MPQ6653A-AEC1

35V/1.2A, Single-Phase BLDC Motor Driver with Integrated Hall Sensor, AEC-Q100 Qualified

DESCRIPTION

The MPQ6653A-AEC1 is a single-phase brushless DC (BLDC) motor driver with integrated power MOSFETs and an embedded Hall sensor. It drives a single-phase BLDC motor, with up to 1.2A of peak coil current. The input voltage (V_{IN}) range is between 3.5V and 35V.

The MPQ6653A-AEC1 controls the motor speed through the pulse-width modulation (PWM) signal or the DC voltage on the PWM pin. The device features configurable soft commutation, a Hall offset angle, and speed curve configurations.

The FG/RD pin acts as either a rotating speed indicator (FG) based on the embedded Hall sensor's output, or locked-rotor indicator (RD) if locked-rotor protection is triggered.

Rich protections include input over-voltage protection (OVP), under-voltage lockout (UVLO), locked-rotor protection, over-current protection (OCP), and thermal shutdown protection.

The MPQ6653A-AEC1 is available in TSOT23-6-SL, TSOT23-6, and wettable-flank TQFN-6 (2mmx3mm) packages. It is available in AEC-Q100 Grade 1.

FEATURES

- 3.5V to 35V Operating Input Voltage (V_{IN}) Range
- On-Chip Hall Sensor
- Integrated High-Side MOSFET (HS-FET) and Low-Side MOSFET (LS-FET): 960mΩ
- Selectable Open-Loop or Closed-Loop Speed
- Configurable Curves
- Configurable Starting Duty Cycle
- Configurable Stopping Duty Cycle
- Soft Commutation
- Configurable Soft Acceleration Time
- Configurable Hall Leading/Lag Angle
- Supports 50Hz to 100kHz Pulse-Width Modulation (PWM) Input Frequency or DC Input
- Automatic Reverse Current Block
- 24kHz PWM Output Frequency
- Configurable Current Limit
- Short-Circuit Protection (SCP)
- Over-Voltage Protection (OVP)
- Standby Mode
- Selectable FG or RD Output
- Available in TSOT23-6-SL, TSOT23-6, and TQFN-6 (2mmx3mm) WF Packages
- Available in AEC-Q100 Grade 1

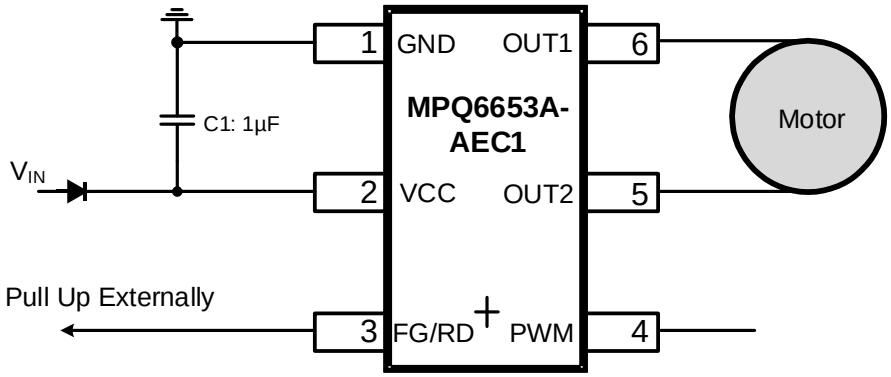
APPLICATIONS

- Automotive Fans
- Seat Fans
- Cooling Fans
- General Fans

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TYPICAL APPLICATION



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ORDERING INFORMATION

Part Number*	Package	Top Marking	MSL Rating
MPQ6653AGJS-xxxx-AEC1**	TSOT23-6-SL	*See Below*	1
MPQ6653AGJ-xxxx-AEC1**	TSOT23-6		
MPQ6653AGDTE-xxxx-AEC1	TQFN-6 (2x3mm) Wettable Flank		

* For Tape & Reel, add suffix -Z (e.g. MPQ6653AGJS-xxxx-AEC1-Z).

** “xxxx” is the configuration code identifier. The four digits of the suffix (xxxx) can be a hexadecimal value between 0 and F. The default code is “0000”. Work with an MPS FAE to create this unique number, even if ordering the “0000” code.

TOP MARKING (MPQ6653AGJS)

CEGY

LLL

CEG: Product code of MPQ6653AGJS
Y: Year code
LLL: Lot number

TOP MARKING (MPQ6653AGJ)

| CEGY

CEG: Product code of MPQ6653AGJ
Y: Year code

TOP MARKING (MPQ6653AGDTE)

$\overline{\text{CEG}}$

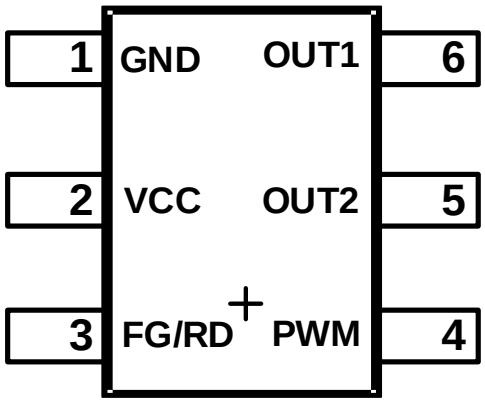
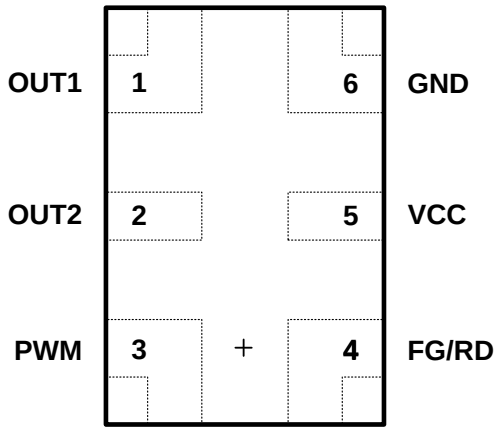
YWW

LLLL

CEG: Product code of MPQ6653AGDTE
Y: Year code
WW: Week code
LLLL: Lot number

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PACKAGE REFERENCE

TOP VIEW	TOP VIEW
	
TSOT23-6-SL, TSOT23-6	TQFN-6 (2mmx3mm) with Wettable Flanks

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PIN FUNCTIONS

Pin # (TSOT23-6-SL, TSOT23-6)	Pin # (TQFN-6 (2mmx3mm)	Name	Description
1	6	GND	**Ground.**
2	5	VCC	**Input power supply.** The VCC pin must be locally bypassed.
3	4	FG/RD	**Speed (FG) or rotor deadlock (RD) indicator output.** The FG/RD pin is an open-drain output. Pull up FG/RD externally.
4	3	PWM	**Speed control pulse-width modulation (PWM) input.** The PWM pin supports a 50Hz to 100kHz PWM input frequency or a 0V to 3V DC input. Pull PWM high internally by 100kΩ.
5	2	OUT2	**Motor driver output 2.** The OUT2 pin is connected to the mid-point of the internal N-channel MOSFET half-bridge.
6	1	OUT1	**Motor driver output 1.** The OUT1 pin is connected to the mid-point of the internal N-channel MOSFET half-bridge.

ABSOLUTE MAXIMUM RATINGS (1)

V_{CC}, PWM, FG/RD .....-0.3V to +38V
OUT1/2 .....-0.3V to V_{CC} + 0.3V
Junction temperature (T_J) .....150°C
Lead temperature .....260°C
Continuous power dissipation (2)
TSOT23-6 ..... 1.25W
TQFN-6 (2mmx3mm)..... 1.78W

ESD Ratings

Human body model (HBM) ..... ±2kV
Charged-device model (CDM).....±2kV

Recommended Operating Conditions (3)

Supply voltage (V_{IN}) .....3.5V to 35V
Operating junction temp (T_J).... -40°C to +150°C

Thermal Resistance (4) θ_{JA} θ_{JC}

TSOT23-6	100	55	°C/W
TQFN-6 (2mmx3mm)	65	10	°C/W

Notes:

1) Absolute maximum ratings are rated under room temperature, unless otherwise noted. Exceeding these ratings may damage the device.
2) The maximum allowable power dissipation is a function of the maximum junction temperature, T_J (MAX), the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable continuous power dissipation at any ambient temperature is calculated by P_D (MAX) = (T_J (MAX) - T_A) / θ_{JA}. Exceeding the maximum allowable power dissipation can produce an excessive die temperature, and the regulator may go into thermal shutdown. Internal thermal shutdown circuitry protects the device from permanent damage.
3) The device is not guaranteed to function outside of its operating conditions.
4) Measured on a JESD51-7, 4-layer PCB.

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ELECTRICAL CHARACTERISTICS

V_{CC} = 12V, T_J = -40°C to 150°C, unless otherwise noted.

Parameter	Symbol	Condition	Min	Typ	Max	Units
VCC voltage (V_{CC}) under-voltage lockout (UVLO) rising threshold	V_{UVLO_R}			3.1	3.4	V
V_{CC} UVLO hysteresis	V_{UVLO_HYS}			0.4		V
Operating supply current	I_{CC}	PWM = high		5	7	mA
Standby current	I_{STD}	PWM = low		120		μA
Pulse-width modulation (PWM) input high threshold	V_{PWM_H}		2.2			V
PWM input low threshold	V_{PWM_L}				0.8	V
DC input high threshold	V_{DC_H}		2.7	3	3.3	V
DC input low threshold	V_{DC_L}		0	130	230	mV
PWM internal pull-up resistance	R_{PWM}			100		kΩ
FG/RD output low level	V_{FG_L}	$I_{FG/RD}$ = 3mA		0.3	0.43	V
Switching frequency	f_{SW}		23.04	24	24.96	kHz
High-side MOSFET (HS-FET) on resistance	R_{HS_ON}	I_{OUT} = 100mA		480		mΩ
Low-side MOSFET (LS-FET) on resistance	R_{LS_ON}	I_{OUT} = 100mA		480		mΩ
Cycle-by-cycle current limit	I_{OCP}	OCP_SEL = 1		1.2		A
Peak current limit	I_{LIM}			1.8		A
Zero-current detection (ZCD) threshold	I_{ZCD}		-5		+5	mA
Soft-on commutation angle	θ_{SON}	SON = 0x10		46.4		deg
Soft-off commutation angle	θ_{SOFF}	SOFF = 0x10		46.4		deg
Hall lead/lag angle	θ_{HAL}	HAL_ANG = 0xF		21.8		deg
Locked-rotor detection time	t_{RD}			0.6		s
Locked-rotor retry time	t_{RE}	LOCK_SEL = 0		3.6		s
Over-voltage protection (OVP) threshold	V_{OVP_H}	OVP_DIS = 0, OVP_H = 1	28	31	34	V
	V_{OVP_L}	OVP_DIS = 0, OVP_H = 0	17	19	21	V
OVP hysteresis	V_{OVP_HYS}			2	3	V
Operate point	B_{OP}			+1	+2	mT
Release point	B_{RP}		-2	-1		mT
Thermal shutdown threshold	T_{ST}			170		°C
Thermal shutdown hysteresis	T_{ST_HYS}			25		°C

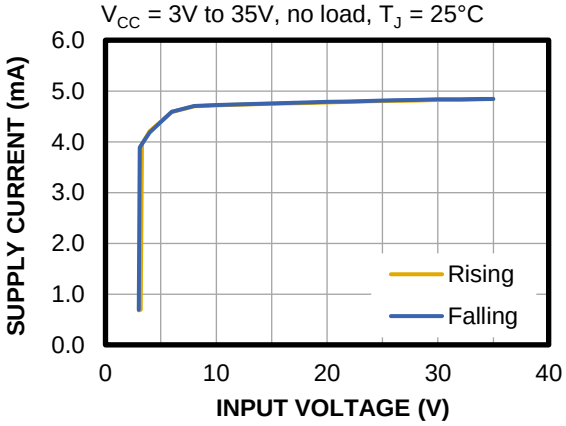
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TYPICAL CHARACTERISTICS

V_{CC} = 12V, T_J = -40°C to +150°C, unless otherwise noted.

