3-phase Sensor-less Fan Motor Driver
AM8959

The AM8959 is a 3-phase sensor-less DC fan motor driver IC. It senses the BEMF (Back Electro-Motive Force) of the motor in rotation and provides corresponding commutation current to the motor. Rotation speed can be controlled by PWM input signal. The drivers include SLOPE mode, STOP/RMI mode, Lock Detection and Thermal Shutdown. Maximum output current is 1600mA.

● Features

1) Operation voltage 3.3V to 16V
2) Direct PWM speed control
3) Built-in FG & RD
4) Soft start function
5) Forward and Reverse control
6) Lock detection/Automatic restart function
7) Over current limiter
8) Over-voltage protection
9) Thermal shutdown protection
10) Soft switching technique to reduce acoustic noise
11) SLOPE mode setting
12) STOP/RMI mode setting
13) START mode setting
14) STOP Synchronize

● Absolute Maximum Ratings (Ta = 25℃)

Parameter	Symbol	Limits	Unit
Supply voltage	V_{CC}	18	V
Output peak current	Iomax	1600	mA
Output continuous current	Io	700**	mA
FG & RD output voltage	V_{FG} & V_{RD}	V_{CC}	V
FG & RD output current	I_{FG} & I_{RD}	10	mA
PWM & F/R strength voltage	V_{PWM} &V_{FR}	V_{CC}	V
CSOFT & OSC strength voltage	V_{CSOFT} & V_{OSC}	V_{REG}	V
SLOPE & STOP strength voltage	V_{SLOPE} & V_{STOP}	V_{REG}	V
Power dissipation	Pd	3600*	mW
Operate temperature range	T_{opr}	-40～＋125	℃
Storage temperature range	T_{stg}	-55～＋150	℃
Junction temperature	Tjmax	150	℃

* Reducing by 28.8mW/℃ over 25℃ (On JEDEC-standard 2s2p board as specified in JESD-51)

** This value is not to exceed Pd.

● Recommended operating conditions

(Set the power supply voltage taking allowable dissipation into considering)

Parameter	Symbol	Min	Typ	Max	Unit
Operating supply voltage range	Vcc	3.3～16			V

● **Storage Condition**

Parameter	Value	Unit
Temperature condition Before Opening	5~40	℃
Humidity condition Before Opening	30~80%	RH
Temperature condition after Opening	<30	℃
Humidity condition after Opening	<60%	RH

● **Electrical Characteristics**

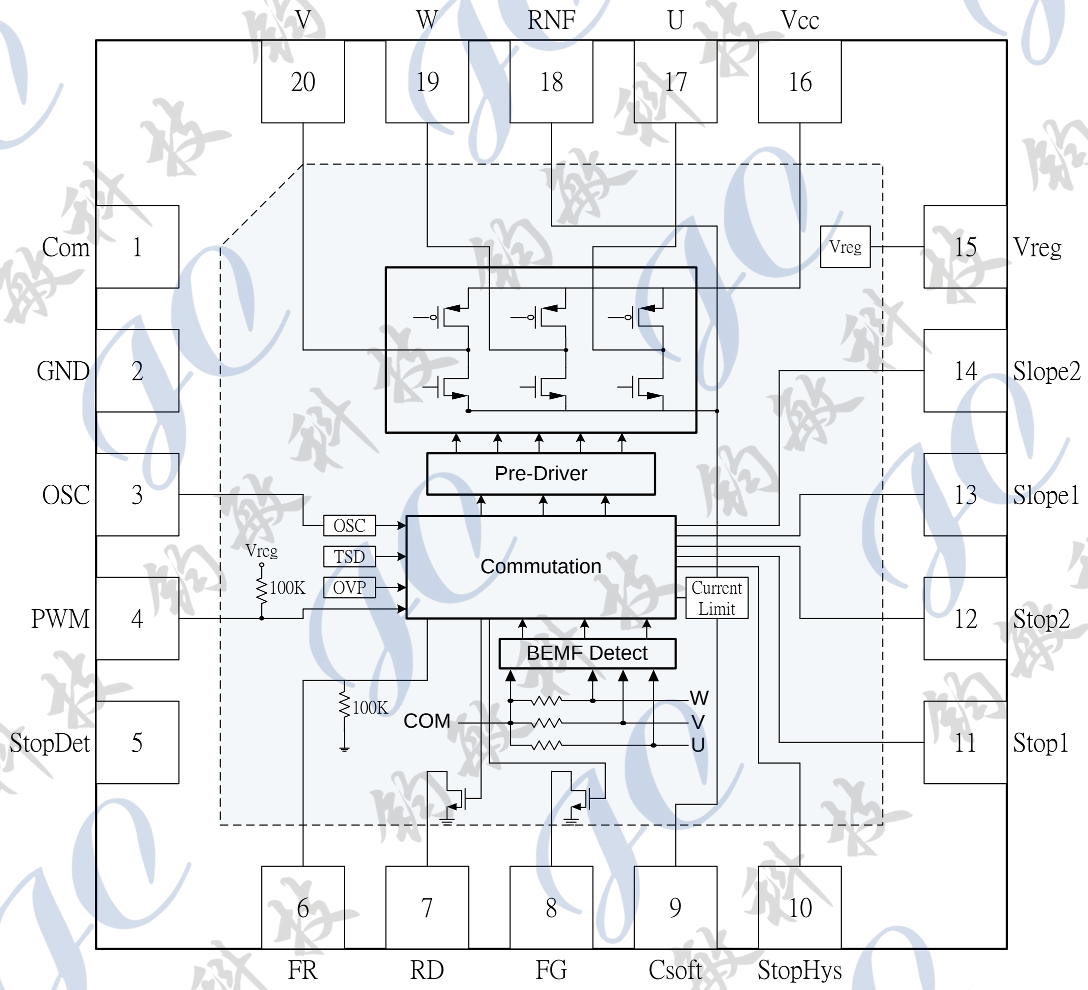
(Unless otherwise specified, Ta = 25℃, VCC = 12.0V)

