Micro Linear

April 1997
PRELIMINARY

ML4421

Variable Speed AC Induction Motor Controller

GENERAL DESCRIPTION

The ML4421 AC induction motor controller provides the PWM Sine 0° and Sine 90° waveforms necessary for controlling single and two phase AC induction motors.

A constant voltage/frequency ratio can be maintained over a 10:1 frequency range. The output variable frequency AC voltages are sensed and fed back to the controller to track the sine wave frequency and amplitude set by the speed control.

On two phase motors, direction is controlled by electronically changing the relative 90° phase difference between the main and secondary motor winding.

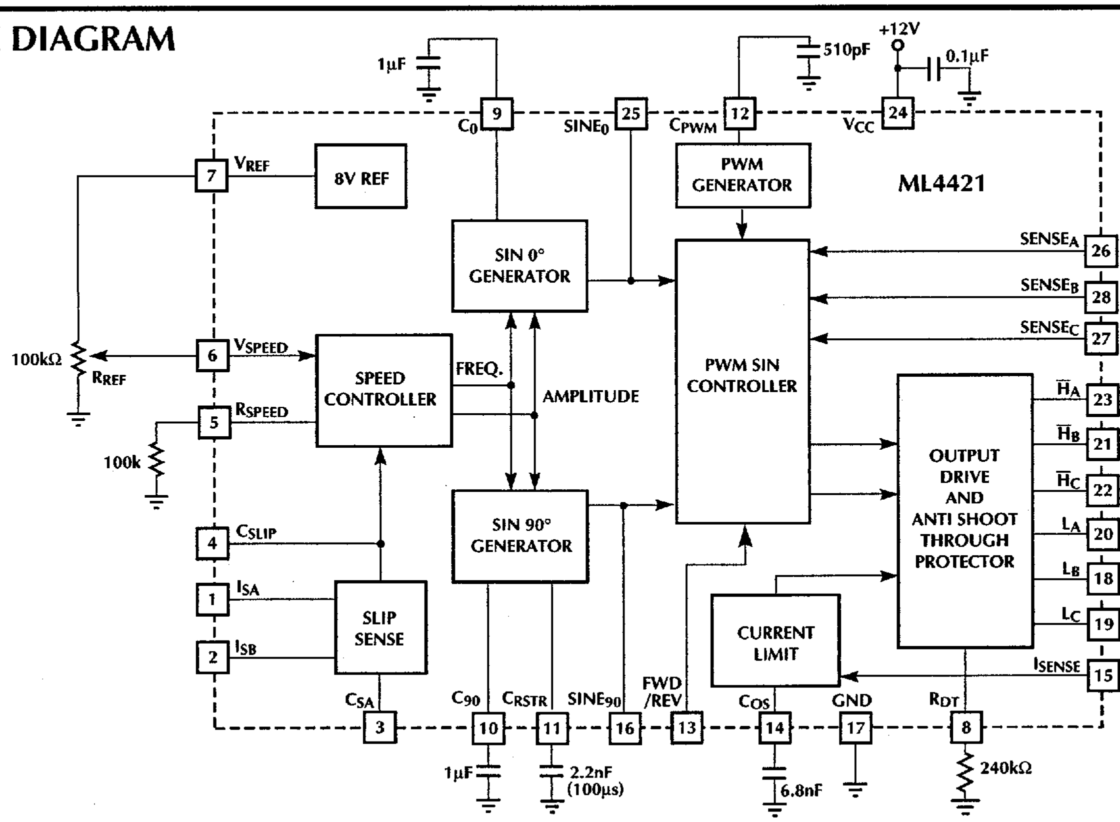
For tighter speed control, the slip angle can be sensed by measuring the phase angle of the current vs. the voltage in the main winding of the motor. The resultant error signal is used to adjust the amplitude of the output Sine 0° and Sine 90° signals in order to maintain a constant speed during changes in motor load.

The ML4421 limits the motor winding current with a constant off-time PWM controlled current limit. Additional circuitry protects the power transistors by preventing shoot through. The ML4421-12 has output drive from zero to V_{CC} (+12V) while the ML4421-5 has output drive from zero to 5V.

