Micro Linear

February 1996
PRELIMINARY

ML4425/ML4426

Sensorless BLDC PWM Motor Controller

GENERAL DESCRIPTION

The ML4425/ML4426 PWM motor controllers provide all of the functions necessary for starting and controlling the speed of delta or wye wound Brushless DC Motors (BLDC) without Hall Effect Sensors.

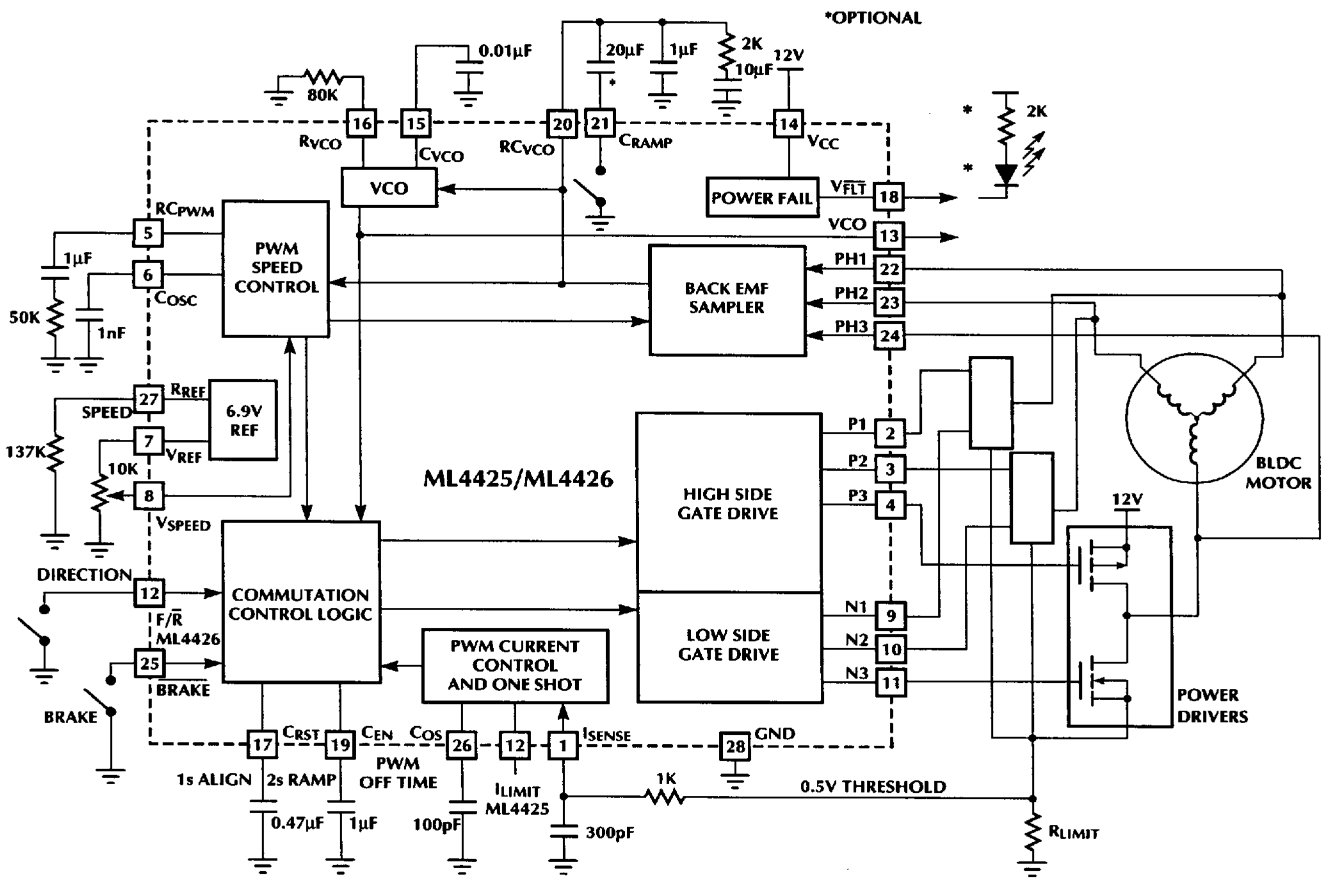
Back EMF voltage is sensed from the motor windings to determine the proper commutation phase sequence using PLL techniques. The patented Back-EMF sensing technique used will commutate virtually any 3-Phase BLDC motor and is insensitive to PWM noise and motor snubbing circuitry.

The ML4425/ML4426 limits the motor current with a constant off-time PWM controlled current. The velocity loop is controlled with an on-board amplifier. An accurate, jitter-free, VCO output is provided equal to the commutation frequency of the motor. The ML4425/ML4426 switches the gates of external N-channel power MOSFETs to regulate the motor current and directly drives

FEATURES

- Stand-alone operation
- Forward and reverse operation: ML4426
- Current limit input: ML4425
- Motor starts and stops with power to IC
- On-board start sequence: Align → Ramp → Set Speed
- Patented Back-EMF commutation technique provides jitterless torque for minimum "spin-up" time
- Simple variable speed control
- On-board voltage reference: 6.9V
- Single external resistor sets all critical currents
- On-board speed control loop

BLOCK DIAGRAM/TYPICAL APPLICATION



GENERAL DESCRIPTION (Continued)

the P-channel MOSFETs for 12V motors. Higher voltage motors are driven using buffer transistors or standard "High side" drivers.

The ML4425/ML4426 has a blanker circuit to prevent false retriggering of the one shot during a motor current spike and circuitry to ensure that there is no shoot through in any state of the power drive FETs.

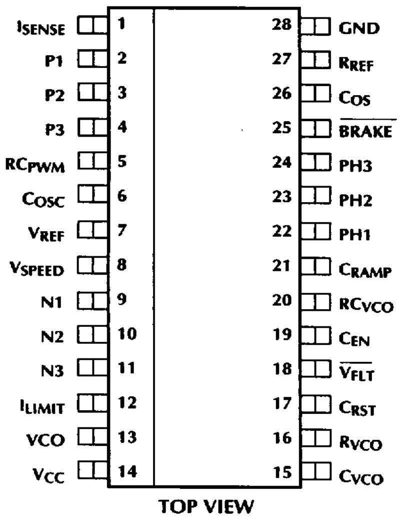
The timing of the start-up sequence is determined with one current setting resistor and two timing capacitors thus allowing for simple optimization for a wide range of motors and loads.

FEATURES (Continued)

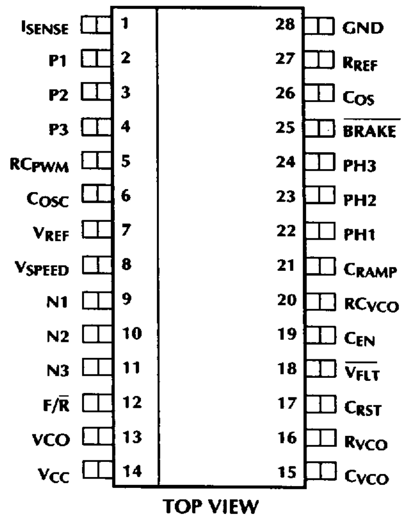
- PLL used for commutation provides noise immunity from PWM spikes, compared to noise sensitive zero crossing technique
- PWM control for maximum efficiency
- Under-voltage fault output
- 12 volt operation
- Direct FET drive for 12V motors
- Drives high voltage motors with IC buffers from IR, IXYS, Harris, Power Integration, Holt, Siliconix, etc.
- Industrial temperature range –40°C to +85°C is available
- Available in 28-pin DIP and SOIC packages

PIN CONFIGURATION

ML4425
28-Pin SOIC (S28)
28-Pin Molded Narrow DIP (P28N)
28-Pin CERDIP (J28)



ML4426
28-Pin SOIC (S28)
28-Pin Molded Narrow DIP (P28N)
28-Pin CERDIP (J28)