Parameter	Symbol	Limit			Unit	Conditions
		Min	Typ	Max		
Supply current	I_{CC}	—	2.1	3	mA	PWM= V_{REG}
Stand-by current	I_{SC}	—	1.4	2.0	mA	PWM= 0V
Regulator voltage	V_{REG}	3.135	3.3	3.465	V	
Oscillator						
OSC pin charge current	I_{OSCC}	—	-12	—	µA	OSC pin= 0.3V
OSC pin discharge current	I_{OSCD}	—	12	—	µA	OSC pin= 1.5V
PWM, F/R input						
Input H level	V_{PWMH}/ V_{FRH}	2.0	—	V_{CC}	V	
Input L level	V_{PWML}/ V_{FRL}	0	—	0.8	V	
PWM input frequency	F_{PWM}	20	—	50	kHz	
SLOPE, STOP input						
Input H level	V_{SLOPEH}/ V_{STOPH}	V_{REG}-0.5		V_{REG}	V	
Input Middle voltage	V_{SLOPEM}/ V_{STOPM}	V_{REG}*0.4		V_{REG}*0.6	V	SLOPE/ STOP Input floating
Input L level	V_{SLOPEL}/ V_{STOPL}	0		0.5	V	
Output						
Output ON resistance	R_{ON} (H+L)	—	0.7	0.95	Ω	I_0=500mA, High and Low total
FG/RD low voltage	V_{FGL}/ V_{RDL}	—	—	0.4	V	$I_{FG/RD}$ = 5mA
FG/RD leakage current	I_{FGH}/ I_{RDH}	—	—	10	µA	$V_{FG/RD}$ = 18V

Lock protection						
Lock detection ON time	T_{ON}	1.4	2	2.6	sec	T_{ON} = start time + lock detect
Lock detection OFF time	T_{OFF}	3.5	5	6.5	sec	
Soft start						
Soft start release voltage	V_{CSOFT}	1.5	2.0	2.5	V	
Soft start charge current	I_{CSOFT}	—	0.5	—	μA	
Current limiter						
Current limit voltage	V_{RNF}	0.2	0.25	0.3	V	
Thermal						
Thermal shutdown	ThSD	150	170	—	℃	*1
Thermal shutdown hysteresis	ΔThSD	—	30	—	℃	*1

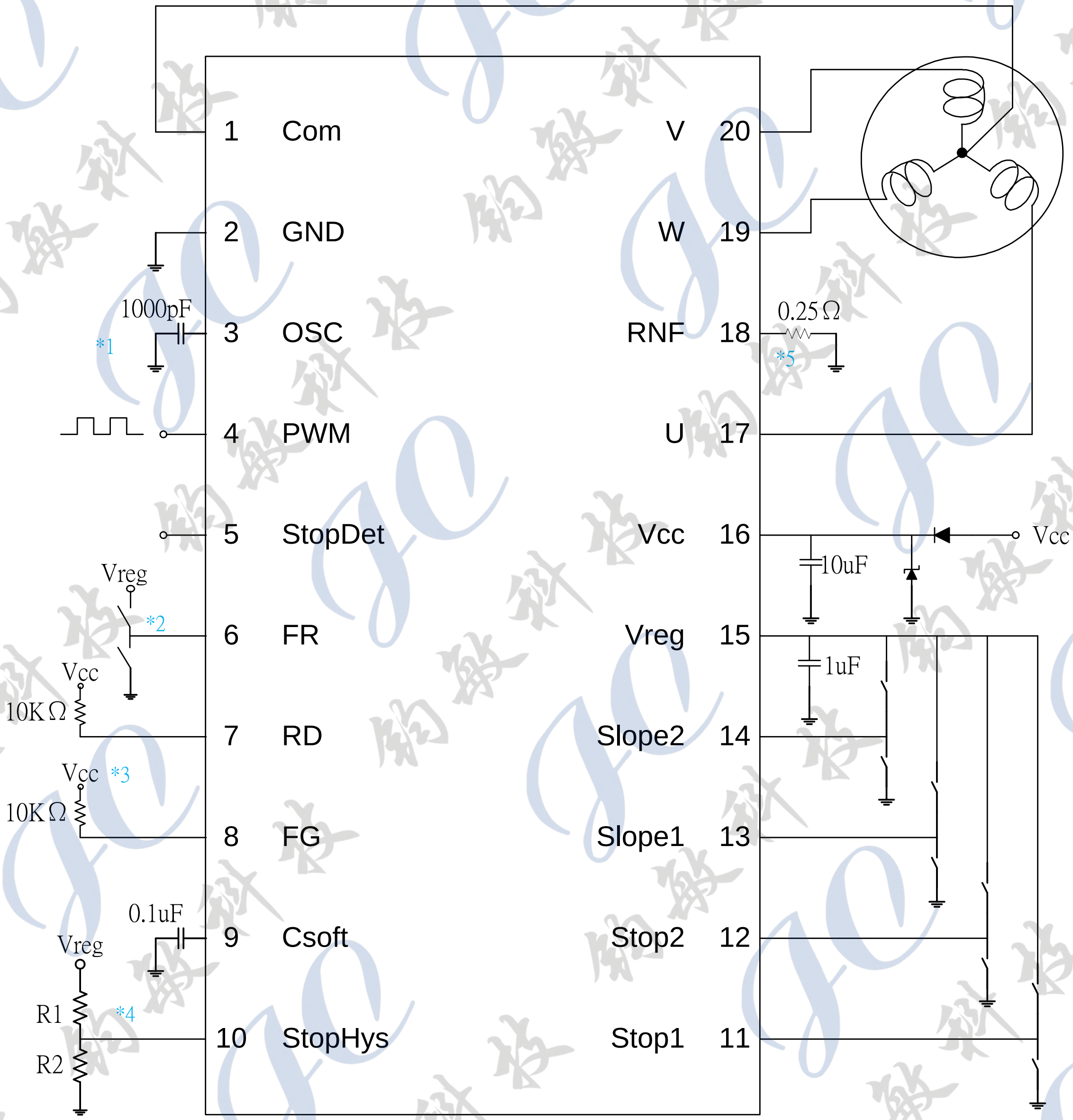
*1: It is design target, not to be measured at production test.

