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SSI 32H569
Servo Motor Driver

December 1993

DESCRIPTION

The SSI 32H569 Servo Motor Driver is a bipolar device intended for use in Winchester disk drive head positioning systems employing linear or rotary voice coil motors. When used in conjunction with a position controller, such as the SSI 32H6220 Servo Controller, and a position reference, such as the SSI 32H6210 Servo Demodulator, the device allows the construction of a high performance, dedicated surface head positioning system.
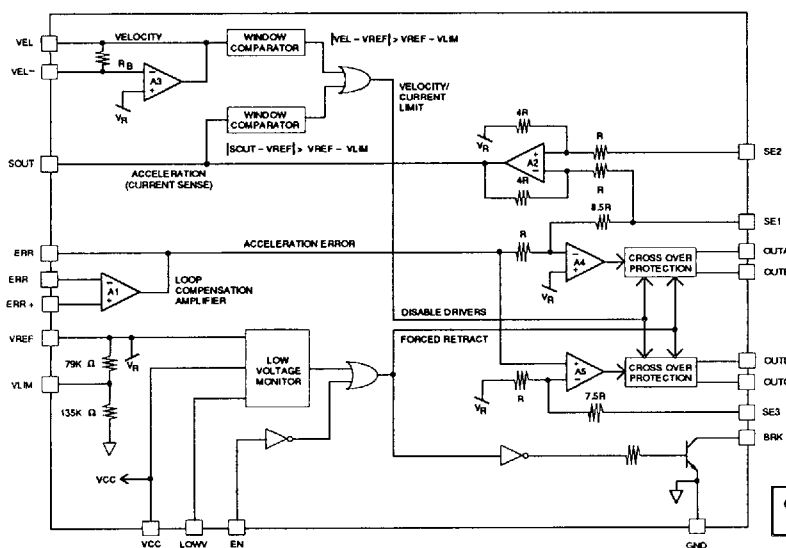
The SSI 32H569 serves as a transconductance amplifier by driving 4 MOSFETs in an H-bridge configuration, performs motor current sensing and limits motor current and velocity. In its linear tracking mode, class B operation is guaranteed by crossover protection circuitry, which ensures that only one MOSFET in each leg of the H-bridge is active. The MOSFET drivers are disabled when motor velocity or current exceed externally programmable limits. In addition, automatic head retraction and spindle braking may be initiated by a low voltage condition or upon external command.
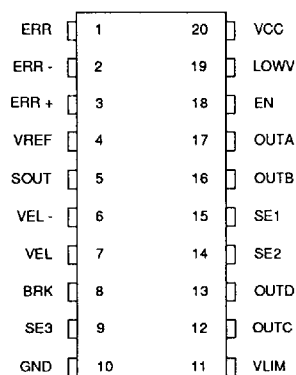
(continued)

FEATURES

- **Predriver for linear and rotary voice coil motors**

- **Interfaces directly to MOSFET H-Bridge motor driver**

- **Class B linear mode and constant velocity retract mode**

- **Precision differential amplifier for motor current sensing**

- **Motor current and velocity limiting circuitry**

- **Automatic head retract and spindle braking signal on power failure**

- **External digital enable**

- **Servo loop parameters programmed with external components**

- **Advanced bipolar IC requires under 240 mW from 12V supply**

- **Available in 20-pin DIP or SO packaging**

BLOCK DIAGRAM

PIN DIAGRAM

ERR	1	20	VCC
ERR -	2	19	LOWV
ERR +	3	18	EN
VREF	4	17	OUTA
SOUT	5	16	OUTB
VEL -	6	15	SE1
VEL	7	14	SE2
BRK	8	13	OUTD
SE3	9	12	OUTC
GND	10	11	VLIM

20-Pin SO, DIP

CAUTION Use handling procedures necessary for a static sensitive component.

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DESCRIPTION (continued)

The SSI 32H569 is implemented in an advanced bipolar process and dissipates less than 240 mW from a 12V supply. The IC is available in 20-pin DIP and 20-pin SO packaging.

FUNCTIONAL DESCRIPTION
(Refer to block diagram and typical application Fig.2)

The SSI 32H569 has two modes of operation, linear and retract. The retract mode is activated by a power supply failure or when the control signal EN is false. Otherwise the device operates in linear mode.

During linear operation, an acceleration signal from the servo controller is applied through amplifier A1, whose three connections are all available externally. RC components may be used to provide loop compensation at this stage. The ERR signal drives two precision amplifiers, each with a gain of 8.5. The first of these amplifiers is inverting, and is formed from opamp A4, an on-chip resistor divider and an off-chip complementary MOSFET pair. The second is non-inverting, and is formed in a similar manner from opamp A5. Feedback from the MOSFET drains, on sense inputs SE1 and SE3, allows the amplifiers gains to be established precisely. The voice coil motor and a series current sense resistor are connected between SE1 and SE3.

Crossover protection circuitry between the outputs of A4 and A5, and the external MOSFETs, ensures class B operation by allowing only one MOSFET in each leg of the H-bridge to be in conduction. The crossover separation threshold, illustrated in Figure 5, is the maximum drive on any MOSFET gate when the motor voltage changes sign. The crossover circuitry can also disable all MOSFETS simultaneously (to limit motor current or velocity) or apply a constant voltage across the motor (to retract the heads at a constant velocity).

