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LV8811G, LV8813G, LV8814J Tuning Guide

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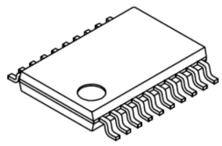
APPLICATION NOTE

Overview

The LV8811G, LV8813G, and LV8814J are 3-phase BLDC motor drivers which are controlled with a single Hall sensor. This document contains description about determination methods for external circuit constants, an adjustment mechanism setting method, and applications proposal for more stabilized operation.

More specifically, PWM pulse to DC conversion circuit and PH pin are mentioned for determining the constants, the phase advance (lead angle) is explained for the setting method with some specific examples, and reduction method for start-up instability due to the hall amplitude are explained.

PACKAGE PICTURE



LV8811G and LV8813G
20-pin TSSOP with exposed pad

LV8814J
20-pin SSOP

Contents

BLOCK AND APPLICATION CIRCUIT DIAGRAM

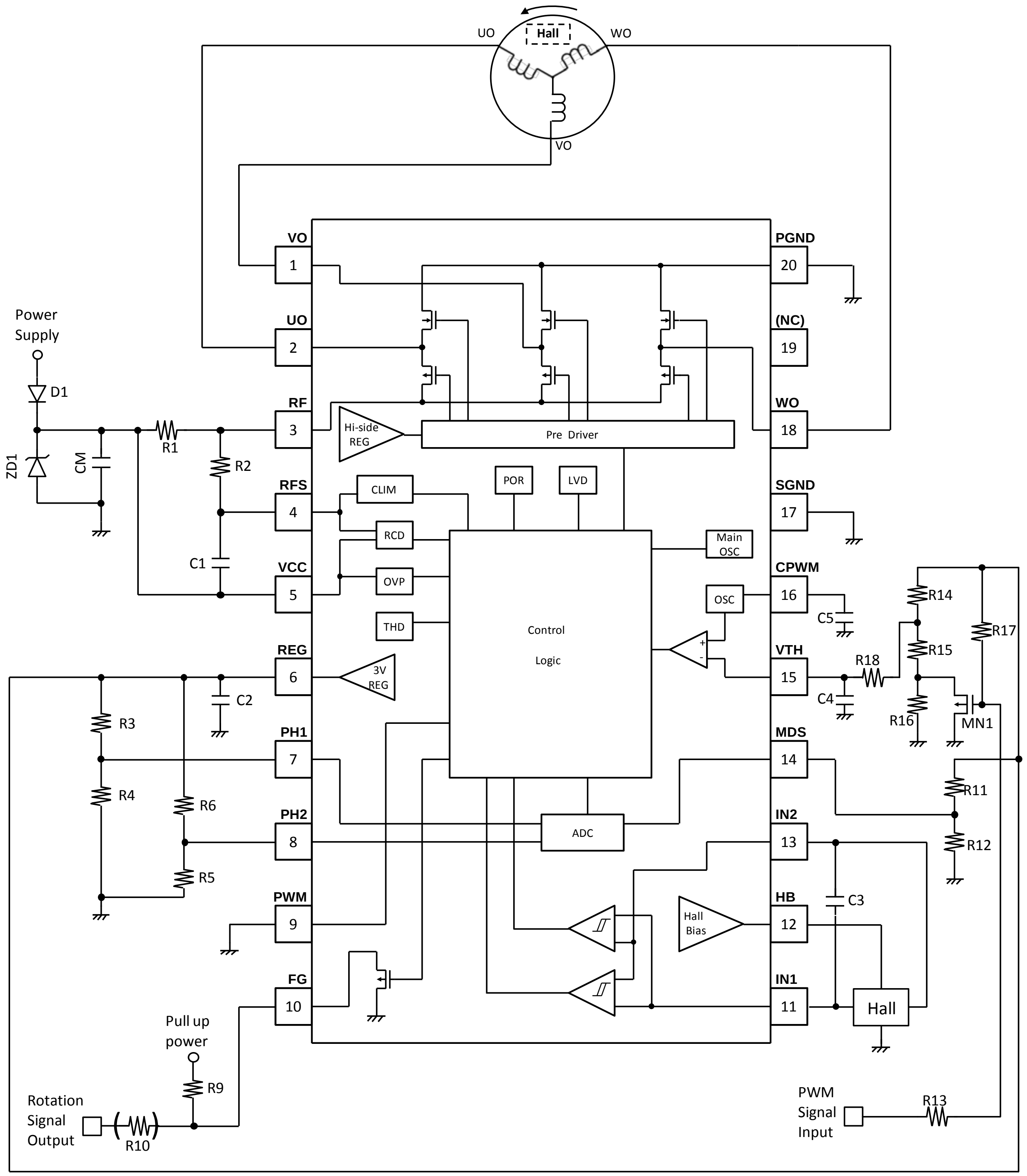


Figure 1: Block and Application circuit Diagram (Speed control by DC voltage)

Lead Angle Adjustment Description

About “the Lead-angle”

Ideally, motor is rotated most efficient when IC is commutated at cross point of Hall signal. Because, Hall signal indicate rotor position. It is same essentially BEMF. However, optimum commutation timing may change due to coil current delay by stator coil inductance. Therefore magnetic field generation for motor drive is delayed. Generally, the optimum timing is considered to be faster than Hall signal timing (Figure 2). Commutation timing is optimum when the Hall signal and the coil current is in-phase. This voltage phase adjustment is named "Lead-angle".

