LB11685AV

Monolithic Digital IC

3-Phase sensor less Motor Driver Application Note

Overview

The LB11685AV is a three-phase full-wave current-linear-drive motor driver which adopts a sensorless control system without a use of Hall effect device. The LB11685AV features a current soft switching circuit for silent operation. This device is optimal for driving cooling fan motors used in refrigerators and various others.

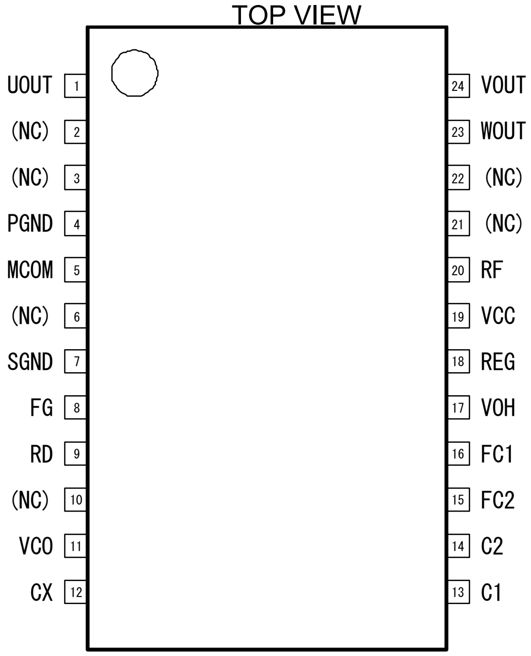
Function

- Three-phase full-wave linear drive (Hall sensor-less method)
- Built-in three-phase output voltage control circuit
- Built-in current limiter circuit
- Built-in motor lock protection circuit
- Motor lock protection detection output
- FG output made by back EMF
- Built-in thermal shut down circuit
- Beat lock prevention circuit

Typical Applications

- Cooling fan for refrigerators

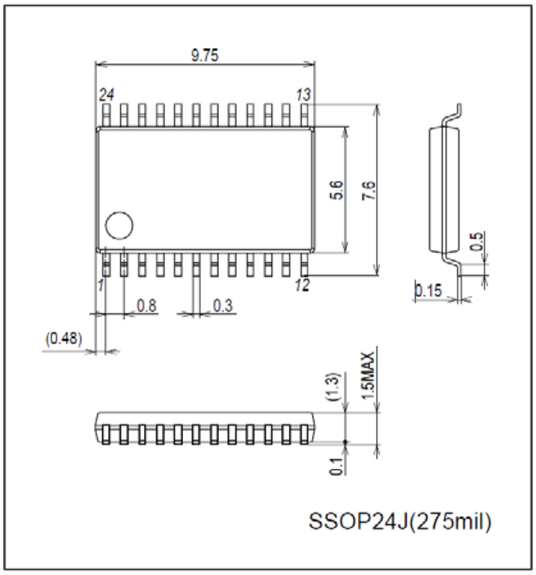
Pin Assignment



Package Dimensions

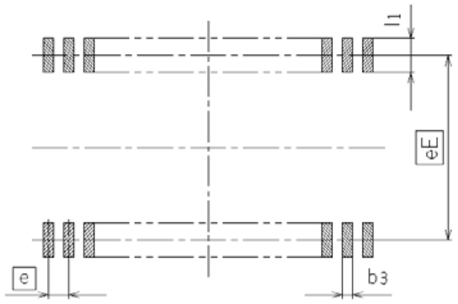
unit : mm (typ)

3315



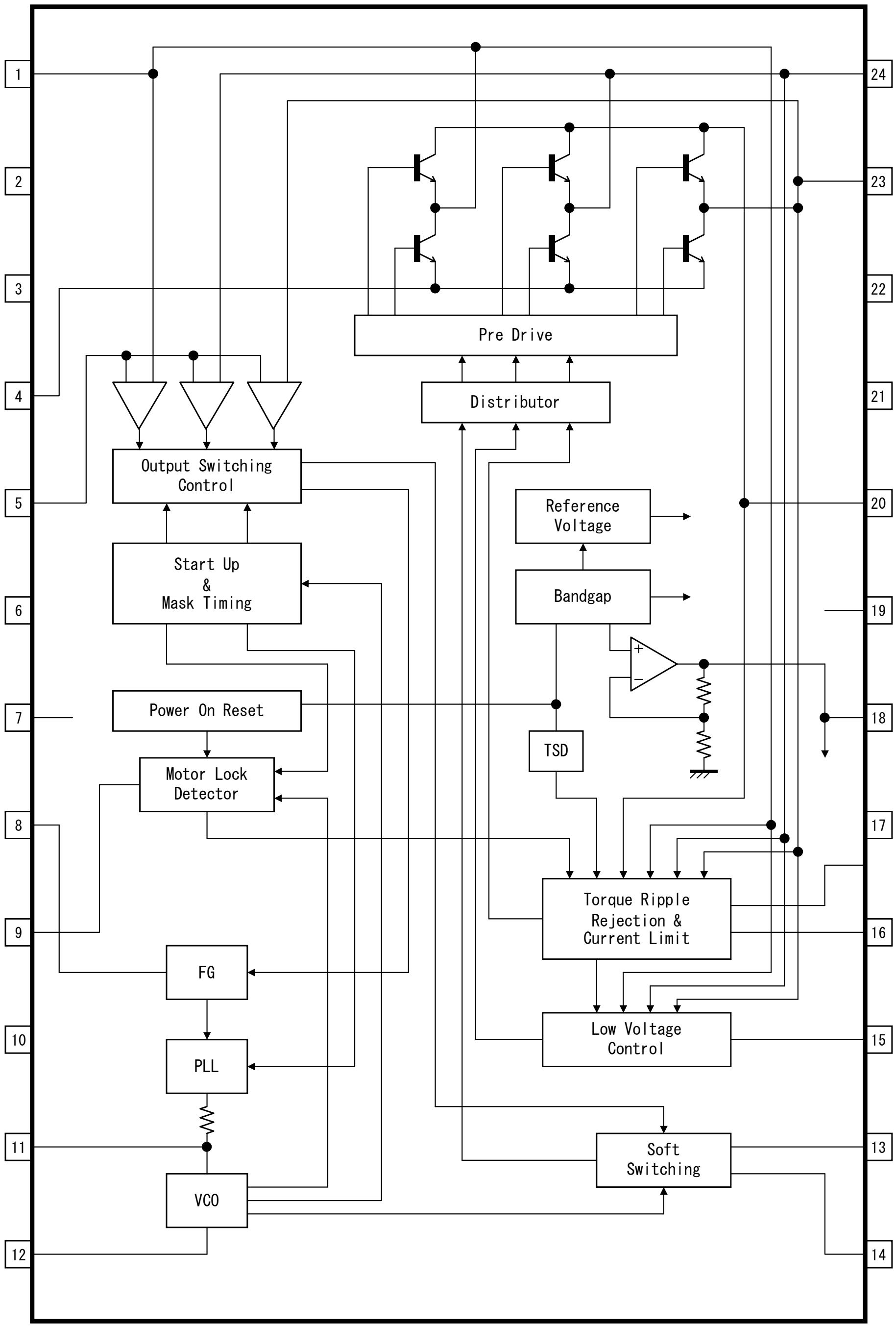
Caution: The package dimension is a reference value, which is not a guaranteed value.

Recommended Soldering Footprint



Reference Symbol	SSOP24J(275mil)
eE	7.00
e	0.80
b3	0.42
l1	1.00

Block Diagram



Specifications

Absolute Maximum Ratings at Ta = 25°C

Parameter	Symbol	Conditions	Ratings	Unit
Maximum supply voltage	V_{CC} max		19	V
Input applied voltage	V_{IN} max		-0.3 to V_{CC} +0.3	V
Maximum output current	I_O max *1		1.2	A
Allowable power dissipation	Pd max	Mounted on a board. *2	1.05	W
Operating temperature	Topr		-40 to 85	deg.
Storage temperature	Tstg		-55 to 150	deg.
Junction temperature	Tj max		150	deg.

*1: The I_O is a peak value of motor-current.

*2: Specified board: 76.1mm × 114.3mm × 1.6mm, glass epoxy board.

Caution 1) Absolute maximum ratings represent the value which cannot be exceeded for any length of time.

Caution 2) Even when the device is used within the range of absolute maximum ratings, as a result of continuous usage under high temperature, high current, high voltage, or drastic temperature change, the reliability of the IC may be degraded. Please contact us for the further details.

Stresses exceeding Maximum Ratings may damage the device. Maximum Ratings are stress ratings only. Functional operation above the Recommended Operating Conditions is not implied. Extended exposure to stresses above the Recommended Operating Conditions may affect device reliability.

Recommended Operating Conditions at Ta = 25°C

Parameter	Symbol	Conditions	Ratings			Unit
			min	typ	max	
Recommended Supply voltage	V_{CC}			12		V
Operating supply voltage	V_{CC} op		4.5		18.0	V

Electrical Characteristics at Ta = 25°C, V_{CC} = 5.0V

Parameter	Symbol	Conditions	Ratings			Unit
			min	typ	max	
Supply current	I_{CC}	FC1=FC2=0V	5	10	20	mA
Internal regulate voltage	VREG		3.0	3.3	3.6	V
Output voltage (source)	VOSOUR	I_O =0.8A *3		1.3	1.7	V
Output voltage (sink)	VOSINK	I_O =0.8A *3		0.5	1.3	V
Current limiter	VOLIM		0.268	0.300	0.332	V
MCOM pin common-input voltage range	VINCOM		0		V_{CC} -2	V
MCOM pin Source current for hysteresis	ICOM+	MCOM=7V	30		80	μA
MCOM pin Sink current for hysteresis	ICOM-	MCOM=7V	30		80	μA
MCOM pin hysteresis current ratio	RTCOM	RTCOM=ICOM+/ICOM-	0.6		1.4	
VCO input bias current	IVCO	VCO=2.3V			0.2	μA
VCO oscillation minimum frequency	f_{VCO} min	VCO=2.1V, CX=0.015μF Design target*2		930		Hz
VCO oscillation maximum frequency	f_{VCO} max	VCO=2.7V, CX=0.015μF Design target*2		8.6		kHz
CX charge / discharge current	ICX	VCO=2.5V, CX=1.6V	70	100	140	μA
CX hysteresis voltage	□VCX		0.35	0.55	0.75	
C1 (C2) charge current	IC1(2)+	VCO=2.5V, C1(2)=1.3V	12	20	28	μA
C1 (C2) discharge current	IC1(2)-	VCO=2.5V, C1(2)=1.3V	12	20	28	μA
C1 (C2) charge/discharge current ratio	RTC1(2)	RTC1(2)=IC1(2)+/IC1(2)-	0.8	1.0	1.2	
C1/C2 charge current ratio	RTCCHG	RTCCHG=IC1+/IC2+	0.8	1.0	1.2	
C1/C2 discharge current ratio	RTCDIS	RTCDIS=IC1-/IC2-	0.8	1.0	1.2	
C1 (C2) cramp voltage width	VCW1(2)		1.0	1.3	1.6	V

Continued on next page.

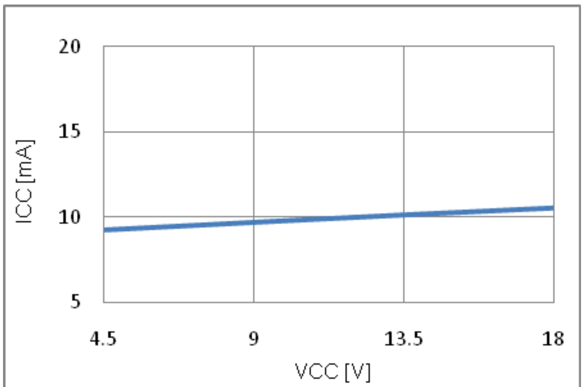
Continued from preceding page.

FG output low level voltage	VFGL	I_{FG} =3mA			0.5	V
RD output low level voltage	VRDL	I_{RD} =3mA			0.5	V
Thermal shut down operating temperature[*1]	TTSD	Junction temperature Design target[*2]	150	180		deg.
Thermal shut down hysteresis width[*1]	ΔTTSD	Junction temperature Design target[*2]		15		deg.

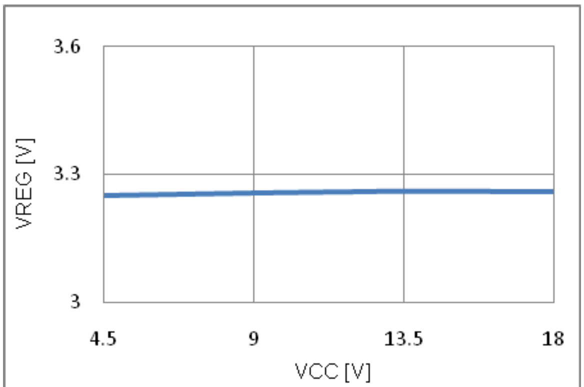
*1: The thermal shut down circuit is built-in for protection from damage of IC. But its operation is out of Topr. Design thermal calculation at normal operation.

*2: Design target value and no measurement is made.

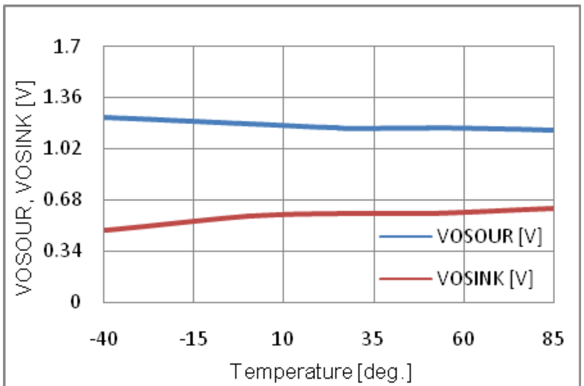
*3: The I_O is a peak value of motor-current.



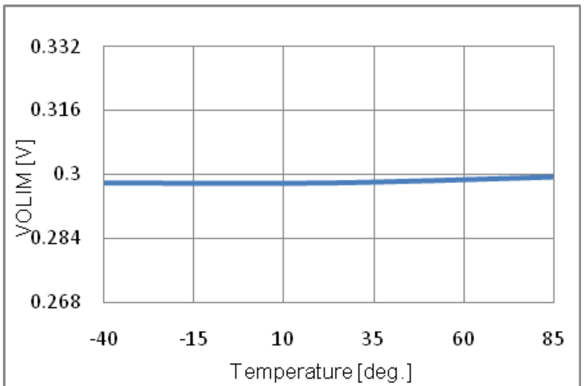
Supply current vs VCC voltage



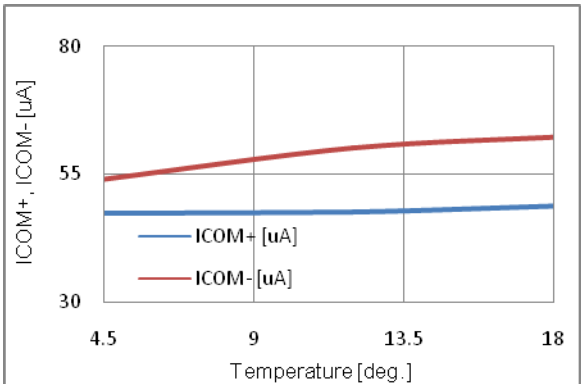
Internal Regulate Voltage vs VCC voltage



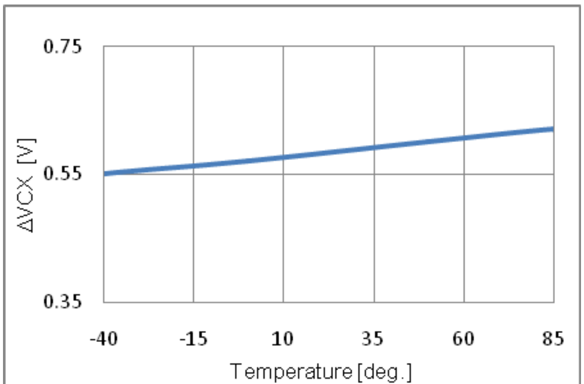
Output voltage vs Temperature



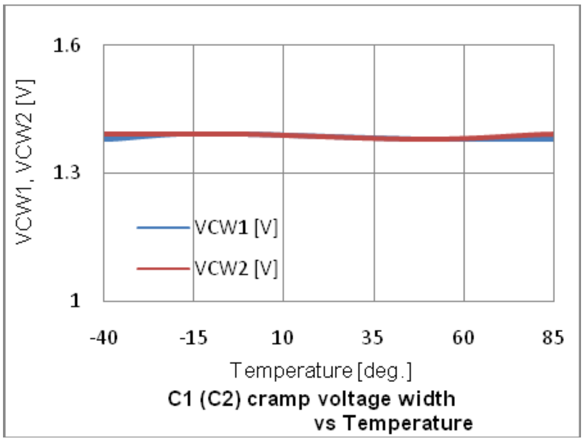
Current limiter vs Temperature



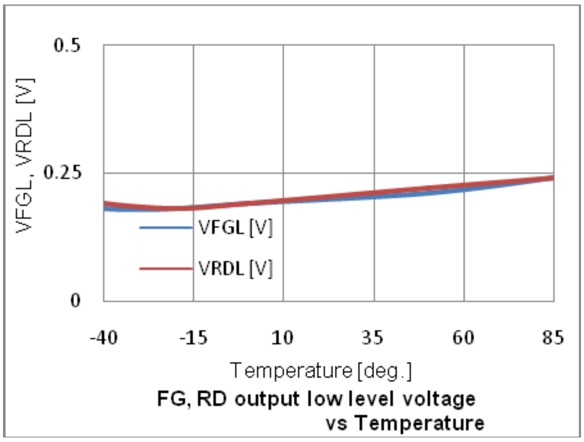
MCOM pin current for hysteresis vs VCC voltage



