

# MOTOROLA SEMICONDUCTOR TECHNICAL DATA

## BRUSHLESS DC MOTOR CONTROLLER

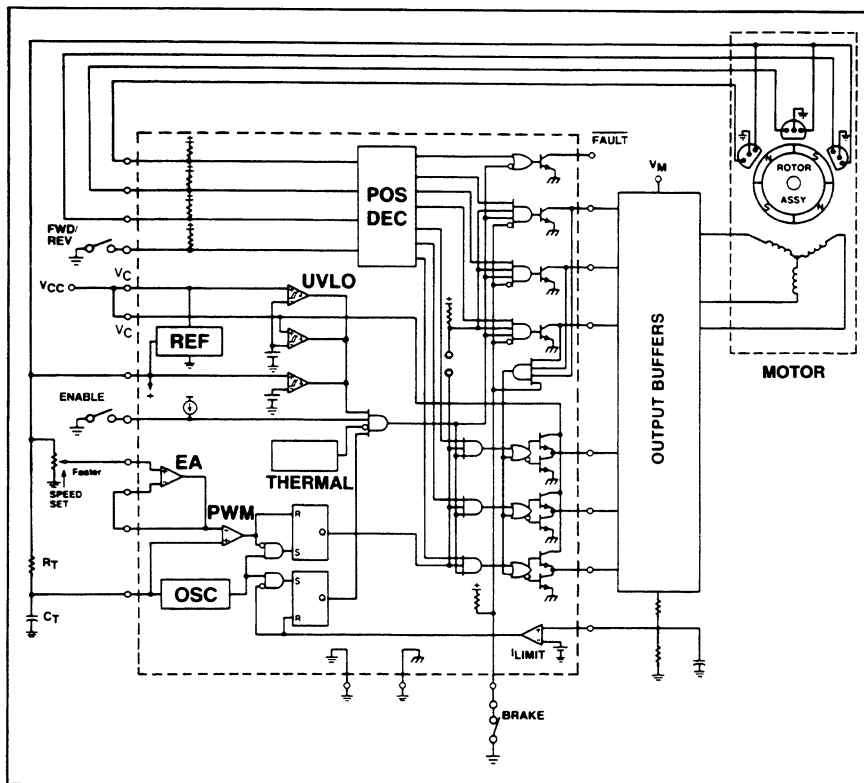
The MC33034 series is a high performance monolithic brushless motor controller containing all of the active functions required to implement a full featured open-loop three or four phase motor control system. These devices consist of a rotor position decoder for proper commutation sequencing, temperature compensated reference capable of supplying sensor power, frequency programmable sawtooth oscillator, fully accessible error amplifier, pulse width modulator comparator, three open collector top drivers, and three high current totem pole bottom drivers ideally suited for driving power MOSFETs.

Also included are protective features consisting of undervoltage lockout, cycle-by-cycle current limiting with a selectable time delayed latched shutdown mode, internal thermal shutdown, and a unique fault output that can be interfaced into microprocessor controlled systems.

Typical motor control functions include open-loop speed, forward or reverse direction, run enable, and dynamic braking.

The MC33034P60 and MC33034P120 are designed to operate with an electrical sensor phasing of 60°/300° and 120°/240° respectively.

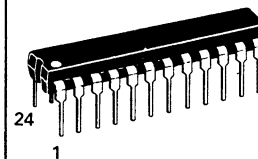
- 10 V to 40 V Operation
- Undervoltage Lockout
- 6.25 V Reference Capable of Supplying Sensor Power
- Fully Accessible Error Amplifier for Servo Applications
- High Current Totem Pole Bottom Drivers
- Cycle-By-Cycle Current Limiting
- Internal Thermal Shutdown



## MC33034

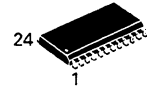
### BRUSHLESS DC MOTOR CONTROLLER

#### SILICON MONOLITHIC INTEGRATED CIRCUIT

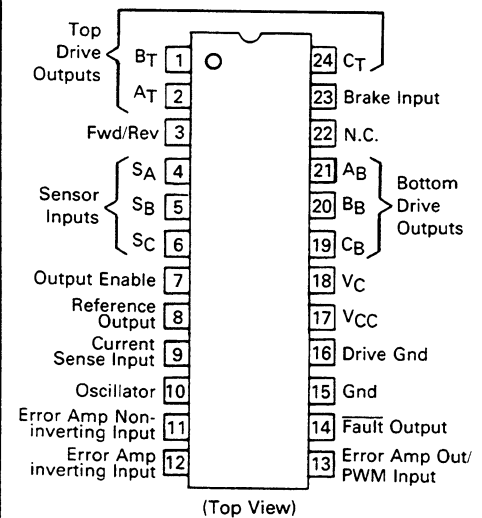


**P SUFFIX**  
PLASTIC PACKAGE  
CASE 724

**DW SUFFIX**  
PLASTIC PACKAGE  
CASE 751E  
(SO-24L)



### PIN CONNECTIONS



### ORDERING INFORMATION

Package	Sensor Electrical Phasing	Device
MC33034DW60	60°/300°	SO-24L
MC33034DW120	120°/240°	SO-24L
MC33034P60	60°/300°	Plastic DIP
MC33034P120	120°/240°	Plastic DIP
Ambient Temperature Range = -40°C to +85°C		

## MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Power Supply Voltage	$V_{CC}$	40	V
Digital Inputs (Pins 3, 4, 5, 6, 7, 23)	—	$V_{ref}$	V
Oscillator Input Current (Source or Sink)	$I_{OSC}$	30	mA
Error Amp Input Voltage Range (Pins 11, 12, Note 1)	$V_{IR}$	−0.3 to 40	V
Error Amp Output Current, Source or Sink (Note 2)	$I_{Out}$	10	mA
Current Sense Input Voltage	$V_{Sense}$	5.0	V
Fault Output Voltage	$V_{CE(Fault)}$	20	V
Fault Output Sink Current	$I_{Sink(Fault)}$	20	mA
Top Drive Voltage (Pins 1, 2, 24)	$V_{CE(top)}$	45	V
Top Drive Sink Current (Pins 1, 2, 24)	$I_{Sink(top)}$	50	mA
Bottom Drive Supply Voltage (Pin 18)	$V_C$	40	V
Bottom Drive Output Current, Source or Sink (Pins 19, 20, 21)	$I_{DRV}$	100	mA
Power Dissipation and Thermal Characteristics Maximum Power Dissipation @ $T_A = 85^{\circ}\text{C}$ Thermal Resistance Junction to Air	$P_D$ $R_{\theta JA}$	867 75	mW $^{\circ}\text{C/W}$
Operating Junction Temperature	$T_J$	+150	$^{\circ}\text{C}$
Operating Ambient Temperature Range	$T_A$	−40 to +85	$^{\circ}\text{C}$
Storage Temperature Range	$T_{stg}$	−65 to +150	$^{\circ}\text{C}$

## ELECTRICAL CHARACTERISTICS ( $V_{CC}$ and $V_C = 20\text{ V}$ , $R_T = 4.7\text{ k}$ , $C_T = 10\text{ nF}$ , $T_A = 25^{\circ}\text{C}$ unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
<b>REFERENCE SECTION</b>					
Reference Output Voltage ( $I_{Ref} = 1.0\text{ mA}$ ) $T_A = 25^{\circ}\text{C}$ $T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$	$V_{ref}$	5.9 5.82	6.25 —	6.5 6.57	V
Line Regulation ( $V_{CC} = 10\text{ V}$ to $40\text{ V}$ , $I_{ref} = 1.0\text{ mA}$ )	$Reg_{line}$	—	12	30	mV
Load Regulation ( $I_{ref} = 1.0\text{ mA}$ to $20\text{ mA}$ )	$Reg_{load}$	—	5.0	30	mV
Output Short Circuit Current (Note 3)	$I_{SC}$	40	60	—	mA
Reference Under Voltage Lockout Threshold	$V_{th}$	4.0	4.5	5.0	V

## ERROR AMPLIFIER

Input Offset Voltage ( $T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$ )	$V_{IO}$	—	2.0	10	mV
Input Offset Current ( $T_A = -40$ to $+85^{\circ}\text{C}$ )	$I_{IO}$	—	10	500	nA
Input Bias Current ( $T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$ )	$I_{IB}$	—	−25	−1000	nA
Input Common Mode Voltage Range	$V_{ICR}$	(0 V to $V_{CC} - 2.0\text{ V}$ )			V
Open-Loop Voltage Gain ( $V_O = 3.0\text{ V}$ , $R_L = 15\text{ k}$ )	$A_{VOL}$	75	95	—	dB
Input Common Mode Rejection Ratio	$CMRR$	55	80	—	dB
Power Supply Rejection Ratio ( $V_{CC}$ and $V_C = 10\text{ V}$ to $40\text{ V}$ )	$PSRR$	65	95	—	dB
Output Voltage Swing High State ( $R_L = 15\text{ k}$ to Gnd) Low State ( $R_L = 15\text{ k}$ to $V_{ref}$ )	$V_{OH}$ $V_{OL}$	4.6 —	5.4 0.7	— 1.0	V

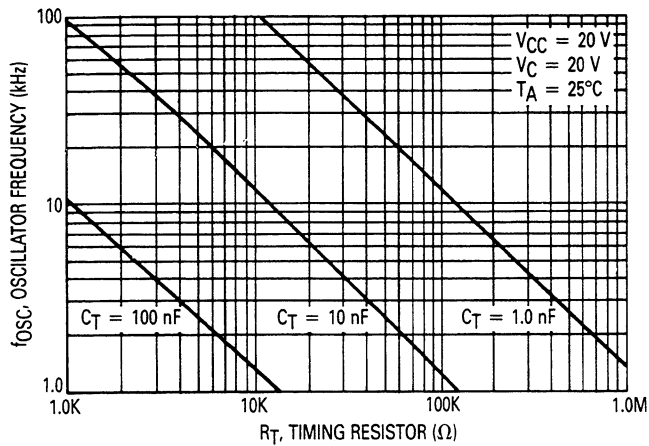
### Notes:

1. The input common mode voltage or input signal voltage should not be allowed to go negative by more than 0.3 V. The upper functional limit of the common mode voltage range is typically  $V_{CC} - 2.0\text{ V}$ , but either or both inputs can go to 40 V, independent of  $V_{CC}$  without device destruction.
2. The compliance voltage must not exceed the range of −0.3 V to  $V_{ref}$ .
3. Maximum package power dissipation limits must be observed.

