VLA TECHNICAL REPORT #10

PUMP REGULATOR

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I. LIST OF RELATED DOCUMENTS

Drawing Title	Number
1. Pump Controller Box	C13110M18
2. A-B Plate, Pump Source Mounting	C13170M71
3. A-B Bracket, Pump Source Angle	C13170M72
4. C-D Plate, Pump Source Mounting	C13170M77
5. C-D Bracket, Pump Source Angle	C13170M79
6. Bracket, Mounting Temperature Sensor	B13140M3
7. Pump Power Supply and Temperature Regulator Drilling/Cutting Diagram	C13140M2
8. Pump Power Supply and Temperature Regulator Component Layout Diagram	C13140P1

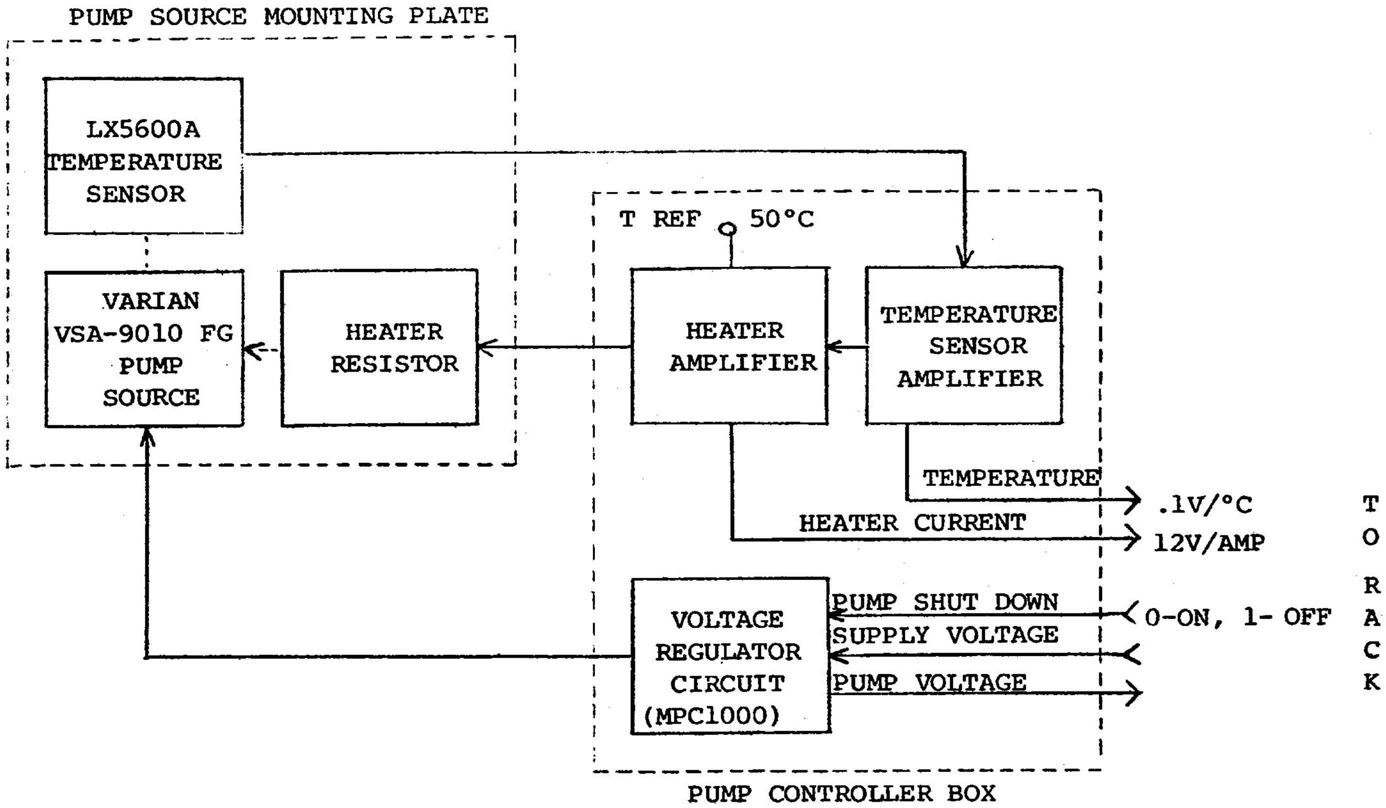


FIGURE 1. Pump Power Supply and Temperature Regulator Block Diagram

NOTES:

1. The heat current is obtained by dividing the voltage by the heater resistor value (i.e. $\frac{V_H}{12\Omega}$).

2. The source temperature in °C is obtained by multiplying the temperature monitor voltage by 10.

3. The source current can be obtained (in amps) by subtracting the pump voltage from the supply voltage.

4. The temperature sensor, pump source, and heater resistor are all thermally coupled on the pump source mounting plate.

5. If the pump is shut down for more than a few seconds up to 10 minutes may be required for temperature restabilization of the pump source.

III. THEORY OF OPERATION

1. Pump Power Supply

The power supply portion of the Pump Power Supply and Temperature Regulator consists of a Motorola MPC1000 voltage regulator I.C. and related outboard components. To allow for component variations, and variations in the voltage required by different pump sources, the output of the regulator has been made adjustable from a minimum of 5.1V to a maximum of 8.4V. This is accomplished by varying R_{18} which, with R_{19} makes up a voltage divider. A second voltage divider (R_{15}, R_{16}) is connected to the non-inverting input of the I.C. The minimum output voltage is set by this second voltage divider. The output of the regulator will be that voltage required to bring the inverting and non inverting inputs to equal potentials.

$$V_0 = \frac{V_{ref} R_{16}}{R_{15} + R_{16}} \times \frac{R_{18} + R_{19}}{R_{19}}$$

Current limiting is accomplished by setting the value of R_{17}. $I_{max} = \frac{0.66}{R_{17}}$. The value used for R_{17} (.24Ω) gives I_{max} of 2.75A.

2. Temperature Controller

In order to keep the power output from the pump source constant, it must be thermally stabilized. The temperature controller used to accomplish this is of the proportional type, that is, the heater power is automatically adjusted to that value that will just replace the heat lost at the stabilized temperature. There are three basic elements in the temperature controller; the temperature sensor, the temperature sensor amplifier, and the heater amplifier.

The temperature sensor used is the LX5600A temperature transducer by National Semiconductor (see data sheet). This I.C. provides a voltage output which changes linearly with temperature at a rate of 10 mV/°C.

The Temperature Sensor amplifier is an AD506KH op amp connected as a gain-of-ten inverting amplifier. An offset circuit is included at the input to allow the circuit to give a reading proportional to the temperature in °C. This also allows corrections to be made for errors in the sensor output. The final output of this amplifier is 100 mV/°C which is fed to the monitor system and to the heater amplifier.

The heater amplifier consists of an AD741KN op amp (I.C.$_2$) connected as a differential amplifier, followed by a Darlington pair emitter follower (Q_1, Q_2) and the heater resistor (R_{14}). A reference voltage (5V nom) is provided to the positive input of IC_2 by voltage divider R_9, R_8. The heater circuit will try to raise the temperature of the source-heater-sensor plate to 50°C (5V out) in order to reduce the voltage differential between + and - inputs of IC_3 to zero. An extremely large DC gain for the circuit is insured by blocking the DC action of C_1, resulting in high precision for the temperature of the plate. Oscillation of the circuit is prevented by choosing C_1 so that the gain of the circuit at frequencies comparable to $\frac{1}{\tau}$ (τ is the thermal time-constant of the plate) is greatly reduced.

IV. TEST AND CALIBRATION

Initial Test

Apply power to the unit through the input connector ZDP4/ZDP6 (see wiring list). The following voltages should be measured at the five test points on top of the unit; and on the connectors:

	TEST POINT COLOR	VOLTAGE	INDICATED VALUE
1.	Black	0.00	Ground
2.	Brown	≈14	Temperature
3.	Red	≈13	Heater Current
4.	Orange	≈ 5.1-8.4V	Pump Voltage
5.	Yellow	Same as above	Supply Voltage

CONNECTOR ZDP4/ZDP6

PIN #	VOLTAGE	INDICATED VALUE
1	+15	+15 Supply
2	0	Ground
3	-15	-15 Supply
4	≈14	Temperature
5	≈13	Heater Current
6	≈.1	Pump Shut Down
7	5.1-8.4	Pump Voltage
8	5.1-8.4	Supply Voltage

CONNECTOR ZDJ5/ZDJ7

PIN #	VOLTAGE	INDICATED VALUE
1	-2	IC_2 Input
2	+15	+15 Supply
3	5.1-8.4	Pump Voltage
4	≈13	Heater Voltage
5	0	Ground

Turn the regulator voltage adjust pot, R_{18}, counterclockwise for minimum voltage as monitored at test point 5, (yellow). This voltage should be approximately 5.1 volts.

Calibration

Connect an LX5600A temperature sensor to the output connector ZDJ5/ZDJ7 (see wiring list). Thermally couple the sensor to something of known temperature (i.e. a thermometer), and apply power as in the in Initial Test section. While monitoring the voltage at the Brown test point, adjust the sensor cal pot until ten times this voltage gives the temperature in °C (i.e. 2.4 volts = 24°C). Keep the sensor with the unit, as calibration is difficult after installation.

V. INSTALLATION/REPLACEMENT

CAUTION

1. DO NOT PLUG IN PUMP SOURCE CONNECTOR UNTIL THE PUMP SOURCE VOLTAGE HAS BEEN REDUCED TO MINIMUM. THIS VOLTAGE IS MONITORED AT TEST POINT 5, (YELLOW), AND IS ADJUSTED BY THE REGULATOR VOLTAGE POT, R18.

2. Install the temperature sensor for which the unit is calibrated in the sensor mount on the pump source. Connect ZDJ8/ZDJ9 to the sensor taking care to see that the tabs are aligned.

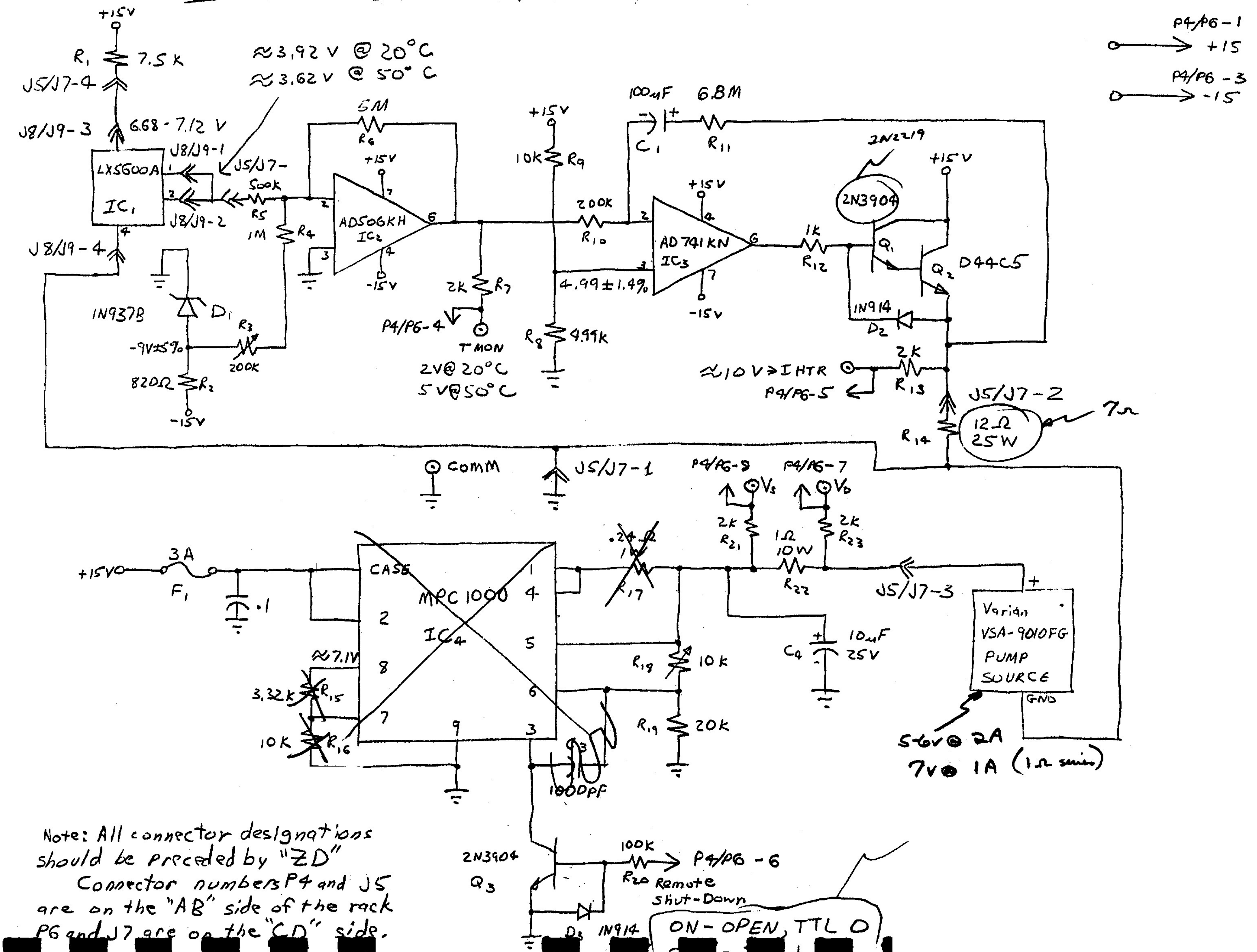
3. Install the unit with the adjustment holes facing away from the dewar. Use 8-32 x 3/4" panhead screws to attach it to the dewar mount plate. Connect P5/P7 and J4/J6 to the unit.

4. Apply power and monitor the temperature. The temperature should immediately begin increasing. Check the I HTR test point; it should give a reading of approximately 13V. If either of these conditions is not met, remove power and find out why.

5. While monitoring the pump voltage (V_s), turn the regulator adjust pot clockwise until the voltage is correct for the pump source being used. Check the pump source current to verify proper operation (Supply V - Pump V).

6. After the temperature has stabilized (≈10 minutes) again check the pump voltage to insure that it is correct, making whatever minor adjustment is needed.

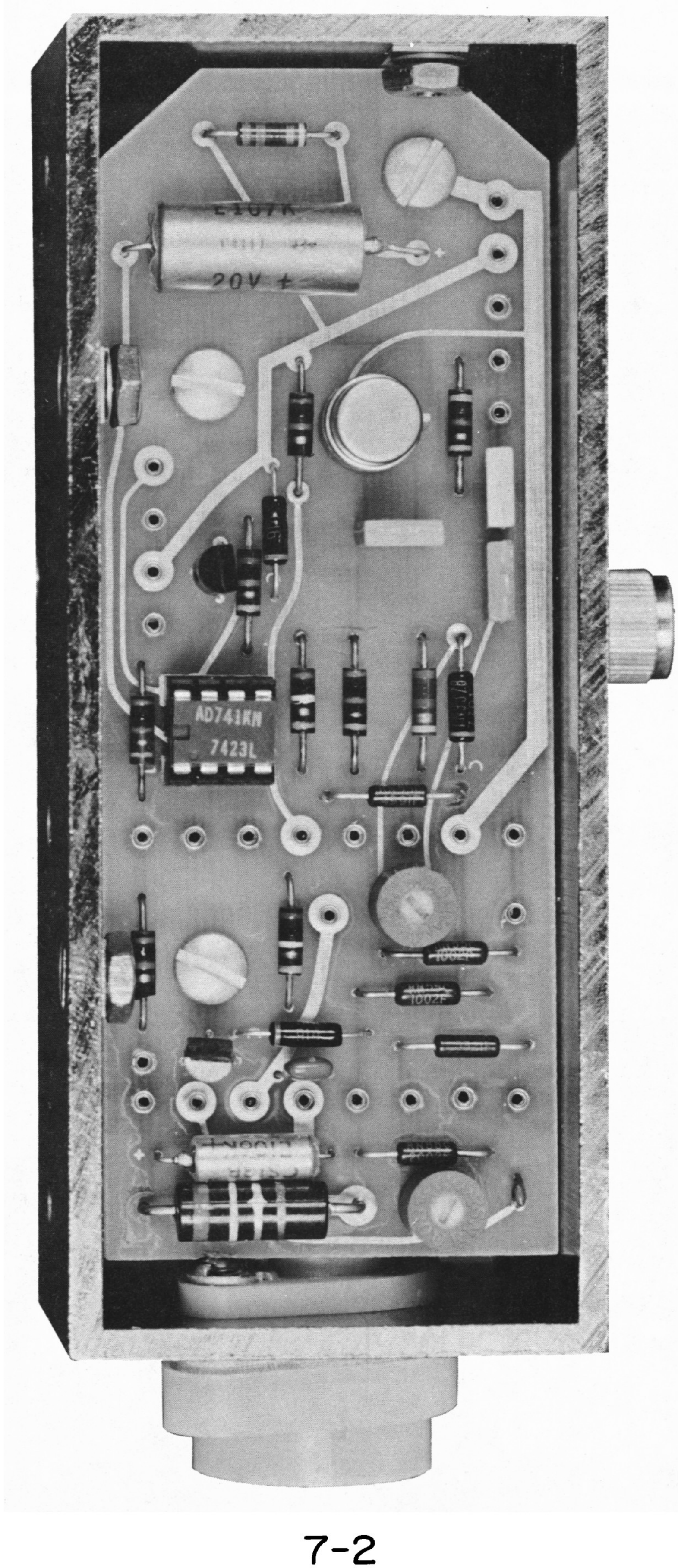
VI PUMP POWER SUPPLY AND TEMPERATURE REGULATOR SCHEMATIC

