1.5µA Max, Dual and Quad Precision Rail-to-Rail Input and Output Op Amps

FEATURES

- **Low Supply Current: 1.5µA Max**
- **Rail-to-Rail Input and Output**
- **Low Offset Voltage: 375µV Max**
- Wide Supply Range: 2.2V to 36V
- Single Supply Input Range: –0.3V to 36V
- Low Input Bias Current: 250pA
- Low Input Offset Current: 20pA
- High A_{VOL}: 100V/mV Minimum Driving 100kΩ Load
- Output Sources and Sinks 500µA Load Current
- Reverse Battery Protected to 18V

APPLICATIONS

- Battery- or Solar-Powered Systems
- Portable Instrumentation
- Remote Sensor Amplifier
- Micropower Filter

DESCRIPTION

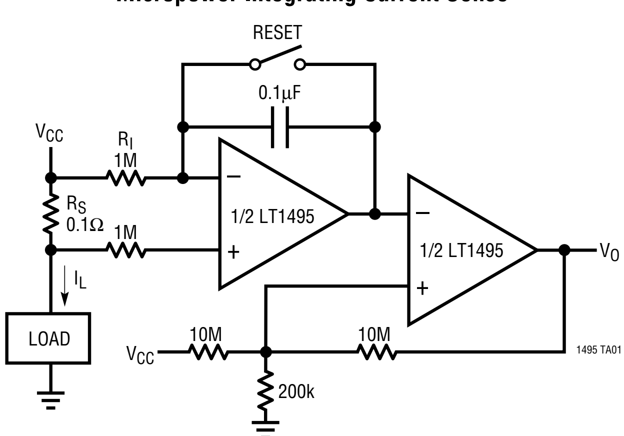
The LT®1495/LT1496 are the lowest power ($I_S \le 1.5\mu A$) op amps with precision specifications. The extremely low supply current is combined with excellent amplifier specifications: input offset voltage is 375µV maximum with a typical drift of only 0.4µV/°C, input offset current is 100pA maximum. A minimum open-loop gain (A_{VOL}) of 100V/mV ensures that gain errors are small. The device characteristics change little over the supply range of 2.2V to ±15V. Supply rejection is 90dB and the common mode rejection ratio is 90dB. Operation is specified for 3V, 5V and ±15V supplies. Reverse battery protection (–18V min) and inputs that operate above the positive supply make the LT1495/LT1496 easy to use in harsh environments.

The low bias currents and offset current of the amplifier permit the use of megohm level source resistors without introducing significant errors. Voltage noise at $4\mu V_{P-P}$ is remarkably low considering the low supply current.

The LT1495 is available in plastic 8-pin PDIP and SO-8 packages with the standard dual op amp pinout. The LT1496 is available in 14-pin SO and PDIP packages.

TYPICAL APPLICATION

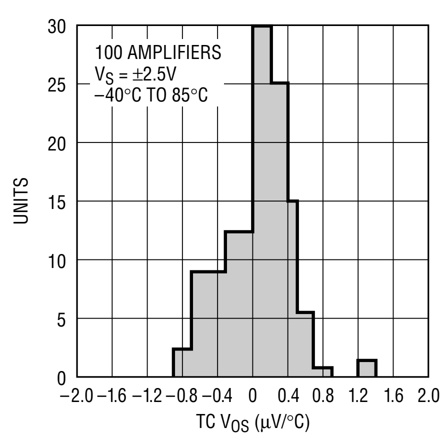
Micropower Integrating Current Sense



OUTPUT SWITCHES WHEN $\int I_L dt = 0.98\, V_{CC} \left(\frac{R_I}{R_S}\right) C$ = (4.9A)(SEC) FOR V_{CC} = 5V

I_S = 3µA DURING INTEGRATION; I_S = 5µA END OF INTEGRATION

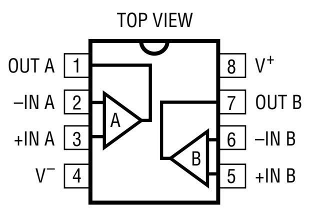
TC V_{OS} Distribution



ABSOLUTE MAXIMUM RATINGS

Total Supply Voltage (V^+ to V^-) 36V
Input Differential Voltage 36V
Input Current ....±10mA
Output Short-Circuit Duration ....Continuous
Operating Temperature Range .... –40°C to 85°C
Specified Temperature Range (Note 1) ... –40°C to 85°C
Storage Temperature Range .... –65°C to 150°C
Junction Temperature ....150°C
Lead Temperature (Soldering, 10 sec) ....300°C