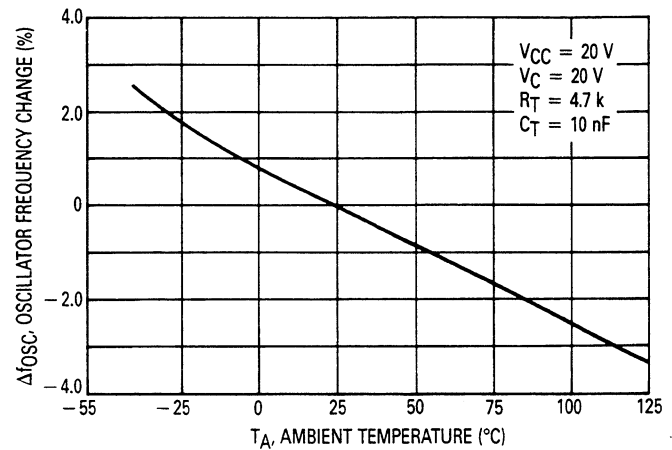
**ELECTRICAL CHARACTERISTICS** ( $V_{CC}$  and  $V_C = 20$  V,  $R_T = 4.7$  k,  $C_T = 10$  nF,  $T_A = 25^\circ\text{C}$  unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
<b>OSCILLATOR SECTION</b>					
Oscillator Frequency	$f_{OSC}$	21	23.5	26	kHz
Frequency Change with Voltage ( $V_{CC} = 10$ V to 40 V)	$\Delta f_{OSC}/\Delta V$	—	0.1	5.0	%
Sawtooth Peak Voltage	$V_{OSC(P)}$	—	4.0	4.2	V
Sawtooth Valley Voltage	$V_{OSC(V)}$	1.2	1.5	—	V
<b>LOGIC INPUTS</b>					
Input Threshold Voltage (Pins 3, 4, 5, 6, 7, 23) High State Low State	$V_{IH}$ $V_{IL}$	2.0 —	1.4 1.4	— 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)	$I_{IH}$ $I_{IL}$	−250 −900	−150 −600	−40 −300	$\mu\text{A}$
Forward/Reverse and Brake Inputs (Pins 3, 23) High State Input Current ( $V_{IH} = 5.0$ V) Low State Input Current ( $V_{IL} = 0$ V)	$I_{IH}$ $I_{IL}$	−150 −600	−88 −325	−25 −150	$\mu\text{A}$
Output Enable High State Input Current ( $V_{IH} = 5.0$ V) Low State Input Current ( $V_{IL} = 0$ V)	$I_{IH}$ $I_{IL}$	−70 −80	−40 −40	−10 −20	$\mu\text{A}$
<b>CURRENT-LIMIT COMPARATOR</b>					
Threshold Voltage	$V_{th}$	75	100	125	mV
Input Bias Current ( $V_{in} = 0$ V to 5.0 V)	$I_{IB}$	—	−1.0	−2.0	$\mu\text{A}$
<b>OUTPUTS AND POWER SECTIONS</b>					
Top Drive Output Sink Saturation ( $I_{sink} = 25$ mA)	$V_{CE(sat)}$	—	0.95	1.5	V
Top Drive Output Off-State Leakage ( $V_{CE} = 40$ V)	$I_{DRV(leak)}$	—	2.0	100	$\mu\text{A}$
Top Drive Output Switching Time ( $C_L = 47$ pF, $R_L = 1.0$ k) Rise Time Fall Time	$t_r$ $t_f$	— —	100 35	300 300	ns
Bottom Drive Output Voltage High State ( $I_{source} = 50$ mA) Low State ( $I_{sink} = 50$ mA)	$V_{OH}$ $V_{OL}$	( $V_C - 3.0$ ) —	( $V_C - 2.4$ ) 1.5	— 2.0	V
Bottom Drive Output Switching Time ( $C_L = 1000$ pF) Rise Time Fall Time	$t_r$ $t_f$	— —	75 65	200 200	ns
Fault Output Sink Saturation ( $I_{sink} = 16$ mA)	$V_{CE(sat)}$	—	225	500	mV
Fault Output Off-State Leakage ( $V_{CE} = 20$ V)	$I_{FLT(leak)}$	—	1.0	100	$\mu\text{A}$
Under Voltage Lockout Drive Outputs Enabled ( $V_{CC}$ or $V_C$ Increasing) Hysteresis	$V_{th(on)}$ $V_H$	8.2 0.1	9.1 0.2	10 0.3	V
Power Supply Current $V_{CC}$ and $V_C = 20$ V $V_{CC}$ Current (Pin 17) $V_C$ Current (Pin 18)	$I_{CC}$ $I_C$	— —	16 3.0	22 7.0	mA

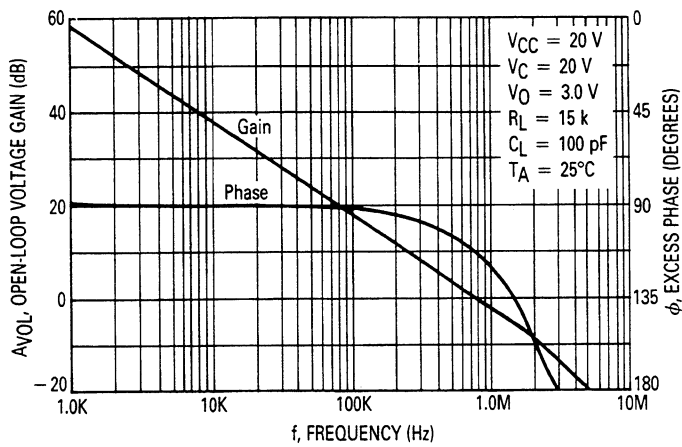
**FIGURE 1 — OSCILLATOR FREQUENCY versus TIMING RESISTOR**



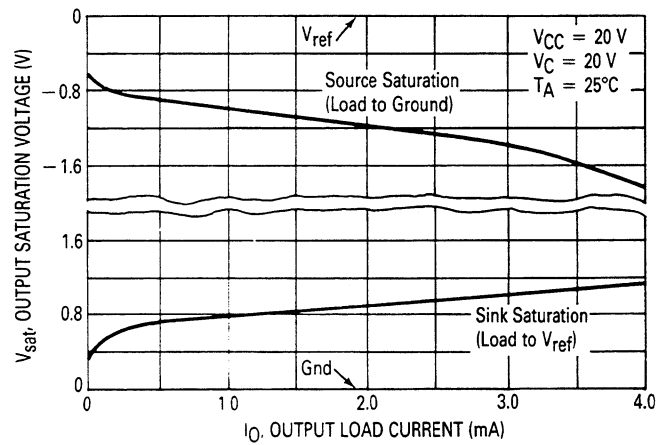
**FIGURE 2 — OSCILLATOR FREQUENCY CHANGE versus TEMPERATURE**



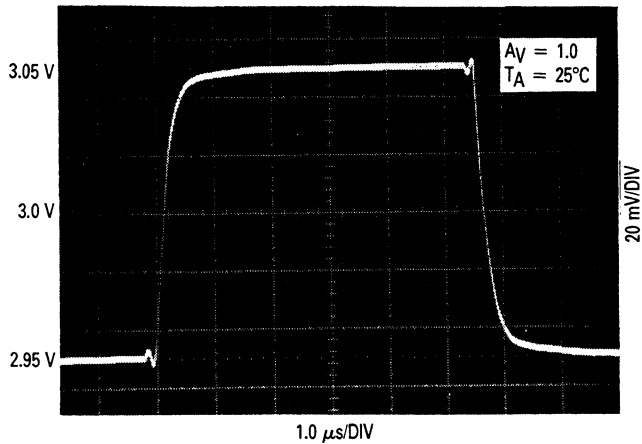
**FIGURE 3 — ERROR AMP OPEN-LOOP GAIN AND PHASE versus FREQUENCY**



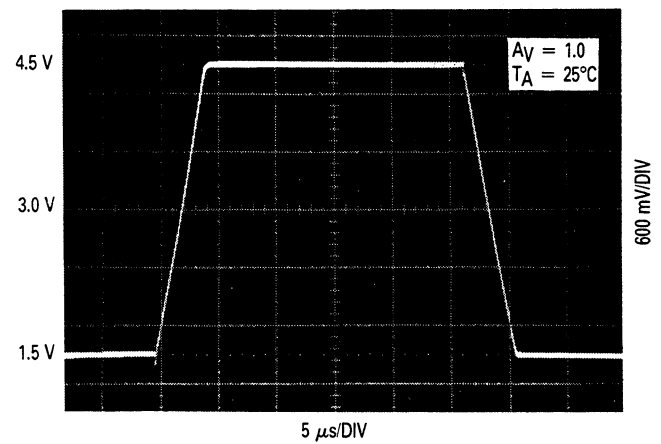
**FIGURE 4 — ERROR AMP OUTPUT SATURATION versus LOAD CURRENT**



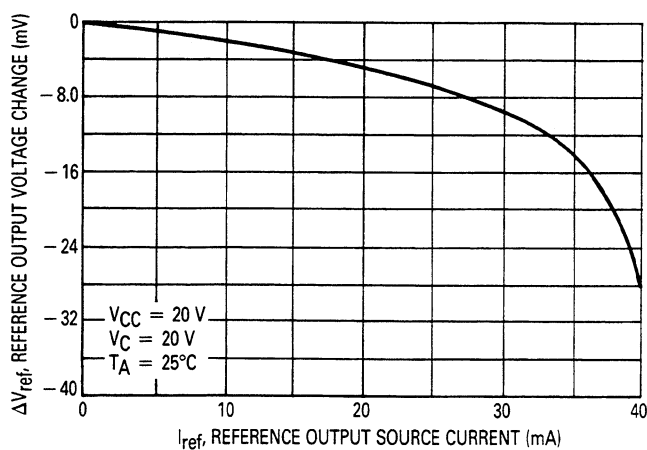
**FIGURE 5 — ERROR AMP SMALL-SIGNAL TRANSIENT RESPONSE**



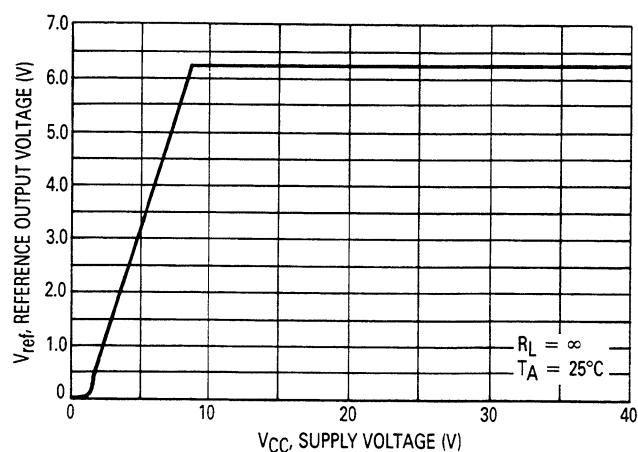
**FIGURE 6 — ERROR AMP LARGE-SIGNAL TRANSIENT RESPONSE**



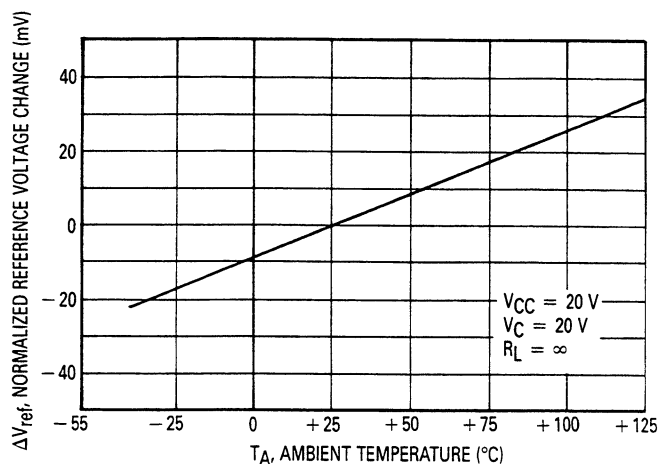
**FIGURE 7 — REFERENCE OUTPUT VOLTAGE CHANGE  
versus SOURCE CURRENT**



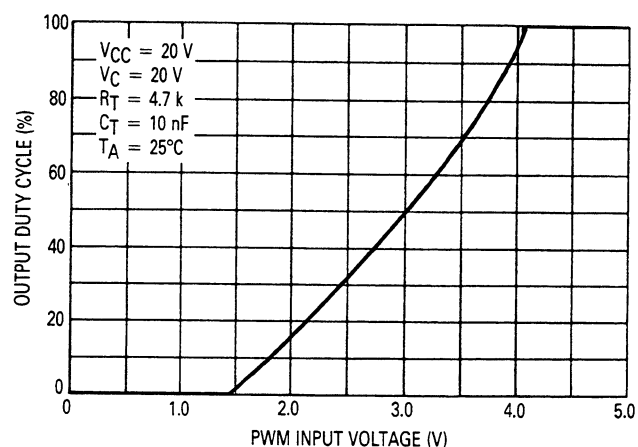
**FIGURE 8 — REFERENCE OUTPUT VOLTAGE  
versus SUPPLY VOLTAGE**



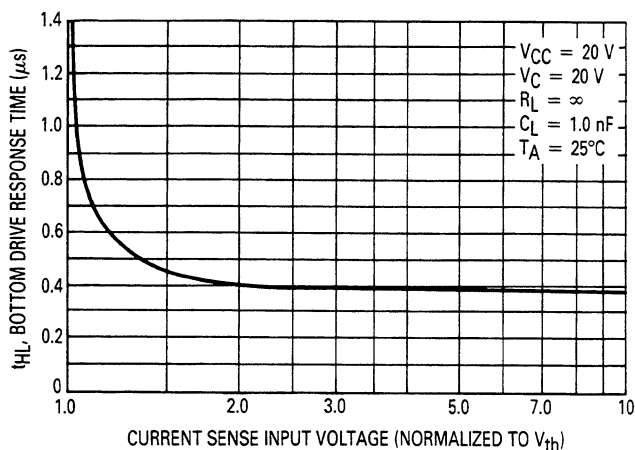
**FIGURE 9 — REFERENCE OUTPUT VOLTAGE  
versus TEMPERATURE**



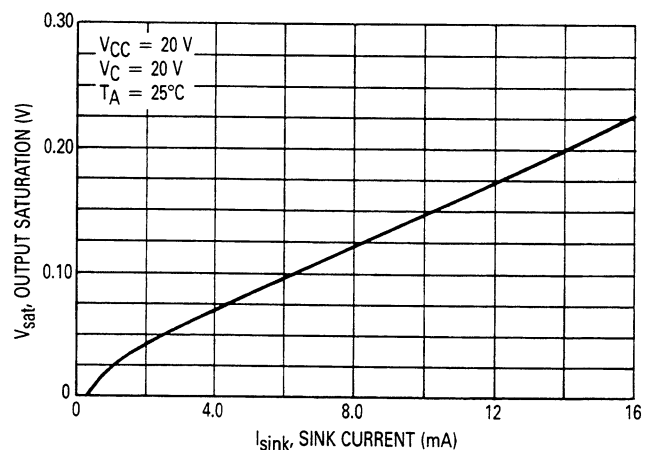
**FIGURE 10 — OUTPUT DUTY CYCLE versus  
PWM INPUT VOLTAGE**