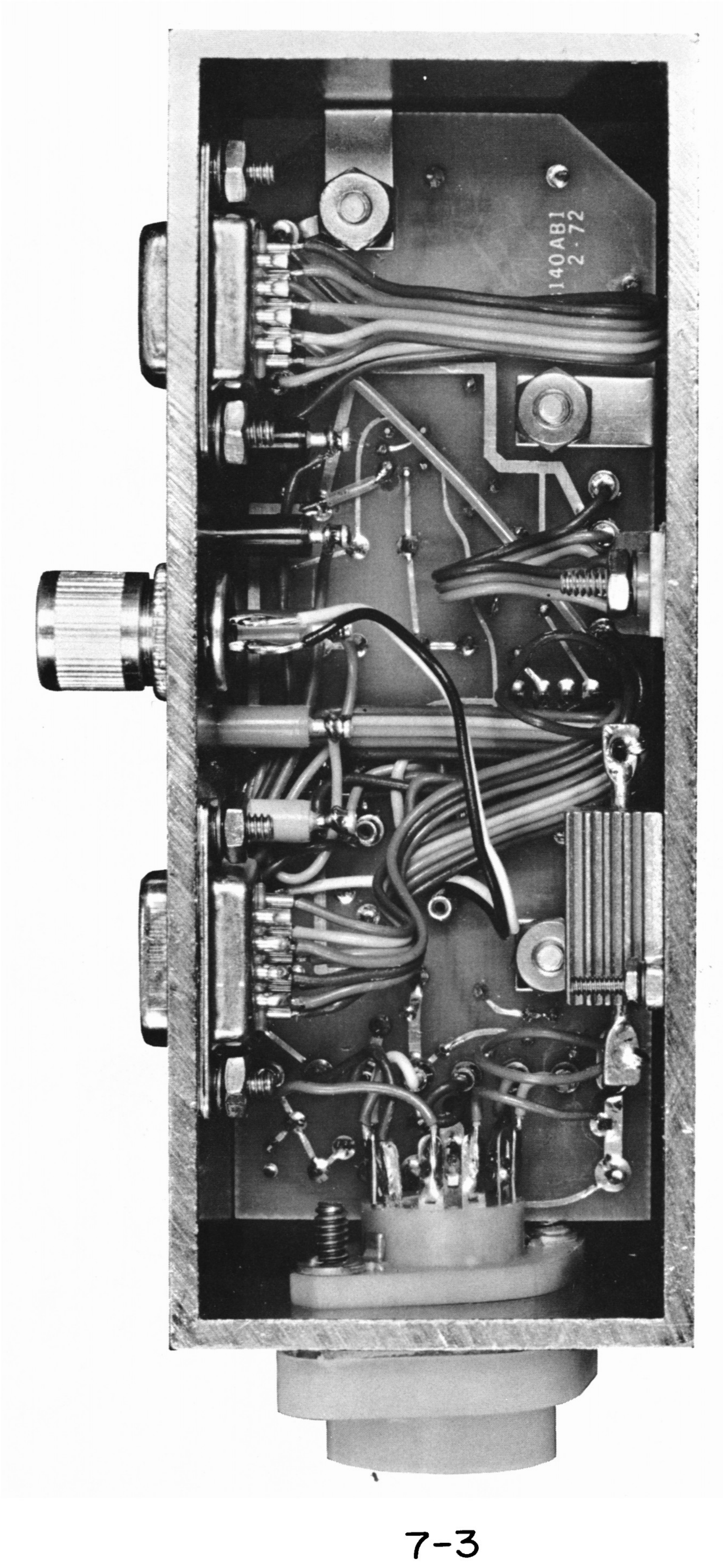


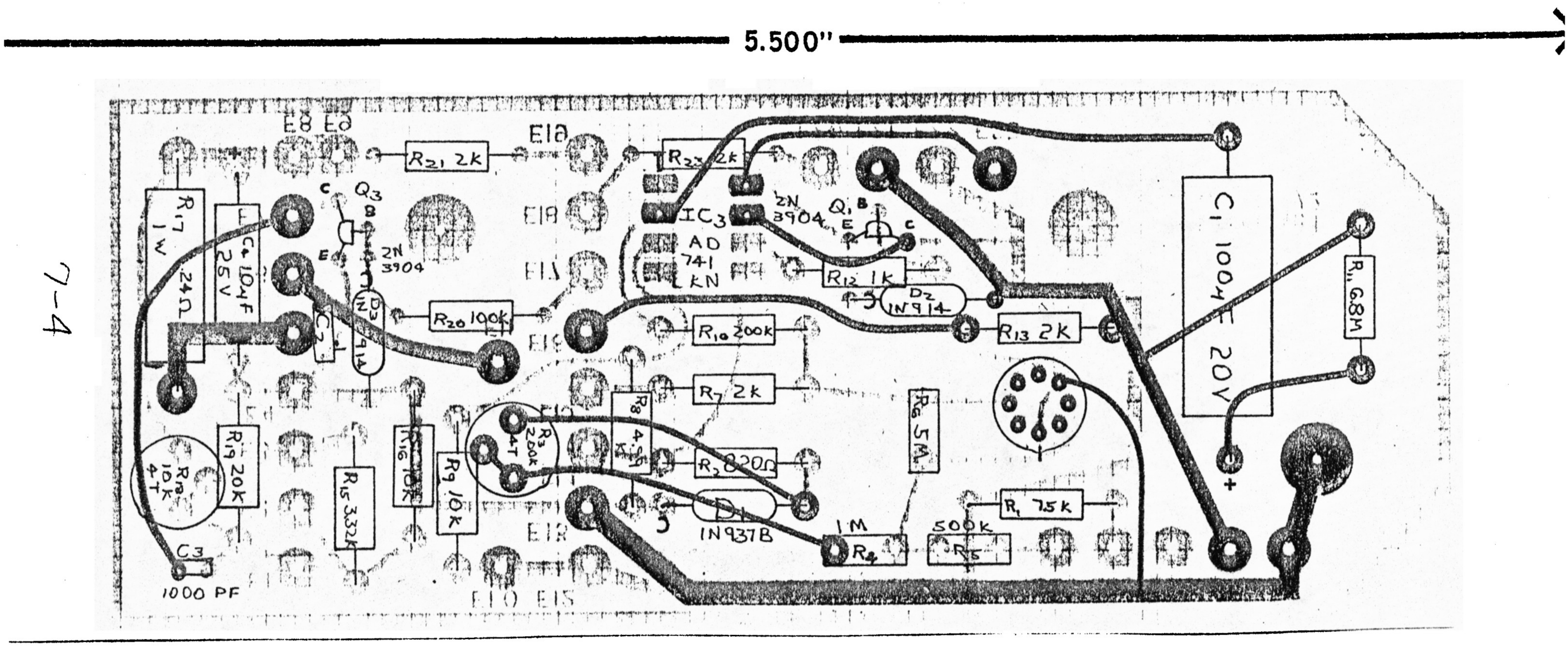
Note: All connector designations should be preceded by "ZD"
Connector numbers P4 and J5 are on the "AB" side of the rack
P6 and J7 are on the "CD" side.

[redacted]


COM
T MON
I HTR
PUMP V
SUPPLY V
TEMP CAL
PUMP VOLTAGE ADJUST


AD741KN
7423L
20V +


140AB1
2·72



DWG C13140P1 - Pump Power Supply and Temperature Regulator Component Layout Diagram

PC WIRING LIST

FROM	COLOR	TO
ZDP4/ZDP6		
PIN		
1	Brown	E12
2	Red	E13
3	Orange	E14
4	Yellow	E15
5	Green	E16
6	Blue	E17
7	Violet	E18
8	Grey	E19
ZDJ5/ZDJ7		
1	Brown	E28
2	Red	E27
3	Orange	E26
4	Yellow	E25
5	Green	E24
FUSE HOLDER		
1	White	E10
2	Black	E11
MPC1000 SOCKET		
1	Brown	E5
2	Red & Bare #22 Buswire	E6 Case terminal nearest
3	Orange	E7
4	#22 Buswire	MPC1000 Socket, Pin 1
5	Green	E8
6	Blue	E1
7	Violet	E2
8	Grey	E3
9	White	E4
D44C5 TRANSISTOR		
Base	Brown	E23
Collector	Red	E22
Emitter	Orange	E21

FROM	COLOR	TO
E20	Insulated #22 Buswire	E26
R22		
1	Violet	E20
2	Blue	E9
TP1	Brown	E13
TP2	Red	E15
TP3	Orange	E16
TP4	Yellow	E18
TP5	Green	E19

BILL OF ERIAL

[ ] ELECTRICAL [ ] MECHANICAL BOM # A13140Z1 REV ______ DATE 1/23/75 PAGE 1 OF 1

MODULE # FRONT END RACK NAME PARAMP PUMP POWER SUPPLY AND TEMPERATURE REGULATOR DWG # C13140P1 SUB ASMB ______ DWG # ______

SCHEMATIC DWG # ______ LOCATION ______ QUA/SYSTEM ______ PREPARED BY S. D. BURGAN APPROVED ______

	ITEM #	REF DESIG	MANUFACTURER	MFG PART #	DESCRIPTION	TOTAL QUA	
*	1		NRAO		HOUSING	1	
*	2		NRAO	A13140Z2	PC BOARD	1	
*	3	IC4	MOTOROLA	MPC1000	VOLTAGE REGULATOR	1	
*	4		ELECTRONIC ESSENTIALS	MI-9-1000	MICA WASHER FOR MPC1000	1	
*	5		KEYSTONE	4632	INSULATING PROTECTIVE COVER FOR TO-3	1	
			* - GOES WITH A13140Z1 ASS'Y		(ALL COMP. NOT MARKED GO TO A13140Z2 PC BOARD SUB ASSY.)		

BILL OF ERIAL

☐ ELECTRICAL ☒ MECHANICAL BOM # A1314021 REV ______ DATE 1/23/75 PAGE 1 OF 1

MODULE # ______ NAME PARAMP PUMP POWER SUPPLY AND TEMPERATURE REGULATOR DWG # ______ SUB ASMB. HOUSING DWG # ______

SCHEMATIC DWG # ______ LOCATION ______ QUA/SYSTEM ______ PREPARED BY ______ APPROVED ______

	ITEM #	REF DESIG	MANUFACTURER	MFG PART #	DESCRIPTION	TOTAL QUA	
*	1		NRAO	C1311OM18	MOD PAK BOX # 708-175-0-0-0-0 MODIFIED AS PER DRAWING	1	
*	2				6-32 X 1/4" PANHEAD SCREWS	3	
*	3				6-32 X 1/4" FLAT HEAD "	3	
*	4				6-32 X 5/8" SOCKET CAP "	1	
*	5				6-32 X " " "	1	
*	6				6-32 LOCK WASHERS	3	
*	7				6-32 X 5/16" HEX NUTS	6	
*	8				4-40 X 3/8" FLAT HEAD SCREW	4	
*	9				4-40 X 1/2" FLAT HEAD SCREW	1	
*	10				4-40 LOCK WASHERS	5	
*	11				4-40 X 1/4" HEX NUTS	5	
*	12				2-56 X 1/2" FLAT HEAD SCREWS	2	
*	13				2-56 LOCK WASHERS	2	
*	14				2-56 X " Hex NUTS	2	

BILL OF ERIAL

☐ ELECTRICAL ☐ MECHANICAL BOM # ______ REV ______ DATE ______ PAGE 1 OF 3

MODULE # ______ NAME PARAMP PUMP POWER SUPPLY AND TEMPERATURE REGULATOR DWG # ______ SUB ASMB. PC BOARD DWG # ______

SCHEMATIC DWG # ______ LOCATION ______ QUA/SYSTEM ______ PREPARED BY ______ APPROVED ______

	ITEM #	REF DESIG	MANUFACTURER	MFG PART #	DESCRIPTION	TOTAL QUA	
	1		NRAO	B13140AB1	PC BOARD	1	
*	2		CINCH	DEE-9S	FEMALE CONNECTOR	1	
*	3		"	DEE-9P	MALE "	1	
*	4		ELECTRONIC ESSENTIALS	MS7-1000	SOCKET FOR MPC-1000 I.C.	1	
*	5		LITTLEFUSE	282-002A	FUSEHOLDER	1	
	6	F_1	"	273-003	FUSE, 3A	1	
*	7	Q_2	GE		D44C8 NPN POWER TRANSISTOR	1	
	8	R_{22}	DALE		RH-10, 1Ω 10W RESISTOR	1	
*	9		E.F. JOHNSON	105-1043-001	BLACK PRESS-IN TIP JACK	1	
*	10		"	105-48-001	BROWN " " " "	1	
*	11		"	105-42-001	RED " " " "	1	
*	12		"	105-46-001	ORANGE " " " "	1	
*	13		"	105-47-001	YELLOW " " " "	1	

BILL OF M ERIAL

NATIONAL RADIO ASTRONOMY OBSERVATORY

[X] ELECTRICAL [ ] MECHANICAL BOM # ______ REV ______ DATE ______ PAGE 2 OF 3

ITEM #	REF DESIG	MANUFACTURER	MFG PART #	DESCRIPTION	TOTAL QUA	
14	IC_2	ANALOG DEVICES		AD506KH FET INPUT OP-AMP	1	
15	IC_3	ANALOG DEVICES		AD741KN OP-AMP	1	
16	Q_1, Q_3	MOTOROLA		2N3904 NPN TRANSISTOR	2	
17	R_1	ALLEN BRADLEY		7.5 K 5% RESISTOR 1/4 W	1	
18	R_2	" "		820Ω " " "	1	
19	$R_7, R_{13}, R_{21}, R_{23}$	" "		2 K " " "	4	
20	R_{10}	" "		200 K " " "	1	
21	R_{11}	" "		6.8 M " " "	1	
22	R_{12}	" "		1 K " " "	1	
23	R_{20}	" "		100 K " " "	1	
24	R_{17}	" "		0.24Ω " " 1 W	1	
25	R_5	CADDOCK		500 K 1% MK132 RESISTOR	1	
26	R_6	"		5 M " " "	1	
27	R_9	TRW-IRC		10 K 1% RN55 RESISTOR	2	
28	R_8	" "		4.99 K " " "	1	
29	R_{15}	" "		3.32 K " " "	1	

BILL OF MATERIAL

NATIONAL RADIO ASTRONOMY OBSERVATORY

[X] ELECTRICAL [ ] MECHANICAL BOM # ______ REV ______ DATE ______ PAGE 3 OF 3

ITEM #	REF DESIG	MANUFACTURER	MFG PART #	DESCRIPTION	TOTAL QUA	
30	R_{19}	TRW-IRC		20K 1% RN55	1	
31	R4	CADDOCK		1M 1% MK132 RESISTOR	1	
32	D_2, D_3	MOTOROLA		1N914 DIODE	2	
33	C_1	SPRAGUE	M39003/01-2061	100 μF 20V TANTALUM CAPACITOR	1	
34	C4	Do.	M39003/01-2046	10 μF 20V Do. Do.	1	
35	C_2	ERIE	8131-050-651-104M	.1 μF 50V REDCAP CAPACITOR	1	
36	C_3	Do.	8101-050-651-102M	.001 μF Do. Do. Do.	1	
37	D_1	MOTOROLA		1N937B ZENER REFERENCE DIODE	1	
38	R_{18}	BOURNS	3339P	10K 4T POTENTIOMETER	1	✓
39	R_3	Do.	Do.	200K 4T Do.	1	✓
40		KEYSTONE	1562-2	TURRET TERMINALS	28	
41		GC ELECTRONICS	6262-C	ANGLE BRACKETS	3	
42		ROBINSON NUGENT	ICN-083-S3	MINI-DIP SOCKET	1	
43		Do. Do.	SD-5178	TO-99 SOCKET	1	

ANALOG DEVICES

Lowest Cost High Accuracy IC Op Amps

AD741J,K,L,S

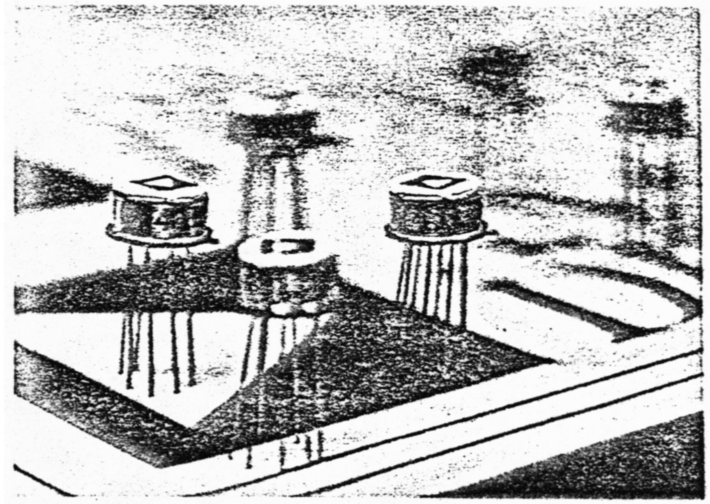
FEATURES

Precision Input Characteristics
- Low V_{OS}: 0.5mV max (L)
- Low V_{OS} Drift: 5μV/°C max (L)
- Low I_b: 50nA max (L)
- Low I_{OS}: 5nA max (L)
- High CMRR: 90dB min (K, L)

High Output Capability
- A_{ol} = 25,000 min, 1kΩ load (J, S) T_{min} to T_{max}
- V_o = ±10V min, 1kΩ load (J, S)

Low Cost (100 pieces)

AD741J	$1.25
AD741K	$2.25
AD741L	$6.00
AD741S	$3.30



GENERAL DESCRIPTION

The Analog Devices AD741J, AD741K, AD741L and AD741S are specially tested and selected versions of the popular AD741 operational amplifier. Improved processing and additional electrical testing guarantee the user precision performance at a very low cost. The AD741J, K and L substantially increase overall accuracy over the standard AD741C by providing maximum limits on offset voltage drift, and significantly reducing the errors due to offset voltage, bias current, offset current, voltage gain, power supply rejection, and common mode rejection (see Error Analysis). For example, the AD741L features maximum offset voltage drift of 5μV/°C, offset voltage of 0.5mV max, offset current of 5nA max, bias current of 50nA max, and a CMRR of 90dB min. The AD741S offers guaranteed performance over the extended temperature range of −55°C to +125°C, with max offset voltage drift of 15μV/°C, max offset voltage of 4mV, max offset current of 25nA, and a minimum CMRR of 80dB.