PIN DESCRIPTION

PIN#	NAME	FUNCTION
1	I_{SENSE}	Motor current sense input. I_{LIMIT} occurs when this pin is approximately 0.5V.
2	P1	Drives the external P-channel transistor driving motor PH1.
3	P2	Drives the external P-channel transistor driving motor PH2.
4	P3	Drives the external P-channel transistor driving motor PH3.
5	RC_{PWM}	The resistor/capacitor combination on this gm amplifier sets the pole-zero of the speed loop in conjunction with a gm of 0.385mmho.
6	C_{OSC}	This capacitor sets the PWM oscillator frequency. A 1nF capacitor will set the frequency to approximately 25KHz.
7	V_{REF}	This voltage reference output can be used to set the speed reference voltage.
8	V_{SPEED}	This input to the amplifier in the speed loop controls the speed target of the motor.
9-11	N1, N2, N3	Drives the external N-channel MOSFETs for PH1, PH2, PH3.
12	$F/\overline{R}$	For the ML4426, the forward/reverse pin controls the sequence of the commutation states and thus the direction of motor rotation.
12	I_{LIMIT}	For the ML4425, this pin is internally set to 2.5V which sets the I_{SENSE} threshold to 0.5V. This voltage can be lowered externally to reduce the I_{SENSE} threshold.
13	VCO	This logic output indicates the commutation frequency of the motor.
14	V_{CC}	12V power supply.

PIN#	NAME	FUNCTION
15	C_{VCO}	Timing capacitor for VCO
16	R_{VCO}	The resistor on this pin sets a process independent current to generate a repeatable VCO frequency.
17	C_{RST}	A 0.75µA current from this pin will charge a capacitor to 1.5V. This is the time the device will remain in reset mode. Connecting this pin to ground forces the chip to the reset state.
18	V_{FT}	A logic "0" indicates the power supply is under-voltage. A logic "1" is > 3.5V.
19	$\overline{C_{EN}}$	After C_{RST} has timed out a 0.75µA current from this pin will charge a capacitor to 1.5V. This is the time the device will remain in the ramp mode.
20	RC_{VCO}	VCO loop filter components. A 0.5µA current from this pin will ramp the VCO after C_{RST} has timed out.
21	C_{RAMP}	This capacitor can be used if necessary to reduce the ramp speed to enhance start-up in high RPM applications. It is logic low until C_{EN} times out.
22	PH1	Motor Terminal 1
23	PH2	Motor Terminal 2
24	PH3	Motor Terminal 3
25	$\overline{BRAKE}$	A "0" activates the braking circuit
26	C_{OS}	A 30µA current from this pin will charge a timing capacitor to GND for fixed off-time PWM current control
27	R_{REF}	This resistor sets constant currents on the device to reduce process dependence and external components. The 137K resistor sets the previously mentioned current levels.
28	GND	Signal and Power Ground

ABSOLUTE MAXIMUM RATINGS

Absolute maximum ratings are those values beyond which the device could be permanently damaged. Absolute maximum ratings are stress ratings only and functional device operation is not implied.

Supply Voltage (pin 14) 14V
Output Current (pins 2, 3, 4, 9,10,11) .... ±50mA
Logic Inputs (pins 17, 19, 25) .... –0.3 to 7V
Junction Temperature .... 150°C
Storage Temperature Range .... –65°C to 150°C
Lead Temperature (Soldering 10 sec.) .... 150°C
Thermal Resistance (θ_{JA}) .... 60°C/W

OPERATING CONDITIONS

Temperature Range
ML4425CS/ML4426CS/
ML4425CP/ML4426CP .... 0°C to 70°C
ML4425IJ/ML4426IJ
ML4425IS/ML4426IS/
ML4425IP/ML4426IP .... –40°C to 85°C
ML4425MJ/ML4426MJ .... –55°C to 125°C
VCC Voltage +12V (pin 14) .... 12V ± 10%

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, T_A = Operating Temperature Range, V_{CC} = 12V ± 10%, R_{SENSE} = 1Ω, C_{VCO} = 0.01µF, C_{OS} = 100pF, R_{REF} = 137kΩ (Note 1)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Oscillator (VCO) Section (V_{PIN16} = 5V)						
Frequency vs. $V_{PIN\ 20}$	0.5V ≤ V_{PIN20} ≤ 7V			300		Hz/V
Frequency	V_{VCO} = 6V		1500	1850	2200	Hz
Sampling Amplifier (Note 2)						
V_{RC}	State R			125	250	mV
I_{RC}	Ramp	C Suffix	0.50		0.72	µA
		I/M Suffix	0.50		0.75	µA
	V_{PIN19} = 5V, State A, V_{PH2} = VCC/3	C Suffix	30		90	µA
		I/M Suffix	27		90	µA
	V_{PIN19} = 5V, State A, V_{PH2} = VCC/2		–15		15	µA
	V_{PIN19} = 5V, State A, V_{PH2} = 2VCC/3	C Suffix	–90		–30	µA
		I/M Suffix	–90		–27	µA
Motor Current Control Section						
I(SENSE) Gain	V_{PIN12} ≤ 2.5V		4.5	5.0	5.5	V/V
One Shot Off Time		C Suffix	9		18	µs
		I/M Suffix	9		20	µs
Power Fail Detection Circuit						
12V Threshold		C Suffix	8.8	9.5	10.2	V
		I/M Suffix	8.6		10.3	V
Hysteresis				150		mV
Logic Inputs						
Voltage High (V_{IH})			2			V
Voltage Low (V_{IL})					0.8	V
Current High (I_{IH})	V_{IN} = 2.7V		–300		300	µA
Current Low (I_{IL})	V_{IN} = 0.4V		–150		150	µA
Braking Circuit						
Current Low (I_{IL}) (Note 3)	V_{PIN25} = 0V			1.1		mA

ELECTRICAL CHARACTERISTICS (Continued)

PARAMETER		CONDITIONS		MIN	TYP	MAX	UNITS
Outputs							
I_P Low	ML4425	$V_P = 2V$		0.5		1.2	mA
	ML4426	$V_P = 2V$		4		7	mA
V_P High		$I_P = -10\mu A$		$V_{CC} - 1.3$			V
P3 Comparator Threshold					$V_{CC} - 3.0$		V
V_N High		$V_{PIN12} = 0V$	C Suffix	$V_{CC} - 2.2$		$V_{CC} - 0.8$	V
			I/M Suffix	$V_{CC} - 2.9$		$V_{CC} - 0.5$	V
V_N Low		$I_N = 1mA$			0.2	0.7	V
LOGIC Low (V_{OL}) ($\overline{V_{FLT}}$, VCO)		$I_{OUT} = 0.4mA$				0.6	V
VCO/$\overline{V_{OH}}$		$I_{OUT} = -100\mu A$		2.2			V
POWER FAIL V_{OH} ($\overline{V_{FLT}}$) (Note 3)		$I_{OUT} = -10\mu A$	C Suffix	3.4	4.5	5.4	V
			I/M Suffix	3.2		5.6	V
Speed Control							
FPWM (Pin 6)		$C_{OSC} = 1nF$			28		kHz
gm Current (Pin 5)				±5		±20	µA
V_{REF}				6.5		7.5	V
Start-Up							
I_{CRST}			C Suffix	0.68		0.98	µA
			I/M Suffix	0.5		1.1	µA
V_{TH} C_{RST}				1.4		1.7	V
I_{CEN}				0.68		0.98	µA
V_{TH} C_{EN}				1.4		1.7	V
Supply Current							
VCC Current					32	50	mA

Note 1: Limits are guaranteed by 100% testing, sampling, or correlation with worst case test conditions.
Note 2: For explanation of states, see Figure 5 and Table 1.
Note 3: The $\overline{BRAKE}$ (pin 25) and $\overline{V_{FLT}}$ (pin 18) each have an internal 4kΩ resistor to a 4.5V internal reference. The range of this internal reference is specified in the POWER FAIL V_{OH} tests with the lower value occurring at high temperatures and the higher value occurring at low temperatures.

