APPLICATION NOTE

RL78/G1F Group

R30AN0227EU0100
Rev.1.00
Oct 22, 2015

6-Step Control of BLDC by Comparator Zero-cross detection

Introduction

This application note provides a 6-step method (120° conduction pattern) that uses a single comparator to detect the Zero-crossing on a Permanent Magnet brushless 3 phase motor. Through the use of hardware resistor divider network and comparator enhancement hardware internal to the RL78/G1F, this method reduces the amount of processing required by the MCU to detect the BEMF Zero-cross versus the Zero-cross detection by ADC method.

Target Device

RL78/G1F, 64 pin version (R5F11BLE)

Contents

1. Overview

This application note provides the theory and accompanying demo program for a brushless DC motor (BLDC) using the RL78/G1F microcontroller, including the proper use of the library of the development support tool, In Circuit Scope (Note 2). The demo program will be described from an “Abstract level”, and the reader is referred to the C project files and the Doxygen folder within the project for code documentation. The app note will focus more on the more on the theory of operation and the RL78/G1F features which allow the implementation.

In this application note, wherever possible, we will use actual scope shots (or DSO data) rather than simulated or mathematically created data.

NOTE: Although this Application note was verified with a block wound motor it should operate with a sinusoidal wound PMSM motor.

Operation checking device

Operations of the sample programs have been checked by using the following device.

- RL78G1F (R5F11BLE)

Target sample programs

The target sample programs of this application note are as follows.

(1) RL78G1F_CMP_BEMF 6-step for RL78G1F (R5F11BE) for T2001 Inverter

(Complementary PWM Positive Side, GPIO Negative Side, see section 3.1 for details)

1.1 Development environment

Table 1-1 shows development environment of the sample programs explained in this application note.

Table 1-1 Development Environment of the Sample Programs

	Sample software	MCU	Inverter board	Motor	E2studio version	Tool Chain
Low-voltage version	(1)	R5F11BLE	T2001 Note 1	BLU063S-24V-32000 Note 3,4	V4.00.00.26	IAR for RL78 V1.40

For purchase and technical support of the low-voltage inverter board T2001, contact Sales representatives and dealers of Renesas Electronics Corporation.

Notes:

1. T2001 is a product of Desk Top Laboratories Inc.
2. The development support tool In Circuit Scope is a product of Desk Top Laboratories Inc.

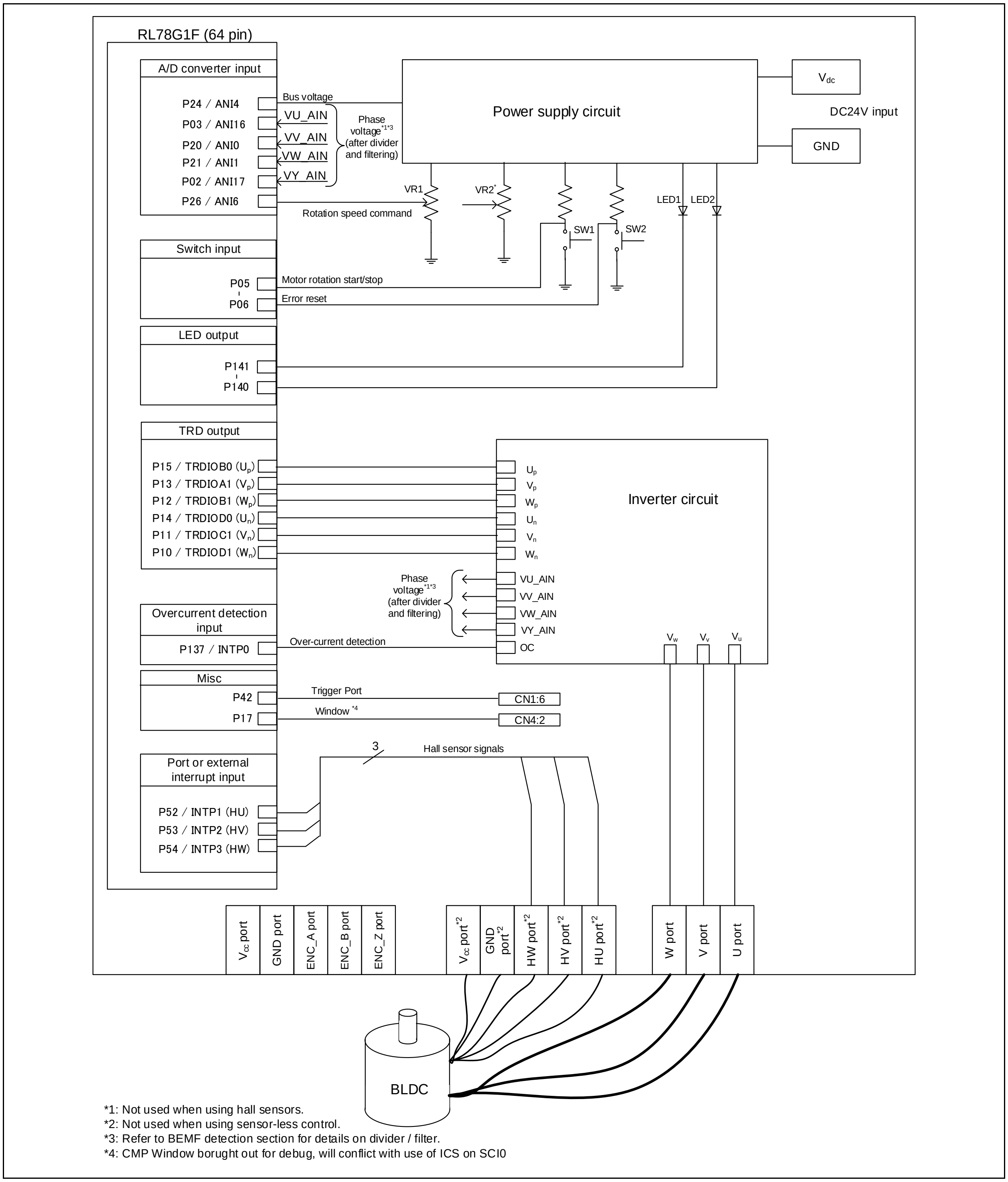
   Desk Top Laboratories Inc. (http://www.desktoplab.co.jp/)
3. Anaheim Motor (http://www.anaheimautomation.com/)
4. Motor Sample signals actually taken from an “off-the-shelf” BLDC power tool motor.

2. System overview

Overview of this system is explained below.

2.1 Hardware configuration

The hardware configuration is shown below.



*1: Not used when using hall sensors.
*2: Not used when using sensor-less control.
*3: Refer to BEMF detection section for details on divider / filter.
*4: CMP Window borught out for debug, will conflict with use of ICS on SCI0

Figure 1: Hardware Configuration Diagram

2.2 BEMF Detection Signals

2.2.1 Signal Levels

We need to connect the Motor Winding drive circuits back into the ADC and Comparator inputs. In addition, for the comparator method we need to create a “virtual neutral” to compare against to find the zero-cross. You can see from Figure 2 that we need to divide from VBus (in this case about 24V) down to a 0 to AVCC range. In addition, we can note from this several important points:

- BEMF goes below 0V
- BEMF visible only during PWM active time
- Zero-cross (Zero BEMF voltage) will occur at ½ of the motor drive signal or ½ VBus

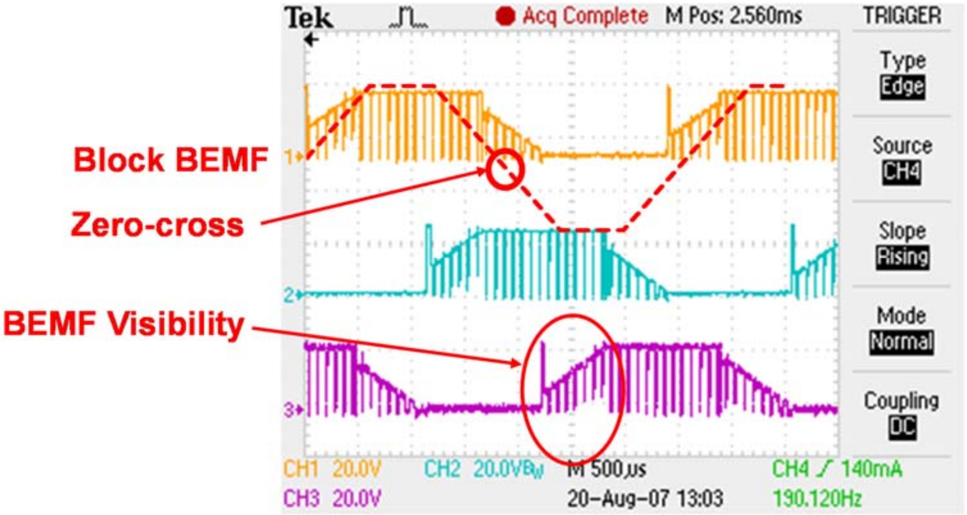


Figure 2: Theoretical BEMF on true Motor Signals

So from this we can deduce that we should make sure:

- our divider does bias up the signals to avoid negative voltages
- bias up the signal to make sure the Zero-cross does not disappear below the 0V signal level
- that we detect BEMF only during active PWM time.

NOTE: Since we are attempting to show true data, an actual picture of block wound BEMF may be found in section 8.1

2.2.2 Divider Networks

Fundamentally we need to get the signals down to a level acceptable by the MCU, and in addition, they need to “cross-over” at the Zero-cross so as to trigger the comparator interrupt. We will discuss the actual hardware method for doing this in section 3 but for now let’s look at the analog aspects of this problem.

Figure 3 shows the divider network for the Motor Terminals. We can determine with simple Ohms law the divider rate for these. The math is not shown here, but the relationship with $V_{NEUTRAL}$ (VY_AIN on the block diagram) will be discussed later in this section.

