élantec

HIGH PERFORMANCE ANALOG INTEGRATED CIRCUITS

EL2007

High Efficiency Precision Servo Driver

Features

- Logic Selection of Class B or D Mode
- Efficient Class D Switching Mode
- Linear Class B Track Mode
- Single Supply Operation 4.5 to 20V
- No External Active Components Required

Applications

- Winchester Disc Head Positioning Servo
- 3.5″ Disc Drive Servo
- Galvo Motors
- Robotics
- DC Motor Controls

Ordering Information

Part No.	Temp. Range	Pkg.	Outline#
EL2007-2CD	−25 to +85°C	24-Pin DIP	MDP0005
EL2007-2CD/E+	−25 to +85°C	24-Pin DIP	MDP0005

General Description

The EL2007 is designed to reduce the power consumption and space required for closed-loop control of voice coil actuator motors in disc head positioning servos and other precision servos. It includes the current sense amplifier, bridge output power drive and the error amplifier.

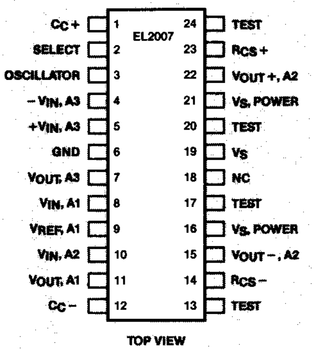
The EL2007 can save power by using a Class D (chopper) mode output drive during the high current "seek" operation. Device dissipation is reduced a factor of three providing higher reliability and easier heat management. During the lower current "tracking" operation, the amplifier switches to conventional Class B analog mode for noise-free data retrieval. A logic input selects the operating mode. The bridge output stage of the 2007 is designed for minimum saturation voltage allowing efficient operation with single supply voltage from 4.5 to 20V.

A low offset differential amplifier senses the output current in the bridge ground return and provides a proportional voltage added to the externally-generated common-mode reference voltage.

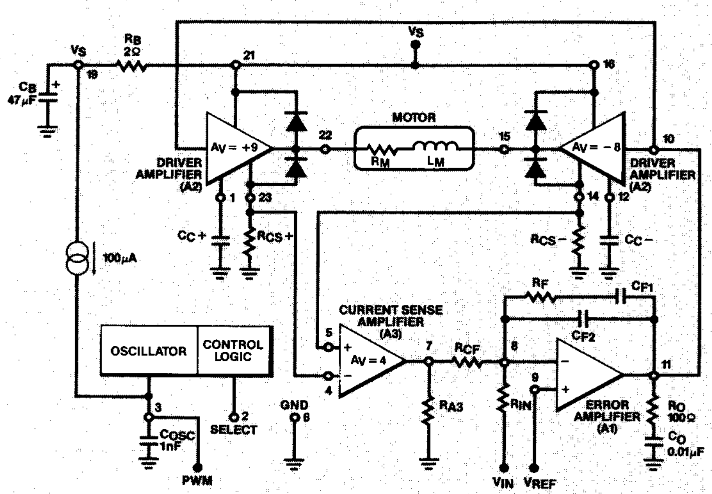
The EL2007 contains all of the control circuitry, the output power transistors and the catch diodes required to drive over 2 Amps in the Class D mode, or 0.75 Amps in the Class B mode. For more current, use the EL2017 with external power transistors.

The EL2007 is available in a 24-lead dual-in-line package.

Connection Diagram



Block Diagram



NOVEMBER 1986 Rev C

Absolute Maximum Ratings (25°C)

V_S	Supply Voltage	20V
V_{IN}	Input Voltage Range (any logic pin)	−0.3V to V_S
	Sense Amp Input Voltage Range	−1.5V to V_S
	Sense Amp Differential Input Voltage Range	±5V
I_{OUT}	Output Current	±2.5A
T_J	Junction Temperature—EL2007	175°C
T_A	Operating Temperature Range	−25°C to +85°C
	Lead Temperature (soldering, 5 seconds)	245°C
T_{ST}	Storage Temperature	−65°C to +150°C
P_D	Power Dissipation—EL2007 (see curves)	10W

Important Note: All parameters having Min./Max. specifications are guaranteed. The Test Level column indicates the specific device testing actually performed during production and Quality Assurance inspection. Elantec performs most electrical tests using modern high-speed automatic test equipment, specifically the LTX 77 Series system. Unless otherwise noted, all tests are pulsed tests, therefore $T_J = T_C = T_A$.

Test Level	Test Procedure
I	100% production tested and QA sample tested per QA test plan QCX0002.
II	100% production tested at $T_A = 25°C$, and QA sample tested at $T_A = 25°C$, T_{MAX} and T_{MIN} per QA test plan QCX0002.
III	QA sample tested per QA test plan QCX0002.
IV	Parameter is guaranteed (but not tested) by Design and Characterization Data.
V	Parameter is typical value for information purposes only.