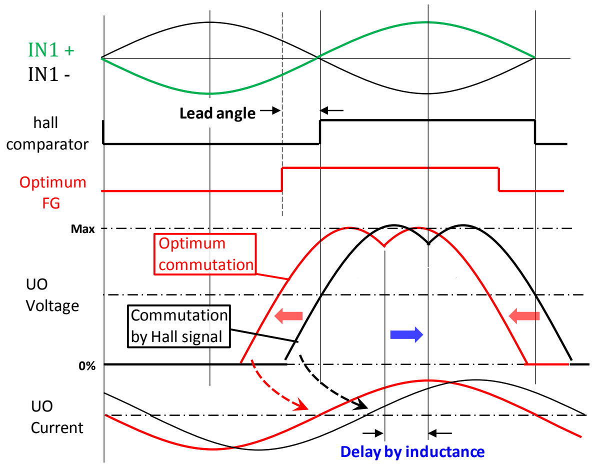


Figure 2: Lead-angle image

Relationship between rotational speed and the lead-angle is shown in Figure 3. It changes by the characteristic of a rotor and the coil inductance, and the lead-angle is almost proportional to the rotational speed.

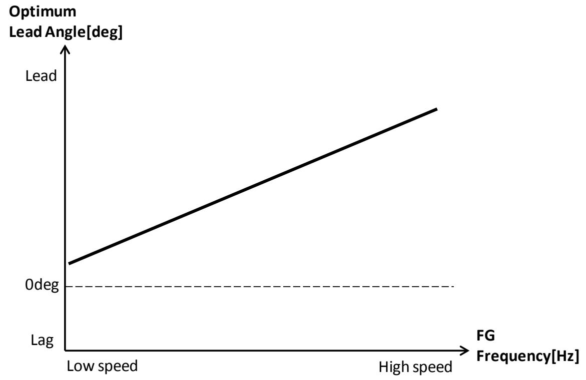


Figure 3: Optimum lead-angle vs FG frequency

Outline of the Lead-angle adjustment

Figure 3 shows general relationship between lead-angle and rotational speed. However, the optimum lead-angle will change according to the motor to be in use. The image is shown in Figure 4. To support various motors types, base and slope of the lead angle can be set individually. The image is shown in Figure 5. Individual adjustments can be realized by applying different DC voltage to PH1 and PH2 pin.

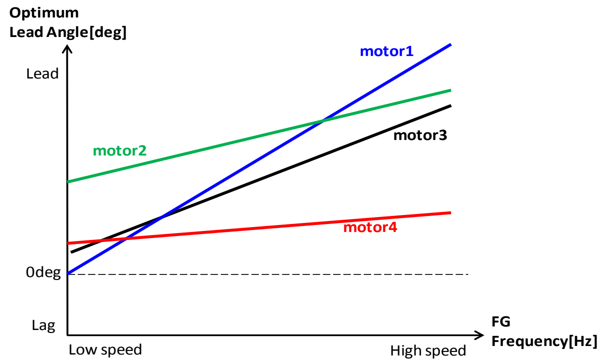


Figure 4: Lead-angle variously changes image

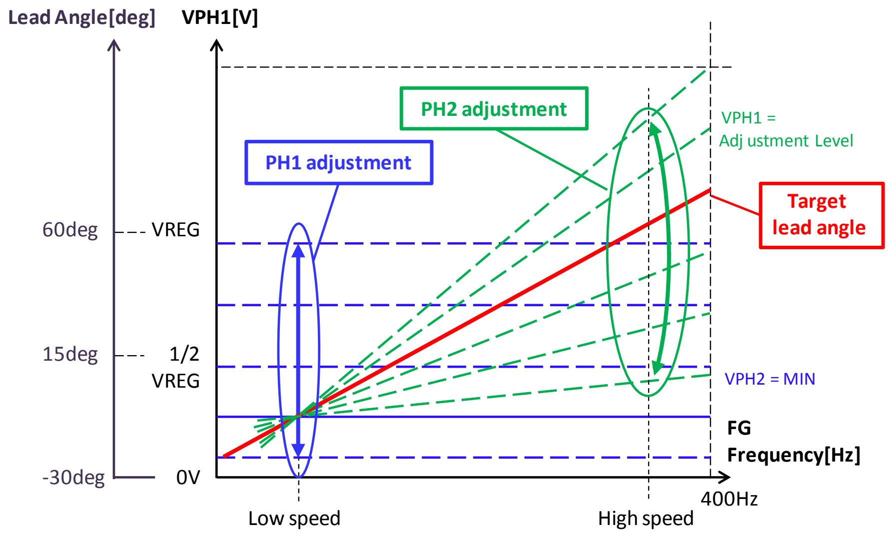


Figure 5: PH1 and PH2 adjustment image

Input condition of PH pins

Default state of this IC

- PH1 and PH2 input voltage = 0 V
  *These pins connect to GND
- Lead-angle base = 15 degree
- Lead-angle slope = 0.15 deg/Hz

Adjustment state of the IC

- PH1 and PH2 input range must be 0.141 to 2.906 V
- Lead-angle base adjustment range is -30 to 60 degree
- Lead-angle slope adjustment range is 0 to 0.3 deg/Hz

These relationships are shown in Figure 6.
Also, refer to page.16, page.28, page.30, and page.31 of the datasheet.