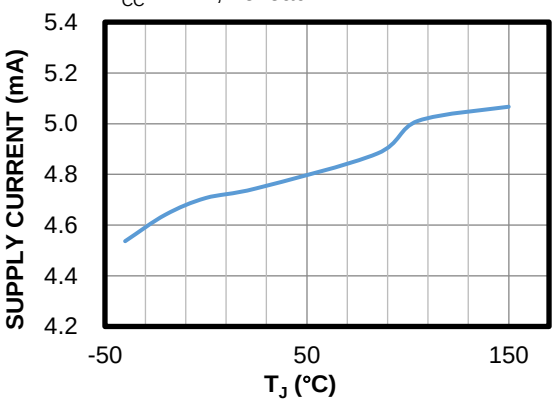
Supply Current vs. Input Voltage

V_{CC} = 3V to 35V, no load, T_J = 25°C

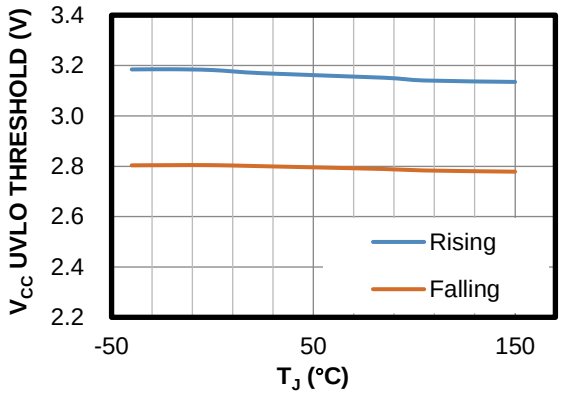


Supply Current vs. T_J

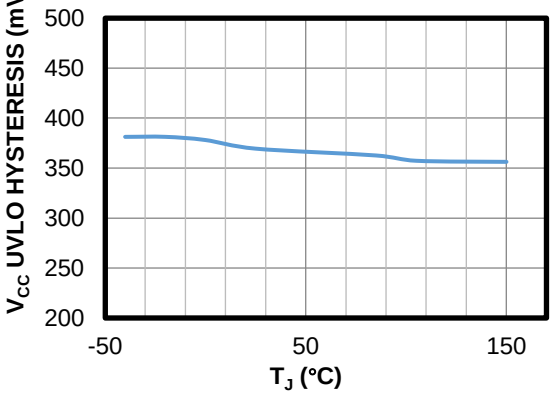
V_{CC} = 12V, no load



V_{CC} UVLO Threshold vs. T_J

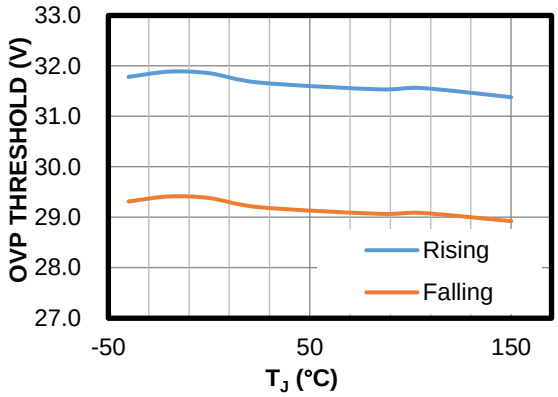


V_{CC} UVLO Hysteresis vs. T_J



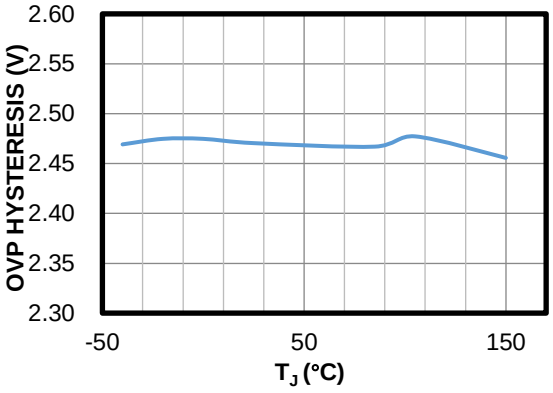
OVP Threshold vs. T_J

OVP threshold = 31V



OVP Hysteresis vs. T_J

OVP threshold = 31V



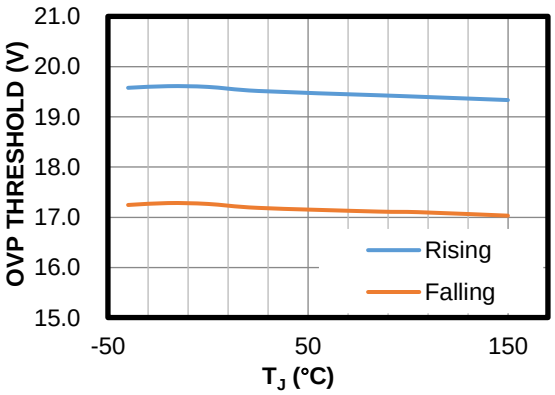
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TYPICAL CHARACTERISTICS *(continued)*

V_{CC} = 12V, T_J = -40°C to +150°C, unless otherwise noted.

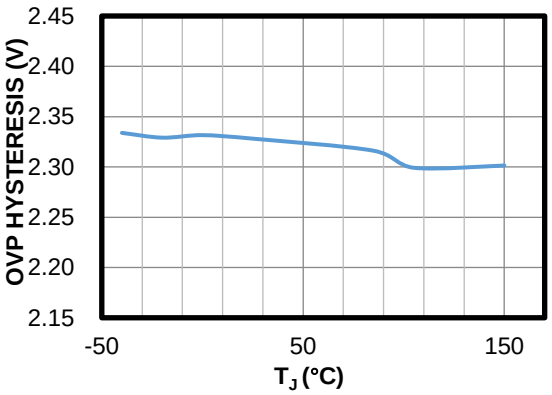
OVP Threshold vs. T_J

OVP threshold = 19V



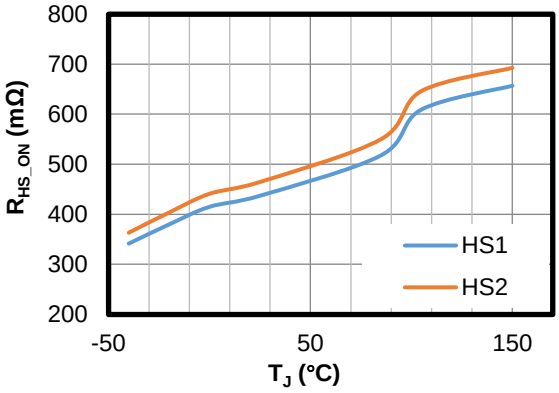
OVP Hysteresis vs. T_J

OVP threshold = 19V



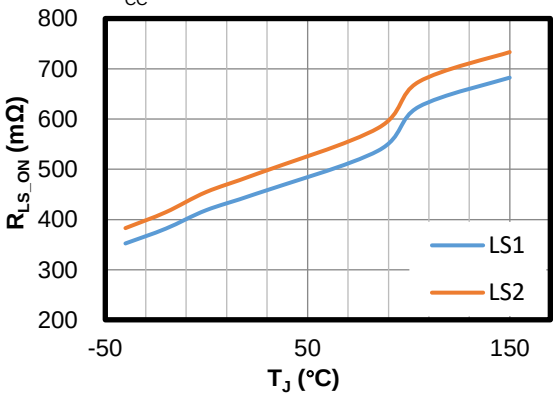
High-Side MOSFET On Resistance vs. T_J

V_{CC} = 12V



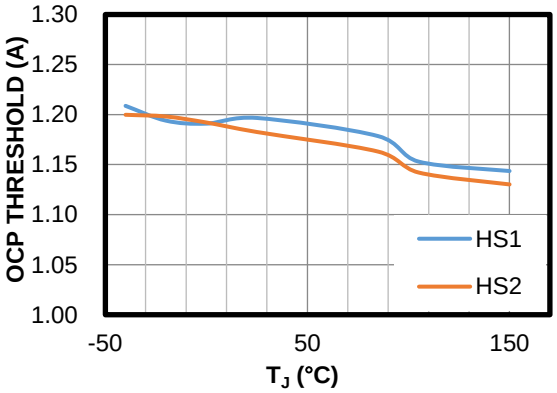
Low-Side MOSFET On Resistance vs. T_J

V_{CC} = 12V



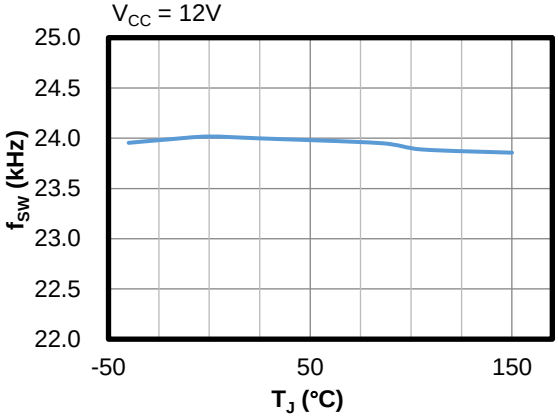
OCP Threshold vs. T_J

V_{CC} = 12V



Switching Frequency vs. T_J

V_{CC} = 12V



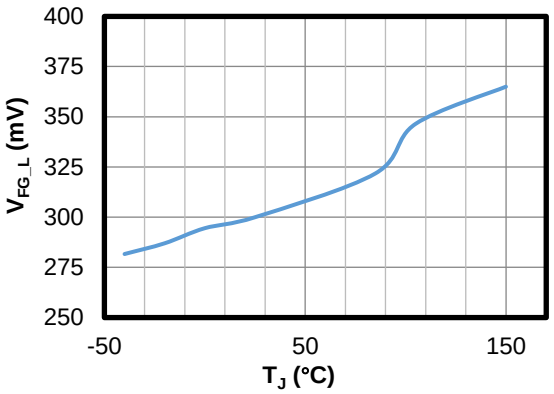
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TYPICAL CHARACTERISTICS *(continued)*

V_{CC} = 12V, T_J = -40°C to +150°C, unless otherwise noted.