FUNCTIONAL DESCRIPTION

The ML4425/ML4426 provides closed-loop commutation for 3-phase brushless motors. To accomplish this task, a VCO, integrating Back-EMF Sampling error amplifier and sequencer form a phase-locked loop, locking the VCO to the back-EMF of the motor. The IC also contains circuitry to control motor speed in PWM mode. Braking and power fail detection functions are also provided on chip. The ML4425/ML4426 is designed to drive external power transistors (N-channel sinking transistors and P-channel sourcing transistors) directly.

Start-up timing sequence is accomplished by means of 2 timing capacitors charged by currents sources on the device. C_{RST} determines the time the motor stays in align mode and C_{EN} determines the time the motor will ramp before the speed set loop closes. Once the speed loop closes the N-channels are in a PWM mode to control the motor current. The voltage set on V_{SPEED} will force the same voltage on RC_{VCO} to control speed.

Speed sensing is accomplished by monitoring the output of the VCO, which will be a signal which is phased-locked to the commutation frequency of the motor.

BACK-EMF SENSING AND COMMUTATOR

The ML4425/ML4426 contains a patented back-EMF sensing circuit which samples the phase which is not energized (Shaded area in figure 2) to determine whether to increase or decrease the commutator (VCO) frequency. A late commutation causes the error amplifier to charge the filter (RC) on pin 20, increasing the VCO input while early commutation causes pin 20 discharge. The analog speed control loop uses pin 20 as a speed feedback voltage.

The input impedance of the three PH inputs is about 8kΩ to GND. When operating with a higher voltage motor, the PH inputs should be divided down in voltage so that the maximum voltage at any PH input does not exceed V_{CC}.

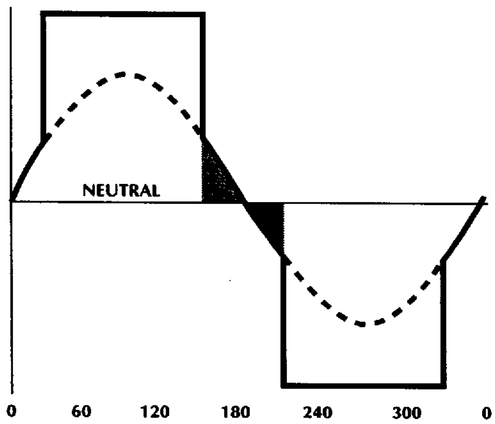


Figure 2. Typical Motor Phase Waveform with Back-EMF Superimposed (Ideal Commutation).

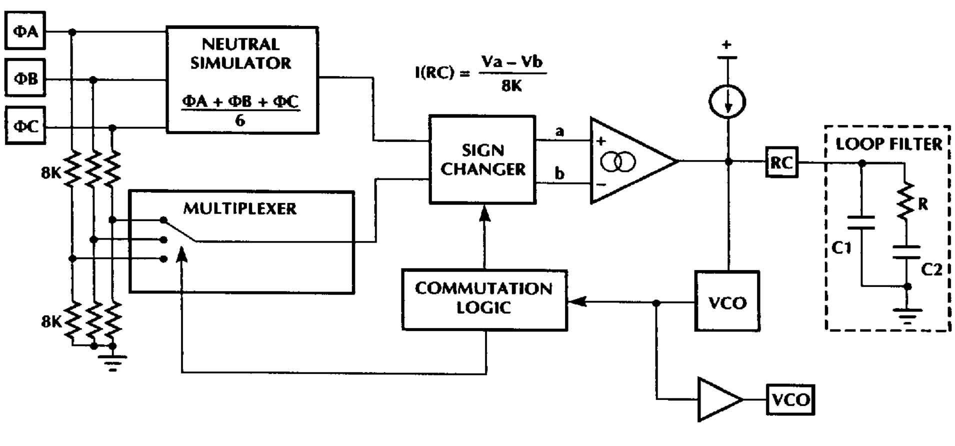


Figure 1. Back EMF Sensing Block Diagram

COMPONENT SELECTION GUIDE

In order to properly select the critical components for the ML4425/ML4426 you should know the following things:

1. The motor operating voltage.
2. The maximum operating current for the motor.
3. The number of poles the motor has.
4. The back EMF constant of the motor.
5. The torque constant of the motor. (This is the same as the back EMF constant, only in different units.)
6. The desired speed of operation.
7. The moment of inertia of the motor and its load.
8. The coefficient of viscous friction.

If you do not know one or more of the above values, it is still possible to pick components for the ML4425/ML4426, but some experimentation may be necessary to determine the optimal value. All quantities are in SI units unless other wise specified. The formulas in the following section are based on linear system models. Since Coulomb friction is not a linear phenomenon, large amounts of friction in a system may require values different from those given below. The following formulas should be considered a starting point from which you can optimize your application.

R_{SENSE}

The function of R_{SENSE} is to provide a voltage proportional to the motor current, for current limit/feedback purposes. The trip voltage across R_{SENSE} is 0.5V so:

$$R_{SENSE} = \frac{0.5}{I_{MAX}}$$

I_{MAX} is the maximum motor current.

The power dissipation is obviously I_{MAX} squared times R_{SENSE}, so the resistor should be sized appropriately. For very high current motors, a smaller resistor can be used, with an op-amp to increase the gain, so that power dissipation in the sense resistor is minimized.

In the ML4425, the trip voltage across R_{SENSE} can be modified with a voltage applied to the I_{LIMIT} pin, pin 12. There is a gain of 5 in the I_{SENSE} path so that 2.5V on pin 12 corresponds to a 0.5V trip voltage across R_{SENSE}. Z_{IN} on the I_{LIMIT} pin is ≈ 6KΩ.

I_{SENSE} FILTER

The I_{SENSE} filter consists of an RC lowpass filter in series with the current sense signal. The purpose of this filter is to filter out noise spikes on the current, which may cause false triggering of the one shot circuit. It is important that this filter not slow down the current feedback loop, or destruction of the output stage may result. The recommended values for this circuit are R = 1KΩ and C= 300pF. This gives a time constant of 300ns, and will filter out spikes of shorter duration. These values should suffice for most applications. If excessive noise is present on the I_{SENSE} pin, the capacitor may be increased at the expense of speed of current loop response. The filter time constant should not exceed 500ns or it will have a significant impact on the response speed of the one shot current limit.

C_{OS}

The one shot capacitor determines the off time after the current limit is activated, i.e. the voltage on the I_{SENSE} pin exceeded 0.5V. The following formula ensures that the motor current is stable in current limit:

$$C_{OS} = \frac{1.11\times10^{-6}\times V_{MOTOR} - 5\times10^{-6}}{947.4}$$

C_{OS} is in Farads

This is the maximum value that C_{OS} should be. Higher average torque during the current limit cycle can be achieved by reducing this value experimentally, while monitoring the motor current carefully, to be sure that a runaway condition does not occur. This runaway condition occurs when the current gained during the on time exceeds the current lost during the off time, causing the motor current to increase until damage occurs. For most motors this will not occur, as it is usually a self limiting phenomenon.

C_{VCO}

As given in the section on the VCO and phase detector:

$$C_{VCO} = \frac{315\times10^{-6}}{N\times RPM}$$

Where N is the number of poles in the motor, and RPM is the motor's maximum operating speed in revolutions per minute.

RESET CAPACITOR

The function of the reset capacitor is to provide a time delay, during which the ML4425/ML4426 will align the rotor to a known position. During this time period the ML4425/ML4426 turns on two of the upper and one of the lower output drivers. This results in a fixed current in the windings, a stationary magnetic field, and a locked rotor. If the position is not at a torque null during the reset period, it will require some time to move to the locked position, and settle. This time period is dependent on the motor, the load, the friction and eddy current losses, and current limit setting. A good starting point for a value for the reset capacitor is:

$$C = \frac{1.5\times10^{-6}}{\delta\times\sqrt{\frac{N\times K\times\tau\times I_{MAX}}{\pi\times J}}}$$

The δ factor is known as the damping factor, and can range from 0.1 in a motor with very little damping to 0.9 in a heavily damped motor. Kτ is the torque constant in N x M/Amp, Imax is the motor current in current limit, and J is the moment of inertia of the motor and the load. If you don't know the damping factor, try a value of 0.3 initially. If you don't know the moment of inertia, start with a 1μF capacitor. In any case, if the motor has come to a full stop well before the ramp up period, you can decrease this value. If the motor does not stop before ramp up, you must increase this value until it does. Motors with very little friction or damping and a large inertial load tend to require larger values of capacitance here.