Motor current is sensed by a small resistor placed in series with the motor. The voltage drop across this resistor is amplified by a differential amplifier with a gain of 4 (A2 and associated resistors), whose inputs are SE1 and SE2. The resulting voltage, SOUT, is proportional to motor current, and hence acceleration. This signal is externally fed back to A1, so that the signal ERR represents the difference between the desired acceleration (from the servo controller) and the actual motor acceleration. If SOUT is integrated, using opamp A3 and an external RC network, the resulting signal, VEL, is proportional to the motor velocity.

Both SOUT and VEL are connected to window comparators, which are used to detect excessive motor current or velocity. The comparator outputs disable the MOSFET drivers until the motor comes within limits again. The VLIM pin may be used to program the voltage limits for the window comparators. The maximum voltage excursion allowed about VREF is (VREF-VLIM). An on-chip resistor divider sets a default value for VLIM and if VLIM is connected to ground, the windowing is effectively disabled.

The SSI 32H569 has low voltage monitor circuitry that will detect a loss of voltage on the VREF, VCC or LOWV pins. The power supply pin, VCC, should be connected to the disk drive's spindle motor so that its stored rotational energy may be used to hold up VCC briefly during a power failure. LOWV is used to detect a system power supply failure. When a low voltage condition is detected, the MOSFET drivers switch from linear operation to retract mode. In this mode a constant voltage is applied across the motor which will cause the heads to move at a constant speed. A mechanical stop must be provided for the heads when they reach a safe location. The current limiting circuitry will disable the MOSFET drivers when motor current increases due to loss of the velocity-induced back EMF. An open collector output, BRK, which is active while the device is in retract mode, is provided for spindle motor braking. An external RC delay may be used to defer braking until the heads are retracted. For proper operation of the SSI 32H569, a pullup resistor on BRK is required even if the BRK output is not used.

An example of an entire servo path implemented with the SSI 32H569 and its companion devices, the SSI 32H6210 and 32H6220, is shown in Figure10.
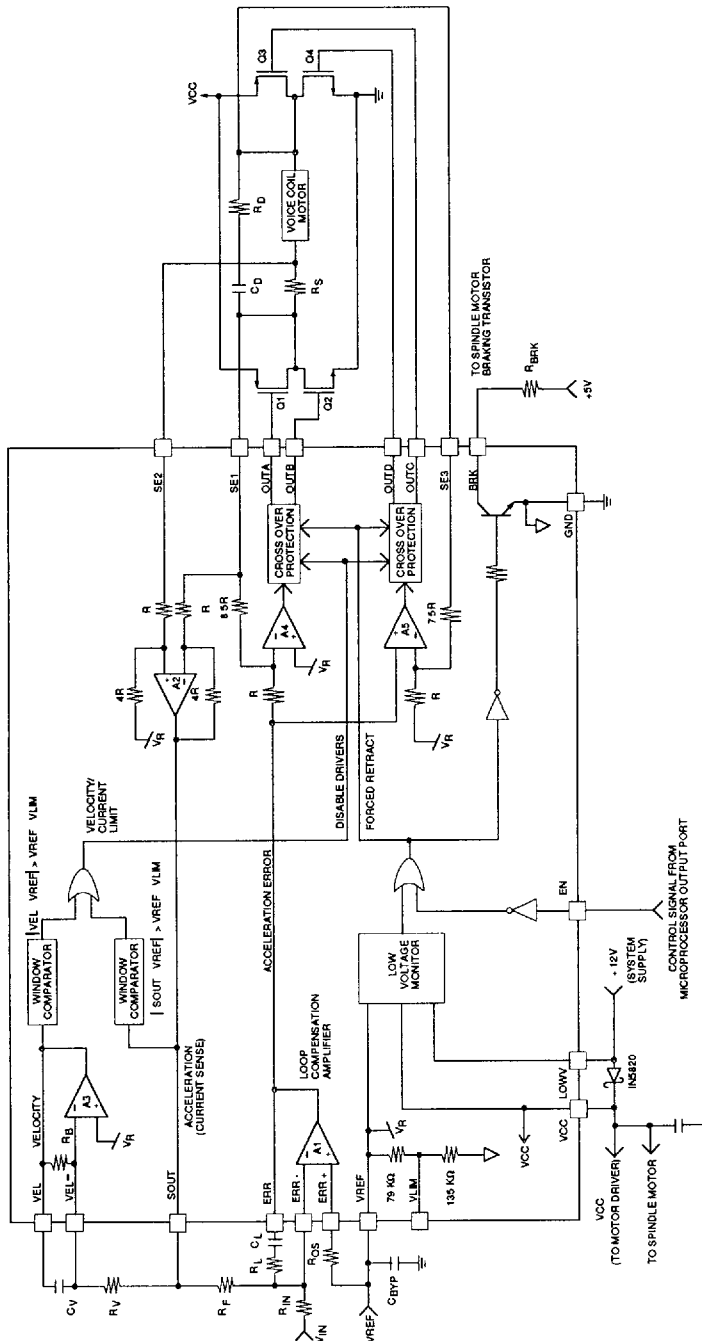
FIGURE 2: Typical Application

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PIN DESCRIPTION

POWER

NAME	PIN	TYPE	DESCRIPTION
VCC	20	-	POSITIVE SUPPLY - 12V power supply. Usually taken from spindle motor supply. Spindle motor stored energy permits head retraction during power failure. If VCC falls below 9V, a forced head retraction occurs.
LOWV	19	I	LOW VOLTAGE - System 12V supply. If this input falls below 9V, a forced head retraction occurs.
VREF	4	I	REFERENCE VOLTAGE - 5.4V input. All analog signals are referenced to this voltage. If VREF falls below 4.3V, a forced head retraction occurs.
GND	10	-	GROUND