CX hysteresis Voltage vs Temperature

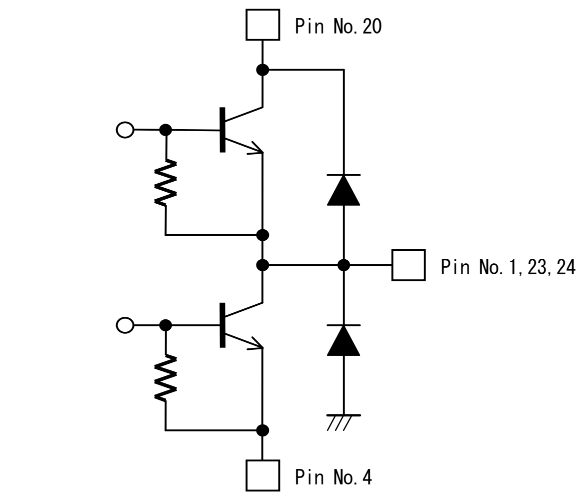
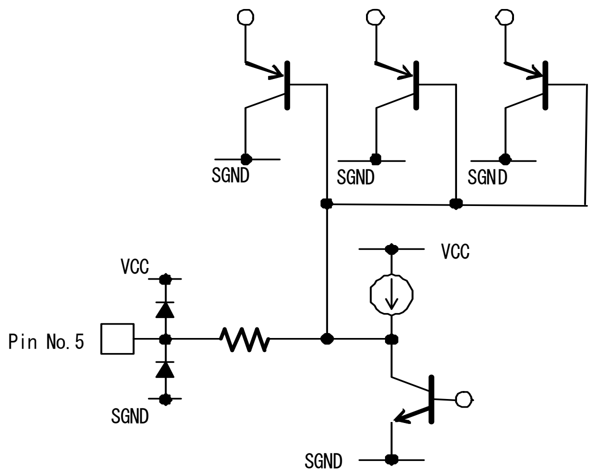


C1 (C2) cramp voltage width vs Temperature



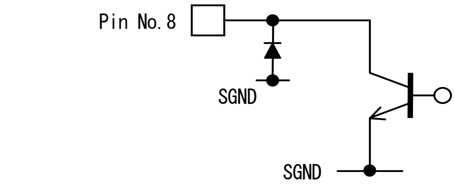
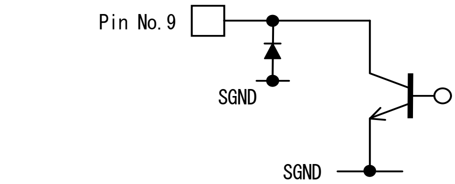
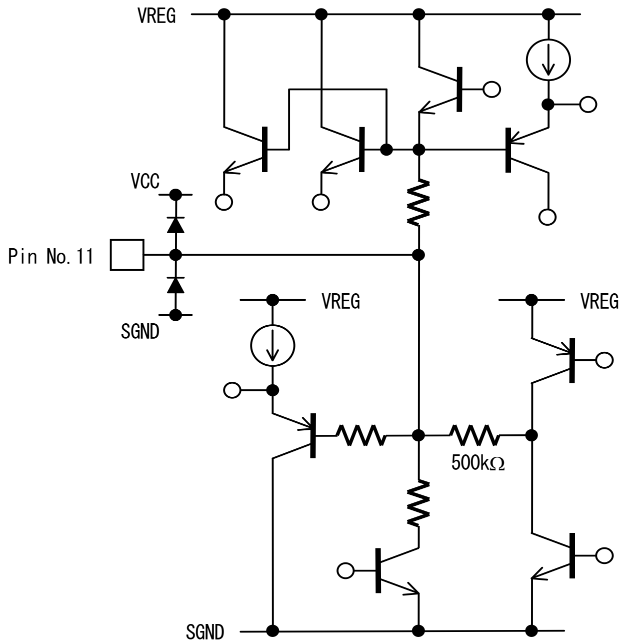
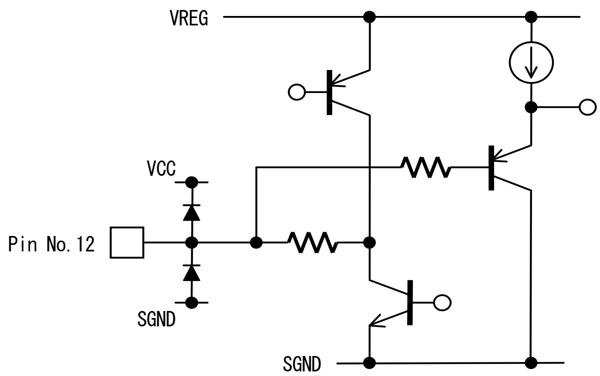
FG, RD output low level voltage vs Temperature

Pin Function

Pin No.	Pin name	Function	Equivalent circuit
1 23 24	UOUT WOUT VOUT	Each output pin of three phases.	
4	PGND	GND pin in the output part. This pin is connected to GND. The SGND pin is also connected to GND.	
20	RF	Pin to detect output current. By connecting a resistor between this pin and VCC, the output current is detected as a voltage. The current limiter is operated by this voltage.	
5	MCOM	Motor coil midpoint input pin. The coil voltage waveform is detected based on this voltage.	
7	SGND	Ground pin (except the output part) This pin is connected to GND. The PGND pin is also connected to GND.	

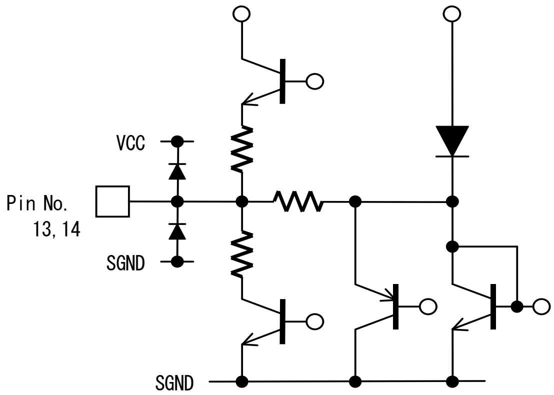
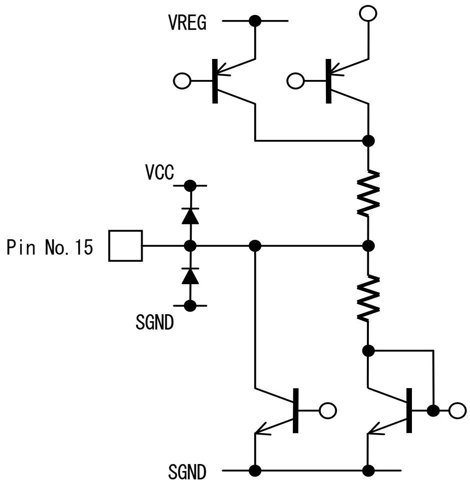
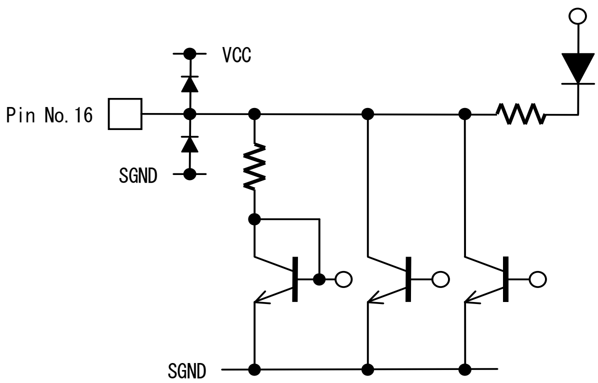
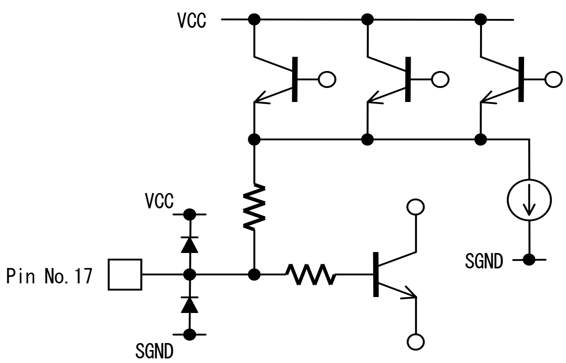
Continued on next page.

Continued from preceding page.

Pin No.	Pin name	Function	Equivalent circuit
8	FG	FG out made by back-EMF pin. It synchronizes FG out with inverted V-phase. When don't use this function, open this pin.	
9	RD	Motor lock protection detection output pin. Output with Low during rotation of motor. Open during lock protection of motor (High-impedance) When don't use this function, open this pin.	
11	VCO	PLL output pin and VCO input pin. To stabilize PLL output, connect a capacitor between this pin and GND.	
12	CX	VCO oscillation output pin. Operation frequency range and minimum frequency are determined by the capacity of a capacitor connected to this pin.	

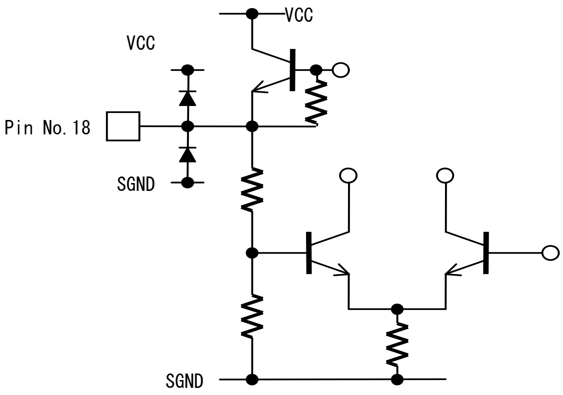
Continued on next page.

Continued from preceding page.

Pin No.	Pin name	Function	Equivalent circuit
13 14	C1 C2	Soft switching adjustment pin. The triangular wave form is formed by connecting a capacitor with this pin. And, the switching of three-phase output is adjusted by the slope.	
15	FC2	Frequency characteristic correction pin 2. To suppress the oscillation of control system closed loop of sink-side, connect a capacitor between this pin and GND.	
16	FC1	Frequency characteristic correction pin 1. To suppress the oscillation of control system closed loop of source-side, connect a capacitor between this pin and GND.	
17	VOH	Three-phase output high level output pin. To stabilize the output voltage of this pin, connect a capacitor between this pin and the VCC pin.	

Continued on next page.

Continued from preceding page.

Pin No.	Pin name	Function	Equivalent circuit
18	VREG	DC voltage (3.3V) output pin. Connect a capacitor between this pin and GND for stabilization.	
19	VCC	Pin to supply power-supply voltage. To curb the influence of ripple and noise, the voltage should be stabilized.	

Operation Description

1. Operation Overview

1-1. Block Description

1-1-1. Regular Rotation mode

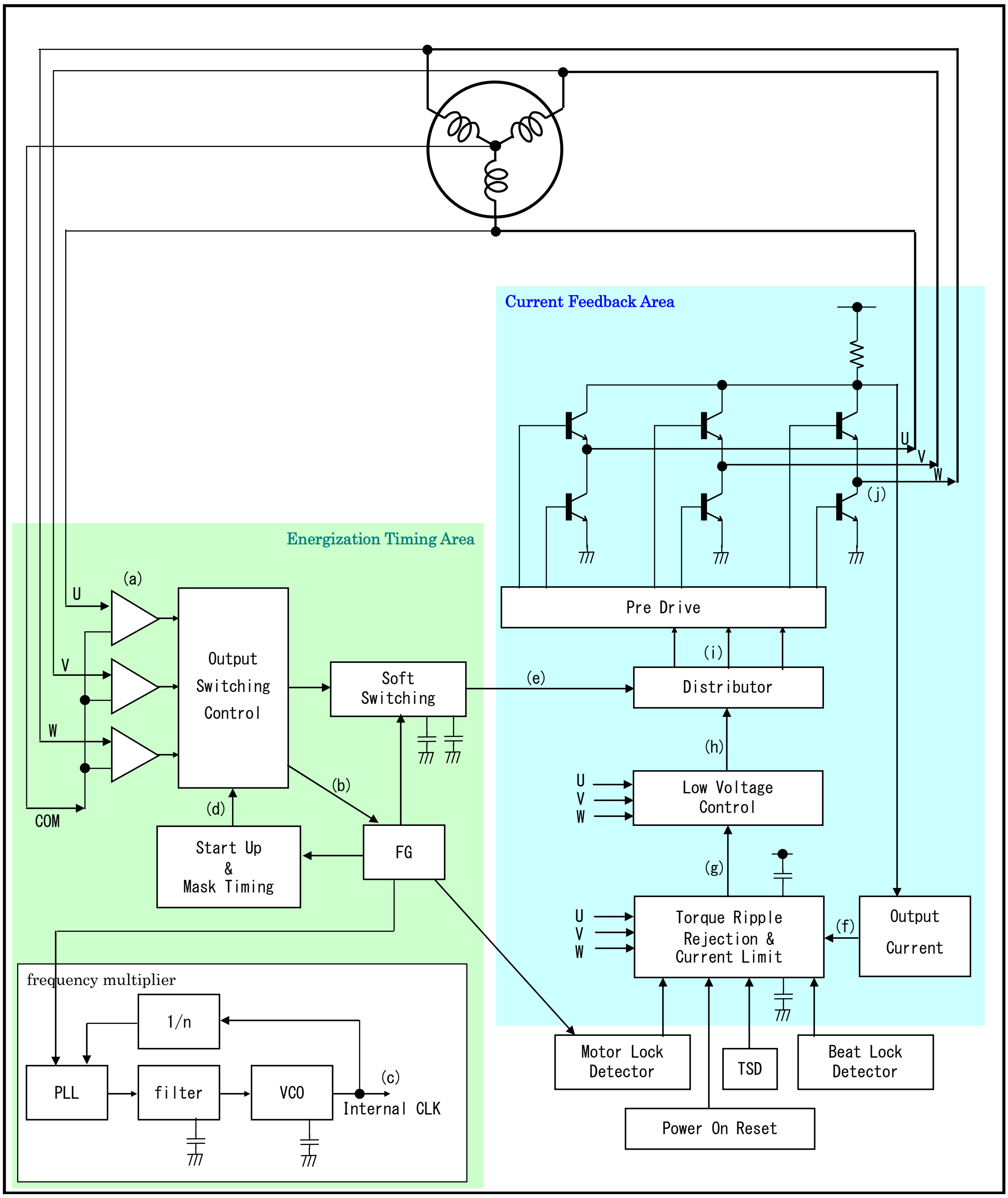
The function of each block at normal motor rotation is explained below. Here, the IC is set to “Regular Rotation mode”.

[Energization Timing Area]

(a) Using COM voltage as a reference, comparators detect Back-EMF signal from the motor in rotation. Timing of each phase (U, V and W) is defined by comparators. From the 3 signals, “Energization Timing signal” is generated in “Output Switching Control” block.
(b) FG signal is generated from this “Energization Timing signal”.
(c) Using FG signal, “Internal CLK” is generated in “frequency multiplier” block.
 (Internal CLK frequency = 48 * FG signal frequency)
 The FG signal and the internal CLK are referential signals for timing in this IC.
(d) In “Mask Timing” block, mask timing is generated to prevent error operation when Back-EMF is detected.
(e) In “Soft Switching”, the timing of soft-switching is added to the “Energization Timing signal” generated in (a), which is synthesized with current signal of each phase in “Distributor” block.

[Current Feedback Area]

(f) Output Current is measured by current detection resistor.
(g) High-level UOUT, VOUT and WOUT voltages are input to the “Torque Ripple Rejection” block. Here, torque ripple is rejected and the high-level voltages are adjusted (non-saturation type).
(h) The low-level UOUT, VOUT and WOUT voltages are input to the “Low Voltage Control”. Then the low-level voltages are adjusted (non-saturation type).
(i) The adjusted signals are synthesized with timing signal of (e) in “Distributor” block.
(j) Output Currents are generated for driving a motor by “Pre Drive” and 6 power transistors. This IC performs feedback to prevent saturation of UOUT, VOUT and WOUT voltage levels.



Block diagram

1-1-2. Startup mode

The functions of each block when a motor is powered are explained as follows. Here, the IC is set to "Startup mode".

[Energization Timing Area]

(c) During "Regular Rotation mode", the internal CLK is generated from back-EMF. But immediately after powering the motor, there is no back-EMF without a continuous motor operation. Instead, internal CLK is generated which is dependent on an external capacitor.

(d) In "Startup" block, the timing signal for startup is generated using the internal CLK as a reference.

(a) The Energization Timing signal is generated from the signal in (d) in "Output Switching Control" block.

(e) The signal in (a) passes through the "Soft Switching" block without adding any timing of soft-switching. In "Distributor" block, it is synthesized with current signal of each phase.

(a) A motor starts rotation using this signal until Back-EMF is detected. After Back-EMF is detected, the IC is set to "Regular Rotation mode".

[Current Feedback Area]
(f) The IC reads an output electric current level by a resistor to monitor current.
(g) “Current Limit adjusts” the output current level to use it as startup current level.
(h) The low-level UOUT, VOUT and WOUT voltages are input to the “Low Voltage Control”. Then the low-level voltages are adjusted (non-saturation type).
(i) The adjusted signals are combined with the timing signal of (e) in “Distributor”.
(j) By the 6 power transistors via “Pre Drive”, output currents are generated to run a motor.