ENABLE CAPACITOR

This capacitor provides a time delay after the reset period for the motor to ramp up to speed. The following equation gives an approximate starting value for this capacitor. If starting is not reliable, this capacitor may be increased until it is. If starting is reliable and minimum spin up time is important, this value can be decreased experimentally to find the minimum practical value. Motors with a large amount of friction or a large inertia will tend to need larger capacitors.

$$C_{EN} = \frac{55.85 \times N \times (C1 + C2)}{Kv}$$

Where N is the number of poles in the motor, C 1 and C2 are the VCO loop filter components on pin 20, and Kv is the VCO Pain (See the section on the VCO and phase detector.)

RAMP CAPACITOR

The ML4425/ML4426 outputs a fixed 0.5μA current on pin 20 during ramp up. This is the input to the VCO. Therefore, the rotor's acceleration is a function of the current, VCO gain and the loop filter components only. In some cases, where the VCO capacitor is small due to a high running speed, and the motor inertia is large, the rotor may not be able to follow the VCO during ramp up. In these cases, it is necessary to add a capacitor from pin 21 to ground. This capacitor is switched in during ramp only, and allows the rate of acceleration during ramp up to be lowered. An approximate starting point for this capacitor is given by the equation below:

$$C_{RAMP} = \frac{J \times 0.5 \times 10^{-6}}{I_{MAX} \times Kt} \times \frac{Kv \times 2 \times \pi}{3 \times N} - (C1 + C2)$$

Where J is the inertia of the motor plus load, Kv is the VCO gain, N is the number of poles, Imax is the maximum motor current, Kt is the torque constant, and C1 and C2 are the loop filter components on pin 20. Normally, the result of the preceding equation will be a negative number, meaning that no ramp capacitor is necessary. If the result of this equation is greater than zero, then the ramp capacitor should be included.

C_{OSC}

This capacitor sets the PWM ramp oscillator frequency. This is the PWM "switching frequency". If this value is too low, <20kHz, then magnetostriction effects in the motor may cause audible noise. If this frequency is too high, >30kHz, then the switching losses in the output drivers may become a problem. 25kHz should be a good compromise for this value, which can be obtained by using a 1nF capacitor.

R_{VCO} AND R_{REF}

R_{VCO} should be 80K and R_{REF} should be 137K for normal operation.

RC_{PWM}

This pin is the output of a transconductance amplifier. A resistor and a capacitor in series with this pin and connected to ground form the speed loop compensation. The motor will have a mechanical time constant, given approximately by:

$$\tau_m = \frac{J \times Rw}{Ke^2}$$

Where J is the moment of inertia of the rotor plus the load, Rw is the winding resistance, and Ke is the back-E.M.F. constant This pole occurs at a relatively low frequency, and will limit the frequency of response of the servo loop. In order to get better response, the RC combination on the RC_{PWM} pin can be used to provide phase lead for the speed loop. This combination also sets the open loop gain characteristics, and therefore the accuracy of the speed loop. In order to pick components for this loop, it is necessary to decide on a desired closed loop bandwidth. The chosen closed loop bandwidth should be substantially lower than the bandwidth of the phase locked loop used for commutation, in order to preserve acceptable phase margin. This is usually not a problem, as the mechanical time constant of the motor is necessarily much lower than the commutation loop response. Depending on the motor and its load, a bandwidth in the 1-10Hz range is easily achievable. The frequency of the compensating zero should be set to be a decade below the unity gain crossover frequency, so that its contribution to the phase lead will be maximum at the crossover. The following formula gives the value of C necessary for these conditions:

$$CC = 482.314 \times N \times \frac{V_{CC} \times C_{VCO}}{\left[freq.\left[Ke\left(\sqrt{2.5 + 98.696 \times \tau_m{}^2 \times freq.^2}\right)\right]\right]}$$

Where f is the desired unity gain crossover frequency, V_{CC} is the supply voltage, C_{VCO} is the VCO capacitor on pin 15, N is the number of poles in the motor, and the other quantities are defined above. Then, the value of R should be

$$R = \frac{10}{2 \times \pi \times CC \times freq.}$$

If the speed loop is unstable, it is possible that the desired bandwidth is too high, and reducing the value of f should solve the problem.

VCO FILTER

See the section on the VCO and Phase detector for information on these components.

VCO AND PHASE DETECTOR CALCULATIONS

The VCO should be set so that at the maximum frequency of operation (the running speed of the motor) the VCO control voltage will be no higher than V_{REF}, or 6.9V. The VCO maximum frequency will be:

$$F_{MAX} = 0.05 \times POLES \times RPM$$

where POLES is the number of poles on the motor and RPM is the maximum motor speed in Revolutions Per Minute.

The minimum VCO gain derived from the specification table (using the minimum F_{VCO} at V_{VCO} = 6V) is:

$$K_{VCO(MIN)} = \frac{2.42 \times 10^{-6}}{C_{VCO}}$$

Assuming that the $V_{VCO(MAX)}$ = 6.5V, then

$$C_{VCO} = \frac{6.5 \times 2.42 \times 10^{-6}}{F_{MAX}}$$

or

$$C_{VCO} = \frac{315}{POLES \times RPM} \mu F$$

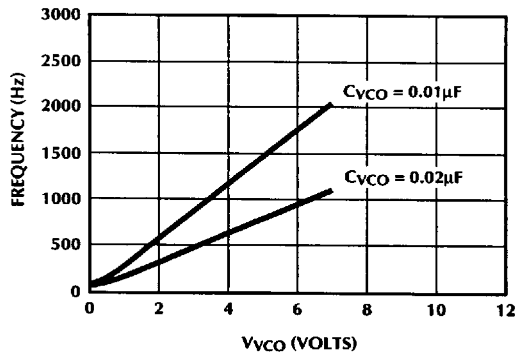


Figure 3. VCO Output Frequency vs. V_{VCO} (Pin 20)

Figure 4 shows the linearized transfer function of the Phase Locked Loop with the phase detector formed from the sampled phase through the Gm amplifier with the loop filtered formed by R, C_1, and C_2. The Phase detector gain is:

$$\frac{Ke \times \omega \times Atten}{2\pi} \times 1.25 \times 10^{-14} A/Radian$$

Where Ke is the motor back-E.M.F. constant in V/Radian/sec, ω is the rotor speed in r/s, and Atten is the back-E.M.F. resistive attenuator, nominally 0.5.

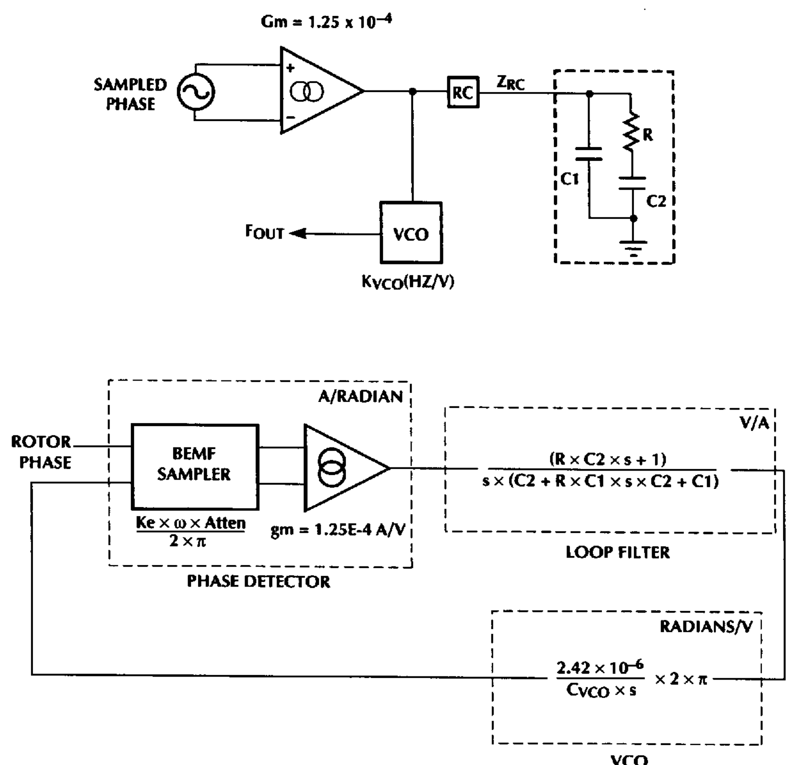


Figure 4. Back-EMF Phase Locked Loop Components.