- **Block Diagram**



Pin No	Pin Name	Function	Pin No	Pin Name	Function
1	COM	Motor center tap voltage input terminal	11	Stop 1	Stop mode setting terminal 1
2	GND	Ground terminal	12	Stop 2	Stop mode setting terminal 2
3	OSC	Start-up frequency output terminal	13	Slope 1	Slope Setting terminal 1
4	PWM	PWM signal input terminal	14	Slope 2	Slope Setting terminal 2
5	StopDet	Stop Detector	15	Vreg	Regulator voltage output terminal
6	FR	Forward and Reverse control terminal	16	Vcc	Power supply terminal
7	RD	RD signal output terminal	17	U	U phase output terminal
8	FG	FG signal output terminal	18	RNF	Output current detection terminal
9	Csoft	Soft start time setting terminal	19	W	W phase output terminal
10	StopHys	Stop hysteresis terminal	20	V	V phase output terminal
E-Pad	GND	Ground terminal			

Application Circuit



*1. OSC: This Capacitor 1000pF is only for reference. Variable Motors should select suitable capacitor for optimum start-up characteristics.

*2. FR: Connect FR to VREG or GND to avoid noise interference.

*3. RD, FG: Open drain output. A pull-up resistances of 10kΩ should be inserted.

*4. StopHys: R1, R2 resistors are bigger, the current is lower. But bigger resistance might cause higher noise. Normally, R1 and R2 resistor value could select 10KΩ ~ 100KΩ resistance.

*5. RNF: Current limiter voltage setting is 0.25V(Typ.). The formula is RNF=0.25V/current limit target. (0.25Ω=0.25V/1A)

Operation notes

1) VCC power supply line

The BEMF causes re-circulate current to power supply. Please connect a capacitor between power supply VCC pin and ground as a route of re-circulate current. And please determine the capacitance after confirmation that the capacitance does not causes any problems.

Need to apply a 18V zenor diode near the Vcc pin to reduce surge power.

2) VREG regulator

VREG is voltage regulator output and using for internal circuits. Connect capacitors to ground for stable operation.

3) Ground potential

Ground potential E-PAD and GND pin connect the lowest voltage on the chip and as short the path as possible.

4) PWM speed control

This IC offer PWM pin direct control motor speed. Output frequency will fix around 25KHz to reduce audible noise. The PWM frequency recommend operating between 20 KHz to 50 KHz.

When PWM is Hi longer than 111us(Typ. 9KHz), the output will keep turn on.

When PWM is Low longer than 111us(Typ. 9KHz), it will go into stand-by mode.

This pin connects internal pull-high resistance of 100K ohm to VREG. When connect to VREG or floating. The motor will rotate in the full speed.

5) Soft Switching Circuits

This IC use duty-variable switching for low acoustic noise and vibration.

6) Start-up

There are three factors that will affect start-up:

A. OSC Setting: The OSC pin is defined a sensor-less start-up commutation frequency. The connecting capacitor is between the OSC pin and ground. Variable Motors start-up characteristic are variable with different capacitors. Variable Motors should select suitable capacitor for optimum start-up characteristics. If the capacitance value is larger, the variation start-up time is longer. Also, if the capacitance value is smaller, the motor start-up time is shorter and might cause start-up failed by motor friction.

B. Soft Start Function: The motor could be smoothly start-up when Soft start pin connecting a capacitor to ground. Longer soft start time might cause start-up insufficient torque and cause start-up NG. Variable Motors should select suitable soft start capacitor for optimum start-up characteristics.

C. Current Limit (RNF): Bigger resistor value will limit more current. Excessive current limit might cause start-up NG. Variable Motors should select suitable current limit resistor (RNF) for optimum start-up characteristics.

7) Start-up Test

In order to make sure start-up normally, after choose OSC capacitor, soft start capacitor and RNF value, it should test every PWM Duty for start-up. Normal start-up test would test PWM Duty 100%~20%, every 5% PWM duty step for each point, make sure start-up status.

Even the motor Coil (U, V, W) BEMF are meet the condition as motor BEMF Requirement, it still need to do the start-up test to verify the start-up status.

8) Soft start function

The motor could be smoothly start-up when Soft start pin connecting a capacitor to ground.

The function release when the voltage reaches 2.0V or more. If the soft start function is not used, keeps this pin floating.

9) Current limiter (RNF)

Apply a RNF resistor for current limit is necessary. Current limiter voltage setting is 0.25V. Connect a resistor to ground to determine the current limit value. The resistor path needs wider and the ground side make shorter to GND.

The formula is RNF=0.25V/current limit target. (0.25Ω=0.25V/1A)

10) FG / RD function

This FG or RD pin is made up with an open drain output. Recommend connect a resistor of 10k ohm to supply. In order to prevent unexpected power to cause FG/RD damage, series connect a 100Ω~200Ω resistor for protection.