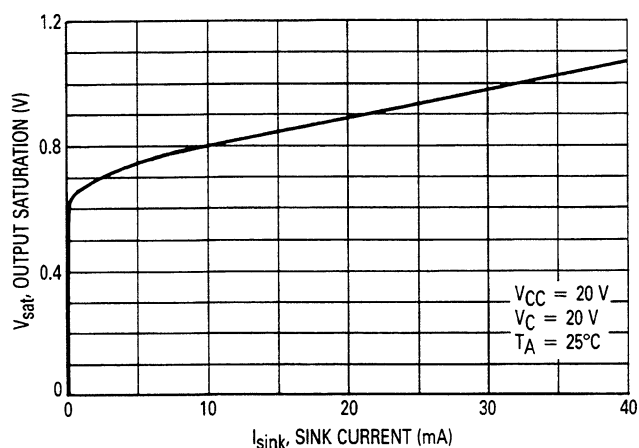
**FIGURE 11 — BOTTOM DRIVE RESPONSE TIME versus  
CURRENT SENSE INPUT VOLTAGE**



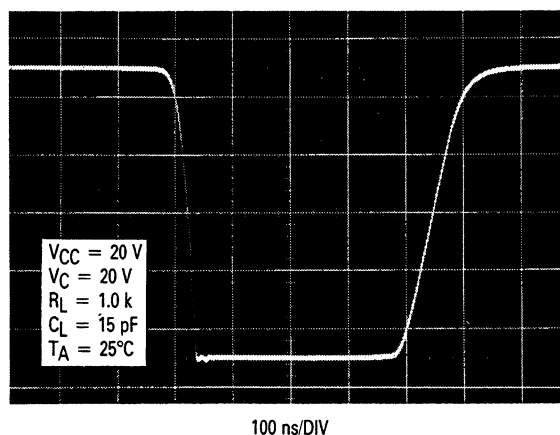
**FIGURE 12 — FAULT OUTPUT SATURATION  
versus SINK CURRENT**



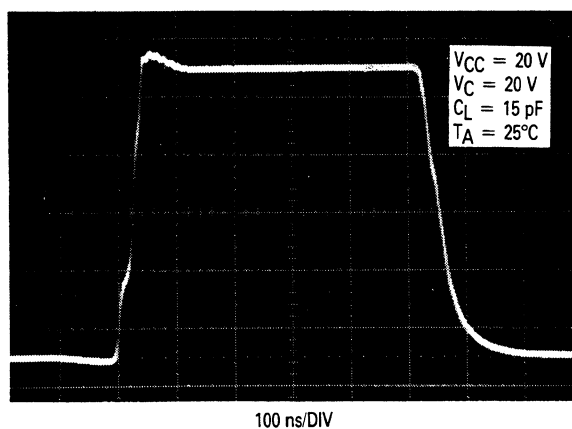
**FIGURE 13 — TOP DRIVE OUTPUT SATURATION  
versus SINK CURRENT**



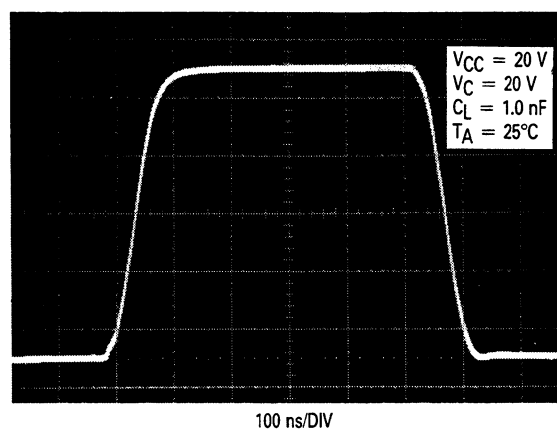
**FIGURE 14 — TOP DRIVE OUTPUT WAVEFORM**



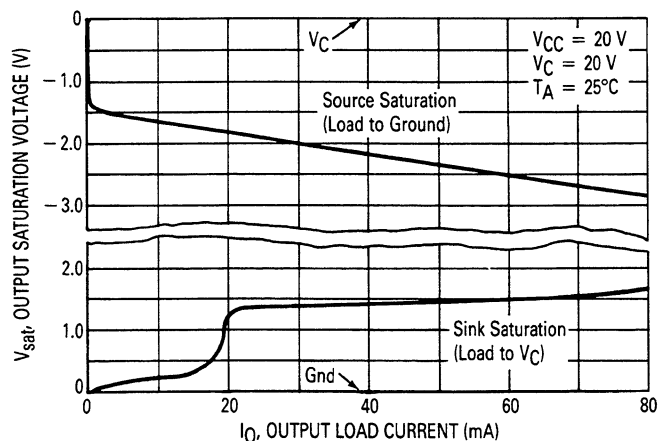
**FIGURE 15 — BOTTOM DRIVE OUTPUT WAVEFORM**



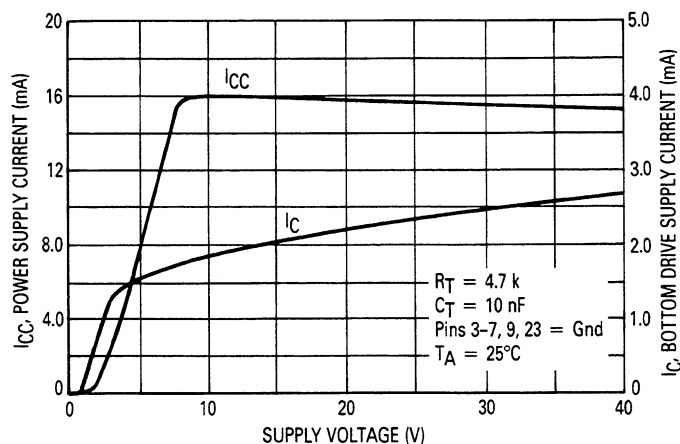
**FIGURE 16 — BOTTOM DRIVE OUTPUT WAVEFORM**



**FIGURE 17 — BOTTOM DRIVE OUTPUT SATURATION  
versus LOAD CURRENT**



**FIGURE 18 — POWER AND BOTTOM DRIVE SUPPLY  
CURRENT versus SUPPLY VOLTAGE**



# PIN FUNCTION DESCRIPTION

Pin No.	Function	Description
1, 2, 24	B <sub>T</sub> , A <sub>T</sub> , C <sub>T</sub>	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.
4, 5, 6	S <sub>A</sub> , S <sub>B</sub> , S <sub>C</sub>	These three Sensor Inputs control the commutation sequence.
7	Output Enable	A logic high at this input causes the motor to run, while a low causes it to coast.
8	Reference Output	This output provides charging current for the oscillator timing capacitor C <sub>T</sub> and a reference for the error amplifier. It can also furnish sensor power.
9	Current Sense Input	A 100 mV signal at this input terminates output switch conduction during a given oscillator cycle.
10	Oscillator	The Oscillator frequency is programmed by the values selected for timing components R <sub>T</sub> and C <sub>T</sub> .
11	Error Amp Noninverting Input	This input is normally connected to the speed set potentiometer.
12	Error Amp Inverting Input	This input is normally connected to the Error Amp Output in open-loop applications.
13	Error Amp Output/PWM Input	This pin is available for compensation in closed-loop applications.
14	Fault Output	This open collector output is active low during one or more of the following conditions: Invalid Sensor Input code, Enable Input at logic 0, Current Sense Input > 100 mV, Undervoltage Lockout activation, and Thermal Shutdown.
15	Ground	This pin is the control circuitry ground return and is connected back to the source ground.
16	Drive Ground	This pin is a separate power ground return that is connected back to the power source. It reduces the effects of switching transient noise on the control circuitry.
17	V <sub>CC</sub>	This pin is the positive supply of the control IC. The controller is functional over a minimum V <sub>CC</sub> range of 10 V to 40 V.
18	V <sub>C</sub>	The high state (V <sub>OH</sub> ) of the Bottom Drive Outputs are set by the voltage applied to this pin. The controller is operational over a minimum V <sub>C</sub> range of 10 V to 40 V.
19, 20, 21	C <sub>B</sub> , B <sub>B</sub> , A <sub>B</sub>	These three totem pole Bottom Drive Outputs are designed for direct drive of the external bottom power switch transistors.
22	N.C.	No connection. This pin is not internally connected.
23	Brake Input	A logic low at this input causes the motor to run, while a high causes rapid deceleration.

FIGURE 19 — REPRESENTATIVE BLOCK DIAGRAM

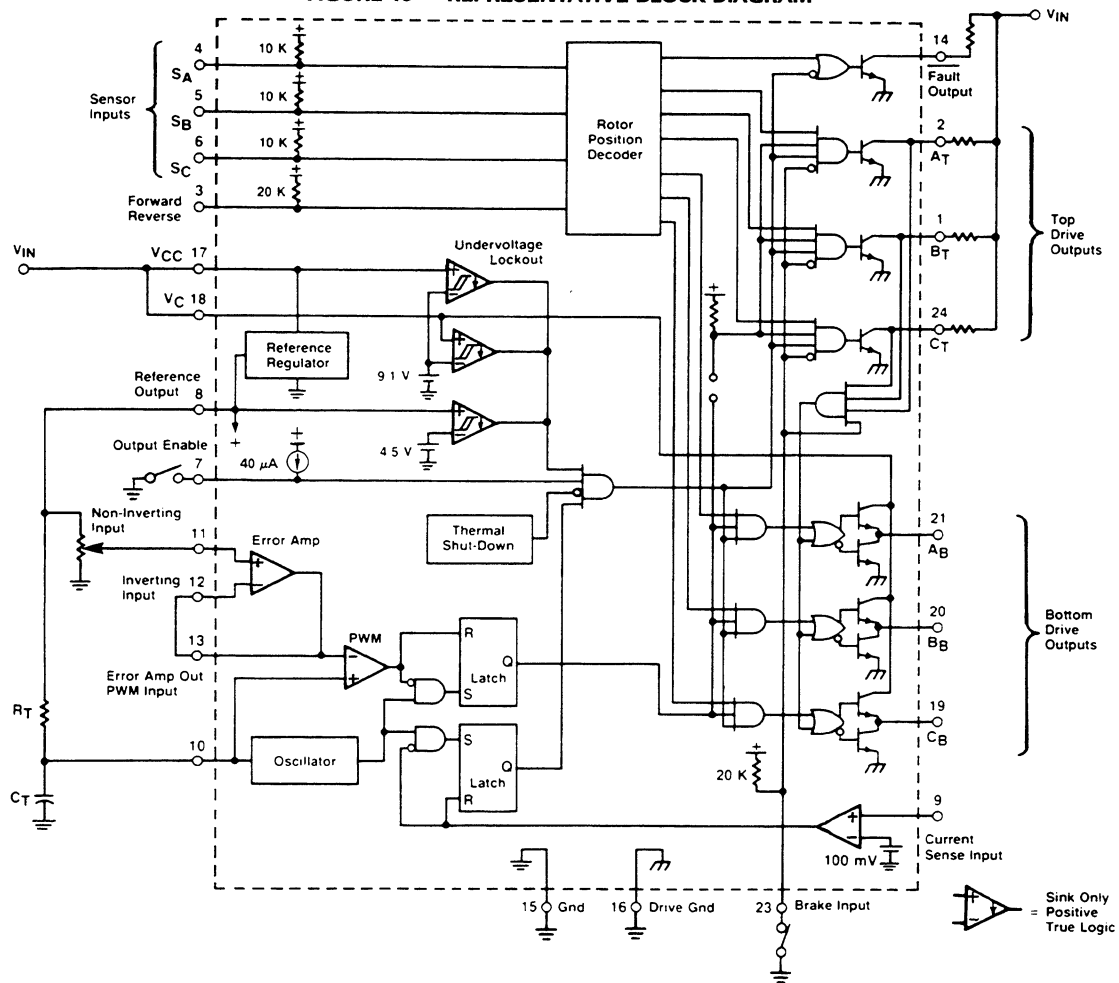


FIGURE 20 — THREE PHASE, SIX STEP COMMUTATION TRUTH TABLE

Inputs (Note 1)										Outputs (Note 2)							
Sensor Electrical Phasing						Current Sense				Top Drives			Bottom Drives			Fault	
MC33034P60 60°			MC33034P120 120°														
SA	SB	SC	SA	SB	SC	F/R	Enable	Brake	Sense	AT	BT	CT	AB	BB	CB		
1	0	0	1	0	0	1	1	0	0	0	1	1	0	0	1	1	
1	1	0	1	1	0	1	1	0	0	1	0	1	0	0	1	1	
1	1	1	0	1	0	1	1	0	0	1	0	1	1	0	0	1	
0	1	1	0	1	1	1	1	0	0	1	1	0	1	0	0	1	
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0	0	1	0	0	1	0	1	0	0	1	0	1	0	0	1	1	
0	0	0	1	0	1	0	1	0	0	1	0	1	1	0	0	1	
1	0	1	0	0	0	X	X	0	X	1	1	1	0	0	0	0	
0	1	0	1	1	1	X	X	0	X	1	1	1	0	0	0	0	
X	X	X	X	X	X	X	0	0	X	1	1	1	0	0	0	0	
V	V	V	V	V	V	X	1	1	0	1	1	1	1	1	1	1	
X	X	X	X	X	X	X	X	1	1	1	1	1	1	1	1	0	
X	X	X	X	X	X	X	X	0	1	1	1	1	0	0	0	0	

Notes:

- The digital inputs (Pins 3, 4, 5, 6, 7, 23) are all TTL compatible. The current sense input (Pin 9) has a 100 mV threshold. A logic 0 for this input is defined as < 80 mV, and a logic 1 is > 120 mV.
- The Fault and top drive outputs are open collectors and are active in the low (0) state.
- V = any one of the six valid sensor combinations.  
X = Don't care.