CONTROL

NAME	PIN	TYPE	DESCRIPTION
ERR	1	O	POSITION ERROR- Loop compensation amplifier output. This signal is amplified by the MOSFET drivers and applied to the motor by an external MOSFET H-bridge, as follows: $$SE3-SE1 = 17(ERR-VREF)$$
ERR-	2	I	POSITION ERROR INVERTING INPUT - Inverting input to the loop compensation amplifier.
ERR+	3	I	POSITION ERROR NON-INVERTING INPUT - Non-inverting input to the loop compensation amplifier.
SOUT	5	O	MOTOR CURRENT SENSE OUTPUT - This output provides a voltage proportional to the voltage drop across the external current sense resistor, as follows: $$SOUT-VREF=4(SE2-SE1)$$
VEL-	6	I	VELOCITY INVERTING INPUT - Inverting input to the velocity integrating amplifier. The non-inverting input is connected internally to VREF.
VEL	7	O	VELOCITY OUTPUT - Output of the velocity integration amplifier. This signal is internally applied to a window comparator whose output limits motor drive current when the voltage at VEL exceeds a set limit.
BRK	8	O	BRAKE OUTPUT - Active high, open collector output which may be used to enable an external spindle motor braking transistor upon power failure or deassertion of EN.
VLIM	11	I	LIMITING VOLTAGE - The voltage at this pin sets motor current and velocity limits. Limiting occurs when: $$\|SOUT-VREF\|>VREF-VLIM$$ or $$\|VEL-VREF\|>VREF-VLIM.$$ An internal resistor divider establishes a default value that may be externally adjusted.

CONTROL (Continued)

NAME	PIN	TYPE	DESCRIPTION
SE2	14	I	MOTOR CURRENT SENSE INPUT - Non-inverting input to the current sense differential amplifier. It should be connected to one side of an external current sensing resistor in series with the motor. The inverting input of the differential amplifier is connected internally to SE1.
EN	18	I	ENABLE - Active high TTL compatible input enables linear tracking mode. A low level will initiate a forced head retract.

FET DRIVE

NAME	PIN	TYPE	DESCRIPTION
SE3	9	I	MOTOR VOLTAGE SENSE INPUT - This input provides feedback to the non-inverting MOSFET driver amplifier. It is connected to one side of the motor. The gain to this point is: $$SE3-VREF = 8.5(ERR-VREF)$$
OUTC	12	O	P-FET DRIVE (NON-INVERTING) - Drive signal for a P channel MOSFET connected between one side of the motor and VCC. This MOSFET drain is connected to SE3.
OUTD	13	O	N-FET DRIVE (NON-INVERTING) - Drive signal for an N channel MOSFET connected between one side of the motor and GND. This MOSFET drain is connected to SE3. Crossover protection circuitry ensures that the P and N channel devices driven by OUTC and OUTD are never enabled simultaneously.
SE1	15	I	MOTOR VOLTAGE SENSE INPUT - This input provides feedback to the inverting MOSFET driver amplifier. It is connected to the current sensing resistor which is in series with the motor. The gain to this point is: $$SE1-VREF = -8.5(ERR-VREF)$$ This input is internally connected to the current sense differential amplifier inverting input.
OUTB	16	O	N-FET DRIVE (INVERTING) - Drive signal for an N channel MOSFET connected between the current sense resistor and GND. This MOSFET drain is also connected to SE1.
OUTA	17	O	P-FET DRIVE (INVERTING) - Drive signal for a P channel MOSFET connected between the current sense resistor and VCC. This MOSFET drain is also connected to SE1. Crossover protection circuitry ensures that the P and N channel devices driven by OUTC and OUTD are never enabled simultaneously.

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ELECTRICAL SPECIFICATIONS

ABSOLUTE MAXIMUM RATINGS
(Maximum limits indicates where permanent device damage occurs. Continuous operation at these limits is not intended and should be limited to those conditions specified in the DC operating characteristics.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
VCC		0		16	V
VREF		0		10	V
SE1, SE2, SE3		-1.5		15	V
All other pins		0		14	V
Storage temperature		-45		165	°C
Solder temperature	10 sec duration			260	°C

RECOMMENDED OPERATION CONDITIONS (Unless otherwise noted, the following conditions are valid throughout this document.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
VCC	Normal Mode	9	12	13.2	V
	Retract Mode	3.5V		14	V
VREF		5		7	V
Operating temperature		0		70	°C

DC CHARACTERISTICS

ICC, VCC current				20	mA
IREF, VREF current				2	mA

A1, LOOP COMPENSATION AMPLIFIER

Input bias current				500	nA
Input offset voltage				3	mV
Voltage swing	About VREF	2			V
Common mode range	About VREF	±1			V
Load resistance	To VREF	4			kΩ
Load capacitance				100	pF
Gain		80			dB
Unity gain bandwidth		0.5			MHz
CMRR	f<20 kHz	60			dB
PSRR	f<20 kHz	60			dB

A2, CURRENT SENSE AMPLIFIER

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input impedance	SE1 to SE2	3.5	5		kΩ
Input offset voltage				2	mV
Output voltage swing		VREF-4		VCC-1.2	V
Common mode range		0		VCC-0.2	V
Load Resistance	To VREF	4			kΩ
Load Capacitance				100	pF
Output impedance	f<40 kHz			20	Ω
Gain (SOUT-VREF)/(SE1-SE2)	$V_{SE2} = V_{REF}$	3.9	4	4.1	V/V
Unity gain bandwidth		0.5			MHz
CMRR	f<20 kHz	52			dB
PSRR	f<20 kHz	60			dB