1-1-3. Protection function

The protection functions are explained below.

[Motor Lock Detector]
When a motor is locked, the output is turned OFF so that the output current is NOT too high. The presence of Back-EMF determines this operation. Then the IC is set to “Motor lock mode”. After a certain period, the IC is set to “StartUp-mode” and the IC starts up again.

[Thermal Shutdown]
Thermal Shutdown turns off outputs when the junction temperature (Tj) exceeds180 degrees (design target), which functions as overheat protection for the IC. This function is used for the case of emergency, so please make sure that Tj is lower than 150 degrees in an application design with sufficient amount of testing.

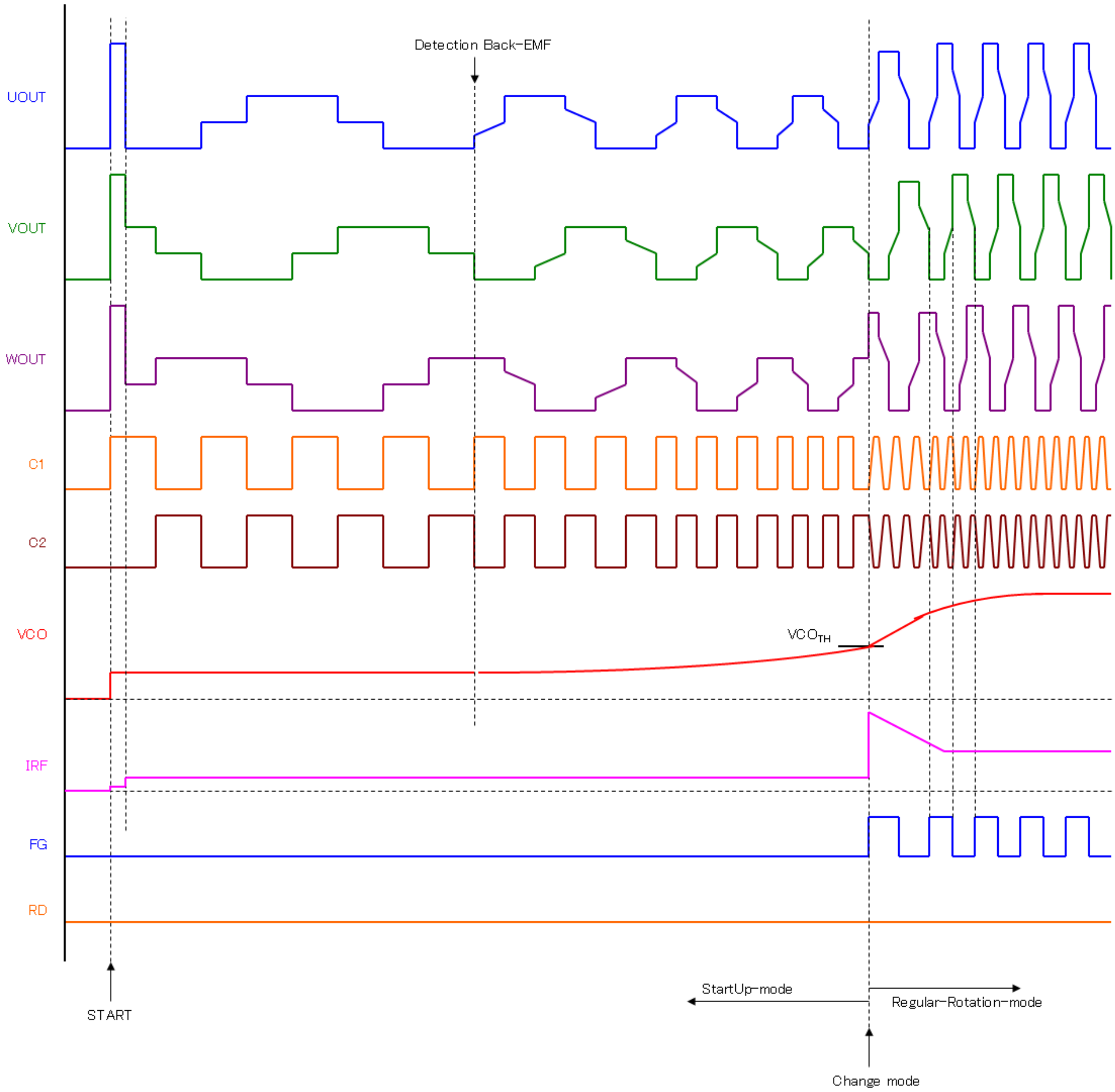
[Beat Lock Detector]
When beat lock occurs during motor rotation, the IC starts up again. Beat lock detection is based on the level of the frequency of FG signal. In other words, when the frequency of FG signal is high, the IC judges that beat lock is present.

[Power On Reset]
When the IC is powered, the output current is turned off until the internal circuit of the IC starts operation.

1-2. Timing Chart Description

1-2-1. StartUp-mode

"StartUp-mode" is set when the IC starts up its operation. Assume that power is supplied at the "START" position in the chart below. After the "START" position, the IC outputs energization timing patterns for startup as shown below in each output (UOUT/VOUT/WOUT) to determine the position of a motor. Based on the timing pattern, the motor starts rotation in which IC detects back-EMF. By detecting back-EMF, the IC determines a motor position. As a result, the IC outputs energization timing which synchronizes with the motor position to the motor. This is how a motor starts rotation.



Startup-mode and Regular rotation mode (Example)

Note that the period between energization and detecting back-EMF (from "START" to "Detection Back-EMF") varies at every startup. The above chart illustrates one example. After detecting back-EMF, a motor begins rotation.

When a motor begins rotation and the rotation speed is faster, VCO voltage is higher. When VCO voltage is over VCO_{TH} (2.1V (typ)), the IC judges that the motor rotation is normal and "Regular rotation mode" is set. Also, the period between back-EMF detection and the point where VCO voltage exceeds VCO_{TH} (from "Detection Back-EMF" to "Change mode") varies depends on a combination with a motor.

During "StartUp-mode", drive current (IRF) is low due to Soft-Start function.

1-2-2. Regular rotation mode

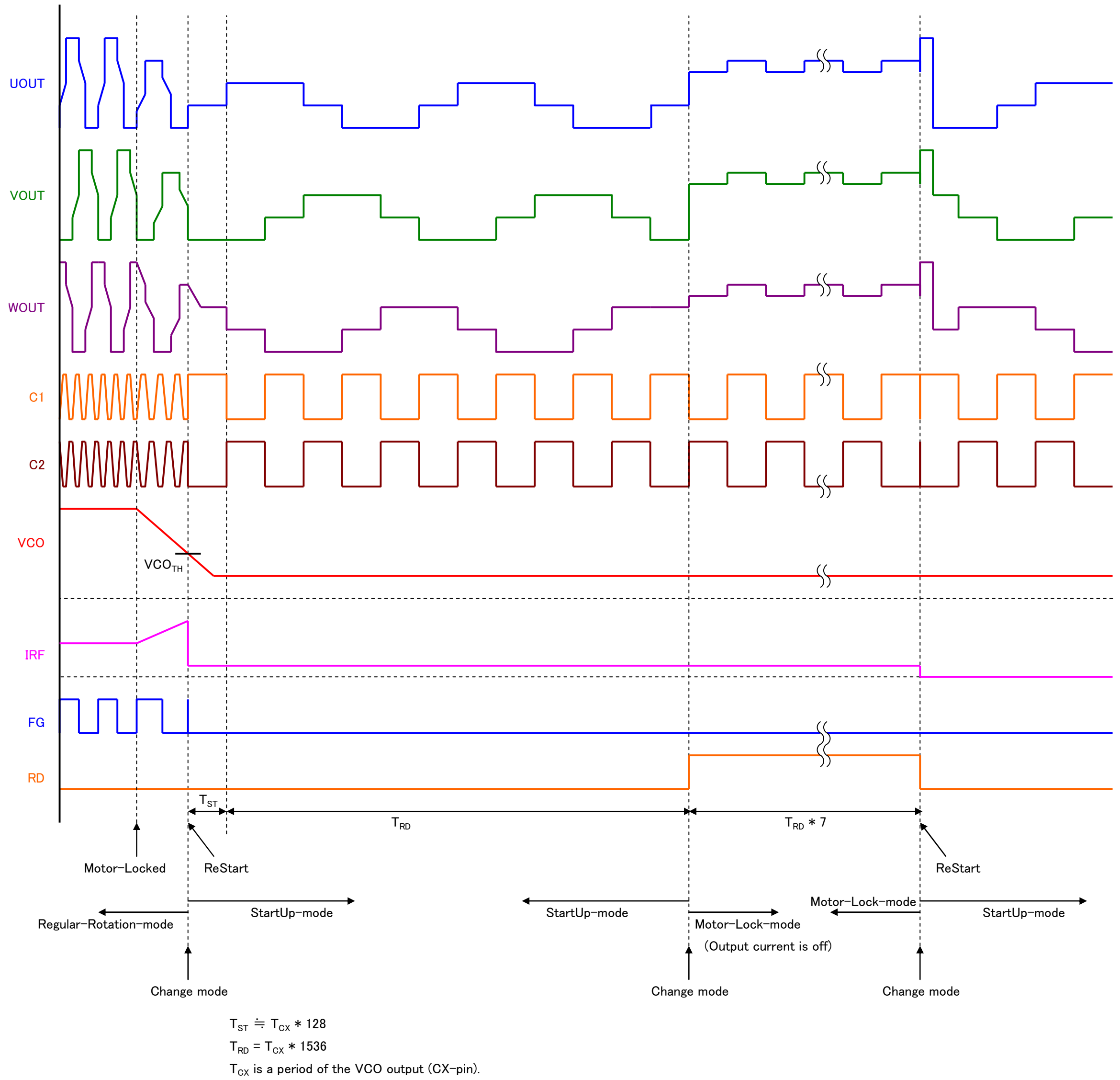
When the IC switches from “StartUp-mode” to “Regular rotation mode”, the driving current (IRF) is switched to full driving mode as shown in the chart below. Then the rotation speed increases until stabilized. Once the rotation speed is stabilized, VCO voltage is stabilized as well.

In addition, the FG signal is output during “Regular rotation mode”.

1-2-3. Motor lock mode & StartUp-mode

Given that a motor is locked by some factor at “Motor-Locked” position of the chart below, VCO voltage decreases because the motor is stopped. When VCO voltage is below VCO_{TH} (2.1V (typ)), the IC is switched to “StartUp-mode”. As mentioned above, the IC outputs energization timing patterns for startup during “StartUp-mode”. During “StartUp-mode”, once the cause of motor lock is removed, the IC starts detecting back-EMF and the motor starts rotation again.

As shown in the chart below, if the state of motor lock continues, the IC turns to “StartUp-mode” and outputs energization timing patterns for startup over the period of T_{ST} + T_{RD}. After that, during the period of T_{RD} * 7, the IC is switched to "Motor lock mode" and all the outputs are turned OFF. Then the IC is set to “StartUp-mode” and tries to restart again. As long as the cause of motor lock remains, this behavior continues.



Motor lock mode and StartUp-mode (Example)

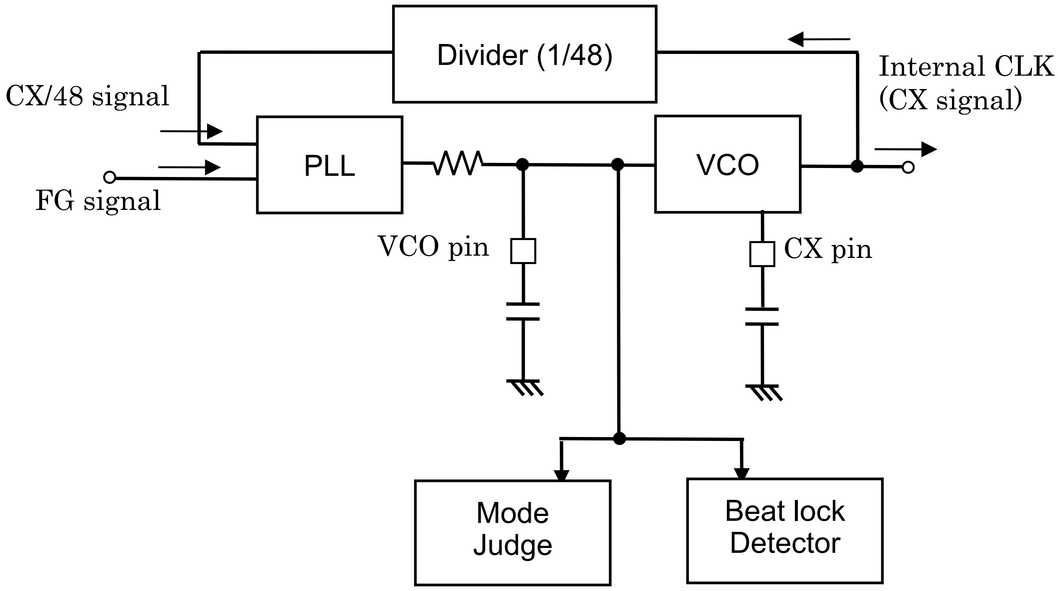
2. Pin detailed function

2-1. VCO pin, CX pin

(a) VCO pin and CX pin are part of the "frequency multiplier" block shown the figure below. This block generates the Internal CLK which synchronizes with FG frequency.
First, FG frequency is compared with the CX/48 frequency in PLL. Then the gap in pulse signal is smoothed out by LPF which consist of internal resistor and VCO capacitor (inserted between VCO-pin and SGND). The frequency of VCO (Voltage Controlled Oscillator) is determined by a smoothed voltage (VCO-voltage) and CX capacitor (which is inserted between CX-pin and SGND), which is used as internal CLK (CX signal). This Internal CLK frequency is divided by 48 and compared with FG frequency in PLL. With the use of internal feedback loop, CX frequency is obtained as follows:

CX frequency = 48 * FG frequency (FG period = 48 * CX period)

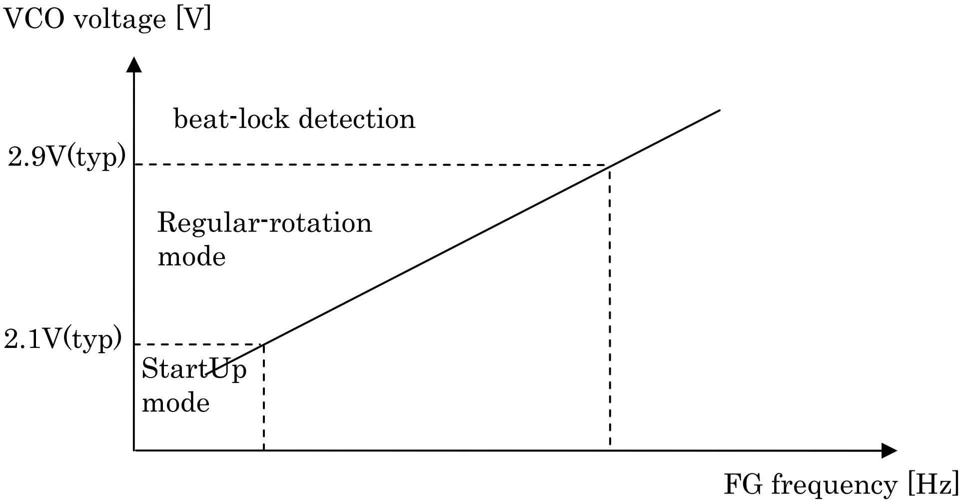
In other words, the CX frequency synchronizes with FG frequency. For example, as FG-signal frequency increases, internal CLK (CX signal) and VCO voltage increases as well.



(b) In addition, VCO voltage is used to switch a mode of the IC. VCO voltage (VCOIN) determines "Start-Up-mode" and "Regular rotation mode". The threshold voltage (VCOTH) is 2.1V (typ). "StartUp-mode" is set where VCOIN < VCOTH. "Regular rotation mode" is set where VCOIN > VCOTH.

(c) This IC has beat-lock protection (*) and VCO voltage is used as a basis for the judgment. When the VCO voltage is higher than the VCOBL (2.9V (typ)), the IC determined that beat-lock is present and VCO voltage is reset (VCO voltage is under the VCOTH) by decreasing current by force. And the IC restarts from "StartUp-mode". This operation is done automatically and internally.

(*) "beat-lock" means the state where a motor stops though the motor is driven by IC. Because it sounds as "Beep", this state is called "Beat-lock". In this case, Back-EMF occurs with high frequency in a motor. Therefore, the VCO voltage rises.



The external capacitor of LPF (the VCO capacitor) is inserted between VCO pin and SGND. The recommended value is around 1uF, but it is necessary to adjust the capacitance value according to a usage motor (for the specification of coil and blade). Hence make sure to determine a capacitance along with the operation of a usage motor.

The recommended value of capacitor connected between the CX pin and SGND is 0.0068 to 0.033uF, but it is necessary to adjust the capacitance according to a usage motor. In the first testing, it is recommended to set 0.015uF. If necessary, make an adjustment based on the result.