FEATURES

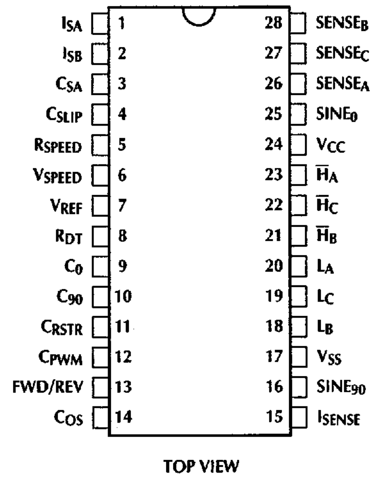
- Drives single and two phase AC motors
- 10:1 variable speed control range
- Constant V/F with programmable ratio
- Forward/reverse for two phase drive
- Optional slip angle control
- PWM sine wave drive
- 5% distortion typical
- Eliminates run capacitor for PSC motors
- Drives IR 2118 high side drivers (ML4421-12)
- 12V ±10% operation
- On-board 8V voltage reference
- Current limit and programmable dead time

BLOCK DIAGRAM

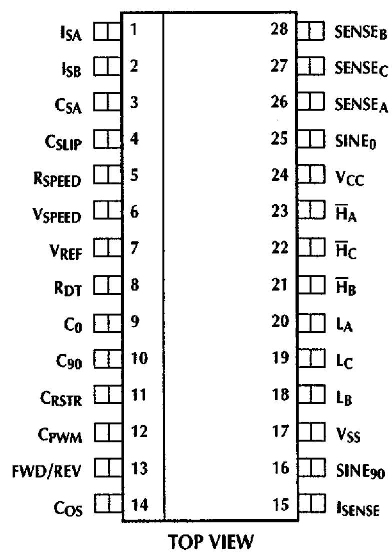


PIN CONFIGURATION

ML4421
28-Pin Narrow DIP (P28N)



ML4421
28-Pin SOIC (S28)



PIN DESCRIPTION

PIN	NAME	FUNCTION
1	I_{SA}	Differential input which senses the current of winding A to determine the phase difference between voltage and current, with I_{SB}.
2	I_{SB}	(See I_{SA}).
3	C_{SA}	The external capacitor sets the slip angle between voltage and current.
4	C_{SLIP}	The voltage on this pin increases the sinewave amplitude at $SINE_0$ and $SINE_{90}$ when the slip angle is exceeded.
5	R_{SPEED}	The external resistor provides a variable current to the sinewave generator. This current is proportional to V_{SPEED}.
6	V_{SPEED}	The voltage on this pin sets the frequency and amplitude of the sinewaves generated at $SINE_0$ and $SINE_{90}$.
7	V_{REF}	This is a dual purpose pin providing a constant reference voltage which can be used for V_{SPEED}. The external 100kΩ resistor (R_{REF}) value sets internal currents used for the PWM frequency and the current limit one shot off time.
8	R_{DT}	The external resistor controls the dead time in the output stage to prevent cross-conduction.
9	C_0	The external capacitor sets the Sine 0° frequency in conjunction with R_{SPEED}.
10	C_{90}	The external capacitor value should match C_0.
11	C_{RSTR}	The external capacitor sets the one shot time period to restore the DC level of the waveform on C_{90}.
12	C_{PWM}	The external capacitor sets the PWM frequency in conjunction with the external 100kΩ resistor (R_{REF}) at V_{REF}.
13	FWD/REV	A logic high causes Phase B to lead Phase A by 90°; a logic low causes Phase A to lead Phase B by 90°.
14	C_{OS}	The external capacitor controls the off time during current limit.
15	I_{SENSE}	Motor current sense input. Current limit occurs when the value exceeds approximately 0.5V.
16	$SINE_{90}$	A test output to observe the internally generated 90° Sine wave.
17	V_{SS}	Signal and power ground.
18	L_B	Low side drive output for phase B.
19	L_C	Low side drive output for phase C.
20	L_A	Low side drive output for phase A.
21	$\overline{H}_B$	High side drive output for phase B.
22	$\overline{H}_C$	High side drive output for phase C.
23	$\overline{H}_A$	High side drive output for phase A.
24	V_{CC}	+12 VDC input.
25	$SINE_0$	A test output to observe the internally generated 0° Sine wave.
26	$SENSE_A$	Differential input which, with respect to $SENSE_C$, feeds back the voltage applied across the A-C motor windings.
27	$SENSE_C$	Reference. (See $SENSE_A$).
28	$SENSE_B$	Differential input which, with respect to $SENSE_C$, feeds back the voltage applied across the B-C motor windings.

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 (V_{CC}) 14V
Output Current (L_B, L_C, L_A, $\overline{H}_B$, $\overline{H}_C$, $\overline{H}_A$) .... ±50mA
F/R Input Voltage .... –0.3 to 7V
Junction Temperature .... 150°C
Storage Temperature Range .... –65°C to 150°C
Lead Temperature (Soldering 10 sec.) .... 260°C
Thermal Resistance (θ_{JA})
Plastic DIP .... 52°C/W
Plastic SOIC .... 75°C/W

OPERATING CONDITIONS

Temperature Range .... 0°C to 70°C
V_{CC} Voltage .... 12V ± 10%

ELECTRICAL CHARACTERISTICS

Unless otherwise specified, T_A = Operating Temperature Range, V_{CC} = 12V ± 10%, R_{SPEED} = 100kΩ, R_{LIMIT} = 0.3Ω, R_{REF} = 100kΩ, C_0 = C_{90} = 1µF, C_{PWM} = 0.51nF, C_{OS} = 6.8nF, C_{RSTR} = 2.2nF, (Note 1).