A3, VELOCITY INTEGRATING AMPLIFIER

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Input bias current				250	nA
Input offset voltage				2	mV
Voltage swing		VREF-4		VCC-1.2	V
Common mode range		4.5		6	V
Load resistance	To VREF	10			kΩ
Load capacitance				100	pF
RB, internal feedback resistor		80		150	kΩ

WINDOW COMPARATORS AND LIMITING

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Window comparator threshold (SOUT-VREF or VEL-VREF)			VREF-VLIM		V
Threshold hysteresis		35	50	65	%
VLIM voltage	No external parts	VREF-1 8		VREF-2.2	V
VLIM input resistance		50			kΩ

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POWER SUPPLY MONITOR

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
VCC fail threshold		8.5	9	9.8	V
LOWV fail threshold	|ILowv| < 0.5 mA	8.5	9	9.8	V
VREF fail threshold		3.9	4.3	4.8	V
Hysteresis (LOWV, VCC)			250		mV
Hysteresis (VREF)			110		mV
EN input low voltage	|IIL| < 0.5 mA	0.8			V
EN input high voltage	|IIH| < 40 uA			2	V
BRK voltage	normal mode, |IOL| < 1 mA			0.4	V
BRK leakage current	retract mode			10	μA
BRK delay (from power fail or EN false to BRK floating)				1	ms

MOSFET DRIVERS

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
SE3 Input impedance	To VREF	10	25		kΩ
OUTA, OUTC voltage swing |Io|<1 mA		0.7		VCC-1	V
OUTB, OUTD voltage swing |Io|<1 mA		1		VCC-1	V
VTH, Crossover separation threshold				2	V
Slew rate (OUTA, OUTB, OUTC, OUTD)	Cl<1000 pF	1.4			V/μs
Crossover time	300 mV step at ERR			5	μs
Output impedance (OUTA,B,C,D)			50		kΩ
Transconductance I(OUTA,B,C,D)/(ERR-VREF)			8		mA/V
Gain (-(SE1-VREF)/(ERR-VREF) or (SE3-VREF)/(ERR-VREF))		8	8.5	9	V/V
Offset current	Rs = 0.2Ω, RF = RIN, VIN=VREF			20	mA
Retract motor voltage (SE1-SE3)		0.7	1	1.3	V

APPLICATIONS INFORMATION

A typical SSI 32H569 application is shown in Figure 2. The selection criteria for the external components shown are discussed below. Figure 3 shows the equivalent circuit and equations for the DC motor used in the following derivations. While the nomenclature chosen is for a rotating motor, the results are equally applicable to linear motors.

MOTOR CURRENT SENSE AND LIMITING

The series resistor which senses motor current, R_s, is chosen to be small compared to the resistance of the motor, R_m. A value of $R_s = 0.2\Omega$ is typical in disk drive applications. The window comparator threshold, programmed by VLIM, must be chosen to cause limiting when the motor current reaches its maximum permissible value. If iMAX is the maximum motor current in Amps, then this value may be chosen as follows:

$$VLIM = VREF - 4 \cdot R_s \cdot iMAX \ (V)$$

VLIM may be set with a resistor divider whose thevenin resistance is substantially less than the output resistance of the VLIM pin (50 kΩ). The window comparators have hysteresis (typically 50% of their threshold, VREF-VLIM) to prevent multiple triggerings of the driver disable signal.

VELOCITY LIMITING

The values of R_v and C_v in the velocity integrator are chosen to produce a voltage excursion of VREF-VLIM, when the motor speed is at its maximum permissible value. R_v must be large enough to prevent overloading of opamp A2. The following equation ignores the effect of R_B, the internal resistor between VEL and VEL- which prevents saturation of A3 due to offsets. For the motor in Figure 3, with maximum velocity ωMAX (rad/s) these components may be chosen as follows:

$$R_V \ // \ R_F > 4 k\Omega \ (A2 \ output \ loading \ restriction)$$

$$C_V = \frac{4 R_s \cdot J\theta \cdot \omega MAX}{(VREF-VLIM) \cdot R_V \cdot K_m} \ (F)$$

LOOP COMPENSATION

The transfer function of the SSI 32H569 in the application of Figure 2 is shown in Figure 4(a). If the zero due to R_L and C_L in the loop compensation circuit is chosen to cancel the pole due to the motor inductance, L_m, then the transfer function can be simplified as shown in figure 4(b), under the assumption that this pole and the pole due to the motor mechanical response are widely separated. C_L may then be chosen to set the desired open loop unity gain bandwidth.

$$C_L = \frac{68 \cdot R_s}{2 \cdot \pi \cdot R_F \cdot (R_m + R_s) \cdot BW}$$

where BW is the unity gain open loop bandwidth

$$R_L = \frac{L_m}{C_L \cdot (R_m + R_s)}$$

The closed loop response of the servo driver and motor combination, using the component values and simplifying assumptions given above, is given by:

$$\frac{i_m}{V_{in}}(s) = - \frac{1}{R_{in}} \cdot \frac{R_F}{4 \cdot R_s} \cdot \frac{1}{(1 + \frac{s}{2 \cdot \pi \cdot BW})}$$

(This analysis neglects the pole due to the output impedance of the MOSFET drivers and the MOSFET gate capacitance, an effect that may be significant in some systems).