11) Thermal design and Thermal shutdown

The thermal design should allow enough margins for actual power dissipation. In case the IC is left running over the allowable loss, the junction temperature rises, and the thermal-shutdown circuit works at the junction temperature of 170°C (typ.) (the outputs of all the channels are turned off). When the junction temperature drops to 145°C (typ.), the IC start operating again.

12) F/R (Forward and Reverse) function

Motor direction can be forward or reverse by switching F/R voltage level.

F/R high (VREG): U -> V-> W and F/R low (ground): U->W->V.

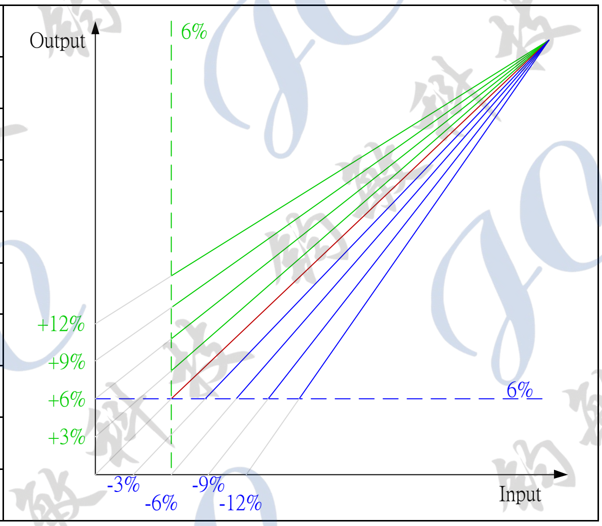
Internal pull low resistance is 100k ohms.

Suggest connecting F/R pin to Vreg or GND to avoid noise interference.

13) Slope mode

SLOPE mode function setting by SLOPE1 and SLOPE2 pin logic input. The setting as below table:

Line	Slope1	Slope2	Output
1	1	1	+12%
2	1	X	+9%
3	1	0	+6%
4	X	1	+3%
5	X	X	0%
6	X	0	-3%
7	0	1	-6%
8	0	X	-9%
9	0	0	-12%



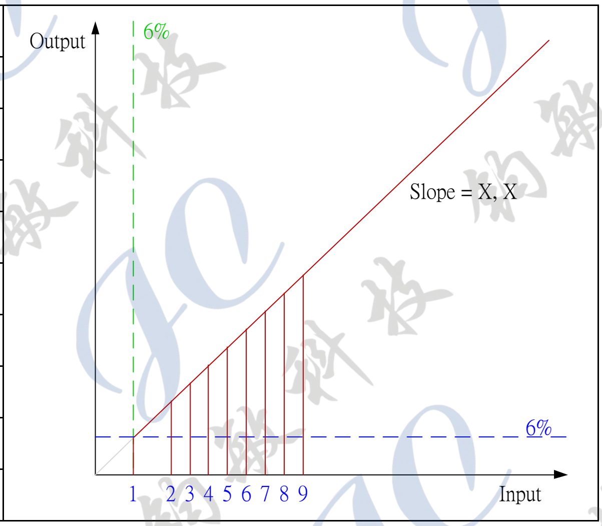
X: Pin floating or connect to Middle voltage. 1: Connect to Vreg. 0: Connect to ground.

A. When rpm curve is lower than input or output 6%, motor will stop.

14) Stop/RMI mode

The Stop speed and RMI speed are setting by STOP1 and STOP2 pin logic input. The setting as below table:

Line	Stop1	Stop2	Output
1	X	X	0%
2	X	1	12.5%
3	X	0	15%
4	1	X	17.5%
5	1	1	20%
6	1	0	22.5%
7	0	X	25%
8	0	1	27.5%
9	0	0	30%

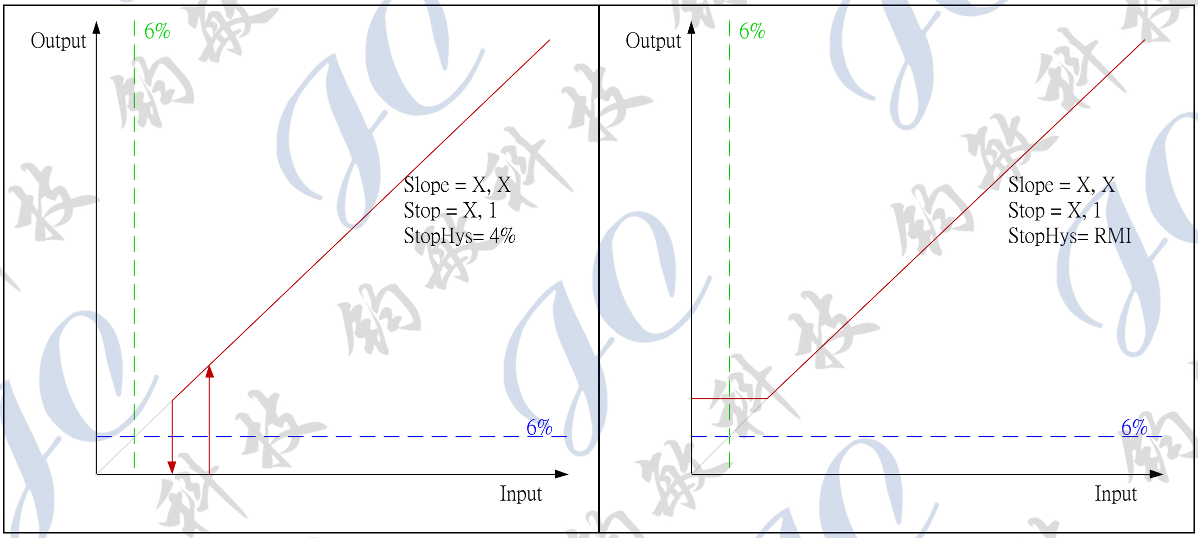


X: Pin floating or connect to Middle voltage. 1: Connect to Vreg. 0: Connect to ground.