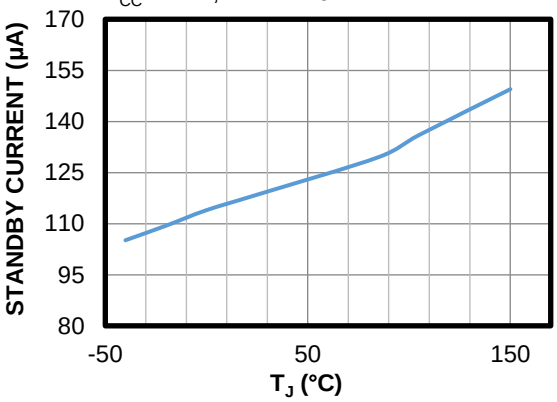
V_{FG_L} vs. T_J

V_{CC} = 12V, $I_{FG/RD}$ = 3mA



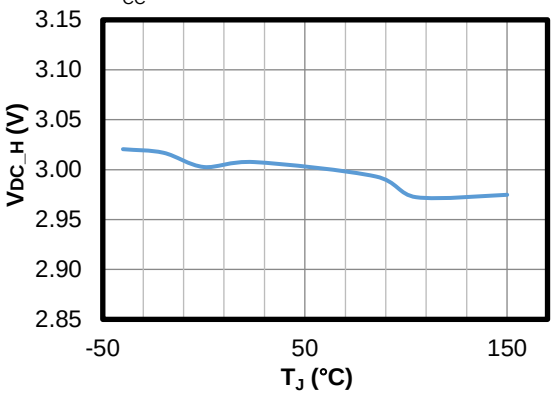
Standby Current vs. T_J

V_{CC} = 12V, PWM = low



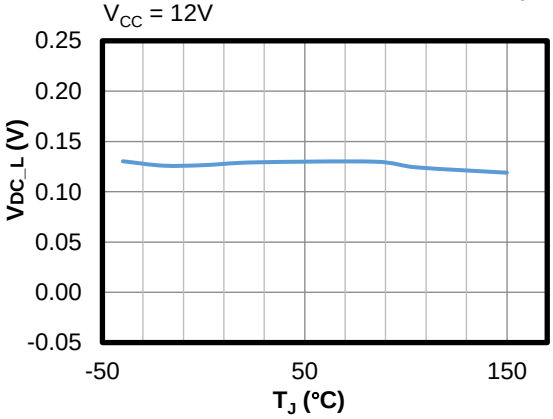
DC Input High Threshold vs. T_J

V_{CC} = 12V



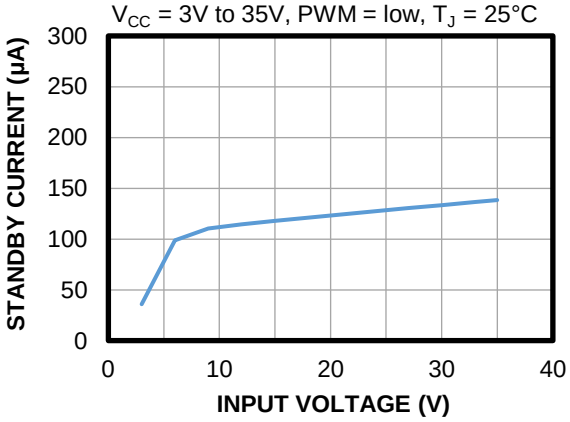
DC Input Low Threshold vs. T_J

V_{CC} = 12V



Standby Current vs. Input Voltage

V_{CC} = 3V to 35V, PWM = low, T_J = 25°C

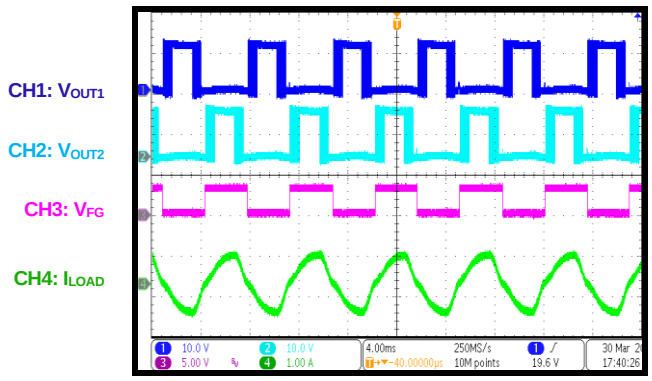


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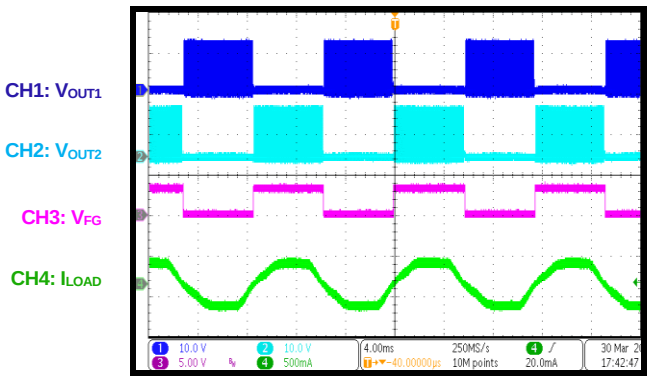
TYPICAL PERFORMANCE CHARACTERISTICS

V_{IN} = 12V, 8025 axial fan, 450mA, 5000rpm, T_A = 25°C, unless otherwise noted.

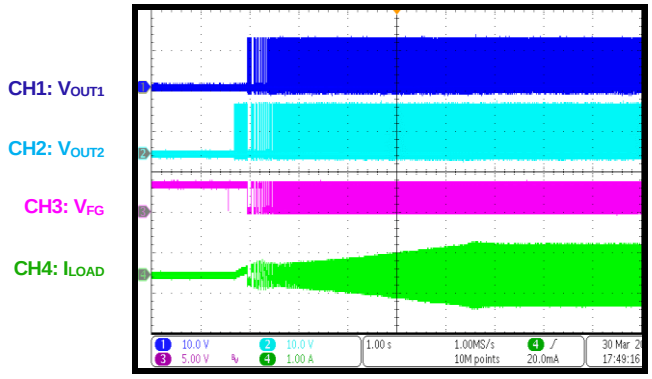
Steady State
PWM duty cycle = 100%



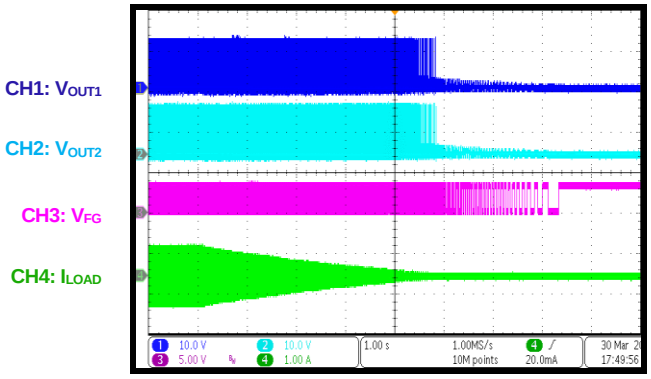
Steady State
PWM duty cycle = 50%



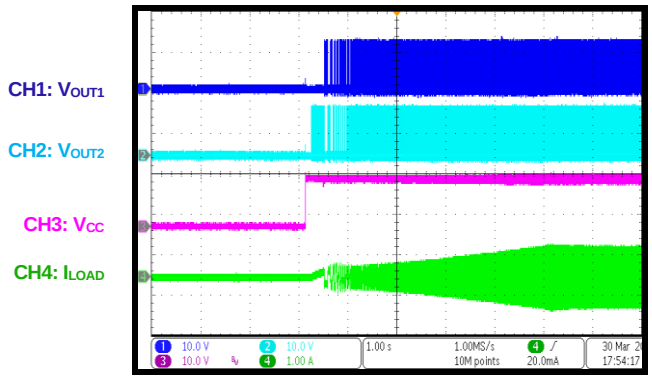
PWM On
PWM duty cycle = 0% to 100%



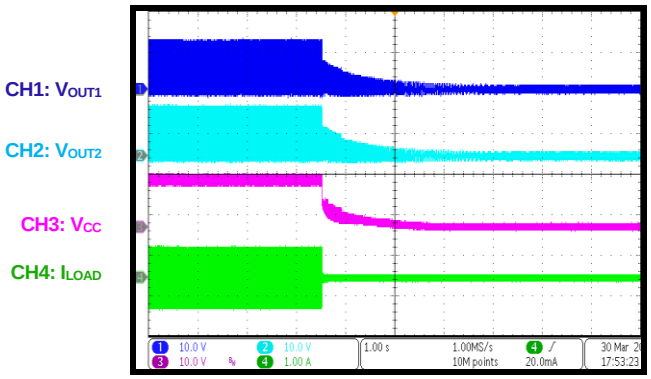
PWM Off
PWM duty cycle= 100% to 0%



Start-Up through VCC
VCC power plugged in



Shutdown through VCC
VCC power not plugged in



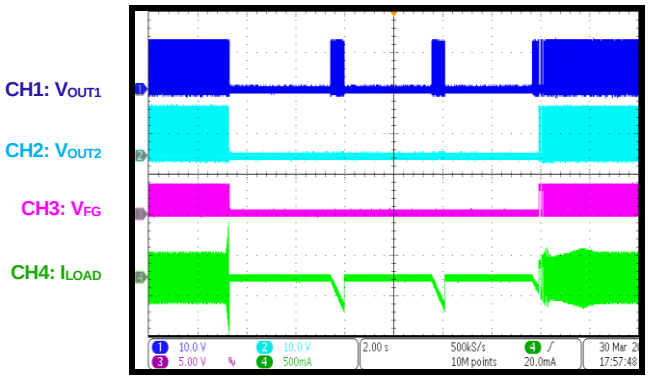
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TYPICAL PERFORMANCE CHARACTERISTICS *(continued)*

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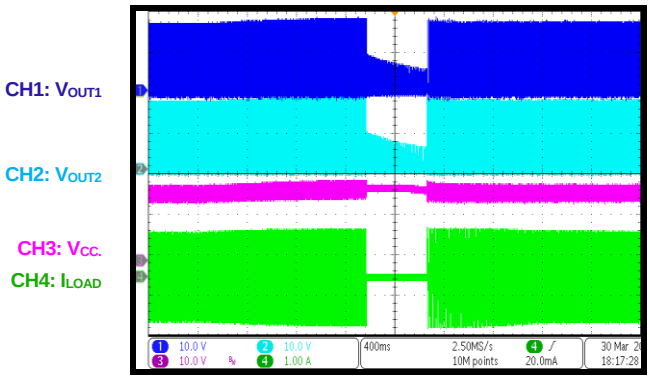
Locked-Rotor Protection