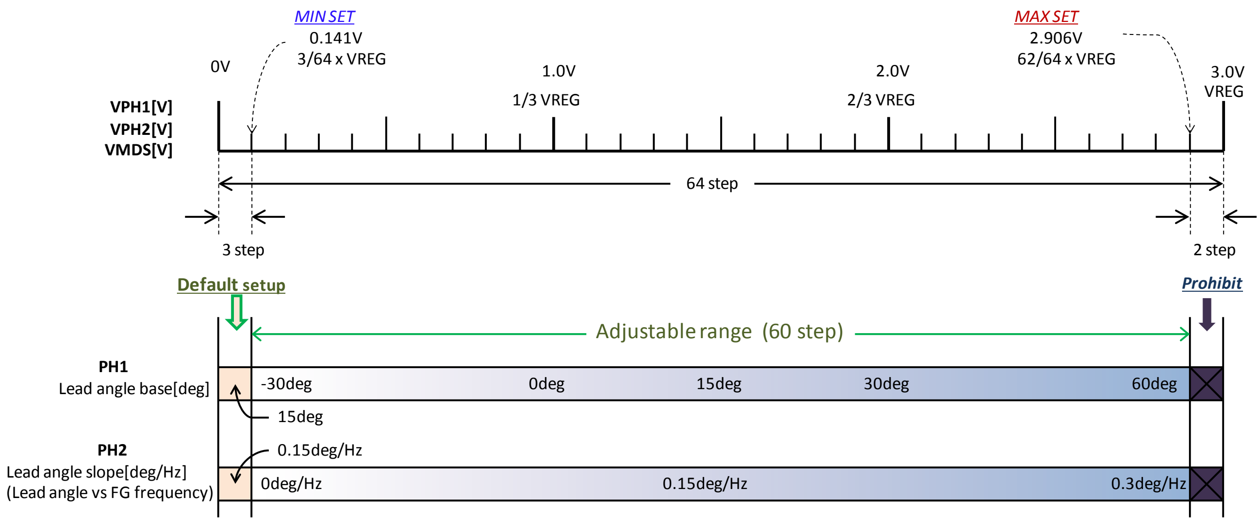


Figure 6: PH pins input voltage range

Adjustment method

The lead-angle is adjusted while external power-supply units are changing PH pin voltage. Input voltage may be different for PH1 and PH2. At first, PH1 pin is adjusted at state of low speed rotation. PH1 voltage is adjusted so that motor operation can be most efficient. Next, PH2 pin is adjusted by motor rotation at the high speed. At this time, PH2 voltage is adjusted so that motor operation can be most efficient. (Figure 5)
The lead-angle adjustment is finished when adjusted voltages are applied to both pins. After the adjustment, constants of external circuit must be determined.

Efficiency calculation formula:

$$\text{Efficiency} = \frac{f_{FG}}{V_{CC} \times I_{CC}}$$

Where
f_{FG}: FG frequency
V_{CC}: supply voltage
I_{CC}: supply current

PH pins are adjusted to achieve the highest efficiency. So that efficiency of above formula can become high. FG frequency can be substituted with motor rotational speed [rpm].
The change of PH voltages occurs the change of motor rotational speed. It should be kept to the same speed by adjusting PWM Duty-cycle or VTH voltage.
Adjustment flow is shown in Figure 7.

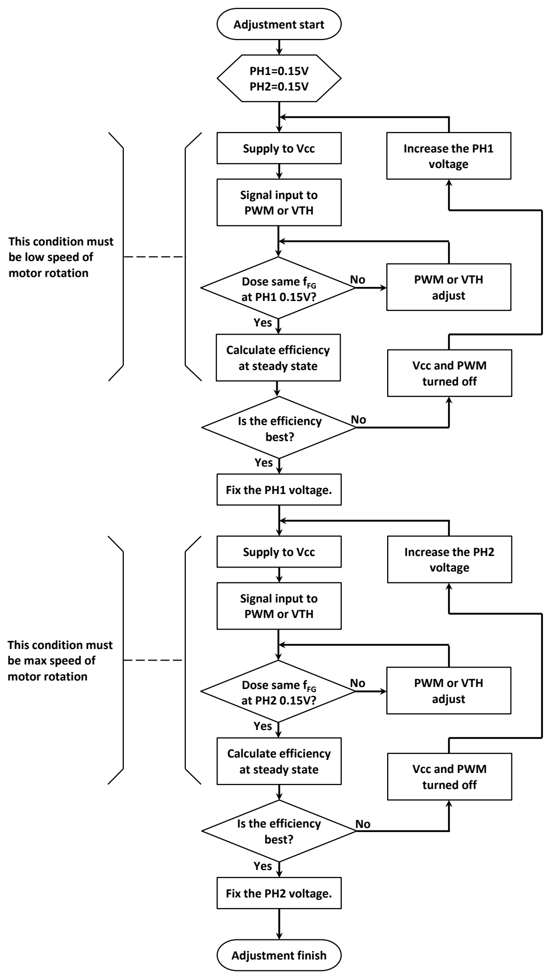


Figure 7: Adjustment flow diagram

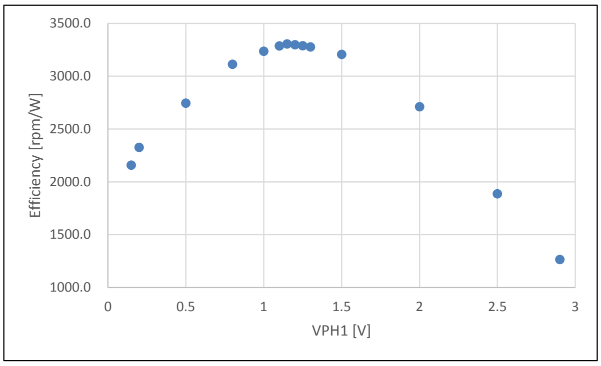
PH1 adjustment method example

In PH1 a motor must rotate in low speed. If controlled by PWM, set the PWM duty-cycle at 10% - 20%. In case of using VTH control, the applied voltage is to get the 10%-20% of maximum rotational speed. 0.15 V is applied to PH1 and PH2 pins. (Base and slope are minimum setting) Power supply voltage is applied after PH pin voltage input. Subsequently, input the PWM signal or the VTH voltage. Measure FG frequency after reaching steady rotation.
Turn off the power after FG frequency is measured. Turn it back on after the PH1 voltage changed.
If the rotational speed changes after PH1 change, get same rotational speed by adjusting PWM Duty-cycle or VTH voltage, then measure the f_{FG} and the I_{CC}. Repeating these procedures will create a table which would look like the one below. The PH pins read the voltage level only when power is on. Therefore, power supply must be turned off and back on after changing the PH voltage.

