Brushless DC Motor Controller

The MC33033 is a high performance second generation, limited feature, monolithic brushless dc motor controller which has evolved from ON Semiconductor's full featured MC33034 and MC33035

....•ON Semiconducto

controllers. It contains aatumff the activefulncion, srequied Morm the]TJOT:0534 Tw[(fipplemststiped1.4(Iff open loop, three rm





(Top View)

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 25 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 25 of this data sheet.

High Current Drivers Can Control External 3–Phase MOSFET Bridge Cycle–By–Cycle Current Limiting Internal Thermal Shutdown Selectable 60 /300 or 120 /240 Sensor Phasings Also Efficiently Control Brush DC Motors with External MOSFET H–Bridge NCV Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC–Q100

Qualified and PPAP Capable

Pb-Free Packages are Available

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Power Supply Voltage	V _{CC}	30	V
Digital Inputs (Pins 3, 4, 5, 6, 18, 19)	-	V _{ref}	V
Oscillator Input Current (Source or Sink)	losc	30	mA
Error Amp Input Voltage Range (Pins 9, 10, Note 1)	VIR	-0.3 to V	

ELECTRICAL (CHARACTERISTICS	(V _{CC} = 20 V, R _T	= 4.7 k, C _T = 10	0 nF, T _A = 25 C	, unless otherwise noted.)
--------------	-----------------	---	------------------------------	-----------------------------	----------------------------

	-			,
Characteristic	Symbol	Min	Тур	Max

ELECTRICAL CHARACTERISTICS	(continued) (V_{CC} = 20 V, R_T = 4.7 k, C_T = 10 nF, T_A = 25 C, unle	ss otherwise noted.)
----------------------------	---	----------------------

Characteristic	Symbol	Min	Тур	Max	Unit
OSCILLATOR SECTION					1
Oscillator Frequency	fosc	22	25	28	kHz
Frequency Change with Voltage (V _{CC} = 10 V to 30 V)	$\Delta f_{OSC} / \Delta V$	_	0.01	5.0	%
Sawtooth Peak Voltage	V _{OSC(P)}	_	4.1	4.5	V
Sawtooth Valley Voltage	V _{OSC(V)}	1.2	1.5	-	V
LOGIC INPUTS					
Input Threshold Voltage (Pins 3, 4, 5, 6, 18, 19) High State Low State	V _{IH} V _{IL}	3.0 _	2.2 1.7	_ 0.8	V
Sensor Inputs (Pins 4, 5, 6) High State Input Current ($V_{IH} = 5.0 V$) Low State Input Current ($V_{IL} = 0 V$)	I _{IH} I _{IL}	-150 -600	-70 -337	-20 -150	A
Forward/Reverse, 60 /120 Select and Output Enable (Pins 3, 18, 19) High State Input Current ($V_{IH} = 5.0 V$) Low State Input Current ($V_{IL} = 0 V$)	I _{IH} I _{IL}	-75 -300	-36 -175	-10 -75	A
CURRENT-LIMIT COMPARATOR					
Threshold Voltage	V _{th}	85	101	115	mV
Input Common Mode Voltage Range	VICR	_	3.0	_	V
Input Bias Current	I _{IB}	_	-0.9	-5.0	А
OUTPUTS AND POWER SECTIONS					
Top Drive Output Sink Saturation (I _{Sink} = 25 mA)	V _{CE(sat)}	_	0.5	1.5	V
Top Drive Output Off-State Leakage (V _{CE} = 30 V)	I _{DRV(leak)}	-	0.06	100	А
Top Drive Output Switching Time ($C_L = 47 \text{ pF}, R_L = 1.0 \text{ k}$) Rise Time Fall Time	t _r t _f	-	107 26	300 300	ns

Bottom Drive Output Voltage High State (V_{CC} = 30 V, I_{source} = 50 mA) Low State (V_{CC} = 30 V, I_{sink} = 50 mA)







Figure 14. Top Drive Output Waveform

Figure 15. Bottom Drive Output Waveform





Figure 17. Bottom Drive Output Saturation Voltage versus Load Current



Figure 18. Supply Current versus Voltage

PIN FUNCTION DESCRIPTION

Pin	Symbol	Description
1, 2, 20	B _T , A _T , C _T	These three open collector Top Drive Outputs are designed to drive the external upper power switch transistors.
3	Fwd//Rev	The Forward/Reverse Input is used to change the direction of motor rotation.