R_F is chosen to be sufficiently large to avoid overloading A2 ($R_F \ // \ R_v > 4k\Omega$). The input resistor, R_{IN}, sets the conversion factor from servo controller output voltage to servo motor current. R_{IN} is chosen such that the servo controller internal voltages are scaled conveniently. The resistor R_{OS} is optional and cancels out the effect of the input bias current of A1.

$$R_{os} = R_{in} \ // \ R_F$$

The external components R_D and C_D have no effect on the motor dynamics, but may be used to improve the stability of the MOSFET drivers. The load represented by the motor, ZM, is given by:

At frequencies above $(R_s+R_m)/(2 \cdot \pi \cdot L_m)$ Hz, this load

$$ZM = (R_s+R_m)(1+s\frac{L_m}{R_s+R_m})(1+\frac{K_m^2}{s \cdot J\theta \cdot (R_s+R_m)})(\Omega)$$

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LOOP COMPENSATION (continued)

becomes entirely inductive, which is undesireable. R_D and C_D may be used to add some parallel resistive loading at these frequencies.

H-BRIDGE MOSFETS

The MOSFETs chosen for the H-bridge should have gate capacitances in the range of 500-1000 pF. The MOSFET input capacitance forms part of the compensation for the MOSFET drivers, so values below 500 pF may cause some driver instability. Excessive input capacitance will degrade the slew mode performance of the drivers.

When the motor voltage is changing polarity, the cross-over protection circuits at outputs OUTA-OUTD ensure that the maximum MOSFET gate drive is less than 2V (the crossover separation threshold), as illustrated in Figure 5. The thresholds of the MOSFET devices chosen should be as large as possible to minimize conduction in this region. If the device thresholds are significantly less than the crossover separation threshold, the N and P channel devices in each leg of the H-bridge will conduct simultaneously, causing unnecessary power dissipation.

POWER FAILURE OPERATION

The power supply for the SSI 32H569, VCC, should be taken from the system 12V supply through a Schottky diode (maximum 0.5V drop at If = 3A) and connected to the disk drive spindle motor. If the system power fails, the IC will continue to operate as the spindle motor becomes a generator. The SSI 32H569 will detect the power failure and cause a forced head retract, continuing to operate with VCC as low as 3.5V. The power fail mode will commence if either VCC or LOWV falls below 9V, or VREF falls below 4.3V, or EN is false. Hysteresis on the low voltage thresholds prevents the device from oscillating between operating modes when the power supply is marginal.

The BRK output, which is pulled low during normal operation, floats during a power failure. This allows an external transistor to be enabled for spindle motor braking. An external RC delay may be added to defer braking until head retraction is complete, since the spindle motor is required to generate the supply voltage during retraction.
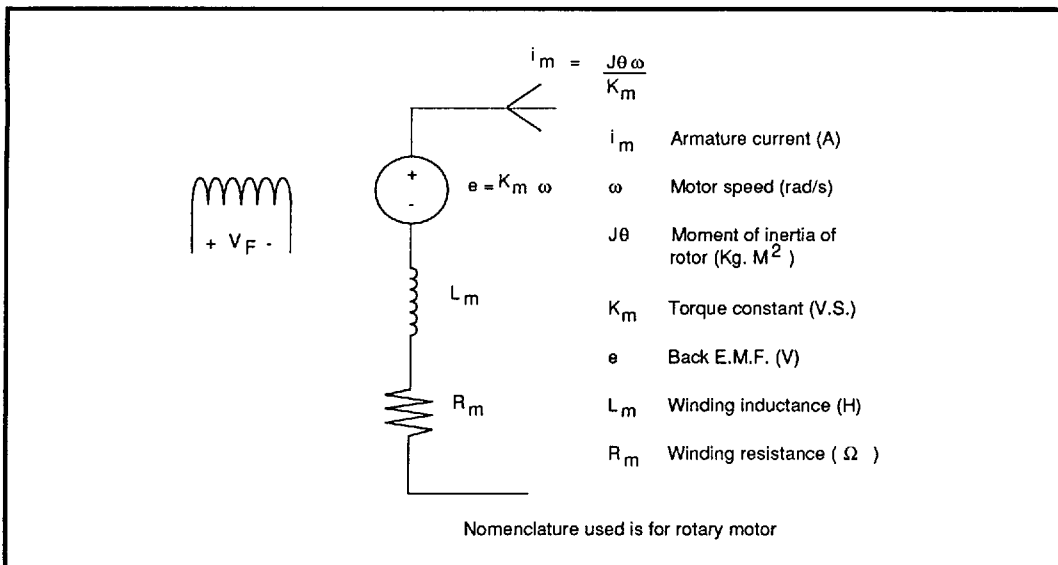

$$i_m = \frac{J\theta\omega}{K_m}$$

i_m	Armature current (A)
ω	Motor speed (rad/s)
$J\theta$	Moment of inertia of rotor (Kg. M^2)
K_m	Torque constant (V.S.)
e	Back E.M.F. (V)
L_m	Winding inductance (H)
R_m	Winding resistance (Ω)