Measurement condition
Vcc = 12.0 V, PH2 = 0.15 V hold
PWM control : PWM freq = 25 kHz

VPH1	ICC	FG	Duty-cycle	Efficiency
0.15	16.33	14.10	21.2	2158.6
0.20	15.09	14.04	20.0	2326.0
0.50	12.84	14.10	19.2	2745.3
0.80	11.29	14.06	18.1	3113.4
1.00	10.86	14.06	17.9	3236.6
1.10	10.69	14.05	17.8	3258.8
1.15	**10.64**	**14.07**	**17.7**	**3305.9**
1.20	10.65	14.05	17.7	3298.1
1.25	10.70	14.07	17.7	3287.4
1.30	10.74	14.08	17.7	3277.5
1.50	10.99	14.09	17.6	3205.2
2.00	12.95	14.04	18.1	2710.4
2.50	18.40	13.89	20.9	1887.2
2.90	27.90	14.11	24.0	1264.3

Table 1: PH1 measurement value example



From the result of this measurement, optimum PH1 voltage for this the motor is 1.15 V.

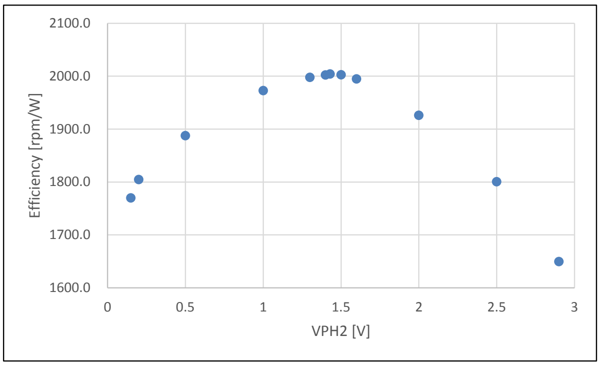
PH2 adjustment method example

In PH2 a motor must rotate at high speed. If controlled by PWM, set the PWM duty-cycle at 90%. In case of using VTH control, the applied voltage is to get the 90% of maximum rotational speed.
Adjusted voltage is applied to PH1 pin (This example is 2.2 V.) and 0.15 V is applied to PH2 pin. (Slope of lead-angle is minimum setting) Power supply voltage is applied after PH pin voltage input. Subsequently input the PWM signal or the VTH voltage. Measure the FG frequency after reaching steady rotation.
Turn off the power after FG frequency is measured. Turn it back on after the PH2 voltage changed.
If the rotational speed changes after PH2 change, get same rotational speed by adjusting PWM Duty-cycle or VTH voltage, then measure the f_{FG} and the I_{CC}. Repeating these procedures will create a table which would look like the one below.

Measurement condition
Vcc = 12.0 V, PH1 = 1.15 V hold
PWM control: PWM freq = 25 kHz

VPH2	ICC	FG	Duty-cycle	Efficiency
0.15	87.5	61.59	90.0	1770.0
0.20	85.7	61.87	88.4	1804.8
0.50	82.0	61.91	87.6	1887.5
1.00	78.5	61.95	85.1	1972.9
1.30	77.5	61.93	83.0	1997.7
1.40	77.3	61.91	82.8	2002.3
1.43	**77.2**	**61.89**	**82.7**	**2004.2**
1.50	77.3	61.92	82.7	2002.6
1.60	77.6	61.92	82.3	1994.8
2.00	80.4	61.94	81.2	1926.0
2.50	85.9	61.87	79.9	1800.6
2.90	93.9	61.96	79.0	1649.6

Table 2: PH2 measurement value example



From the result of this measurement, optimum PH2 voltage in the motor is 1.43 V.

From these two data, the optimum lead-angle with the best efficiency in all rotational speed range are 1.15 V for PH1 and 1.43 V for PH2.

The efficiency after adjustment

Example graph of efficiency is shown in Figure 8. It shows optimum adjustment and default setting(PH1 and PH2 are 0 V).

With the optimum lead-angle adjustment, the motor can drive at the minimum power consumption in all rotational speed range.

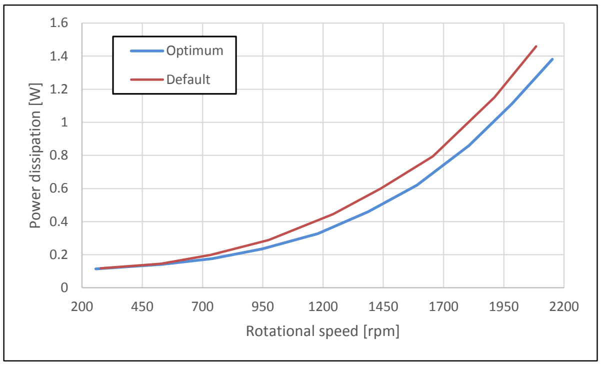


Figure 8: Efficiency vs Rotational speed

Resistance selection method of PH1, PH2

It is recommended to use VREG, with the resistance divider, to create the PH input voltage because the PH internal circuit operates by VREG. External circuit of PH pin is shown in Figure 9.
Relationship between divider voltage and resistance value is calculated with this formula:

$$V_{PH} = \frac{R_{GND}}{R_{REG} + R_{GND}} \times V_{REG}$$

When the total of divider resistance value (R_{REG}+R_{GND}) is too small, efficiency may deteriorate because REG current will increase. In contrast, when it is too large, IC may operate abnormally because PH wires receive noise. Therefore, recommended value range is between 20 kΩ to 100 kΩ.
If lead-angle setting is influenced by the noise, add capacitor in between PH pin and the GND. Additional capacitor value is calculated by formula at below.

$$A \times f_{NOISE} = \frac{1}{2\pi \times C_{ADD} \times R_{PH}}$$

Where
f_{NOISE}: Frequency of interference
C_{ADD}: Additional capacitor between PH and GND
R_{PH}: Total of divider resistancel

A value of C_{ADD} must be selected to make the value of A to fit in the range of 40-50.