INTRODUCTION

The MC33033 is one of a series of high performance monolithic dc brushless motor controllers produced by ON Semiconductor. It contains all of the functions required to implement a limited–feature, open loop, three or four phase motor control system. Constructed with Bipolar Analog technology, it offers a high degree of performance and ruggedness in hostile industrial environments. The MC33033 contains a rotor position decoder for proper commutation sequencing, a temperature compensated reference capable of supplying sensor power, a frequency programmable sawtooth oscillator, a fully accessible error amplifier, a pulse width modulator comparator, three open collector top drive outputs, and three high current totem pole bottom driver outputs ideally suited for driving power MOSFETs.

Included in the MC33033 are protective features consisting of undervoltage lockout, cycle-by-cycle current limiting with a latched shutdown mode, and internal thermal shutdown.

Typical motor control functions include open loop speed control, forward or reverse rotation, and run enable. In addition, the MC33033 has a 60/120 select pin which configures the rotor position decoder for either 60 or 120 sensor electrical phasing inputs.

FUNCTIONAL DESCRIPTION

A representative internal block diagram is shown in Figure 19, with various applications shown in Figures 35, 37, 38, 42, 44, and 45. A discussion of the features and function of each of the internal blocks given below and referenced to Figures 19 and 37.

Rotor Position Decoder

An internal rotor position decoder monitors the three sensor inputs (Pins 4, 5, 6) to provide the proper sequencing of the top and bottom drive outputs. The Sensor Inputs are designed to interface directly with open collector type Hall Effect switches or opto slotted couplers. Internal pull-up resistors are included to minimize the required number of external components. The inputs are TTL compatible, with their thresholds typically at 2.2 V. The MC33033 series is designed to control three phase motors and operate with four of the most common conventions of sensor phasing. A 60/120 Select (Pin 18) is conveniently provided which affords the MC33033 to configure itself to control motors having either 60, 120, 240 or 300 electrical sensor phasing. With three Sensor Inputs there are eight possible input code combinations, six of which are valid rotor positions. The remaining two codes are invalid and are usually caused by an open or shorted sensor line. With six valid input codes, the decoder can resolve the motor rotor position to within a window of 60 electrical degrees.

The Forward/Reverse input (Pin 3) is used to change the direction of motor rotation by reversing the voltage across the stator winding. When the input changes state, from high to low with a given sensor input code (for example 100), the enabled top and bottom drive outputs with the same alpha designation are exchanged (A_T to A_B , B_T to B_B , C_T to C_B). In effect the commutation sequence is reversed and the motor changes directional rotation.

Motor on/off control is accomplished by the Output Enable (Pin19). When left disconnected, an internal pull-up resistor to a positive source enables sequencing of the top and bottom drive outputs. When grounded, the Top Drive Outputs turn off and the bottom drives are forced low, causing the motor to coast.

The commutation logic truth table is shown in Figure 20. In half wave motor drive applications, the Top Drive Outputs are not required and are typically left disconnected.

Error Amplifier

A high performance, fully compensated Error Amplifier with access to both inputs and output (Pins 9, 10, 11) is provided to facilitate the implementation of closed loop motor speed control. The amplifier features a typical dc voltage gain of 80 dB, 0.6 MHz gain bandwidth, and a wide input common mode voltage range that extends from ground to V_{ref} . In most open loop speed control applications, the amplifier is configured as a unity gain voltage follower with the Noninverting Input connected to the speed set voltage source. Additional configurations are shown in Figures 30 through 34.

Oscillator

The frequency of the internal ramp oscillator is programmed by the values selected for timing components R_T and C_T . Capacitor C_T is charged from the Reference Output (Pin 7) through resistor R_T and discharged by an internal discharge transistor. The ramp peak and valley voltages are typically 4.1 V and 1.5 V respectively. To provide a good compromise between audible noise and output switching efficiency, an oscillator frequency in the range of 20 to 30 kHz is recommended. Refer to Figure 2 for component selection.

Pulse Width Modulator

The use of pulse width modulation provides an energy efficient method of controlling the motor speed by varying the average voltage applied to each stator winding during the commutation sequence. As C_T discharges, the oscillator sets both latches, allowing conduction of the Top and Bottom Drive Outputs. The PWM comparator resets the upper latch, terminating the Bottom Drive Output conduction when the positive–going ramp of C_T becomes greater than the Error Amplifier output. The pulse width modulator timing diagram is shown in Figure 21. Pulse width modulation for speed control appears only at the Bottom Drive Outputs.

operation can result if the reference output voltage should fall below 4.5 V. If one or both of the comparators detects an undervoltage condition, the top drives are turned off and the

Bottom Drive Outputs are held in a low state. Each of the comparators contain hysteresis to prevent oscillations when crossing their respective thresholds.