PWM duty cycle = 50%, locked rotor



Over-Voltage Protection

VCC ramps up, then ramps down, OVP threshold = 19V



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FUNCTIONAL BLOCK DIAGRAM

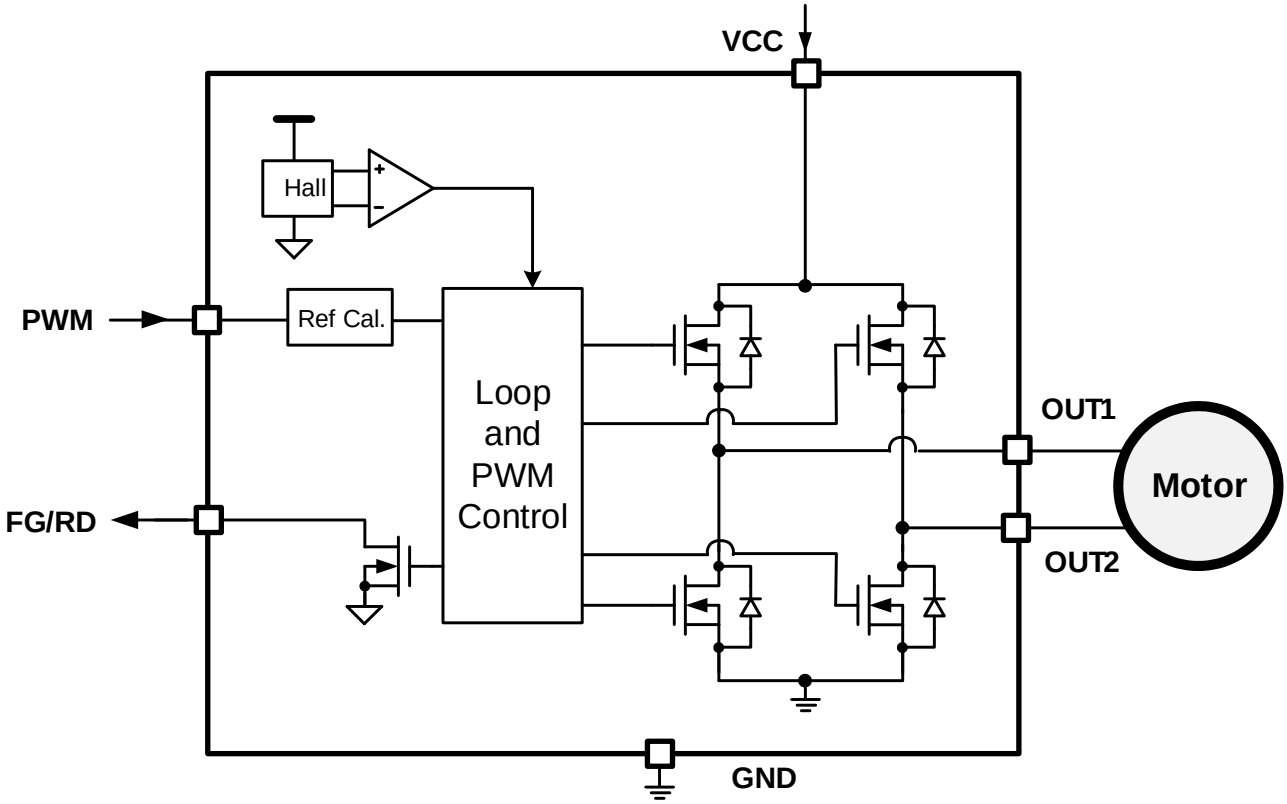


Figure 1: Functional Block Diagram

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OPERATION

The MPQ6653A-AEC1 is a single-phase brushless DC (BLDC) motor driver with integrated power MOSFETs and a Hall-effect sensor. The device controls the motor speed through the pulse-width modulation (PWM) signal or DC voltage on the PWM pin in either open-loop or closed-loop speed control. The device features configurable soft-on/off commutation and a Hall angle offset angle to flexibly optimize performance.

The MPQ6653A-AEC1 also provides rotational speed detection. The rotational speed detector (the FG/RD pin) is an open drain that outputs a high or low voltage relative to the internal Hall comparator's output.

Rich protection includes input over-voltage protection (OVP), under-voltage lockout (UVLO), locked-rotor protection, over-current protection (OCP), and thermal shutdown protection.

Speed Control

The PWM signal or DC voltage applied on the PWM pin controls the fan's rotation speed. These options can be selected via an internal register bit.

In PWM input mode, the input PWM duty cycle is detected, and the rotation speed is controlled by the input PWM duty cycle. In DC input mode, the DC input voltage is converted to a PWM duty cycle that controls the rotation speed.

By default, the PWM signal is selected. A wide 50Hz to 100kHz PWM frequency (f_{PWM}) range is supported by the register setting.

If LOW_F = 0, the f_{PWM} range is between 1kHz and 100kHz, and the PWM signal resolution is 163ns. If LOW_F = 1, the f_{PWM} range is between 50Hz and 2kHz, and the PWM signal resolution is 2.6µs.

The MPQ6653A-AEC1 provides open-loop or closed-loop speed control, which is configured by the register setting.

In open-loop speed control, the output duty cycle of OUT1 or OUT2 are adjusted based on the input PWM duty cycle or DC input voltage on the PWM pin.

In closed-loop speed control, the input PWM duty cycle or DC input voltage is detected, then converted to a reference speed. The motor's rotation speed is fed back to the control loop, and the output duty cycle is adjusted by the control loop to make the rotation speed equal to the reference speed.

Starting Duty Cycle

The D0[6:0] bits set the starting duty cycle. When the input duty cycle is below the starting duty cycle, the MPQ6653A-AEC1 responds based on the SPD_ZERO bit selection (see Figure 2).

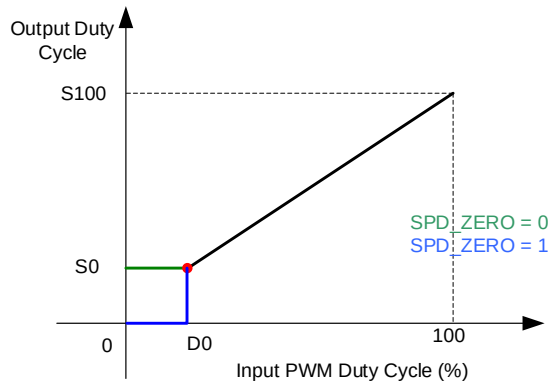


Figure 2: Minimum Speed with SPD_ZERO Setting

If SPD_ZERO = 0, OUT1/OUT2 maintains the minimum output duty cycle, or the fan maintains the minimum speed that is set by S0[7:0] when the input duty cycle is below the starting duty cycle.

If SPD_ZERO = 1, there is no switching, and the fan stops when the input duty cycle is below the starting duty cycle.

Stopping Duty Cycle

The MPQ6653A-AEC1 supports stopping the fan when the input PWM duty cycle exceeds the stopping duty cycle (see Figure 3 on page 14).

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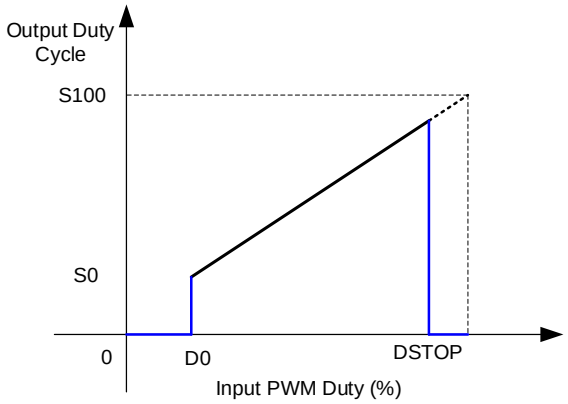


Figure 3: Fan Stopping at High Duty Cycle

The register bits configure the stopping duty cycle, as described below:

- If DSTOP[1:0] = 00, there are no stops.
- If DSTOP[1:0] = 01, the stopping duty cycle is 100%.
- If DSTOP[1:0] = 10, the stopping duty cycle is 95%.
- If DSTOP[1:0] = 11, the stopping duty cycle is 90%.

OUT1/2 Normal Operation

During steady-state operation, the MPQ6653A-AEC1 controls the switching of the H-bridge MOSFETs based on the internal Hall sensor's output (see Figure 4). This reduces the speed variation and increases system efficiency.

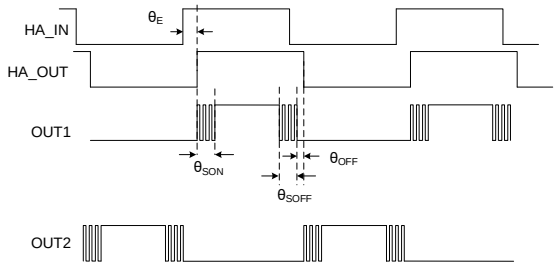


Figure 4: Operation with a Hall Offset Angle

The operation sequence is based on the Hall signal coming from the embedded Hall sensor. HA_IN is the original Hall from the embedded Hall. HA_OUT is generated based on HA_IN with a phase shift, and the shifted phase (θ_E) is configured by the Hall offset angle register.

If the H_{A_OUT} signal is high, OUT2 remains low constantly while OUT1 switches phases. If the H_{A_OUT} signal is low, OUT1 remains low constantly while OUT2 switches phases. The Hall offset angle is dependent on the following factors:

- The Hall offset angle is dependent on HAL_ANG[3:0].
- The Hall offset angle leading/lag direction is set by the HAL_FLAG bit.
- When HAL_ANG[3:0] = 0000, the Hall offset angle is 0.

Soft-On Commutation

During soft-on commutation (denoted as θ_{SON} in Figure 4), the output duty cycle of the switching phase gradually increases from 0% to the target set duty cycle, and the other phase keeps the low-side MOSFETs (LS-FETs) on.

The SON[4:0] bits set the soft-on commutation angle between 0° and 90°. A high soft-on commutation angle leads to a lower rotating speed under the same conditions.

Soft-Off Commutation

During soft-off commutation (denoted as θ_{SOFF} in Figure 4), the output duty cycle of the switching phase gradually decreases from the target setting duty cycle to 0%, and the other phase keeps the LS-FETs on.

The SOFF[4:0] bits set the soft-off commutation angle between 0° and 90°. A larger soft-off commutation angle helps to eliminate the reverse current, but it also leads to a lower rotating speed under the same conditions.

Soft-On/Off Commutation Angle Linear Interpolation

The soft-on/off commutation angle can be set to linearly change as the output varies. The SON[4:0] and SOFF[4:0] bits set the soft-on and soft-off commutation angle when the output duty cycle is 100%. The commutation angle linearly increases to 90° when the output duty cycle decreases to 0% (see Figure 5 on page 15).

