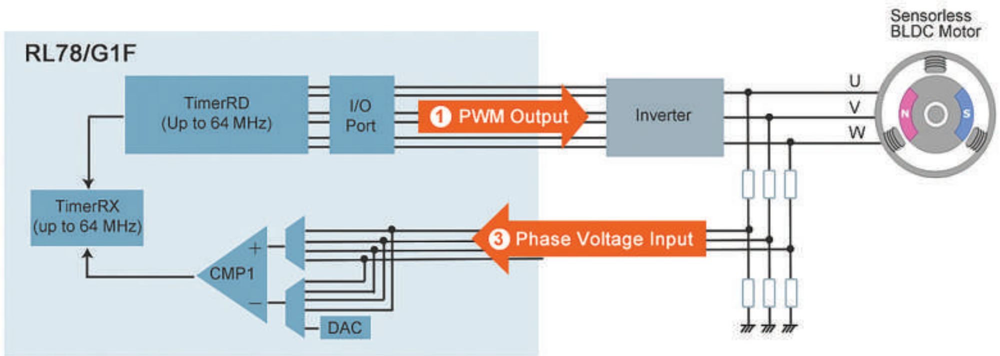



Figure 5: Circuit configuration for processing Step 1 (Position detection within 180 degrees)

First, the power supply voltage is applied to phase U, and the time elapsed until the phase V voltage (VUV) reaches the threshold reference voltage (VREF1) is measured. The operation principle of this process is shown in Figure 6. The VUV and VREF1 phase voltage detection inputs are supplied to the comparator (CMP1) for matching detection, and the counter value of the Timer RX is used to determine the time until VUV matches VREF1. The Timer RX starts counting in sync with the PWM output of the Timer RD and captures the count value in sync with CMP1.

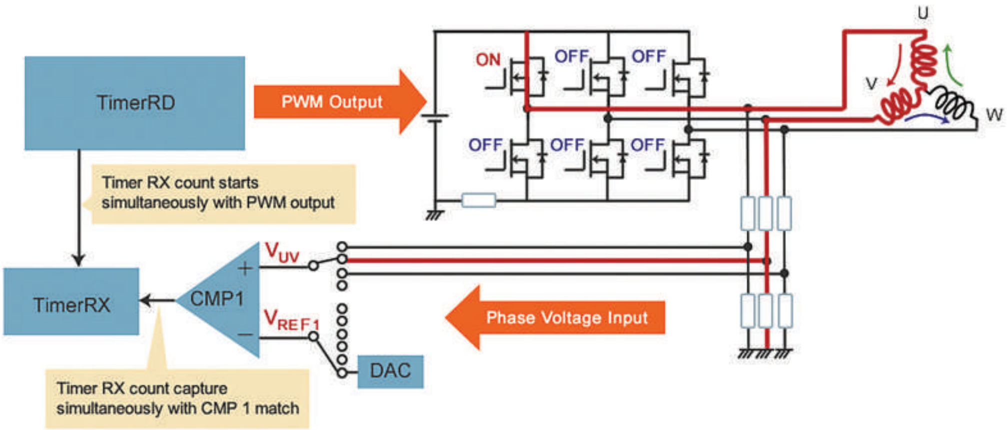



Figure 6: U → V voltage application and measurement of time to reach comparison reference voltage

This process is performed for all three channels, U → V, V → W, and W → U, respectively, and the rotor position along the three axes is determined using the following criteria:

If tUV > tVW and tWU, then the magnetic pole direction of the rotor is along W axis (Refer Figure 7)

CMP1 can use up to four switched external inputs for matching comparison. As the above operation uses three of the inputs, repeatable results can be achieved using the time measurement values.