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
DC Characteristics						
I_{CC}	V_{CC} Current Operating		8		20	mA
V_{REF}	8V Reference		7.2	8.0	8.8	V
Digital Inputs						
V_{IL}	Input Low Voltage				0.8	V
V_{IH}	Input High Voltage		2			V
Output Drive ML4421-12						
V_{OL}	Output Low Voltage	I_{OL} = 2mA		0.4	0.8	V
V_{OH}	Output High Voltage	I_{OL} = –2mA		V_{CC} – 0.2		
Output Drive ML4421-5						
V_{OL}	Output Low Voltage	I_{OL} = 1mA			0.8	V
V_{OH}	Output High Voltage	I_{OL} = –1mA	4.0			V
Sinewave Generator Section						
V_{P-P}	Sinewave Voltage	V_{SPEED} = 5.5V	2.7	3.2	3.6	V
FREQ	Sinewave Frequency		63	68	83	Hz
	Linearity	V_{SPEED} = 2V to 8V	–5		+5	%
	Distortion			5		%
PWM Generator						
V_{P-P}	Peak to Peak Voltage			3.6		V
F_{PWM}	Frequency		18	22	30	kHz
Current Limit Section						
V_{TH}	Threshold Voltage		0.35	0.5	0.55	V
T_{OFF}	One Shot Off Time		90	115	150	µs

Note 1: Limits are guaranteed by 100% testing, sampling or correlation with worst case test conditions.

FUNCTIONAL DESCRIPTION

The ML4421 generates two reference sinewaves separated by 90°. These sinewaves can be varied in amplitude and frequency from a voltage at the speed input. Signals across the motor windings are sensed and the ML4421 drives the external output power stage with the PWM signal necessary to cause the sensed waveform to match the internal reference sinewaves. The ML4421 protects the output power stage by providing constant off time current limit and a programmable dead time circuit to prevent cross conduction. Tighter speed control can be provided by a slip control circuit which holds a constant slip angle between motor voltage and current.

CIRCUIT BLOCKS AND COMPONENT SELECTION

VREF

V_{REF} serves a dual function. A 100kΩ resistor to ground sets internal currents used for the PWM frequency and the current limit off time. If a 100kΩ low temperature coefficient potentiometer is used it can also be a voltage reference for V_{SPEED}.

Speed Control

The voltage on V_{SPEED} controls the sinewave frequency and amplitude. A 100kΩ resistor to ground on R_{SPEED} converts the voltage on V_{SPEED} to a current which is used to control the frequency of the sinewaves. The amplitude of the sinewaves increases linearly with V_{SPEED} until it reaches 4.4V. Above this voltage the amplitude remains constant and only the frequency changes as shown in figures 1 and 2.

$SINE_0$ Generator

The capacitor to ground on C_0 sets the frequency range of the sinewave according to the following relationship. This should be a low temperature coefficient capacitor for best results.

$$FREQ. = \frac{V_{SPEED}/R_{SPEED}}{2(C_0)0.356V} \quad (1)$$

For R_{SPEED} = 100kΩ

$$FREQ. = \frac{V_{SPEED}}{71200\,C_0} \quad (2)$$

The $SINE_0$ pin can be used to observe the $SINE_0$ sinewave.

$SINE_{90}$ Generator

The capacitor to ground on C_{90} should match C_0. The 2.2nF capacitor to ground on C_{RSTR} sets a 100µs restore time during which the $SINE_{90}$ waveform is allowed to reestablish the DC reference voltage of $SINE_{90}$ during it's positive transition through neutral. A small positive or negative step in the waveform may occur at this time. The $SINE_{90}$ pin may be used to observe the $SINE_{90}$ sinewave.