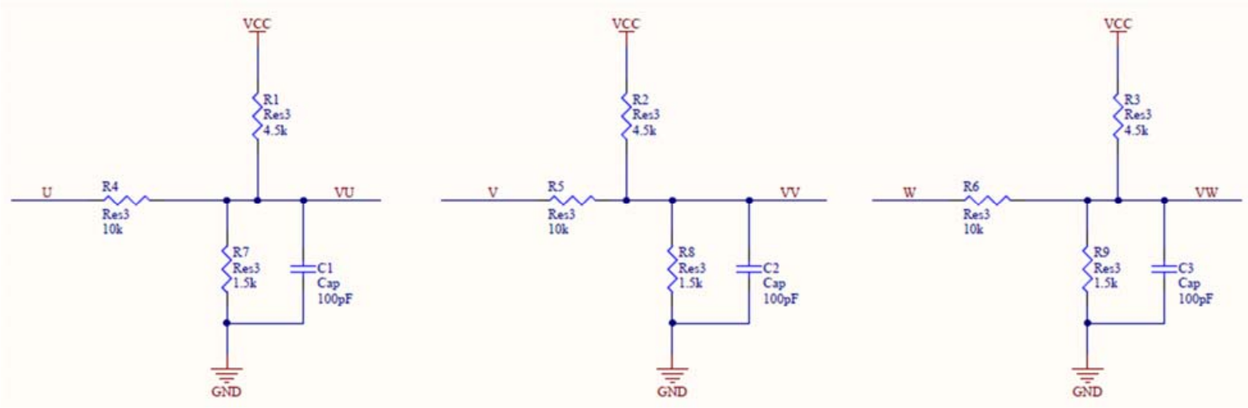


Figure 3: Motor Winding Divider and Filter

Figure 4 shows the divider and filter for the $V_{NEUTRAL}$. You will note one things, the values create a 1/3 divider for the summed voltage on the 3 motor windings while maintain the bias point. This will cause a 1/3 slope on the $V_{NEUTRAL}$ node which sets up the perfect signal for a zero-cross detection in the comparator.

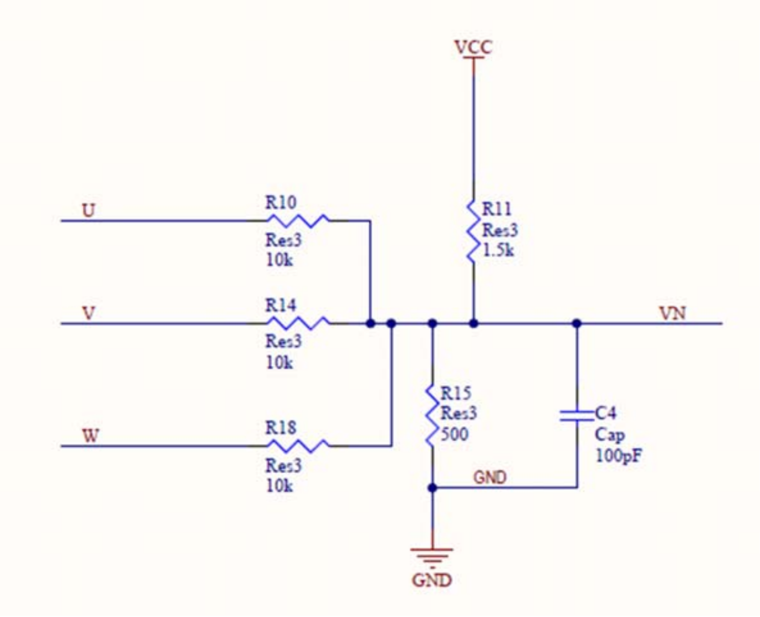


Figure 4: $V_{NEUTRAL}$ network

You will also note, that the filters on these networks are not very “strong”. It is intended to provide High-frequency noise reduction (i.e. inverter switching noise) while not causing large phase delays which may keep the motor from running at low-duty cycles or highest speeds. We will discuss “windowing” the comparator in a later section.

DESIGN NOTE: Since the 1/3 R value may not be a standard value, R11 and R15 are sometimes achieved by placing 3 resistors in parallel that match the dividers on the motor phases. Since they are the same value and typically from the same lot (on a reel), the accuracy of the 1/3 division ratio is almost guaranteed.

Looking at Figure 5, we can see the resulting signals from these R-Networks as delivered to the ADC/analog inputs to the MCU.

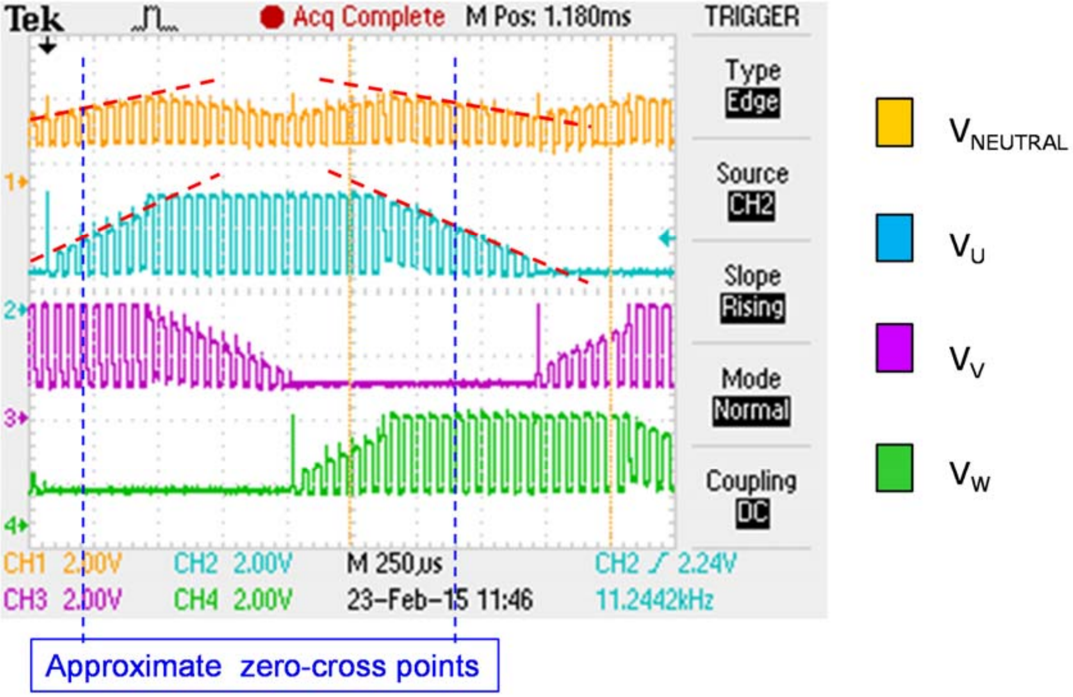


Figure 5: Analog Motor Signals

A couple of important things to note, the “virtual neutral” slope is about 1/3 of the Motor winding signals. This means at the zero-cross, the comparator will switch making it easy to use an interrupt to signal Zero-Cross and take the appropriate action.

Also note that they swap “polarity” when comparing rising edge to falling edge (i.e. on rising motor rises above neutral and on falling motor signal falls below neutral), therefore if we want the interrupt edge to be consistent, we need some mechanism to swap the comparator inputs. This will be discussed in section 3.3.

To make a little easier to see what the comparator is looking at we extracted the DSO data from the rising and falling zero-cross points and show a close up in Figure 6. In this close up, it is easier to see that the comparator requires a different connection to the inputs if we wish to make the hardware implementation easier.

NOTE: As mention before, we have the comparator closed after the zero-cross and do not open it until one carrier interrupt after. The highlighted commutation “spike” shows that comparator operation here would be unpredictable.

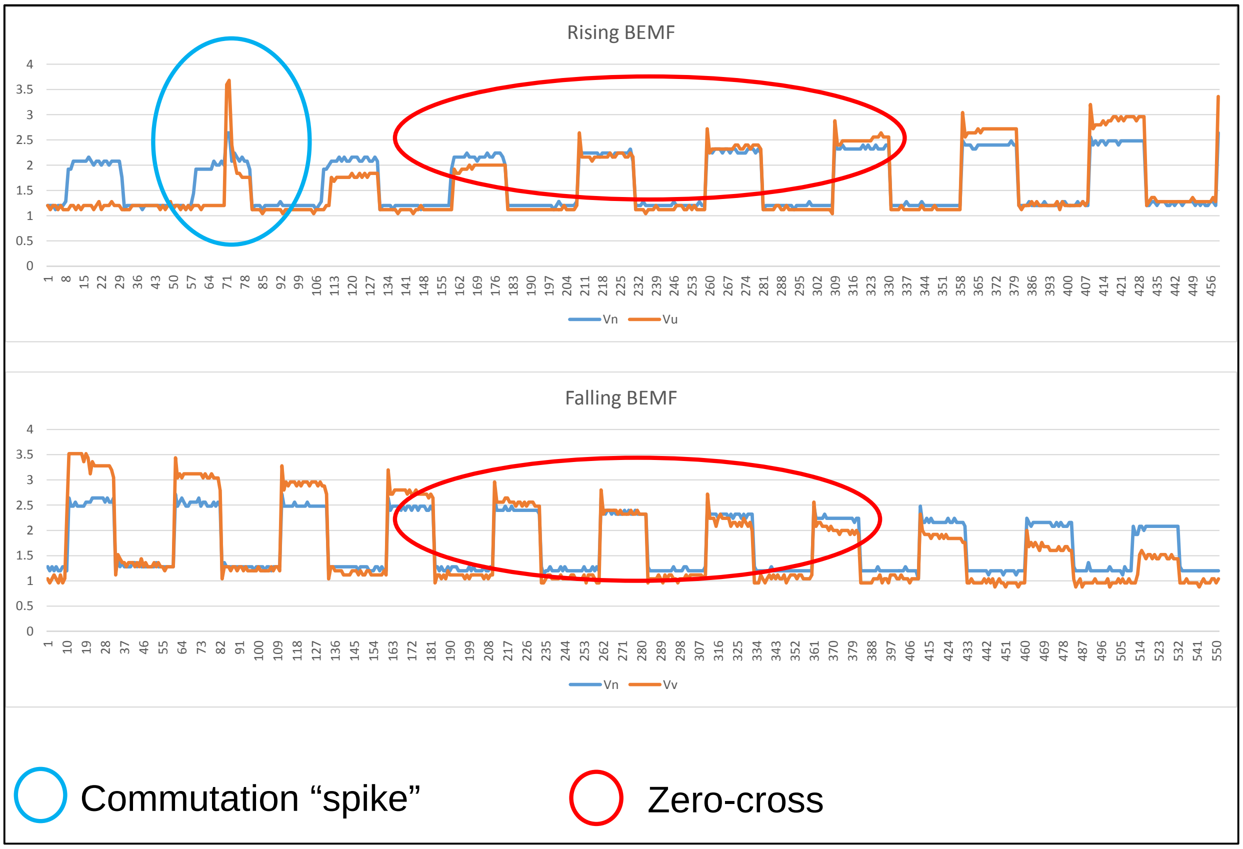


Figure 6: Zero-cross (post R Networks), a close look

3. BEMF Comparator Operation

We now have the correct analog signals that we can feed into our comparator, so we need to create of the following conditions:

- Only look at the BEMF at the correct time - comparator windowing
- Have the comparator inputs correctly assigned, (correct setting for + and – inputs)

3.1 Modulation Method

Figure 5 shows that the BEMF is only visible during the active part of the PWM cycle, so we need to understand the modulation method being used, at least from the standpoint of "active" time, and when we can open the Comparator Window (see Figure 7).