Electrical Characteristics $T_J = T_A = 25°C$, $R_L = 10\Omega$ (see test figure) (Note 7)

	Parameter	Mode	Volts V_S	Volts V_{REF}	Volts V_{IN}	Min.	Typ.	Max.	Test Level	Units
SYSTEM, CLOSED-LOOP										
K	Gain Constant, I_{OUT}/V_{IN}, $I_{OUT} = \pm 100mA$	B	12	5	Note 1	0.85	1	1.15	I	A/V
I_{OS}	Output Offset Current	B	12	5	5	−35	5	35	I	mA
		B	12	8	8	−40	5	40	I	mA
		B	12	2	2	−40	5	40	I	mA
		B	4.5	2	2	−40	5	40	I	mA
		B	20	2	2	−40	5	40	I	mA
		B	20	16	16	−40	5	40	I	mA
I_Q	Quiescent Supply Current	B	12	5	Open		25	50	I	mA
		D	12	5	Open		20	50	I	mA
		Standby	12	5	Open		12	25	I	mA
		B	20	5	Open		40	100	I	mA
		D	20	5	Open		25	100	I	mA
		Standby	20	5	Open		20	50	I	mA
I_{OUT}	Maximum Output Current $R_L = 5\Omega$	B	12	5	Note 2	±0.75	±1		I	A
		D	12	5	Note 2	±2	±2.5		I	A
V_{SAT}	Total Saturation Voltage, $I_{OUT} = \pm 2A$ (Note 3)	D	12	5	Note 2		1.7	2	I	V
R_{OUT}	Standby Output Resistance (Note 4)	Standby	12	5	Open	1	4		I	kΩ
I_{IH}	Select High Current (20V)	B	12	5	5		0	10	I	µA
I_{IL}	Select Low Current (0V)	D	12	5	5		−10	−200	I	µA
I_{IL}	Oscillator Low Current (0.4V)	Standby	12	5	5		−100	−400	I	µA
I_{BREF}	Reference Voltage Bias Current	Standby	12	5	Open	0.2	0.6	1	I	mA

Electrical Characteristics — (Continued) $T_J = T_A = 25°C$, $R_L = 10\Omega$ (see test figure)

	Parameter	Mode	Volts V_S	Volts V_{REF}	Volts V_{IN}	Min.	Typ.	Max.	Test Level	Units
CURRENT SENSE AMPLIFIER										
A3	Current Sense Amp Gain, Pin 5 = ±400 mV	Standby	12	5	Open	3.6	4	4.4	I	V/V
V_{OSO}	Current Sense Amp Output Offset	Standby	12	5	Open	−20	5	20	I	mV
		Standby	12	8	Open	−30	5	30	I	mV
		Standby	12	2	Open	−30	5	30	I	mV
		Standby	4.5	2	Open	−30	5	30	I	mV
		Standby	20	2	Open	−30	5	30	I	mV
		Standby	20	16	Open	−30	5	30	I	mV
RVRR	Reference Voltage Rejection Ratio	Standby	20	Note 5	Open	50	75		I	dB
PSRR	Power Supply Rejection Ratio	Standby	Note 6	2	Open	50	75		I	dB
CMRR	Common-Mode Rejection Ratio Pin 4 = Pin 5 = ±500 mV	Standby	12	5	Open	50	75		I	dB
I_{OUT}	Output Source Current	Standby	12	5	Open	+5	+10		I	mA
I_B	Input Current	Standby	12	5	Open	0.2	0.6	1	I	mA
ERROR AMPLIFIER										
V_{OS}	Offset Voltage	B	12	5	Open	−10	2	10	I	mV
		B	12	8	Open	−10	2	10	I	mV
		B	12	2	Open	−10	2	10	I	mV
		B	4.5	2	Open	−10	2	10	I	mV
		B	20	2	Open	−10	2	10	I	mV
		B	20	16	Open	−10	2	10	I	mV
RVRR	Reference Voltage Rejection Ratio	B	20	Note 5	Open	50	75		I	dB
PSRR	Power Supply Rejection Ratio	B	Note 6	2	Open	50	75		I	dB
I_{OUT}	Output Current	B	12	5	Open	±5	±20		I	mA
DRIVER AMPLIFIER										
A2	Driver Amp Gain, $I_{OUT} = \pm 750$ mA	B	12	5	Note 1	10	17	20	I	V/V
f_{OSC}	Switching Frequency, $I_{OUT} = \pm 500$ mA	D	12	5	Note 1	20	30	40	I	kHz
	Duty Cycle, $I_{OUT} = \pm 500$ mA	D	12	5	Note 1	35	45	55	I	%
V_S	Supply Voltage Operating Range	Guaranteed by above tests				4.5	12	20	I	V
V_{REF}	Reference Operating Range	Guaranteed by above tests				2	5	$V_S - 4$	I	V

Note 1: V_{IN} is adjusted to set I_{OUT}.

Note 2: $V_{IN} = 2V$ for $I_{OUT} < 0A$, and $V_{IN} = 8V$ for $I_{OUT} > 0A$.

Note 3: Total Saturation Voltage includes the drops across both the PNP and NPN output transistors and the 500mV drop across the 0.25Ω current sense resistor. $R_L = 5\Omega$.

Note 4: $V_{OUT} = V_S/2$.