HIGH OUTPUT CAPABILITY

Both the AD741J and AD741S offer the user the additional advantages of high guaranteed output current and gain at low values of load impedance. The AD741J guarantees a minimum gain of 25,000, swinging ±10V into a 1kΩ load from 0°C to +70°C. The AD741S guarantees a minimum gain of 25,000, swinging ±10V into a 1kΩ load from −55°C to +125°C.

All devices feature full short circuit protection, high gain, high common mode range, and internal compensation. The AD741J, K and L are specified for operation from 0°C to +70°C, and are available in both the TO-99 and mini-DIP packages. The AD741S is specified for operation from −55°C to +125°C, and is available in the TO-99 package.

GUARANTEED ACCURACY

The vastly improved performance of the AD741J, AD741K, AD741L and AD741S provides the user with an ideal choice when precision is needed and economy is a necessity. An error budget is calculated for all versions of the AD741 (see page 3); it is obvious that these selected versions offer substantial improvements over the industry-standard AD741C and AD741. A typical circuit configuration (see Figure 1) is assumed, and the various errors are computed using maximum values over the full operating temperature range of the devices. *The results indicate a factor of 8 improvement in accuracy of the AD741L over the AD741C, a factor of 5 improvement using the AD741K, and a factor of 2.5 improvement using the AD741J. The AD741S, similarly, achieves a factor of 3.5 improvement over the standard AD741.* Note that the total error has been determined as a sum of component errors, while in actuality, the total error will be much less. Also, while the circuit used for the error analysis is only one of a multitude of possible applications, it effectively demonstrates the great improvement in overall 741 accuracy achievable at relatively low cost with the AD741J, K, L or S.

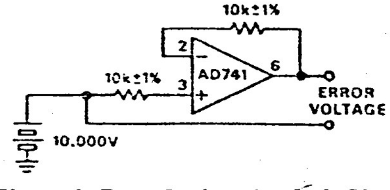


Figure 1. Error Budget Analysis Circuit

Route 1 Industrial Park; P.O. Box 280; Norwood, Mass. 02062
Tel: 617/329-4700 TWX: 710/394-6577

SPECIFICATIONS (typical @ +25°C and ±15VDC, unless otherwise specified)

MODEL	AD741J	AD741K	AD741L	AD741S
OPEN LOOP GAIN				
R_L = 1kΩ, V_o = ±10V	50,000 min (200,000 typ)			*
R_L = 2kΩ, V_o = ±10V		50,000 min (200,000 typ)	50,000 min (200,000 typ)	
Over Temp Range, T_{min} to T_{max}, same loads as above	25,000 min	*	*	*
OUTPUT CHARACTERISTICS				
Voltage @ R_L = 1kΩ, T_{min} to T_{max}	±10V min (±13V typ)			*
Voltage @ R_L = 2kΩ, T_{min} to T_{max}		±10V min (±13V typ)	±10V min (±13V typ)	
Short Circuit Current	25mA	*	*	*
FREQUENCY RESPONSE				
Unity Gain, Small Signal	1MHz	*	*	*
Full Power Response	10kHz	*	*	*
Slew Rate, Unity Gain	0.5V/μsec	*	*	*
INPUT OFFSET VOLTAGE				
Initial, $R_S \leq$ 10kΩ (adjustable to zero)	3mV max (1mV typ)	2mV max (0.5mV typ)	0.5mV max (0.2mV typ)	2mV max (1mV typ)
T_{min} to T_{max}	4mV max	3mV max	1mV max	*
Avg vs Temperature (untrimmed)	20μV/°C max	15μV/°C max (6μV/°C typ)	5μV/°C max (2μV/°C typ)	15μV/°C max (6μV/°C typ)
vs Supply, T_{min} to T_{max}	100μV/V max (30μV/V typ)	15μV/V max (5μV/V typ)	15μV/V max (5μV/V typ)	*
INPUT OFFSET CURRENT				
Initial	50nA max (5nA typ)	10nA max (2nA typ)	5nA max (2nA typ)	10nA max (2nA typ)
T_{min} to T_{max}	100nA max	15nA max	10nA max	25nA max
Avg vs Temperature	0.1nA/°C	0.2nA/°C max (0.02nA/°C typ)	0.1nA/°C max (0.02nA/°C typ)	0.25nA/°C max (0.1nA/°C typ)
INPUT BIAS CURRENT				
Initial	200nA max (40nA typ)	75nA max (30nA typ)	50nA max (30nA typ)	75nA max (30nA typ)
T_{min} to T_{max}	400nA max	120nA max	100nA max	250nA max
Avg vs Temperature	0.6nA/°C	1.5nA/°C max (0.6nA/°C typ)	1nA/°C max (0.6nA/°C typ)	2nA/°C max (0.6nA/°C typ)
INPUT IMPEDANCE				
Differential	1MΩ	2MΩ	2MΩ	2MΩ
INPUT VOLTAGE RANGE (Note 1)				
Differential, max safe	±30V	*	*	*
Common Mode, max safe	±15V	*	*	*
Common Mode Rejection, $R_S \leq$ 10kΩ, T_{min} to T_{max}, V_{in} = ±12V	80dB min (90dB typ)	90dB min (100dB typ)	90dB min (100dB typ)	*
POWER SUPPLY				
Rated Performance	±15V	*	*	*
Operating	±(5 to 18)V	±(5 to 22)V	±(5 to 22)V	±(5 to 22)V
Current, Quiescent	3.3mA max (2.0mA typ)	2.8mA max (1.7mA typ)	2.8mA max (1.7mA typ)	2.8mA max (2.0mA typ)
TEMPERATURE RANGE				
Operating, Rated Performance	0°C to +70°C	*	*	−55°C to +125°C
Storage	−65°C to +150°C	*	*	*

Note 1: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.
*Specifications same as AD741J.
Specifications subject to change without notice.

ERROR BUDGET ANALYSIS

PARAMETER	AD741C SPEC (0°C to +70°C)	AD741C ERROR	AD741J SPEC (0°C to +70°C)	AD741J ERROR	AD741K SPEC (0°C to +70°C)	AD741K ERROR	AD741L SPEC (0°C to +70°C)	AD741L ERROR	AD741 SPEC (−55°C to +125°C)	AD741 ERROR	AD741S SPEC (−55°C to +125°C)	AD741S ERROR
Gain *(Error = 10V$_{in}$/G)*	15,000	660μV	25,000[1]	400μV	25,000	400μV	25,000	400μV	25,000	400μV	25,000[1]	400μV
I_b *(Error = I_b x resistor mismatch)*	800nA	160μV	400nA	80μV	120nA	24μV	100nA	20μV	1500nA	300μV	250nA	50μV
I_{os} *(Error = I_{os} x 10kΩ)*	300nA	3000μV	100nA	1000μV	15nA	150μV	10nA	100μV	500nA	5000μV	25nA	250μV
$\Delta V_{os}/\Delta T$ *(Error = $\Delta V_{os}/\Delta T$ x ΔT)*	25μV/°C[2]	1125μV	20μV/°C	900μV	15μV/°C	675μV	5μV/°C	225μV	25μV/°C[2]	2500μV	15μV/°C	1500μV
CMRR *(Error = 10V/CMRR)*	70dB	3300μV	80dB	1000μV	90dB	330μV	90dB	330μV	70dB	3300μV	80dB	1000μV
PSRR *(assume a ±5% power supply variation)*	150μV/V	450μV	100μV/V	300μV	15μV/V	45μV	15μV/V	45μV	150μV/V	450μV	100μV/V	300μV
TOTAL		8.7mV		3.7mV		1.6mV		1.1mV		12.0mV		3.5mV
PRICE *(100 pieces)*	$1.00		$1.25		$2.25		$6.00		$2.00		$3.30	

[1] AD741J and AD741S...Open Loop Gain is guaranteed with a 1kΩ load.
[2] AD741C and AD741..$\Delta V_{os}/\Delta T$ is not guaranteed (for complete specifications, contact the factory for data sheet).

INPUT CHARACTERISTICS

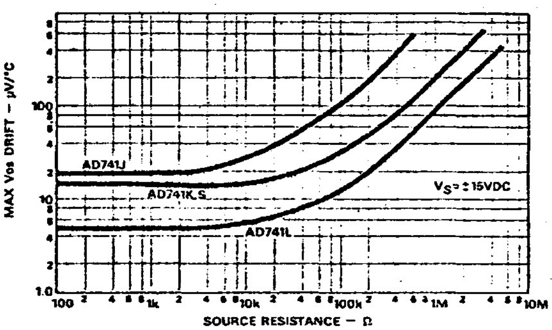


Figure 2. Max Equivalent Input Offset Drift vs. Source Resistance

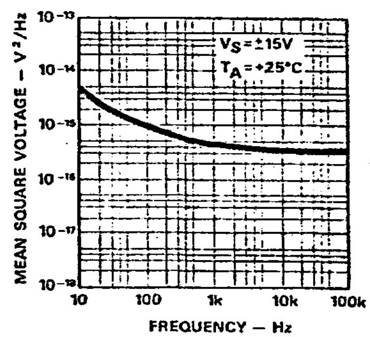


Figure 5. Input Noise Voltage vs. Frequency

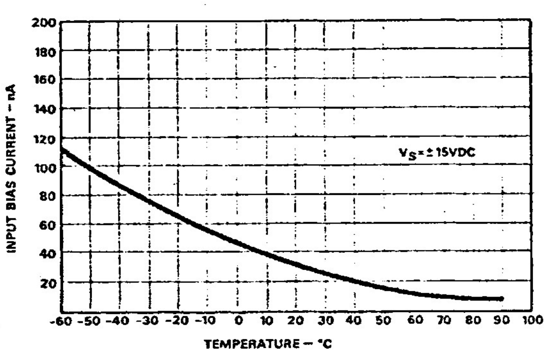


Figure 3. Input Bias Current vs. Temperature

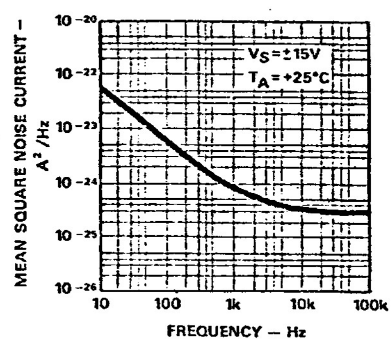


Figure 6. Input Noise Current vs. Frequency

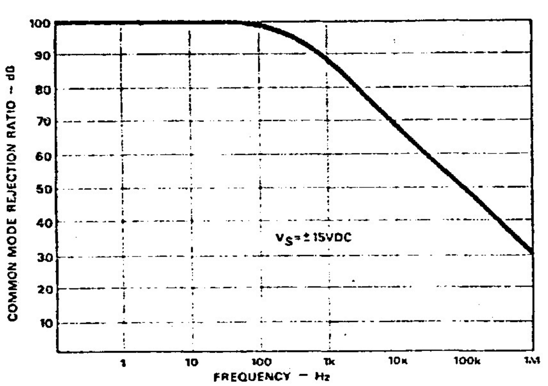


Figure 4. Common Mode Rejection vs. Frequency

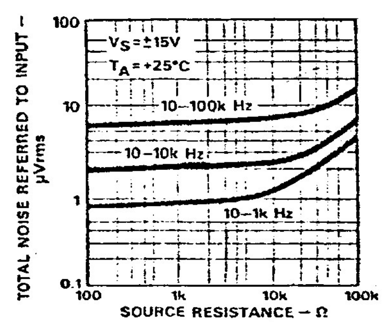


Figure 7. Broadband Noise vs. Source Resistance

OUTPUT CHARACTERISTICS

The AD741J and AD741S are specially selected for high output current capability. High efficiency output transistors, thermally balanced chip design and precise short circuit current control insure against gain degradation at high current levels and temperature extremes. The AD741J guarantees a minimum gain of 25,000, swinging ±10V into a 1kΩ load from 0°C to +70°C. The AD741S guarantees minimum gain of 25,000, swinging ±10V into a 1kΩ load from −55°C to +125°C. The AD741K and AD741L are guaranteed with the standard 2kΩ load.

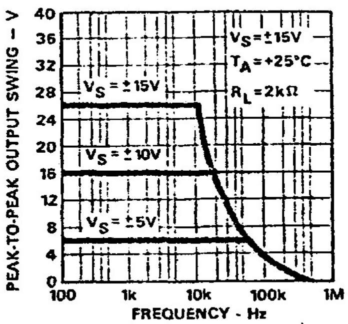


Figure 8. Output Voltage Swing vs. Frequency

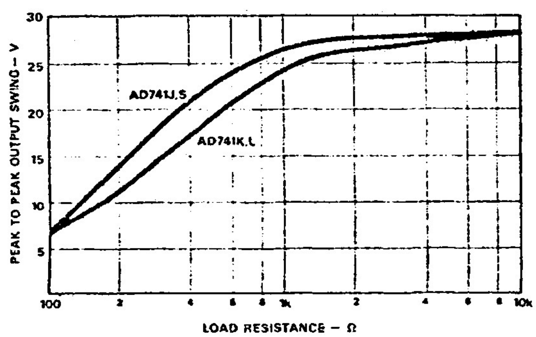


Figure 9. Output Voltage Swing vs. Load Resistance

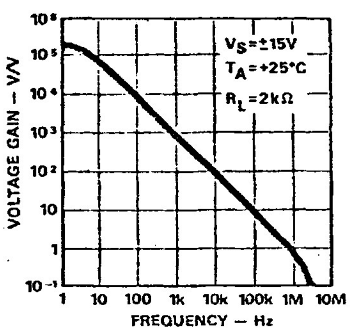
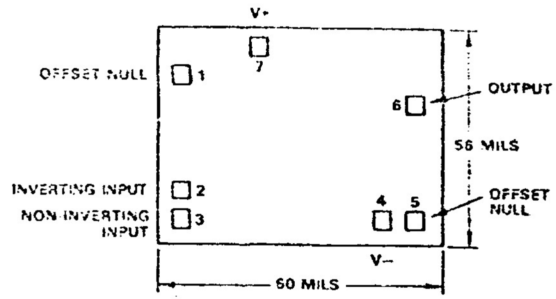


Figure 10. Open Loop Gain vs. Frequency

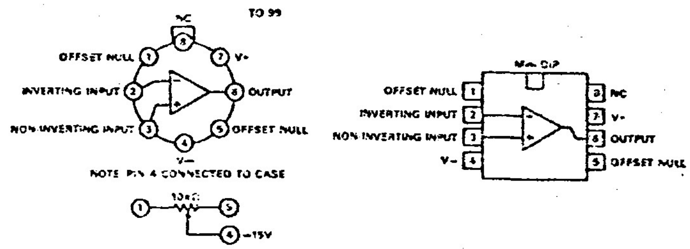
BONDING DIAGRAM

All versions of the AD741 are available in chip or wafer form, fully tested at +25°C. Because of the critical nature of using unpackaged devices, it is suggested that the factory be contacted for specific information regarding price, delivery and testing.



CONNECTION DIAGRAMS

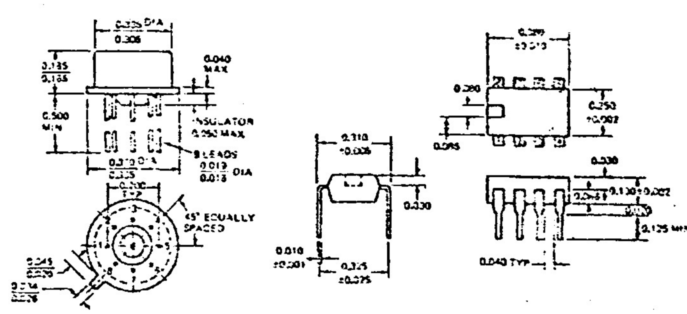
(Top View)



(H package) (N package)

PHYSICAL DIMENSIONS

(In Inches)



MIL-STANDARD-883

The AD741S is available with 100% screening to MIL-STD-883, Method 5004, Class A, B, or C. Consult the factory for pricing and delivery.

ORDERING GUIDE

MODEL	TEMP. RANGE	ORDER NUMBER	PRICE (1–24)	PRICE (25–99)	PRICE (100–999)
AD741J	0°C to +70°C	AD741J*	$1.85	$1.50	$1.25
AD741K	0°C to +70°C	AD741K*	$3.40	$2.70	$2.25
AD741L	0°C to +70°C	AD741L*	$9.00	$7.20	$6.00
AD741S	−55°C to +125°C	AD741SH	$4.95	$4.00	$3.30

*Add Package Type Letter; H = TO-99, N = Mini-DIP.

AD

503J 506J
503K 506K
503S 506S

INTEGRATED CIRCUIT FET INPUT OPERATIONAL AMPLIFIERS

FEATURES

Low I_B
- 15pA max (AD503/AD506J)
- 10pA max (AD503/AD506K, S)

Low V_{OS} Drift
- (100% computer tested)
- 25µV/°C max (AD503/AD506K)

Low V_{OS}
- 1.5mV max (AD506K)

High Slew Rate
- 6V/µsec typical

Small Size (TO-99 can)

APPLICATIONS

Sample and Hold Amplifiers
High Impedance Buffer Amplifiers
Precision Integrators
Current Measurements from pH Transducers

ANALOG DEVICES
LINEAR INTEGRATED CIRCUITS
ROUTE ONE INDUSTRIAL PARK
P. O. BOX 280, NORWOOD, MASS. 02062
TEL: 617/329-4700 TWX: 710/394-6577

PRODUCT DESCRIPTION

The AD503J/AD506J, AD503K/AD506K, and AD503S/AD506S are IC FET input op amps which provide the user with input currents of a few pA, high overall performance, low cost, and accurately specified, predictable operation. The devices achieve maximum bias currents as low as 10pA, minimum gain of 50,000, CMRR of 80dB, and a minimum slew rate of 3V/µsec. They are free from latch-up and are short circuit protected. No external compensation is required as the internal 6dB/octave rolloff provides stability in closed loop applications.

The AD503 is suggested for all general purpose FET input amplifier requirements where low cost is of prime importance. The AD506, with specifications otherwise similar to the AD503, offers significant improvement in offset voltage and nulled offset voltage drift by supplementing the AD503 configuration with internal laser trimming of thin film resistors to provide typical offset voltages below 1mV.