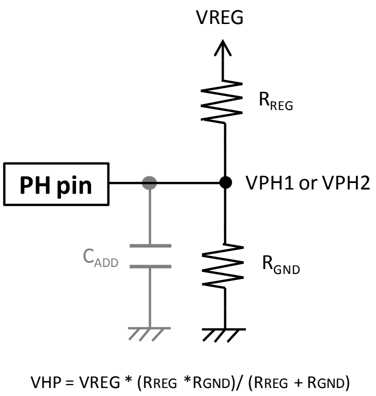


Figure 9: PH pin application circuit

HALL ELEMENT DESCRIPTION

About the output signal of Hall element

Hall element signal is very important, because it transmits rotor position to IC. The signal is input into IN1 and IN2 pin. In general, larger hall signal amplitude will provide more stable operation. Necessary amplitude will vary by the S/N ratio, but in principle, it will have stable operation at approximately 150 m to 200 mVpp. (Figure 10)

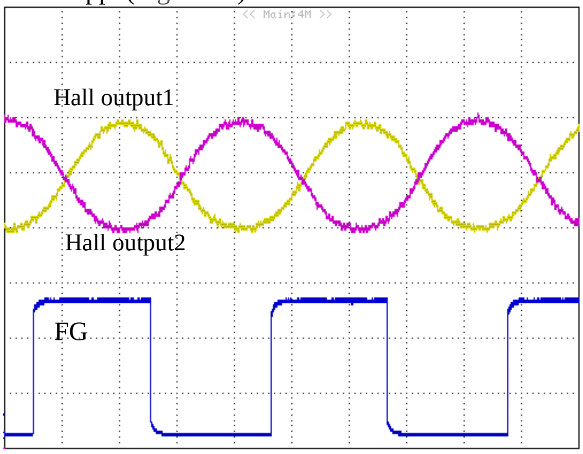


Figure 10: Hall signal waveform

The amplitude is influenced by 3 factors:

- Hall element bias current
- Magnetic flux density of a rotor
- Distance between a rotor and a Hall element.

The image is shown in Figure 11.

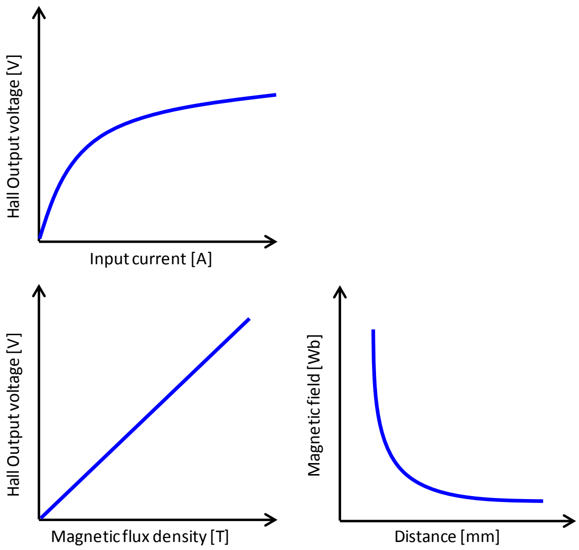


Figure 11: General characteristics of Hall element

To increase the amplitude more, Hall element and rotor position should be as close as possible. And to decrease noise influence more, wire distance between Hall and IC is designed at its shortest distance.

The IC determines the commutation timing by referring to the cross point of Hall signal. Therefore, magnetic field of stator coil is changed by cross point of the signal.

If a Hall element is placed too close to a stator coil, it may be affected by magnetic field of the stator coil. In such a case, magnetic field transition by the change of commutation would be detected by the IC and cause to output an error signal. Thus, be sure to place a Hall element to where it will not be affected.

For stable operation, it is recommended to have trapezoidal hall signal waveform because steep slope makes it easier to detect cross point of the hall signal. Using trapezoid magnetizing type rotor will realize this. (Figure 12)

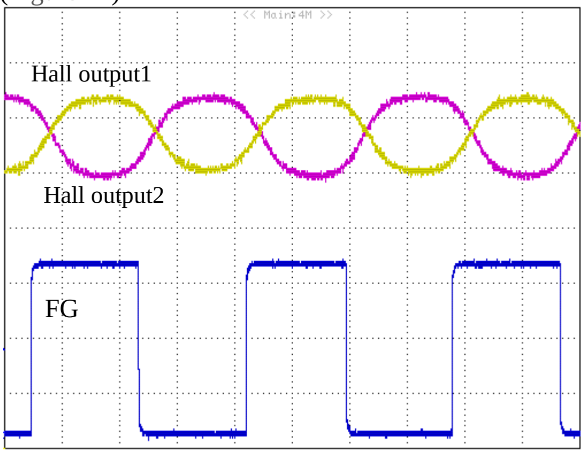


Figure 12: Hall signal waveform (trapezoid)

Output amplitude adjustment of Hall element by input bias

When the voltage (1.2 V) of the Hall bias pin HB is not enough, the regulator output pin REG (3 V) may be useful. Thereby, Hall output amplitude increase by current increase. Apposite applied voltage and apposite output bias are determined by add a few elements to circuit. Circuit example is shown in Figure 13.