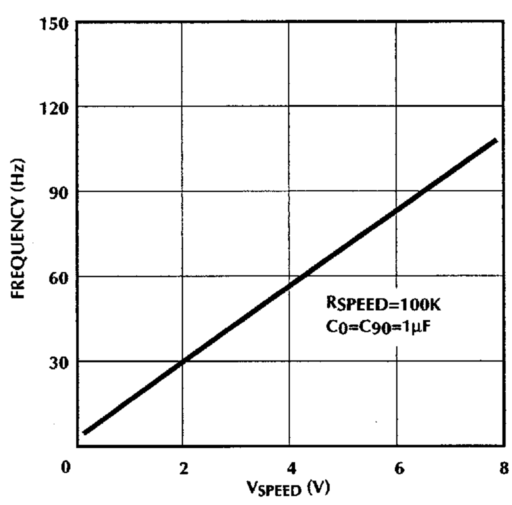


Figure 1. Frequency vs V_{SPEED}

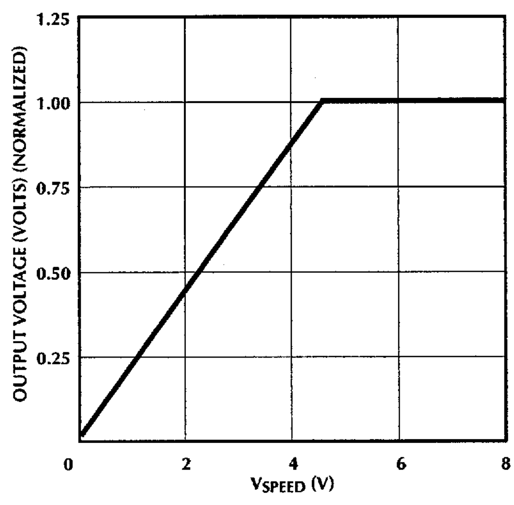


Figure 2. Normalized Output Voltage vs V_{SPEED}
Pin 4 grounded.

PWM Generator

A triangle PWM frequency will be generated on a capacitor to ground on C_{PWM}. The frequency is set by the following equation:

$$f_{PWM} = \frac{V_{REF}}{(R_{REF})(7.2)\,C_{PWM}}$$

$$f_{PWM} = \frac{11.2\times10^{-6}}{C_{PWM}} \quad (\text{when } R_{REF} = 100k) \qquad (3)$$

This frequency (in Hz) is recommended to operate above 20kHz to eliminate PWM noise. This should be a low temperature coefficient capacitor for best results. The frequency is adjustable to accommodate lower frequency IGBT switching power devices.

Current Limit

Motor current is sensed on I_{SENSE}. R_{LIMIT} should be selected so that

$$R_{LIMIT} = \frac{0.5V}{I_{MAX}} \qquad (4)$$

The 1kΩ and 330pF filters the high frequency diode recovery spikes occurring in the output.

C_{OS} – One Shot Current Limit Timer

When voltage exceeds 0.5V on the I_{SENSE} pin, the output pulse is terminated. The sensed current limit is constant off time based, set by the one shot period. The one shot period may be smaller or larger than the PWM period. Use one shot period = 0.5 x PWM period as a starting point.

PWM SINE Controller

This circuit block compares the sinewaves at $SINE_0$ and $SINE_{90}$ to the sampled inputs $SENSE_A$–$SENSE_C$ and $SENSE_B$–$SENSE_C$. The PWM loop then drives the outputs to force these differential waveforms to equal the internal reference waveforms at $SINE_0$ and $SINE_{90}$. The differential signals $SENSE_A$–$SENSE_C$ and $SENSE_B$–$SENSE_C$ will be approximately 1.6 volts peak. The signals at these pins should be filtered to remove the PWM frequency.
The high voltages at the motor terminals are divided down to 1.6 volts to provide voltage feedback to the controller. See Figure 3. The 0.33µF capacitors (Figure 3) to ground on $SENSE_A$, $SENSE_B$ and $SENSE_C$ will create 1kHz filtering at these inputs. Voltage on the motor is set by the divider ratios.

$$V_{P\,MOTOR} = \frac{R5(1.6V)}{1k\Omega} \qquad (5)$$

OUTPUT DRIVE

The 6 output drivers of the ML4421-12 drive the H and L output from 0 to 12 volts. The outputs will drive about 2mA and are designed to drive output buffers and high side drivers requiring 12 volt swings. The ML4421-5 provides low current 0 to 5 volt drive for high side/low side drivers requiring 5 volt swings.

SHOOTTHROUGH PROTECTION

A dead time circuit is provided to prevent shootthrough currents in the output stage. The dead time is controlled by a resistor to ground on R_{DT}. The dead time should be sufficient to prevent cross conduction in the output stage.

$$R_{DT} = 5.2\times10^{4}\times t_{DEAD}\ (\text{in } \mu s) \qquad (6)$$

SLIP CONTROL (OPTIONAL)