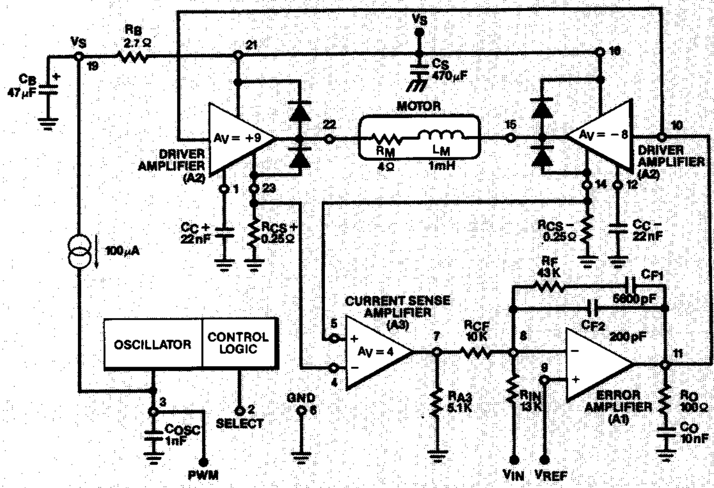
Note 5: $2V < V_{REF} < 16V$.

Note 6: $4.5V < V_S < 20V$.

Note 7: Mode B is forced with pin 2 = 2.0V and pin 3 open. Mode D is forced with pin 2 = 0.6V and pin 3 open. Standby is forced with pin 2 = 0.6V and pin 3 = 0.4V.

External Component Guide

Component	Recommended Value	Purpose	Effect: Smaller	Effect: Larger	Comments
C_C+, C_C-	$0.01\mu F$	A2 Compensation	Oscillation	Crossover	Optimizes linear driver to motor
C_{OSC}	$0.001\mu F$	PWM Oscillator	Higher Frequency	Lower Frequency	Switching Frequency $f = 30\,kHz @ 0.001\mu F$
$R_{CS}+$, $R_{CS}-$	0.25Ω	Senses output current	Higher I_{OS}	Lower $I_{O\,max}$	$R_{CS} \leq \frac{0.5\,V}{I_{O\,max}}$
R_{IN}	$10\,k\Omega$	Sets Overall Gain Constant	Higher Gain	Lower gain	$K = \frac{R_{CF}}{4 \times R_{CS} \times R_{IN}}$
R_{CF}	$10\,k\Omega$	Current Sense Amp Feedback	Loads A3	ok	
R_O	100Ω	Stabilize A1	Oscillation	Oscillation	Use the values shown
C_O	$0.01\mu F$				
R_B	$2.7\Omega \pm 10\%$	Filter the supply to the control circuit	Possible jitter in switch mode	Thermal Runaway	May not be necessary
C_B	$47\mu F$			ok	
R_F	$10\,k\Omega$–$100\,k\Omega$	R_F, C_{F1} cancel the motor pole and set the loop gain	Loop Oscillations	Loop Oscillations	$C_{F2} = \frac{30.4\,R_{CS}}{L_M \cdot R_{CF}\,(2\,\pi\,BW)^2}$
C_{F1}	$1\,nF$–$4.7\,nF$				$C_{F1} = \left(\frac{60.7\,R_{CS}}{R_M \cdot R_{CF} \cdot 2\,\pi\,BW}\right) - C_{F2}$
C_{F2}	0–$1\,nF$	Filters switching transients	Jitter in switch mode	Loop Oscillations	$R_F = \frac{L_M}{R_M \cdot C_{F1}}$
R_{A3}	$5\,k\Omega$	Provides sink current for A3	$I_{quiescent}$ increases	Limits swing of A3	$I_{SINK} = \frac{V_{O\,min}}{R_{A3}}$



Design Example

Design Example

Given the following design parameters, calculate the external components required to optimize the performance of the EL2007.

System Requirements:

1.6 Amps Max — Gain = 750 mA/V
Bandwidth = 10 kHz — V_{REF} = 5 V
Current Sense Amp Load = 5 k to V_{REF}
Switching frequency > 20 kHz

Motor Characteristics: $R_M = 4\Omega$ $L_M = 1$ mH

Step 1. System-Dictated Components

a. $R_{CS}+$ and $R_{CS}-$

The optimum value of R_{CS} times the maximum output current should equal 400 mV. This ensures that the input signal to the current sense amp is as large as possible without ever overloading those inputs.

$$R_{CS}+ = R_{CS}- = +0.4\,V/I_{OUT}\,(max) = 0.4/1.6 = 0.25\Omega$$

Power Dissipation

$$P = I^2 \cdot R \qquad P_{Dmax} = (1.6)^2 \cdot 0.25 = 0.64\,W$$

b. R_{CF}

Choose R_{CF} to be 10k.