## INTRODUCTION

The Motorola MC33034 is a high performance monolithic brushless motor controller containing all of the active functions required to implement a full featured, open-loop, three or four phase motor control system. These integrated circuits are constructed with Bipolar Analog technology which offers a high degree of performance and ruggedness in hostile industrial environments. The MC33034 consists of a rotor position decoder for proper commutation sequencing, temperature compensated reference capable of supplying sensor power, frequency programmable sawtooth oscillator, fully accessible error amplifier, pulse width modulator comparator, three open collector top drivers, and three high current totem pole bottom drivers ideally suited for driving power MOSFETs.

Also included are protective features consisting of undervoltage lockout, cycle by cycle current limiting with a selectable time delayed latched shutdown mode, internal thermal shutdown, and a unique Fault output that can be interfaced into microprocessor controlled systems.

Typical motor control functions include open-loop speed control, forward or reverse direction, run enable, and dynamic braking.

## FUNCTIONAL DESCRIPTION

A representative internal block diagram and a typical system application are shown in Figures 19 and 36. A discussion of the features and function of each of the internal blocks is given below.

### 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 the thresholds typically at 1.4 volts. The MC33034 series consists of two device types, each is designed to control three phase motors and operate with two of the four most common conventions of sensor phasing. The MC33034P60 is intended to operate with an electrical sensor phasing of 60° or 300° and the MC33034P120 with 120° or 240°. With three sensor inputs there are eight possible input code combinations, six of these are valid rotor positions. The remaining two codes are invalid and are usually caused by an open or shorted sensor line. When an invalid input condition exists, the  $\overline{\text{Fault}}$  output is activated and the drive outputs are disabled. With six valid input codes, the decoder can resolve the 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 this 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  $A_B$ ,  $C_B$  to  $C_T$ ). In effect the commutation sequence is reversed.

Motor on/off control is accomplished by the output enable (Pin 7). When left disconnected, an internal 40  $\mu\text{A}$  current 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 and activating the Fault output.

Dynamic motor braking allows an additional margin of safety to be designed into the final product. Braking is accomplished by placing the brake input (Pin 23) in a high state. This causes the top drive outputs to turn off and the bottom drives to turn on, shorting the motor-generated back EMF. The brake input has unconditional priority over all other inputs. The internal 20 k $\Omega$  pull-up resistor simplifies interfacing with the system safety-switch by ensuring brake activation if opened or disconnected. The commutation truth table is shown in Figure 20. A four input AND gate is used to monitor the brake input and the three top drive outputs. Its purpose is to disable braking until the top drive outputs attain a high state. This helps to avoid simultaneous conduction of the top and bottom power switches. In half wave motor drive applications, the top drive outputs are not required and are typically left disconnected. Under these conditions braking will be disabled by the AND gate. If required, it can be enabled by connecting a single pull-up resistor from  $V_{CC}$  to the three open collector outputs. Figure 38 shows a pull-up method utilizing the enable input current source.

### Error Amplifier

A high performance, fully compensated error amplifier with access to both inputs and output (Pins 11, 12, 13) is provided to facilitate the implementation of closed-loop motor speed control. The amplifier features a typical DC voltage gain of 95 dB, 800 kHz gain bandwidth, and a wide input common mode voltage range that extends from ground to  $V_{CC} - 2.0\text{ V}$ . In most open-loop speed control applications, the amplifier is configured as a unity gain voltage follower with the non-inverting input connected to the speed set voltage source. Additional configurations are shown in Figures 31 through 35.

### 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 8) through resistor  $R_T$  and discharged by an internal transistor. The ramp peak and valley voltages are typically 4.0 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 kHz to 30 kHz is recommended. Refer to Figure 1 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 bottom drive output conduction when the positive-going ramp on  $C_T$  becomes greater than the error amplifier output. The pulse width modulation timing diagram is shown in Figure 21. Pulse width modulation for speed control appears only at the bottom drive outputs.

## Current Limit

Continuous operation of a motor that is severely overloaded results in overheating and eventual failure. This destructive condition can best be prevented with the use of cycle-by-cycle current limiting. That is, each on-cycle is treated as a separate problem. This is implemented by monitoring the stator current build-up each time the output switch conducts, and upon sensing an over current condition, immediately turns off the switch and holds it off for the duration of the oscillator ramp-up period. The stator current is converted to a voltage by inserting a ground-referenced sense resistor  $R_S$  (Figure 36) in series with the three bottom switch transistors (Q4, Q5, Q6). This voltage is monitored by the current sense input (Pin 9), and compared to an internal 100 mV reference. If exceeded, the comparator resets the lower latch and terminates output switch conduction. The value for the sense resistor is:

$$R_S = \frac{0.1}{I_{\text{stator(max)}}$$

The  $\overline{\text{Fault}}$  output is activated during the over current condition. The dual-latch PWM configuration ensures that only a single output conduction pulse will occur

during any given oscillator cycle, whether terminated by the output of the error amp or current limit comparator.

## Reference

The on chip 6.25 V regulator (Pin 8) provides charging current for the oscillator timing capacitor, a reference for the error amplifier, and has a current capability of 40 mA for direct power of the sensors in low voltage applications. In higher voltage applications it may become necessary to transfer the power dissipated by the regulator off the I.C. This is easily accomplished with the addition of an external pass transistor as shown in Figure 22. A 6.25 V reference level was chosen to allow implementation of the simpler NPN circuit, where  $V_{\text{ref}} - V_{\text{BE}}$  exceeds the minimum voltage required by Hall Effect sensors over temperature. With proper transistor selection, and adequate heatsinking, up to 1.0 amp of load current can be obtained.

FIGURE 22 — REFERENCE OUTPUT BUFFERS

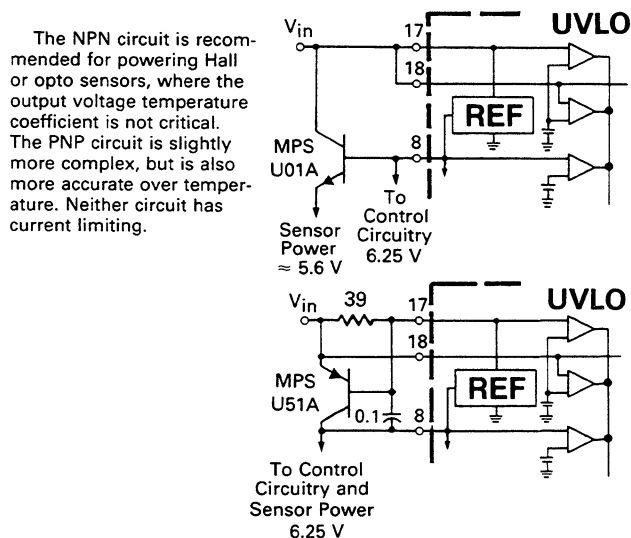
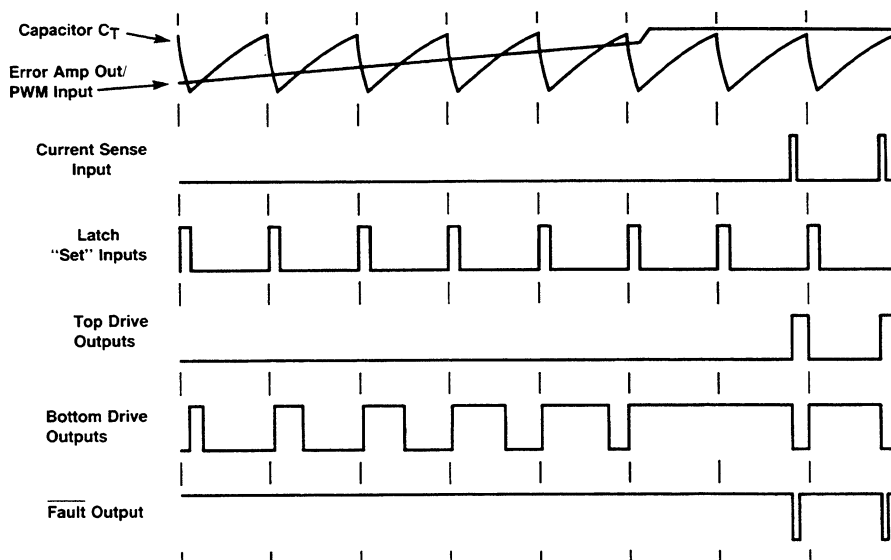


FIGURE 21 — PULSE WIDTH MODULATOR TIMING DIAGRAM



## Undervoltage Lockout

A triple Undervoltage Lockout has been incorporated to prevent damage to the control IC and the external power switch transistors. Under low power supply conditions, it guarantees that the IC and sensors are fully functional, and that there is sufficient bottom drive output voltage. The positive power supplies to the IC ( $V_{CC}$ ) and the bottom drives ( $V_C$ ) are each monitored by separate comparators that have their thresholds at 9.1 V. This level ensures sufficient gate drive for low  $r_{DS(on)}$  when interfacing with standard power MOSFETs. When directly powering the Hall sensors from the reference, improper sensor operation can result if the output voltage should fall below 4.5 V. A third comparator is used to detect this condition. If one or more of the comparators detects an undervoltage condition, the  $\overline{\text{Fault}}$  output is activated, 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.

## Fault Output

The open collector  $\overline{\text{Fault}}$  output (Pin 14) was designed to provide diagnostic information in the event of a system malfunction. It has a sink current capability of 16 mA and can directly drive a light emitting diode for visual indication. Additionally, it is easily interfaced with TTL/CMOS logic for use in a microprocessor controlled system. The  $\overline{\text{Fault}}$  output is active low when one or more of the following conditions occur:

- 1) Invalid Sensor Input code.
- 2) Enable Input at Logic "0."
- 3) Current Sense Input > 100 mV.
- 4) Undervoltage Lockout, activation of one or more of the comparators.
- 5) Thermal Shutdown, maximum junction temperature has been exceeded.

This unique output can also be used to distinguish between motor start-up or sustained operation in an overloaded condition. With the addition of an R/C network between the  $\overline{\text{Fault}}$  output and the enable input, it is possible to create a time-delayed latched shutdown for overcurrent. The added circuitry shown in Figure 23, makes easy starting of motor systems which have high inertial loads by providing additional starting torque, while still preserving overcurrent protection. This task is accomplished by setting the current limit to a higher than nominal value for a predetermined time. During an excessively long overcurrent condition, capacitor  $C_{DLY}$  will charge causing the enable input to cross its threshold to a low state. A latch will now be formed by a positive feedback loop from the  $\overline{\text{Fault}}$  output to the enable input. Once set by the current sense input, it can only be reset by shorting  $C_{DLY}$  or cycling the power supply.

## Drive Outputs

The three top drive outputs (Pins 1, 2, 24) are open collector NPN transistors capable of sinking 50 milliamps with a minimum breakdown of 45 volts. Interfacing into higher voltage applications is easily accomplished with the circuits shown in Figures 24 and 25.