15) Stop hysteresis and RMI selection

After detect Stop mode, the start duty hysteresis is setting by StopHys Pin R_{Hys} resistor ratio. The setting is as following table.

Voltage(V)	Hys
0~0.15*Vreg	2%
(0.25~0.35)*Vreg	4%
(0.45~0.55)*Vreg	6%
(0.65~0.75)*Vreg	8%
(0.85~1)*Vreg	RMI



X: Pin floating or connect to Middle voltage. 1: Connect to Vreg. 0: Connect to ground.

16) RPM curve setting

RPM curve is adjust with Slope pin, Stop/RMI pin and StopHys pin. There are some rules are describe as following:

A. When motor trigger stop mode, the start duty hysteresis is setting by StopHys Pin R_{Hys} resistor ratio.

B. When rpm curve is lower than input or output 6% before stop mode setting, motor will stop. The start hysteresis duty will be about 1.5%.

17) StopDet (Stop Detector)

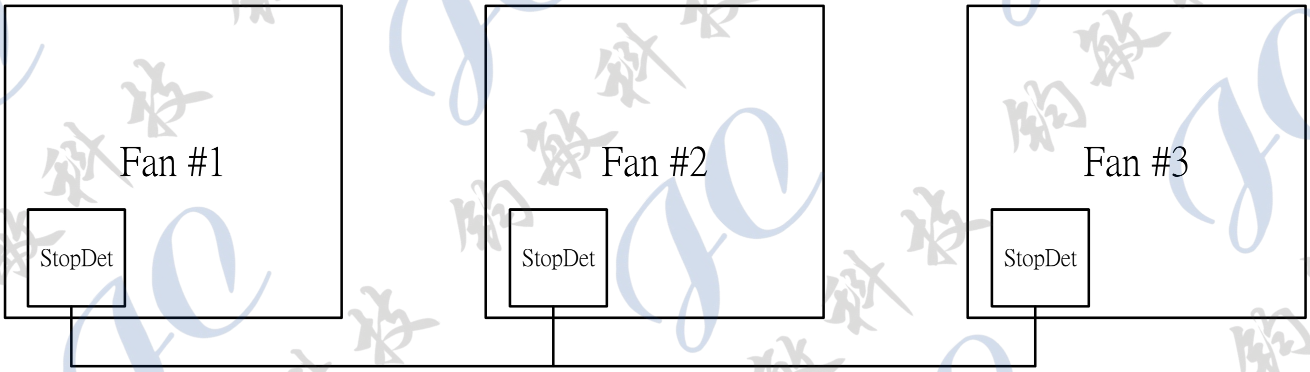
StopDet pin is for plural motors stop simultaneously.

A. Motor is running, StopDet=1. Motor is in stop mode, StopDet=0.

B. All the motors StopDet pin connect together, one of the motor stop, the others will stop simultaneously.

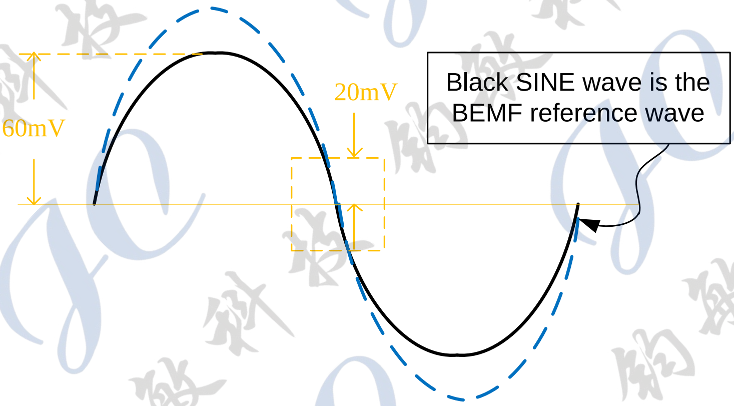
C. When in the RMI mode, the StopDet pin is disable.