This is a convenient, arbitrary value that is a compromise between loading of A3 and high-impedance pick-up problems.

c. R_{A3}

Amplifier A3 must be loaded to provide output sink capability. The amount of sink current required is 2 V divided by the load, in this case R_{CF} and another load of perhaps 5k in a different part of the overall system (for example the input of an integrator). The minimum value of A3's output is 2 V less than V_{REF}, hence:

$$R_{A3} = (V_{REF} - 2)/I_{SINK\,(max)} = 3/(2/3.3k) = 5k$$

d. R_{IN}

Use R_{IN} to set the overall gain constant, K, because R_{IN} does not affect any other parameters.

$$R_{IN} = R_{CF}/(4 \cdot R_{CS} \cdot K) = 10k/(4 \cdot 0.25 \cdot 0.75) = 13.3k$$

Step 2. Motor Compensation Components

The design equations for the compensation components are derived in the loop operation and compensation section of this data sheet. The value for the bandwidth, BW, is not as straightforward as most of the other parameters. Certainly the bandwidth should be large enough so the electrical system adds a minimum of phase-shift and the overall response is dominated by the slower mechanical system; but too wide a bandwidth will only introduce more noise into the loop. Usually the overall servo system will be designed with a bandwidth of 500 Hz to 2500 Hz, so an electrical bandwidth of 10 times that will only introduce 6° of phase shift. The small signal rise time of the current in the motor for a step function input voltage is approximately: $t_{RISE} = 0.35/BW$.

a. C_{F2}

$$C_{F2} = (30.4 \cdot R_{CS})/(L_M \cdot R_{CF} \cdot (2\pi\,BW)^2) = 30.4 \cdot 0.25/(1\,mH \cdot 10k\,(2\pi \cdot 10\,kHz)^2) = 193\,pF$$

b. C_{F1}

$$C_{F1} = (60.7 \cdot R_{CS})/(R_M \cdot R_{CF} \cdot 2\pi\,BW) - C_{F2} = 60.7 \cdot 0.25/(4 \cdot 10k \cdot 2\pi \cdot 10\,kHz) - 193\,pF = 5{,}845\,pF$$

c. R_F

$$R_F = L_M/(R_M \cdot C_{F1}) = 1\,mH/(4 \cdot 5{,}845\,pF) = 42.77k$$

The linear power amplifier A2 requires compensation capacitors C_C+ and C_C-; the derivation of the following formula is in the detailed circuit descriptions.

d. C_C+ and C_C-

$$C_C+ = C_C- = L_M/(R_M \cdot 10k) = 1\,mH/(4 \cdot 10k) = 0.025\,\mu F$$

Step 3. EL2007 Components

a. C_{OSC}

$C_{OSC} = 0.001\mu F \cdot 30\,kHz/f_{OSC}$, Choose $C_{OSC} = 0.001\mu F$ initially

Capacitor C_{OSC} determines the switching frequency of the class D pulse width modulator. The switching frequency and the L_M/R_M time constant of the motor determine how much ripple there is in the output current. Usually, the mechanical response of the motor to this ripple is negligible. However this AC signal does generate power losses in the motor. Therefore, efficiency is better when the ripple is minimized, but the EL2007 power transistors have finite switching times and losses that limit how fast the oscillator can operate. Typically, the efficiency worsens for oscillator frequencies above 35 kHz. It is easy to change C_{OSC} and monitor the supply current to evaluate efficiency for a given motor.

b. R_O and C_O

Choose $R_O = 100\Omega$ and $C_O = 0.01\mu F$

The values of R_O and C_O should not be changed, they compensate the internal circuitry of A2.

c. R_B and C_B

R_B and C_B form an optional filter between the main power supply and the internal control circuitry's supply, pin 19. If the main supply is very well bypassed with a good quality capacitor near the EL2007, then R_B and C_B are not required and pin 19 should be shorted to pins 16 and 21. To evaluate the need for R_B and C_B, check the very high current switch mode performance without them.

The maximum value of R_B is 2.7Ω (±20%).

Step 4. Standard Values

The components just calculated should be rounded off to the nearest standard value available. All components can be 20% tolerance, however the resulting variation in gain constant would not be desireable. The value of R_{IN}, R_{CF}, $R_{CS}+$ and $R_{CS}-$ should be tighter tolerance (5%) for good control of the gain constant.

Application Information

Circuit Description

The EL2007 is a precision servo driver that contains all of the active circuitry required to control the current in a variety of DC servo motors. To optimize accuracy, speed and efficiency of the system with a given motor the only external parts required are inexpensive passive components.

To form a closed-loop control system three amplifiers are required: the power driver, the current sense amplifier, and the error amplifier. All three of these and special control circuitry are included on the EL2007. Each of these amplifiers on the EL2007 has been optimized for its particular function.

Error Amplifier

Error amplifier, A1, is a conventional operational amplifier that is configured as an inverting summing amplifier. Its gain characteristics are set by a user-selected feedback network. The controlling input, V_{IN}, is fed to the summing node of this amplifier, and is summed with the reference voltage applied to the V_{REF} input. The difference between these two voltages causes a current to flow through the feedback network. The result is an error voltage at the output of the error amplifier which is used to control the power driver.

Power Driver

The power driver A2 is a unique bridge amplifier that can be operated in either a linear, class B mode, or as a switching amplifier in the class D mode. It has a single-ended input and a differential output with the gain preset at 17V/V for either mode. The mode is controlled by a logic signal to the SELECT input. A low forces the amplifier into its class D (Pulse Width Modulation) mode. These two modes are provided to allow the user to select the optimum mode for the particular operating requirement. Class B linear mode is recommended for tracking operations where less than 500 mA is required and noise must be kept to a minimum. This is applicable during data transfer or while on track. Class D mode is used for rapid motor movements such as those required during seek operations.