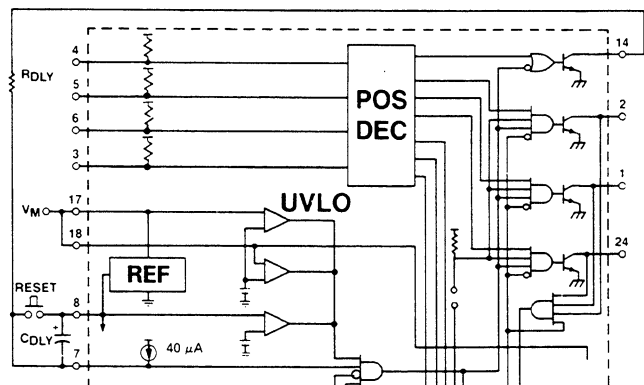
The three totem pole bottom drive outputs (Pins 19, 20, 21) are particularly suited for direct drive of 'N' channel MOSFETs or NPN bipolar transistors (Figures 26, 27 and 28). Each output is capable of sourcing and sinking up to 100 mA. Power for the bottom drives is supplied from  $V_C$  (Pin 18). This separate supply input allows the designer added flexibility in tailoring the drive voltage, independent of  $V_{CC}$ . A zener clamp is typically connected to this input when driving power MOSFETs in systems where  $V_{CC}$  is greater than 20 V.

A separate drive ground (Pin 16) is included to reduce the effects of switching transient noise imposed on the current sense input. This feature becomes particularly useful when driving current sensing power MOSFETs (Figure 29).

## Thermal Shutdown

Internal thermal shutdown circuitry is provided to protect the IC in the event that the maximum junction temperature is exceeded. When activated, typically at 170°C, the IC acts as though the enable input was grounded.

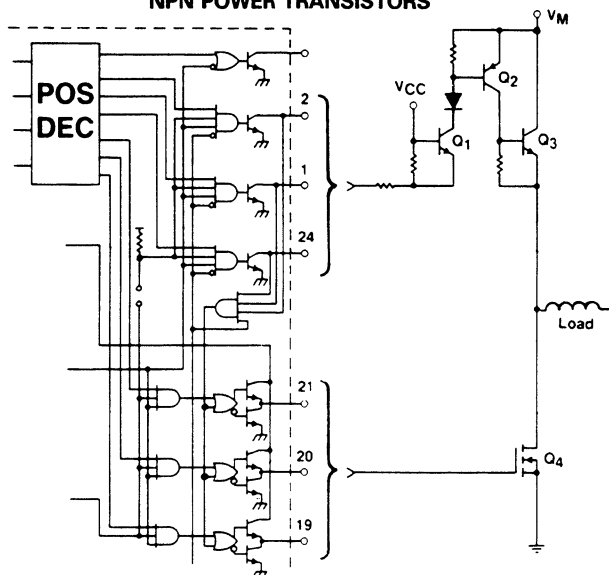
FIGURE 23 — TIMED DELAYED LATCHED OVER-CURRENT SHUTDOWN



$$t_{DLY} \approx R_{DLY} C_{DLY} \ln \left( \frac{V_{ref} - (I_{IL \text{ enable}} R_{DLY})}{V_{th \text{ enable}} - (I_{IL \text{ enable}} R_{DLY})} \right)$$

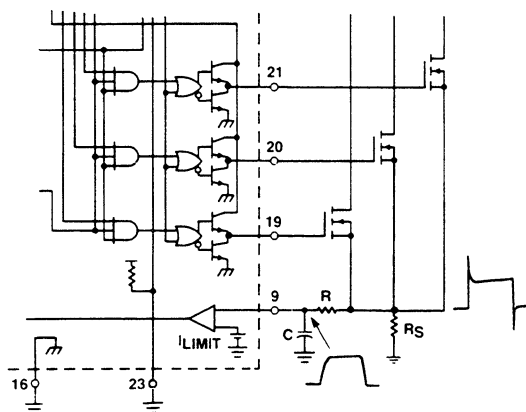
$$\approx R_{DLY} C_{DLY} \ln \left( \frac{6.25 - (40 \times 10^{-6} R_{DLY})}{1.4 - (40 \times 10^{-6} R_{DLY})} \right)$$

**FIGURE 24 — HIGH VOLTAGE INTERFACE WITH NPN POWER TRANSISTORS**



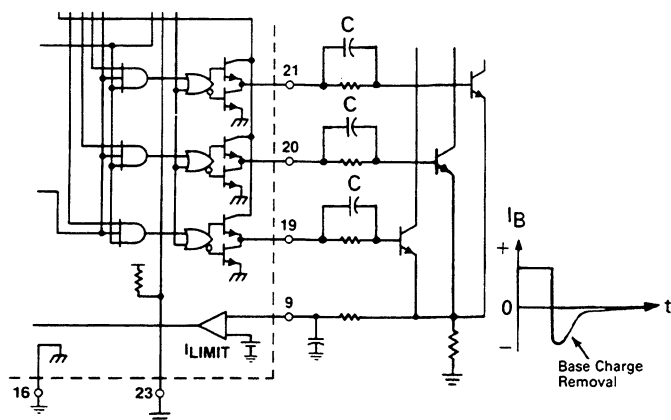
Transistor Q1 is a common base stage used to level shift from  $V_{CC}$  to the high motor voltage  $V_M$ . The collector diode is required if  $V_{CC}$  is present while  $V_M$  is low.

**FIGURE 26 — CURRENT WAVEFORM SPIKE SUPPRESSION**



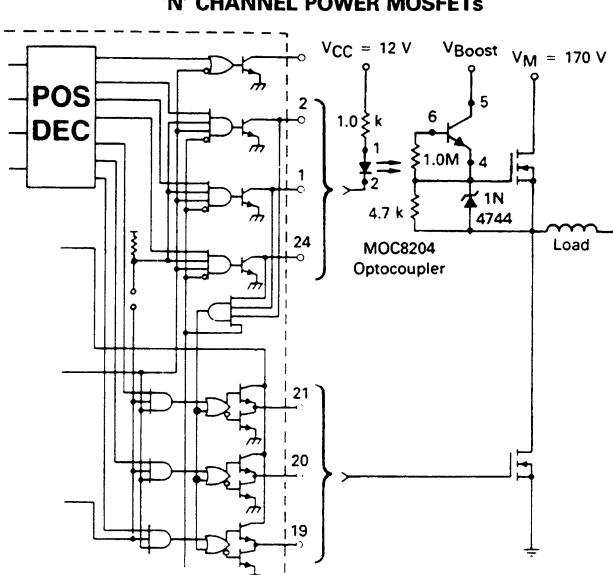
The addition of the RC filter will eliminate current-limit instability caused by the leading edge spike on the current waveform. Resistor  $R_S$  should be a low inductance type.

**FIGURE 28 — BIPOLAR TRANSISTOR DRIVE**

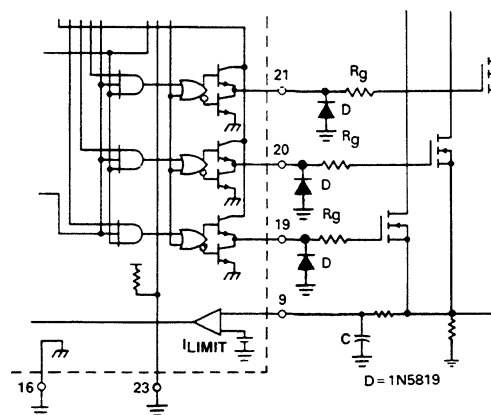


The totem-pole output can furnish negative base current for enhanced transistor turn-off, with the addition of capacitor C.

**FIGURE 25 — HIGH VOLTAGE INTERFACE WITH 'N' CHANNEL POWER MOSFETs**

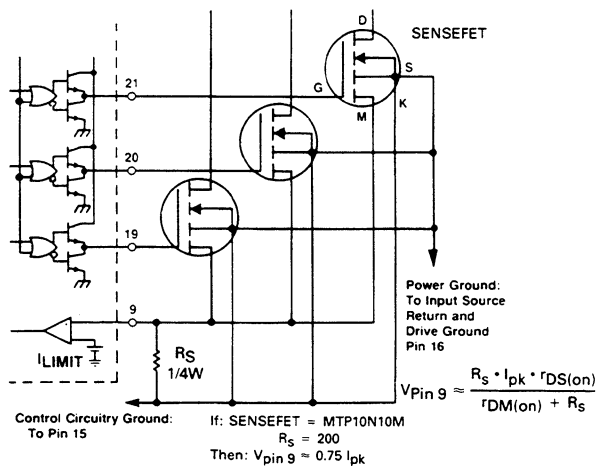


**FIGURE 27 — MOSFET DRIVE PRECAUTIONS**



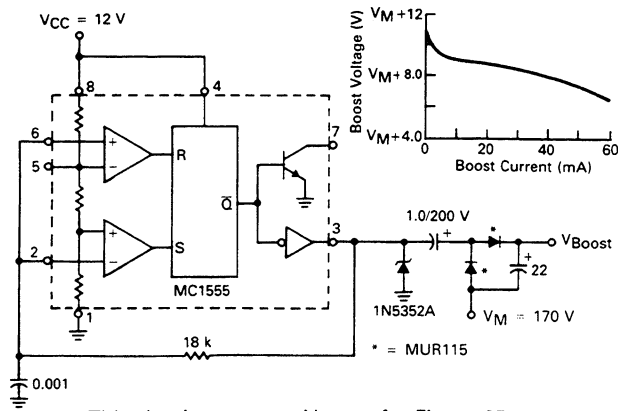
Series gate resistor  $R_g$  will damp any high frequency oscillations caused by the MOSFET input capacitance and any series wiring inductance in the gate-source circuit. Diode D is required if the negative current into the Bottom Drive Outputs exceeds 5.0 mA peak.

**FIGURE 29 — CURRENT SENSING POWER MOSFETs**



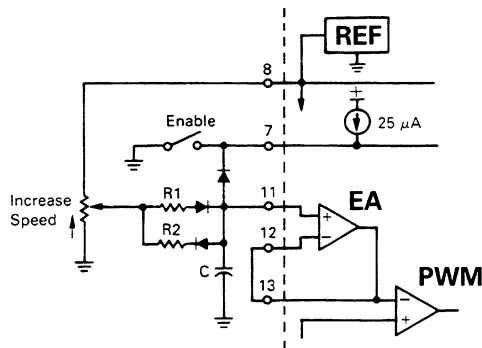
Virtually lossless current sensing can be achieved with the implementation of SENSEFET power switches.

FIGURE 30 — HIGH VOLTAGE BOOST SUPPLY



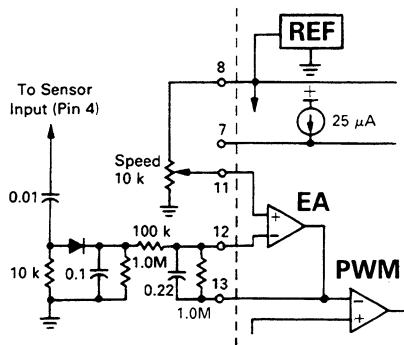
This circuit generates  $V_{Boost}$  for Figure 25.

FIGURE 32 — CONTROLLED ACCELERATION/DECELERATION



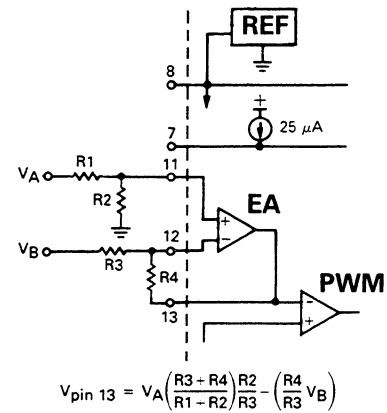
Resistors R1 with capacitor C sets the acceleration time constant while R2 controls the deceleration. The values of R1 and R2 should be at least ten times greater than that of the speed set potentiometer to minimize time constant variations with different speed settings.

FIGURE 34 — CLOSED-LOOP SPEED CONTROL



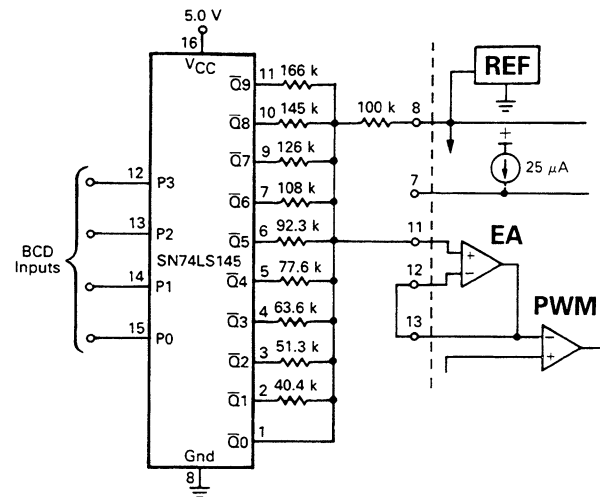
The rotor position sensors can be used as a tachometer. By differentiating the positive-going edges and then integrating them over time, a voltage proportional to speed can be generated. The error amp compares this voltage to that of the speed set to control the PWM.