Both the AD503 and AD506 provide performance comparable to modular FET op amps. Because of their monolithic construction, however, their cost is significantly below that of modules, and becomes even lower in large quantities.

All the circuits are supplied in the TO-99 package; the AD503J and AD506J and the AD503K and AD506K are specified for 0°C to +70°C temperature range operation; the AD503S and AD506S for operation from –55°C to +125°C.

PRODUCT BENEFITS

1. The AD503 and AD506 op amps meet their published input bias current and offset voltage specs after full warmup. Conventional high speed IC testing does not allow for self-heating of the chip due to internal power dissipation under operating conditions.
2. The bias currents of the AD503 and AD506 are specified as a maximum for either input. Conventional IC FET op amps generally specify bias currents as the average of the two input currents.
3. Offset voltage nulling of the AD503 and AD506 is accomplished without affecting the operating current of the FET's and results in relatively small changes in temperature drift characteristics. The additional drift induced by nulling is only ±0.8µV/°C per millivolt of nulled offset for the AD506 and ±2.0µV/°C per millivolt of nulled offset for the AD503, compared to several times this for other IC FET op amps.
4. The gain of the AD503 and AD506 is measured with the offset voltage nulled. Nulling a FET input op amp can cause the gain to decrease below its specified limit. The gain of the AD503 and AD506 is fully guaranteed with the offset voltage both nulled and unnulled.
5. Bootstrapping of the input FET's achieves a superior CMRR of 80dB, while reducing bias currents and maintaining them constant through the CMV range.
6. To maximize the reliability inherent in IC construction, every AD503/AD506 is stored for 48 hours at 200°C, temperature cycled from –65°C to +125°C, and receives a high impact shock test. All guaranteed DC parameters are 100% computer tested, including offset voltage drift. AC performance and noise parameters are continually reviewed.

APPLYING THE AD503 AND AD506

The AD503 and AD506 are especially designed for applications involving the measurement of low level currents or small voltages from high impedance sources, in which bias current can be a primary source of error. Input bias current contributes to error in two ways: (1) in current measuring configurations, the bias current limits the resolution of a current signal; (2) the bias current produces a voltage offset which is proportional to the value of input resistance (in the case of an inverting configuration) or source impedance (when the non-inverting "buffer" connection is used). The AD503 and AD506 IC FET input amplifiers, therefore, are of use where small currents are to be measured or where relatively low voltage drift is necessary despite large values of source resistance.

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USE THE AD503 when external V_{os} trimming is not inconvenient, and low noise is of considerable importance.

ELECTRICAL SPECIFICATIONS (typical at +25°C and ±15VDC, unless otherwise noted)

PARAMETER	AD503J	AD503K	AD503S
OPEN LOOP GAIN (Note 1)			
V_{out} = ±10V, $R_L \geqslant 2k\Omega$	20,000 min (50,000 typ)	50,000 min (120,000 typ)	50,000 min (120,000 typ)
T_A = min to max	15,000 min	40,000 min	25,000 min
OUTPUT CHARACTERISTICS			
Voltage @ $R_L = 2k\Omega$, T_A = min to max	±10V min (±13V typ)	*	*
@ $R_L = 10k\Omega$, T_A = min to max	±12V min (±14V typ)	*	*
Load Capacitance (Note 2)	750pF	*	*
Short Circuit Current	25mA	*	*
FREQUENCY RESPONSE			
Unity Gain, Small Signal	1.0MHz	*	*
Full Power Response	100kHz	*	*
Slew Rate, Unity Gain	3.0V/μsec min (6.0V/μsec typ)	*	*
Settling Time, Unity Gain (to 0.1%)	10μsec	*	*
INPUT OFFSET VOLTAGE (Note 3)	50mV max (20mV typ)	20mV max (8mV typ)	20mV max (8mV typ)
vs. Temperature, T_A = min to max	75μV/°C max (30μV/°C typ)	25μV/°C max (10μV/°C typ)	50μV/°C max (20μV/°C typ
vs. Supply, T_A = min to max	400μV/V max (200μV/V typ)	200μV/V max (100μV/V typ)	200μV/V max (100μV/V ty
INPUT BIAS CURRENT			
Either Input (Note 4)	15pA max (5pA typ)	10pA max (2.5pA typ)	10pA max (2.5pA typ)
INPUT IMPEDANCE			
Differential	$10^{11}\Omega \parallel 2pF$	*	*
Common Mode	$10^{12}\Omega \parallel 2pF$	*	*
INPUT NOISE			
Voltage, 0.1Hz to 10Hz	15μV (p-p)	*	*
5Hz to 50kHz	5.0μV (rms)	*	*
f = 1kHz (spot noise)	30.0nV/√Hz	*	*
INPUT VOLTAGE RANGE			
Differential (Note 5)	±3.0V	*	*
Common Mode, T_A = min to max	±10V min (±12V typ)	*	*
Common Mode Rejection, V_{in} = ±10V	70dB min (90dB typ)	80dB min (90dB typ)	80dB min (90dB typ)
POWER SUPPLY			
Rated Performance	±15V	*	*
Operating	±(5 to 18)V	*	±(5 to 22)V
Quiescent Current	7mA max (3mA typ)	*	*
TEMPERATURE			
Operating, Rated Performance	0°C to +70°C	*	−55°C to +125°C
Storage	−65°C to +150°C	*	*

NOTES:
1. Open Loop Gain is specified with V_{os} both nulled and unnulled.
2. A conservative design would not exceed 500pF of load capacitance.
3. Input offset voltage specifications are guaranteed after 5 minutes of operation at T_A = +25°C.
4. Bias current specifications are guaranteed after 5 minutes of operation at T_A = +25°C. For higher temperatures, the current doubles every 1
5. See comments in Input Considerations section of data sheet.

*Specifications same as for AD503J.

USE THE AD506 for low untrimmed initial offset voltage or for the lowest trimmed V_{OS} drift, high capacitive drive, and higher differential voltage capability.

ELECTRICAL SPECIFICATIONS (typical at +25°C and ±15VDC, unless otherwise noted)

PARAMETER	AD506J	AD506K	AD506S
OPEN LOOP GAIN (Note 1)			
V_{out} = ±10V, $R_L \geqslant 2k\Omega$	20,000 min (50,000 typ)	50,000 min (120,000 typ)	50,000 min (120,000 typ)
T_A = min to max	15,000 min	40,000 min	25,000 min
OUTPUT CHARACTERISTICS			
Voltage @ $R_L = 2k\Omega$, T_A = min to max	±10V min (±13V typ)	*	*
@ $R_L = 10k\Omega$, T_A = min to max	±12V min (±14V typ)	*	*
Load Capacitance (Note 2)	1000pF	*	*
Short Circuit Current	25mA	*	*
FREQUENCY RESPONSE			
Unity Gain, Small Signal	1.0MHz	*	*
Full Power Response	100kHz	*	*
Slew Rate, Unity Gain	3.0V/µsec min (6.0V/µsec typ)	*	*
Settling Time, Unity Gain	10µsec	*	*
INPUT OFFSET VOLTAGE (Note 3)	3.5mV max (1.0mV typ)	1.5mV max (0.5mV typ)	1.5mV max (0.5mV typ)
vs. Temperature, T_A = min to max	75µV/°C max (30µV/°C typ)	25µV/°C max (10µV/°C typ)	50µV/°C max (20µV/°C typ)
vs. Supply, T_A = min to max	200µV/V max (100µV/V typ)	100µV/V max (50µV/V typ)	100µV/V max (50µV/V typ)
INPUT BIAS CURRENT			
Either Input (Note 4)	15pA max (5pA typ)	10pA max (2.5pA typ)	10pA max (2.5pA typ)
INPUT IMPEDANCE			
Differential	$10^{11}\Omega \|\| 2pF$	*	*
Common Mode	$10^{12}\Omega \|\| 2pF$	*	*
INPUT NOISE			
Voltage, 0.1Hz to 10Hz	40µV (p-p)	*	*
5Hz to 50kHz	8µV (rms)	*	*
f = 1kHz (spot noise)	80nV/$\sqrt{Hz}$	*	*
INPUT VOLTAGE RANGE			
Differential (Note 5)	±4V	*	*
Common Mode, T_A = min to max	±10V min (±12V typ)	*	*
Common Mode Rejection, V_{in} = ±10V	70dB min (90dB typ)	80dB min (90dB typ)	80dB min (90dB typ)
POWER SUPPLY			
Rated Performance	±15V	*	*
Operating	±(5 to 18)V	*	±(5 to 22)V
Quiescent Current	7mA max (5mA typ)	*	*
TEMPERATURE			
Operating, Rated Performance	0°C to +70°C	*	−55°C to +125°C
Storage	−65°C to +150°C	*	*

NOTES:
1. Open Loop Gain is specified with V_{OS} both nulled and unnulled.
2. A conservative design would not exceed 750pF of load capacitance.
3. Input offset voltage specifications are guaranteed after 5 minutes of operation at T_A = +25°C.
4. Bias current specifications are guaranteed after 5 minutes of operation at T_A = +25°C. For higher temperatures, the current doubles every 10°C.
5. See comments in Input Considerations section of data sheet.

* Specifications same as for AD506J.

APPLICATIONS CONSIDERATIONS

Bias Current

Most IC FET op amp manufacturers specify maximum bias currents as the value immediately after turn-on. Since FET bias currents double every 10°C and since most FET op amps have case temperature increases of 15°C to 20°C above ambient, initial "maximum" readings may be only ¼ of the true warmed up value. Furthermore, most IC FET op amp manufacturers specify I_b as the average of both input currents, sometimes resulting in twice the "maximum" bias current appearing at the input being used. The total result is that 8X the expected bias current may appear at either input terminal in a warmed up operating unit.

The AD503 and AD506 specify maximum bias currents at either input after warmup, thus giving the user the values he expected.

Improving Bias Current Beyond Guaranteed Values

Bias currents can be substantially reduced in the AD503 and AD506 by decreasing the junction temperature of the device. One technique to accomplish this is to reduce the operating supply voltage. This procedure will decrease the power dissipation of the device, which will in turn result in a lower junction temperature and lower bias currents. The supply voltage effect on bias current is shown in Figure 1.

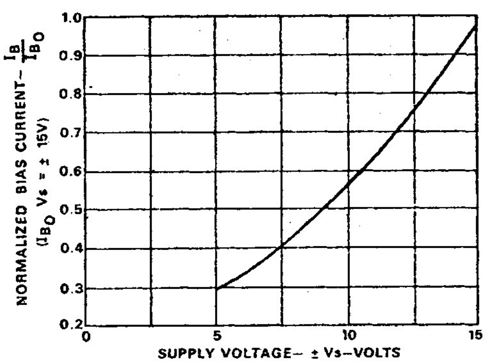


Figure 1. Normalized Bias Current vs. Supply Voltage

Operation of the AD503K and AD506K at ±5V reduces the warmed up bias current by 70% to a typical value of 0.75pA.

A second technique is the use of a suitable heat sink. Wakefield Engineering Series 200 heat sinks were selected to demonstrate this effect. The characteristic bias current vs. case temperature above ambient is shown in Figure 2. Bias current has been normalized with unity representing the 25°C free air reading. Note that the use of the Model 209 heat sink reduces warmed up bias current by 60% to 1.0pA in the AD503/506K.

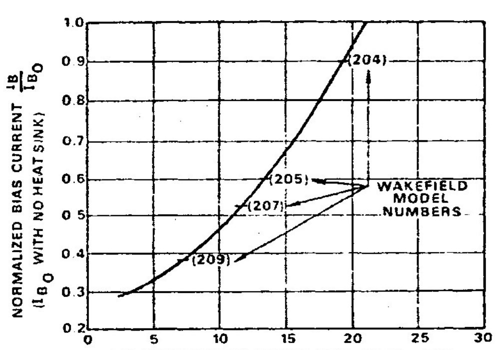


Figure 2. Normalized Bias Current vs. Case Temperature

Both of these techniques may be used together for obtaining lower bias currents. Remember that loading the output can also affect the power dissipation.

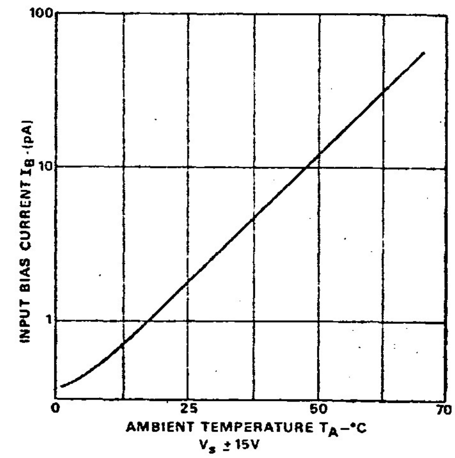


Figure 3. Input Bias Current vs. Temperature

Input Considerations

The common mode input characteristic is shown in Figure 4. Note that positive common mode inputs up to +13.5 volts and negative common mode inputs to $-V_S$ are permissible, without incurring excessive bias currents. To prevent possible damage to the unit, do not exceed $V_{CM} = V_S$.

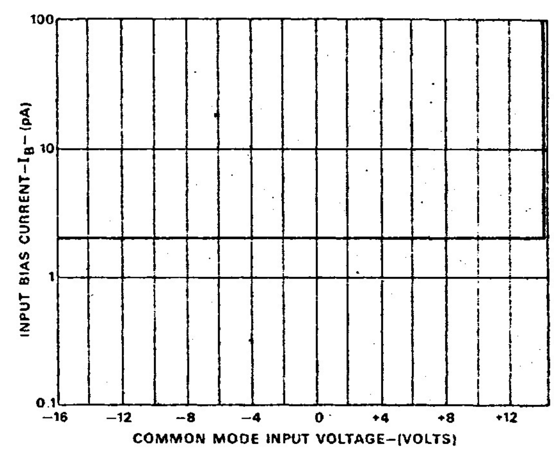


Figure 4. Input Bias Current vs. Common Mode Voltage

Like most other FET input op amps, the AD503 and AD506 display a degraded bias current specification when operated at moderate differential input voltages. The AD503 maintains its specified bias current up to a differential input voltage of ±3V typically, while the AD506's bias current performance is not significantly degraded for $V_{diff} \leqslant 4V$ typically. Above V_{diff} = ±3V in the AD503 and V_{diff} = ±4V in the AD506, the bias current will increase to approximately 400μA. This is not a failure mode. Above ±10V differential input voltage, the bias current will increase 100$\mu A/V_{diff}$ (in volts), and other parameters may suffer degradation. If these effects are undesirable, the user should investigate the AD513 or AD516 as a possible alternative.

Offset Voltage Drift

Most commercially available IC FET op amps are nulled by adjusting the FET operating currents, causing the offset voltage temperature coefficients to vary 3 to 6μV/°C per millivolt of offset nulled. Thus a FET op amp with a 20mV initial offset, when nulled may display an additional offset drift of 60 to 120μV/°C, in addition to its unnulled value.

The AD503 and AD506 achieve nulling without disturbing the operating currents of the FET's, which reduces the additional drift substantially. In addition, the AD506 includes a temperature compensated current source for the differential input stage, further reducing the offset voltage drift over temperature. In Figure 5, data is displayed to demonstrate the offset drift performance of the AD503 and AD506 when nulled. The AD503 and AD506 nulled drift contributions differ since the AD506 is constructed with low temperature coefficient (200ppm/°C) thin film resistors, and the AD503 uses a diffusion process resulting in 2000ppm/°C resistors. It can be shown that the additional drift induced by nulling a thin film amplifier with an industrial potentiometer is considerably less than that induced by nulling a diffused amplifier. There are two curves each for the AD503 and AD506 to account for both positive and negative offset drifts.

From the curves in Figure 5 it is possible to determine $\Delta V_{OS}/\Delta T$ for both the AD503 and AD506. The AD503 has an initial offset of 20mV and initial offset drift of −20μV/°C. The AD506 has an initial offset voltage of 1mV and initial offset drift of −20μV/°C. It can be determined that the additional drift induced by nulling the AD506 is only ±0.8μV/°C per millivolt of offset voltage, and ±2.0μV/°C per millivolt for the AD503. Both of these curves indicate performance considerably better than many other IC FET op amps which null V_{OS} by varying the operating currents of the FET's.

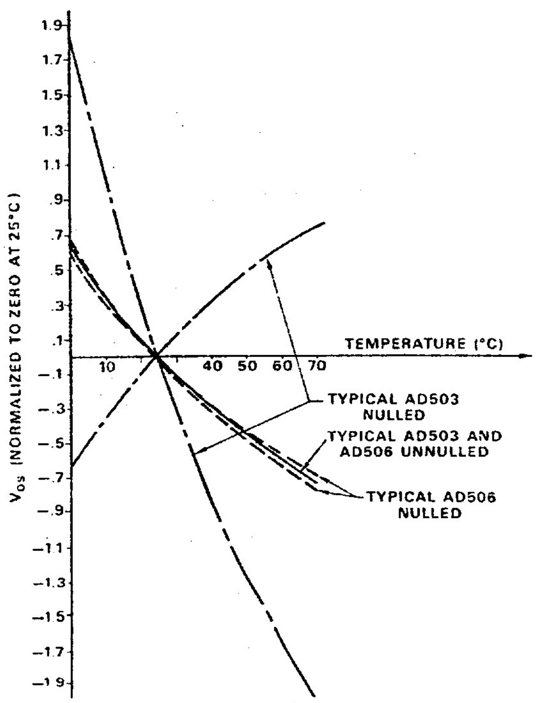


Figure 5. V_{OS} vs. Temperature

Noise Performance

The noise spectral density vs. frequency for the AD503 and AD506 is given in Figure 6. The curve for the AD503 shows approximately 300nV/√Hz at 10Hz, declining in a l/f fashion (l/f for power, 1/√f for voltage) to approximately 12nV/√Hz at higher frequencies.