Current Sense Amplifier

The current sense amplifier A3 is a differential input instrumentation amplifier with a preset gain of 4V/V. It senses motor current by taking the voltages from the two current sense resistors $R_{SC}+$ and $R_{SC}-$. It is the value of these current sense resistors and the values of R_{IN} and R_{CF} that set the gain constant ($K = I_{OUT}/V_{IN}$) of the loop. The inputs from the current sense resistors are then amplified and summed with the V_{IN} input to complete the servo loop.

Oscillator

An oscillator with a frequency of 30 kHz is provided to switch the amplifier when the class D mode is selected. The PWM input is controlled from this pin. By pulling this pin low while the SELECT pin is low the amplifier can be put into a high output impedance mode.

Logic Control Inputs

There are three modes of operation for the EL2007. They are operation in the class B mode, in the class D mode and the STANDBY mode. These three modes of operation (see Mode Control Truth Table) of the EL2007 are controlled by the SELECT input (pin 2) and the PWM input (pin 3). The SELECT input is a high-impedance logic input with TTL thresholds. The PWM input is also the oscillator capacitor connection. This capacitor is charged by an internal current source that supplies approximately 100 μA. Operation of the oscillator requires about 90 μA so it is important not to draw over 10 μA from this input. *For proper oscillator operation the PWM input should be driven by an open collector without any external pull-up resistor.*

Mode Control Truth Table

MODE	SELECT	PWM
Class B	1	X
Class D	0	Open
Standby	0	0

Power-Up

The EL2007 powers up without any transient being applied to the motor if the V_{IN} input voltage is equal to the V_{REF} input voltage, and if this voltage is within the normal operating range. If these conditions cannot be met at power-up and power should not be applied to the motor, the control logic inputs should be held low for power-up in the STANDBY mode.

Power-Down

The EL2007 will continue to operate normally with reduced supply voltage (down to 4.5 V) as long as the reference voltage is 2 V less than the supply voltage and greater than 2 V above ground.

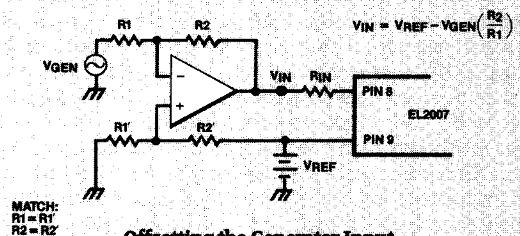
If the reference voltage is within 1.5 V of the supply voltage the output will force maximum current through the motor. If no current is desired through the motor during power-down then the control inputs should be held low forcing the output into the STANDBY mode.

If power is required through the motor during power-down, then it should be in the direction corresponding to a low V_{IN} signal (pin 15 low and pin 22 high). This will prevent the problems caused by the supply dropping to within 1.5 V of V_{REF}. If a power-down logic signal is available, it can be used to force V_{IN} or pin 8 low. This will force the motor drive outputs in the same direction as the supply decays. The only change in this would be if the reference voltage decays faster than the supply voltage.

Evaluation

The EL2007 is designed to be used with a single supply voltage. This operation requires a V_{REF} voltage above ground. As most function generators are ground-referenced, the circuit shown below is an easy way to offset the generator.

Op amp input offset voltage and resistor mis-match will introduce additional output offset current into the motor. For a unity gain circuit with 0.1% resistors and a 5 mV offset op amp the worst case additional output offset current is 20 mA.



Offsetting the Generator Input

Loop Operation and Compensation

The following equivalent circuit (figure 1) is used to calculate the passive components required for the feedback network of the error amplifier. The forward gain of the loop is defined as $G(s) = I_{OUT}/I_{IN}$ and the feedback factor is $H(s) = I_F/I_{OUT}$. For stability the product, $G(s) \bullet H(s)$, cannot equal −1.

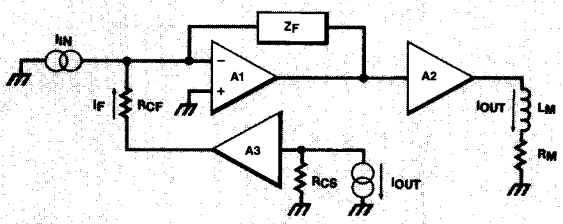


Figure 1. System Loop-Equivalent Circuit

$$G(s) = I_{OUT}/I_{IN} = \frac{Z_F \cdot A2}{R_M} \; \frac{1}{sL_M/R_M + 1} \tag{1}$$

$$H(s) = I_F/I_{OUT} = \frac{R_{CS} \cdot A3}{R_{CF}} \tag{2}$$

$$G(s)\,H(s) \neq -1 \tag{3}$$

$$-1 \neq \frac{Z_F \cdot A2}{R_M} \; \frac{1}{sL_M/R_M + 1} \; \frac{R_{CS} \cdot A3}{R_{CF}} \tag{4}$$

Z_F can be any network that satisfies the stability criterion above. For maximum bandwidth, Z_F should have a zero that cancels the pole due to the L_M/R_M time constant of the motor. Z_F should also have the dominant pole of the feedback loop and another non-dominant pole for additional filtering that is desirable in the class D switching mode. The following network (figure 2) for Z_F has these characteristics.