The simplified impedance of the loop filter is

$$Z_{RC}(s) = \frac{1}{C_1 s} \frac{(s+\omega_{LEAD})}{(s+\omega_{LAG})}$$

Where the lead and lag frequencies are set by:

$$\omega_{LEAD} = \frac{1}{RC_2}$$

$$\omega_{LAG} = \frac{C_1 + C_2}{RC_1C_2}$$

Requiring the loop to settle in 20 PLL cycles with $\omega_{LAG} = 10 \times \omega_{LEAD}$ produces the following calculations for R, C_1 and C_2:

$$C_1 \approx \frac{4.07 \times 10^{-11} \times K_e \times RPM}{C_{VCO} \times F_{VCO}^2}$$

$$C_2 = 9 \times C_1$$

$$R = \frac{9.02}{C_2 \times F_{VCO}}$$

where K_e is the back-EMF constant in volts per radian per second, and RPM is the rotor speed. See Micro Linear application note 35 for derivation of the above formulas.

START-UP SEQUENCING

When the motor is initially at rest, it is generating no back-EMF. Because a back-EMF signal is required for closed loop commutation, the motor must be started "open-loop" until a velocity sufficient to generate some back-EMF is attained (around 100 RPM). The following steps are a typical procedure for starting a motor which is at rest.

Align: The IC is held in reset (state R) with full power applied to the windings (see figure 6). This aligns the rotor to a position which is 30° (electrical) before the center of the first commutation state. This time is

$$t = \frac{(1.5V)\ C_{RST}}{0.75\mu A}$$

Ramp: Align is released, and a fixed 0.5µA current is input to pin 20, and will ramp the VCO input voltage, accelerating the motor at a fixed rate. This time is

$$t = \frac{(1.5V)\ C_{EN}}{0.75\mu A}$$

Run: When the motor speed reaches about 100 RPM, the back-EMF loop can be used in closed loop speed control and the voltage on the RC_{VCO} pin will ramp to the same voltage applied to V_{SPEED}. This allows speed selection referring to figure 3.

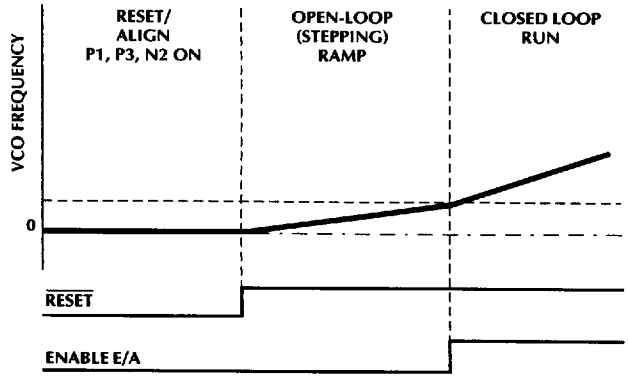


Figure 6. Typical Start-up Sequence.

Using this technique, some reverse rotation is possible. The maximum amount of reverse rotation is 360/N, where N is the number of poles. For an 8 pole motor, 45° reverse rotation is possible.

MODE	PIN 17	PIN 19	I_{LIMIT}
Align	0	0	I_{MAX}
Ramp	1	0	I_{MAX}
Run	1	1	I_{MAX}

Table 2. Start-up Sequence.

ALIGN: The IC is held in reset (state R).

RAMP: After the reset pin has reached 1.5V the C_{EN} pin begins to charge. During this time the RC_{VCO} components are charged with 0.5µA and the VCO begins to ramp up in frequency. This continues until the C_{EN} pin reaches 1.5V and times out. The motor must be able to keep up with the VCO ramp rate.

RUN: After C_{EN} has timed out the device begins closed loop operation using the BEMF of the motor.

DIRECTION: The direction of motor rotation is controlled by the commutation states as given in Table 1. The state sequence is controlled by the $F/\overline{R}$ (pin 12).

STATE	DIRECTION	OUTPUTS						INPUT SAMPLES	
	REVERSE	N3	N2	N1	P3	P2	P1		
	FORWARD	N1	N2	N3	P1	P2	P3	FORWARD	REVERSE
R OR 0		OFF	ON	OFF	ON	OFF	ON	N/A	N/A
A		OFF	OFF	ON	ON	OFF	OFF	PH2	PH2
B		OFF	OFF	ON	OFF	ON	OFF	PH1	PH3
C		ON	OFF	OFF	OFF	ON	OFF	PH3	PH1
D		ON	OFF	OFF	OFF	OFF	ON	PH2	PH2
E		OFF	ON	OFF	OFF	OFF	ON	PH1	PH3
F		OFF	ON	OFF	ON	OFF	OFF	PH3	PH1

Table 1. Commutation States.

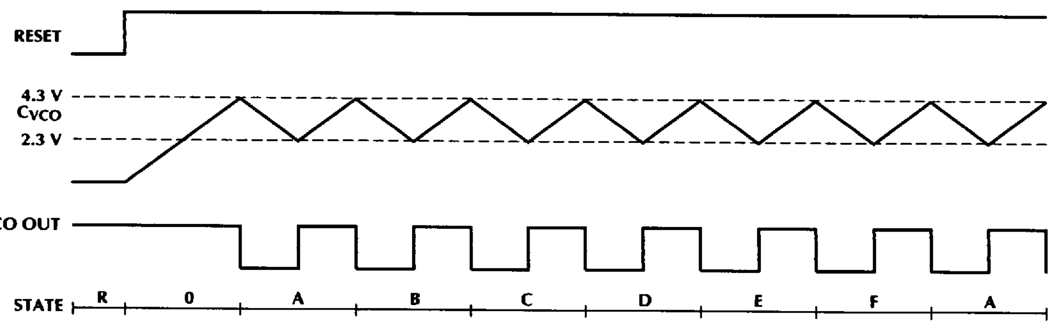


Figure 5. Commutation Timing and Sequencing.

ADJUSTING OPEN LOOP STEP RATE (RAMP)

Align

Motor alignment occurs when power is first applied and C_{RST} (pin 17) and C_{EN} (pin 19) are low. The device will stay in the align mode until the 0.75µA current out of C_{RST} charges the external capacitor to 1.5V at which time ramp mode is enabled.

During align P-channels P1 and P3 will be driven on and N-channel N2 will be on to provide high torque to position rotor on pole.

Motor loads with larger inertia will require longer alignment periods or larger values of C_{RST} for possibly higher currents (I_{LIMIT}).

Maximum current limit can be set by the R_{LIMIT} from the I_{SENSE} pin (1). The threshold on this pin is approximately 0.5V thus

$$I_{LIMIT} = \frac{0.5V}{R_{LIMIT}}$$

I_{LIMIT} is also under PWM control with t_{OFF} set by a capacitor connected to C_{OS} (pin 26) and given by

$$t_{OFF} = C_{OS}\frac{2.5V}{25\mu A}$$

Ramp

Motor ramping begins when C_{RST} has exceeded 1.5V at which time the capacitor connected to C_{EN} (pin 19) which had been held at ground will begin to charge with 0.75µA from the pin. When C_{EN} reaches 1.5V the device will enter run mode.

During ramp mode a 0.5µA current from the RC_{VCO} pin (20) will charge the filter components and begin to ramp the VCO frequency and begin commutating states A through F of the motor in an open loop fashion. C_{RAMP} is shorted to ground during ramp allowing additional flexibility in starting high speed motors.