In this demonstration, we will use complementary drive on the "positive" side of the motor and GPIO on the negative side of the motor. This provides:

- a defined signal for triggering "Window" timer (one-shot gating comparator)
- low-side drive always on during the step, so sampling "shunt" current is a little bit simpler.
- PWM rotates among the signals to "level" the switching losses in the power devices.
- active rectification of positive side drive (i.e. fly-back goes through MOSFET instead of recovery diodes)

Figure 7 shows the 6 STEPs of modulation, you can see the PWM modulating the positive side of the motor.

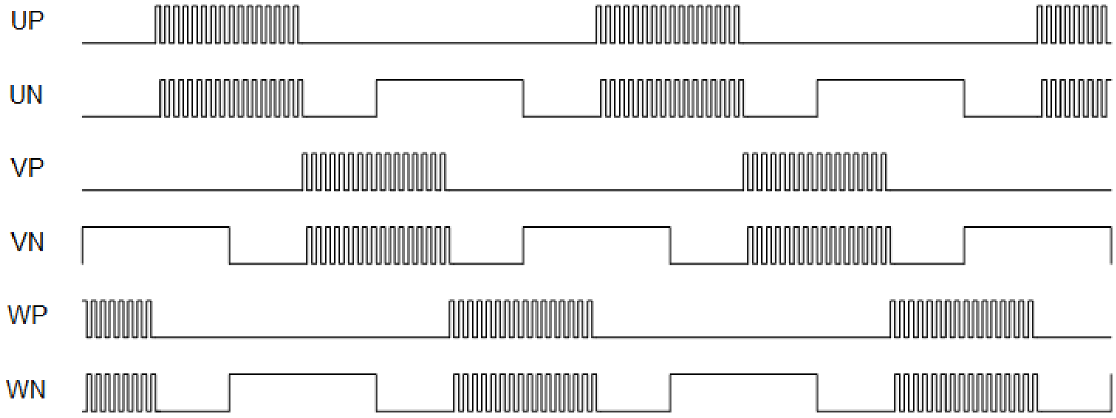


Figure 7: Modulation Diagram (active high drive)

3.2 BEMF Window

To generate the "window" that can open and close at the correct times, a "one-shot" is the perfect solution. In this case since we want to look only during the "Active portion" of the PWM cycle, the high side of the signal modulating the Inverter should be used as the "trigger". Since the motor may be running at very short duty cycles or very long duty cycles, this needs to happen in hardware as any software delay in this window cannot be tolerated.

Figure 8 shows the timer window trigger and duration relationship to the PWM. When the code is running, this “window pulse” is available on P17 (see Figure 1)

NOTE: The values are calculated at the time the duty cycle is calculated.

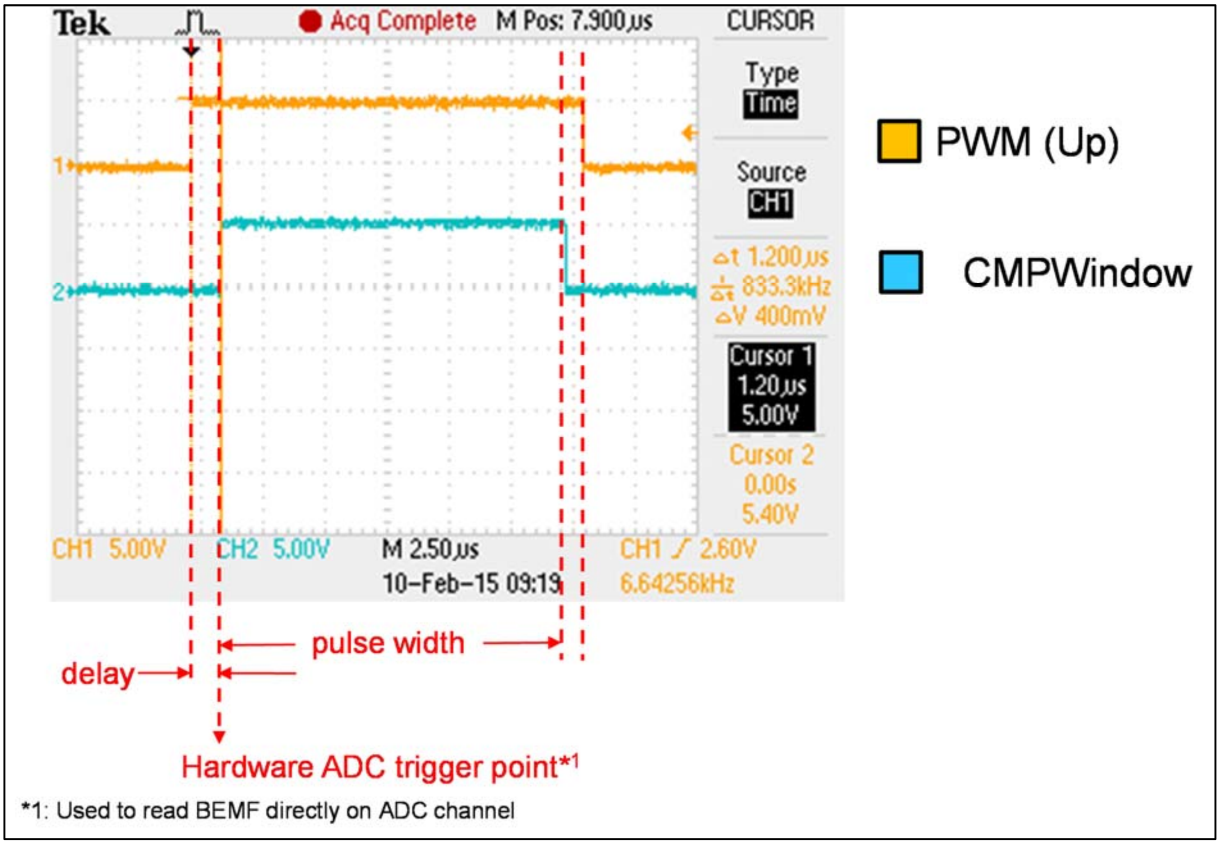


Figure 8: Compare Window Example

The delay is calculated to “open” the window away from the switching edge of the inverter where there is likely to be a lot of switching noise. Likewise the pulse width is calculated to “close” the window before the falling edge, again where there is likely to be a lot of switching noise. We use the ADC trigger point to “balance” the BEMF readings on rising and falling to get the rotor and commutation “in sync”.

NOTE: Both a Minimum Window to account for ADC Sampling and a Maximum Window so window does not stay open past end of PWM (95% duty – Dead-time) are defined.

3.3 Comparator Input Multiplexing

In order for all this to work, the RL78/G1F must provide a mechanism in hardware to switch the analog inputs to both the ADC and the comparator. In addition, it must be able to switch the input of the timer used for the "window" generation to be switched to the proper PWM signal that defines the high side of the modulated channel.

First let's look at CMP1, which has the extra support for using this "window" mechanism.

Figure 9 shows both the multiplexing for the Analog inputs and the CMP Window "gate". Since we have a multiplexer on each input of the comparator we can effectively "swap" the "+" and "-" inputs. The analog inputs for this functionality are "hard" defined by the input pins. If you intend to use the CMP Zero-cross method, these analog channels should be assigned first in your design per this application note.

We can also see that Channel 2 of the TAU is dedicated to this "compare gating" function. This hard defines the "slave" of the one-shot pair in TAU for our "window" generation.

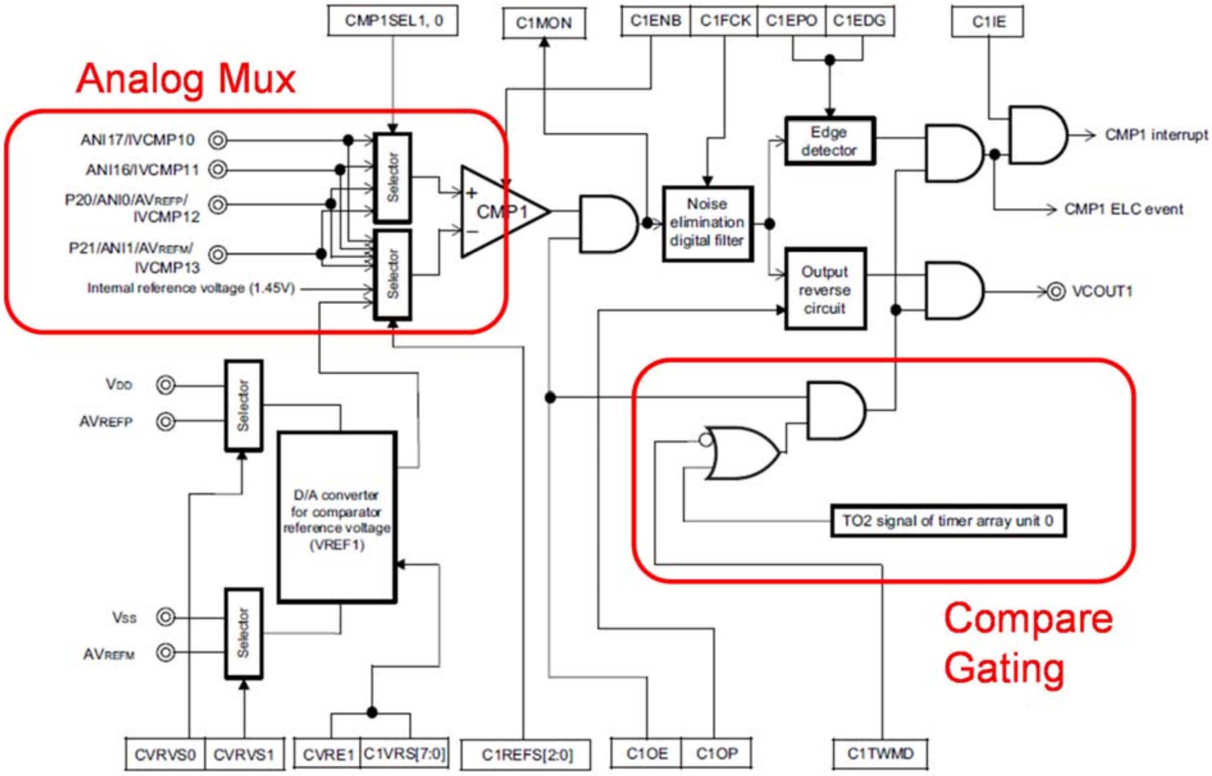


Figure 9: Analog Mux and Compare Gate

3.4 TimerRD TAU trigger Multiplexing

Figure 10 shows the multiplexing provided on the RL78/G1f on TAU channel 0 to allow the various PWM signals of TimerRD to be the trigger. So this allows TAU channel 2 to be the Master of a Master/Slave pair of a “one-shot”.