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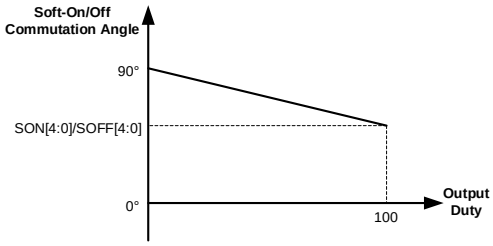


Figure 5 Soft-On/Off Commutation Angle Linear Interpolation

Curve Configurations

The MPQ6653A-AEC1 provides curve configurations. The input duty cycle or the output duty cycle speed can be configured by the corresponding register setting.

Four different configurable points are available, including the starting duty (D0[6:0]) and 100% input duty cycle. Figure 6 shows the curve configuration, where the input duty cycle is set by Dx (where x = 0 for D0[6:0], 1 for D1[7:0], or 2 for D2[7:0]) and is calculated as Dx / 255.

In open-loop speed control, the corresponding output duty is set by Sx (where x = 0 for S0[7:0], 1 for S1[7:0], 2 for S2[7:0]), or 100 for S100[11:4]) and is calculated as Sx / 255.

In closed-loop speed control, S100[11:0] sets the maximum speed when the input duty cycle is 100%, and the other speed is set as S100[11:0] x (Sx / 255) (where x = 0 for S0[7:0], 1 for S1[7:0], or 2 for S2[7:0]).

The difference between S1[7:0] and S0[7:0] (S1[7:0] - S0[7:0]) should be below 128.

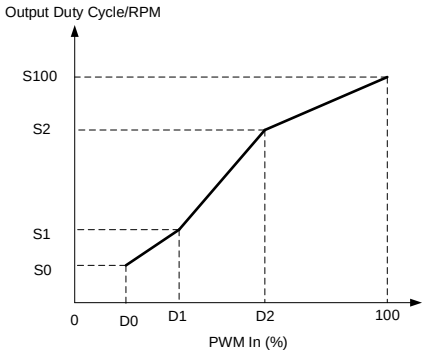


Figure 6: Curve Configuration

Standby Mode

If the voltage on the VCC pin (V_{CC}) exceeds the UVLO rising threshold and the PWM pin remains keeps low, then the IC enters standby mode. The IC exits this mode when the PWM input signal is high or power is cycled on the MPQ6653A-AEC1.

Pre-Startup

Once the input voltage (V_{IN}) exceeds the UVLO threshold or the input PWM duty exceeds the starting duty set by D0[6:0], the MPQ6653A-AEC1 first enters the pre-startup stage. The output duty cycle increases with a set slope by ignoring the final steady-state output duty cycle. After several Hall cycles, the MPQ6653A-AEC1 exits pre-startup and enters the soft start (SS) stage.

With different pre-startup timer configurations, the MPQ6653A-AEC1 can provide sufficient torque to spin up the motor.

Soft Start (SS)

After pre-startup, SS is employed. The output duty cycle ramps up and down step by step with the TIME_SS[1:0] configuration.

To reduce the input inrush current during start-up, several configurations are available to meet the requirements of different applications. The dropping duty cycle can be configured as 1x or 2x of TIME_SS[1:0].

Rotor Speed Indicator (FG) or Rotor Deadlock Indicator (RD)

The speed indicator or locked rotor (rotor deadlock) indicator can be output on the FG/RD pin with different configurations. The FGRD[2:0] bits set the FG/RD pin's output, with the different configurations described below:

- If FGRD[2:0] = 000, the FG/RD pin outputs one pulse every electrical cycle (1x).
- If FGRD[2:0] = 001, the FG/RD pin outputs one pulse every two electrical cycles (1/2x).
- If FGRD[2:0] = 010, the FG/RD pin outputs two pulses every electrical cycle (2x).
- If FGRD[2:0] = 011, the FG/RD pin outputs one pulse every electrical cycle during normal operation and outputs the RD signal in rotor deadlock protection. The RD signal output polarity is set by the RD_H_L bit.
- If FGRD[2:0] = 100, the FG/RD pin is set as the locked-rotor indicator. The RD signal output polarity is set by the RD_H_L bit.

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- If FGRD[2:0] = 101, the FG/RD pin is set by the fault indicator to output a signal when a fault is detected.
- If FGRD[2:0] = 110, the FG/RD pin is set as the external Hall signal input. The external Hall signal sensor replaces the internal Hall sensor in operation.

Protection Circuits

The MPQ6653A-AEC1 is fully protected against over-voltage (OV), under-voltage (UV), over-current (OC), and over-temperature (OT) events.

Cycle-by-Cycle Current Limit (OCP)

During normal switching, if the current flowing through the high-side MOSFET (HS-FET) of the H-bridge exceeds the threshold set by the OCP_SEL bit after a blanking time, then the HS-FET turns off. The HS-FET resumes switching in the next switching cycle. The OCP threshold can be set to 0.6A or 1.2A via the OCP_SEL bit.

Peak Current Limit Short-Circuit Protection (SCP)

If the current is not limited by the cycle-by-cycle limit, there is also a peak current limit. Once the peak current limit threshold (typically 1.8A) is reached, all the MOSFETs turn off. The MOSFETs resume operation after a locked retry time.

Thermal Shutdown (TSD)

The MPQ6653A-AEC1 provides thermal monitoring. If the temperature exceeds 170°C, the MOSFETs of the switching half-bridge turn off. Once the die temperature drops to a safe level, operation automatically resumes.

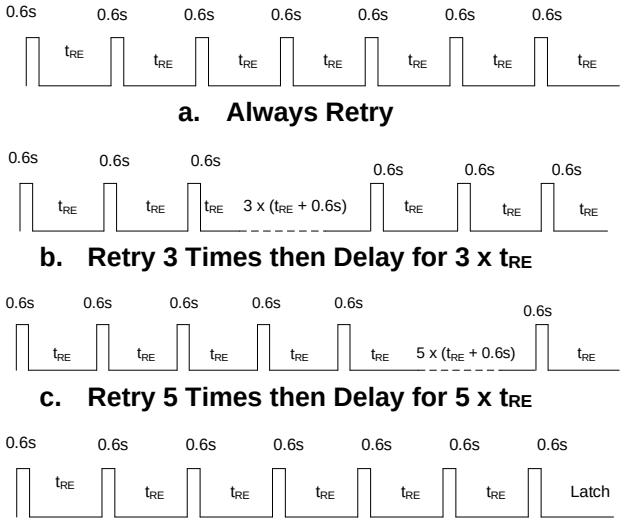
Under-Voltage Lockout (UVLO)

If V_{CC} drops below the UVLO falling threshold, all the circuitry in the device is disabled and the internal logic resets. Operation resumes once V_{CC} exceeds the UVLO rising threshold.

Locked-Rotor Protection (RD)

The internal Hall signal is detected to determine whether rotor deadlock protection is triggered. If no Hall signal edge is detected during the 0.6s detection time, the rotor deadlock protection is triggered, and both LS-FETs of the H-bridge turn on. After a lock retry time (t_{RE}) set by the LOCK_SEL bit, the IC automatically tries again to start up. The lock retry time is configured as 3.6s or 8.4s.

The MPQ6653A-AEC1 also supports retrying several times until the locked retry time becomes longer via the register (see Figure 7).



a. Always Retry

b. Retry 3 Times then Delay for 3 x t_{RE}

c. Retry 5 Times then Delay for 5 x t_{RE}

d. Latch after Retrying 7 Times

Figure 7 Lock Protection and Retry Time

The FG/RD pin releases only after the locked-rotor condition is released and three Hall signal edges are detected.

Over-Voltage Protection (OVP)

The MPQ6653A-AEC1 provides two OVP thresholds for different applications.

If V_{CC} exceeds the OVP threshold (19V or 31V), the OUT1/OUT2 output is disabled. The OUT1/OUT2 output resumes normal operation once V_{CC} drops below the OVP falling threshold (17V or 28V), and the Hall edge is detected during the OVP interval.

Fault Diagnosis

Once the fault is triggered, the corresponding fault bit for OCP, SCP, TSD, OVP, or RD is set, and all the fault bits can be read. The fault bit can be reset after the fault bit is read.

Test Mode and Factory Mode

To configure the internal register, the MPQ6653A-AEC1 provides a test mode. In this test mode, the internal register can be set to read/write (R/W) operation. After the design is finalized, the register value can be configured to the non-volatile memory (NVM).

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REGISTER MAP

Add	D[7]	D[6]	D[5]	D[4]	D[3]	D[2]	D[1]	D[0]
00h (OTP/REG)	S0[7:0]							
01h (OTP/REG)	S1[7:0]							
02h (OTP/REG)	S2[7:0]							
03h (OTP/REG)	S100[11:4]							
04h (OTP/REG)	D1[7:0]							
05h (OTP/REG)	D2[7:0]							
06h (OTP/REG)	RD_H_L	D0[6:0]						
07h (OTP/REG)	OVP_H	FAST_DN	PWM_POL	SON[4:0]				
08h (OTP/REG)	SINE	SPD_SEL[1:0]		SOFF[4:0]				
09h (OTP/REG)	WAIT_DIS	T_PRE[1:0]		HAL_FLAG	HAL_ANG[3:0]			
0Ah (OTP/REG)	RESERVED	INT_EN	RESERVED	LOCK_SEL	OCP_SEL	ASYNC	PWM_WAIT	TADV_EN
0Bh (OTP/REG)	OVP_DIS	TADV[1:0]		TIME_SS[1:0]		FGRD[2:0]		
0Ch (OTP/REG)	PWM_DC	CLOSE	LOW_F	LOCK_BHV[1:0]		SPD_ZERO	COA_SLOW	DN_SCAEL
0Dh (OTP/REG)	KI[6:0]							ZCD_POS
0Eh (OTP/REG)	FIX_ST[1:0]		DSTOP[1:0]		S100[3:0]			
14h (REG)	OCP	SCP	OVP	TSD	RD	RESERVED		
15h (REG)	RESERVED	LOCK_DIS	RESERVED					
16h (REG)	RESERVED	OTP_PAGE[1:0]	RESERVED					

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SPEED_CURVE_1 (00h)

The SPEED_CURVE_1 command configures the output duty cycle or speed when the input pulse-width modulation (PWM) duty cycle is at D0[6:0].

Bits	Access	Bit Name	Default	Description
7:0	R/W	S0[7:0]	0x20	Sets the output duty cycle or speed when the input PWM duty cycle is at D0[6:0]. For open-loop control, set the output duty cycle when the input PWM duty cycle is at D0[6:0]. The output duty cycle can be calculated with the following equation: Output Duty Cycle= S0[7:0] / 256 For closed-loop control, set the speed reference when the input PWM duty cycle is at D0[6:0]. The speed (electrical speed) can be calculated with the following equation: Speed = S0[7:0] / 256 x S100[11:0] x 16

SPEED_CURVE_2 (01h)

The SPEED_CURVE_2 command configures the output duty cycle or speed when the input PWM duty cycle is at D1[7:0].