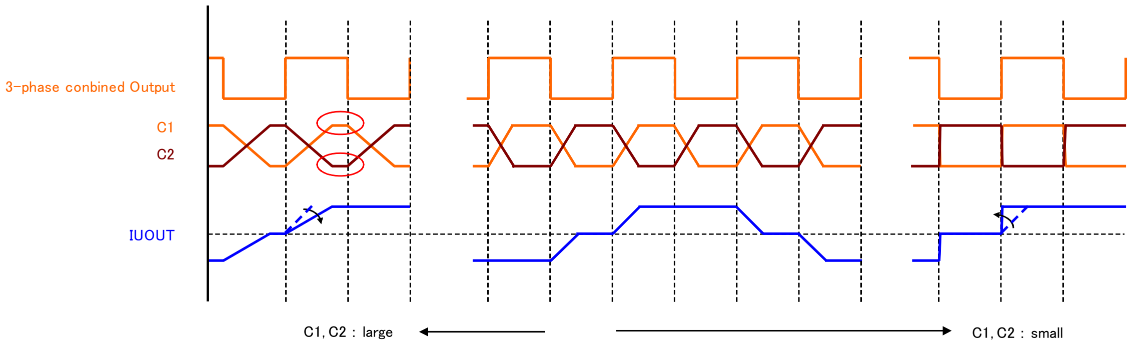
When the value of VCO capacitor is too low, VCO voltage cannot be smoothed out properly and motor rotation might be unstable. As a result, the LSI might reacts against irregular noises. On the other hand, when the value of the VCO capacitor is too high, startup characteristic gets worse because a response toward the change of rotation speed gets weaker. (For example, it takes longer for the IC to switch from “Start-Up-mode” to “Regular rotation mode”. Or a motor might have abnormal rotation.)

Taking all the above factors into consideration, please confirm that VCO voltage is $2.1V < VCO_{IN} < 2.6V$ during "Regular rotation mode" to allow sufficient margin.

2-2. C1 pin, C2 pin

This IC incorporates soft switching for silent drive.

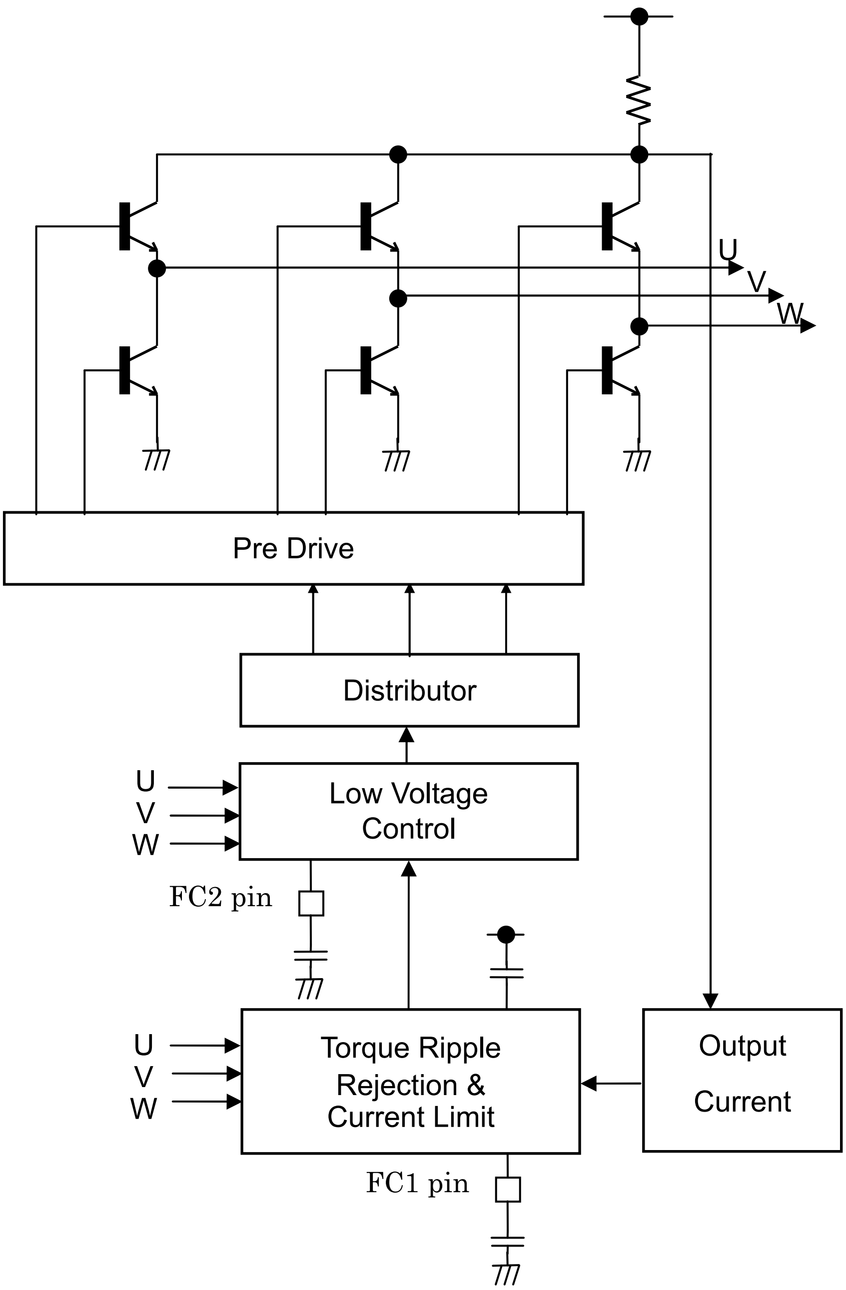
Switching speed of the outputs energization is set by capacitors connected between C1 (and C2) pin and SGND, respectively. The voltage waveform of C1 and C2 is in trapezoid shape. When the slopes of trapezoid is gentle (C1 and C2 capacitances are high), the switching speed is softer. Here, note that C1 and C2 capacitances are the same and the top-side and base-side of trapezoid are flat, especially, when the RPM is high. If these two sides are not flat, the operation of a motor is unstable.



C1 and C2 capacitances are in proportion to CX capacitance. When CX capacitance value is changed, C1 and C2 capacitance value should be changed as well. The recommended values are C1 (=C2) = 0.7 * CX. For example, if CX=0.015uF, then C1=C2=0.010uF. But it is necessary to adjust capacitance according to usage motor (based on the specification of coil and blade). In the first testing, it is recommended to set C1 (=C2) = 0.7 * CX = 0.010uF. If necessary, make an adjustment based on the result.

2-3. FC1 pin, FC2 pin

By connecting a capacitor between FC1 pin and SGND, the oscillation of closed-loop current control system in upper-side outputs is preventable. Similarly, by connecting a capacitor between FC2 pin and SGND, the oscillation of closed-loop current control system in lower-side outputs is preventable. The recommended capacitance for FC1 is around 1uF, and for FC2 is around 0.1uF. But it is necessary to adjust a capacitance according to a usage motor.



2-4. VOH pin

The VOH voltage is used to control high level output voltage. VOH voltage is smoothed out by connecting a capacitor between VOH and VCC. The recommended value of VOH is around 1uF. But it is necessary to adjust a capacitance according to a usage motor.

If speed response to the change of VCC voltage is weak, the bad response of VOH pin could be the cause. In this case, decrease the capacitance observing the waveforms. On the other hand, if motor rotation is unstable, the voltage of VOH pin maybe unstable. In this case, increase the capacitance observing the waveforms.

2-5. RF pin

RF pin detects output electric current.

The output current is limited by connecting a resistor between RF pin and VCC. Given that the resistance is is R_{RF} (ohms), the maximum current I_{OMAX} of the output is obtained as follows.

$I_{OMAX} = V_{OLIM} / R_{RF}$ [A]

V_{OLIM}: current limiter setting value (=0.30V(typ))

Also, R_{RF}[Ω] is used to set current in “StartUp-mode”. The startup current I_{ST} in “StartUp-mode” is obtained as follows.

$I_{ST} = V_{STLIM} / R_{RF}$

V_{STLIM} : startup current setting value (=0.045V(typ))

When you design a layout for PCB, please design R_{RF} (resistor) as close as possible to RF pin and VCC and the line should be wide enough in case of high current.

2-6. FG pin & RD pin

FG pin outputs a rectangular waveform in reverse to VOUT pin output. RD pin outputs operation ON / OFF signal (when the signal is ON, the signal level of RD pin is low). These pins are the open collector outputs of NPN transistor. Therefore, they should be pulled up to optimum voltage using a resistor. When this signal is unused, this pin should be open. When a pull-up resistor is used, it is recommended using a power supply voltage of a controller (which receives FG signal or RD signal). The pull-up resistors must output current lower than 3mA.

When the IC detects that a motor is locked, the RD-output turns High and the IC is switched to “Motor lock mode” (3-phase-outputs are OFF). After the period of “Motor lock mode”, the IC starts up again by “StartUp-mode”.

When you design a layout for PCBs in which the FG line or the RD line is long, please insert a resistor (around 100 Ohms) to protect the IC.

2-7. UOUT pin, VOUT pin & WOUT pin

Depends on a combination with a motor, oscillation may occur in the outputs of three-phase circuit. In this case, please connect a capacitor of 0.1uF (0.01uF to 0.33uF) between each output pin and MCOM pin if necessary.

The lines should be as wide as possible in case of high current.

2-8. MCOM pin

This is an input pin for the middle point of a motor coil. When back EMF is detected, this voltage used as reference.

2-9. VCC pin

In order to stabilize power supply, make sure to connect a capacitor between VCC pin and GND. The capacitance should be higher than 10uF against low-frequency noise. The recommended capacitance is approximately 0.1uF, which has good frequency characteristic. Connect the resistor as close as possible to the VCC pin to reject high-frequency noise. But optimum capacitance varies depends on a usage motor and PCB.

The line should be as wide as possible in case of high current.

2-10. VREG pin

This is a DC output pin (3.3V). To stabilize this voltage, make sure to connect capacitor between VREG pin and SGND. This voltage is used for the internal circuits of the IC and the applications. This cannot be used as external power supply.

2-11. SGND pin & PGND pin

SGND pin is used as signal GND and PGND pin is used as power-GND. SGND line and PGND line should be separated because of high current flows into PGND. And the lines should be connected at single-point GND at the ground-side of 10uF between VCC pin and GND in case of low-frequency noise.

PGND line should be as wide as possible against high current.

2-12. NC pin

Basically, NC pin should be left unconnected. However, if the use of NC pin is inevitable in PCB layout design, please make sure to connect with stable lines in which voltage or current should be stable with low impedance.

3. How to set constants and caution

Make sure to set each constant per usage motor. When constants are set, please refer to the following check list as a reference. Because this is just reference, please confirm a motor behavior to fit a motor specification, application, usage environment, temperature characteristics and tolerance really.

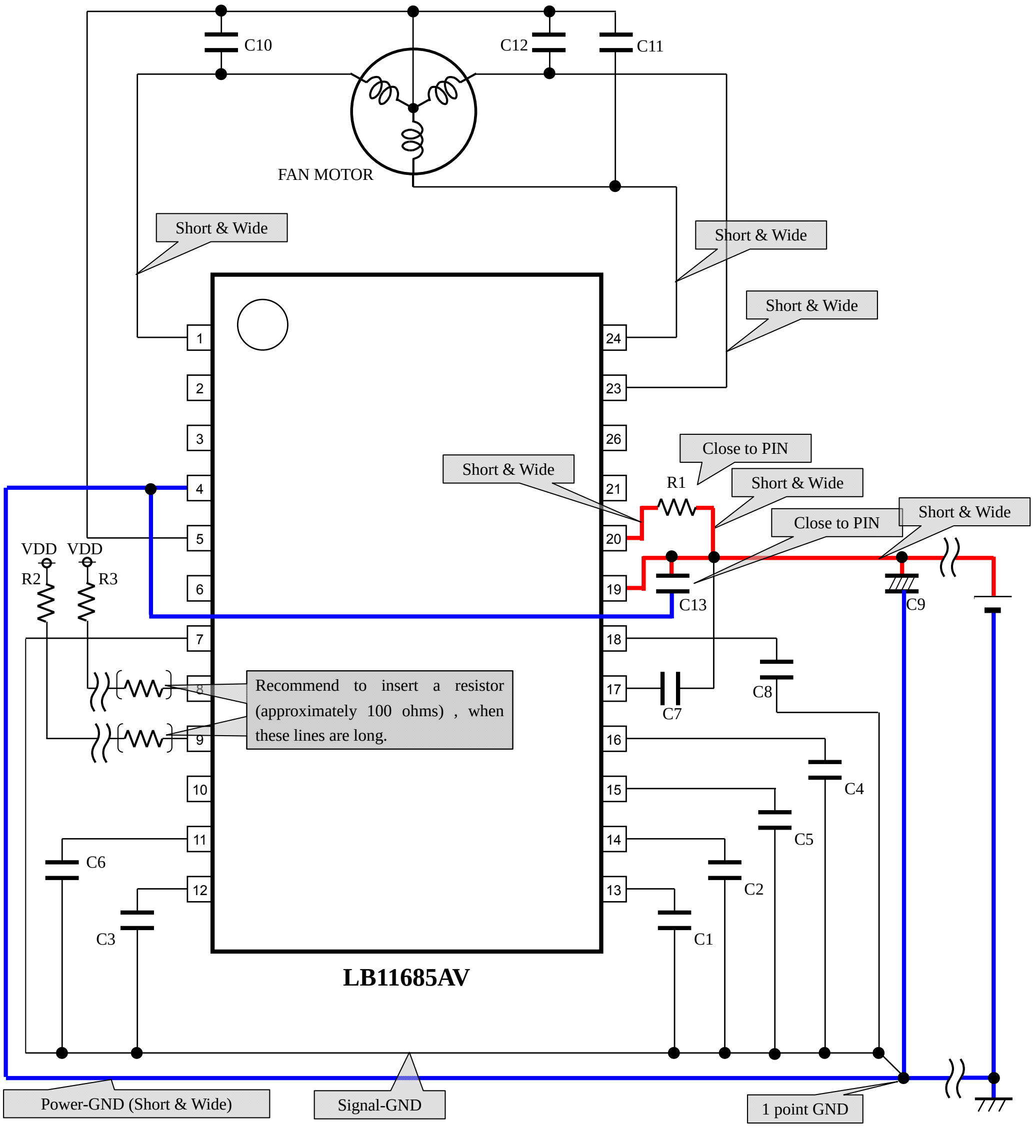
At the power supply voltage range and the temperature range, please check the followings.

- The behavior of the “Regular-Rotation-mode” (confirm that a motor rotates stably and does NOT have abnormal rotation).
- The booting characteristic (e.g., confirm that a motor starts rotation smoothly without failure or abnormal rotation within 5 seconds.)
- Each voltage and current waveform (in the "Regular-rotation-mode", confirm that the VCO voltage is under 2.7V and each voltage/current waveform is normal.)
- The behavior when a motor is locked (confirm that the behavior of "Motor lock mode" is as appears in the timing chart for motor lock state)
- The startup voltage (e.g., confirm that a motor starts rotation under VCC=4V.)
- The thermal check (confirm that the junction temperature Tj is under 150 degrees. Please check with a PCB implemented to a motor.)

The above check list is for an independent IC only. Further confirmation is required together with a usage motor under practical environment.

3-1. The example of application circuit

It is recommended to use the following application circuit for the initial testing to define constants. After checking the values against the operation of motor, please change the constants accordingly.



The Example of Application Circuit

The voltage of "VDD" should be used as supply voltage for controller.
If FG line or RD line is too long, insert a resistor (around 100 Ohms) for IC protection.

The Example of Constants

No.	Value	No.	Value	No.	Value
C1	0.010uF	C7	1uF	C13	0.1uF
C2	0.010uF	C8	0.1uF	R1	0.3 ohms
C3	0.015uF	C9	10uF	R2	100k ohms
C4	1uF	C10	0.1uF	R3	100k ohms
C5	0.1uF	C11	0.1uF		
C6	1uF	C12	0.1uF		

3-2. CX pin setup

CX pin is part of VCO (Voltage Controlled Oscillator). CX pin oscillates by repeating charge and discharge under the amplitude of 0.55V (typ). This oscillation frequency is used as internal CLK of the IC. The recommended value of capacitor (C3) connected between CX pin and SGND is 0.0068 to 0.033uF, but it is necessary to adjust the capacitance according to a usage motor. In the initial testing, use the recommended value of 0.015uF. And then make an adjustment if necessary. The capacitances of C1 and C2 are in proportion to the capacitance of CX. Hence, when CX capacitance is changed, C1 and C2 capacitances are changed as well. The recommended values are C1 (=C2) = 0.7 * CX. For example, when CX=0.015uF, the capacitance of C1 and C2 are as follows: C1=C2=0.010uF.

As determining a capacitance, make sure that a motor starts rotation smoothly when powered. Note that the value of capacitor influences energization timing signal.

When the value of capacitor (C3) is too low, the energization timing speed becomes so fast that a motor cannot start rotation smoothly due to low torque (startup characteristic gets worse). In this case, please use a capacitor (C3) with higher value to improve startup characteristic. To use relatively larger fan with heavy load, this method should be effective. On the other hand, when a capacitance is too high, the motor rotation might be clumsy as well because back EMF is too weak. Also, it may take too long to switch from “StartUp-mode” to “Regular rotation mode” during startup. In this case, please use a capacitor with lower value.

Within the VCC (RPM) range used, the VCO voltage should be between 2.1V and 2.6V in the “Regular rotation mode” in consideration of a margin. Where RPM is fixed, when a capacitor is large, then the VCO voltage is high. On the other hand, when it is small, then the VCO voltage is low. Please note that you should use a high-impedance-measurement-system when you measure the VCO voltage because the internal circuit of IC is high-impedance (around 500kOhms).