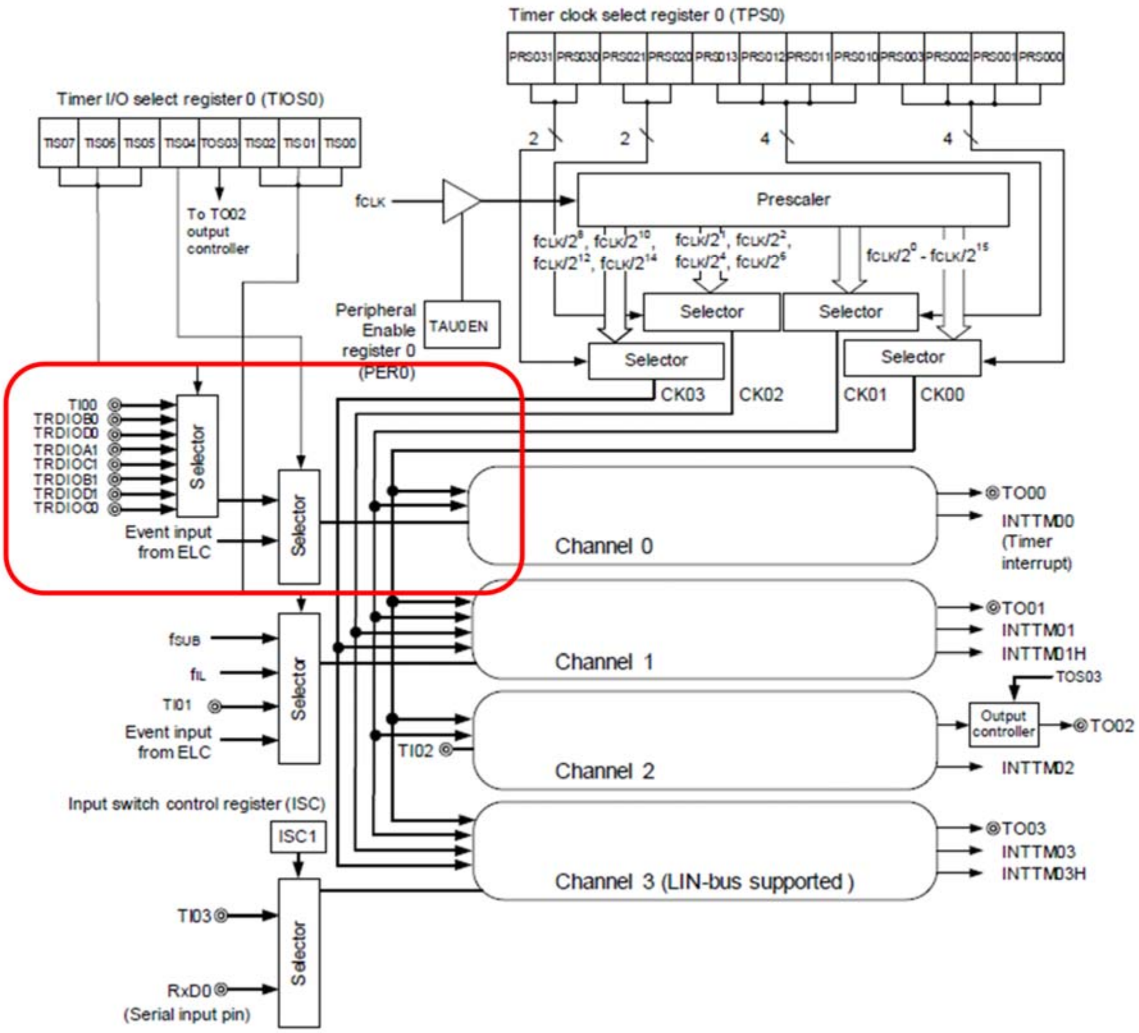

Timer clock select register 0 (TPS0)
PRS031 PRS030 PRS021 PRS020 PRS013 PRS012 PRS011 PRS010 PRS003 PRS002 PRS001 PRS000
2
2
4
4
Timer I/O select register 0 (TIOS0)
TIS07 TIS06 TIS05 TIS04 TOS03 TIS02 TIS01 TIS00
To TO02 output controller
fCLK
Prescaler
fCLK/2^8, fCLK/2^10, fCLK/2^12, fCLK/2^14
fCLK/2^1, fCLK/2^2, fCLK/2^4, fCLK/2^6
fCLK/2^0 - fCLK/2^15
Selector
Selector
Selector
Selector
Peripheral Enable register 0 (PER0)
TAU0EN
CK03
CK02
CK01
CK00
TI00
TRDIOB0
TRDIOD0
TRDIOA1
TRDIOC1
TRDIOB1
TRDIOD1
TRDIOC0
Selector
Event input from ELC
Selector
Channel 0
TO00
INTTM00 (Timer interrupt)
fSUB
fIL
TI01
Event input from ELC
Selector
Channel 1
TO01
INTTM01
INTTM01H
TOS03
Output controller
TO02
TI02
Channel 2
INTTM02
Input switch control register (ISC)
ISC1
Channel 3 (LIN-bus supported)
TO03
INTTM03
INTTM03H
TI03
RxD0
(Serial input pin)
Selector

Figure 10: TAU / TimerRD signal multiplexing

One final note, the CMP Window we generate can be routed through the ELC and be used for other things. For example, when making the transition from Open-loop to CMP BEMF mode, we will use it to trigger the ADC and balance the rising and falling BEMF before transitioning. Please see section 4.2 MTR_OPEN_LOOP and Threshold for more details.

3.5 TAU timer allocation

Since the hardware featured in the RL78/G1F define the timer pairs used for Comparator BEMF detection, the TAU timers are allocated as follows:

- TAU channel 0 and 2 paired as a MASTER/SLAVE to implement the one-shot for CMP windowing
- TAU channel 1 is a free running timer for doing speed measurement
- TAU channel 3 is used for the commutation timer

NOTE: The speed measurement can be moved to TimerRX on the RL78/G1F if the TAU channel is needed by other tasks.

4. Controlling Program Description

In this section we will give an abstract view of the motor control program. For details on the program the reader is referred to the Doxygen output folder (index.html) for code structure, variables, definitions, and call/caller details.

4.1 System States

Figure 11 shows the system states as defined by a call to the Motor Event Function (`R_MTR_ExecEvent()`) and the events it can be called with.

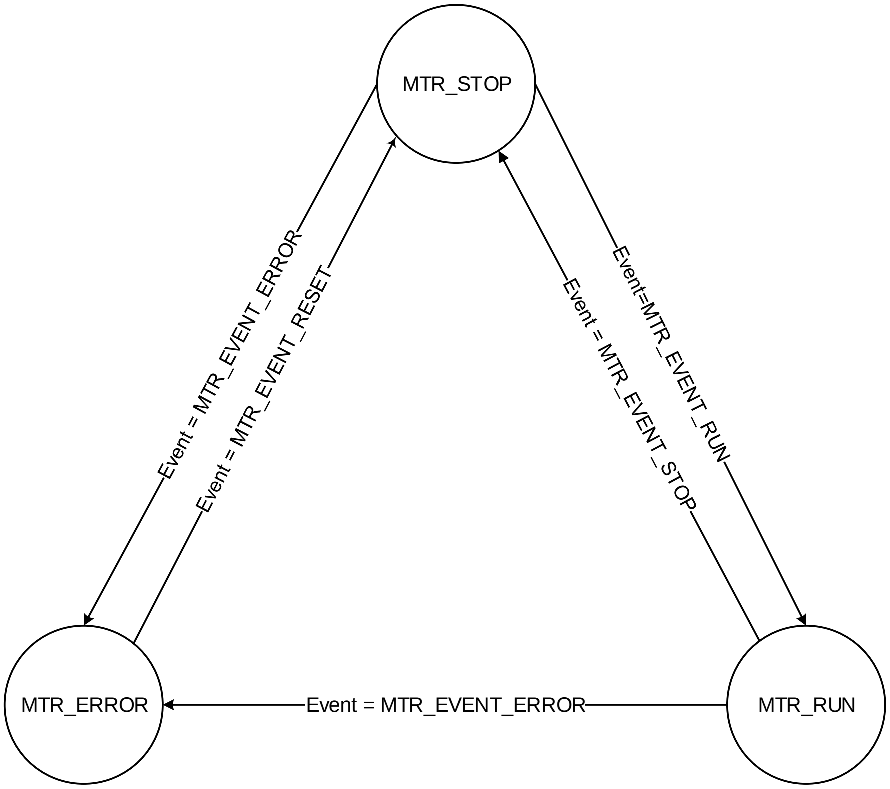


Figure 11: Motor Event States

A call to the function R_MTR_ExecEvent() also makes an indirect (function table) call to the default actions required by the transition into the new state.

For example, a MTR_EVENT_ERROR could be any number of items that indicate the motor or the system is not in a condition to run properly, including but not limited to Over-voltage on the VBus, Over-current while motor is running, and Over-speed.

4.2 Motor States

Figure 12 shows the motor states for this algorithm. The motor state transition are caused by various values and events within the system as the motor runs, stalls, etc.

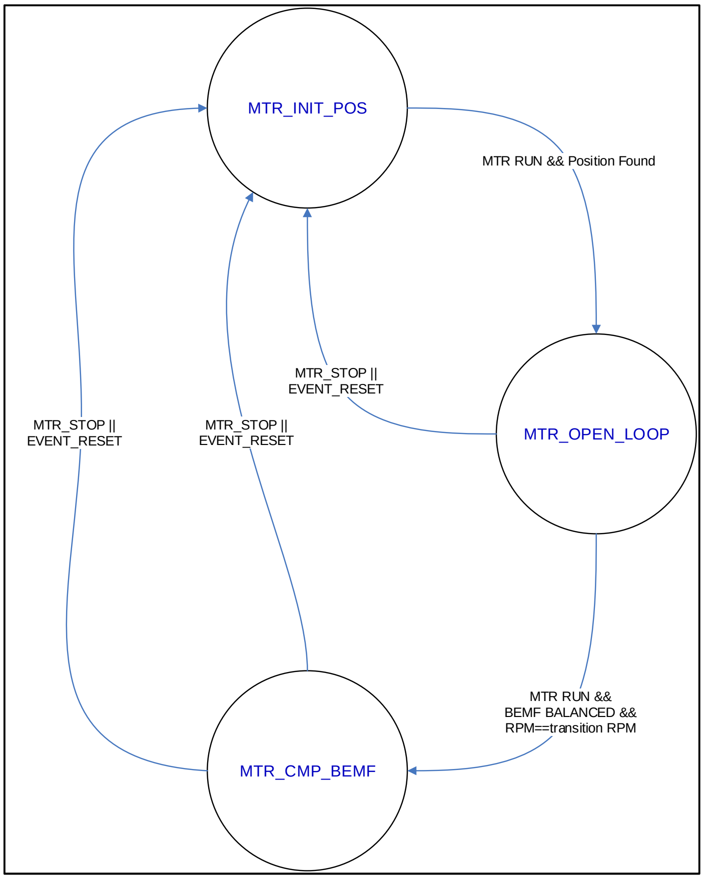

MTR_INIT_POS
MTR RUN && Position Found
MTR_STOP \|\| EVENT_RESET
MTR_OPEN_LOOP
MTR_STOP \|\| EVENT_RESET
MTR_STOP \|\| EVENT_RESET
MTR RUN && BEMF BALANCED && RPM==transition RPM
MTR_CMP_BEMF

Figure 12: Motor State Diagram

Motor State transitions are a little harder to track, so a brief description of each.