Current noise in the AD503 and AD506 is approximately 0.001pA/√Hz at low frequencies. Above 300Hz, the current noise generated by the op amp increases at a 3dB/octave rate, determined by $\omega e_n C_{in}$, where e_n = spectral noise density and C_{in} = input capacitance. In most practical applications, the current noise from source or feedback resistors will be larger than the low frequency current noise from the amplifier.

At high frequencies, the total circuit current noise is equal to $\omega e_n C$, where C is the sum of all input and feedback capacitors. In well-shielded circuits, C is usually 10 to 100pF, so that the $\omega e_n C$ can be a significant factor. Thus the user should attempt to minimize C.

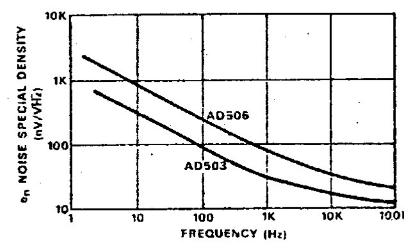


Figure 6. Noise Spectral Density vs. Frequency

Dynamic Performance

The AD503 and AD506 are internally compensated to achieve a −3dB bandwidth of 1MHz (see Figure 7). At unity gain the full power bandwidth is 50kHz minimum, and typically 100kHz. Slew rates are 3V/μsec minimum and 6V/μsec typical (see Figure 8 and Figure 9).

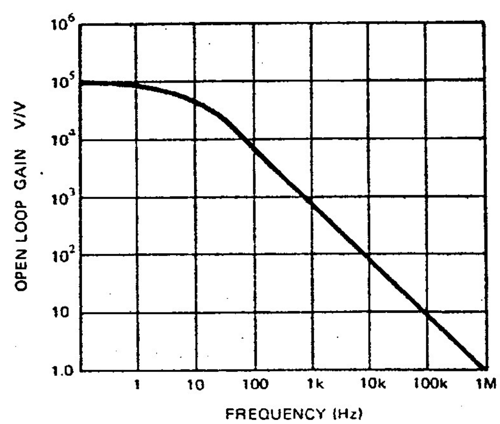


Figure 7. Small Signal Gain vs. Frequency

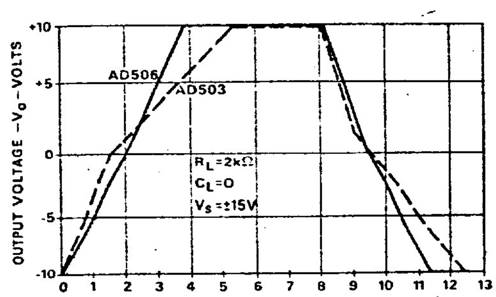


Figure 8. Voltage Follower Step Response

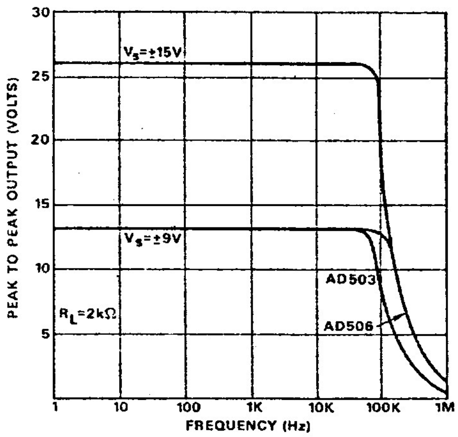


Figure 9. P-P Output vs. Frequency

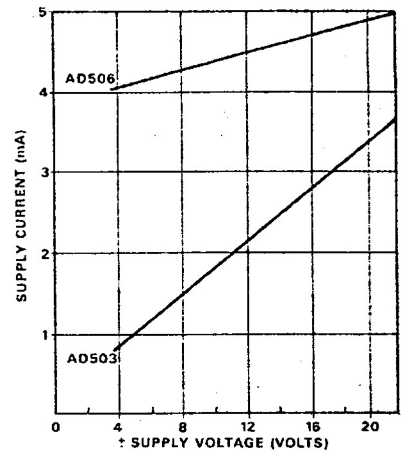


Figure 12. Supply Voltage vs. Supply Current

Common Mode Rejection Ratio

The high CMRR of both the AD503 and AD506 (see Figure 10) minimizes common mode error. For example, when either is connected as a unity gain non-inverting amplifier with a ±10V input signal, the resultant common mode error referred to the input is only 0.01% (1mV).

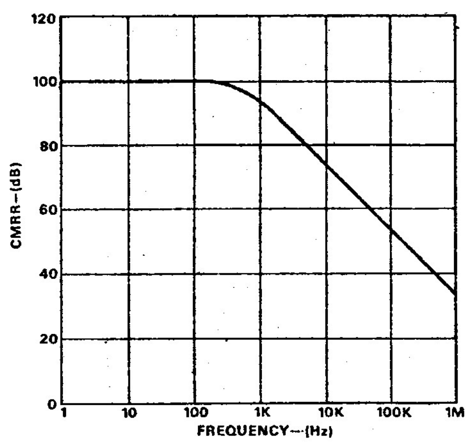


Figure 10. CMRR vs. Frequency

Output Characteristics

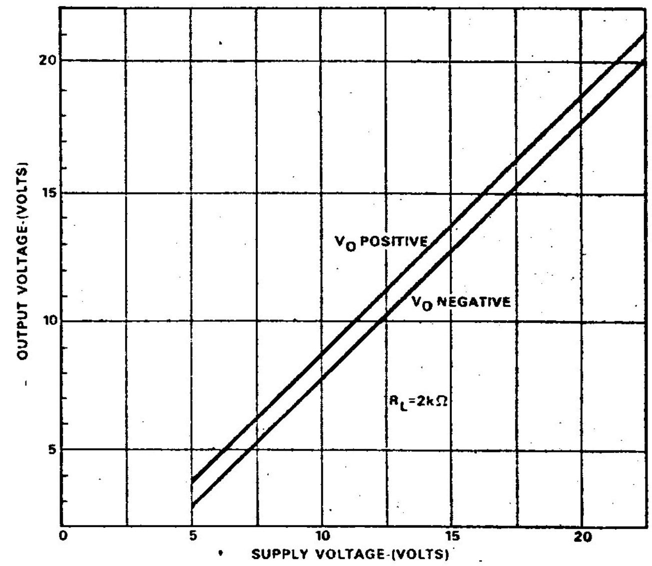


Figure 13. Output Voltage vs. Supply Voltage

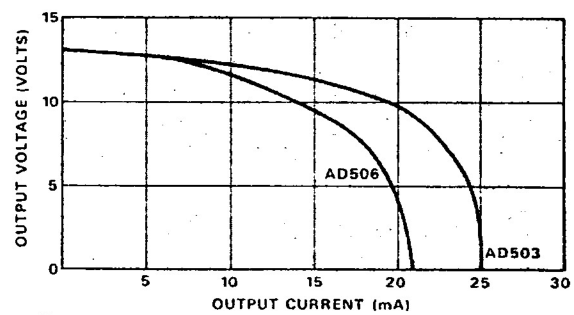


Figure 14. Output Voltage vs. Output Current

Supply Characteristics

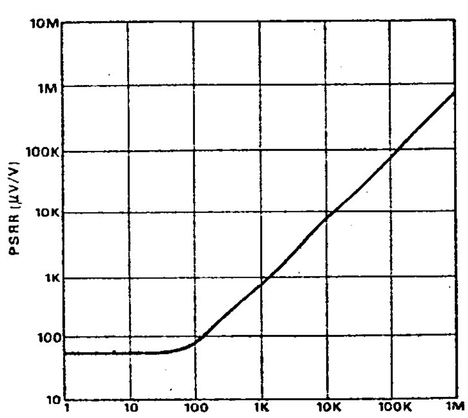
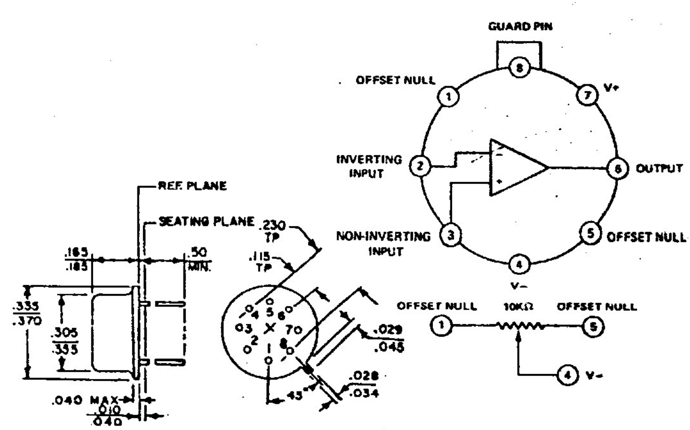


Figure 11. PSRR vs. Frequency



Outline Dimensions & Pin Designations

AUGUST 1974

LX5600/LX5600A, LX5700/LX5700A temperature transducers

general description

The LX5600/LX5700 series temperature transducers are highly accurate temperature measurement or control systems for use over a −55°C to +125°C temperature range. Fabricated on a single monolithic chip they include a temperature sensor, stable voltage reference and operational amplifier.

The output of the LX5600/LX5700 is directly proportional to temperature in degrees Kelvin at 10 mV/°K. Using the internal op amp with external resistors any temperature scale factor is easily obtained. By connecting the op amp as a comparator, the output will switch as the temperature transverses the set-point making the device useful as an on-off temperature controller.

An active shunt regulator is connected across the power leads to the LX5600/LX5700 to provide a stable voltage reference. In addition to providing a reference, it regulates the operating voltage to 6.8V. This allows the use of any power supply voltage with suitable external resistors.

The op amp can amplify the 10 mV/°K from the sensor to almost any desired output. The input bias current is low and relatively constant with temperature, ensuring high accuracy when high source impedance is used. Further, the output collector can be returned to a voltage higher than 6.8V allowing the LX5600/LX5700 to drive lamps and relays from a 28V supply.

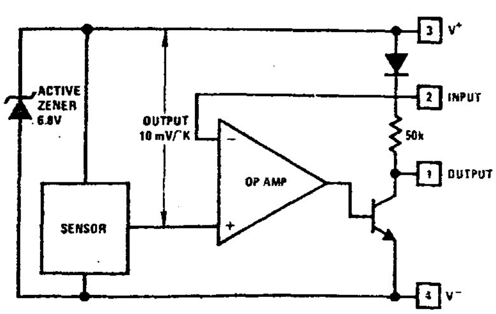
The LX5600 uses the difference in emitter-base voltage of transistors operating at different current densities as the basic temperature sensitive element. Since this output depends only on transistor matching the same reliability and stability as present op amps can be expected.

The LX5600 and LX5600A operate over a −55°C to +125°C range and are available in 4 lead TO-5 package. The LX5700 and LX5700A also operate over the −55°C to +125°C range and are available in the 4 lead TO-46 package.

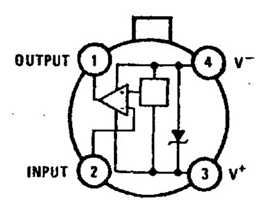
features

- Calibration accuracy of ±4°C over −55°C to +125°C
- Internal op amp with frequency compensation
- Linear output of 10 mV/°K (10 mV/°C)
- Directly calibrated in degrees Kelvin
- Output can drive loads up to 35V
- Internal stable voltage reference
- Four lead device—minimizing wiring

block and connection diagrams



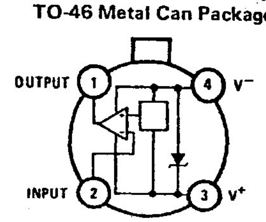
TO-5 Metal Can Package



TOP VIEW

NOTE: PIN 4 CONNECTED TO CASE

TO-46 Metal Can Package



TOP VIEW

NOTE: PIN 4 CONNECTED TO CASE

B25M84/Printed in U.S.A.

absolute maximum ratings

Supply Voltage	Internally Regulated	Output Short Circuit Duration	Indefinite
Supply Current (Externally Set)	10 mA	Operating Temperature Range	−55°C to +125°C
Output Collector Voltage	36V	Storage Temperature Range	−65°C to +150°C
Input Voltage Range	0V to +7.0V	Lead Temperature (Soldering, 10 seconds)	300°C

electrical characteristics (Note 1)

PARAMETER	CONDITIONS	LX5600A/LX5700A			LX5600/LX5700			UNITS
		TYP VOLTS	ERROR ±mV	ERROR ± % OF SPAN	TYP VOLTS	ERROR ±mV	ERROR ± % OF SPAN	
Output Voltage (Note 2)	T_A = +25°C	2.98	40	2.22	2.98	80	4.44	
Output Voltage (Note 2)	T_A = −55°C	2.18	40	2.22	2.18	80	4.44	
Output Voltage (Note 2)	T_A = +125°C	3.98	40	2.22	3.98	80	4.44	
Linearity	$\Delta T \leq +180°C$	0.018			0.018			
Long Term Stability	T_A = 125°C	±0.002			±0.002			
Repeatability	T_A = 125°C	±0.002			±0.002			
VOLTAGE REFERENCE		**MIN**	**TYP**	**MAX**	**MIN**	**TYP**	**MAX**	**UNITS**
Reverse Breakdown Voltage	1 mA $\leq I_z \leq$ 5 mA	6.68	6.85	7.12	6.55	6.85	7.25	V
Reverse Breakdown Voltage Change With Current	1 mA $\leq I_z \leq$ 5 mA		10	25		10	35	mV
Temperature Stability			20	60		20	85	mV
Dynamic Impedance	I_z = 1 mA		3.0			3.0		Ω
RMS Noise Voltage	10 Hz $\leq f \leq$ 10 kHz		30			30		µV
Long Term Stability	T_A = +125°C		6.0			6.0		mV
OP AMP								
Input Bias Current	T_A = +25°C		35	75		35	150	nA
Input Bias Current			45	150		45	250	nA
Voltage Gain	R_L = 36k, V^{++} = 36V	2000	15000		1500	15000		V/V
Output Leakage Current	T_A = 25°C (Note 3)		0.2	1.0	2.0	0.2		µA
Output Leakage Current	(Note 3)		1.0	5.0	8.0	1.0		µA
Output Source Current	$V_{OUT} \leq 4.05$	10			10			µA
Output Sink Current	$1V \leq V_{OUT} \leq 36V$	2.0			2.0			mA

Note 1: These specifications apply for $-55°C \leq T_A \leq +125°C$ and $0.9\ mA \leq I_{SUPPLY} \leq 1.1\ mA$ unless otherwise specified.

Note 2: The output voltage applies to the basic thermometer configuration with the output and feedback terminals shorted and a load resistance of $\geq$ 1.0 MΩ. This is the feedback sense voltage and includes errors in both the sensor and op amp. This voltage is specified for the sensor in a rapidly stirred oil bath.

Note 2: The output leakage current is specified with $\geq$ 100 mV overdrive. Since this voltage changes with temperature, the voltage drive for turn-off changes and is defined as V_{OUT} (with output and input shorted) −100 mV. This specification applies for V_{OUT} = 36V.

application hints

Although the LX5600/LX5700 were designed to be as trouble-free as possible, certain precautions should be taken to insure the best possible performance.

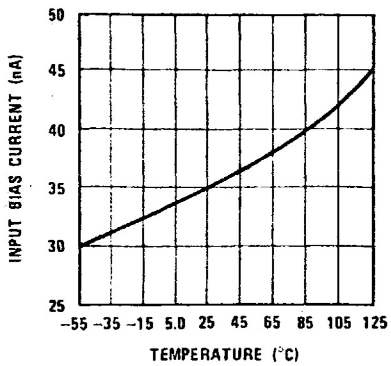
Like any temperature sensor, internal power dissipation will raise the sensor temperature above ambient. Nominal operating current for the shunt regulator is 1.0 mA and causes 7.0 mW of power dissipation. In free, still, air this raises the package temperature by about 1.2°K. Although the regulator will operate at higher reverse currents and the output will drive loads up to 5.0 mA, these higher currents can raise the sensor temperature over 19°K above ambient—degrading accuracy. Therefore, the sensor should be operated at the lowest possible power level.

With moving air, liquid or surface temperature sensing, self heating is not as great a problem since the measured media will conduct the heat from the sensor. Also, there are many small heat sinks designed for transistors which will improve heat transfer to the sensor from the surrounding medium. A small finned clip-on heat sink is quite effective in free-air. It should be mentioned that the LX5600 die is on the base of the package and therefore coupling to the base is preferrable.