D. Keep StopDet floating if not use.

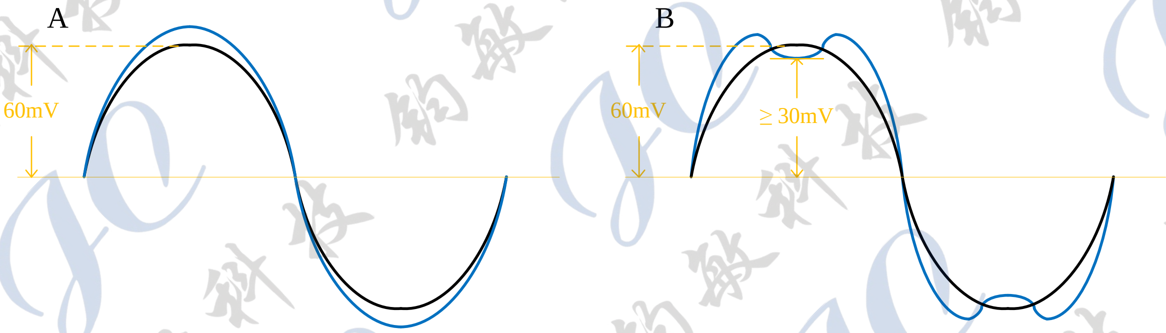


- **Motor BEMF Requirement**

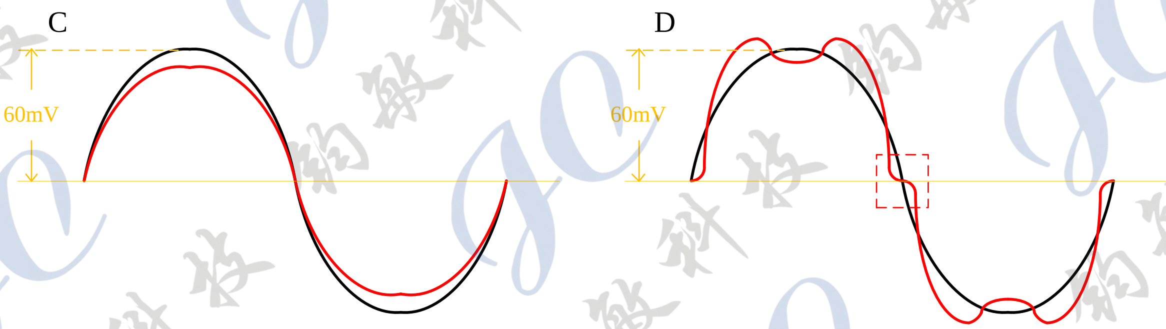
1. Motor Coil (U, V, W) BEMF amplitude minimum need to over 60mV at 1000rpm.
2. Motor Coil (U, V, W) BEMF Zero Cross Slope need equal or greater than SINE wave within ±20mV.



3. **Acceptable.**
   A. BEMF wave greater than 60mV
   B. BEMF wave greater than 60mV. The wave middle side need to greater than ±30mV.



4. **Unacceptable**
   C. BEMF wave smaller than 60mV.
   D. BEMF Zero Cross Slope less than SINE wave within ±20mV.



Thermal Information

Θja	junction-to-ambient thermal resistance	34.72℃/W
Ψjt	junction-to-top characterization parameter	0.95℃/W

- **Θja** is obtained in a simulation on a JEDEC-standard 2s2p board as specified in JESD-51.
- The **Θja** number listed above gives an estimate of how much temperature rise is expected if the device was mounted on a standard JEDEC board.
- When mounted on the actual PCB, the **Θja** value of JEDEC board is totally different than the **Θja** value of actual PCB.
- **Ψjt** is extracted from the simulation data to obtain **Θja** using a procedure described in JESD-51, which estimates the junction temperature of a device in an actual PCB.

- The thermal characterization parameter, **Ψjt**, is proportional to the temperature difference between the top of the package and the junction temperature. Hence, it is useful value for an engineer verifying device temperature in an actual PCB environment as described in JEDEC JESD-51-12.
- When Greek letters are not available, **Ψjt** is written Psi-jt.
- Definition:

$$\text{DFEINITION:}\Psi_{jt} = (T_j - T_t) / P_d$$

Where :

Ψjt (Psi-jt) = Junction-to-Top(of the package) °C/W
Tj= Die Junction Temp. °C
Tt= Top of package Temp at center. °C
Pd= Power dissipation. Watts

- Practically, most of the device heat goes into the PCB, there is a very low heat flow through top of the package, So the temperature difference between **Tj** and **Tt** shall be small, that is any error caused by PCB variation is small.

- This constant represents that **Ψjt** is completely PCB independent and could be used to predict the **Tj** in the environment of the actual PCB if **Tt** is measured properly.

- **How to predict Tj in the environment of the actual PCB**

Step 1 : Used the simulated **Ψjt** value listed above.

Step 2 : Measure **Tt** value by using

- **Thermocouple Method**

  We recommend use of a small ~40 gauge(3.15mil diameter) thermocouple. The bead and thermocouples wires should touch the top of the package and be covered with a minimal amount of thermally conductive epoxy. The wires should be heat-insulated to prevent cooling of the bead due to heat loss into wires. This is important towards preventing "too cool" **Tt** measurements, which would lead to the calculated **Tj** also being too cool.

- **IR Spot Method**

  An IR Spot method should be utilized only when using a tool with a small enough spot area to acquire the true top center "hot spot".
  Many so-called "small spot size" tools still have a measurement area of 0~100+mils at "zero" distance of the tool from the surface. This spot area is too big for many smaller packages and likely would result in cooler readings than the small thermocouple method. Consequently, to match between spot area and package surface size is important while measuring **Tt** with IR sport method.