Bits	Access	Bit Name	Default	Description
7:0	R/W	S1[7:0]	0x60	Sets the output duty cycle or speed when the input PWM duty cycle is at D1[7:0]. For open-loop control, set the output duty cycle when the input PWM duty cycle is at D1[7:0]. The output duty cycle can be calculated with the following equation: Output Duty Cycle= S1[7:0] / 256 For closed-loop control, set the speed reference when the input PWM duty cycle is at D1[7:0]. The speed (electrical speed) can be calculated with the following equation: Speed = S1[7:0] / 256 x S100[11:0] x16 The difference between S1[7:0] and S0[7:0] (S1[7:0] - S0[7:0]) should be below 128.

SPEED_CURVE_3 (02h)

The SPEED_CURVE_3 command configures the output duty cycle or speed when the input PWM duty cycle is at D2[7:0].

Bits	Access	Bit Name	Default	Description
7:0	R/W	S2[7:0]	0xC0	Sets the output duty cycle or speed when the input PWM duty cycle is at D2[7:0]. For open-loop control, set the output duty cycle when the input PWM duty cycle is at D2[7:0]. The output duty cycle can be calculated with the following equation: Output Duty Cycle= S2[7:0] / 256 For closed-loop control, set the speed reference when the input PWM duty cycle is at D2[7:0]. The speed (electrical speed) can be calculated with the following equation: Speed = S2[7:0] / 256 x S100[11:0] x16

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SPEED_CURVE_4 (03h)

The SPEED_CURVE_4 command configures the output duty cycle or speed when the input PWM duty cycle is at 100%.

Bits	Access	Bit Name	Default	Description
7:0	R/W	S100[11:4]	0xFF	Sets the output duty cycle or the 8 most significant bits (MSB) for the speed when the input PWM duty cycle is at 100%. For open-loop control, set the output duty cycle when the input PWM duty cycle is at 100%. The output duty cycle can be calculated with the following equation: Output Duty Cycle= S100[11:4] / 256 For closed-loop control, set the maximum speed reference when the input PWM duty cycle is at 100%. Combined with S100[3:0], the maximum speed (electrical speed) can be calculated with the following equation: Max Speed = 16rpm x S[11:0]

SPEED_CURVE_5 (04h)

The SPEED_CURVE_5 command configures input duty cycle 1 (D1).

Bits	Access	Bit Name	Default	Description
7:0	R/W	D1[7:0]	0x60	Sets the input duty cycle for curve configuration. The input PWM duty cycle can be calculated with the following equation: Input PWM Duty Cycle= D1[7:0] / 256

SPEED_CURVE_6 (05h)

The SPEED_CURVE_6 command configures input duty cycle 2 (D2).

Bits	Access	Bit Name	Default	Description
7:0	R/W	D2[7:0]	0xC0	Sets the input duty cycle for curve configuration. The input PWM duty cycle can be calculated with the following equation: Input PWM Duty Cycle= D2[7:0] / 256

RD_D0 (06h)

The RD_D0 command sets the FG/RD pin’s output polarity and starting duty cycle.

Bits	Access	Bit Name	Default	Description
7	R/W	RD_H_L	0	Selects RD/FT output polarity. 0: The output is low when protection is triggered (default) 1: The output is high when protection is triggered
6:0	R/W	D0[6:0]	0x20	Sets the starting duty cycle for curve configuration. The starting PWM duty cycle can be calculated with the following equation: Starting Corner PWM Duty Cycle= D0[6:0] / 256

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CFR_1 (07h)

The CFR_1 command is for control function register 1, which sets the over-voltage protection (OVP) threshold, fast off, input PWM polarity, and soft-on commutation angle.

Bits	Access	Bit Name	Default	Description
7	R/W	OVP_H	1	Selects the OVP threshold. 0: 19V 1: 31V (default)
6	R/W	FAST_DN	0	Enables fast off. 0: Disable fast off (default) 1: Enable fast off when PWM is off. The IC quickly stops switching when the input duty cycle drops below the starting duty cycle
5	R/W	PWM_POL	0	Selects input PWM polarity. 0: Positive duty cycle (default) 1: Negative duty cycle
4:0	R/W	SON[4:0]	0x10	Sets the soft-on commutation angle. 00000: 2.9° 00001: 5.8° …. 11111: 90° The soft-on angle can be calculated with the following equation: Soft-On Angle = (SON[4:0] + 1) x 2.9° 2.9° per step.

SOFF_CLK (08h)

The SOFF_CLK command sets soft on/off mode, the digital clock, and the soft-off commutation angle.

Bits	Access	Bit Name	Default	Description
7	R/W	SINE	0	Selects the soft-on/off mode. 0: Linear (default) 1: Sine
6:5	R/W	SPD_SEL[1:0]	00	Selects the digital clock. A higher frequency results in a higher calculation resolution; however, it also leads to a higher minimum speed. The bits listed below indicate the supported minimum electrical speeds. 00: 200rpm (default electrical speed) 01: 800rpm 10: 1600rpm 11: 3200rpm
4:0	R/W	SOFF[4:0]	0x10	Sets the soft-off commutation angle. 00000: 2.9° 00001: 5.8° …. 11111: 90° The soft-off angle can be calculated with the following equation: Soft-Off Angle = (SOFF[4:0] + 1) x 2.9° 2.9° per step.

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CFR_2 (09h)

The CFR_2 command is for control function register 2, which sets the waiting function, pre-startup timer, and Hall offset angle.

Bits	Access	Bit Name	Default	Description
7	R/W	WAIT_DIS	0	Disables the waiting function at start-up. 0: Enabled (default) 1: Disabled
6:5	R/W	T_PRE[1:0]	01	Selects the pre-startup timer. 00: 21.33ms/step 01: 10.67ms/step (default) 10: 5.36ms/step 11: 2.73ms/step
4	R/W	HAL_FLAG	0	Selects the Hall offset angle lag/lead. 0: Lag (default) 1: Lead
3:0	R/W	HAL_ANG[3:0]	0000	Sets the Hall offset angle. 0000: 0° (default) 0001: 1.4° … 1111: 21° The Hall offset angle can be calculated with the following equation: Hall Offset Angle = HAL_ANG[3:0] x 1.4° 1.4° per step

CFR_3 (0Ah)

The CFR_3 command is for control function register 3, which sets the soft-on/off angle, locked retry time, current limit, asynchronized rectification function, waiting function, and the advanced turn-off function.

Bits	Access	Bit Name	Default	Description
7	R	RESERVED	0	Reserved.
6	R/W	INT_EN	0	Enables soft-on/off commutation angle linear interpolation. 0: Disable the soft-on/off commutation angle, which linearly increase to 90° when the duty cycle drops (default) 1: Enable the soft-on/off commutation angle, which linearly increase to 90° when the duty cycle drops
5	R	RESERVED	1	Reserved.
4	R/W	LOCK_SEL	0	Selects the deadlock protection retry time. 0: 3.6s (default) 1: 8.4s
3	R/W	OCP_SEL	1	Selects the current limit threshold. 0: 0.6A 1: 1.2A (default)
2	R/W	ASYNC	0	Enables the asynchronized rectification function. 0: Disabled (default) 1: Enabled

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1	R/W	PWM_WAIT	0	Enables the waiting function at PWM on start-up. 0: Disabled (default) 1: Enabled
0	R/W	TADV_EN	1	Enables advanced turn-off. 0: Disables advanced turn-off 1: Enables advanced turn-off (default)

CFR_4 (0Bh)

The CFR_4 command is for control function register 4, which enables OVP, and sets the advanced soft-off angle, soft-start time (t_{SS}), and the FG/RD pin.

Bits	Access	Bit Name	Default	Description
7	R/W	OVP_DIS	0	Enables OVP. 0: Enables OVP (default) 1: Disables OVP
6:5	R/W	TADV[1:0]	00	Selects the advanced off angle. 00: Automatic (default) 01: 5.6° 10: 11.2° 11: 22.5°
4:3	R/W	TIME_SS[1:0]	01	Selects t_{SS}, the time during which the output duty cycle transitions from 0% to 100%. 00: 2.73s 01: 5.46s (default) 10: 8.19s 11: 10.92s
2:0	R/W	FGRD[2:0]	000	Selects the FG/RD pin's function(s). 000: 1 x FG (default) 001: 1/2 x FG 010: 2 x FG 011: FG + RD, where the FG signal is output during normal operation, and the RD signal is output if deadlock protection is detected 100: RD, where the RD signal polarity is set by the RD_H_L register 101: FT, where the fault signal is output if a fault is detected. The FT polarity is set by the RD_H_L register 110: HALL_IN, where the FG/RD pin is set as the external Hall input pin

CFR_5 (0Ch)

The CFR_5 command is for control function register 5, which sets the PWM/DC input, open-/closed-loop speed control, PWM frequency, locked-rotor (deadlock) protection mode, coasting down threshold, zero-speed, and output duty cycle ramping down scale.

Bits	Access	Bit Name	Default	Description
7	R/W	PWM_DC	0	Selects the DC input or PWM input for the PWM/DC pin. 0: PWM input (default) 1: DC input
6	R/W	CLOSE	0	Enables closed-loop speed control. 0: Open-loop speed control (default) 1: Closed-loop speed control

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5	R/W	LOW_F	0	Selects the low-frequency PWM input. 0: The high frequency is set between 1kHz and 100kHz (default) 1: The low frequency is set between 50Hz to 2kHz
4:3	R/W	LOCK_BHV[1:0]	00	Selects deadlock protection mode. 00: Always retry (default) 01: Retries for 3 times, then the lock retry time is 3x 10: Retries for 5 times, then the lock retry time is 5x 11: Retries for 7 times, then latch up
2	R/W	SPD_ZERO	1	Enables zero speed. 0: Maintain the minimum speed when the input duty cycle is below the duty cycle set by D0[6:0] 1: Stop when the input duty cycle is below the duty cycle set by D0[6:0] (default)
1	R/W	COA_SLOW	0	Selects the coasting down speed threshold (electrical speed). The IC remains coasting until the fan rotation's coasting down speed drops below the speed threshold during start-up. 0: 1400rpm (default) 1: 700rpm
0	R/W	DN_SCALE	0	Selects the PWM output duty cycle ramping down scale as the output duty cycle drops from 100% to 0%. 0: 1 x TIME_SS[1:0] (default) 1: 2 x TIME_SS[1:0]

KI_ZCD (0Dh)

The KI_ZCD command sets the integral parameter for closed-loop control and the zero-current detection (ZCD) active angle position.

Bits	Access	Bit Name	Default	Description
7:1	R/W	KI[6:0]	0x10	Sets the integral parameter for closed-loop speed control.
0	R/W	ZCD_POS	0	Selects the ZCD active angle position. 0: ZCD is active once soft-on commutation ends (default) 1: ZCD is active after 90°.