For tighter speed control, slip sense can be activated by connecting capacitors from C_{SA} and C_{SLIP} to ground respectively, and adding the circuit in Figure 4. The slip control circuit compares the phase of the current in winding A sensed at pin I_{SA} with respect to pin I_{SB} and the phase A voltage at pin $SENSE_A$ with respect to pin $SENCE_C$. The capacitor on C_{SA} to ground sets the timing window that current is allowed to lag behind voltage. See Figure 5. Under no load conditions, the angle between the motor phase voltage and current is close to 90°. When the motor is loaded, this phase difference reduces, and it is compared to the timing window set by C_{SA}. The result is integrated by the capacitor on C_{SLIP}. When V_{CSLIP} exceeds V_{SPEED}, the voltage applied to the motor will be increased. This pin can be grounded to disable the slip control, or set to a given voltage to insure a minimum starting voltage independent of frequency. This pin sources or sinks about 80µA. For a given angle:

$$C_{SA} = 7.9\times10^{-4}(C_0)$$

or (7)

$$\theta = \frac{C_{SA}}{(7.9\times10^{-4}C_0)} \quad (\theta \text{ is in degrees})$$

For slip control to function properly, C_{SA} has to be less than 7.1 x $10^{-2}(C_0)$. A transimpedance amplifier is used to convert the sensed current in winding A to voltage in the same phase. The resistor R1 should be chosen so the peak to peak voltage between I_{SA} and I_{SB} is greater than 500mV. (See Figure 4)

Note: when V_{CSLIP} reaches 4.4V, the motor voltage is at its maximum.