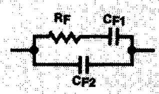


Figure 2. Feedback Network

$$Z_F = \frac{sR_F \cdot C_{F1} + 1}{s(C_{F1} + C_{F2}) \left(\frac{sR_F \cdot C_{F1} \cdot C_{F2}}{C_{F1} + C_{F2}} + 1 \right)} \tag{5}$$

In this network the zero is due to R_F and C_{F1}. The dominant pole is due to C_{F1} in parallel with C_{F2}. The non-dominant pole is due to R_F and the series combination of C_{F1} and C_{F2}. C_{F1} is usually much greater than C_{F2} so there is minimal interaction.

To cancel the motor pole, the zero of the feedback network is used. The resulting equation is:

$$R_F \cdot C_{F1} = L_M / R_M \tag{6}$$

Substituting this Z_F into the stability equation (3) gives:

$$G(s)\,H(s) = \frac{A2 \cdot R_{CS} \cdot A3}{s(C_{F1}+C_{F2})\left(\frac{sR_F \cdot C_{F1} \cdot C_{F2}}{C_{F1}+C_{F2}}+1\right) R_M \cdot R_{CF}} \tag{7}$$

The frequency where the magnitude of G(s) H(s) equals 1 is the bandwidth of the closed-loop system. It will be useful to refer to this frequency so we will define it as BW. For a feedback system to have no output overshoot for a squarewave input, there should be about 60° of phase margin. This will result in a very stable system and is the criteria that we will use in calculating the values for Z_F. If G(s) H(s) is equal to 1 at one half the frequency of the non dominant pole then there will be 22° of phase shift due to that pole. There will also be 90° of phase shift due to the dominant pole resulting in about 68° of phase margin. This meets our criteria so we will use it. The bandwidth of the system can now be defined as:

$$BW = \frac{1}{2}\left(\frac{1}{2\pi \frac{R_F \cdot C_{F1} \cdot C_{F2}}{C_{F1}+C_{F2}}}\right) = \frac{C_{F1}+C_{F2}}{4\pi R_F \cdot C_{F1} \cdot C_{F2}} \tag{8}$$

By again substituting into the stability equation (7):

$$G(s)\,H(s) = \frac{A2 \cdot R_{CS} \cdot A3}{R_M \cdot R_{CF}\, s(C_{F1}+C_{F2})\left(\frac{s}{4\pi BW}+1\right)} \tag{9}$$

Now let $s = j2\pi BW$ and magnitude $G(s)\,H(s) = 1$:

$$1 = \frac{A2 \cdot R_{CS} \cdot A3}{R_M \cdot R_{CF}\, 2\pi BW\,(C_{F1}+C_{F2})\, 1.12} \tag{10}$$

(Note: $|j/2+1| = 1.12$)

Solve equation (10) for $(C_{F1}+C_{F2})$, take the motor pole cancellation constraint equation (6) and substitute those results into the bandwidth definition equation (8) and solve for C_{F2}. The result is:

$$C_{F2} = \frac{A2 \cdot R_{CS} \cdot A3}{R_{CF}\, 2(1.12)\, L_M\, (2\pi BW)^2} \tag{11}$$

Equations (10) and (11) are now solved for C_{F1} resulting in:

$$C_{F1} = \frac{A2 \cdot R_{CS} \cdot A3}{R_M \cdot R_{CF}\, 1.12\,(2\pi BW)} - C_{F2} \tag{12}$$

Rewriting equation (6) for R_F yields:

$$R_F = \frac{L_M}{R_M \cdot C_{F1}} \tag{13}$$

To simplify this further we can now substitute in the constants of the EL2007. These constants are the gains of the current sense amplifier, $A3 = 4$, and the gain of the power amplifier, $A2 = 17$. This yields the final equations for the feedback network:

$$C_{F2} = \frac{30.4\, R_{CS}}{L_M \cdot R_{CF}\,(2\pi BW)^2} \tag{14}$$

$$C_{F1} = \frac{60.7\, R_{CS}}{R_M \cdot R_{CF} \cdot 2\pi BW} - C_{F2} \tag{15}$$

$$R_F = \frac{L_M}{R_M \cdot C_{F1}} \tag{16}$$

Detailed Circuit Description: Current Sense Amplifier

The current sense amplifier is a differential input amplifier with low offset and good common-mode rejection for signals above and below ground. Common-mode inputs below ground occur when the EL2007 is operated in the switched mode.