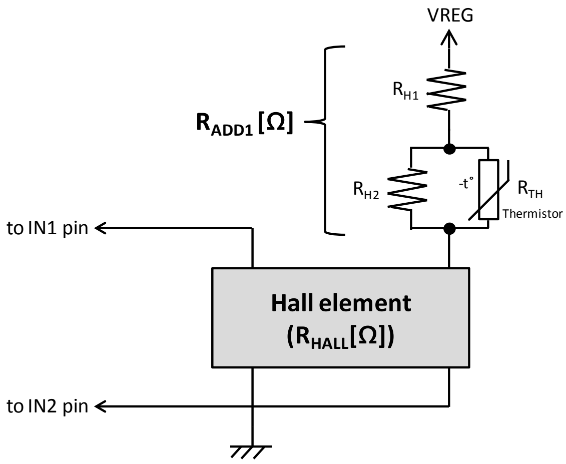


Figure 13: Circuit example for amplitude increase

In this case, to cancel sudden temperature of Hall characteristics, negative temperature coefficient (NTC) thermistor is used. General Hall temperature characteristics and the thermistor temperature characteristics are shown in Figure 14.

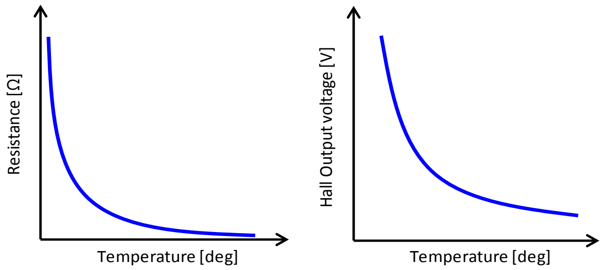


Figure 14: General Hall temperature characteristics and general thermistor characteristics

Hall element apply voltage and Hall element output bias are calculated by formula at below.

$$V_{HALL\_IN} = \frac{R_{HALL}}{R_{HALL} + R_{ADD1}} \times V_{REG}$$

$$V_{HALL\_BIAS} = \frac{1}{2} \times V_{HALL\_IN}$$

Where

V_{HALL_IN}: Hall input voltage

V_{HALL_BIAS}: Hall output bias voltage

V_{ADD1}: $\left(\frac{R_{H2} \times R_{TH}}{R_{H2} + R_{TH}}\right) + R_{H1}$

Note that R_{TH} and R_{HALL} are function of temperature.

Even though output Hall signal by magnetic flux detection, V_{HALL_BIAS} must be designed output level range within 0.3-1.8 V. The output level means spec of IN1, IN2 input voltage range. V_{HALL_IN} will vary according to Hall element type to be in use. Be sure to refer to the hall element datasheet when designing these.

An example of constant is shown in Figure 15, when using real elements. In this condition, a temperature characteristic of Hall amplitude is shown in Figure 16. Be sure to determine a constant through experiment.

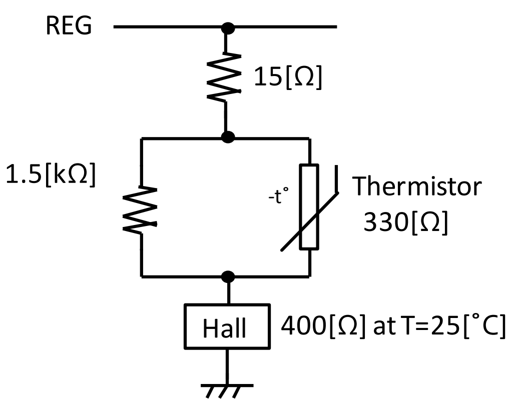


Figure 15: An example of fixed number

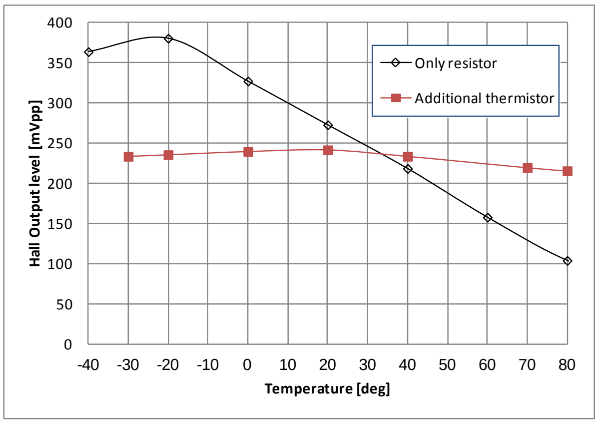


Figure 16: Temperature characteristics compensator of Hall signal amplitude

When Hall amplitude is too large, Hall power consumption can reduce by insertion resistor between Hall and GND. (The elements are inserted in between Hall and GND to satisfy IN1, IN2 input voltage range.) Efficiency is slightly enhanced by this method. In this case, current reduction quantity must be determined while IC operations check stable operation by experiment, because Hall current and Hall amplitude reduce simultaneously. (Figure 17)

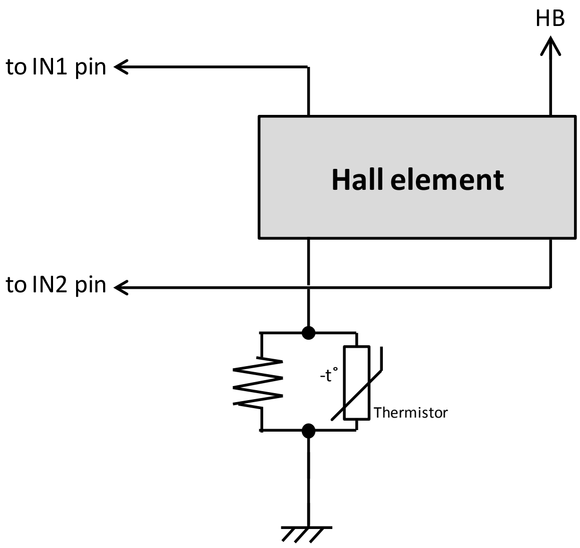


Figure 17: Efficiency improvement application

DC-PWM CONVERSION DESCRIPTION

Speed control by V_{VTH} pin

It has more flexibility and can select min speed setting when rotational speed is controlled by DC voltage. When the speed controlled by PWM pulse, min speed setting cannot be selected. Slope of the DC voltage and rotational speed are adjustable. (Figure 18)

This DC voltage is applied to V_{VTH} pin. Figure 20 shows the conversion from PWM input to V_{VTH} DC voltage.