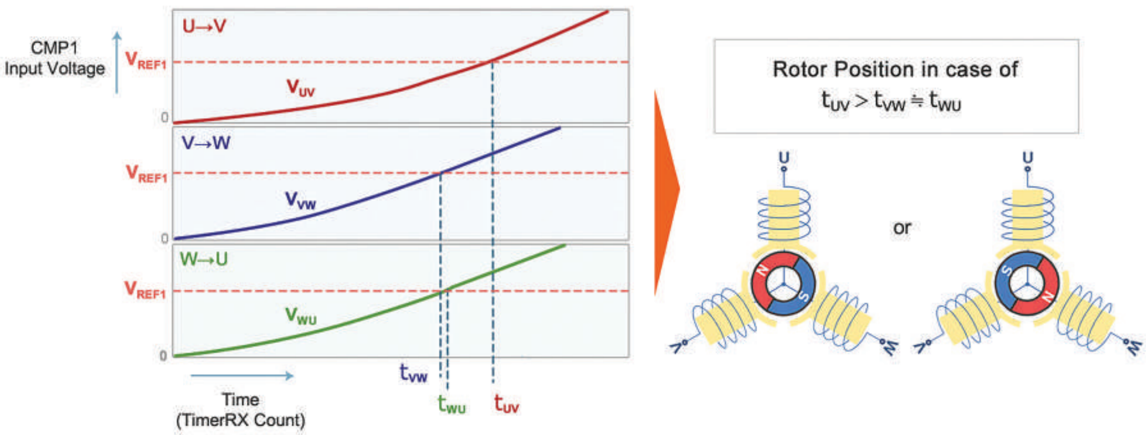



Figure 7: Detecting the rotor position from measurement times for U → V, V → W, and W → U

The inductance between the respective phase terminals changes according to the position of the rotor due to the effect on the magnetic field of the permanent magnet. The magnitude of this effect also changes Timer RX count values with the same trend. For example, assume that the inductance across terminals and the rotor position and the Timer RX count values change as shown in Figure 8. Using the resulting diagram, the rotor position can be determined. Taking the example of Figure 7, the tUV > tVW ≒ tWU relationship is established at an electrical angle of 60 degrees and 240 degrees in Figure 8. Because this change is repeated in two cycles over the 360 degrees range, it is not possible to determine which of the two angles (180 degrees apart) is correct at any given point.

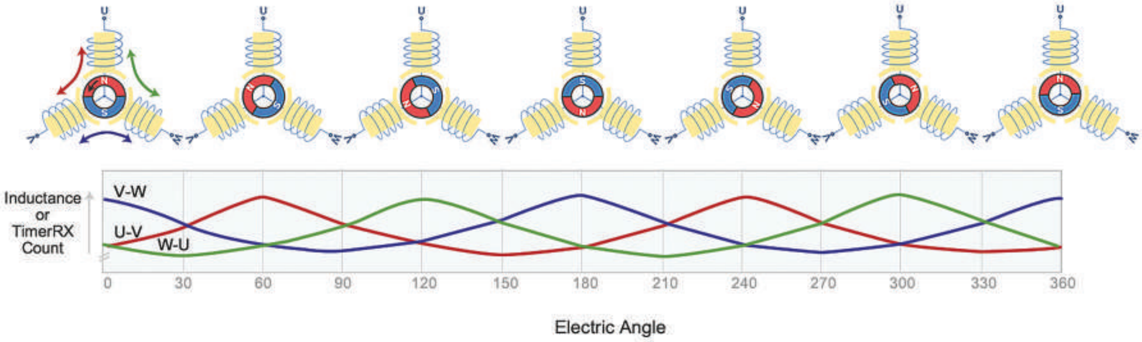



Figure 8: Change of inductance across terminals depending on rotor position and Timer RX count values

The inductance across terminals and the respective change according to rotor position differs depending on the motor. Furthermore, the behavior of the phase voltage, which is input to CMP1, is affected not only by the motor inductance, but also by the inverter circuit. The user, therefore, will need to first assess the change in the count value of Timer RX according to the rotor position, along with setting the comparison reference voltage for CMP1.

### Processing Step 2: Comparing shunt voltage behavior for evaluation

This section explains the second processing step that serves for polarity detection. The usage configuration of G1F peripheral functions is shown in Figure 9. Because this process uses the motor current as input voltage for the microcontroller, a shunt resistor is required. This input can be used for overcurrent detection during rotation.