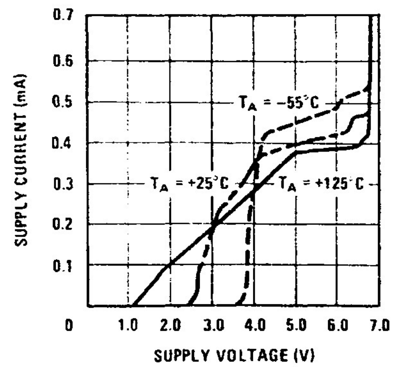
The internal reference regulator provides a temperature stable voltage for offsetting the temperature output or setting a comparison point in temperature controllers. However, since this reference is at the same temperature as the sensor temperature changes will also cause reference drift. For application where maximum accuracy is needed an external reference should be used. Of course, for fixed temperature controllers the internal reference is adequate.

typical applications (con't)

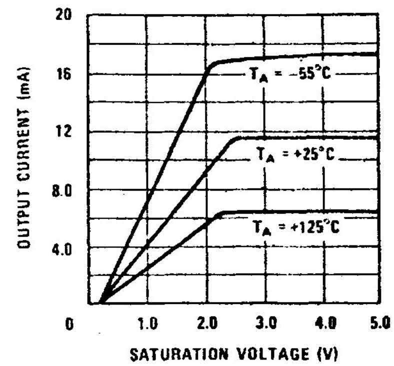
Input Current



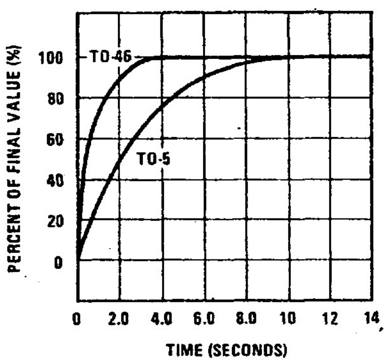
Start-Up



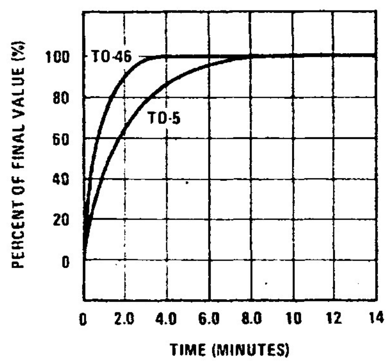
Output Saturation Voltage



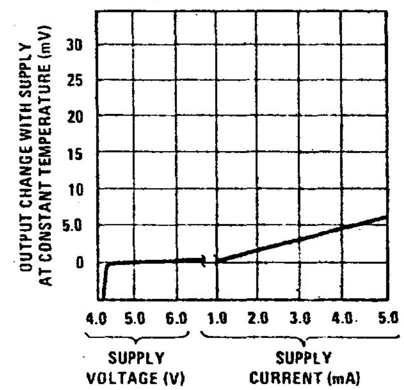
Thermal Time Constant in Stirred Oil Bath



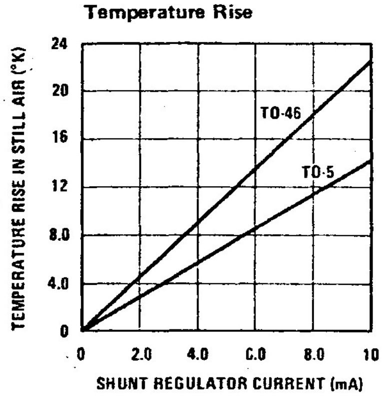
Thermal Time Constant in Still Air



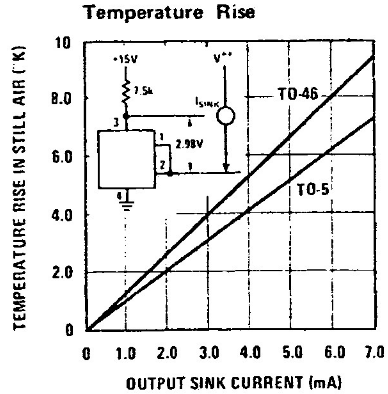
Supply Sensitivity



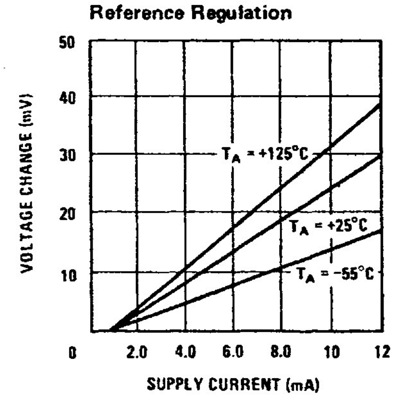
Temperature Rise



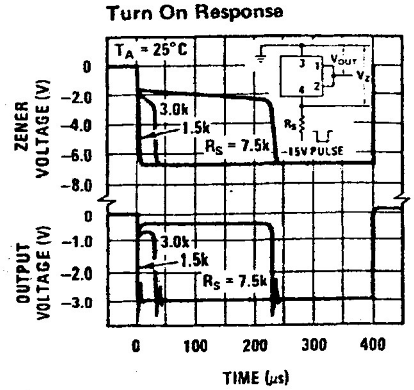
Temperature Rise



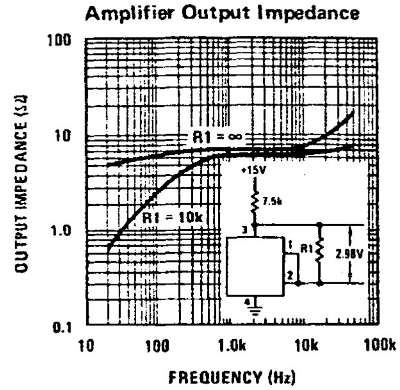
Reference Regulation



Turn On Response



Amplifier Output Impedance



Temperature Conversion

$T_{CENTIGRADE} = T_C$

$T_{FARENHEIT} = T_F$

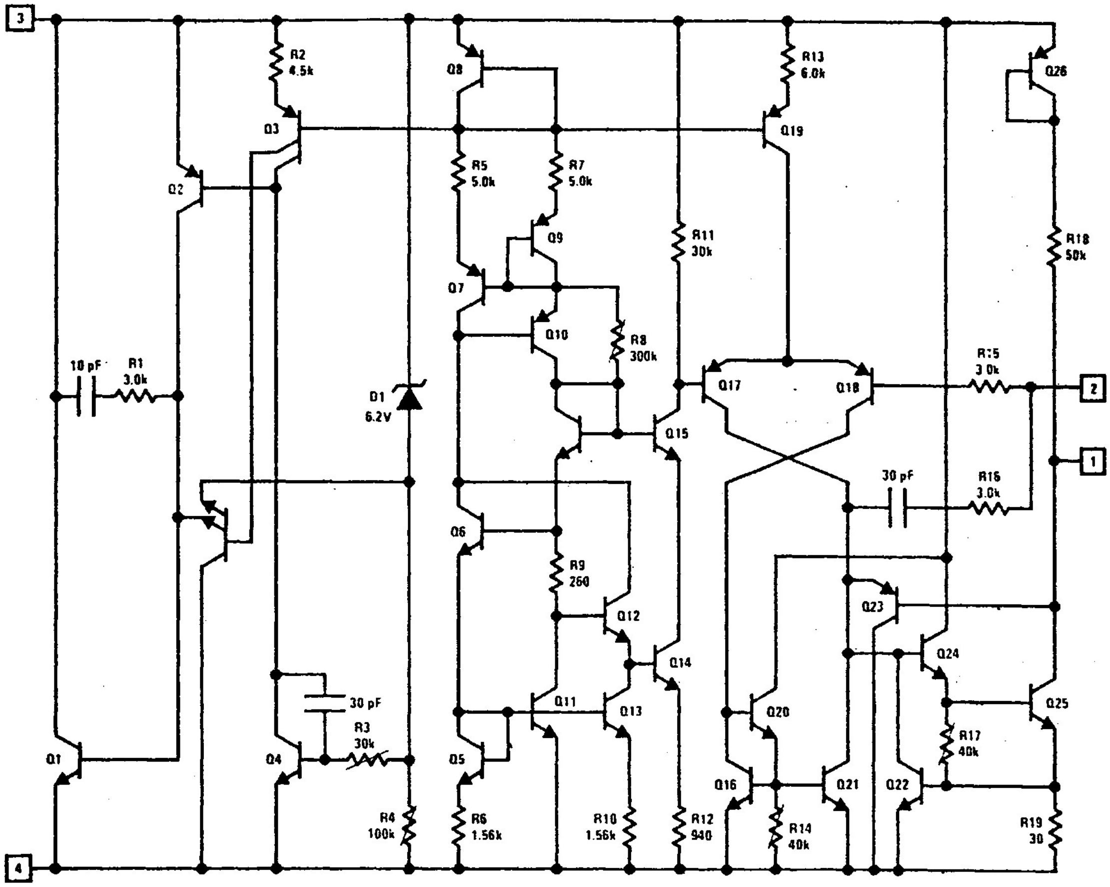
$T_{KELVIN} = T_K$

$T_K = T_C + 273$

$$T_C = (40 + T_F)\ \frac{5}{9} - 40$$

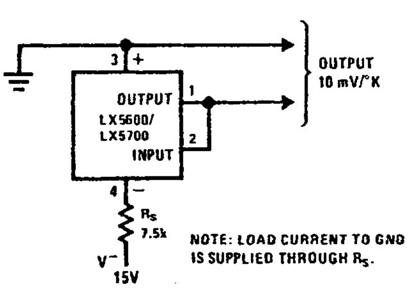
$$T_F = (40 + T_C)\ \frac{9}{5} - 40$$

schematic diagram



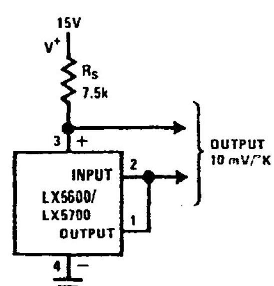
typical applications

Basic Thermometer for Negative Supply



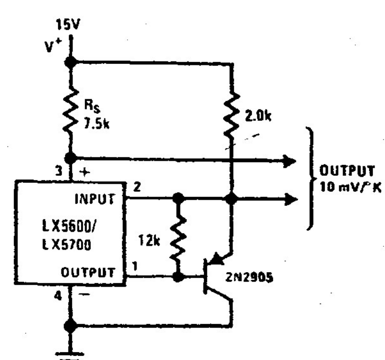
$R_S = (V^- - 6.8V) \times 10^3\Omega$

Basic Thermometer for Positive Supply



$R_S = (V^+ - 6.8V) \times 10^3\Omega$

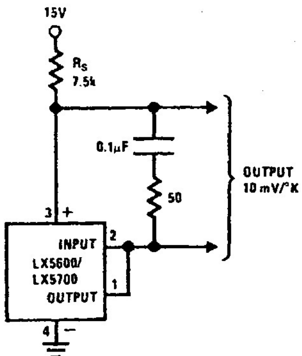
Increasing Gain and Output Drive



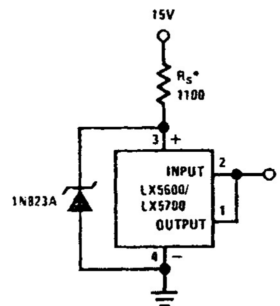
$R_S = (V^+ - 6.8V) \times 10^3\Omega$

typical applications (con't)

External Frequency Compensation for Greater Stability

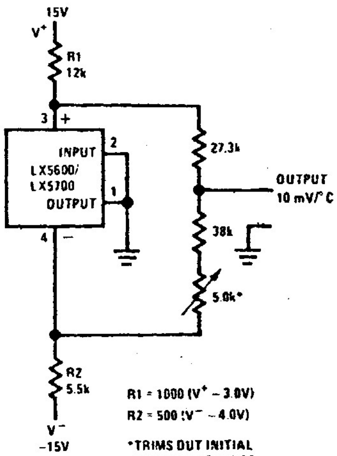


Operating With External Zener for Lower Power Dissipation and Better Reference Stability



*Depends on Zener current.

Ground Referred Centigrade Thermometer

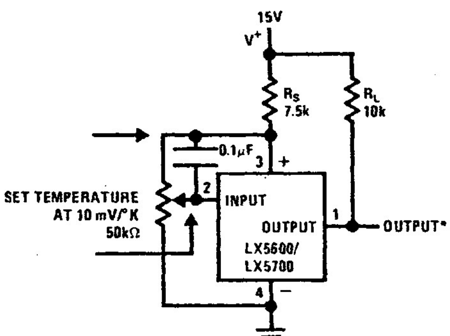


R1 = 1000 (V^+ − 3.8V)

R2 = 500 (V^- − 4.0V)

*TRIMS OUT INITIAL ZENER TOLERANCE. SET OUTPUT TO READ C

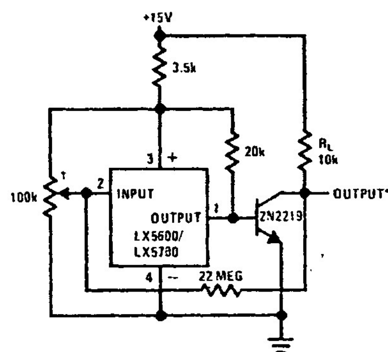
Basic Temperature Controller



*OUTPUT GOES NEGATIVE ON TEMPERATURE INCREASE

R_S = (V^+ − 6.8V) kΩ

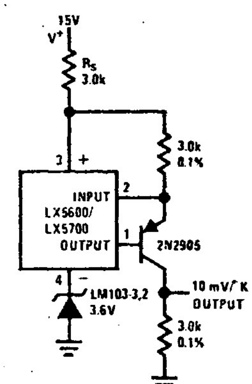
Temperature Controller With Hysteresis



*OUTPUT GOES POSITIVE ON TEMPERATURE INCREASE

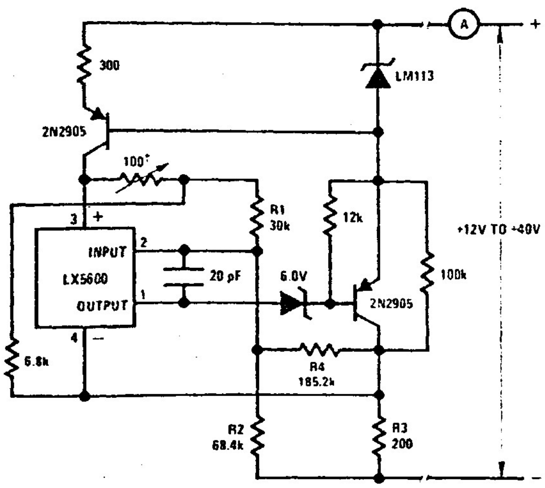
†SET TEMPERATURE

Kelvin Thermometer With Ground Referred Output



$$R_S = \frac{V_S^+ - 6.8V \times 10^3 \Omega}{2}$$

Two Terminal Temperature to Current Transducer*



$$R2\,(\Omega) = \frac{\left(V_Z - 0.01\,T_L\right)\left(I_H - \frac{0.01\,T_H}{R1}\right) + \left(V_Z - 0.01\,T_H\right)\left(\frac{0.01\,T_L}{R1} - I_L\right)}{\frac{0.01}{R1\,R3}\left[T_H\left(V_Z - 0.01\,T_L\right) - T_L\left(V_Z - 0.01\,T_H\right)\right]}$$

$$R3\,(\Omega) \geqq \frac{V_Z\left(\frac{T_H}{T_L} - 1\right)}{I_H - \frac{I_L\,T_H}{T_L}}$$

$$\frac{1}{R4} = \frac{1}{\left(V_Z - 0.01\,T_L\right)(R2)}\left[\frac{(R2)(0.01\,T_L)}{R1} + \frac{\left(\frac{V_Z - 0.01\,T_L}{R2} - I_L\right)}{\frac{1}{R2} + \frac{1}{R3}} - \frac{1}{R2}\right]$$

T_L = TEMPERATURE FOR I_L (°K)

T_H = TEMPERATURE FOR I_H (°K)

V_Z = ZENER VOLTAGE (VOLTS)

I_L = LOW TEMPERATURE OUTPUT CURRENT (mA)

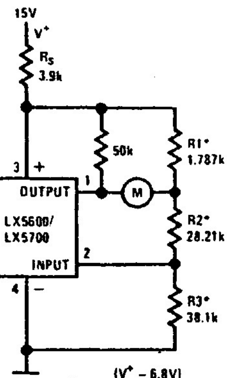
I_H = HIGH TEMPERATURE OUTPUT CURRENT (mA)

*VALUES SHOWN FOR I_{OUT} = 1 mA TO 10 mA FOR 10°F TO 100°F

†SET TEMPERATURE

typical applications (con't)

Thermometer With Meter Output



$R_S = \frac{(V^+ - 6.8V)}{0.001A + I_M + I_Q}$

*VALUES SHOWN FOR:
T_O = 300 K, ΔT = 100 K,
I_M = 1.0 mA, I_Q = 100μA

$$R1^* = \frac{(V_Z)(10\ mV)(\Delta T)}{I_M (V_Z - 0.01\ T_O)}$$

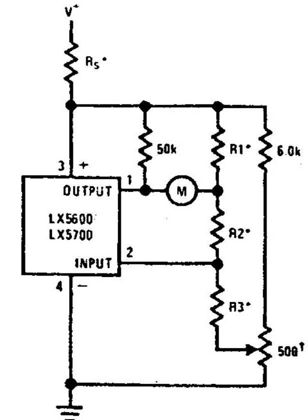
$$R2 = \frac{0.01\ T_O - I_Q\ R1}{I_Q}$$

$$R3 = \frac{V_Z}{I_Q} - R1 - R2$$

$$\left(I_Q \le \frac{2V}{R1}\right)$$

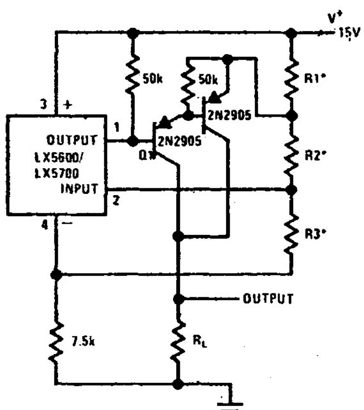
V_Z = SHUNT REGULATOR VOLTAGE (USE 6.85)
ΔT = METER TEMPERATURE SPAN (°K)
I_M = METER FULL SCALE CURRENT (A)
T_O = METER ZERO TEMPERATURE (°K)
I_Q = CURRENT THROUGH R1 R2 R3 AT ZERO METER CURRENT (10μA TO 1.0 mA) (A)

Meter Thermometer With Trimmed Output



*SELECTED AS FOR METER THERMOMETER EXCEPT T_O SHOULD BE 5°K MORE THAN DESIRED AND I_Q = 100μA.
†CALIBRATES T_O.