In addition, a capacitor (C3) also influences the period of “Motor lock mode”. Where a capacitor is large, the period is long. Please refer to another section for the calculating formula.

3-3. RF pin setup

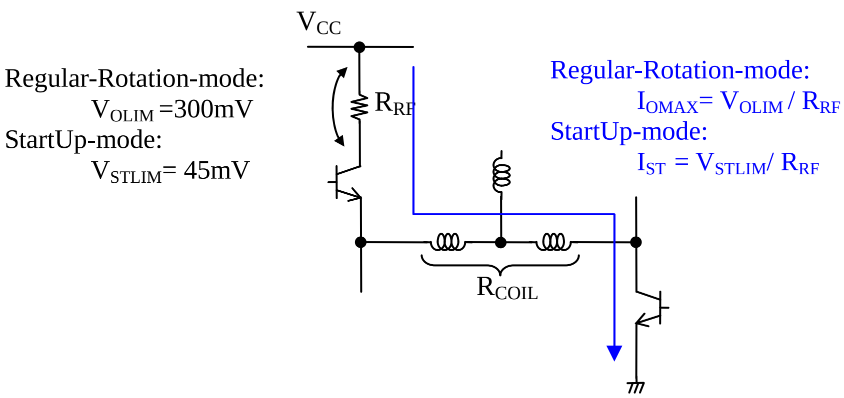
The R_{RF} (which is connected between the RF pin and the VCC) is used for limiting the output current at “Regular rotation mode”. The R_{RF} is also used for setting current in “StartUp-mode”.

When the Start-Up characteristic is not good because a torque is not enough for booting, please adjust the RF resistor (R1).

The startup current I_{ST} of “StartUp-mode” is as follows.

$I_{ST} = V_{STLIM} / R_{RF}$

V_{STLIM} : startup current setting value (=0.045V(typ))



[Calculation Example]

Where RRF=0.5 ohms, IOMAX=300mV / 0.5Ω=600mA, IST=45mV / 0.5Ω=90mA

Where RRF=0.33 ohms, IOMAX=300mV / 0.33Ω=1A, IST=45mV / 0.33Ω=135mA

3-4. VCO pin setup

When a motor is locked, if the behavior is unstable without shifting to “Motor lock mode”, the IC might detect falsely by noise at the Back-EMF detection. In this case, please check the output waveform and change a capacitor (C6) into a larger one. The behavior might be improved.

In addition, when a capacitor is too large, the shift time from “StartUp-mode” to “Regular rotation mode” might be long at startup. In this case, please change a capacitor into a smaller one. The shift time may be shortened.

3-5. FC1 pin setup

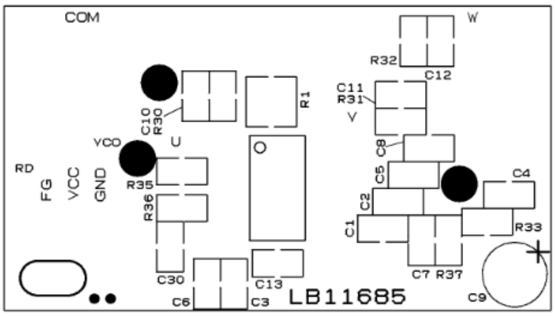
By connecting a capacitor between the FC1 pin and SGND, the oscillation of current control system which occurs in closed-loop of upper-side outputs is preventable. When a motor is locked, if the behavior is unstable without shifting to “Motor lock mode”, the IC may be under oscillation. In this case, please check the output waveform and change a capacitor (C4) into a larger one. The behavior might improve.

4. Caution for assembling PCB

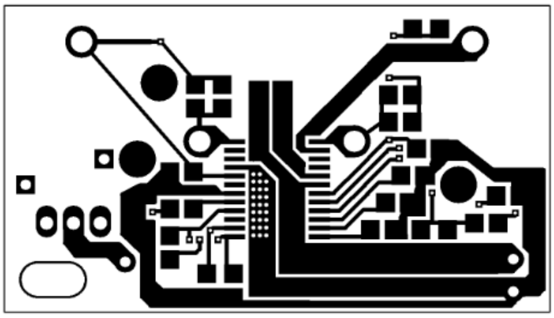
4-1. Example of PCB layout

The example of PCB layout is shown below.

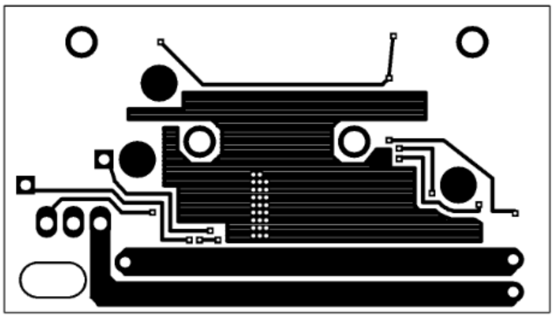
Silk TOP



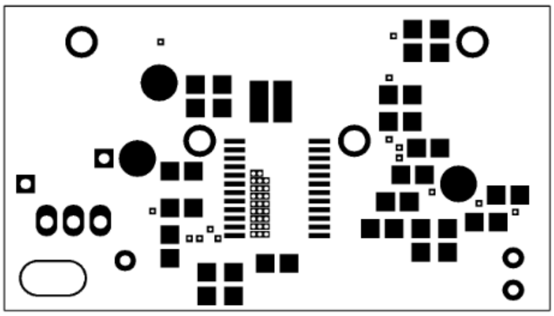
Pattern TOP



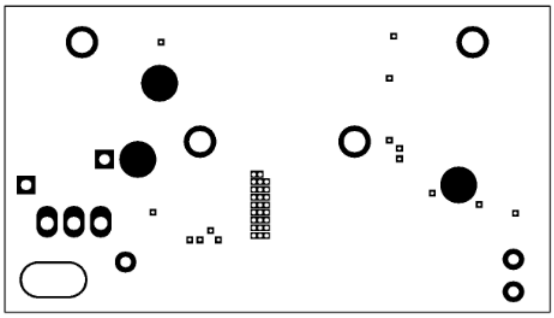
Pattern BOTTOM



Resist TOP



Resist BOTTOM



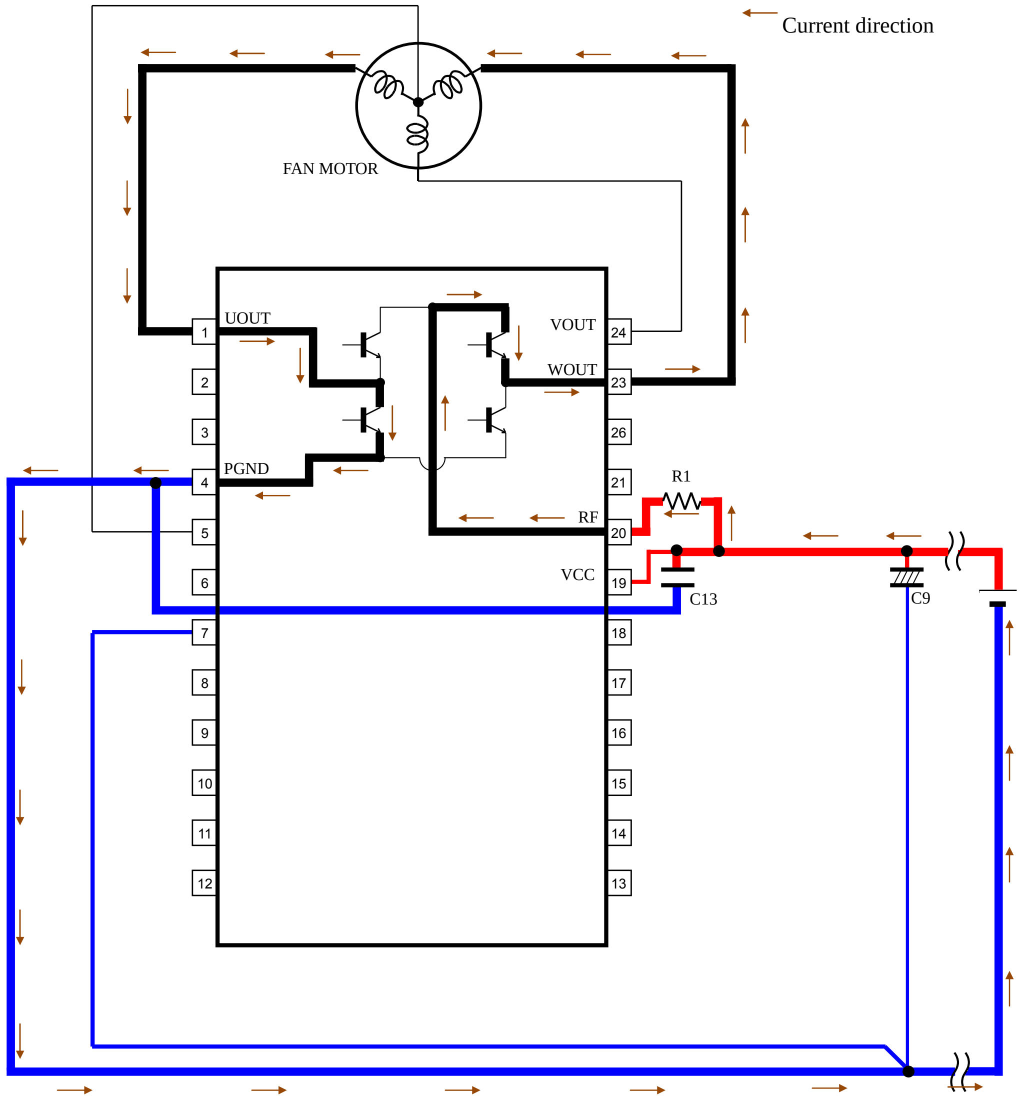
4-2. Route of high current

The lines of high current should be as wide and short as possible. Here, the case where current passes from WOUT to UOUT is explained. The same rule applies to the line between equivalent pins.

The route of large current is;

the + side of the power supply -> RF resistor(R1) -> 20pin(RF) -> inside of the IC -> 23pin(WOUT) -> the coil of motor -> 1pin(UOUT) -> inside of the IC -> 4pin(PGND) -> the - side of the power supply

These lines should be as wide as possible.

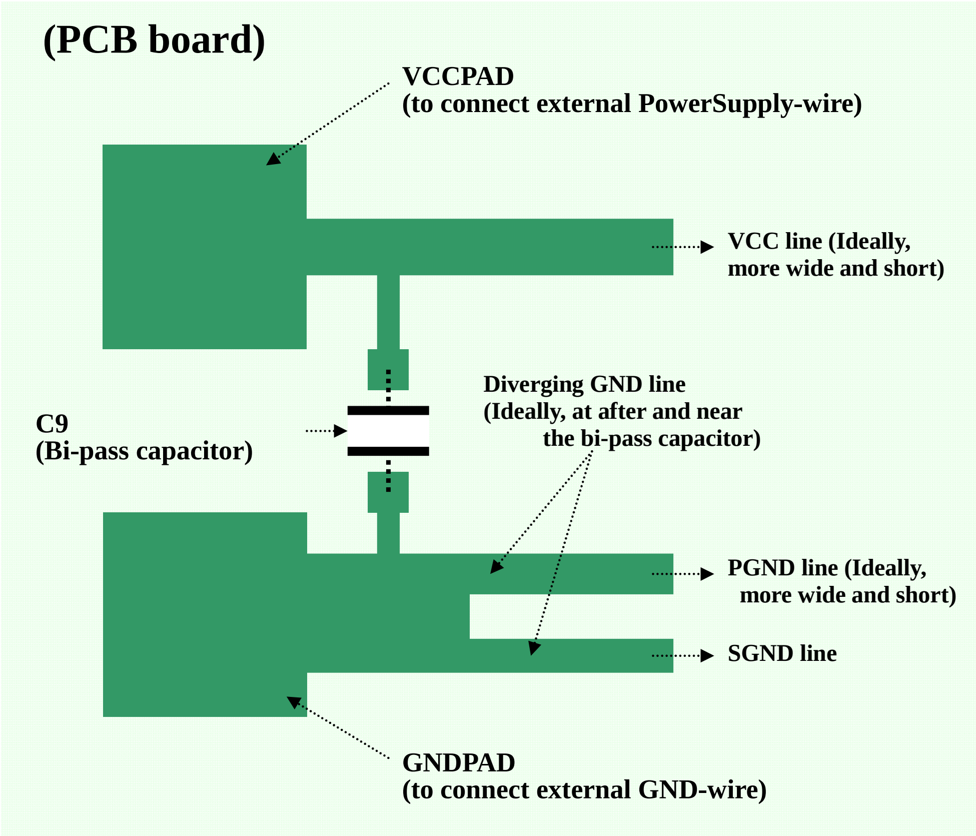


4-3. VCC and GND layout

To stabilize the power supply, connect a capacitor between the VCC pin and GND. Connect a capacitor (C9) against low-frequency noise and a capacitor (C13) against high-frequency noise. The C13 capacitor should be connected to the pin as close as possible.

The SGND is for signal-GND and the PGND is for power-GND. Divide the SGND-line and the PGND-line because the PGND bears high current. And connect these lines at one point on the ground-side of the C9 capacitor.

The PGND line should be as wide as possible because high current runs through.

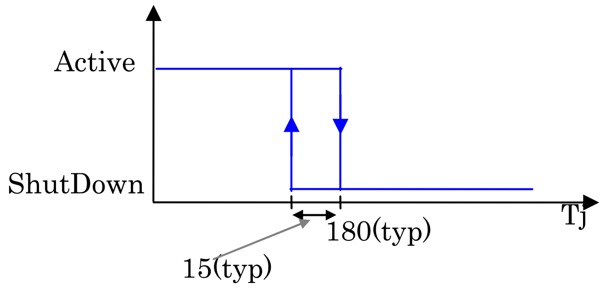


5. Thermal design

Please examine thermal design thoroughly to assure that the junction temperature Tj of the IC is under 150 degrees. If Tj is over 150 degrees and it continues, it may lead to the IC destruction.

5-1. TSD (Thermal ShutDown) Function

When the junction temperature Tj is over 180 degrees (typ), the TSD function works. And when the Tj is under 165 degrees (typ), the IC works again. The TSD operates under emergency. Thermal design should be examined thoroughly so that the junction temperature Tj of the IC is under 150 degrees.



5-2. How to calculate values for thermal design

5-2-1. How to calculate Pd (under regular rotation mode)

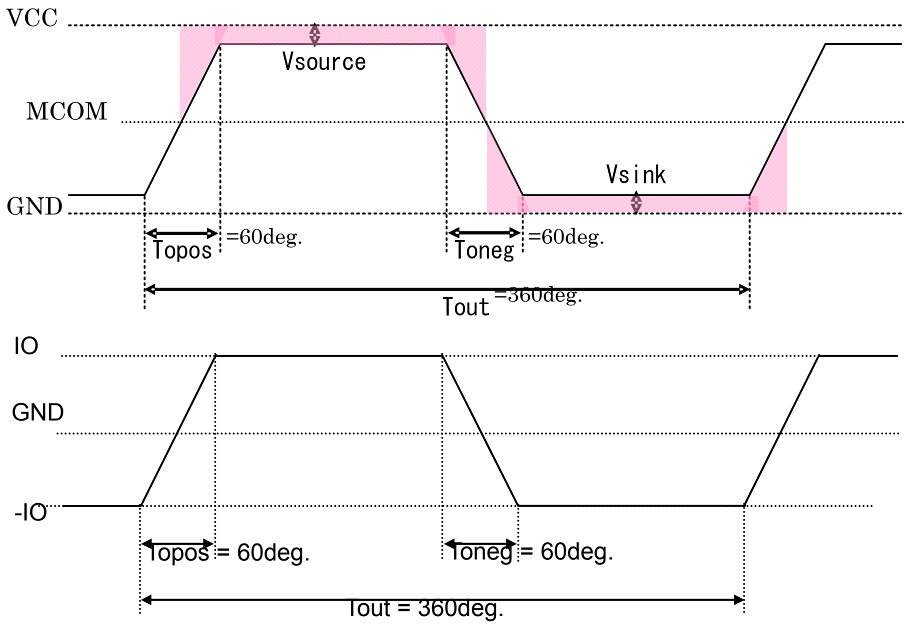
P1, power-dissipation caused by ICC, is obtained as:

P1 = VCC * (ICC + IO/100)
IO : Output current
ICC : IC current (not of motor)

Assuming that Topos is the rise-time and Toneg is the fall-time at the output switching in OUT and Tout is OUT cycle, then P2 caused by the output switching time in OUT is obtained as follows:

P2 = IO/2 * (VCC-MCOM)/2 * (Topos/2/Tout + Toneg/2/Tout) * 3phase
+ IO/2 * MCOM/2 * (Topos/2/Tout + Toneg/2/Tout) * 3phase
= IO/2 * (VCC-MCOM)/2 * 60/360 * 3 + IO/2 * MCOM/2 * 60/360 * 3
= IO * VCC * 1/8 (Assuming Topos = Toneg)

P3 caused by the output is obtained as follows,
P3 = Vsource(ave) * IO + Vsink * IO
Vsource(ave) : The average of high level of output voltage



Therefore, total Pd is
Pd = P1 + P2 + P3

[Calculation Example]

In the case where VCC=16.0V, ICC=11mA, IO=0.3A, Vsource=1.5V, Vsink=0.7V, MCOM=7V,