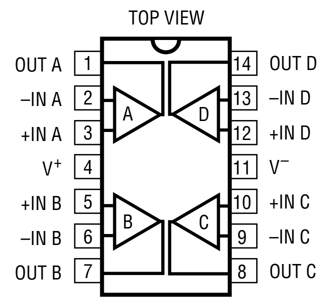
PACKAGE/ORDER INFORMATION



N8 PACKAGE 8-LEAD PDIP
S8 PACKAGE 8-LEAD PLASTIC SO

T_{JMAX} = 150°C, θ_{JA} = 130°C/W (N8)
T_{JMAX} = 150°C, θ_{JA} = 190°C/W (S8)

ORDER PART NUMBER
LT1495CN8 LT1495CS8
S8 PART MARKING
1495



N PACKAGE 14-LEAD PDIP
S PACKAGE 14-LEAD PLASTIC SO

T_{JMAX} = 150°C, θ_{JA} = 110°C/W (N8)
T_{JMAX} = 150°C, θ_{JA} = 150°C/W (S8)

ORDER PART NUMBER
LT1496CN LT1496CS

Consult factory for Industrial and Military grade parts.

ELECTRICAL CHARACTERISTICS

T_A = 25°C, V_S = 5V, 0V; V_S = 3V, 0V; V_{CM} = V_O = half supply, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	V_S = 5V V_S = 3V		150 200	375 475	µV µV
I_B	Input Bias Current	(Note 3) V_{CM} = 10V (Note 4)		250 180	1000 360	pA nA
I_{OS}	Input Offset Current	(Note 3)		20	100	pA
	Input Noise Voltage	0.1Hz to 10Hz		4		μV_{P-P}
e_n	Input Noise Voltage Density	f = 100Hz		185		$nV/\sqrt{Hz}$
i_n	Input Noise Current Density	f = 100Hz		10		$fA/\sqrt{Hz}$
A_{VOL}	Large-Signal Voltage Gain	V_S = 5V, V_O = 0.25V to 4.5V, R_L = 100k V_S = 3V, V_O = 0.25V to 2.5V, R_L = 100k	100 50	500 250		V/mV V/mV
	Input Voltage Range		0		36	V
CMRR	Common Mode Rejection Ratio	V_{CM} = 0V to 4V, V_S = 5V V_{CM} = 0V to 10V, V_S = 5V	90 74	106 95		dB dB
PSRR	Power Supply Rejection Ratio	V_S = 2.2V to 12V, V_{CM} = V_O = 0.5V	90	99		dB
	Minimum Operating Supply Voltage			2.1	2.2	V
V_{OL}	Output Voltage Swing LOW	No Load I_{SINK} = 100µA		50 210	100 410	mV mV

ELECTRICAL CHARACTERISTICS

T_A = 25°C, V_S = 5V, 0V; V_S = 3V, 0V; V_{CM} = V_O = half supply, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OH}	Output Voltage Swing HIGH	No Load I_{SOURCE} = 100µA		V^+ – 0.07 V^+ – 0.32	V^+ – 0.035 V^+ – 0.160		V V
I_{SC}	Short-Circuit Current	(Note 3)		0.7	1.3		mA
I_S	Supply Current per Amplifier	(Note 4)			1.0	1.5	µA
	Reverse Supply Voltage	I_S = 10µA per Amplifier		–18			V
SR	Slew Rate	A_V = –1, V_S = ±5V		0.4	1.0		V/ms
GBW	Gain Bandwidth Product	f = 100Hz			2.7		kHz