$e = K_m \omega$

Nomenclature used is for rotary motor

FIGURE 3: Equivelant Circuit For Fixed Field DC Motor
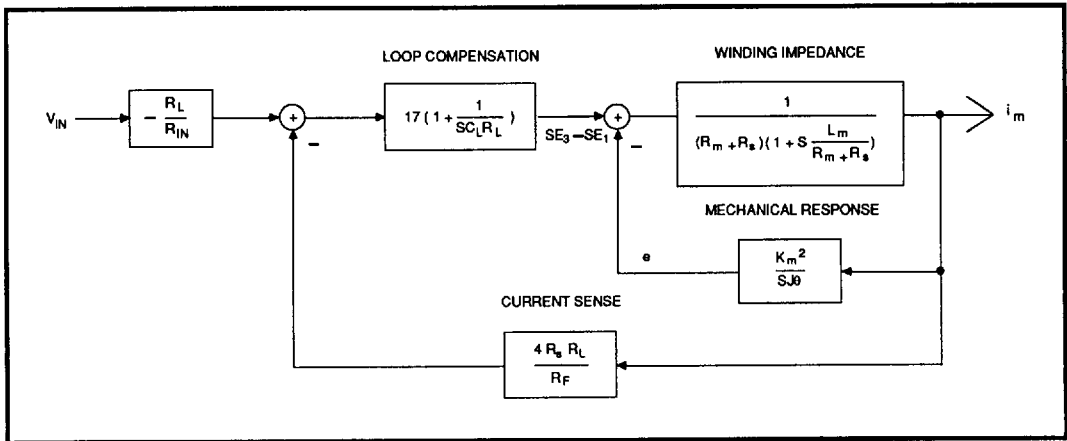
FIGURE 4(A): Transfer Function of SSI 32H569 in Typical Application with Fixed Field DC Motor
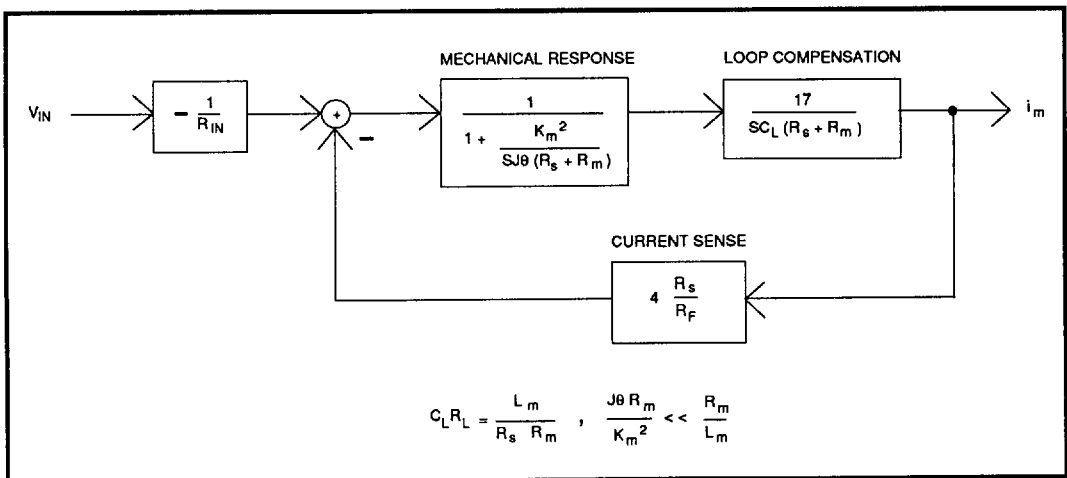

$$C_L R_L = \frac{L_m}{R_s \; R_m} \quad , \quad \frac{J\theta R_m}{K_m^2} << \frac{R_m}{L_m}$$

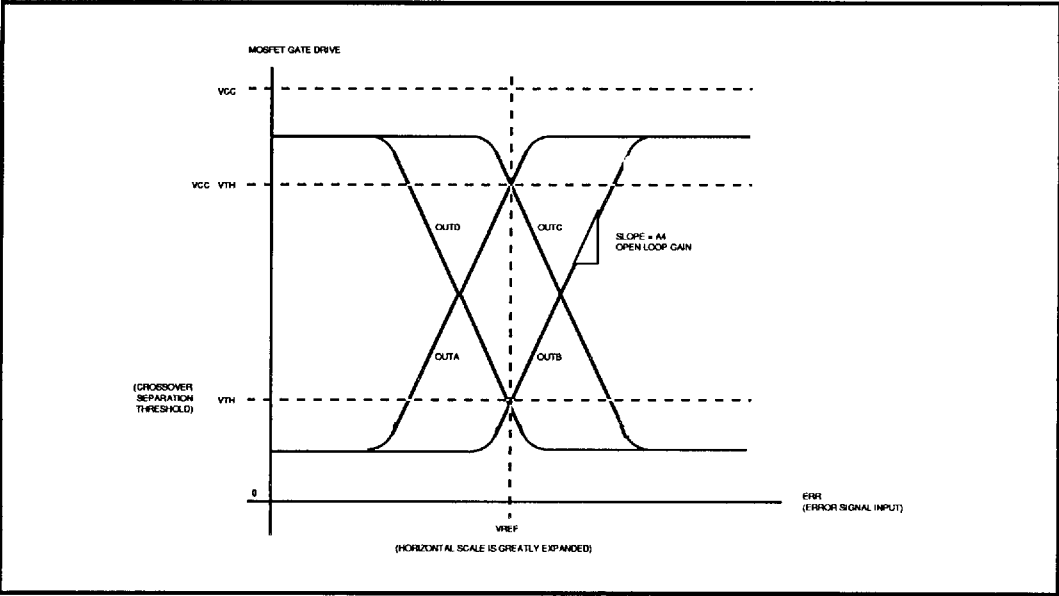**FIGURE 4(B): Simplified Transfer Function of SSI 32H569 in DC Motor Application**
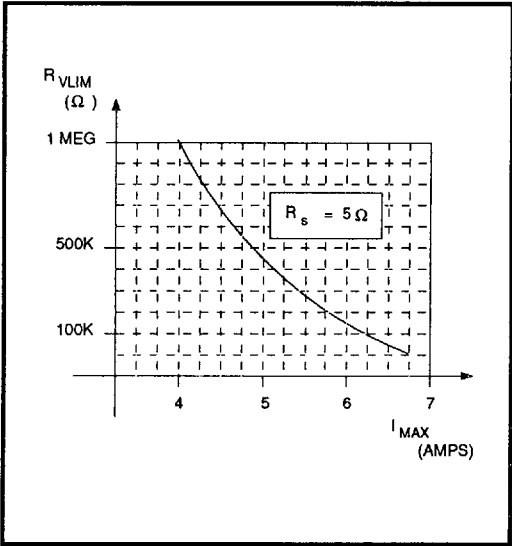
FIGURE 5): Crossover Protection
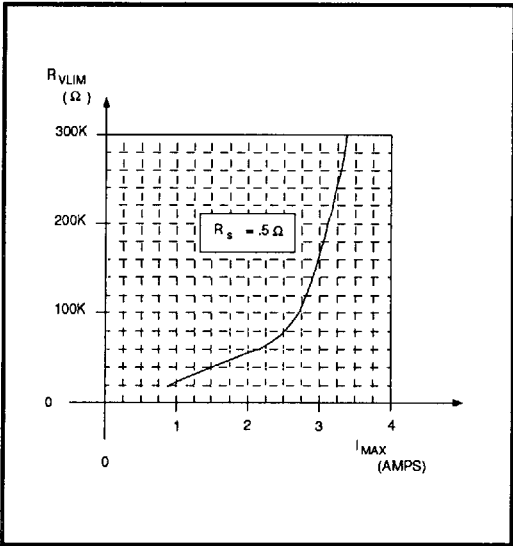