Figure 21. PWM Timing Diagram





The addition of the RC filter will eliminate current–limit instability caused by the leading edge spike on the current waveform. Resistor ${\sf R}_S$ should be a low inductance type.

Figure 25. Current Waveform Spike Suppression

Series gate resistor R_g will damp any high frequency oscillations caused by the MOSFET input capacitance and any series wiring induction in the gate–source circuit. Diode D is required if the negative current into the Bottom Drive Outputs exceeds 50 mA.

Figure 26. MOSFET Drive Precautions





Resistor R₁ with capacitor C sets the acceleration time constant while R₂ controls the deceleration. The values of R₁ and R₂ should be at least ten times greater than the speed set potentiometer to minimize time constant variations with different speed settings.

Figure 31. Controlled Acceleration/Deceleration

The SN74LS145 is an open collector BCD to One of Ten decoder. When connected as shown, input codes 0000 through 1001 steps the PWM in increments of approximately 10% from 0 to 90% on-time. Input codes 1010 through 1111 will produce 100% on-time or full motor speed.

Figure 32. Digital Speed Controller

an RC filter in series with the Current Sense Input. Using a low inductance type resistor for R_S will also aid in spike reduction. Figure 36 shows the commutation waveforms over two electrical cycles. The first cycle (0 to 360) depicts motor operation at full speed while the second cycle (360)

to 720) shows a reduced speed with about 50% pulse width modulation. The current waveforms reflect a constant torque load and are shown synchronous to the commutation frequency for clarity.



Figure 35. Three Phase, Six Step, Full Wave Motor Controller



Figure 36. Three Phase, Six Step, Full Wave Commutation Waveforms

Figure37

Three Phase Closed Loop Controller

The MC33033, by itself, is capable of open loop motor speed control. For closed loop speed control, the MC33033 requires an input voltage proportional to the motor speed. Traditionally this has been accomplished by means of a tachometer to generate the motor speed feedback voltage. Figure 38 shows an application whereby an MC33039, powered from the 6.25 V reference (Pin 7) of the MC33033, is used to generate the required feedback voltage without the need of a costly tachometer. The same Hall sensor signals used by the MC33039. Every positive or negative going transition of the Hall sensor signals on any of the sensor lines causes the MC33039 to produce an output pulse of defined amplitude and time duration, as determined by the external resistor R_1 and capacitor C_1 . The resulting output train of

pulses present at Pin 5 of the MC33039 are integrated by the Error Amplifier of the MC33033 configured as an integrator, to produce a dc voltage level which is proportional to the motor speed. This speed proportional voltage establishes the PWM reference level at Pin 11 of the MC33033 motor controller and completes or closes the feedback loop. The MC33033 outputs drive a TMOS power MOSFET 3-phase bridge. High current can be expected during conditions of start-up and when changing direction of the motor.

The system shown in Figure 38 is designed for a motor having 120/240 degrees Hall sensor electrical phasing. The system can easily be modified to accommodate 60/300 degree Hall sensor electrical phasing by removing the jumper (J₁) at Pin 18 of the MC33033.

• 0



Figure 38. Closed Loop Brushless DC Motor Control With the MC33033 Using the MC33039

Sensor Phasing Comparison

There are four conventions used to establish the relative phasing of the sensor signals in three phase motors. With six step drive, an input signal change must occur every 60 electrical degrees, however, the relative signal phasing is



þ

Rotor Electrical Position (Degrees)



Figure 43. Four Phase, Four Step, Full Wave Commutation Waveforms

ORDERING INFORMATION

Device	Operating Temperature Range	Package	Shipping [†]
MC33033DW		SO-20L	38 Units / Rail
MC33033DWG		SO-20L (Pb-Free)	
MC33033DWR2		SO-20L	1000 Tape & Reel
MC33033DWR2G	T _A = -40 C to +85 C	SO–20L (Pb–Free)	
MC33033P		PDIP-20	18 Units / Rail
MC33033PG		PDIP–20 (Pb–Free)	
NCV33033DWR2*		SO-20L	1000 Tape & Reel
	T _A = -40 C to +125 C		



PDIP CASE 738–03 ISSUE E

DATE 06/26/1987



SCALE 1:1







DATE 22 APR 2015