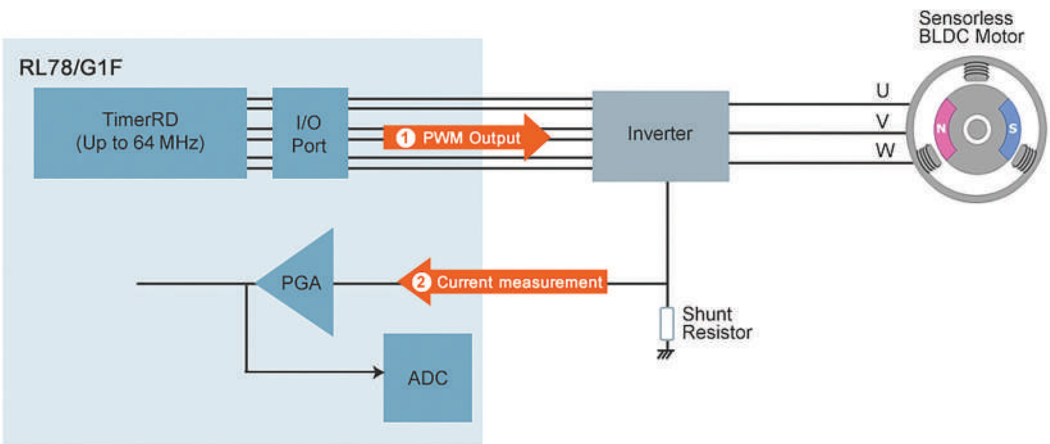



Figure 9: Circuit configuration for processing Step 2 (polarity detection)

Based on the result of processing Step 1, the phase along which the magnet is oriented is identified. In this step, the specific current is applied between the +ve (One phase) and –ve (Two phases) of the windings for a constant time interval (tCONST). The shunt voltage at that point (current detection input) is amplified by the programmable gain amp (PGA) and measured with the A/D converter (ADC). The upper circuit in Figure 10 (red signal paths) shows the signal when the current flows from W to U and V.

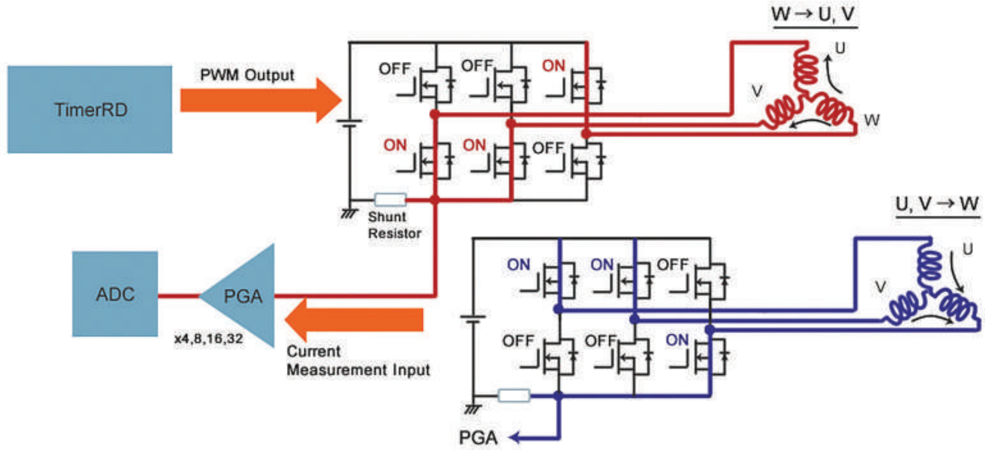



Figure 10: Shunt voltage measurement for W → U, V current and U, V → W current

Subsequently, a current is made to flow in the reverse direction for the same time interval (tCONST), and the same shunt voltage measurement is performed. The lower circuit in Figure 10 (blue signal paths) shows the signal when the current flows from U and V to W.

The magnitude relationship of these two measurement values makes it possible to determine the magnetic flux orientation of the permanent magnet. In the example of Figure 11, the current value (IW+) when the current flows from W to U and V direction is larger than the current value (IW-) when the current flows in the opposite direction. Therefore, it can be determined that the rotor direction is the direction in which the magnetic flux of the W phase is strengthened (magnetic flux direction of current from W to U; V is the same as the magnetic flux direction of the permanent magnet).