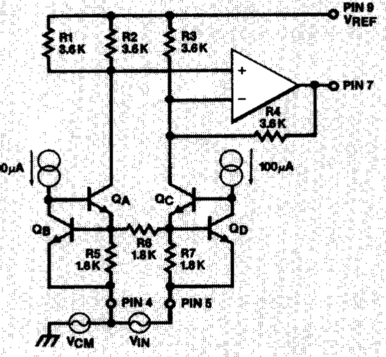


Figure 3. Current Sense Amplifier

To simplify analysis of the current sense amplifier, assume that all of the transistors shown in Figure 3 have zero base current. Transistor Q_b operates with a constant V_{CE} and a constant I_C; therefore the base-emitter voltage of Q_b is constant and the current in R5 is constant. The same is true of Q_d and R7. Since the V_{BE} of Q_b and Q_d are constant, the voltage across R6 is equal to the differential input voltage, V_{IN}, and everything is independent of the common-mode voltage, V_{CM}.

The collector current of Q_a is equal to the current in R5 less the current in R6. Similarly the collector current in Q_c is equal to the current in R7 plus the current in R6. Both of these collector currents are independent of V_{REF} and V_{CM}. This results in good high-frequency CMRR. The conversion of the differential input voltage into current allows easy level shifting to the reference voltage.

A differential amplifier and four equal value resistors convert the differential current to a single-ended output voltage. This configuration has a gain of 2, resulting in an overall gain of 4V/v. The maximum allowable differential input voltage is determined by the current that flows in R6. This current cannot exceed the current in R5 or R7. Since R5, R6, and R7 are all equal, the maximum input voltage is one V_{BE}. This is about 500 mV over temperature.

Power Driver—Switched-Mode

The switched-mode (class D) section (see figure 4) of the EL2007 consists of a triangle wave oscillator, two comparators, and the output power transistors that are connected as an "H" bridge.

The oscillator circuit uses a 0.001µF external capacitor on pin 3 to set the frequency at approximately 30 kHz. The voltage on the capacitor is buffered by an emitter follower, Q1. Comparators U1 and U2 monitor the buffered voltage and compare it to the voltage at the R1, R2, R3 resistive divider string. When U1 senses the oscillator voltage equal to the upper trip voltage, U1 sets the flip-flop and turns on the 2I current source that discharges the external capacitor. When U2 senses the buffered voltage equal to the lower trip voltage, U2 resets the flop-flop turning off the 2I current source, allowing the external capacitor to recharge. The result is a triangle wave at the inputs of U1 and U2 that is centered at half the supply voltage with a peak-to-peak amplitude equal to 10% of the supply voltage.

Resistors R4, R5 and R6 level-shift the voltage at the input of U1 and U2 by 5% of the supply. The resulting voltage applied to comparator U3 is a triangle wave going from 50% to 60% of the supply. Similarly the voltage fed to U4 is from 40% to 50% of the supply. The signal on pin 10 determines if U3 or U4 switches and for how long they stay on.

The output of U3 switches a transistor that drives one side of the "H" bridge and U4 drives the other. Level shifting the triangle wave to the comparators ensures that only one side of the bridge is on at any time. This maximizes efficiency and eliminates the possibility of overlapping conduction of the output power bridge.

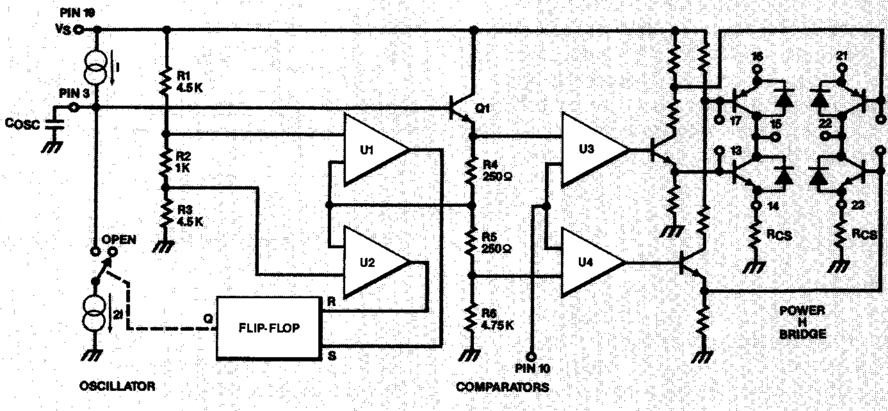


Figure 4. Pulse Width Modulator

Power Driver—Linear Mode

In the linear mode (class B), the power driver consists of two identical amplifiers that are connected as a bridge amplifier (figure 5). One amplifier is set up with an inverting gain of −8V/V and the other with a noninverting gain of 9V/V. This gives a total gain of 17V/V for the bridge amplifier.