C_{RAMP} should be set so that the VCO's frequency ramp during "open loop stepping" phase of motor starting is less than the motor's acceleration rate. In other words, the motor must be able to keep up with the VCO's ramp rate in open loop stepping mode. The VCO's input voltage ($V_{PIN\ 20}$) ramp rate is given by:

$$\frac{dV_{VCO}}{dt} \approx \frac{0.5\mu A}{C_1 + C_2 + C_{RAMP}}$$

since

$$F_{VCO} = K_{VCO} \times V_{VCO}$$

$$K_{VCO(MAX)} = \frac{4 \times 10^{-6}}{C_{VCO}}$$

then combining the 3 equations C_{RAMP} can be calculated from the desired maximum open loop stepping rate the motor can follow.

$$0.5\mu A < \frac{dF_{VCO}}{dt}\frac{C_{VCO} \times (C_1 + C_2 + C_{RAMP})}{4 \times 10^{-6}}$$

The motor will start more consistently and tolerate a wider variation in open loop step rate if there is some damping on the motor during the open loop modes.

The tolerance of the open loop step VCO acceleration $\left(\frac{dF_{VCO}}{dt}\right)$ depends on the tolerances of K_{VCO}, C_{RAMP}, C_1, C_2, and C_{VCO}.

Larger motors and loads will require longer ramp periods or larger values of C_{EN}.

Run

When the C_{EN} pin exceeds 1.5V the device will enter run mode. At this time the motor speed should be high enough to generate a detectable BEMF and allow closed loop operation to begin. The commutation position compensation has been previously discussed.

The motor will continue to accelerate as long as the voltage on the RC_{VCO} pin (20) is less than the voltage on V_{SPEED} (pin 8). During this time the motor will receive full N-channel drive limited only by I_{LIMIT}. As the voltage on pin 20 approaches that of pin 8 the C_{PWM} capacitor will charge and begin to control the gate drive to the N-channel transistor by setting a level for comparison on the 25kHz PWM saw tooth waveform generated on C_{OSC} (pin 6). The compensation of the speed loop is accomplished on C_{PWM} (pin 5) which is the output of a transconductance amplifier with a gm = 3.85×10^{-4}℧.

OUTPUT DRIVERS

The P-channel drivers are emitter follower type with 5mA pull down currents. This allows for fast turn off to prevent cross conduction. The N-channel drivers are totem pole with a 750Ω resistor in series with the pull up device again reducing cross conduction.

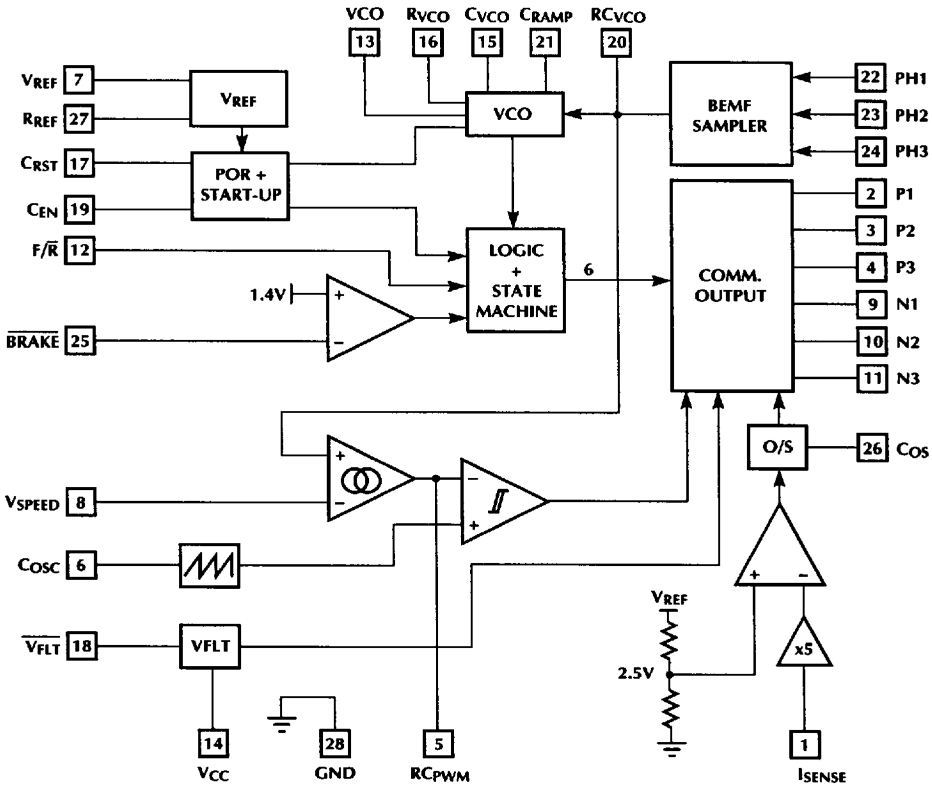


Figure 8. Block Diagram.

BRAKING

When $\overline{BRAKE}$ pin (25) is pulled low all 3 P-channel drivers will be turned off and all 3 N-channel drivers will be turned on.

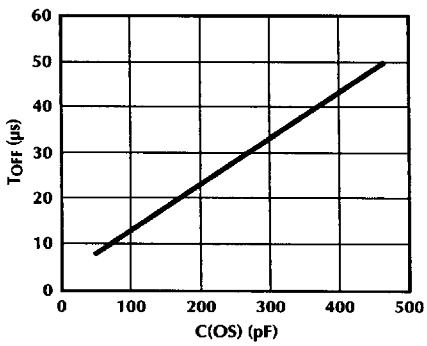


Figure 7. I_{LIMIT} **Output Off-Time vs.** C_{OS}**.**

HIGHER VOLTAGE MOTOR DRIVE

The ML4425/ML4426 can be used to drive higher voltage motors by means of level shifters to the high side drive transistors. This can be accomplished by using dedicated high side drivers for applications greater than 60V or a simple NPN level shift as shown in figure 9 for applications below 60V. Figure 10 shows how to interface to the IR2110, a 3-phase bridge driver from I.R. This allows driving motors up to 600V. If the reset phase is short, the $\overline{BRAKE}$ pin can be pulsed prior to startup with an RC circuit. This charges the bootstrap capacitors for three inexpensive high side drivers, allowing the reset phase to operate normally. This is shown in Figure 11.