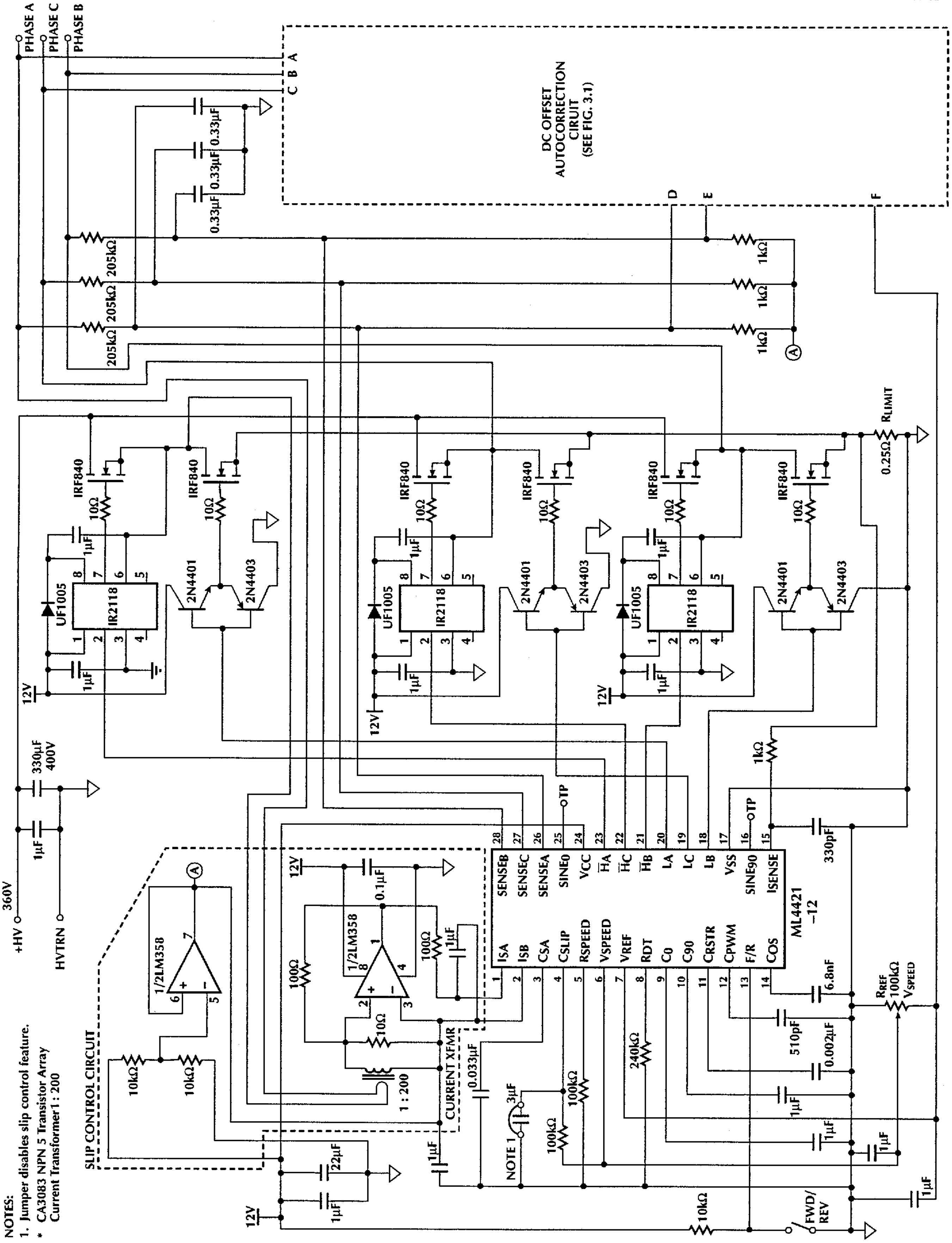


Figure 3. Typical Application of the ML4421 Variable Speed AC Motor Controller

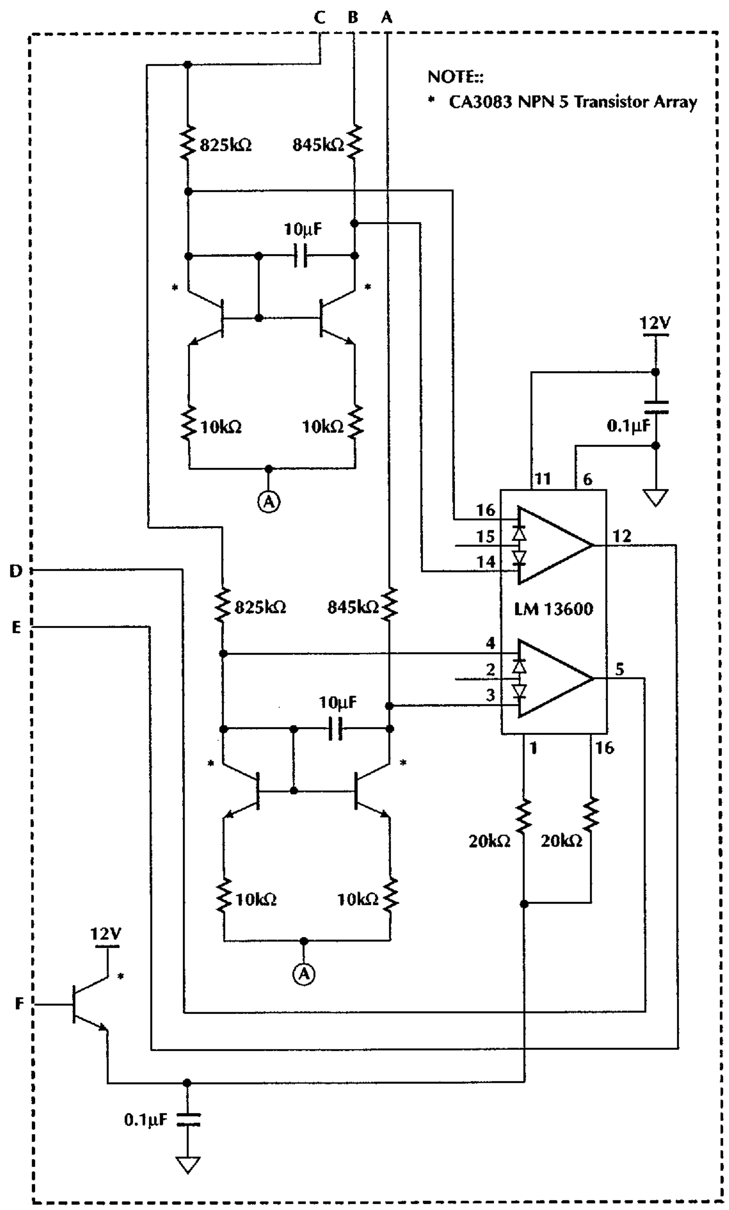


Figure 3.1. DC Offset Autocorrection Circuit

DESIGN CONSIDERATIONS

The ML4421 provides all the signals and sampling necessary to drive the output power stage connected to the motor. The components around the ML4421 for a typical application is shown in Figure 3. The V_{MOTOR} voltage power should be greater than the largest signal waveform requested or output clipping may result. The printed circuit board should have a ground plane to minimize ground loops.

OFFSET COMPENSATION

The auto offset circuit is used to reduce potential DC currents in the windings. The LM13600 transconductance op amp senses a DC voltage across a motor winding and outputs a correction current to the $SENSE_A$ and $SENSE_B$ inputs to automatically compensate for sensed DC offset voltages. The 825kΩ resistors produce additional currents to the base of the NPN transistor pair. If another transistor array is used, with different Beta, then the 825kΩ and/or 845kΩ resistors may need to be reselected. (Figure 3.1)

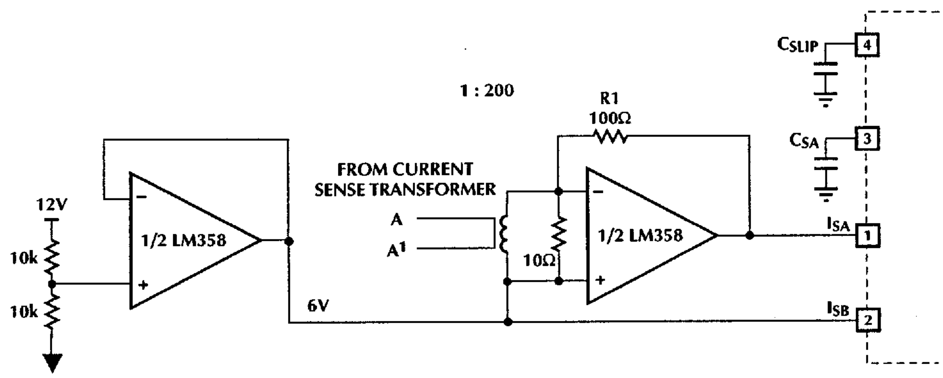


Figure 4.