P1=VCC*(ICC+IO/100)=16V*(11mA+0.3/100)=224mW

P2=IO*VCC*1/8

=0.3A*16V/8

=600mW

P3=Vsource(ave)*IO + Vsink*IO

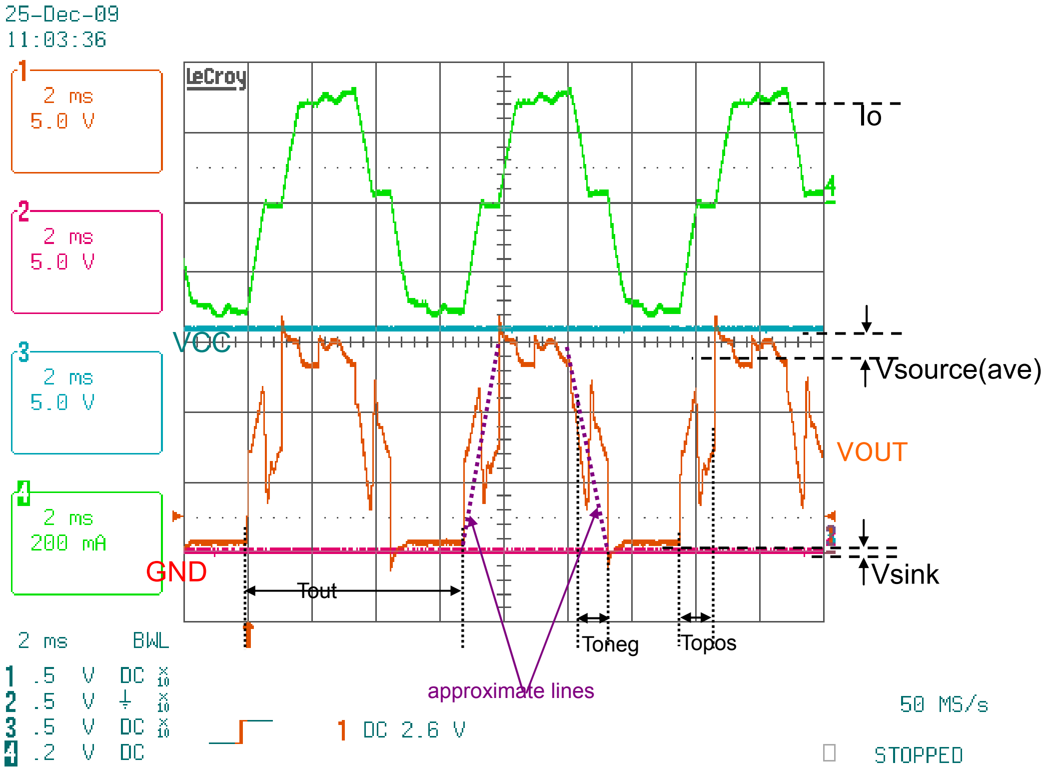
=IO*(Vsource(ave)+Vsink)

=0.3A*(1.5V+0.7V)

=660mW

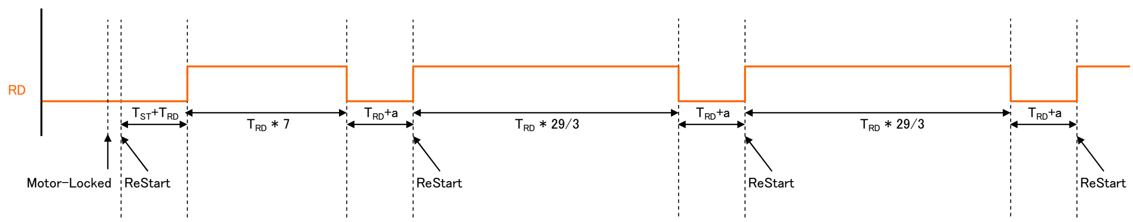
Therefore, total Pd is

Pd=224mW+600mW+660mW= 1.48W



5-2-2. How to calculate Pd (under motor lock mode)

During motor lock, "StartUp-mode" and "Motor lock mode" repeat alternately. Until a motor locked is cancelled and rotates again, this behavior continues.



$T_{ST} \fallingdotseq T_{CX} * 128$

$T_{RD} = T_{CX} * 1536$

T_{CX} is a period of the VCO output (CX-pin).

"a" is setup-time for IC depended on capacitance value of FC1 and FC2.

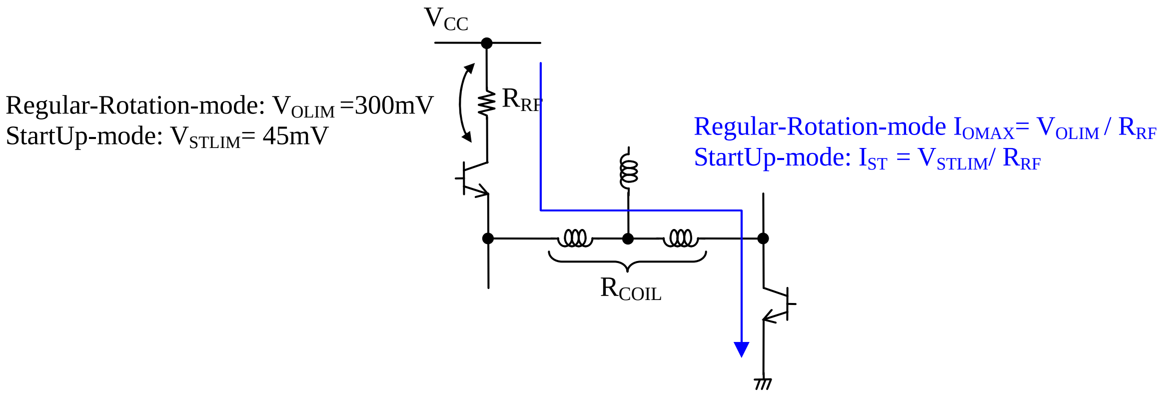
Where "a", which is setup-time for IC, is ignored, the period of the "StartUp-mode" (T_{RD}) is,

$T_{RD}=T_{CX} * 1536$

Then the Pd_{ST} (in this period) can be calculated as follows.
Assuming that I_{ST} is the current in the "StartUp-mode" and R_{RF} is the resistance value of RF, then,

$I_{ST} = V_{STLIM} / R_{RF}$

V_{STLIM} : current limiter setting value at the "StartUp-mode" (=0.045V(typ))



Assuming that R_{COIL} is a real part of a coil-impedance (between a phase and another phase), V_{COIL} is a voltage by R_{COIL} and I_{ST}, V_{IC} is a remaining voltage of the IC and Pd_{ST} is the Pd at "StartUp-mode" then,

$V_{COIL} = I_{ST} * R_{COIL}$
$V_{IC} = V_{CC} - V_{COIL}$
$Pd_{ST} = V_{IC} * I_{ST} + V_{CC} * I_{CC}$
$= ((V_{CC} - (V_{STLIM} / R_{RF} * R_{COIL})) * V_{STLIM} / R_{RF} + V_{CC} * I_{CC}$

After the 2nd period of the "Motor lock mode", the period is,

$T_{RD} * 29/3$

Then the Pd_{OFF} that is the Pd at this period is,

$Pd_{OFF} = V_{CC} * I_{CC}$

Therefore, during locking a motor,

"StartUp-mode" T_{RD}
$Pd_{ST} = ((V_{CC} - (V_{STLIM} / R_{RF} * R_{COIL})) * V_{STLIM} / R_{RF} + V_{CC} * I_{CC}$
"Motor lock mode" $T_{RD} * 29/3$
$Pd_{OFF} = V_{CC} * I_{CC}$

are alternately repeated.

[Calculation Example]

In the case where VCC=16.0V, ICC=11mA, RRF=0.3 Ohms, VSTLIM = 45mV, RCOIL = 9 Ohms, then,

"StartUp-mode" TRD
Pd_{ST} = ((16 – (0.045/0.3*9)) * 0.045/0.3 + 16*0.011 = 2.37W
"Motor lock mode" TRD * 29/3
Pd_{OFF} = 16 * 0.011 = 0.18W

5-2-3. The relation equation of the thermal resistance

Assuming that Tj is the junction temperature, theta(jc) [W/deg.] is "Thermal resistance between junction–case", theta(ja) [W/deg.] is "Thermal resistance between junction–ambient", Tc is case temperature and Ta is ambient temperature. Then these parameters have following relation. Note that theta (ja) and theta (jc) vary depend on usage PCB.

Tj = Pd * theta (ja) + Ta
Tj = Pd * theta (jc) + Tc

[Calculation Example (case1)]
For example, Pd = 1.5W, theta (jc) = 20degree/W, Tc = 140degree. Then,

Tj = Pd * theta (jc) + Tc = 1.5 * 20 + 140 = 170 degree

When TSD operates at Tc=140degree, you can assume that Tj=170degree. Therefore, it can be assumed that ICs must be used under the temperature lower than Tc=120degree.

[Calculation Example (case2)]
For example, Pd = 0.5W, theta (ja) = 120degree/W, theta (jc) = 20degree/W, Ta = 25degree. Then,

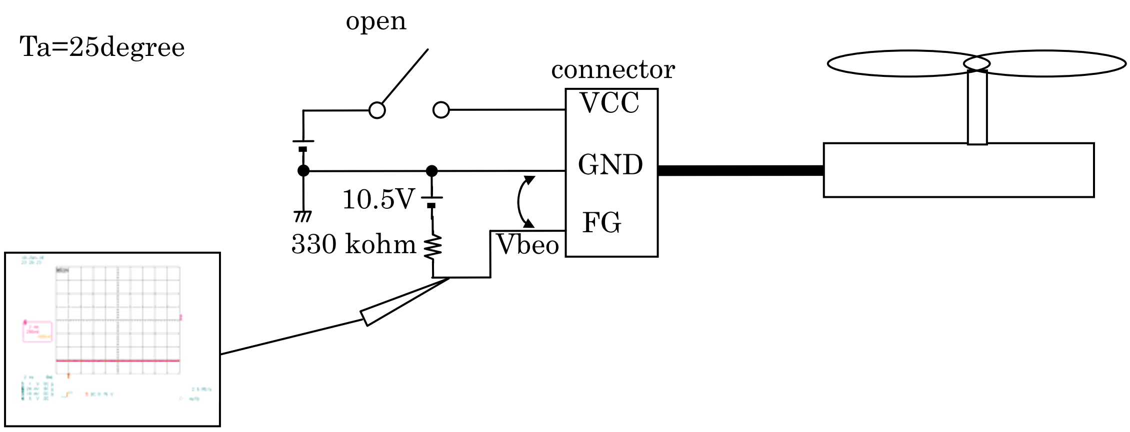
Tj = Pd * theta (ja) + Ta = 0.5 * 120 + 25 = 85 degree
Tc = Tj – Pd * theta (jc) = 85 – 0.5 * 20 = 75 degree

So, Tc = 75degree.

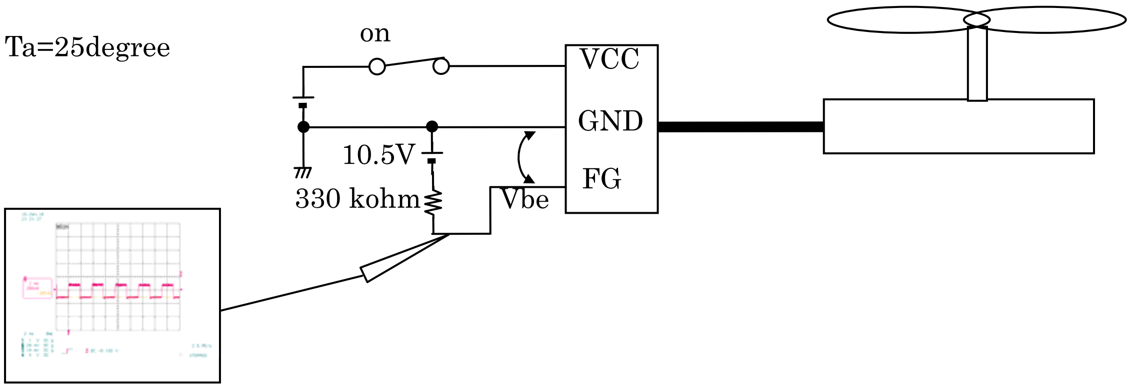
5-3. Measurement method for junction temperature (Tj)

5-3-1. Measurement method for Tj (under regular rotation mode)

After leaving well enough under Ta=25degree, please set Vcc=OFF and connect 10.5V power-supply-voltage and 330k ohms resistor between Gnd and FG. (The Gnd side is "+".) The measurement circuit is as shown below in the figure. Please note that the GND terminal of the power-supply-voltage is NOT connected to Earth such as a case-GND. The voltage between Gnd and FG is the "Vbeo" measured by an oscilloscope. Please do not connect a resistor for the FG-PullUp.



Next, please operate the IC with "Start-Up mode" and "Regular rotation mode". After leaving well enough, please measure the base-value voltage by an oscilloscope (One with higher absolute value) and assign "Vbe" to the value.



Then, the junction temperature Tj is,

Tj = (Vbeo – Vbe – 30mV) / 2.0427mV + 25degree

[Calculation Example]

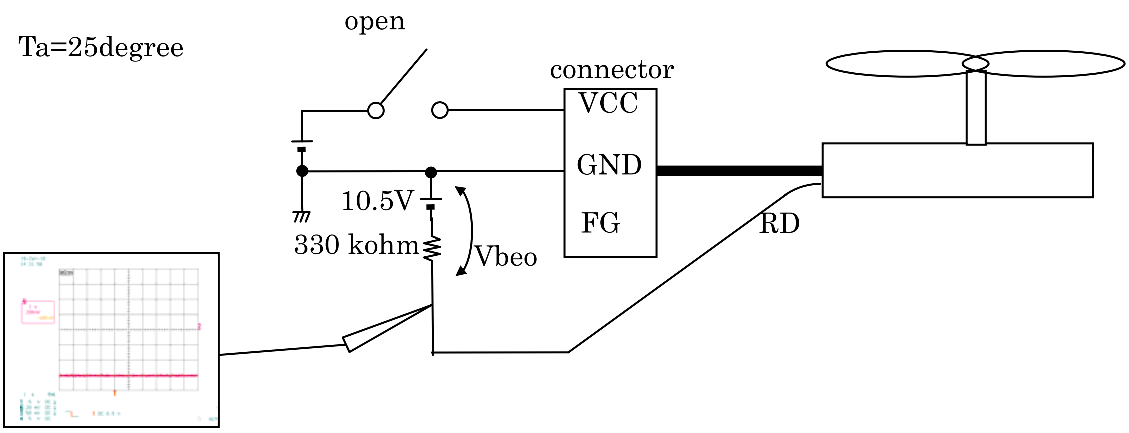
In the case of Vbeo=606mV, Vbe=305mV, then,

Tj = (606 – 305 – 30) / 2.0427 + 25 = 158 degree

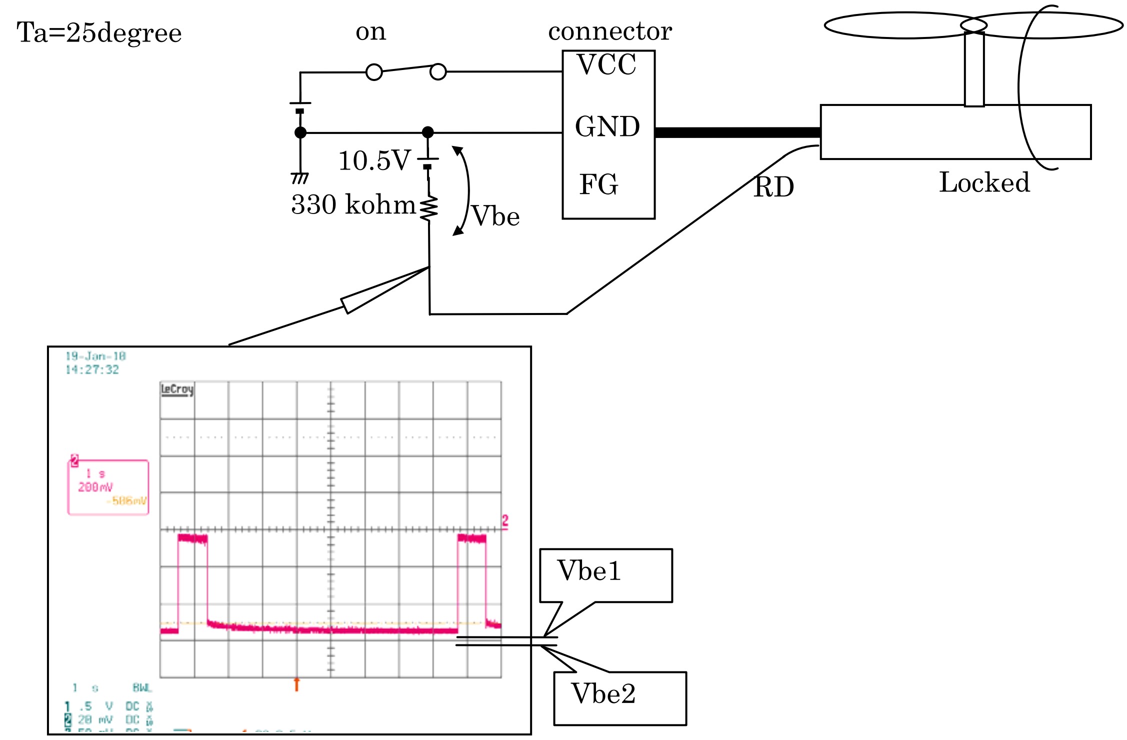
5-3-2. Measurement method for Tj (motor lock mode)

Make sure to place the RD terminal of the IC outside the motor.