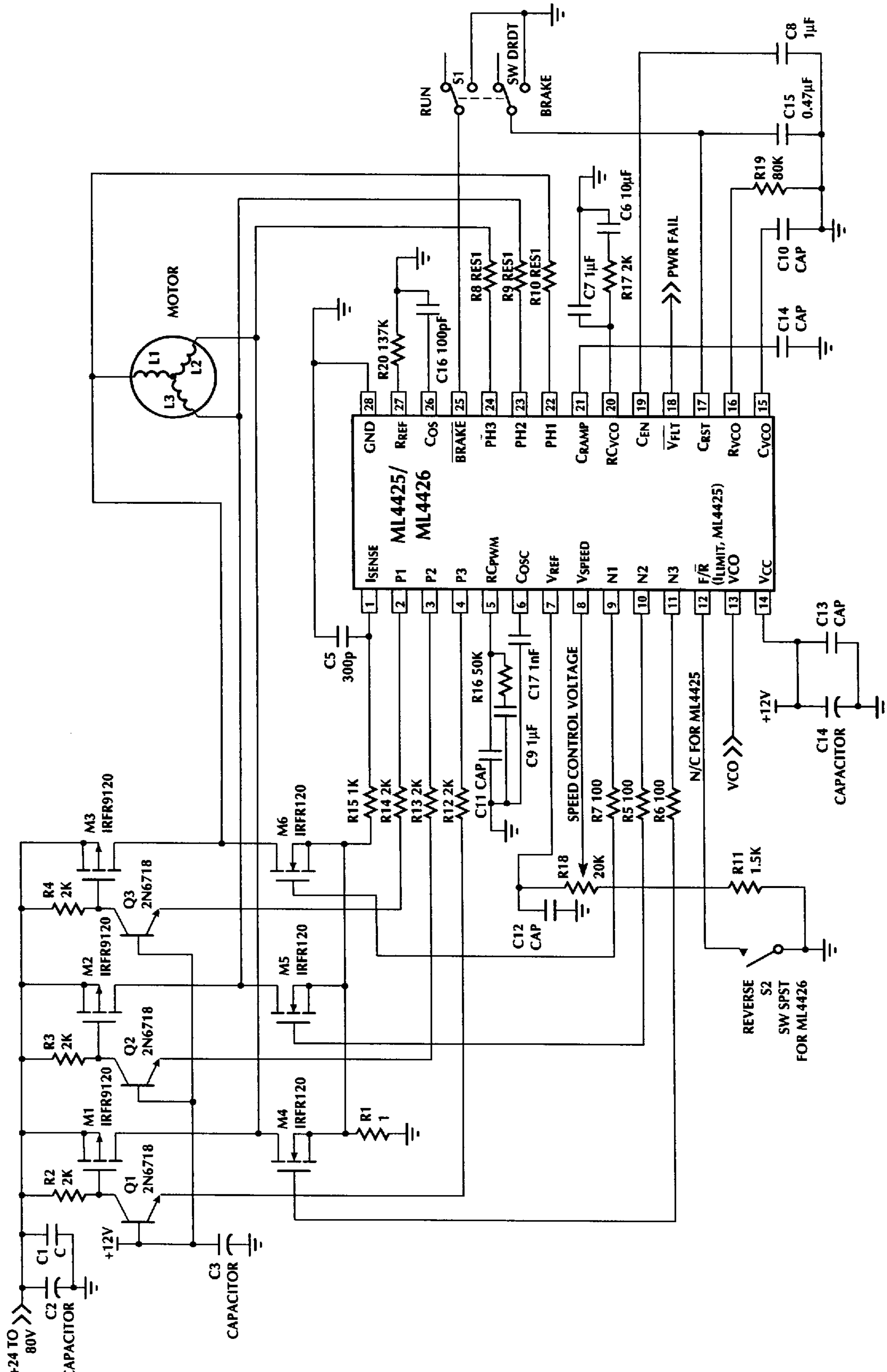


Figure 9. Driving Higher Voltage Motors: 24V to 80V.

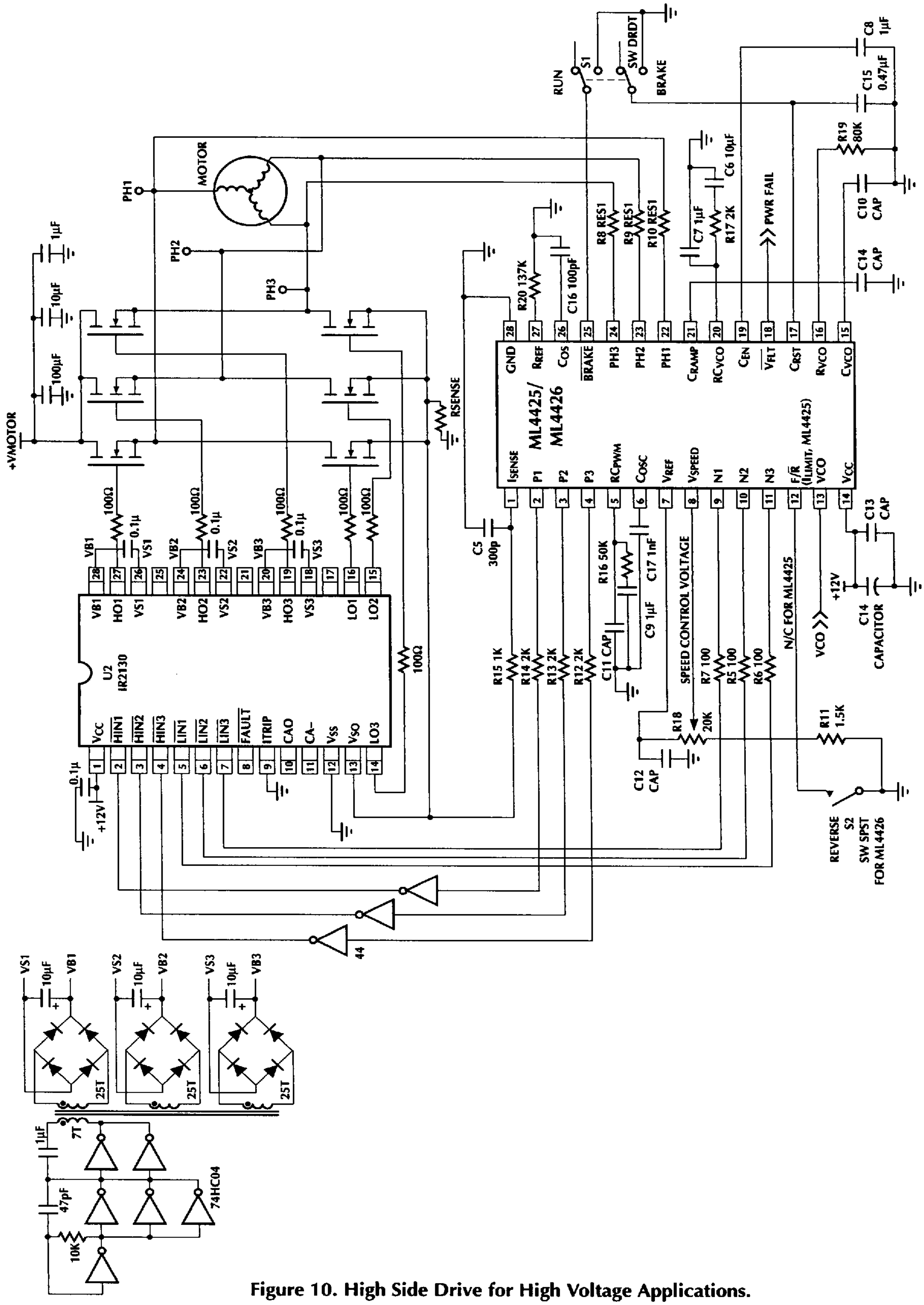


Figure 10. High Side Drive for High Voltage Applications.