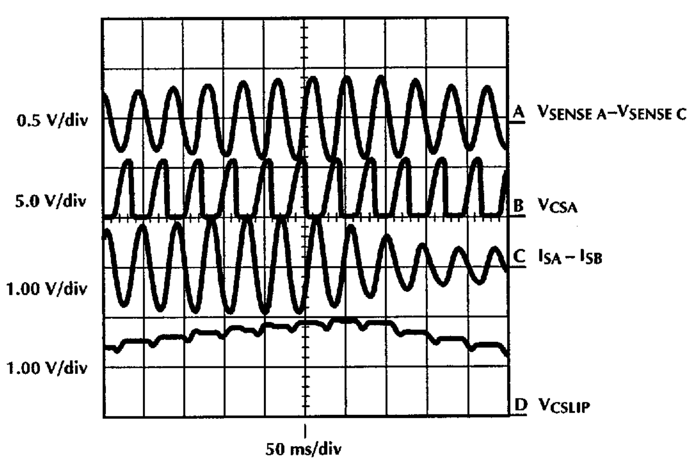


Figure 5. Response to Torque Variation.

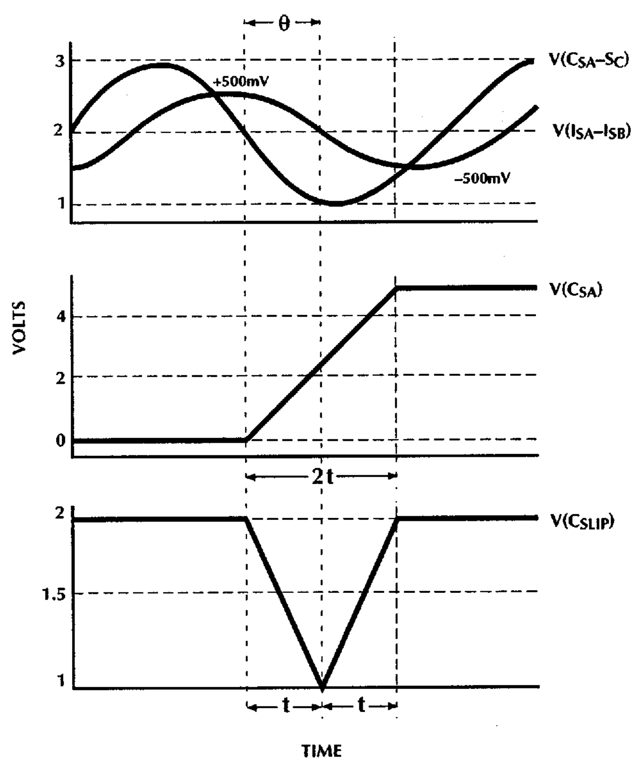


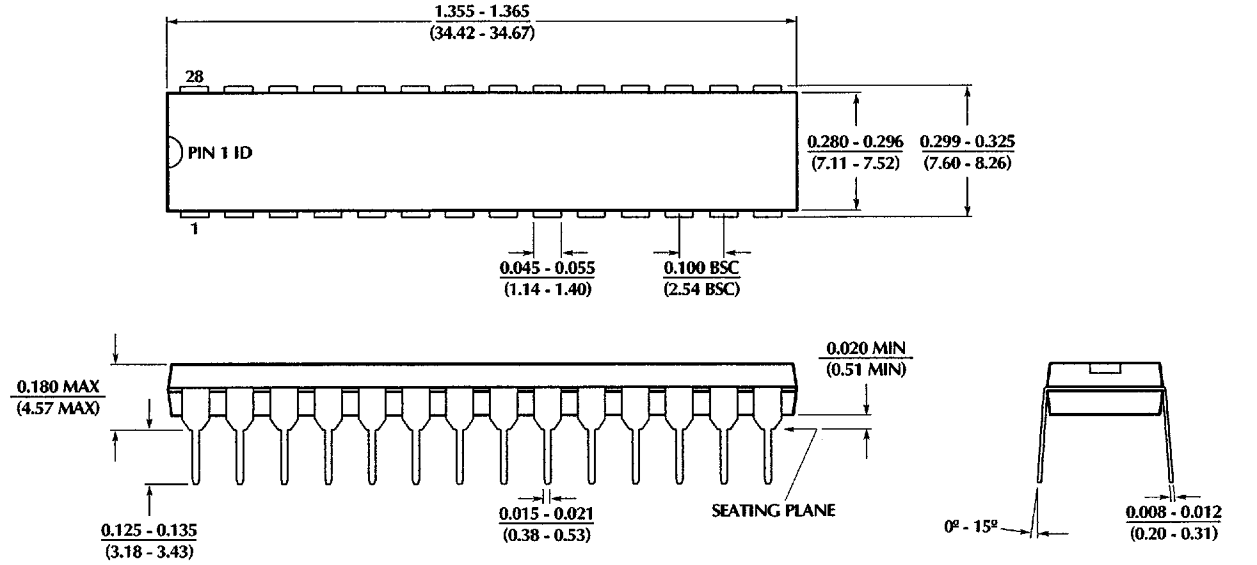
Figure 6. Steady State.