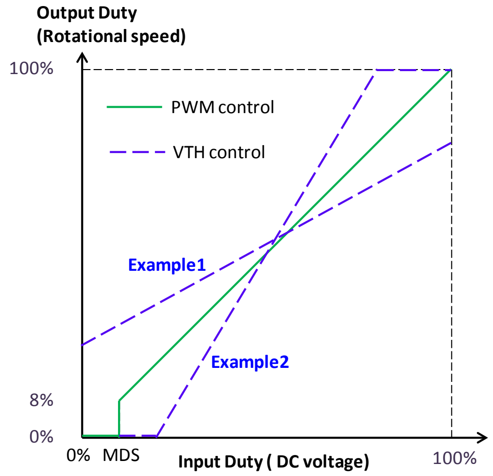


Figure 18: Image of speed control by DC voltage

Relations of V_{VTH} voltage and output duty-cycle

Output duty-cycle determines rotational speed. The duty-cycle is determined by V_{VTH}. The relationship between both is calculated by formula at below.

$$V_{VTH} = V_{CPWMH} - (V_{CPWMH} - V_{CPWML}) \times \frac{D_{OUT}}{100} \quad (1.0)$$

Where D_{OUT}: Output PWM duty cycle
V_{CPWMH}: 0.67(typ) $\times$ V_{REG}
V_{CPWML}: 0.18(typ) $\times$ V_{REG}
V_{REG}: 3.0(typ)

Be sure to refer to the Datasheet (page 26 ~ 27) for the allowable input range of V_{VTH} pin input voltage. Extra caution is necessary for 0% and 100% duty-cycle.

Relations of V_{VTH} voltage and input duty-cycle

Input PWM signal converts to DC voltage by external circuit. The conversion must be performed optimum dividing and optimum filtering. Assuming that the circuit has optimum filtering, this section is focused only on divider block description. (Refer to p.17 of the data sheet)

Relationship between input duty-cycle and V_{VTH} voltage is shown at below. Also refer to Figure 19.

$$V_{VTH} = V_{REG} \times \left\{\frac{R_{15}+R_{16}}{R_A} - \frac{R_{14}\times R_{16}}{R_A \times R_B} \times \frac{D_{PWM}}{100}\right\} \quad (2.0)$$

When $R_A = R_{14} + R_{15} + R_{16}$
$R_B = R_{14} + R_{15}$

When input duty-cycle is 100% or more, the R16 resistor is disabled because MOS is full on. Therefore, V_{VTH} is calculated at below.

$$V_{VTH} = V_{REG} \times \left(\frac{R_{15}}{R_{14}+R_{15}}\right) \quad (2.1)$$

Similarly, input duty-cycle is 0% or less, V_{VTH} is calculated at below because MOS is turn-off.

$$V_{VTH} = V_{REG} \times \left(\frac{R_{15}+R_{16}}{R_{14}+R_{15}+R_{16}}\right) \quad (2.2)$$

- When input duty-cycle is 100% or more;
  Formula (1.0) and (2.1) are used
- When input duty-cycle is 0% or less;
  Formula (1.0) and (2.2) are used

R16 resistance value must be select large enough than on-resistance of MOS transistor.

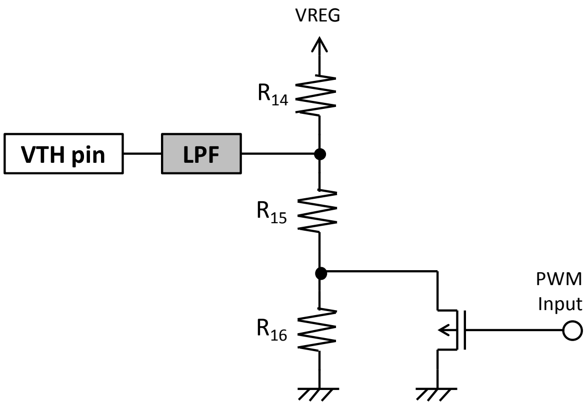


Figure 19: External circuit of V_{VTH} pin

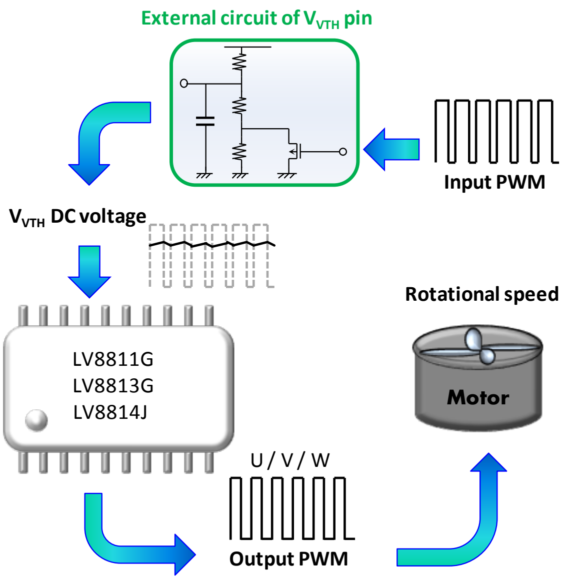


Figure 20: Speed control signal flow

Resistance selection method of V_{VTH} external circuit

When input duty-cycle is 100%, (1.0) and (2.1) formulas determine rotational speed (output duty-cycle). Optimum R14 and R15 are determined by these formulas. Then, when input duty-cycle is 0%, (1.0) and (2.2) formulas determine rotational speed (output duty-cycle). Remaining R16 is determined by these formulas.