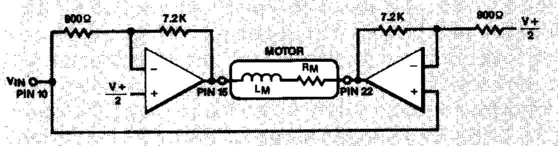


Figure 5. Linear Mode Driver Amplifier

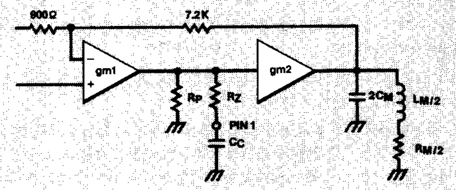


Figure 6. One A2 Amplifier—Equivalent Circuit and Load

Figure 6 shows the unusual amplifier configuration chosen to give maximum output swing and high slew rate. To understand the compensation capacitors, C_C+ and C_C−, we must look at the equivalent circuit of one of the two amplifiers. From figure 6 it is apparent that the open-loop gain of the amplifier is a function of the load impedance. The forward open-loop gain with no resistive feedback can be expressed as:

$$A_{VOL} = \quad (17)$$

$$gm1\left(\frac{R_P(1+s\,R_Z\,C_C)}{1+sC_C(R_P+R_Z)}\right)\cdot\left(gm2\,\frac{(R_M/2)(1+s\,L_M/R_M)}{1+s\,C_M\,R_M+s^2\,C_M\,L_M}\right)$$

For minimum phase shift in the critical low frequency region, the zero due to the L_M/R_M time constant should be canceled by the pole due to C_C. The resulting open-loop gain will be a bandpass with the normal zero at the origin moved out to a higher frequency near the motor coil resonance. This is a two pole, one zero circuit and is stable with resistive feedback. The EL2007 constants for equation (17) are:

gm1 = 1mMho, gm2 = 2 Mho, R_P = 10k, R_Z = 100Ω.

This and the cancellation requirement give the following design equation:

$$C_C = \frac{L_M}{R_M \cdot 10\,k} \quad (18)$$

The high-frequency response of this amplifier is a function of the coil impedance and the resistor R_Z in series with C_C. This response is usually not important in a servo system because it is well above the bandwidth of the total loop. Because the feedback resistors used in the power driver are internal, the open-loop response cannot be measured. To measure the closed-loop response, the circuit shown in figure 7 below is recommended. The 10k potentiometer is adjusted for an output current of about 50 mA to eliminate crossover distortion in the small signal response.

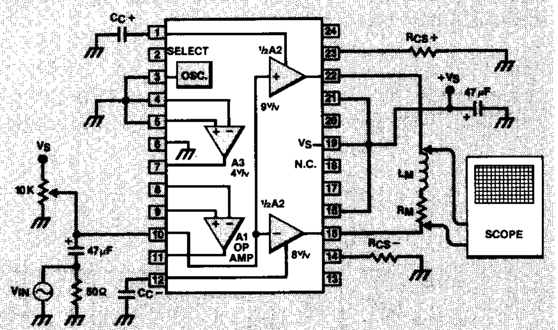
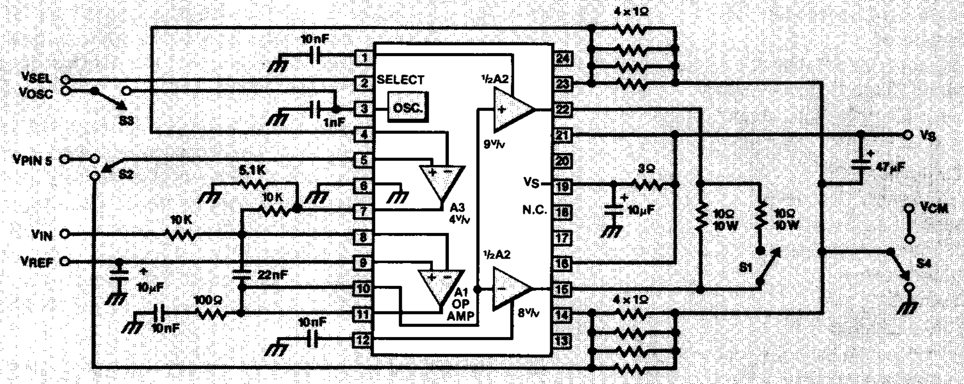


Figure 7. Evaluation Circuit for A2

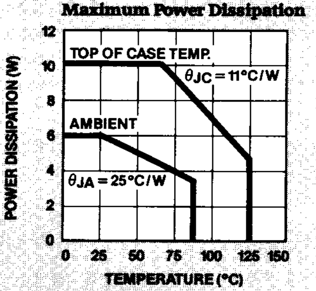
For additional applications help dial (800) 821-7429, in California (408) 945-1323.

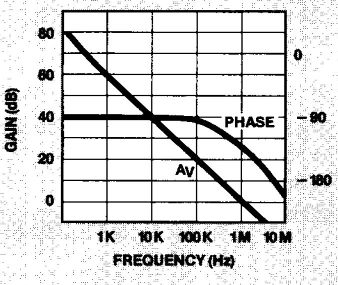
Test Circuit

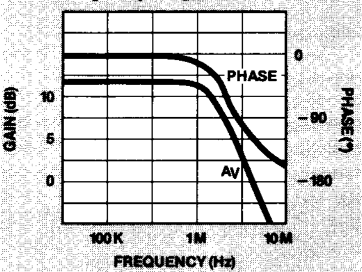


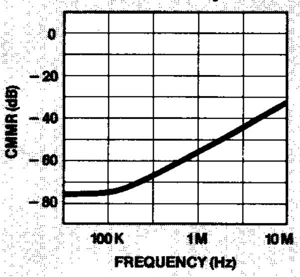
ALL RESISTORS 1%

Typical Performance Curves









Burn-In Circuit