Step 3 : calculating power dissipation by

$$P \cong (VCC - |Vo_{\_Hi} - Vo_{\_Lo}|) \times I_{out} + VCC \times Icc$$

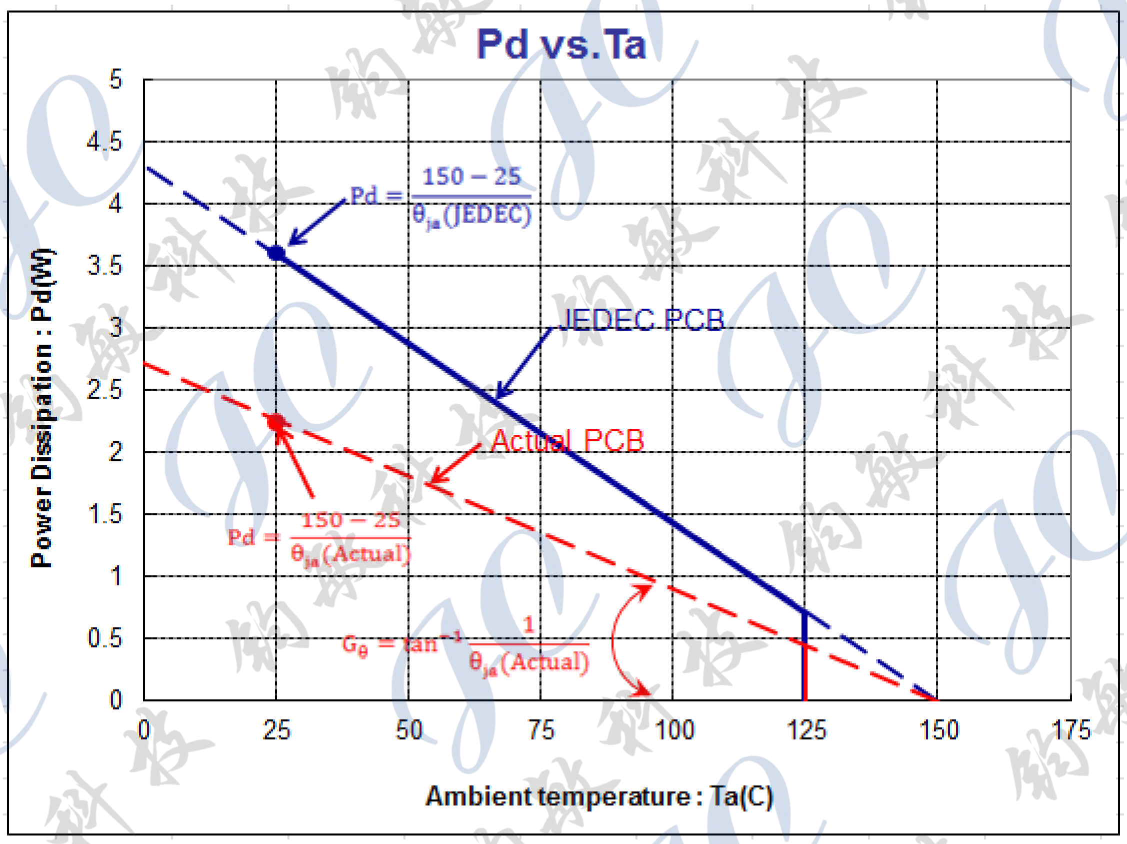
Step 4 : Estimate **Tj** value by

$$Tj = \Psi jt \times P + Tt$$

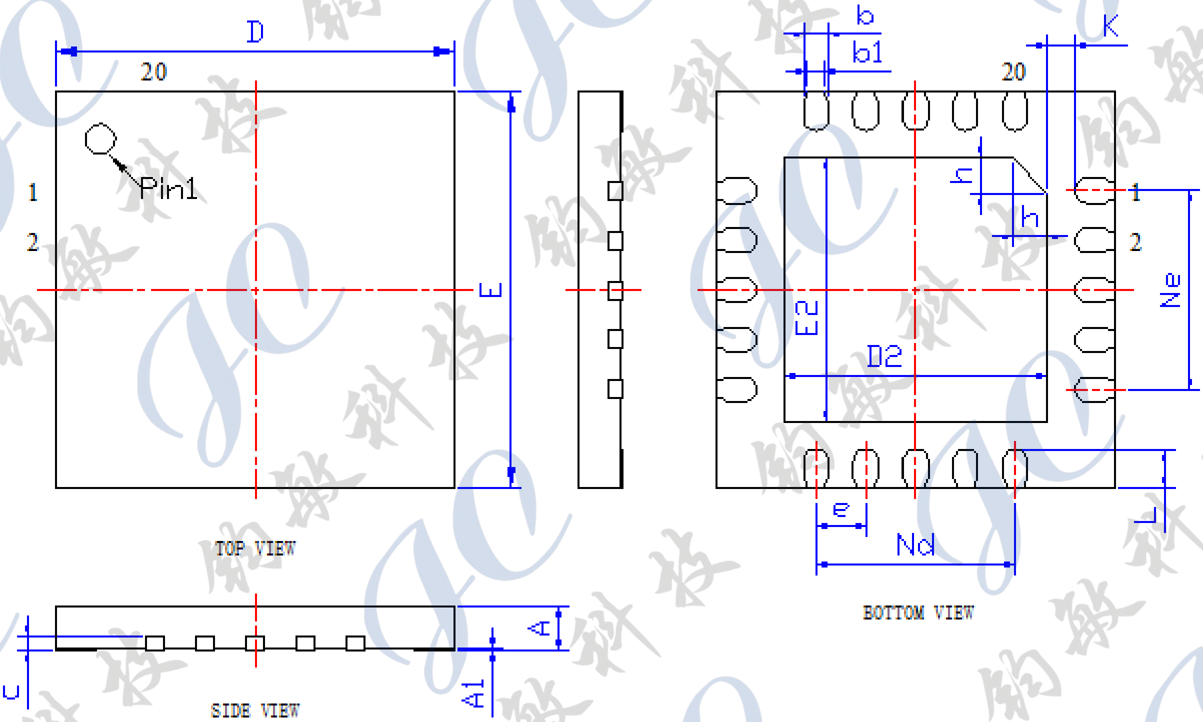
Step 5: Calculated Θja value of actual PCB by the known **Tj**

$$\Theta ja(actual) = (Tj - Ta)/P$$

Maximum Power Dissipation (de-rating curve) under JEDEC PCB & actual PCB



- **Packaging outline --- QFN 4x4-20L** Unit : mm



SYMBOL	MILLIMETERS		INCHES	
	Min.	Max.	Min.	Max.
A	0.40	0.50	0.016	0.020
A1	0.00	0.05	0.000	0.002
c	0.152 REF		0.006 REF	
b	0.20	0.30	0.008	0.012
b1	0.18 REF		0.007 REF	
D	3.90	4.10	0.154	0.161
E	3.90	4.10	0.154	0.161
D2	2.55	2.75	0.100	0.108
E2	2.55	2.75	0.100	0.108
Ne	2.00 BSC		0.079 BSC	
Nd	2.00 BSC		0.079 BSC	
L	0.35	0.45	0.014	0.018
h	0.30	0.40	0.012	0.016
K	0.275 REF		0.011 REF	
e	0.50 BSC		0.020 BSC	