FIGURE 31 — DIFFERENTIAL INPUT SPEED CONTROLLER



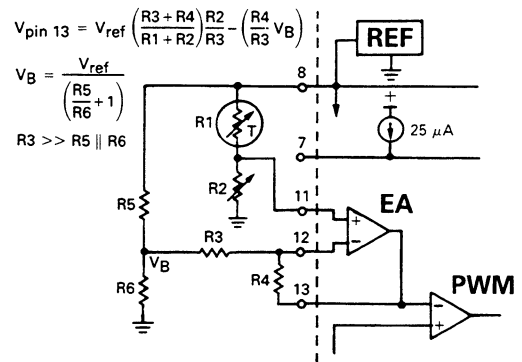
$$V_{pin\ 13} = V_A \left( \frac{R_3 + R_4}{R_1 - R_2} \right) \frac{R_2}{R_3} - \left( \frac{R_4}{R_3} V_B \right)$$

FIGURE 33 — DIGITAL SPEED CONTROLLER



The SN74LS175 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 35 — CLOSED-LOOP TEMPERATURE CONTROL



This circuit can control the speed of a cooling fan proportional to the difference between the sensor and set temperatures. The control loop is closed as the forced air cools the NTC thermistor. For controlled heating applications, exchange the positions of R1 and R2.

## SYSTEM APPLICATIONS

### Three Phase Motor Commutation

The three phase application shown in Figure 36 is a full-featured open-loop motor controller with full wave, six step drive. The upper power switch transistors are Darlington's while the lower devices are power MOS-FETs. Each of these devices contains an internal parasitic catch diode that is used to return the stator inductive energy back to the power supply. The outputs are capable of driving a delta or wye connected stator, and a grounded neutral wye if split supplies are used. At any given rotor position, only one top and one bottom power switch (of different totem poles) is enabled. This configuration switches both ends of the stator winding from supply to ground which causes the current flow to be bidirectional or full wave. A leading edge spike is usually present on the current waveform and can cause a current-limit instability. The spike can be eliminated by adding 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. Care must be taken in the selection of the bottom power switch transistors so that the current during braking does not exceed the device rating. During braking, the peak current generated is limited only by the series resistance of the conducting bottom switch and winding.

$$I_{\text{peak}} = \frac{V_M + \text{EMF}}{R_{\text{switch}} + R_{\text{winding}}}$$

If the motor is running at maximum speed with no load, the generated back EMF can be as high as the supply voltage, and at the onset of braking the peak current may approach twice the motor stall current. Figure 37 shows the commutation waveforms over two electrical cycles. The first cycle ( $0^\circ$  to  $360^\circ$ ) depicts motor operation at full speed while the second cycle ( $360^\circ$  to  $720^\circ$ ) shows a reduced speed with about 50 percent pulse width modulation. The current waveforms reflect a constant torque load and are shown synchronous to the commutation frequency for clarity.