Ground Referred Thermometer



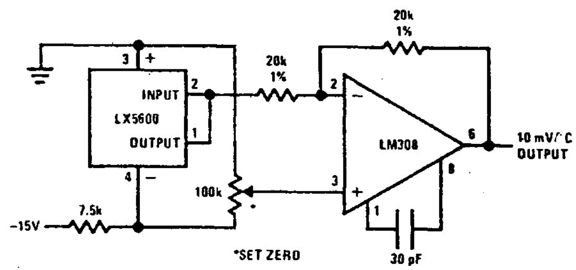
$$R1 = \frac{(V_Z)(10\ mV)(\Delta T)}{\frac{V_O}{R_L}(V_Z - 0.01\ T_O)}$$

$$R2 = \frac{0.01\ T_O - I_Q\ R1}{I_Q}$$

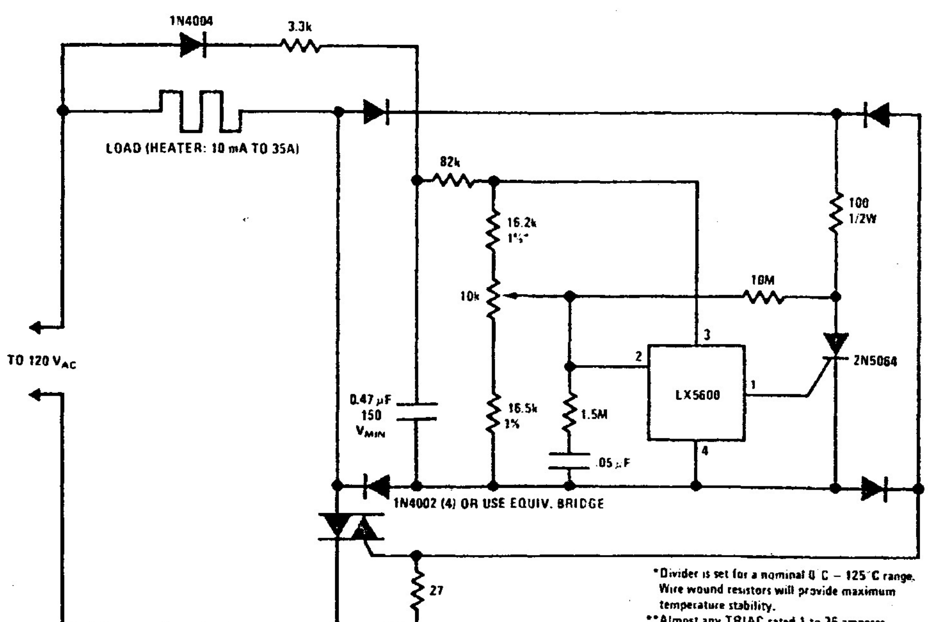
$$R3 = \frac{V_Z}{I_Q} - R1 - R2$$

V_Z = SHUNT REGULATOR VOLTAGE
ΔT = TEMPERATURE SPAN (K)
T_O = TEMPERATURE FOR ZERO OUTPUT (K)
V_O = FULL SCALE OUTPUT VOLTAGE ≤ 10V
I_Q = CURRENT THROUGH R1, R2, R3, AT ZERO OUTPUT VOLTAGE (TYPICALLY 100μA TO 1.0 mA)

Ground Referred Centigrade Thermometer



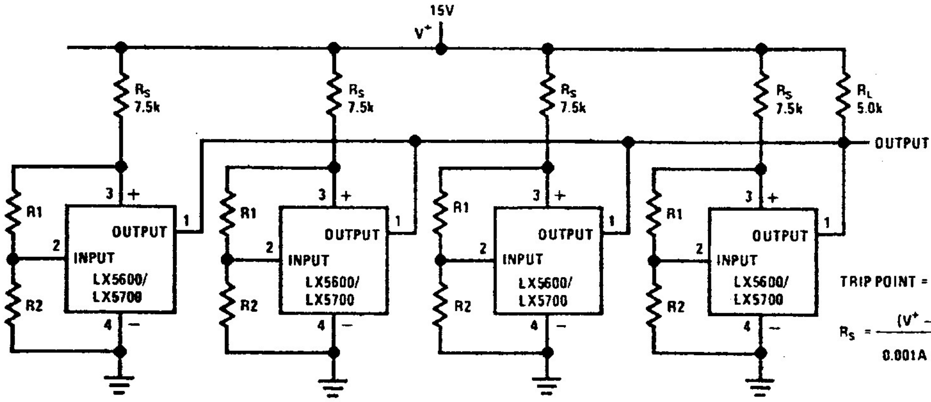
Three Wire Electronic Thermostat



*Divider is set for a nominal 0°C – 125°C range. Wire wound resistors will provide maximum temperature stability.
**Almost any TRIAC rated 1 to 35 amperes usable with appropriate load.

typical applications (con't)

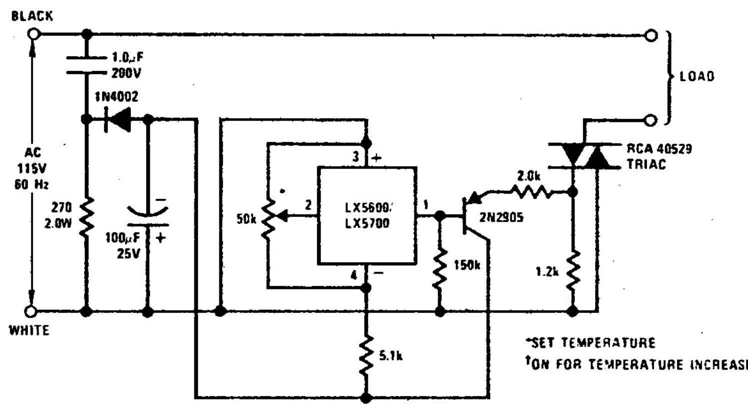
Over Temperature Detectors With Common Output



$$\text{TRIP POINT} = V_Z \frac{R1}{R1 + R2}$$

$$R_S = \frac{(V^+ - 6.8V)}{0.001A + \frac{6.8V}{R1 + R2}}$$

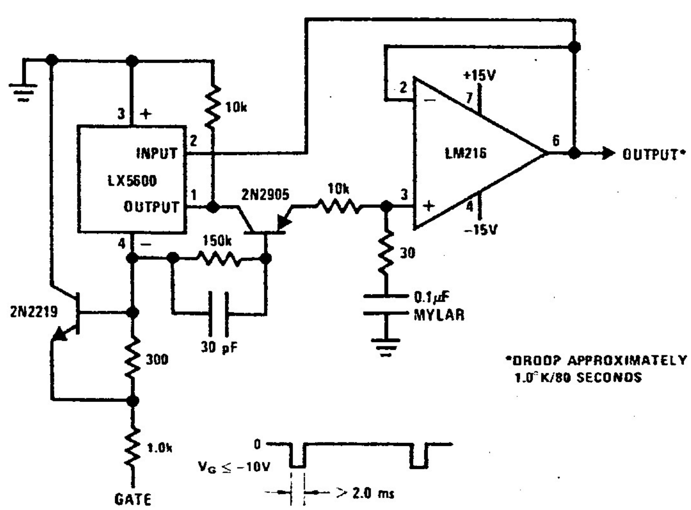
Temperature Controller Driving TRIAC



*SET TEMPERATURE

†ON FOR TEMPERATURE INCREASE

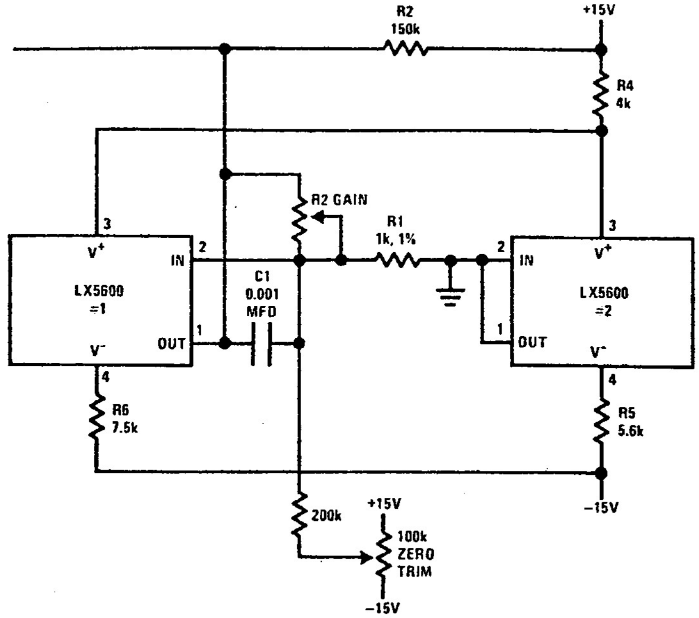
Low Duty Cycle Thermometer



*DROOP APPROXIMATELY 1.0°K/80 SECONDS

typical applications (con't)

Differential Thermometer



$V_{OUT} = (10\,mV/^\circ C)\left(\frac{R_1 + R_2}{R_1}\right)(T_2 - T_1)$

OUTPUT CAN SWING ±3V AT ±50μA WITH LOW OUTPUT IMPEDANCE.

definition of terms

Output Voltage: The voltage referred to the V+ terminal from the output terminal with the input and output connected. (This voltage is the temperature output of the LX5600 and so includes errors in the sensor section and op amp section.)

Linearity: The deviation in output voltage from a straight line output over a specified temperature excursion.

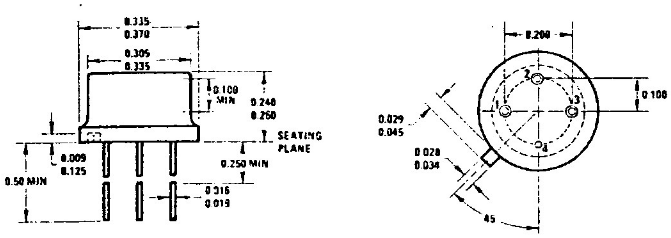
Reverse Breakdown Voltage: The voltage appearing between the V+ and V− terminals at a specified current.

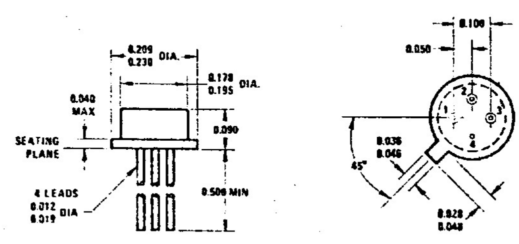
Temperature Stability: The percentage in output voltage for a thermal variation from room temperature to either temperature extreme.

Output Source Current: The current available to flow into a load from the output to V−, over a specified output voltage range.

Output Sink Current: The current available to flow into a load from a positive supply over a specified output voltage range.

physical dimensions





NOTES: ALL DIMENSIONS IN INCHES.
LEADS ARE GOLD PLATED KOVAR.
PIN 4 INTERNALLY CONNECTED TO CASE.
PACKAGE WEIGHT IS 0.36 GRAM.

TO-5 Metal Can Package (H)

Order Number LX5600AH or LX5600H

TO-46 Metal Can Package (H)

Order Number LX5700AH or LX5700H

Manufactured under one or more of the following U.S. patents: 3083262, 3189758, 3231797, 3303356, 3317671, 3323071, 3381071, 3408542, 3421025, 3426423, 3440498, 3518750, 3519897, 3557431, 3560765, 3566218, 3571630, 3575609, 3579059, 3593069, 3597640, 3607469, 3617859, 3631312, 3633052, 3638131, 3648071, 3651565, 3693248.

National Semiconductor Corporation
2900 Semiconductor Drive, Santa Clara, California 95051, (408) 732-5000/TWX (910) 339-9240
National Semiconductor GmbH
808 Fuerstenfeldbruck, Industriestrasse 10, West Germany, Tele. (08141) 1371/Telex 05-27649
National Semiconductor (UK) Ltd.
Larkfield Industrial Estate, Greenock, Scotland, Tele. (0475) 33251/Telex 778-632

varian

SOLID STATE OSCILLATOR

OPERATING INSTRUCTIONS

SOLID STATE
CW
GUNN EFFECT
OSCILLATOR

INTRODUCTION

These instructions provide basic information for installing and operating the standard Varian solid state CW Gunn Effect oscillator. Following is a brief discussion of some of the general characteristics of this type of device. The specific characteristics of your solid state oscillator are given in the Test Performance Sheet enclosed in the shipping package.

PROTECTIVE MEASURES

The operating simplicity of this device ensures satisfactory performance and maximum life with a minimum amount of protective circuitry. A simple low voltage dc bias potential is all that is necessary to create oscillations within the specified frequency range. However, the following precautions must be observed in order to protect the oscillator from possible damage.

In attaching the bias voltage to the oscillator the proper direction of polarity must be observed. The white lead or solder pin must be positive with respect to the ground lug. Reversing the polarity can permanently damage the oscillator.

Large voltage transients, such as those which might occur during bias voltage turn-on, or an accidental shorting of the positive bias lead to the oscillator body, can be damaging. A voltage-limiting zener diode has been placed in the oscillator to help reduce these transients, but if the bias voltage maximum rating is exceeded, the protective diode may be destroyed. Additional protective circuitry is advisable to restrict the applied voltage to the maximum value specified on the Test Performance Sheet. Proper voltage clamping of the zener diode requires a minimum of one ohm of series resistance in the external power supply-zener diode circuit. If a lower series resistance is used, adequate transient protection is not guaranteed. Consistent with the requirements of the foregoing, the oscillator may be turned on at any speed.

The oscillator is conduction cooled through the output flange. Under normal operating conditions adequate heat sinking is provided by the system waveguide. If, in certain restrictive environments, the waveguide flange temperature should approach or exceed approximately 85°C (185°F) additional cooling methods will be required.

OPERATING CHARACTERISTICS

A typical current vs voltage curve is shown below. As you will note, the bias voltage for operation is between two and three times higher than the threshold voltage, and the peak current drawn at the threshold point is higher than the operating current. Because of this, the bias power supply must be capable of supplying not only the operating voltage and current but also the peak current required at threshold.

BIAS CHARACTERISTICS

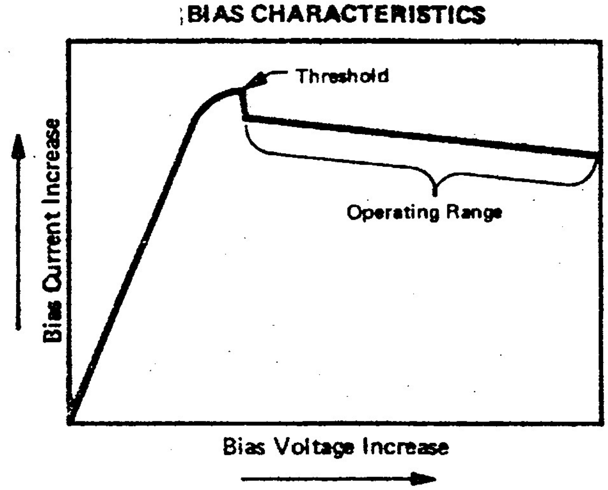


Figure 1

Since this type of solid state oscillator exhibits a negative differential resistance, certain bias circuit impedances can cause low frequency spurious oscillations. A filter network has been built into the oscillator to eliminate these spurious oscillations at the rated bias voltage.

All the tests indicated on the Test Performance Sheet have been made with the oscillator operating into a load VSWR of 1.1:1, or less. A greater VSWR will not damage the device but performance will deviate from that indicated.

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Printed in U.S.A.

INSTALLATION AND OPERATION

Remove the protective cover from the output flange and bolt the oscillator to the mating waveguide. Any mounting position can be used. Connect the white lead to the positive side and the ground lug to the negative side of the bias supply (see Figure 2). Apply the specified voltage as indicated on the Test Performance Sheet

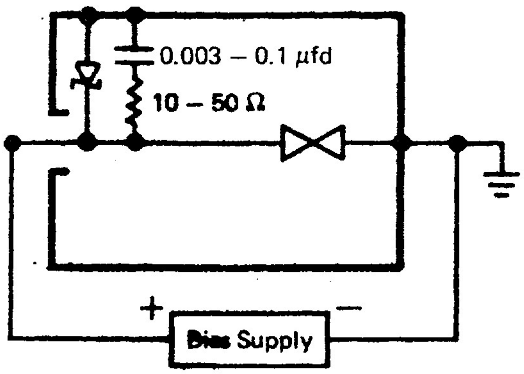


Figure 2

After applying the proper voltage, the oscillator will operate within the specified frequency range. Frequency changes can be accomplished by adjusting the tuning screw. A clockwise rotation will lower the frequency and a counterclockwise rotation will increase the frequency. Although the oscillator normally will tune beyond the specified frequency range, the performance characteristics will change from those specified.

Should any difficulties or questions arise while installing or operating the Varian CW solid state oscillator, please contact:

Varian Associates
Solid State West
Application Engineering
611 Hansen Way
Palo Alto, California 94303

SPECIAL INSTRUCTIONS FOR VOLTAGE TUNABLE OSCILLATORS

For oscillators with provisions for voltage tuning, the following additional instructions must be complied with.

a. The Gunn oscillator should be operated as described above.

b. Voltage tuning is accomplished by applying a POSITIVE bias voltage of the specified amplitude to the center conductor of the coaxial lead. Unless specifically noted on the Test Performance Sheet provided with the oscillator, never apply a negative bias or exceed the specified value.

c. If the voltage tuner is not used, it is recommended that the center conductor be short circuited to the outer (shield braid) conductor. This procedure will prevent FM modulation which could be caused by ac pickup on the lead.

MOTOROLA

Trev K8JVG

MPC1000

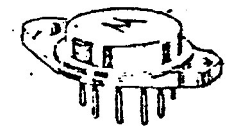
HIGH POWER POSITIVE VOLTAGE REGULATOR

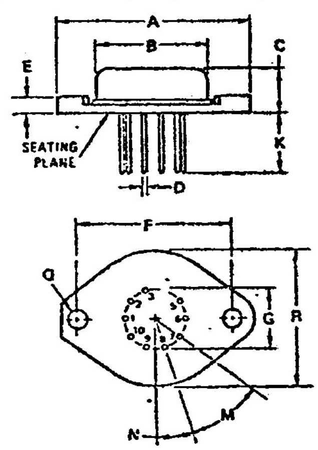
The MPC1000 is a positive voltage regulator designed to deliver load current to 10 Adc. Output current capability can be increased further through use of one or more external pass transistors. The MPC1000 is specified for operation over the junction temperature range (-55 to +175°C)

- 100 Watt Power Capability
- Output Voltage Adjustable – 2 to 35 Vdc
- Output Current to 10 Adc Without External Pass Transistors
- 0.1% Line and Load Regulation
- Temperature Stability 0.005%/°C Typ
- Adjustable Overload Protection

VOLTAGE REGULATOR

HIGH-CURRENT
10 AMPERE





DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	–	38.61	–	1.520
B	–	21.03	–	0.830
C	6.35	8.13	0.250	0.320
D	0.97	1.09	0.038	0.043
E	–	3.43	–	0.135
F	29.90	30.40	1.177	1.197
G	11.94 BSC		0.470 BSC	
K	7.11	8.13	0.280	0.320
M	35° BSC		35° BSC	
N	15° BSC		15° BSC	
Q	3.84	4.09	0.151	0.161
R	–	26.67	–	1.050

NOTE:
1. LEADS WITHIN 0.13 mm (0.005) DIA OF TRUE POSITION AT MAXIMUM MATERIAL CONDITION.