Case1 (Example1 of Figure 18)

This example postulate below:

- Input duty-cycle at 0% is output duty-cycle at 20%.
- Input duty-cycle at 100% is output duty-cycle at 80%.

When these condition, the resistance value calculate by (1.0), (2.1) and (2.2). Behavior image is shown by Figure 21.

Input duty-cycle 100% is output 80% ;

$$2.01-\left(1.47\times\frac{80}{100}\right)=3.0\times\left(\frac{R_{15}}{R_{14}+R_{15}}\right)$$

$$3.0\times\left(\frac{R_{15}}{R_{14}+R_{15}}\right)=0.834$$

$R_{14}\cong 62\ \text{k}\Omega,\quad R_{15}\cong 24\ \text{k}\Omega$ (An example)

Input duty-cycle 0% is output 20% ;

$$2.01-\left(1.47\times\frac{20}{100}\right)=3.0\times\left(\frac{R_{15}+R_{16}}{R_{14}+R_{15}+R_{16}}\right)$$

$$3.0\times\left(\frac{24k+R_{16}}{62k+24k+R_{16}}\right)=1.716$$

$$R_{16}\cong 59.3\ \text{k}\Omega=56\ \text{k}\Omega+3.3\ \text{k}\Omega$$

R14 = 62 kΩ, R15 = 24 kΩ, R16 = 56 kΩ + 3.3 kΩ

Three constant values are determined. There are determined by kΩ order because there considered the influence of MOS on-resistor. When these resistance values are used, calculation results are shown in Figure 21 parentheses value. However, the value is an example by the standard IC characteristic. Be sure to have adequate margin in the actual design.

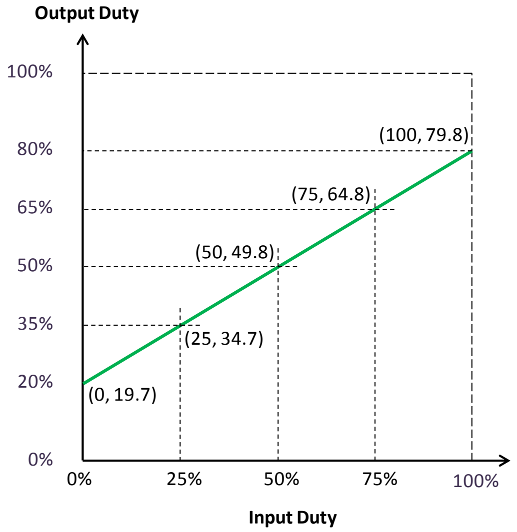


Figure 21: Case1: Relationship between in/out duty-cycle (An example)

Case2 (Example2 of Figure 18)

Case2 postulate below:

- Input duty-cycle at 15% is output duty-cycle at 0%.The duty-cycle range between 0 to 15% is rotation stop.
- Input duty-cycle at 85% is output duty-cycle at 100%. The duty-cycle range between 85 to 100% is the maximum speed.

Behavior image is shown by Figure 22.

To use (2.1) and (2.2), output duty-cycles must be calculated at input duty-cycle 0% and 100%. These are calculated backward from the slope. Image and results is shown in Figure 22. Calculation in case 2 is very similar to the one of case1; it uses values from two points

Input duty-cycle is 100% is output 121.43% ;

$$2.01-\left(1.47\times\frac{121.43}{100}\right)=3.0\times\left(\frac{R_{15}}{R_{14}+R_{15}}\right)$$

$R_{14}\cong 18\ \text{k}\Omega,\quad R_{15}\cong 1.5\ \text{k}\Omega$ (An example)

Input duty-cycle is 0% is output -21.43% ;

$$2.01-\left(1.47\times\frac{-21.43}{100}\right)=3.0\times\left(\frac{R_{15}+R_{16}}{R_{14}+R_{15}+R_{16}}\right)$$

$$R_{16}\cong 60.3\ \text{k}\Omega=56\ \text{k}\Omega+4.3\ \text{k}\Omega$$

R14 = 18 kΩ, R15 = 1.5 kΩ, R16 = 56 kΩ + 4.3 kΩ

Three constant values are determined. When these resistance values are used, calculation results are shown in Figure 22 parentheses value. Case1 similarly, when actually design, the design must be have margin.

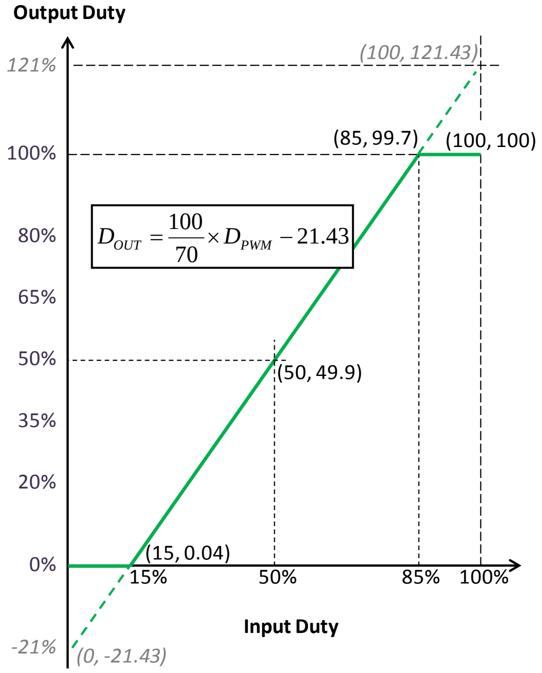


Figure 22: Case2: Relationship between in/out duty-cycle (An example)