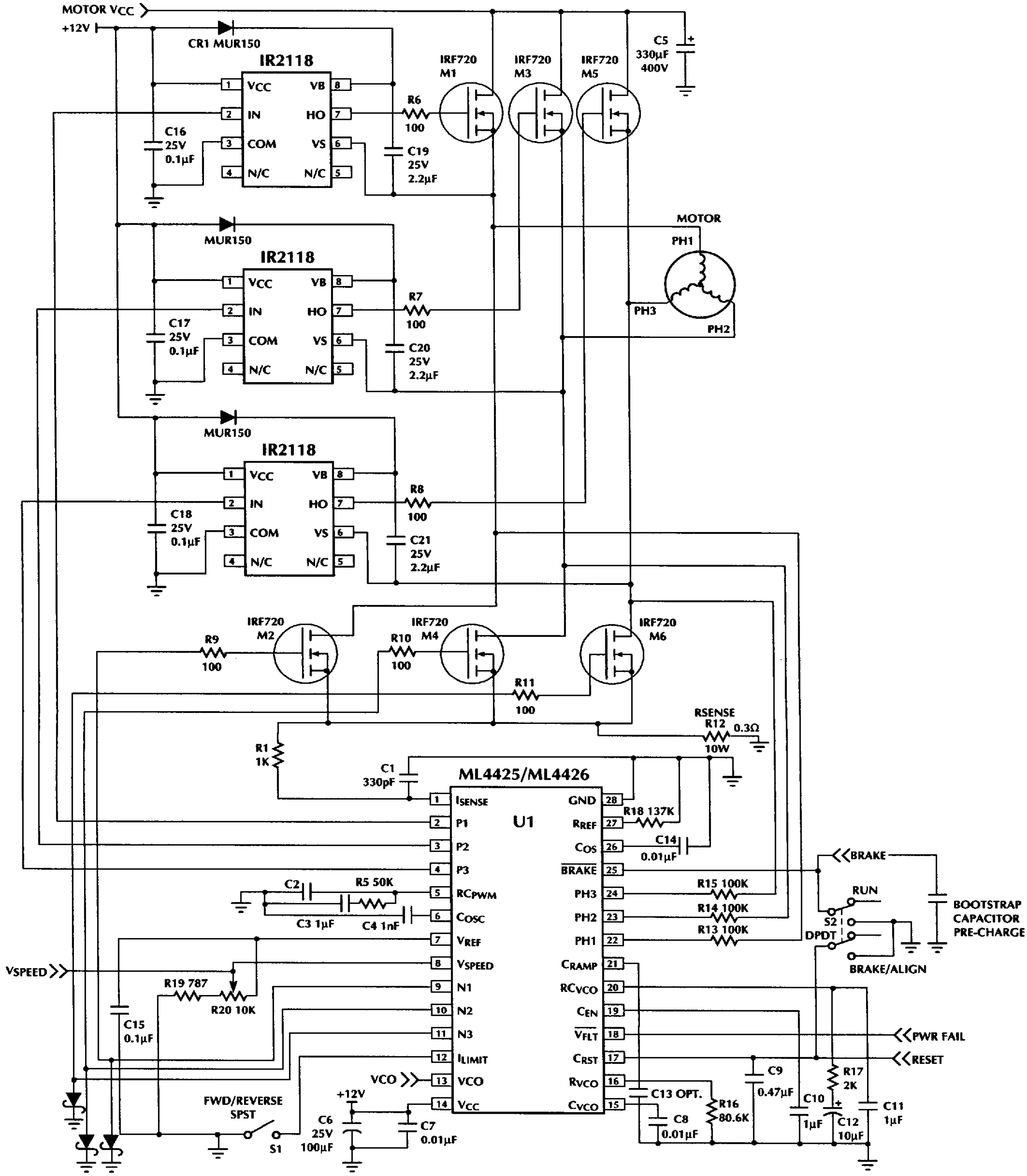
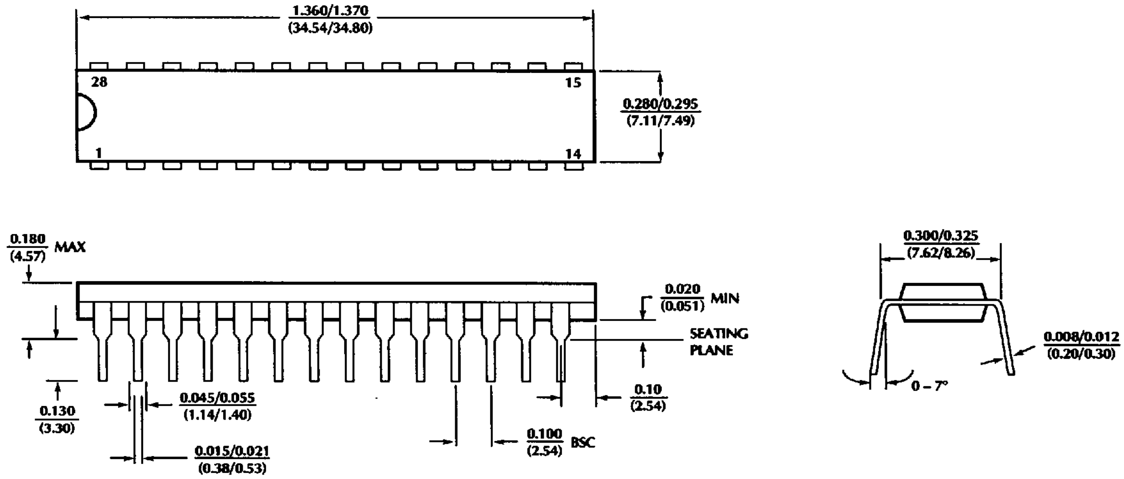


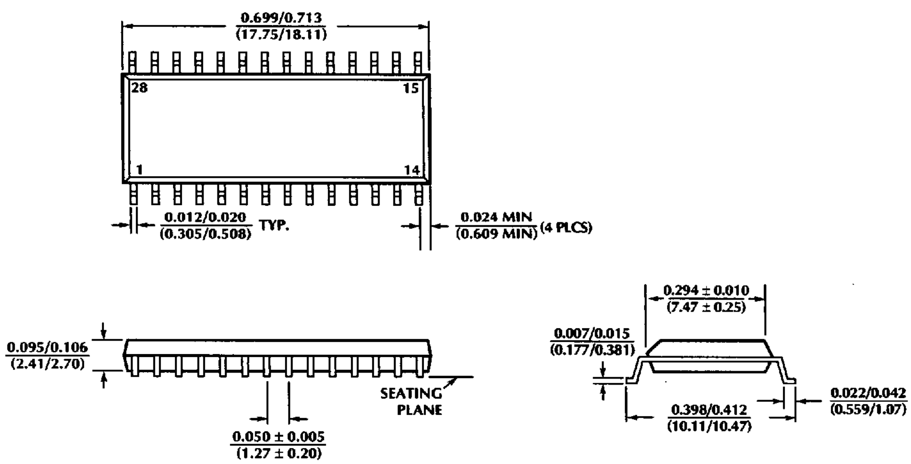
Figure 11. ML4425/ML4426 High Voltage Motor Driver

PHYSICAL DIMENSIONS inches (millimeters)

Package: P28N
28-Pin Narrow DIP

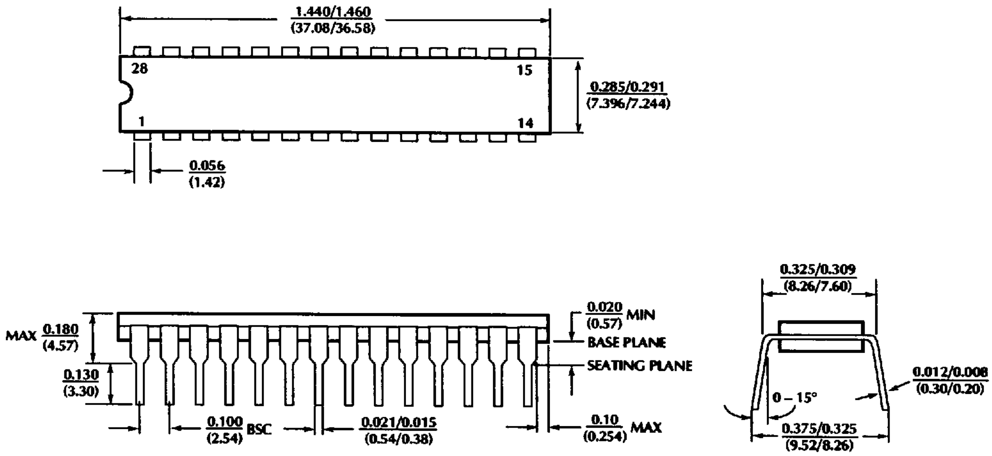


Package: S28
28-Pin SOIC



PHYSICAL DIMENSIONS inches (millimeters) (Continued)

Package: J28N
28-Pin CERDIP



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ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE
ML4425CP ML4425CS	0°C to +70°C 0°C to +70°C	28-Pin DIP (P28N) 28-Pin SOIC (S28)
ML4425IJ ML4425IP ML4425IS	–40°C to +85°C –40°C to +85°C –40°C to +85°C	28-Pin CERDIP (J28) 28-Pin DIP (P28N) 28-Pin SOIC (S28)
ML4425MJ	–55°C to +125°C	28-Pin CERDIP (J28)
ML4426CP ML4426CS	0°C to +70°C 0°C to +70°C	28-Pin DIP (P28N) 28-Pin SOIC (S28)
ML4426IJ ML4426IP ML4426IS	–40°C to +85°C –40°C to +85°C –40°C to +85°C	28-Pin CERDIP (J28) 28-Pin DIP (P28N) 28-Pin SOIC (S28)
ML4426MJ	–55°C to +125°C	28-Pin CERDIP (J28)

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