**FIGURE 6: RVLIM To Ground Typical Motor
Current Limit**
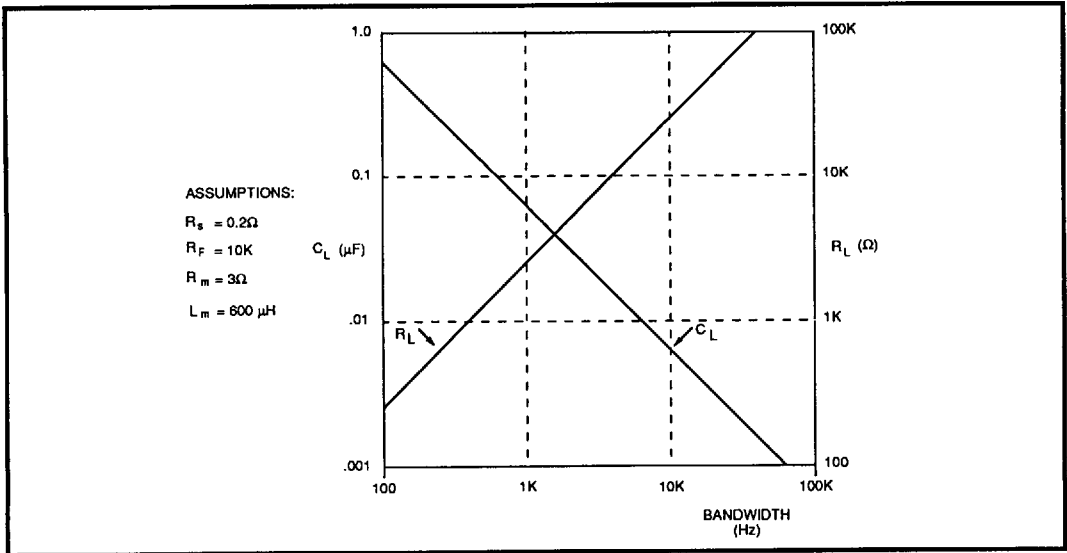

**FIGURE 7: RVLIM To VREF Typical Motor
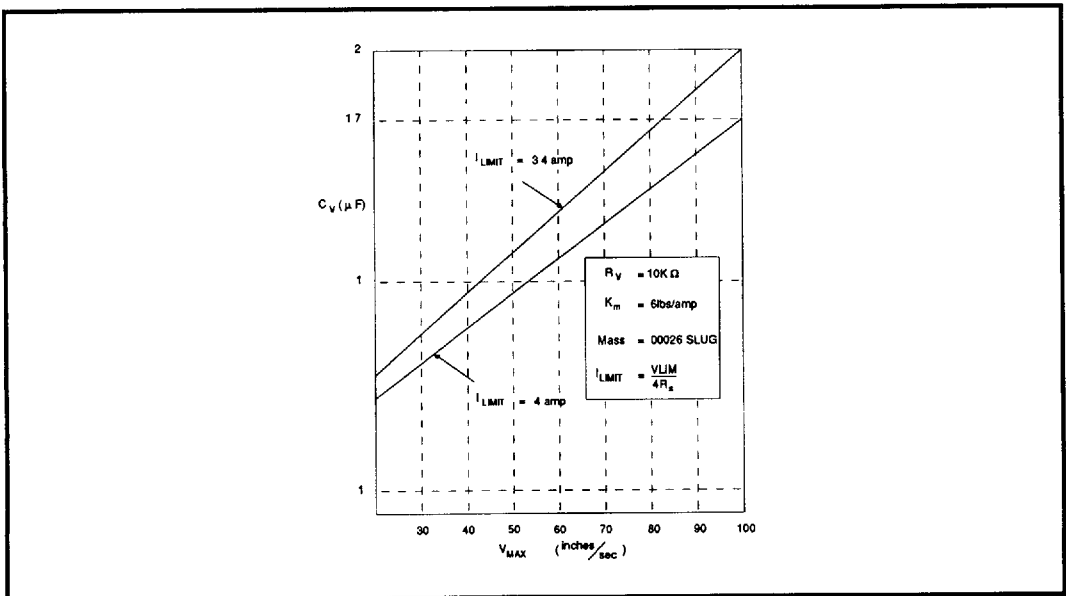Current Limit**

FIGURE 8: Typical Motor Driver Compensation

FIGURE 9: Typical Motor Velocity Limit
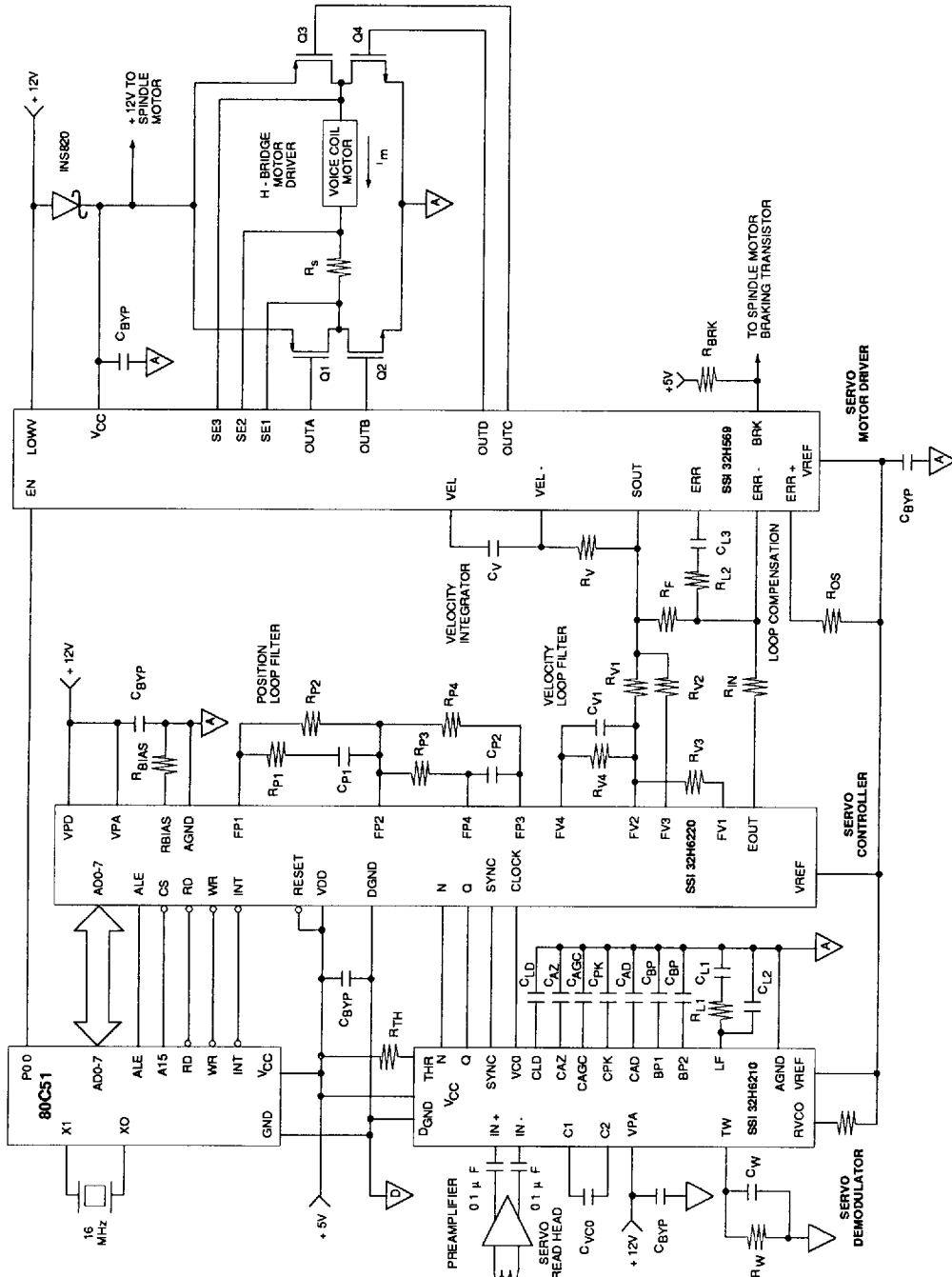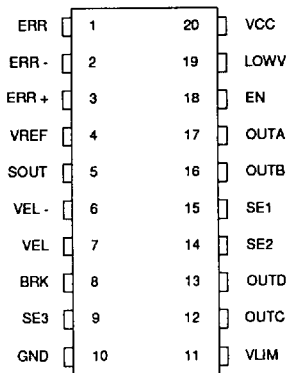
FIGURE 10: Complete Example of Servo Path Electronics Using the SSI 32H6210/ 6220/ 569

PACKAGE PIN DESIGNATIONS

(Top View)

Pin	Signal		Pin	Signal
1	ERR		20	VCC
2	ERR -		19	LOWV
3	ERR +		18	EN
4	VREF		17	OUTA
5	SOUT		16	OUTB
6	VEL -		15	SE1
7	VEL		14	SE2
8	BRK		13	OUTD
9	SE3		12	OUTC
10	GND		11	VLIM

20-Pin SO, DIP

> CAUTION: Use handling procedures necessary for a static sensitive component.

ORDERING INFORMATION

PART DESCRIPTION	ORDER NUMBER	PACKAGE MARK
SSI 32H569, Servo Motor Driver		
20-Pin DIP	32H569-CP	32H569-CP
20-Pin SOL	32H569-CL	32H569-CL

8253965 0009821 803 SIL