MTR_INIT_POS: This is the starting state for the Motor operation. It is here after a MTR_EVENT_RESET. It remains here until the System State goes to the MTR_RUN mode at which time this state determines the initial position of the rotor. In the case of this Demo, we use an alignment procedure (see Figure 14 for detail). Once the initial position of the rotor is determined without an error, it transitions to the OPEN Loop state.

MTR_OPEN_LOOP: In this state, the motor starts a pre-determined profile to spin the motor to a given RPM. During this period, it uses a hardware trigger (see Figure 8) to read and average both the rising and falling BEMF of the motor by sampling the un-driven winding of the motor. Once the BEMF is balanced and we are at an RPM that can create enough BEMF for the Comparator to detect zero-cross, the Motor moves to the MTR_CMP_BEMF mode.

We know we can only see the BEMF during active PWM, and BEMF will be stable somewhere in the center of the commutation cycle. During the open-loop commutation, we sample 4 readings in the center of the 120 degrees conduction on the non-driven winding. When the BEMF is balanced we know we our commutation is “in-sync” with the moving rotor. Figure 13 shows the BEMF values from the ADC when we are “balanced” on the rising and falling BEMF on the undriven motor terminal.

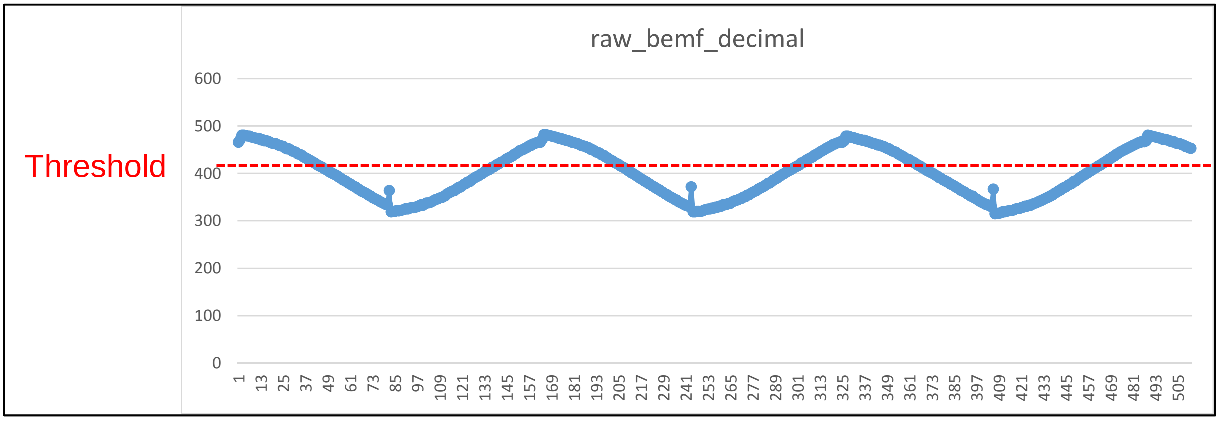


Figure 13: Balanced BEMF and Threshold

MTR_CMP_BEMF: The motor stays here until a MTR_STOP event or a MTR_EVENT RESET. Stop is usually done by a commanded RPM of 0 or SW1 turned off. EVENT_RESET can be caused by any number of dynamic events, but most common is over-current.

4.3 6-step state machine

4.3.1 State Description

Once the motor is running in either OPEN loop of Comparator mode, the commutation is a finite machine of 6 states, basically either an up or down counter depending on the direction of the motor. The state machine is given in Figure 14. The length of time in the Alignment state is empirically derived for the motor and the inertia of the load.

We align so that STEP 5 is the next state, so the next state will depend on the direction the motor will be commanded to go.

IMPORTANT: In addition to changing the pattern on the inverter pins, the commutation actually sets the inputs of the multiplexers for the comparator so it detects the correct BEMF, rising or falling. It also sets the multiplexer for the TAU trigger so we are looking at the correct PWM signal for firing the "one-shot" that opens the BEMF sampling window.

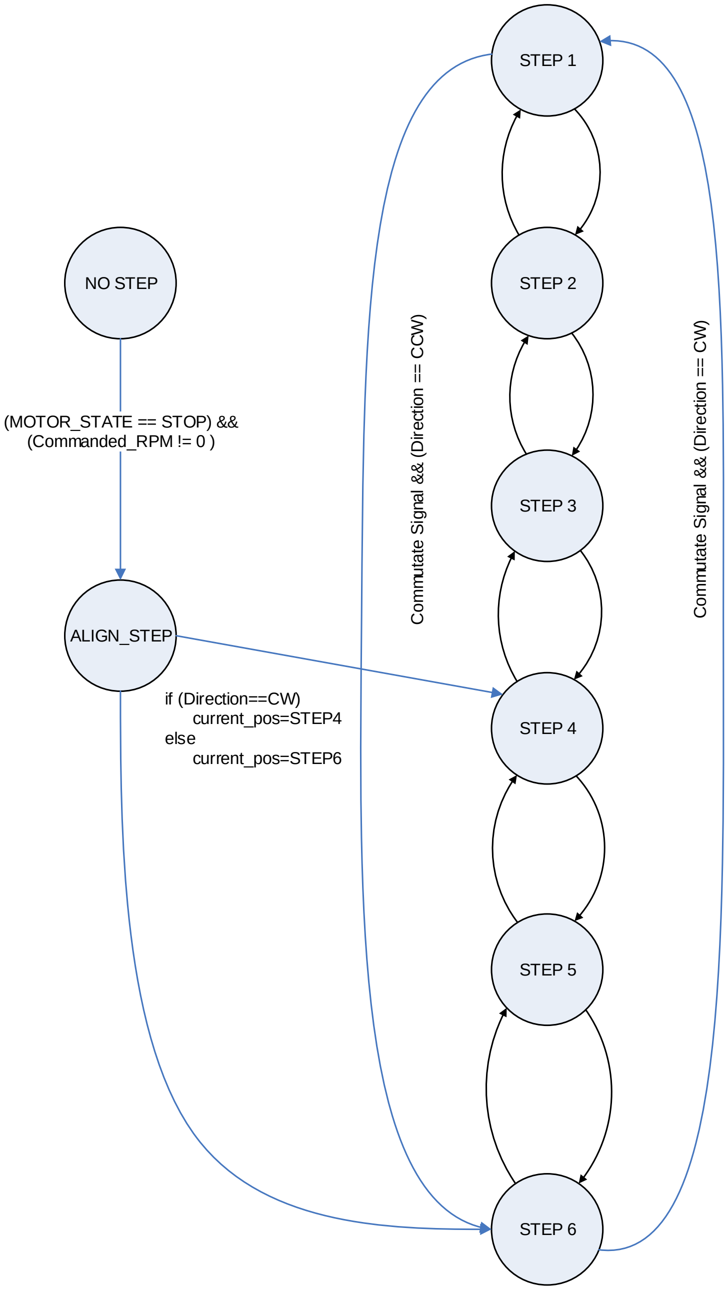


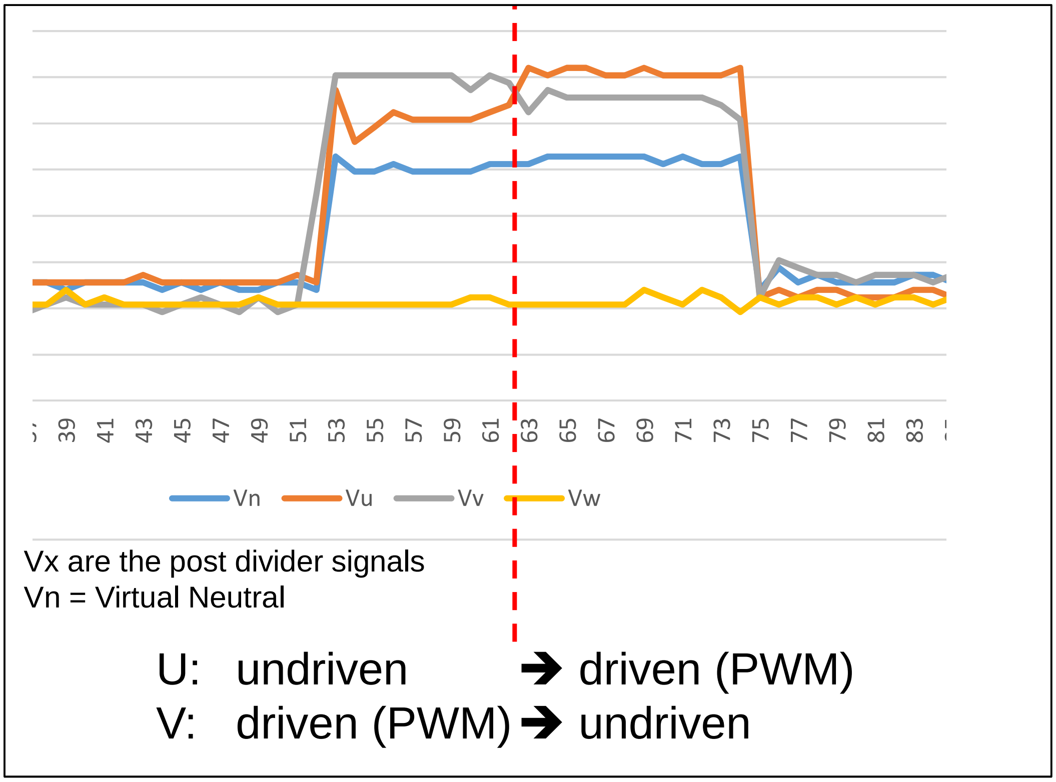
Figure 14: Motor 6-Step States Diagram

4.3.2 Asynchronous Commutation

One of the issues when performing commutation in any BLDC/PMSM is that the BEMF zero-cross point (or HALL for sensor based algorithms) may not be in–sync with the carrier. For low-speed application, it is easy to move the commutation into sync with the carrier and live with any small error in the Speed accuracy, etc.