FIGURE 36 — THREE PHASE, SIX STEP, FULL WAVE MOTOR CONTROLLER

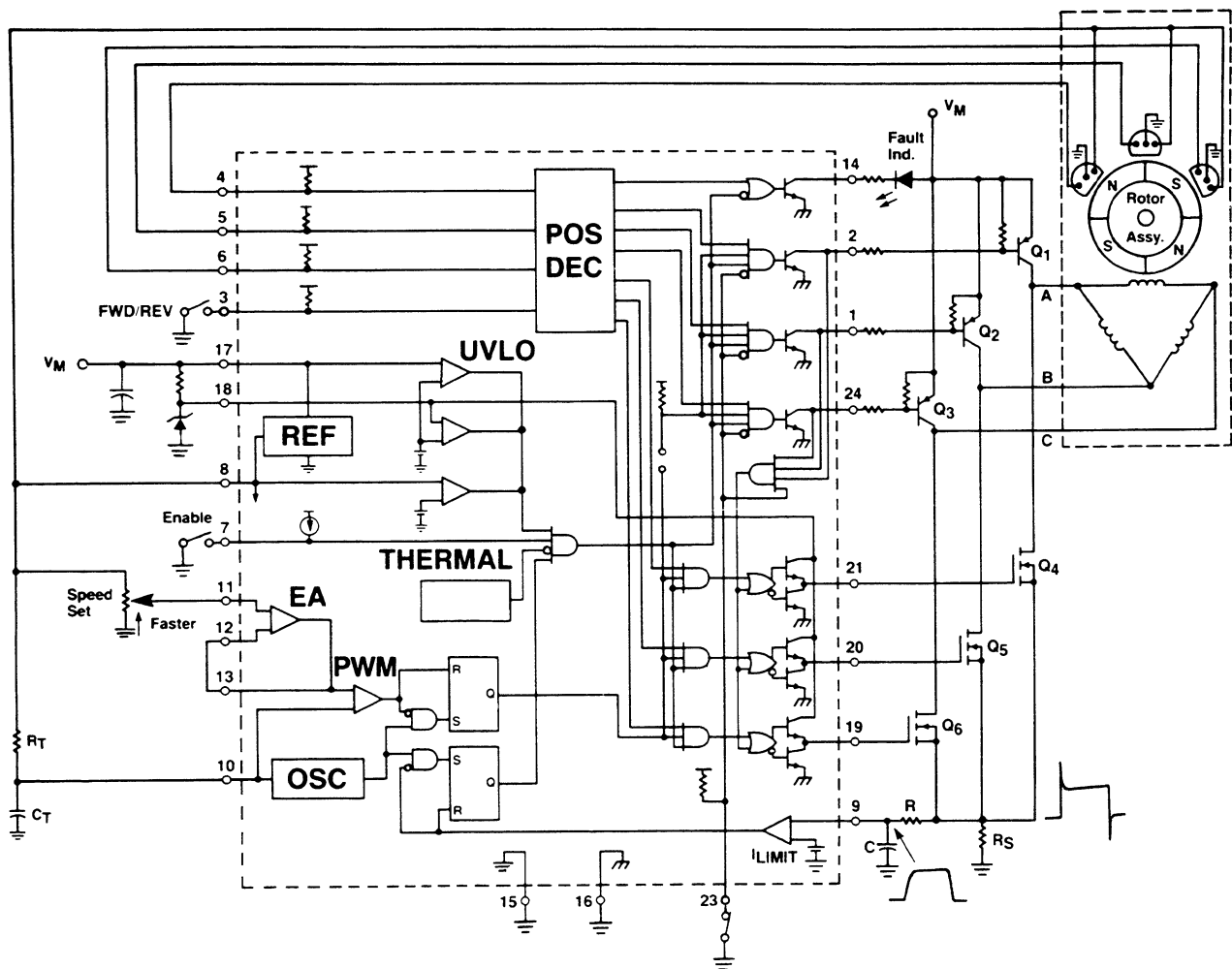


FIGURE 37 — THREE PHASE, SIX STEP, FULL WAVE COMMUTATION WAVEFORMS

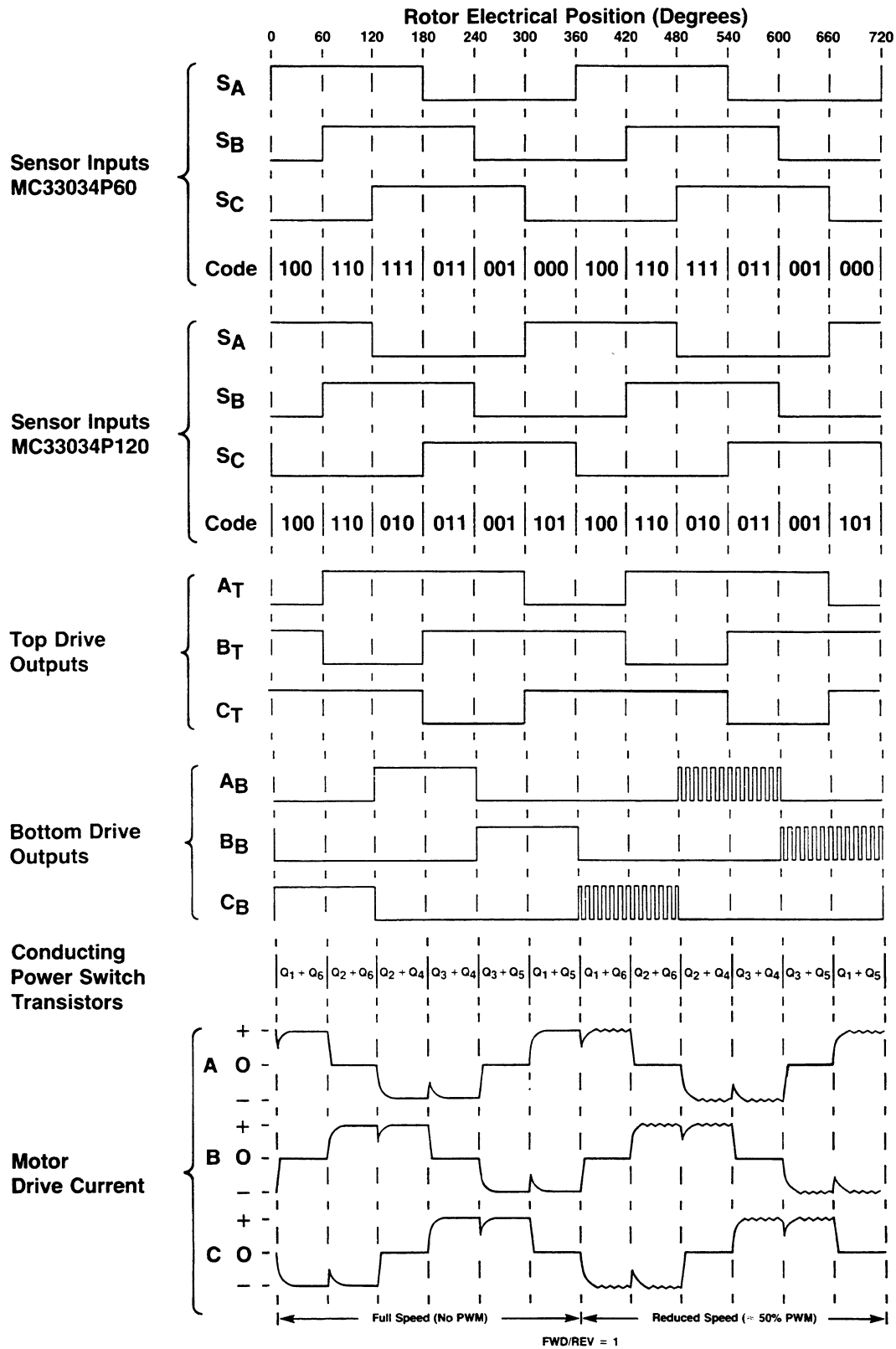


FIGURE 38 — THREE PHASE, THREE STEP, HALF WAVE MOTOR CONTROLLER

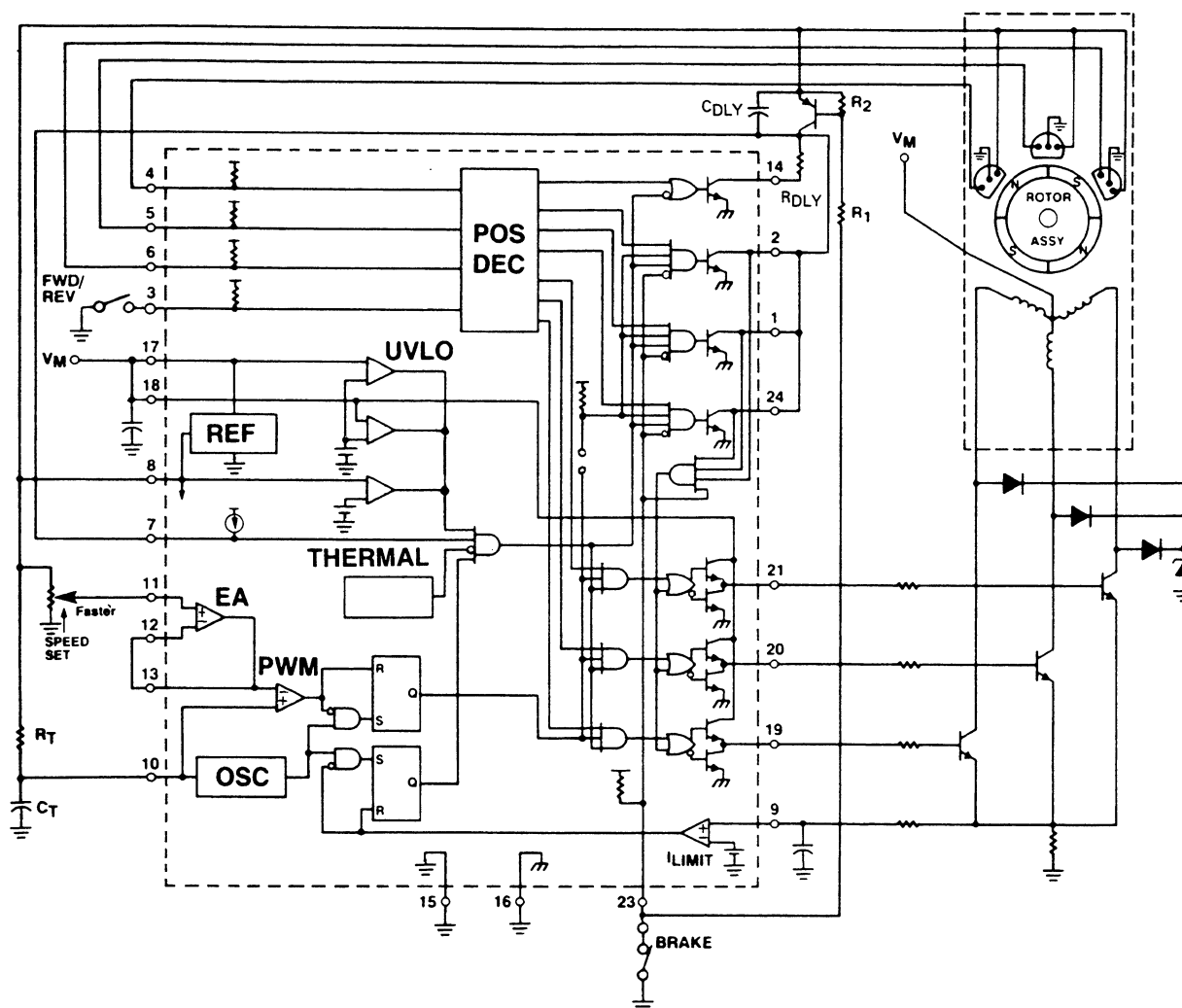


Figure 38 shows a three phase, three step, half wave motor controller. This configuration is ideally suited for automotive and other low voltage applications since there is only one power switch voltage drop in series with a given stator winding. Current flow is unidirectional or half wave because only one end of each winding is switched. Continuous braking with the typical half wave arrangement presents a motor overheating problem since stator current is limited only by the winding resistance. This is due to the lack of upper power switch transistors, as in the full wave circuit, used to disconnect the windings from the supply voltage  $V_M$ . A unique

solution is to provide braking until the motor stops and then turn off the bottom drives. This can be accomplished by using the fault output in conjunction with the enable input as an over current timer. Components  $R_{DLY}$  and  $C_{DLY}$  are selected to give the motor sufficient time to stop before latching the enable input and the top drive AND gate low. To enabling the motor, the PNP transistor along with resistors  $R_1$  and  $R_3$  are used to reset the latch by discharging  $C_{DLY}$  upon brake switch closure. The stator flyback voltage is clamped by a single zener and three diodes.

### 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 dependent upon the mechanical sensor placement. A comparison of the conventions in electrical degrees is shown in Figure 39(a). From the sensor phasing table, Figure 39(b), note that the order of input codes for 60° phasing is the reverse of 300°. This means that a P60 suffix part will operate with either convention with a resulting change in rotor direction. The same is true for the P120 part operating between 120° and 240° conventions. Further examination of the 60° and 120° columns reveal that either suffix part will operate with any of the sensor conventions with the addition of an

inverter and the interchanging of S<sub>B</sub> and S<sub>C</sub> inputs as shown in Figure 40.

In this data sheet, the rotor position has always been given in electrical degrees, since the mechanical position is a function of the number of rotating magnetic poles. The relationship between the electrical and mechanical position is:

$$\text{Electrical Degrees} = \text{Mechanical Degrees} \left( \frac{\# \text{Rotor Poles}}{2} \right)$$

An increase in the number of magnetic poles causes more electrical revolutions for a given mechanical revolution. General purpose three phase motors typically contain a four pole rotor which yields two electrical revolutions for one mechanical.

FIGURE 39(a) — SENSOR PHASING COMPARISON

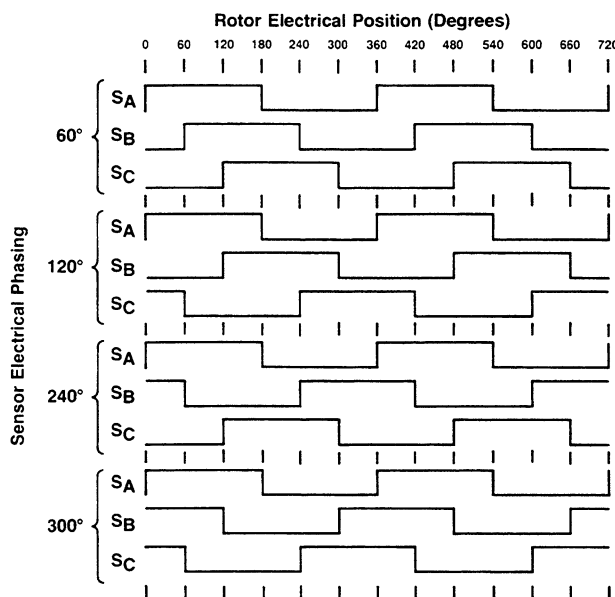
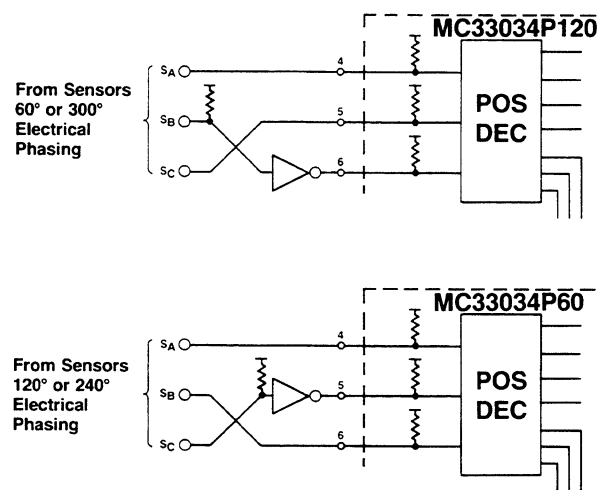


FIGURE 39(b) — SENSOR PHASING TABLE

Sensor Electrical Phasing (Degrees)											
60°			120°			240°			300°		
S <sub>A</sub>	S <sub>B</sub>	S <sub>C</sub>	S <sub>A</sub>	S <sub>B</sub>	S <sub>C</sub>	S <sub>A</sub>	S <sub>B</sub>	S <sub>C</sub>	S <sub>A</sub>	S <sub>B</sub>	S <sub>C</sub>
1	0	0	1	0	1	1	1	0	1	1	1
1	1	0	1	0	0	1	0	0	1	1	0
1	1	1	1	1	0	1	0	1	1	0	0
0	1	1	0	1	0	0	0	1	0	0	0
0	0	1	0	1	1	0	1	1	0	0	1
0	0	0	0	0	1	0	1	0	0	1	1

FIGURE 40 — SENSOR PHASING CONVERSION



## Two and Four Phase Motor Commutation

The MC33034P60 is also capable of providing a four step output that can be used to drive two or four phase motors. The truth table in Figure 41 shows that by connecting sensor inputs  $S_B$  and  $S_C$  together, it is possible to truncate the number of drive output states from six to four. The output power switches are connected to  $B_T$ ,  $C_T$ ,  $B_B$ , and  $C_B$ . Figure 42 shows a four phase, four step, full wave motor control application. Power switch transistors Q1 through Q8 are Darlington type, each

with an internal parasitic catch diode. With four step drive, only two rotor position sensors spaced at 90 electrical degrees are required. The commutation waveforms are shown in Figure 43. Note that speed control cannot be accomplished with this circuit, since pulse width modulation does not appear at the top drive outputs.

Figure 44 shows a four phase, four step, half wave motor controller. It has the same features as the circuit in Figure 38, except for the deletion of braking.

FIGURE 41 — TWO AND FOUR PHASE, FOUR STEP, COMMUTATION TRUTH TABLE

MC33034P60						
Inputs			Outputs			
Sensor Electrical Spacing = 90°			Top Drives		Bottom Drives	
$S_A$	$S_B$	F/R	$B_T$	$C_T$	$B_B$	$C_B$
1	0	1	1	1	0	1
1	1	1	0	1	0	0
0	1	1	1	0	0	0
0	0	1	1	1	1	0
1	0	0	1	0	0	0
1	1	0	1	1	1	0
0	1	0	1	1	0	1
0	0	0	0	1	0	0