CAUTION!!!

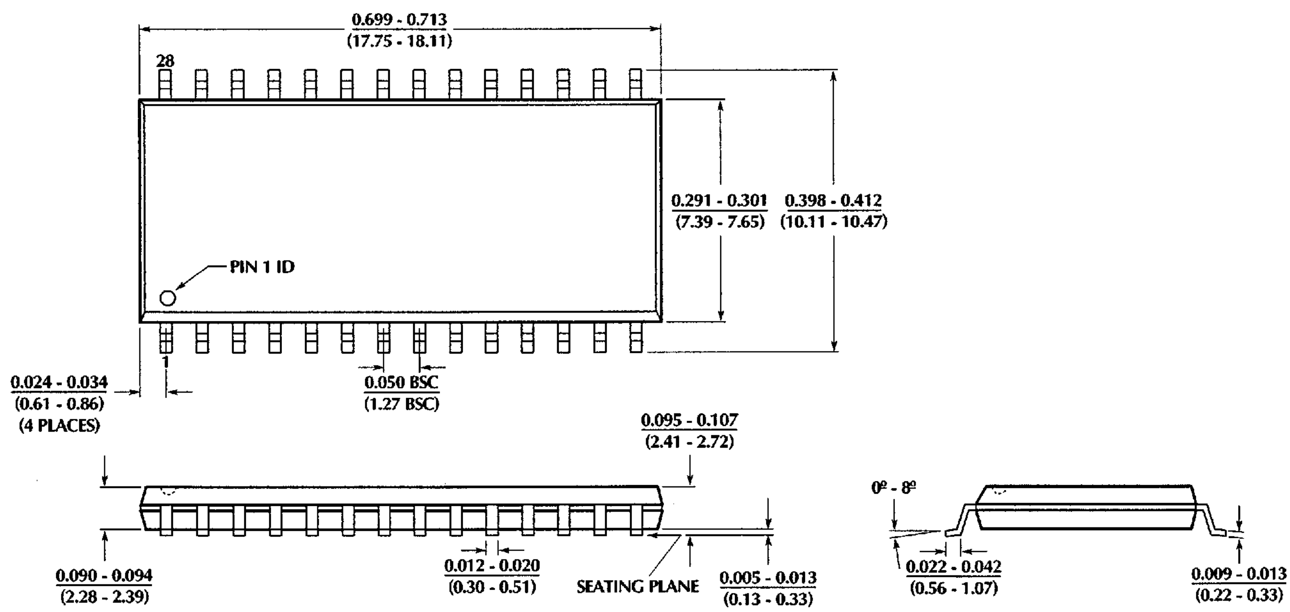
Systems built with the ML4421 may contain voltage potentials capable of causing serious injury and components which, when failed, or subject to improper use may shatter or explode. Please use extreme caution when operating these parts. The use of protective eye wear is strongly recommended!!! To safely observe in-circuit waveforms an isolation transformer should be inserted between the AC line and the circuit under test. Caution is required when testing the part with motors. loose fitting clothing can catch in the rotor or motor load causing injury. Ties are especially dangerous. Do not attempt to hold or stop the rotor with your hand, as this can cause injury as well. Use a dynamometer for load testing.

PHYSICAL DIMENSIONS inches (millimeters)

Package: P28N
28-Pin Narrow PDIP



Package: S28
28-Pin SOIC



ORDERING INFORMATION

PART NUMBER	TEMPERATURE RANGE	PACKAGE
ML4421CS-12 ML4421CPN-12	0°C to 70°C 0°C to 70°C	28-PIN SOIC (S28) 28-PIN Narrow DIP (P28N)
ML4421CS-5 ML4421CPN-5	0°C to 70°C 0°C to 70°C	28-PIN SOIC (S28) 28-PIN Narrow DIP (P28N)

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