Condition of Soldering

1). Manual Soldering

Time / Temperature $\leq$ 3 sec / 400 ± 10 °C （1 Cycle）

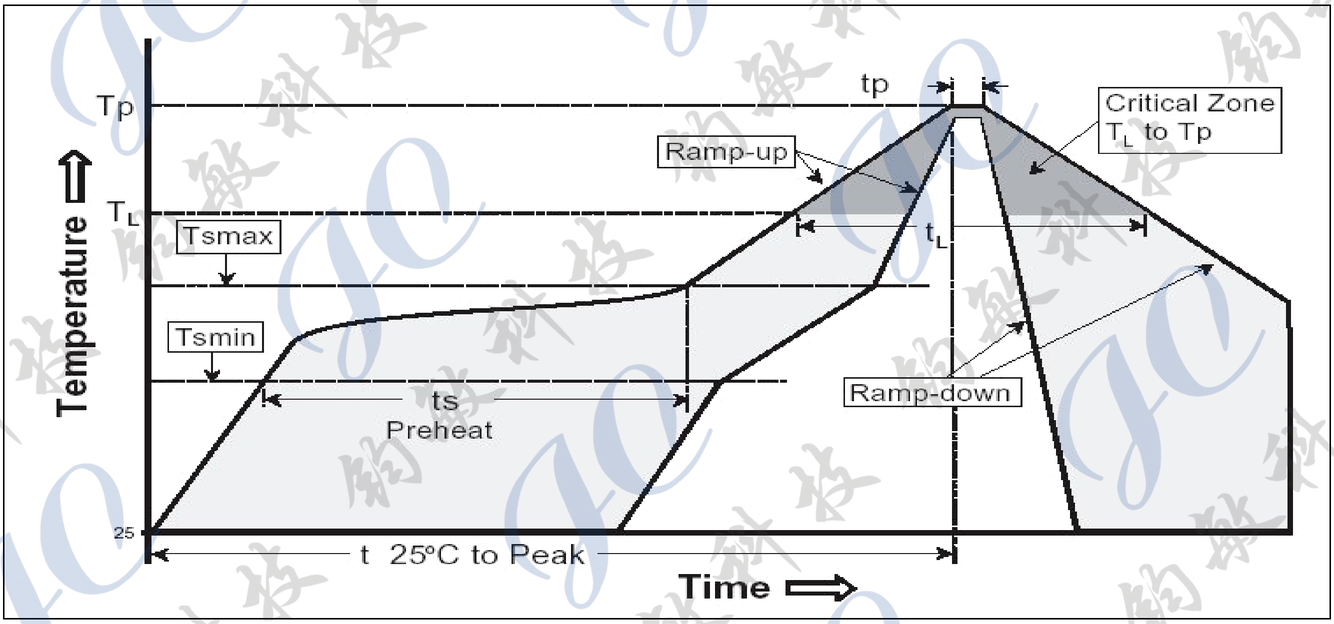
Test Results：0 fail/ 22 tested

Manual Soldering count：2 Times

2). Re-flow Soldering (follow IPC/JEDEC J-STD-020D)

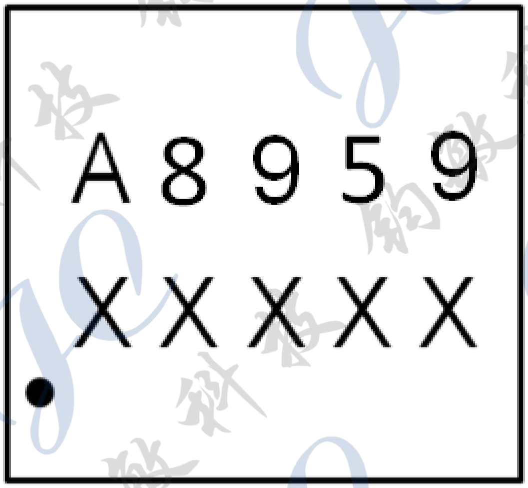
Classification Reflow Profile

Profile Feature	Pb-Free Assembly
Average ramp-up rate (T_L to T_P)	3°C/second max.
Preheat - Temperature Min (Ts min) - Temperature Max (Ts max) - Time (ts) from (Tsmin to Tsmax)	 150°C 200°C 60-120 seconds
Ts max to T_L - Temperature Min (Ts min)	 3°C/second max.
Time maintained above: - Liquid us temperature (T_L) - Time (t_L) maintained above TL	 217°C 60-150 seconds
Peak package body temperature (Tp)	260 +0/-5°C
Time with 5°C of actual Peak - Temperature (tp)	30 seconds
Ramp-down Rate	6°C/second max.
Time 25°C to Peak Temperature	8 minutes max.



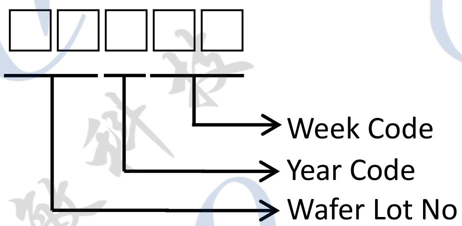
Test Results：0 fail/ 32 tested Reflow count：3 cycles

- **Marking Identification**



Row1 ：Device Name

Row2 ：Wafer Lot No use two codes + Assembly Year use one code + Assembly Week use two codes



Example: Wafer lot no is AG + Year 2019 is J + Week 46 is 46， we type 〝AGJ46〞

The last code of assembly year, explanation as below:

(Year：A=0,B=1,C=2,D=3,E=4,F=5,G=6,H=7,I=8,J=9. For example: year 2019=J)