FIX_DSTOP_S100 (0Eh)

The FIX_DSTOP_S100 command sets the initial output duty cycle, stopping input duty cycle, and maximum speed reference.

Bits	Access	Bit Name	Default	Description
7:6	R/W	FIX_ST[1:0]	00	Selects the initial output duty cycle at start-up. 00: The initial output duty cycle is 0% (default) 01: The initial output duty cycle is 12.5% 10: The initial output duty cycle is 25% 11: The initial output duty cycle is 50%
5:4	R/W	DSTOP[1:0]	00	Selects the stopping input duty cycle. The IC stops switching when the input PWM duty cycle is equal to or exceeds the selected stopping input duty cycle. 00: Does not stop (default) 01: 100% 10: 95% 11: 90%

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3:0	R/W	S100[3:0]	0000	Sets the maximum speed reference when the input PWM duty cycle is at 100% for closed-loop control. Combined with S100[11:4], the maximum speed (electrical speed) can be calculated with the following equation. Max Speed = 16rpm / LSB

FAULT_BIT(14h)

The FAULT_BIT command indicates faults including the cycle-by-cycle current limit (OCP), peak current limit (SCP), input over-voltage (OV) conditions, thermal shutdown, and rotor deadlock.

Bits	Access	Bit Name	Default	Description
7	R	OCP	0	Indicates whether OCP has occurred. 0: OCP is not triggered 1: OCP is triggered
6	R	SCP	0	Indicates whether an I_{LIMIT_PEAK} fault has occurred. 0: SCP is not triggered 1: SCP is triggered
5	R	OVP	0	Indicates whether an input OV fault has occurred. 0: Input OVP has occurred 1: No input OVP has occurred
4	R	TSD	0	Indicates whether a thermal shutdown fault has occurred. 0: Thermal shutdown protection has occurred 1: No thermal shutdown protection has occurred
3	R	RD	0	Indicates whether a rotor deadlock fault has occurred. 0: Rotor deadlock protection has occurred 1: No rotor deadlock protection has occurred
2:0	R	RESERVED	000	Reserved.

LOCK_DIS (15h)

The LOCK_DIS command enables locked-rotor (rotor deadlock) protection.

Bits	Access	Bit Name	Default	Description
7	R	RESERVED	0	Reserved.
6	R/W	LOCK_DIS	0	Enables rotor deadlock protection. 0: Rotor deadlock protection is enabled 1: Rotor dead lock protection is disabled
5:0	R	RESERVED	0x00	Reserved.

OTP_PAGE (16h)

The OTP_PAGE command is the one-time programmable (OTP) memory page indicator.

Bits	Access	Bit Name	Default	Description
7	R	RESERVED	0	Reserved.
6:5	R	OTP_PAGE[1:0]	00	Sets the OTP page indicator (read-only). 00: No OTP page is configured 01: First OTP page is configured 10: Second OTP page is configured
4:0	R	RESERVED	0x00	Reserved.

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APPLICATION INFORMATION

Selecting the Input Capacitor

Place an input capacitor (C_{IN}) as close to the VCC and GND pins as possible to maintain a stable V_{IN} and reduce noise at the input. C_{IN} must have a low impedance at f_{SW}.

Ceramic capacitors with X7R dielectrics are recommended for their low-ESR characteristics. The ceramic capacitance is dependent on the DC voltage rating. If the ceramic capacitor is biased to its DC voltage rating, then its capacitance drops below 50%.

Leave enough voltage rating margin when selecting the component. For most applications, a 1µF to 10µF ceramic capacitor is sufficient.

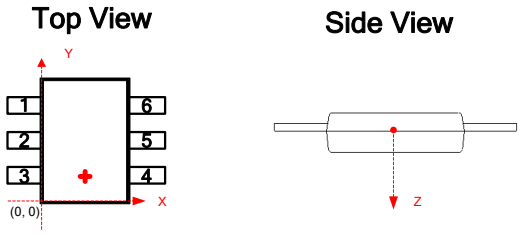
In some applications, an additional larger-value electrolytic capacitor may be required to absorb the motor's energy.

Selecting the Input Snubber

Due to the input capacitor's charge/discharge energy during phase commutation, I_{IN} has switching cycle ringing. If necessary, place an RC snubber (a 2Ω resistor in series with a 1µF capacitor) in parallel with C_{IN}. This effectively prevents switching cycle ringing.

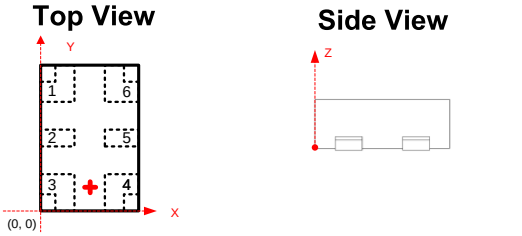
Hall Sensor Position

Figure 8 and Figure 9 show the embedded Hall sensor locations for TSOT and TQFN packages, respectively.



TSOT (X, Y, Z) = (800µm, 481µm, 80µm)

Figure 8: Hall Sensor Position



TQFN (X, Y, Z) = (1001µm, 531µm, 280µm)

Figure 9: Hall Sensor Position

Selecting an Input Clamping Circuit

A voltage-clamping circuit may be required to prevent V_{IN} from being charged by the energy stored in the motor. Typically, a 15V SOD-123 Zener diode or TVS diode is sufficient for most 12V applications. A higher clamping voltage is used if a higher V_{IN} range is applied.

Selecting the Reverse Blocking Diode

To avoid damage if the fan experiences a reverse plug-in, or a reverse voltage is applied on the input terminal, a reverse blocking diode is required. The reverse blocking diode prevents the bus voltage from charging via the fan's reverse current.

The blocking diode's reverse voltage rating must exceed the maximum operating voltage under all conditions.

System-Level ESD

Some fan products must pass system-level ESD testing. System-level ESD follows the IEC 61000-4-2 standard. There are differences between human body model (HBM) ESD and system-level ESD (IEC 61000-4-2). Figure 10 shows the equivalent circuit of an HBM ESD circuit.

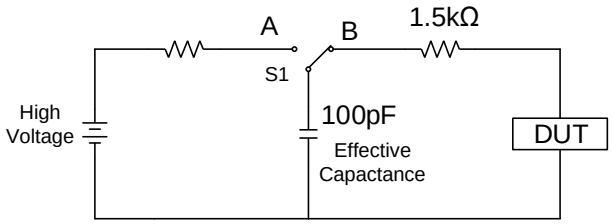


Figure 10: Equivalent Circuit of an HBM ESD Circuit

Figure 11 shows the equivalent circuit of a system-level ESD circuit.

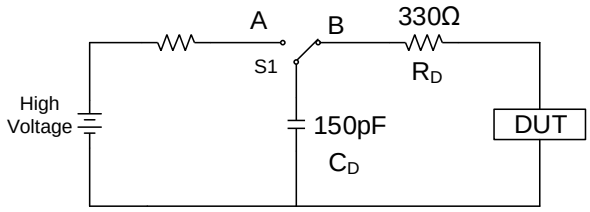


Figure 11: Equivalent Circuit of a System-Level ESD

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Compared to HBM ESD, the discharge capacitance exceeds the human body's effective capacitance, and the discharge resistance of IEC-level ESD is much smaller. As a result, the system-level ESD's discharging energy is much higher than HBM ESD.

If a high system-level ESD is required, then an external circuit may be required to enhance the ESD capability (see Figure 12).

Figure 12 shows an external ESD-enhanced circuit using a Zener or ESD diode.

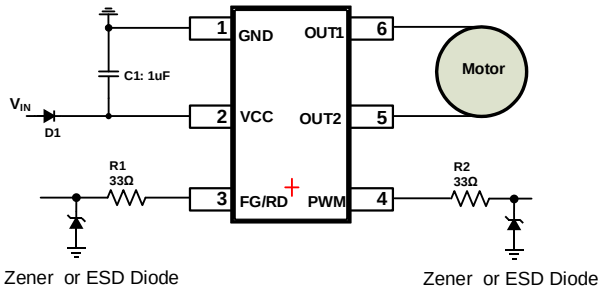


Figure 12: Enhanced ESD Using a Zener Diode or ESD Diode

PCB Layout Guidelines

Efficient PCB layout is critical for stable operation. For the best results, refer to Figure 13 and follow the guidelines below:

1. To improve EMI performance, place a 0402 capacitor as close as possible to the VCC and GND pins (C2 in Figure 13).
2. Place the input capacitor close to the VCC and GND pins (C1 in Figure 13).

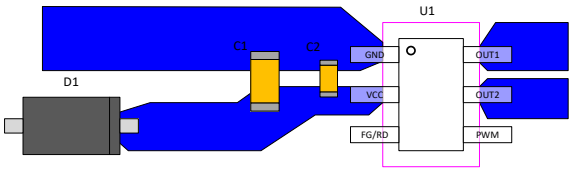


Figure 13: Recommended PCB Layout

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TYPICAL APPLICATION CIRCUITS