$S_B$  connected to  $S_C$

FIGURE 42 — FOUR PHASE, FOUR STEP, FULL WAVE MOTOR CONTROLLER

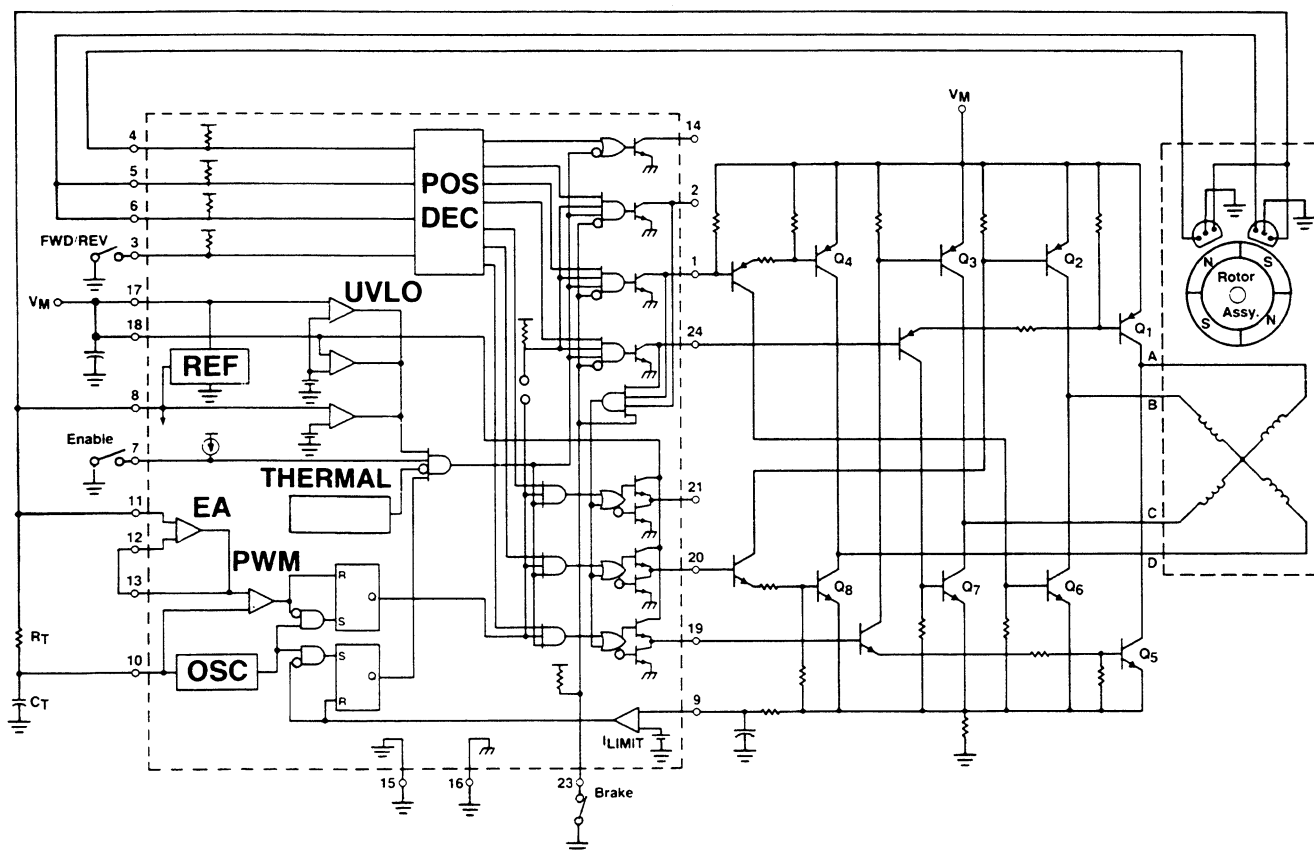
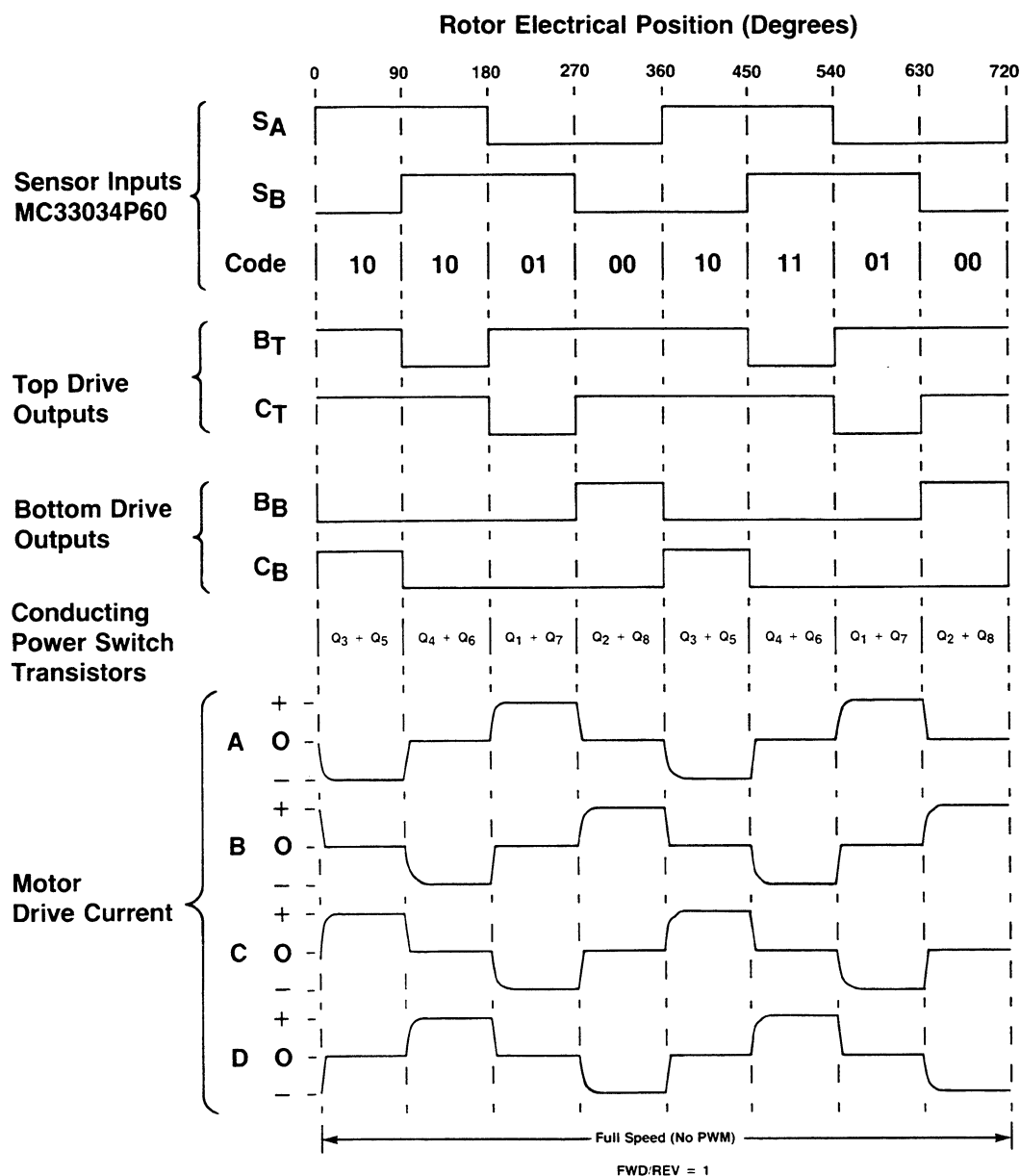


FIGURE 43 — FOUR PHASE, FOUR STEP, FULL WAVE COMMUTATION WAVEFORMS

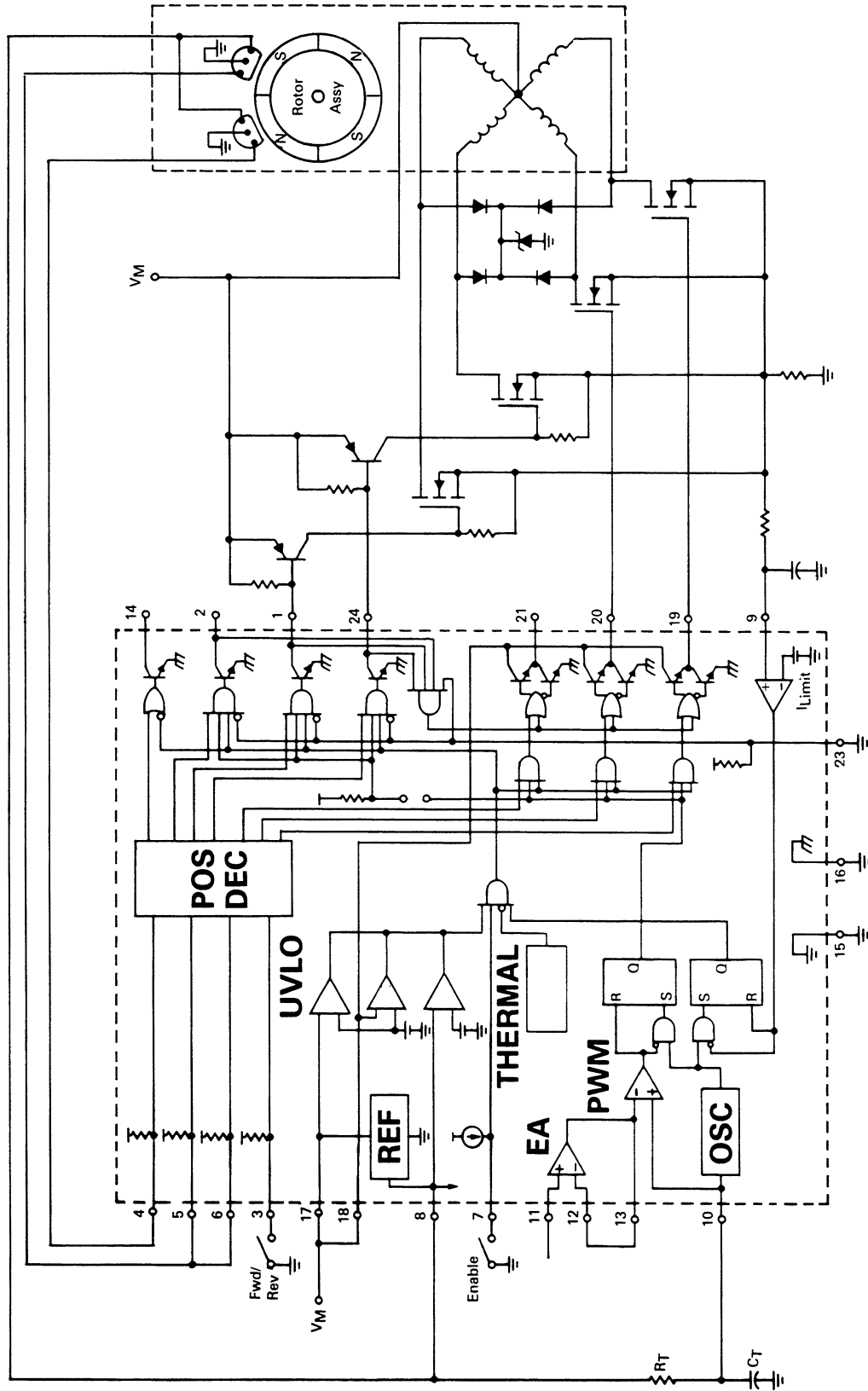


## LAYOUT CONSIDERATIONS

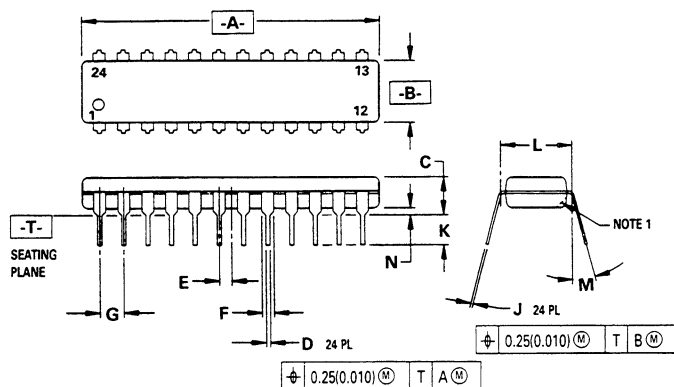
Do not attempt to construct any of the brushless motor control circuits on wire-wrap or plug-in prototype boards. High frequency printed circuit layout techniques are imperative to prevent pulse jitter. This is usually caused by excessive noise pick-up imposed on the current sense or error amp inputs. The printed circuit layout should contain a ground plane with low current signal and high current drive and output buffer grounds

returning on separate paths back to the power supply input filter capacitor  $V_M$ . Ceramic bypass capacitors (0.1  $\mu$ F) connected close to the integrated circuit at  $V_{CC}$ ,  $V_C$ ,  $V_{ref}$  and the error amp non-inverting input may be required depending upon circuit layout. This provides a low impedance path for filtering any high frequency noise. All high current loops should be kept as short as possible using heavy copper runs to minimize radiated EMI.

FIGURE 44 — FOUR PHASE, FOUR STEP, HALF WAVE MOTOR CONTROLLER



## OUTLINE DIMENSIONS

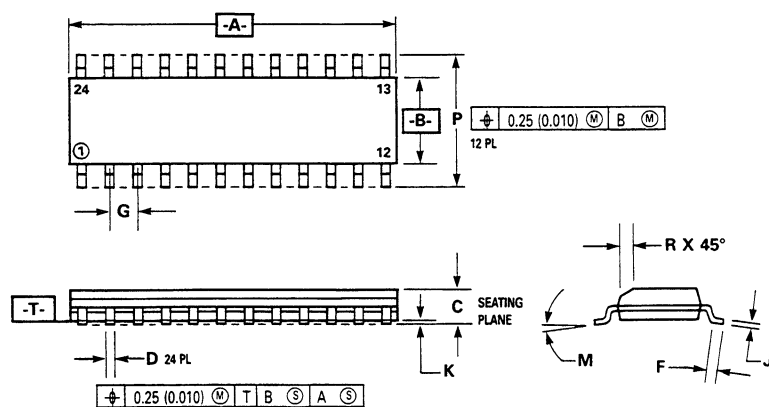


**P SUFFIX**  
PLASTIC PACKAGE  
CASE 724-03

### NOTES:

1. CHAMFERED CONTOUR OPTIONAL.
2. DIM "L" TO CENTER OF LEADS WHEN FORMED PARALLEL.
3. DIMENSIONS AND TOLERANCES PER ANSI Y14.5M, 1982.
4. CONTROLLING DIMENSION: INCH.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	31.25	32.13	1.230	1.265
B	6.35	6.85	0.250	0.270
C	3.69	4.44	0.145	0.175
D	0.38	0.51	0.015	0.020
E	1.27 BSC		0.050 BSC	
F	1.02	1.52	0.040	0.060
G	2.54 BSC		0.100 BSC	
J	0.18	0.30	0.007	0.012
K	2.80	3.55	0.110	0.140
L	7.62 BSC		0.300 BSC	
M	0°	15°	0°	15°
N	0.51	1.01	0.020	0.040



**DW SUFFIX**  
PLASTIC PACKAGE  
CASE 751E-03  
(SO-24L)

### NOTES:

1. DIMENSIONS A AND B ARE DATUMS AND T IS A DATUM SURFACE.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
3. CONTROLLING DIMENSION: MILLIMETER.
4. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
5. MAXIMUM MOLD PROTRUSION 0.15 (0.006) PER SIDE.


DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	15.25	15.54	0.601	0.612
B	7.40	7.60	0.292	0.299
C	2.35	2.65	0.093	0.104
D	0.35	0.49	0.014	0.019
F	0.41	0.90	0.016	0.035
G	1.27 BSC		0.050 BSC	
J	0.229	0.317	0.0090	0.0125
K	0.127	0.292	0.0050	0.0115
M	0°	8°	0°	8°
P	10.05	10.55	0.395	0.415
R	0.25	0.75	0.010	0.029

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