CASE 662-01

SOCKET/WASHER NOTE:

Mica Insulating Washer: Electronic Essentials Part No. MI-9-1000

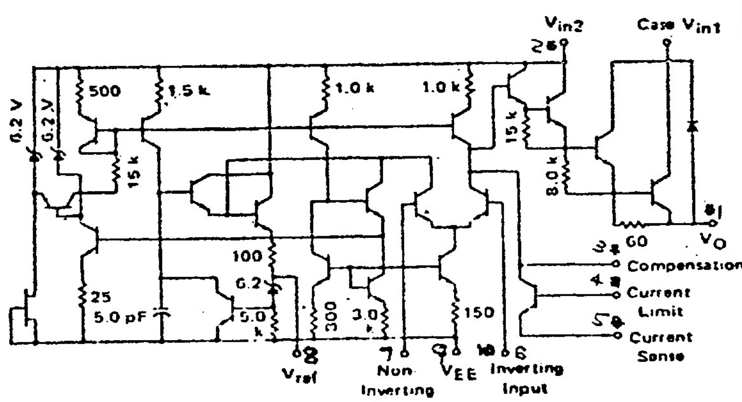
Socket: Electronic Essentials Part No. MS 9-1000
Electronic Essentials, Inc.
49 Bleecker Street
New York, New York 10012

The Case 662-01 pin configuration is compatible with 9 pin-miniature vacuum tube sockets.

MAXIMUM RATINGS (T_C = +25°C, unless otherwise noted.)

Rating	Symbol	Value	Unit
Pulse Voltage from V_{in2} to V_{EE} (50 ms)	$V_{in2(p)}$	50	V_{peak}
Continuous Voltage from V_{in2} to V_{EE}	V_{in2}	40	Vdc
Input-Output Voltage Differential	V_{in1}-V_O	60	Vdc
Output Current	I_L	10	Adc
Current from V_{ref}	I_{ref}	15	mA
Internal Power Dissipation @ T_C = 25°C Derate above T_C = 25°C	P_D $1/R_{\theta JC}$	100 0.667	Watts W/°C
Operating Junction Temperature Range	T_J	-55 to +175	°C
Storage Temperature Range	T_{stg}	-65 to +175	°C
Operating Case Temperature Range	T_C	-55 to +150	°C

FIGURE 1 – CIRCUIT SCHEMATIC



ELECTRICAL CHARACTERISTICS (T_C = 25°C, V_{in1} = V_{in2} = 12 Vdc, V_{EE} = 0, V_O = 5.0 Vdc, I_L = 10 mAdc, unless otherwise noted.)

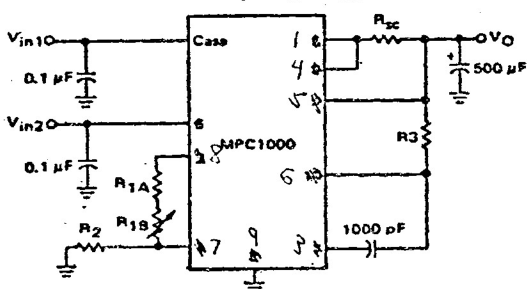
Characteristic	Figure No.	Note	Symbol	Min	Max	Unit
Input Voltage Range	2	1	V_{in2}	9.5	40	Vdc
Output Voltage Range	2	–	V_O	2.0	35	Vdc
Input-Output Voltage Differential (I_L = 10 mAdc)	2	2	V_{in1}-V_O V_{in2}-V_O	– –	60 38	Vdc
(I_L = 4.0 Adc)	2	2	V_{in1}-V_O V_{in2}-V_O	3.0 5.0	– –	
Reference Voltage	2	3	V_{ref}	6.8	7.5	Vdc
Standby Current Drain (I_L = 0, V_{in1} = V_{in2} = 30 Vdc, V_O = 5.0 Vdc)	2	8	I_{IB}	–	5.0	mAdc
Line Regulation (V_{in1} = V_{in2} = 12 Vdc to 15 Vdc)	2	2,6	Reg_{in}	–	0.1	%V_O
(V_{in1} = V_{in2} = 12 Vdc to 40 Vdc)	2	2,6	Reg_{in}	–	0.5	%V_O
Load Regulation (I_L = 100 mAdc to I_L = 4.0 Adc, pulsed)	2	2,4,7	Reg_{load}	–	0.1	%V_O

TEMPERATURE PERFORMANCE (I_L = 10 mAdc, V_O = 5.0 Vdc, V_{EE} = 0, unless otherwise noted.)

Characteristic	Figure No.	Note	Symbol	Max	Unit
Line Regulation (V_{in1} = V_{in2} = 12 Vdc to 15 Vdc)	2	2,6	Reg_{in}		
T_C = −55°C				0.5	%V_O
T_C = +125°C				0.5	%V_O
Load Regulation (I_L = 100 mAdc to 4.0 Adc, V_{in1} = V_{in2} = 12 Vdc)	2	2,4,7	Reg_{load}		
T_C = −55°C				0.6	%V_O
T_C = +125°C				0.6	%V_O
Temperature Coefficient of Output Voltage (V_{in1} = V_{in2} = 12 Vdc, I_L = 1.0 Adc, ΔT_C = 180°C, T_C = −55°C to +125°C)	2	2,4,5	TC_{VO}	0.015	%V_O/°C

TYPICAL CIRCUIT CONNECTIONS

FIGURE 2 – $V_O < V_{ref}$



Parameter Values for Best Results

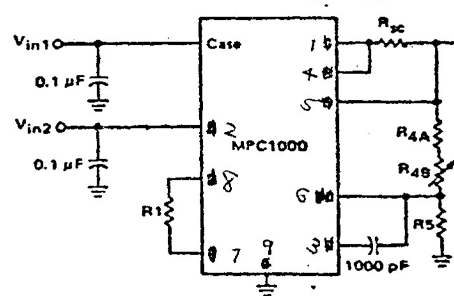
R1	$\geq \frac{R2\,(V_{ref} - V_O)}{V_O}$
R2	10 k < R1 + R2 < 100 k
R3	$= \left[\frac{R1\,R2}{R1 + R2}\right]$
R_{sc}	$\geq \frac{0.66}{I_{sc}}$ @ T_J = 25°C

To Allow For Variations In V_{ref}

(1) $R_{1A} \leq \frac{R2_{min}\,(V_{ref(min)} - V_O)}{V_O}$

(2) $(R_{1A} + R_{1B}) \geq \frac{R2_{max}\,(V_{ref(max)} - V_O)}{V_O}$

FIGURE 3 – $V_O > V_{ref}$



Parameter Values for Best Results

R1	$= \frac{R4\,R5}{R4 + R5}$
R4	$\geq \frac{R5\,(V_O - V_{ref})}{V_{ref}}$
R5	10 k < R5 < 100 k
R_{sc}	$\geq \frac{0.66}{I_{sc}}$ @ T_J = 25°C

To Allow For Variations In V_{ref}

(1) $R_{4A} \leq \frac{R5_{min}\,(V_O - V_{ref(min)})}{V_{ref(min)}}$

(2) $(R_{4A} + R_{4B}) \geq \frac{R5_{max}\,(V_O - V_{ref(max)})}{V_{ref(max)}}$

In most applications V_{in1} and V_{in2} can be connected together to eliminate one of the two capacitors shown in the above connection diagram. In either situation all capacitors should be as close as possible to the device to minimize lead inductance.

1. "Minimum Input Voltage" is the minimum "total instantaneous input voltage" required to properly bias the internal zener reference diode.
2. Set R_{sc} = 0 (short circuit)
3. V_{ref} voltage is measured from Pin 2 to Pin 3.
4. Pulse test conditions: Load current must be switched from minimum to maximum value at a repetition rate of 10 pps or less with a duty cycle of 1% or less in order to minimize heating effects.
5. The temperature coefficient of output voltage is defined as:

$$T_{CVO} = \frac{\pm(V_{O\,max} - V_{O\,min})\ (100)}{(\Delta T_C)\ (V_O\ @\ T_C = 25^oC)}$$

6. The input line regulation is defined as:

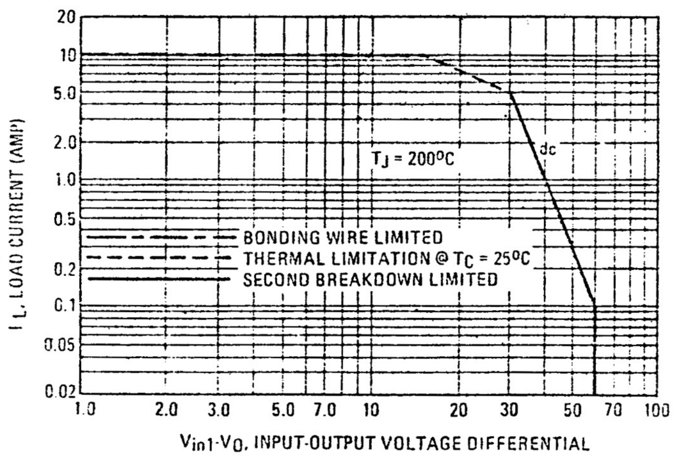
$$Reg_{in} = \frac{\pm\ (V_O\ @\ V_{in\ high} - V_O\ @\ V_{in\ low})}{V_O\ @\ V_{in\ low}} \times 100$$

7. Load regulation is defined as:

$$Reg_{load} = \frac{\pm\ (V_O\ @\ I_{Llow} - V_O\ @\ I_{Lhigh})\ (100)}{(V_O\ @\ I_{Llow})}$$

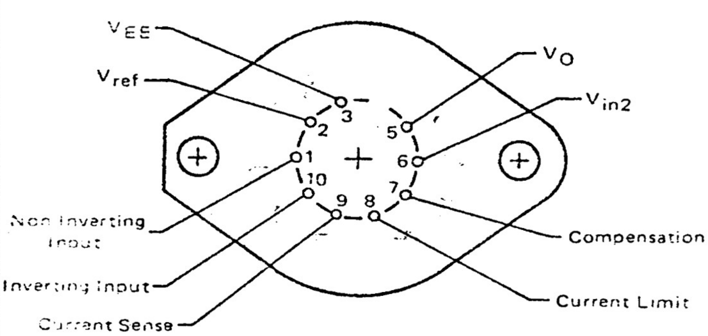
8. Standby current drain is defined as that value of current measured at Pins 6 and Case when R_L is open circuited.

FIGURE 3 — ACTIVE-REGION SAFE OPERATING AREA



There are two limitations on the power handling ability of a power semiconductor: average junction temperature and second breakdown. Safe operating area curves indicate I_L, $(V_{in1} - V_O)$ limits of the circuit that must be observed for reliable operation;

FIGURE 4 — PIN CONNECTION — BOTTOM VIEW



NOTE: Case is V_{in1}

FIGURE 5 — CURRENT LIMITING CHARACTERISTICS

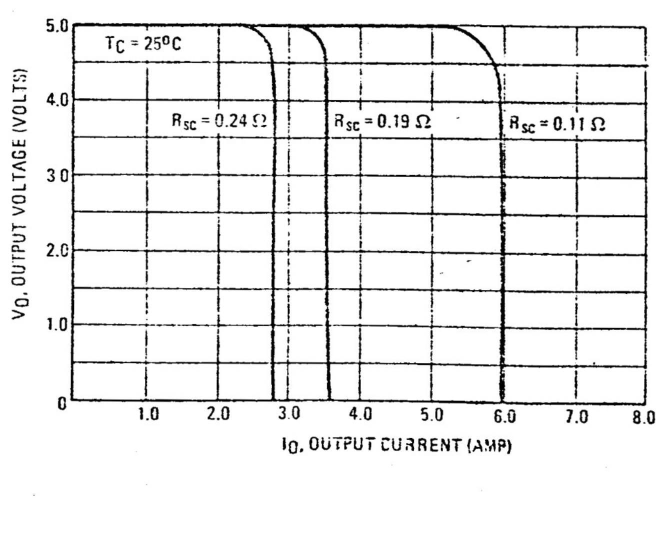


FIGURE 6 – LINE REGULATION AS A FUNCTION OF INPUT-OUTPUT VOLTAGE DIFFERENTIAL

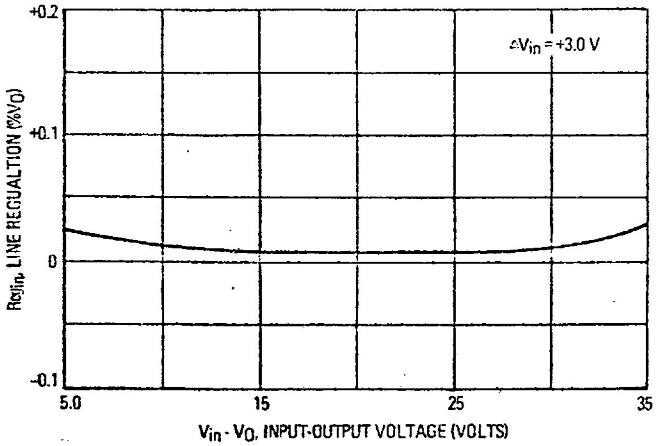


FIGURE 7 – STANDBY CURRENT DRAIN AS A FUNCTION OF INPUT VOLTAGE

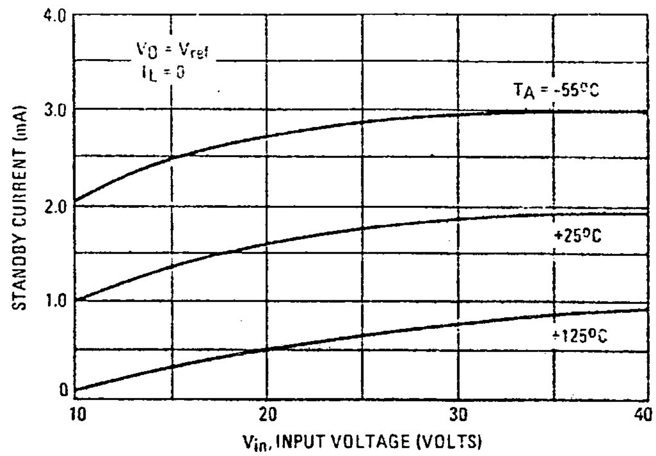


FIGURE 8 – LOAD TRANSIENT RESPONSE

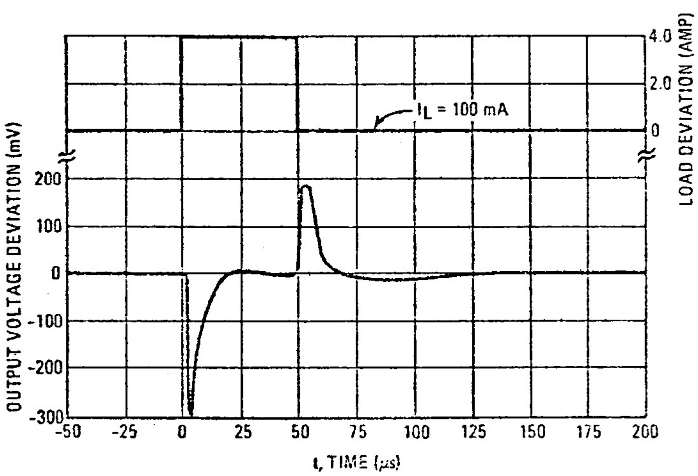


FIGURE 9 – LOAD REGULATION CHARACTERISTICS WITHOUT CURRENT LIMITING

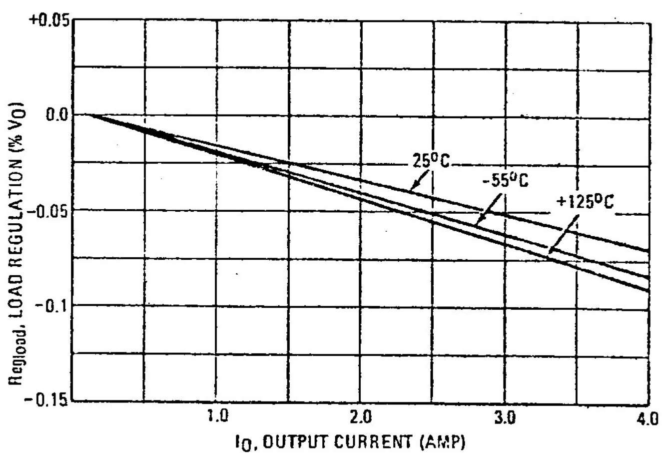
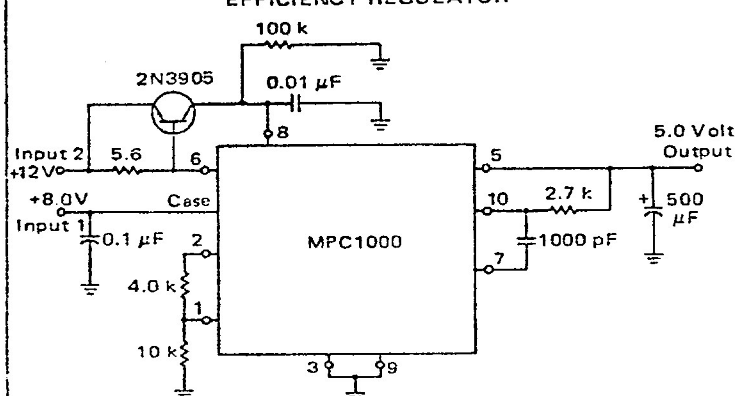


FIGURE 10 – 5 VOLT, 10 AMPERE HIGH EFFICIENCY REGULATOR



Regulator is protected by current limiting if input 1 is removed.

FIGURE 11 – 5 VOLT, 50 AMPERE POWER REGULATOR WITH REMOTE SENSE