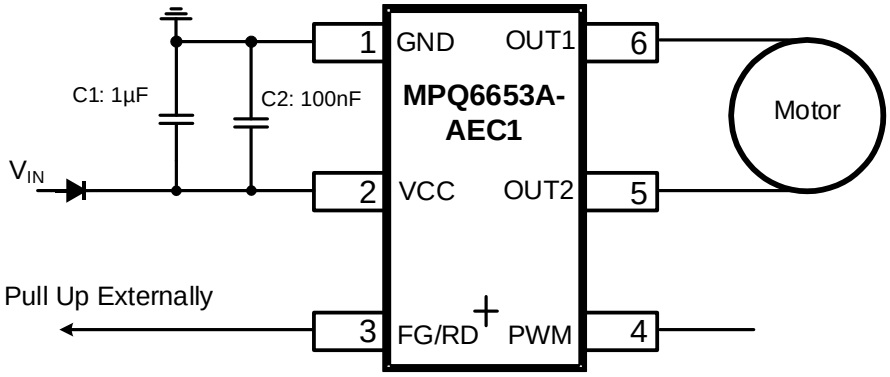


Figure 14: Typical Application Circuit

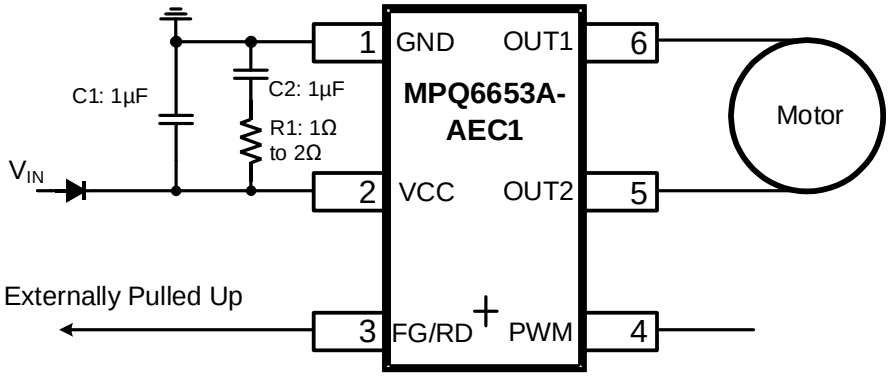


Figure 15: Typical Application Circuit with RC Snubber

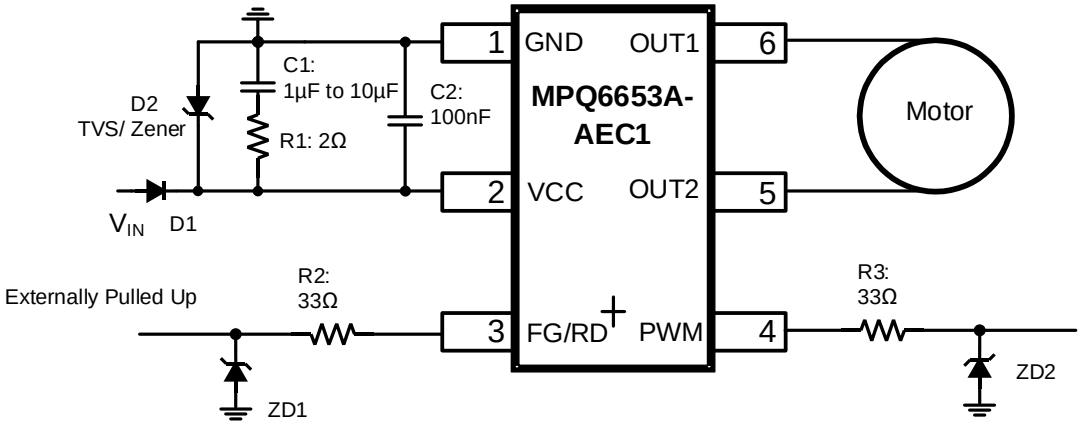
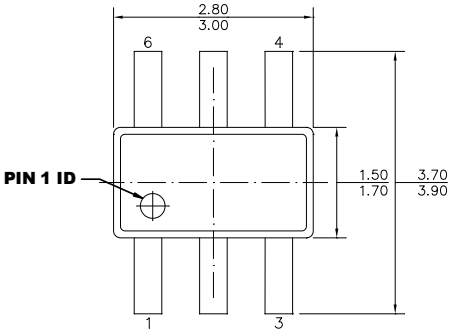


Figure 16: Typical Application Circuit with Voltage Clamping and Enhanced ESD

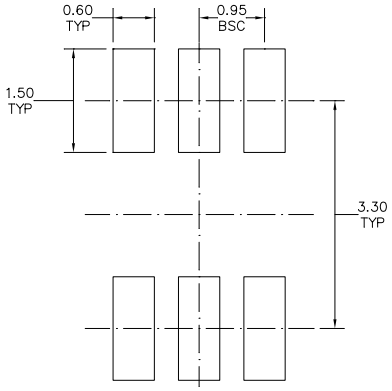
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PACKAGE INFORMATION

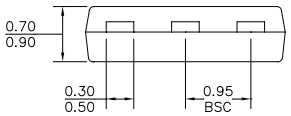
TSOT23-6-SL



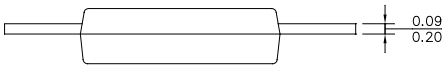
TOP VIEW



RECOMMENDED LAND PATTERN



FRONT VIEW



SIDE VIEW

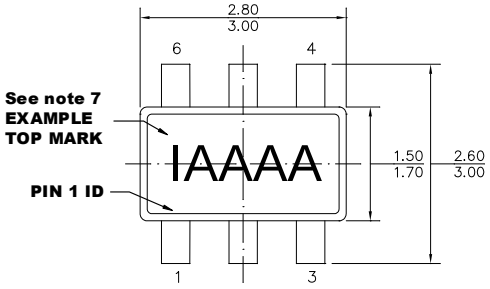
NOTE:

1) ALL DIMENSIONS ARE IN MILLIMETERS.
2) PACKAGE LENGTH DOES NOT INCLUDE MOLD FLASH, PROTRUSION, OR GATE BURR.
3) PACKAGE WIDTH DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION.
4) LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.10 MILLIMETERS MAX.
5) DRAWING REFERENCE IS JEDEC MO-193.
6) DRAWING IS NOT TO SCALE.

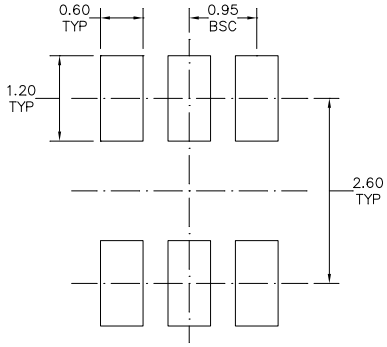
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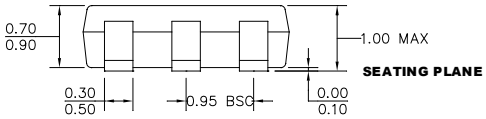
TSOT23-6



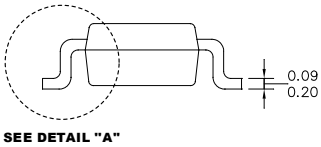
TOP VIEW



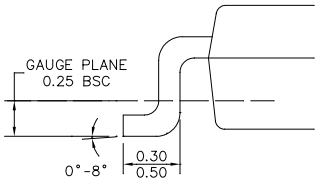
RECOMMENDED LAND PATTERN



FRONT VIEW



SIDE VIEW



DETAIL "A"

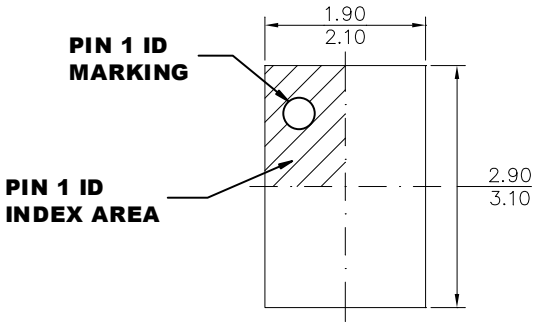
NOTE:

1) ALL DIMENSIONS ARE IN MILLIMETERS.
2) PACKAGE LENGTH DOES NOT INCLUDE MOLD FLASH, PROTRUSION, OR GATE BURR.
3) PACKAGE WIDTH DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSION.
4) LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.10 MILLIMETERS MAX.
5) DRAWING CONFORMS TO JEDEC MO-193, VARIATION AB.
6) DRAWING IS NOT TO SCALE.
7) PIN 1 IS LOWER LEFT PIN WHEN READING TOP MARK FROM LEFT TO RIGHT, (SEE EXAMPLE TOP MARK)

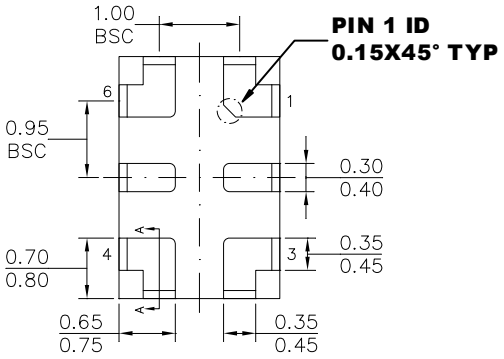
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PACKAGE INFORMATION *(continued)*

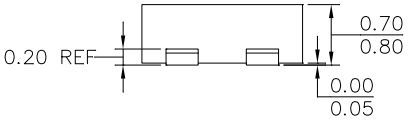
TQFN-6 (2mmx3mm) with Wettable Flank



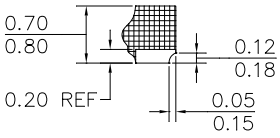
TOP VIEW



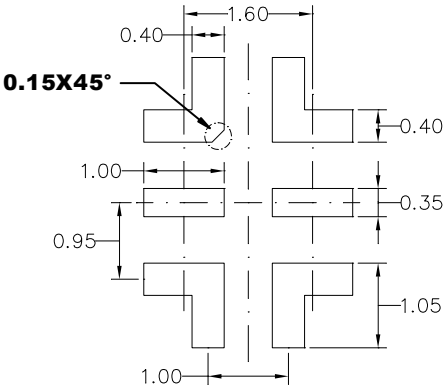
BOTTOM VIEW



SIDE VIEW



SECTION A-A



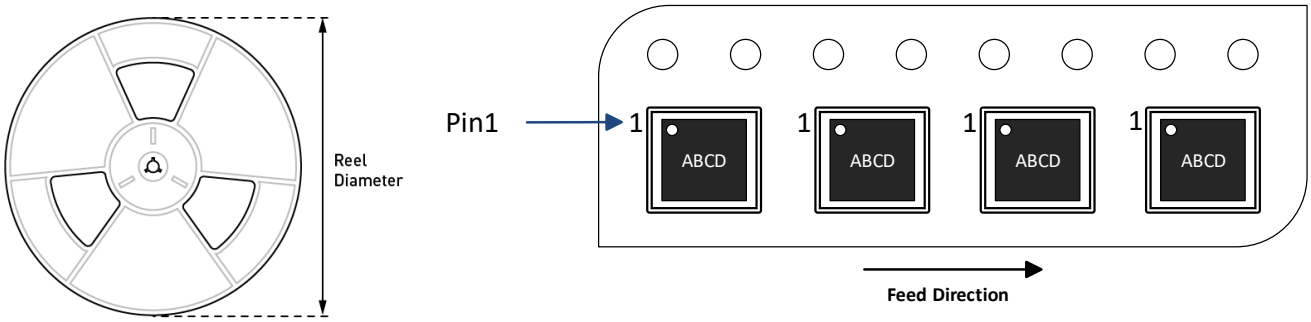
RECOMMENDED LAND PATTERN

NOTE:

1) THE LEAD SIDE IS WETTABLE.
2) ALL DIMENSIONS ARE IN MILLIMETERS.
3) LEAD COPLANARITY SHALL BE 0.08 MILLIMETERS MAX.
4) JEDEC REFERENCE IS MO-220.
5) DRAWING IS NOT TO SCALE.

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CARRIER INFORMATION



Part Number	Package Description	Quantity/ Reel	Quantity/ Tube	Quantity/ Tray	Reel Diameter	Carrier Tape Width	Carrier Tape Pitch
MPQ6653AGJS-xxxx-AEC1-Z	TSOT23-6-SL	5000	N/A	N/A	13in	12mm	8mm
MPQ6653AGJ-xxxx-AEC1-Z	TSOT23-6	3000	N/A	N/A	7in	8mm	4mm
MPQ6653AGDTE-xxxx-AEC1-Z	TQFN-6 (2mmx3mm) Wettable Flanks	5000	N/A	N/A	13in	12mm	8mm

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REVISION HISTORY

Revision #	Revision Date	Description	Pages Updated
1.0	8/19/2024	Initial Release	-

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