After leaving well enough under Ta=25degree, please set Vcc=OFF and connect 10.5V power-supply-voltage and 330k ohms resistor between Gnd and RD. (The Gnd side is “+”.) The measurement circuit is shown in the figure. Please note that the GND terminal of the power-supply-voltage is NOT connected to Earth such as a case-GND. Then, the voltage between Gnd and RD is the “Vbeo” measured by an oscilloscope. Do not connect a resistor for the RD-PullUp.



Next, please operate the IC with “Motor lock mode”. After a while, please measure the following voltage by an oscilloscope. Immediately after the falling-edge of the RD-wave, the voltage is referred to as “Vbe1”. And immediately before the rising-edge of the RD-wave, the voltage is referred to as “Vbe2”.



Then, the junction temperature Tj is,

“StartUp-mode” T_{RD}: Tj = (Vbeo – Vbe1 – 30mV)/2.0427mV + 25degree

“Motor lock mode” T_{RD}×29/3: Tj = (Vbeo – Vbe2 – 30mV)/2.0427mV + 25degree

ex)

In the case where Vbeo=606mV, Vbe1=506mV, Vbe2=547mV:

“StartUp-mode” T_{RD}: Tj = (606– 506– 30)/2.0427mV + 25degree = 59 degree

“Motor lock mode” T_{RD}×29/3: Tj = (606– 547– 30)/2.0427mV + 25degree = 39 degree

6. Other NOTE

6-1. Behavior without load

Since the IC is used for refrigerators, it is assumed that the IC is always with load. Therefore, at NO load, the IC may repeat Start/Stop. But it is NOT because of the malfunction of the IC.

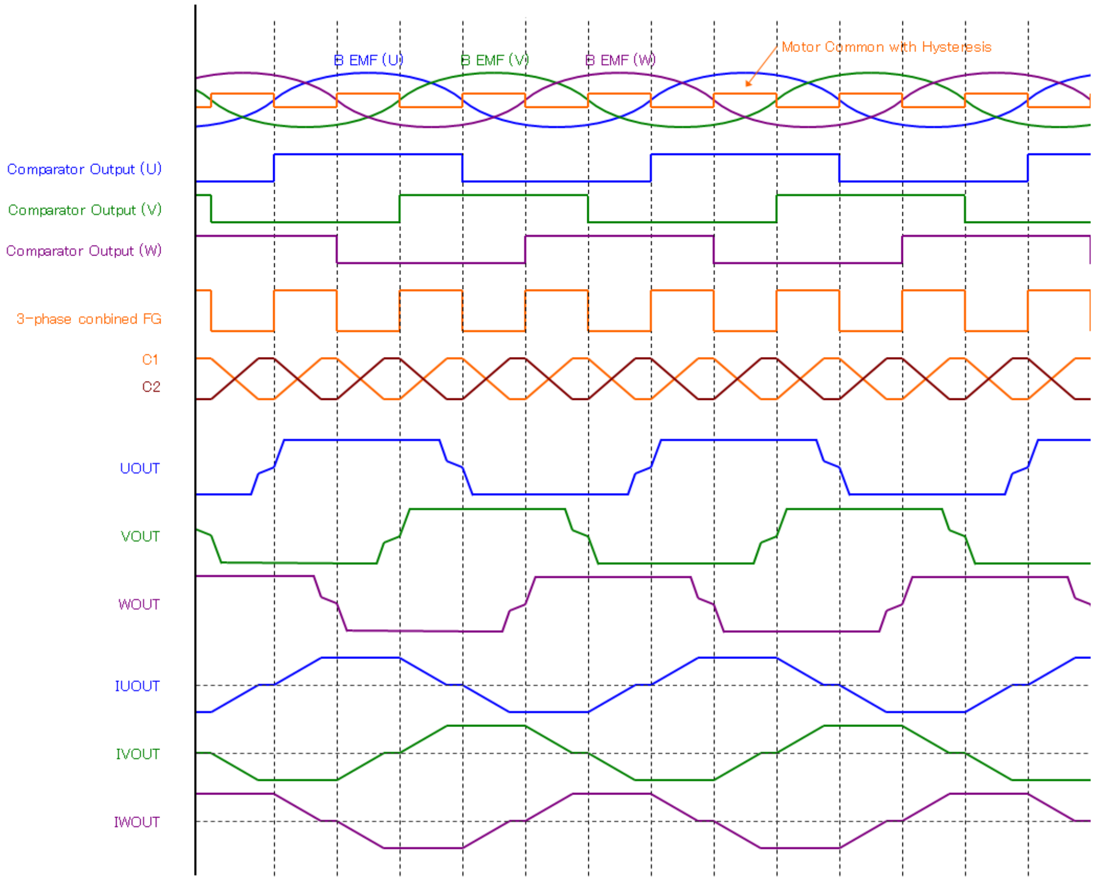
When the Vcc is constant, RPM changes according to loads. With no-load, RPM rises. The VCO voltage depends on RPM. Therefore, the VCO voltage rises when RPM rises.
If the VCO voltage becomes higher than 2.9V (typ), the IC judges that the motor is in a state of beat-lock and resets the VCO voltage. (The VCO voltage is lowered below 2.1V)
When the Vcc rises and the VCO voltage is over 2.9V (typ) with NO load, from the above-mentioned reasons, the IC repeats Start/Stop.

To check IC operation without load for a simple verification, we suggest you to check the operation with lower Vcc where the VCO voltage is lower than 2.7V for a margin.

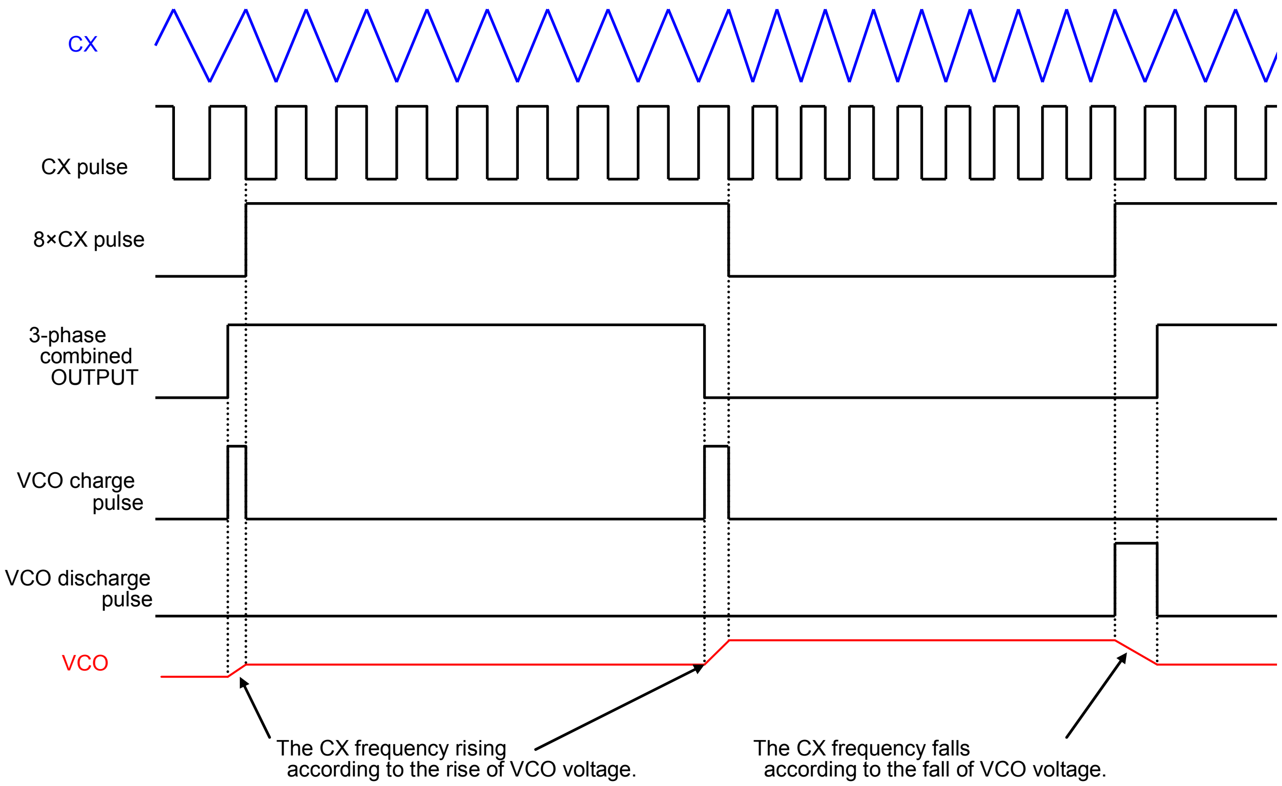
A. Appendix

A-1. Timing Chart (internal behavior)

A-1-1. Regular rotation mode (internal behavior)



A-1-2. Voltage-Controlled-Oscillator (VCO) (internal behavior)



*NOTE Charge/discharge current of C1 and C2 is modified according to the change of VCO voltage.

* Colored: external input/output, Black: internal signal
* 3-phase combined OUTPUT is 3 times the FG frequency.

A-2. How to calculate the period of “motor lock”

The period of “motor lock” depends on the CX capacitor value. During “motor lock mode”, the charge and the discharge current for CX is 15uA(typ), and the voltage amplitude of CX is 0.55V(typ). Therefore, the period of CX (T_{CX}) is

$$T_{CX} = (C_{CX} * 0.55/(15 * 10^{-6})) * 2$$
$$= C_{CX} * 73.3 * 10^{3}$$

Before the “Motor lock mode”, there is a period of the “StartUp mode” (T_{RD}).

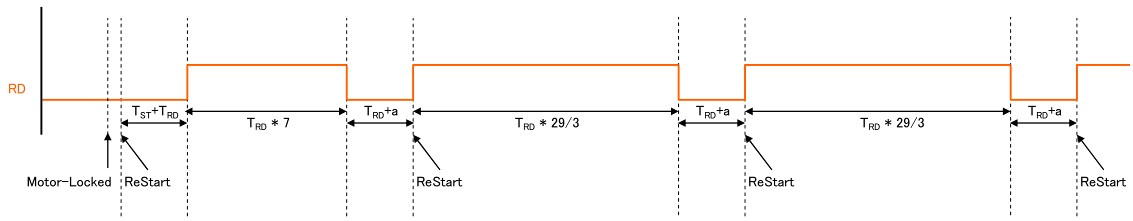
$$T_{RD}=T_{CX} * 1536$$

The IC has 2 periods of the “Motor lock mode”.

The 1st period : $T_{RD} * 7$
After the 2nd period : $T_{RD} * 29/3$

[Calculation Example (case1)]
In the case where C_{CX} = 0.01uF
T_{CX} = 0.73ms
The period of the “StartUp mode” is 1.12s.
The (1st) period of the “Motor lock mode” is 7.8s.

[Calculation Example (case2)]
In the case where C_{CX} = 0.022uF
T_{CX} = 1.61ms
The period of the “StartUp mode” is 2.48s.
The (1st) period of the “Motor lock mode” is 17.3s.



$T_{ST} ≒ T_{CX} * 128$
$T_{RD} = T_{CX} * 1536$
T_{CX} is a period of the VCO output (CX-pin).
"a" is setup-time for IC depended on capacitance value of FC1 and FC2.

A-3. The relational expression at the "Regular rotation mode"

The CX pin is the output terminal of VCO. This pin oscillates by the repetition of the charge and the discharge. And the voltage amplitude of CX is 0.55V (typ). Assuming that CCX is a capacitor value between the CX-pin and SGND, I_{CX} is the charge and discharge current of CX and T_{CX} is the period of CX-oscillation. Then, T_{CX} is,

$$T_{CX} = \frac{2 \times 0.55 \times C_{CX}}{I_{CX}} [Hz](typ)$$

I_{CX} is decided by the internal constant elements and calculated as follows.

$$I_{CX} = \frac{\Delta VCOin}{3.6k} + 15uA \quad [A](typ)$$

$$\Delta VCOin = VCOin - 2.1V \quad [V] \quad (VCOin > 2.1V)$$

$$0 \quad [V] \quad (VCOin < 2.1V)$$

Assuming that FG is the frequency of FG, N is RPM and p is the number of poles. Then FG is,

$$FG = \frac{p}{2} \times \frac{N}{60} \quad [Hz]$$

Assuming that T_{FG} is the period of FG. Then T_{FG} is,

$$T_{FG} = \frac{120}{p \times N}$$

The T_{FG} and the T_{CX} are the following relation by the internal constant elements.

$$\frac{T_{FG}}{6} = 8 \times T_{CX}$$

Therefore, the C_{CX} and VCOin are the following relation.

$$\frac{120}{6 \times p \times N} = 8 \times \frac{2 \times 0.55 \times C_{CX}}{I_{CX}}$$

$$C_{CX} = \frac{120}{6 \times p \times N \times 8 \times 2 \times 0.55} \times \left(\frac{VCOin - 2.1}{3.6k} + 15uA \right)$$

$$= \frac{2.27}{p \times N} \left(\frac{VCOin - 2.1}{3.6k} + 15uA \right)$$

The above calculation is only theoretical. It does not include temperature, dispersion, parasitic elements and so on. Therefore, please measure VCOin voltage and make sure that it is in the following relation: 2.1V < VCOin < 2.6V. In addition, the C_{CX} capacitor value influences the behavior of the "StartUp-mode". Therefore, please also check the behavior of the "StartUp-mode" as you define a C_{CX} capacitor value.

[Calculation Example (case1)]

To verify the propriety of VCO-cap value where p=12, N=1525rpm, C_{CX}=0.01uF,

$$0.01 \times 10^{-6} = \frac{2.27}{12 \times 1525} \left(\frac{VCOin - 2.1}{3.6 \times 10^{3}} + 15 \times 10^{-6} \right)$$

$$\therefore VCOin = 2.34V$$

The above conditions meet 2.1V < VCOin < 2.6V, therefore satisfies the limit of the VCOin voltage.

[Calculation Example (case2)]

To check the maximum value of C_{CX} where p=12 and Nmax=1500,

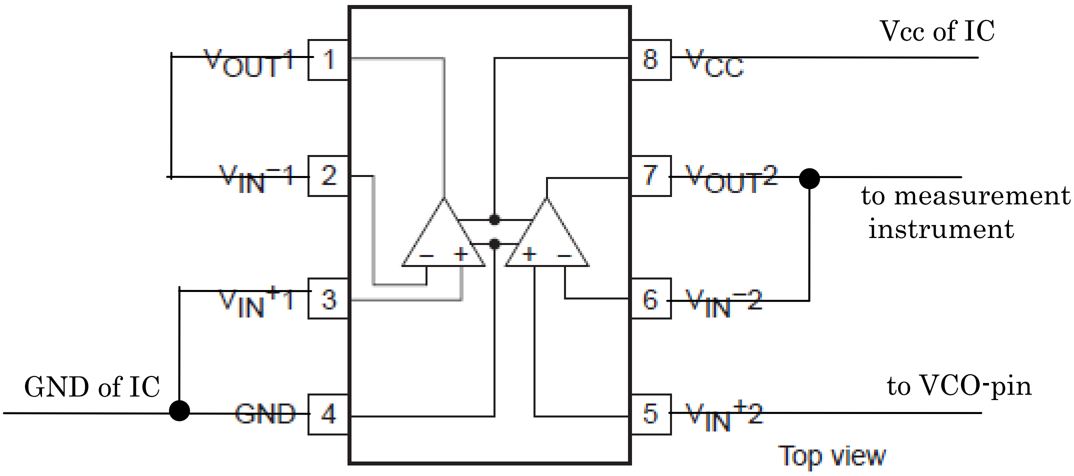
$$C_{CX} < \frac{2.27}{12 \times 1500} \left(\frac{2.6 - 2.1}{3.6 \times 10^{3}} + 15 \times 10^{-6} \right)$$

$$\therefore C_{CX} < 0.019uF$$

C_{CX} < 0.019uF satisfies the limit of the VCOin voltage.

A-4. Caution for measuring VCO voltage

Because internal impedance is high in the VCO terminal (approximately 500k ohms), when you measure the VCO voltage, please use a measurement equipment with high impedance. If such high impedance equipment is not available, you can use op-amp with high impedance instead.