For a High-speed motor, this is not the case (i.e. motor commutation rate cannot possibly be an integral multiple of the carrier frequency of the PWM). For example: at 25kRPM with a 4-pole motor using a carrier of 20kHz would incur up to a 25% error if we wait for the carrier to commutate. When the zero-cross occurs and 30° has elapsed, you must commutate to avoid this.

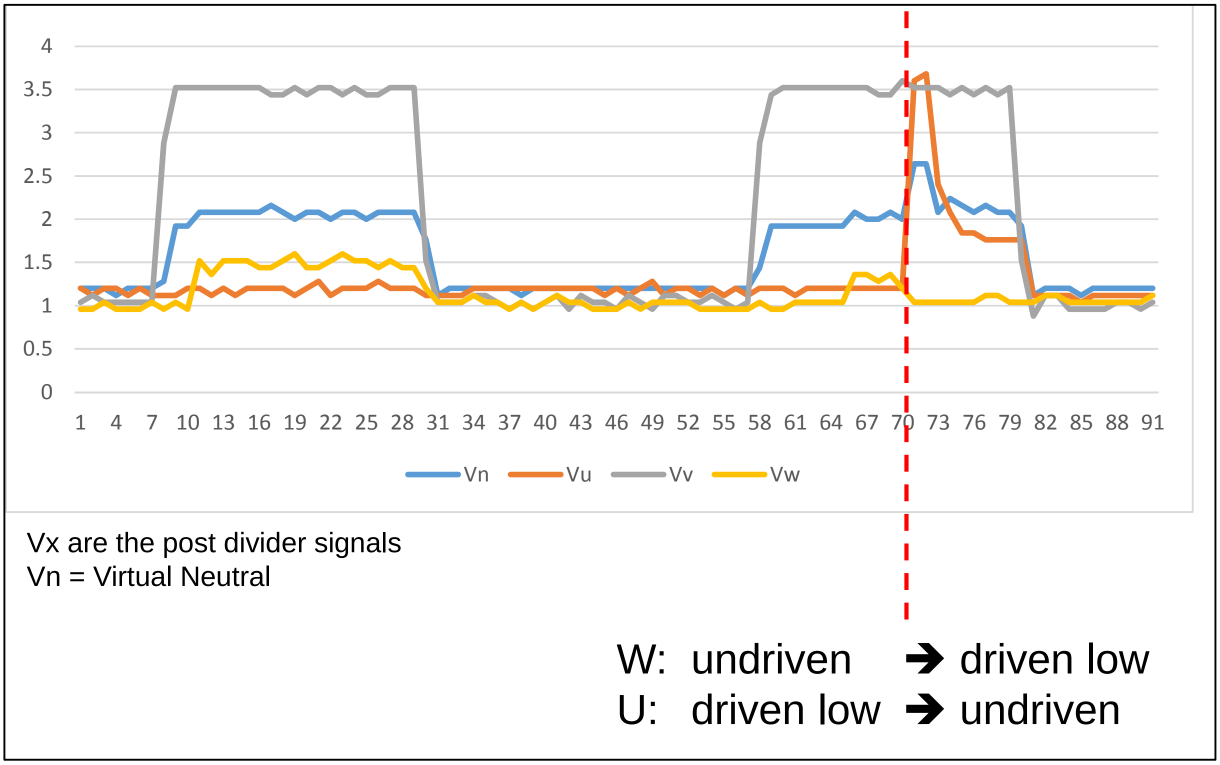
This demo commutates using a delay timer based on the zero-cross and the speed. Therefore it will be asynchronous to the carrier and your design should be robust enough to support “runt pulses” and endure any additional switching loss due to this. Figure 15 and Figure 16 (DSO scope data plotted) provide pictures of the inverter outputs when the commutation occurs mid-PWM cycle.



Vx are the post divider signals
Vn = Virtual Neutral

U: undriven ➔ driven (PWM)
V: driven (PWM) ➔ undriven

Figure 15: positive-side (PWM) switching mid-cycle



Vx are the post divider signals
Vn = Virtual Neutral

W: undriven → driven low
U: driven low → undriven

Figure 16: Low-side (GPIO) switching mid-cycle

4.4 CMP Mode Operation

We now have all the analog data, the hardware, and the state information that we need to allow the software to commutate the motor using hardware and “minimalist” interrupt routines. So let’s see how this goes together.

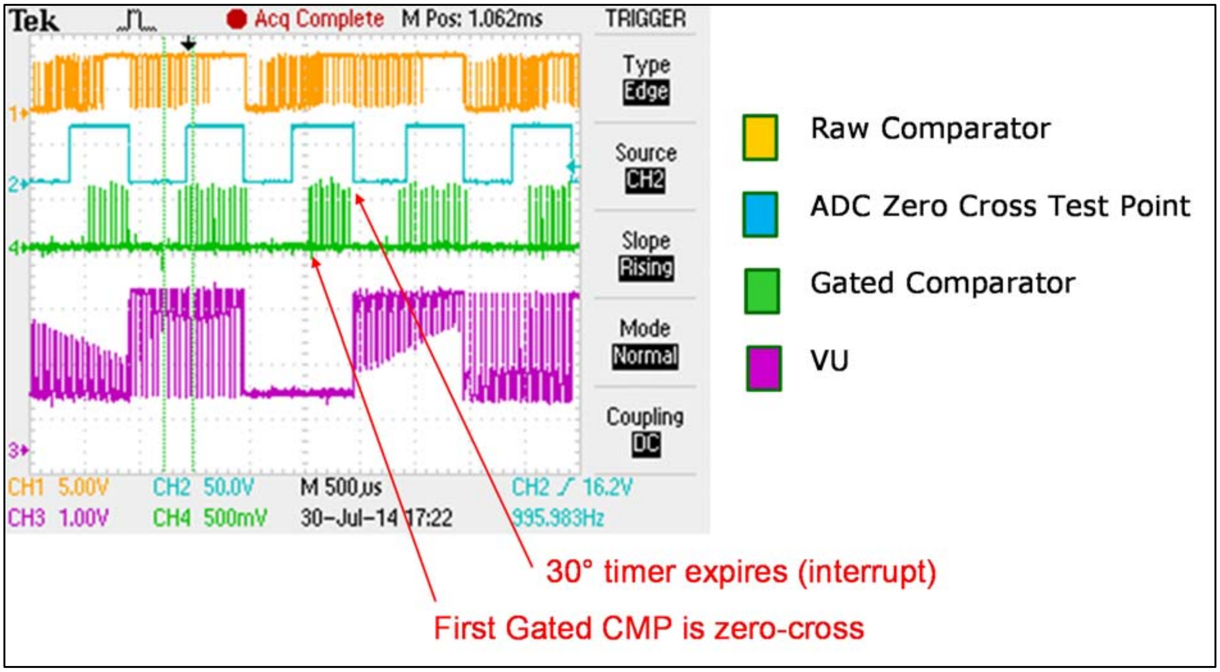
In the transition from state to state, the 6-step state machine does the following:

- Calculates and low-pass filters the motor speed count.
- Indicates which phase we should be measuring (un-driven phase) based on state (STEP) we are entering and the direction
- Sets the Comparator input MUX based on state we are entering and direction
- Selects the correct TAU trigger edge from the TimerRD signals (remember, typically only one is on)
- Commutates the Inverter drive output (GPIO side first, PWM side second)
- Sets a flag to indicate we just commutated (skip flag to avoid commutation noise in the comparator)

After we skip one carrier interrupt after commutation (flag used to move away from all the inverter noise generated during commutation), we enable the comparator in Windowed mode. At this time we start looking for the first interrupt from the comparator which will indicate that the undriven Motor Winding and $V_{NEUTRAL}$ nodes have crossed (voltage levels).

When we see that first CMP1 interrupt (the zero-cross), we calculate a timer value based on a “filtered speed count” that represents a 30° electrical rotation angle. If we have phase advance implemented, from this count value we subtract the amount that represents the “advance angle”. We do ***not*** commutate on Zero-cross, but 30 degrees later (if we are not phase advancing). See Figure 5 to see actual zero-cross to commutation relationship (commutation points are obvious by the transition from driven to un-driven/BEMF on the inverter signals).

The relationship of the motor signals BEMF to the comparator output, the gated comparator output, and the commutation is shown in Figure 17.



30° timer expires (interrupt)

First Gated CMP is zero-cross

Figure 17: Gated compare output

So basically commutation in high-speed mode using the comparator is a function of accepting the zero-cross comparator interrupt, setting the delay timer for commutation, accepting the Delay timer interrupt and commutating which sets the hardware to repeat the process on the next CMP zero-cross detect. This requires very little CPU bandwidth. Since the commutation is asynchronous to the carrier, for speed controlled applications (not this demo), we can run the PI speed loops in the 1mS system timer tick.

4.5 Phase Advance

Earlier in the discussion about calculating the Delay timer for commutation we mentioned phase advance. We will not discuss in detail phase advance, but suffice to say it provides a method in 6-step to achieve higher RPMs in the motor, typically higher than the rated maximum speed of the motor. This puts the commutation in advance of the actual rotor mechanical position thus shifting the BEMF within the commutation period.

One of the issues with phase advance, is that this shifting of the BEMF shifts within the commutation time (see Figure 18), could be taken too far and the BEMF zero-cross could shift off so much as to be missed entirely by the hardware.

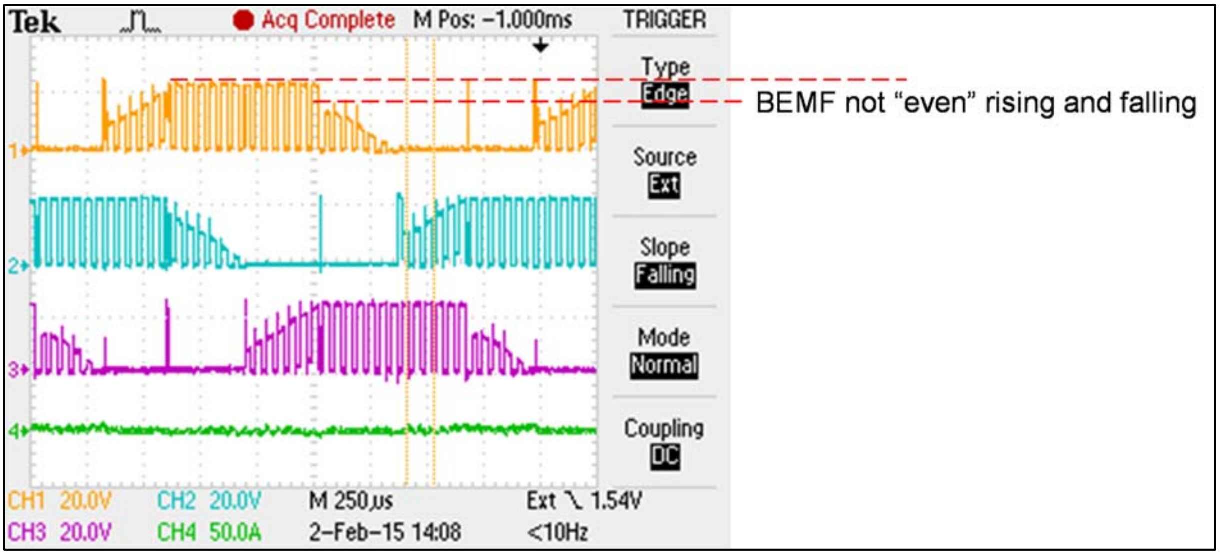


Figure 18: BEMF shifted by Phase Advance

In this particular demo, we limit the phase advance to 24 degrees maximum, but that is based on empirical testing of the asymmetry of the BEMF from the motor (i.e. BEMF is non-symmetrical in BLDC based on quality of construction, magnetism of the motor, and other factors). This is the same reason we must do some minimal low-pass filtering of the speed calculation to remove this asymmetry. The speed would jump between reading too much to be used as a "stable" reference from which to calculate or 30° commutation delay.