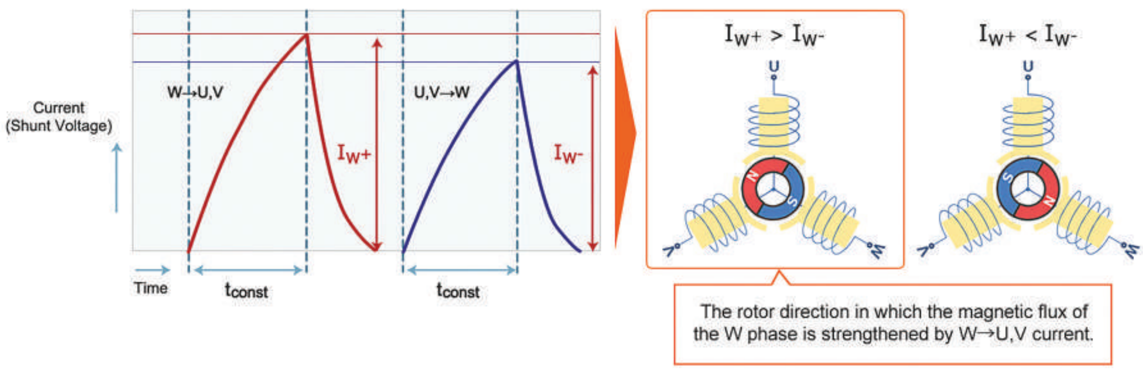



Figure 11: Rotor polarity evaluation current (shunt voltage)

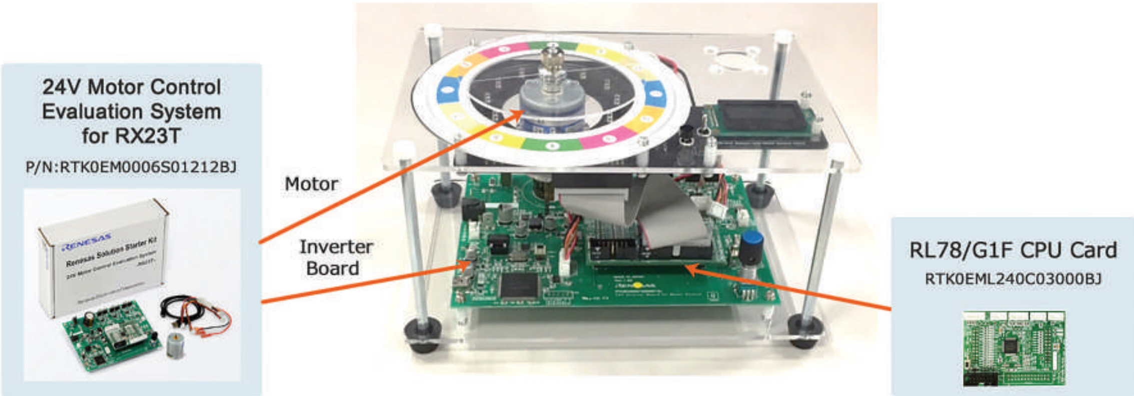
From the results of processing Steps 1 and 2, the initial position of the rotor can be determined.

## Visit the Renesas web site for more information

The Renesas web site provides extensive information about the initial rotor position detection method described here. This includes application notes, sample code, a demonstration video, and more. The video provides an opportunity to visually confirm how the startup motion of a motor changes depending on the presence or absence of initial position detection. For more information, please access the URLs shown below.

- Initial position detection demonstration video:

https://www.renesas.com/promotions/solutions/event/others2017/sensor-less-bldc-motor-control.html




- Application note:

https://www.renesas.com/search/keyword-search.html#q=r01an3596&genre=document

- Sample code:

https://www.renesas.com/search/keyword-search.html#q=r01an3596&genre=sampleprogram

- Renesas motor control solutions:

https://www.renesas.com/solutions/proposal/motor-control.html

- RL78/G1F:

https://www.renesas.com/products/microcontrollers-microprocessors/rl78/rl78g1x/rl78g1f.html

This paper describes a sensorless method for initial rotor position detection suitable for applications using brushless DC motors. Advantages include smooth and fast high-torque startup and low power consumption. The method involves a combination of two processing operations designed for low current draw and fast processing times. Because peripheral functions provided by the RL78/G1F microcontroller for motor applications are used as is, additional costs are kept to a minimum. Renesas Electronics holds pending patents related to this initial position detection technology. We believe that this method can be helpful in developing low-cost, high-value-added motor application products.

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