[LA6358N, 6358NM, 6358NT]

A-5. How to change the period of "Motor lock mode"

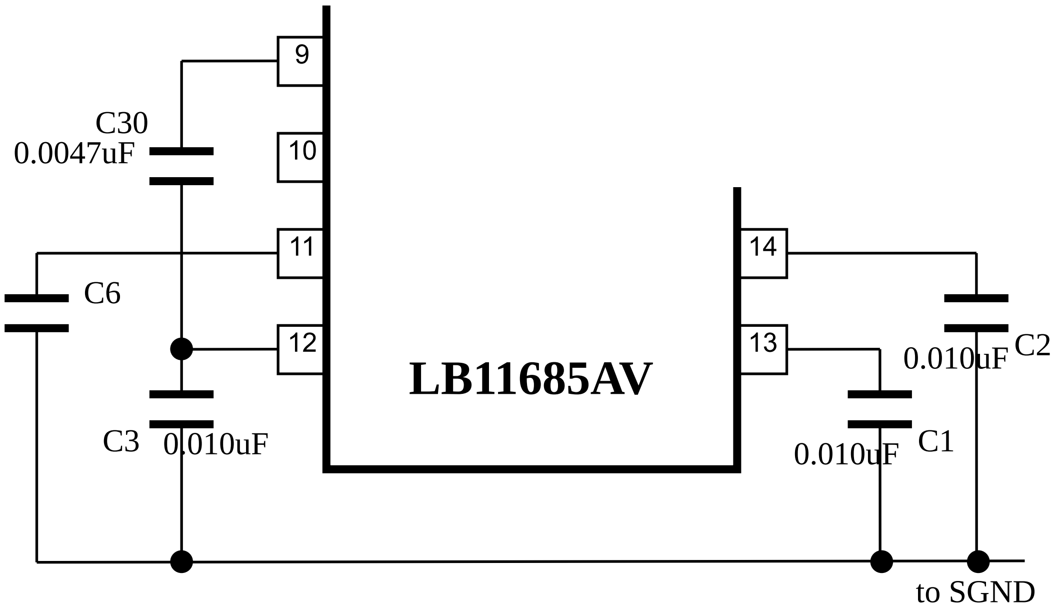
The capacitor value of CX influences a Start-Up characteristic and a period of “Motor lock mode”.
In Start-Up characteristic, the following tendencies are observed for load and capacitor value of CX.

Where the C_{CX} is small: Load of FAN is light.
Where the C_{CX} is large: Load of FAN is heavy.

Also, the period of “Motor lock mode” depends on a capacitor value of the CX.

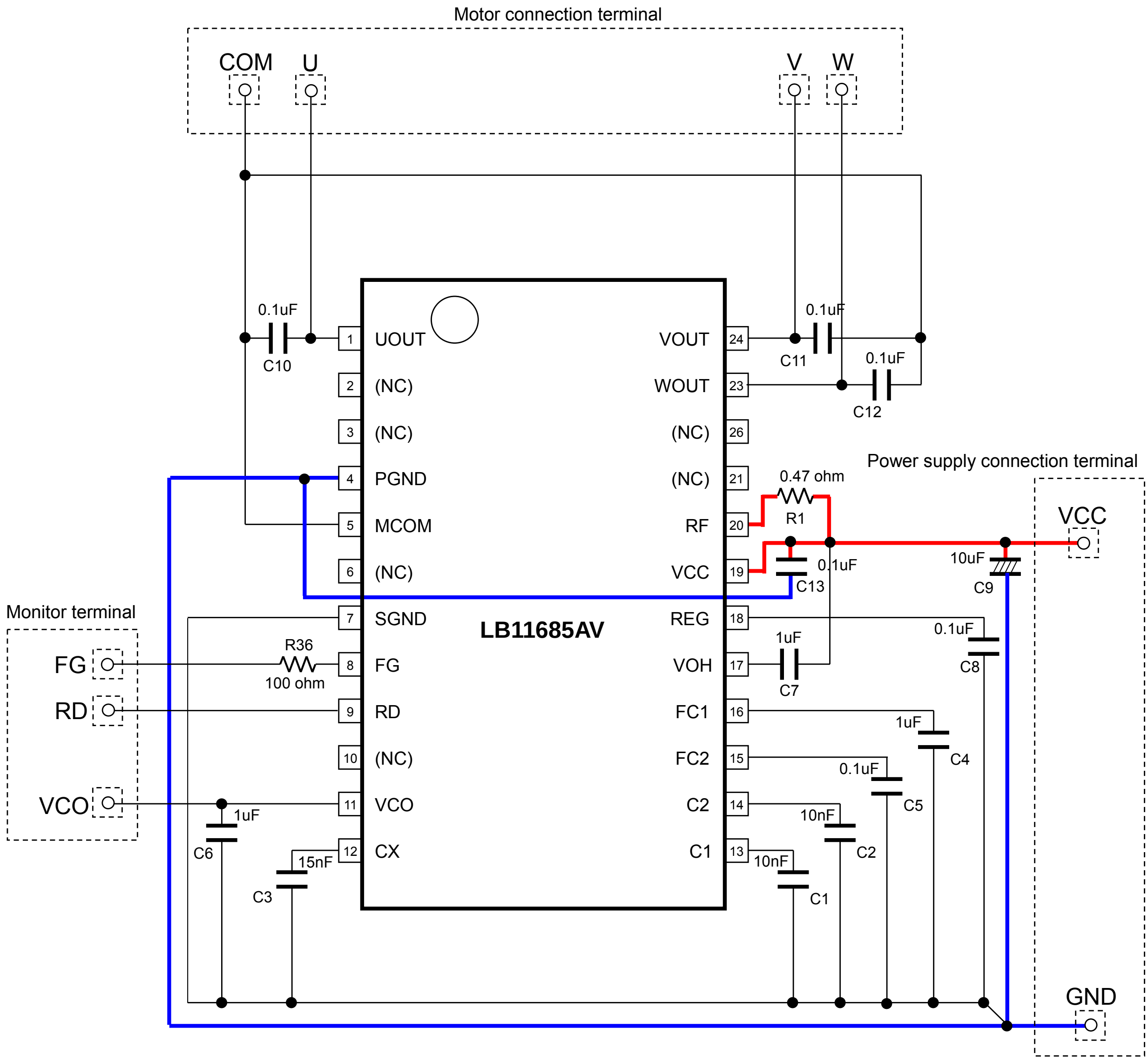
Where C_{CX} = 0.010uF: approximately 8 seconds.
Where C_{CX} = 0.015uF: approximately 12 seconds.
Where C_{CX} = 0.022uF: approximately 17 seconds.

For example, for the sake of Start-Up characteristic, assume that C_{CX}=0.015uF is set. If you wish to set the period of “Motor lock mode” for approximately 8 seconds, the period of “Motor lock mode” is configurable by the application circuit below.



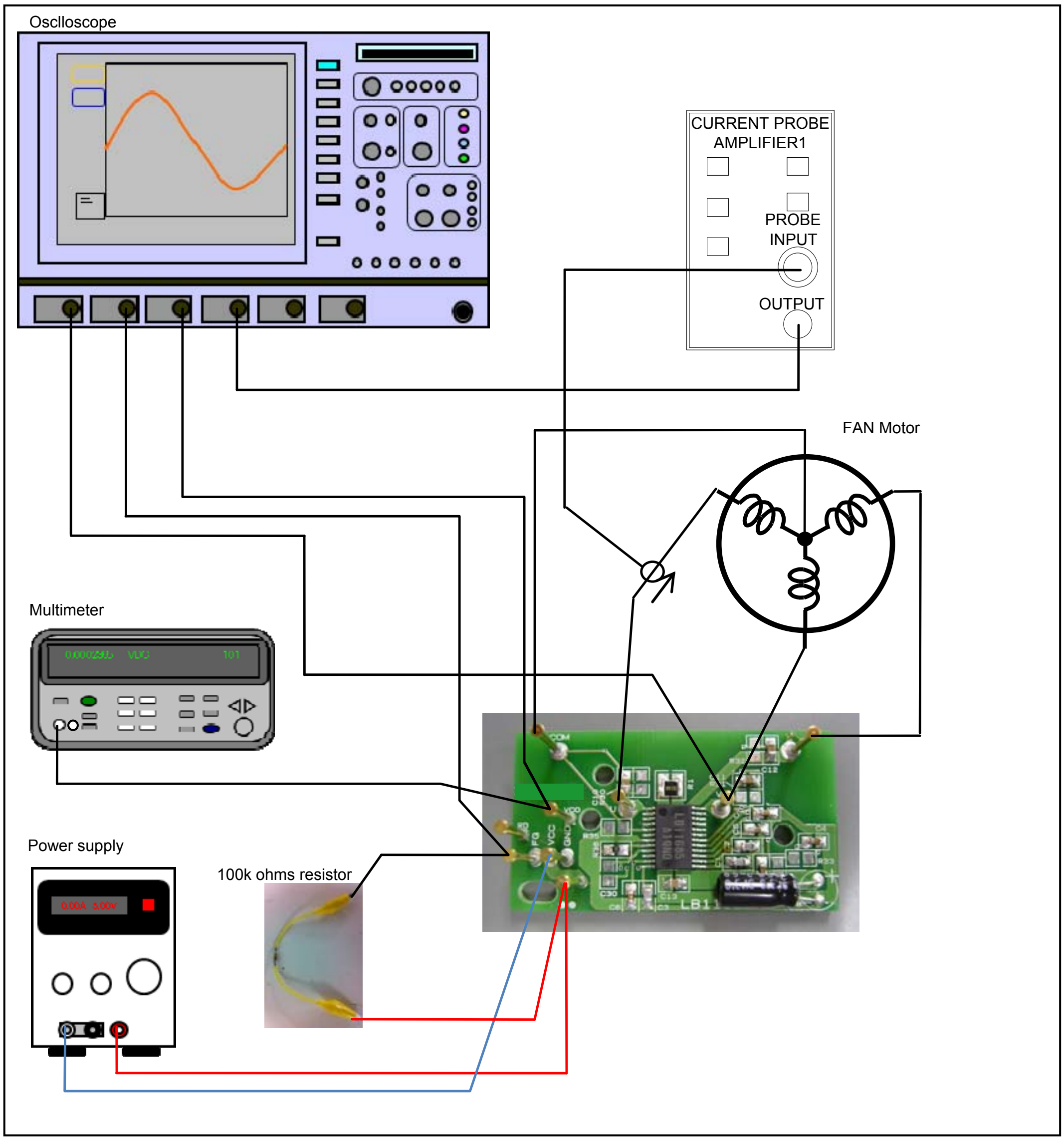
Evaluation Board Manual

1. Evaluation Board circuit diagram



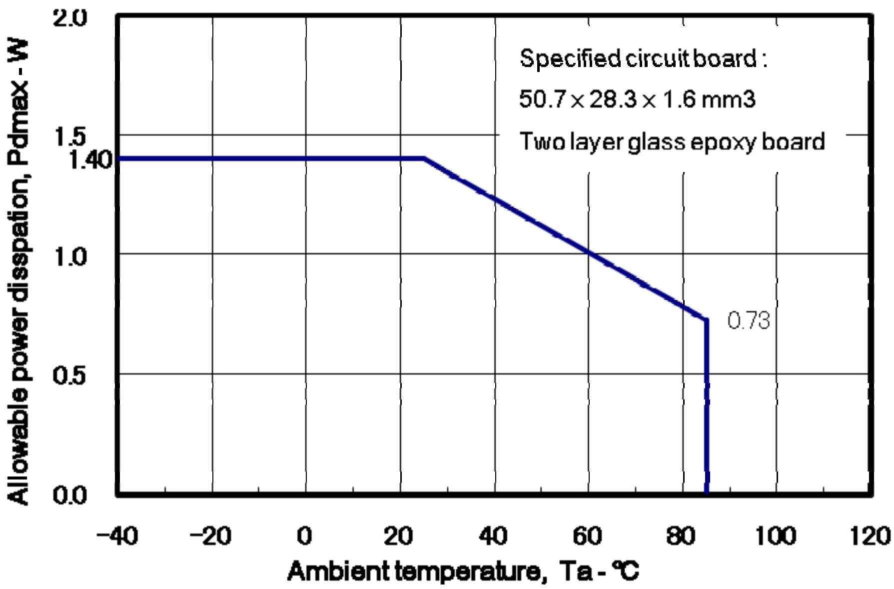
Bill of Materials for LB11685AV Evaluation Board

Designator	Quantity	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed	Lead Free
IC1	1	Motor Driver			SSOP24J (275mil)	ON Semiconductor	LB11685AV	No	yes
C1, C2	2	C1, C2 capacitor	0.01μF 50V	±5%	2012	MURATA	GRM2192C1H 103JA01D	yes	yes
C3	1	CX capacitor	0.015μF 50V	±5%	2012	MURATA	GRM2192C1H 153JA01D	yes	yes
C4, C6, C7	3	FC1, VCO, VOH capacitor	1μF 10V	±10%	1608	MURATA	GRM188R71A 105KA61D	yes	yes
C5, C8, C10-C13	6	FC2, VREG capacitor, Motor noise reduction capacitor	0.1μF 25V	±10%	1608	MURATA	GRM188R11E 104KA01D	yes	yes
C9	1	VCC Bypass capacitor	10μF 50V			Electronic Industries	50ME10HC	yes	yes
R1	1	RF resistor	0.47Ω,0.5W	±1%	3225	ROHM	MCR25JZHFL R470	yes	yes
R36	1	FG protection resistor	100Ω,0.1W	±5%	1608	KOA	RK73B1JT101 J	yes	yes
TP1, TP2	9	Test points				MAC8	ST-1-3	yes	yes



Test circuit

Pdmax - Ta



2. Test Procedure

2-1. Connect the test setup as shown above.

2-2. Initial check

Boot up at the VCC = 4.5V.
Confirm that the motor rotates smoothly and in a right direction.

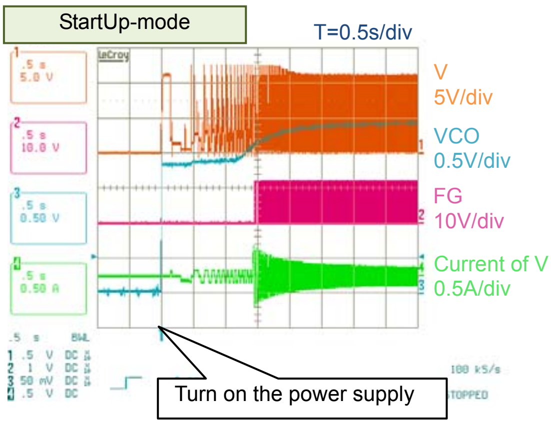
2-3. Booting check (StartUp-mode)

Check whether a booting of a motor is stable. (Booting)
Boot up at the VCC = 4.5V and 18V.
Then, at each VCC, check whether a motor boots 100 times out of 100times.

Check lowest VCC which a motor can start. (StartUp voltage)
Boot up at the VCC by 0.1V step from 2.5V to 4.5V.
When the VCC is changed, turn it off once.
The lowest voltage which a motor can boot is the StartUp voltage.
Check whether this StartUp voltage is less than 4.0V.

Check the some waveforms. (Booting waveforms)
Boot up at the VCC =12V.
Check the V, FG and VCO voltage waveform at scope CH1, CH2 and CH3, and the output current waveform of V at scope CH4 by the Oscilloscope.

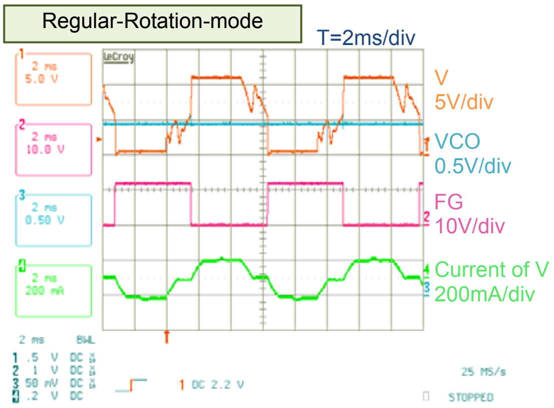
ex) These waveforms are different per motor.



2-4. Normal rotation check (Regular rotation mode)

Check some waveforms. (Rotation waveforms)
Supply the VCC=12V.
Check the V, FG and VCO voltage waveform at scope CH1, CH2 and CH3, and the output current waveform of V at scope CH4 by the oscilloscope.

ex) These waveforms are different per motor.



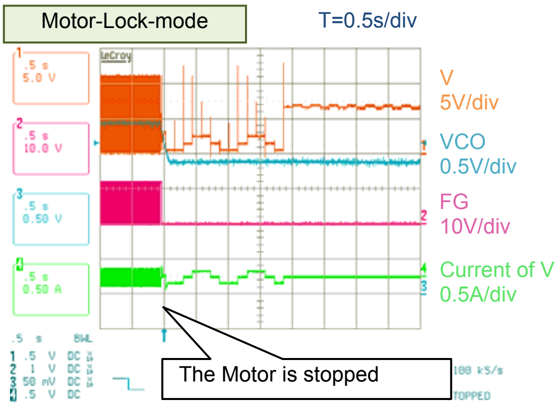
Check VCO voltage. (VCO voltage)
Supply VCC=4.5V and 18V.
At each VCC, check the VCO voltage by a multimeter whether the voltage is within 2.10V and 2.7V at Normal Rotation (Regular rotation mode).

Check the output current. (Io)
Supply the VCC=4.5V and 18V.
At each VCC, check the current of the power supply.

2-5. Lock detection check (Motor lock mode)

Check the Lock detection behavior. (Lock)
Supply the VCC=4.5V, 12V and 18V.
At each VCC, stop the Motor manually.
Then, check the V, FG and VCO voltage waveform at scope CH1, CH2 and CH3, and the output current waveform of V at scope CH4 by the Oscilloscope.

ex) These waveforms are different per motor.



2-6. Evaluation result

The evaluation table is shown below.

VCC	Booting	Booting waveforms	Rotation waveforms	VCO voltage	Io	Lock
4.5V	100/100 OK	-	-	2.10 to 2.70V OK	value	OK
12V	-	OK	OK	-	-	OK
18V	100/100 OK	-	-	2.10 to 2.70V OK	value	OK

StartUp voltage < 4.0V : OK

A sample of evaluation result is shown below.

VCC	Booting	Booting waveforms	Rotation waveforms	VCO voltage	Io	Lock
4.5V	100/100	-	-	2.16V	0.03A	OK
12V	-	OK	OK	-	-	OK
18V	100/100	-	-	2.58V	0.20A	OK

StartUp voltage = 3.2V