5. Miscellaneous Operations related to Motor Control

5.1 Speed Measurement

5.1.1 Zero-cross to Zero-cross

Since we commutate based on a fixed time (open loop) or zero-cross detection, at each commutation (step of 6 step machine), we grab the free-running timer (TAU channel 1) and subtract it from the previous reading. This gives us a delta count, and since we know the base clock, we can derive speed:

RPM = (60 * TAU clock / (6*number of pole pairs)) / Δ counter value.

5.1.2 Speed Filtering

We do not need to do the speed calculation to filter for the commutation timer. We simply filter the free running counter's delta readings. The filtering of the speed count is not very aggressive, it just needs to be enough to eliminate the jumps in the speed count value so we can get a fairly accurate 30° calculation for our commutation delay timer. In this case since we have 6 commutation cycle, we can average 8 readings and we should get rid of the jumps due to asymmetry since we will have moved greater than one full electrical cycle. In addition, by doing a power of 2, the averaging simply becomes and add and a shift, not consuming much CPU time. The raw data versus the filtered data is shown in Figure 19.

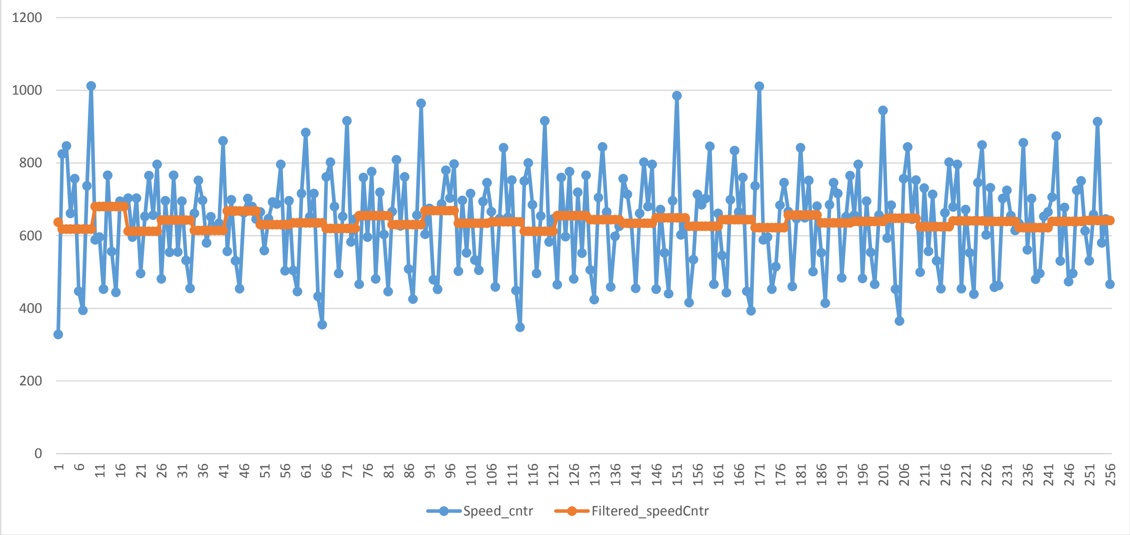


Figure 19: Raw speed counter versus Filtered speed count

5.2 Speed Control

In this application we run a simple duty cycle control. This demo was intended to show applications where the operator is the "speed control loop" (i.e. variable speed tool where a trigger controls the speed). So the potentiometer in this case is acting as the trigger and we do a straight line calculation of 0-MAX_DUTY based on the trigger position.

5.3 Over-current (INTP0 operation for this app note)

The demo is currently set-up to use the INTP0 signal as the overcurrent indicator. The platform that this was tested on was multi-shunt with the proper "window" comparator built onto the inverter. For a simpler implementation, the user can connect a single shunt design to the CMP0 for on chip, programmable over-current detection.

6. Demo Project

6.1 Importing and Building

1) Open the e2studio workspace you want project located in

2) Use the standard Import Feature of e2studio to Import an Existing Project

3) Browse (root directory) and select the sub-directory *Workspace\RL78G1F_CMP_BEMF* where you unzipped the file.

4) Select *RL78G1F_CMP_BEMF* and FINISH.

5) If asked, Browse to your IAR install location and click APPLY, then OK

6) Project should look like Figure 20:

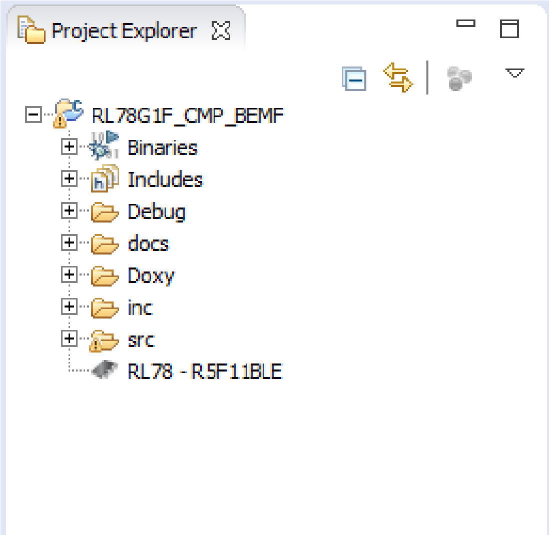


Figure 20: Project Explorer Panel after Import

7) Select menu Project Build →All (or 🔨).

NOTE: there may be some warnings due to the use of volatiles in the program.

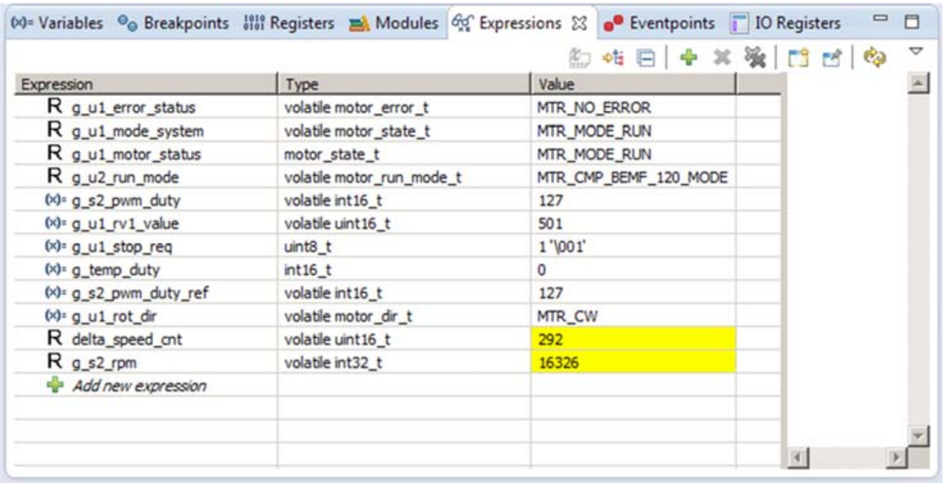
6.2 Tips and Tricks

6.2.1 Expressions

Most of the State Machines use enumerated values for their state variables, so it makes it easy to "watch" these in the expressions window to determine the whole state of your "machine". For example, in Figure 21, from our Auto-refresh variable (large R indicator) we can see that:

- Our system mode is in MTR_MODE_RUN,
- NO errors have occurred
- Our motor run mode is Comparator BEMF mode
- We are running at approximately 16k RPM in the Clockwise direction.

It should be noted, that the real time refresh rate is typically in the 100's of milliseconds, so cannot always be used for troubleshooting real time values such as motor current sampling, etc. For higher speed sampling, it is recommended to use the In-Circuit Scope (see section 7)



Expression	Type	Value
R g_u1_error_status	volatile motor_error_t	MTR_NO_ERROR
R g_u1_mode_system	volatile motor_state_t	MTR_MODE_RUN
R g_u1_motor_status	motor_state_t	MTR_MODE_RUN
R g_u2_run_mode	volatile motor_run_mode_t	MTR_CMP_BEMF_120_MODE
(x)= g_s2_pwm_duty	volatile int16_t	127
(x)= g_u1_rv1_value	volatile uint16_t	501
(x)= g_u1_stop_req	uint8_t	1 '\001'
(x)= g_temp_duty	int16_t	0
(x)= g_s2_pwm_duty_ref	volatile int16_t	127
(x)= g_u1_rot_dir	volatile motor_dir_t	MTR_CW
R delta_speed_cnt	volatile uint16_t	292
R g_s2_rpm	volatile int32_t	16326
Add new expression		

Figure 21: real time refresh Expressions

6.2.2 TODOs

Using e2Studio Task management feature, a number of comments have been marked with TODO text. These provide markers to places for "tuning and tweaking" to match a specific Motor/environment. Typically these will be numbers used to match a motor/systems performance, inertia, etc. for proper operation. TUNING MAY BE REQUIRED.

6.2.3 Doxygen

In the Doxy folder under the project, the CALLER/CALL graphs, definitions, variables, files structure, etc. can be browsed by clicking on the index.html file under the Project Explorer panel (or maybe opened outside in a conventional Web browser).

After changes are made to the software, you can update the Doxygen files by re-running the wizard and loading the Doxyfile in the Doxy directory.

6.2.4 Checking Comparator Interrupt / Commutation timer operation

Some of the problem with making this work is checking the comparator operation. We have brought the comparator out on an external pin so you can watch the gated operation. In addition, you can lock the motor operation into an "open-loop, balanced BEMF mode" for monitoring Zero-cross detect and commutation timer operation on the trigger port. In file *mtr_common.c*, uncomment the line:

```
//#define STAY_OPEN_LOOP_COMMUTATION        // keeps it from closing BEMF by Zero-cross
```

The above will tell you if you're getting CMP1 interrupts, but for debug purposes you may want to view VCOUT1. The comparator output can be brought out port 7 bit 0 (VCOUT1). In file *mtr_common.c*, uncomment the line:

```
//#define CMP1_OUT_USED    // uses CMP1 out of the MCU for debug
```

6.2.5 An overall Signal view

Once your algorithm appears to be running, you can hook up an MSO and monitor the various test points for correct operation. Figure 22 shows a sample of the TRIGGER test point, the gated CMP1 output (VCOUT1), the Comparator Time Window created by TAU, and the 4 analog signals created by the resistor networks (V_U, V_V, V_W and $V_{NEUTRAL}$).

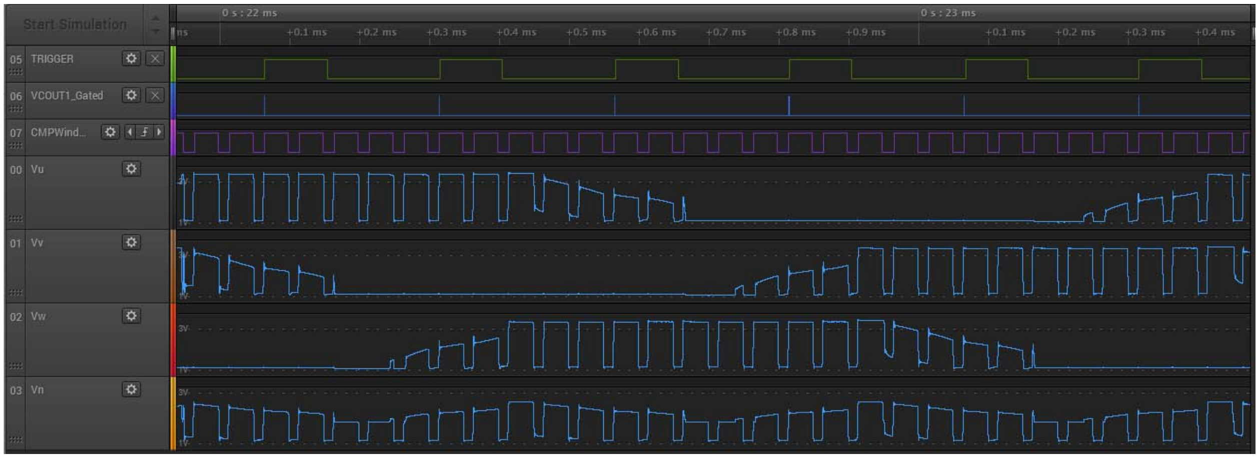


Figure 22: Mixed Signal Sample, Motor running

7. References

- RL78G1F Group User’s Manual: Hardware (R01UH0516EJ0050)
- R01AN2657EJ0100 - Application note: ‘120-degree conducting control of permanent magnetic synchronous motor: algorithm’
- Applilet for RL78/G14 V1.01.01, used for sample TAU one-shot code generation
- In Circuit Scope Manual
  - Downloadable from: http://www.desktoplab.co.jp/download.html
  - Trial series “T2001” 50W 60VA Low Voltage Inverter Unit User’s Manual

8. Appendix A

8.1 Block Wound BEMF

Figure 23 shows the actual BEMF from a block wound motor measure by constructing a “virtual neutral” with Y-connected load resistors and spinning the motor with another motor. Notice the “flat tops”, indicative of block winding.

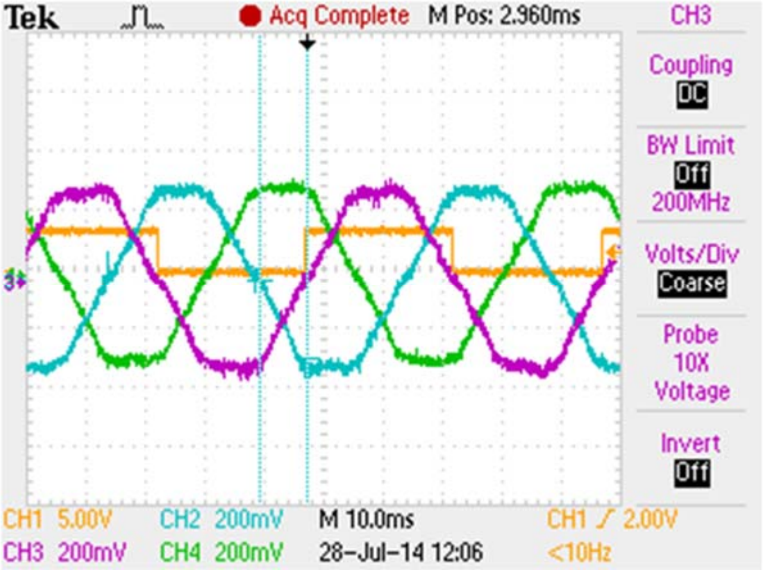


Figure 23: Block wound BEMF

8.2 Glossary

BEMF – Back Electromotive Force

BLDC Motor – brushless DC motor (typically requires electronic commutation)

DSO – Digital Signal Oscilloscope

MSO – Mixed Signal Oscilloscope

PWM - Pulse Width Modulation

TAU – Timer Array Unit

Website and Support

Renesas Electronics Website
http://www.renesas.com/

Inquiries
http://www.renesas.com/contact/

Revision History

		Description	
Rev.	Date	Page	Summary
1.0	10/22/2015		Initial Release

General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Handling of Unused Pins

   Handle unused pins in accordance with the directions given under Handling of Unused Pins in the manual.

   — The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at Power-on

   The state of the product is undefined at the moment when power is supplied.

   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of Access to Reserved Addresses

   Access to reserved addresses is prohibited.

   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock Signals

   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.

   — When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.

5. Differences between Products

   Before changing from one product to another, i.e. to a product with a different part number, confirm that the change will not lead to problems.

   — The characteristics of an MPU or MCU in the same group but having a different part number may differ in terms of the internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation of these circuits, software, and information in the design of your equipment. Renesas Electronics assumes no responsibility for any losses incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics has used reasonable care in preparing the information included in this document, but Renesas Electronics does not warrant that such information is error free. Renesas Electronics assumes no liability whatsoever for any damages incurred by you resulting from errors in or omissions from the information included herein.
3. Renesas Electronics does not assume any liability for infringement of patents, copyrights, or other intellectual property rights of third parties by or arising from the use of Renesas Electronics products or technical information described in this document. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You should not alter, modify, copy, or otherwise misappropriate any Renesas Electronics product, whether in whole or in part. Renesas Electronics assumes no responsibility for any losses incurred by you or third parties arising from such alteration, modification, copy or otherwise misappropriation of Renesas Electronics product.
5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The recommended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.

   "Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; and industrial robots etc.

   "High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control systems; anti-disaster systems; anti-crime systems; and safety equipment etc.

   Renesas Electronics products are neither intended nor authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems, surgical implantations etc.), or may cause serious property damages (nuclear reactor control systems, military equipment etc.). You must check the quality grade of each Renesas Electronics product before using it in a particular application. You may not use any Renesas Electronics product for any application for which it is not intended. Renesas Electronics shall not be in any way liable for any damages or losses incurred by you or third parties arising from the use of any Renesas Electronics product for which the product is not intended by Renesas Electronics.
6. You should use the Renesas Electronics products described in this document within the range specified by Renesas Electronics, especially with respect to the maximum rating, operating supply voltage range, movement power voltage range, heat radiation characteristics, installation and other product characteristics. Renesas Electronics shall have no liability for malfunctions or damages arising out of the use of Renesas Electronics products beyond such specified ranges.
7. Although Renesas Electronics endeavors to improve the quality and reliability of its products, semiconductor products have specific characteristics such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Further, Renesas Electronics products are not subject to radiation resistance design. Please be sure to implement safety measures to guard them against the possibility of physical injury, and injury or damage caused by fire in the event of the failure of a Renesas Electronics product, such as safety design for hardware and software including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult, please evaluate the safety of the final products or systems manufactured by you.
8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. Please use Renesas Electronics products in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. Renesas Electronics assumes no liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
9. Renesas Electronics products and technology may not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You should not use Renesas Electronics products or technology described in this document for any purpose relating to military applications or use by the military, including but not limited to the development of weapons of mass destruction. When exporting the Renesas Electronics products or technology described in this document, you should comply with the applicable export control laws and regulations and follow the procedures required by such laws and regulations.
10. It is the responsibility of the buyer or distributor of Renesas Electronics products, who distributes, disposes of, or otherwise places the product with a third party, to notify such third party in advance of the contents and conditions set forth in this document, Renesas Electronics assumes no responsibility for any losses incurred by you or third parties as a result of unauthorized use of Renesas Electronics products.
11. This document may not be reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products, or if you have any other inquiries.

(Note 1) "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its majority-owned subsidiaries.

(Note 2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.

SALES OFFICES Renesas Electronics Corporation http://www.renesas.com

Refer to "http://www.renesas.com/" for the latest and detailed information.

Renesas Electronics America Inc.
2801 Scott Boulevard Santa Clara, CA 95050-2549, U.S.A.
Tel: +1-408-588-6000, Fax: +1-408-588-6130

Renesas Electronics Canada Limited
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3
Tel: +1-905-237-2004

Renesas Electronics Europe Limited
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K
Tel: +44-1628-585-100, Fax: +44-1628-585-900

Renesas Electronics Europe GmbH
Arcadiastrasse 10, 40472 Düsseldorf, Germany
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

Renesas Electronics (China) Co., Ltd.
Room 1709, Quantum Plaza, No.27 ZhiChunLu Haidian District, Beijing 100191, P.R.China
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

Renesas Electronics (Shanghai) Co., Ltd.
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, P. R. China 200333
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

Renesas Electronics Hong Kong Limited
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong
Tel: +852-2265-6688, Fax: +852 2886-9022

Renesas Electronics Taiwan Co., Ltd.
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan
Tel: +886-2-8175-9600, Fax: +886 2-8175-9670

Renesas Electronics Singapore Pte. Ltd.
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949
Tel: +65-6213-0200, Fax: +65-6213-0300

Renesas Electronics Malaysia Sdn.Bhd.
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

Renesas Electronics India Pvt. Ltd.
No.777C, 100 Feet Road, HALII Stage, Indiranagar, Bangalore, India
Tel: +91-80-67208700, Fax: +91-80-67208777

Renesas Electronics Korea Co., Ltd.
12F., 234 Teheran-ro, Gangnam-Gu, Seoul, 135-080, Korea
Tel: +82-2-558-3737, Fax: +82-2-558-5141

Colophon 5.0