0°C ≤ T_A ≤ 70°C, V_S = 5V, 0V; V_S = 3V, 0V; V_{CM} = V_O = half supply, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	V_S = 5V V_S = 3V	● ●		175 225	425 525	µV µV
V_{OS} TC	Input Offset Voltage Drift	(Note 2)	●		0.4	2	µV/°C
I_B	Input Bias Current	(Note 3) V_{CM} = 10V (Note 4)	● ●		250 240	1200 500	pA nA
I_{OS}	Input Offset Current	(Note 3)	●		20	120	pA
A_{VOL}	Large-Signal Voltage Gain	V_S = 5V, V_O = 0.25V to 4.5V, R_L = 100k V_S = 3V, V_O = 0.25V to 2.5V, R_L = 100k	● ●	75 40	280 150		V/mV V/mV
	Input Voltage Range		●	0		36	V
CMRR	Common Mode Rejection Ratio	V_{CM} = 0.2V to 4V, V_S = 5V V_{CM} = 0.2V to 10V, V_S = 5V	● ●	89 64	106 85		dB dB
PSRR	Power Supply Rejection Ratio	V_S = 2.4V to 12V, V_{CM} = V_O = 0.5V	●	89	99		dB
	Minimum Operating Supply Voltage		●		2.3	2.4	V
V_{OL}	Output Voltage Swing LOW	No Load I_{SINK} = 100µA	● ●		55 225	110 450	mV mV
V_{OH}	Output Voltage Swing HIGH	No Load I_{SOURCE} = 100µA	● ●	V^+ – 0.08 V^+ – 0.36	V^+ – 0.04 V^+ – 0.18		V V
I_{SC}	Short-Circuit Current	(Note 3)	●	0.6	1.1		mA
I_S	Supply Current per Amplifier	(Note 4)	●		1.2	1.8	µA

–40°C ≤ T_A ≤ 85°C, V_S = 5V, 0V; V_S = 3V, 0V; V_{CM} = V_O = half supply, unless otherwise noted. (Note 1)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	V_S = 5V V_S = 3V	● ●		200 250	475 575	µV µV
V_{OS} TC	Input Offset Voltage Drift	(Note 2)	●		0.4	2	µV/°C
I_B	Input Bias Current	(Note 3) V_{CM} = 10V (Note 4)	● ●		250 275	1700	pA nA
I_{OS}	Input Offset Current	(Note 3)	●		20	170	pA
A_{VOL}	Large-Signal Voltage Gain	V_S = 5V, V_O = 0.25V to 4.5V, R_L = 100k V_S = 3V, V_O = 0.25V to 2.5V, R_L = 100k	● ●	55 30	215 115		V/mV V/mV
	Input Voltage Range		●	0		36	V
CMRR	Common Mode Rejection Ratio	V_{CM} = 0.2V to 4V, V_S = 5V V_{CM} = 0.2V to 10V, V_S = 5V	● ●	88	106 75		dB dB
PSRR	Power Supply Rejection Ratio	V_S = 2.7V to 12V, V_{CM} = V_O = 0.5V	●	88	99		dB
	Minimum Operating Supply Voltage		●		2.6	2.7	V

ELECTRICAL CHARACTERISTICS

$-40°C \le T_A \le 85°C$, V_S = 5V, 0V; V_S = 3V, 0V; $V_{CM} = V_O$ = half supply, unless otherwise noted. (Note 1)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OL}	Output Voltage Swing LOW	No Load	●		60	120	mV
		I_{SINK} = 100µA	●		245	490	mV
V_{OH}	Output Voltage Swing HIGH	No Load	●	V^+ – 0.10	V^+ – 0.05		mV
		I_{SOURCE} = 100µA	●	V^+ – 0.38	V^+ – 0.19		mV
I_{SC}	Short-Circuit Current	(Note 3)	●	0.4	0.9		mA
I_S	Supply Current per Amplifier	(Note 4)	●		1.5	2.3	µA

T_A = 25°C, V_S = ±15V, $V_{CM} = V_O$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage				200	575	µV
I_B	Input Bias Current				25	1000	pA
I_{OS}	Input Offset Current				20	100	pA
A_{VOL}	Large-Signal Voltage Gain	V_O = ±10V, R_L = 100k		100	360		V/mV
	Input Voltage Range			–15		21	V
CMRR	Common Mode Rejection Ratio	V_{CM} = –15V to 14V		100	120		dB
PSRR	Power Supply Rejection Ratio	V_S = ±5V to ±15V		96	120		dB
V_{OL}	Output Voltage Swing LOW	R_L = 1M			–14.85	–14.70	V
		R_L = 100k			–14.75	–14.50	V
V_{OH}	Output Voltage Swing HIGH	R_L = 1M		14.78	14.89		V
		R_L = 100k		14.62	14.81		V
I_{SC}	Short-Circuit Current			0.7	1.5		mA
I_S	Supply Current per Amplifier				1.4	2.0	µA

$0°C \le T_A \le 70°C$, V_S = ±15V, $V_{CM} = V_O$ = 0V, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage		●		225	625	µV
I_B	Input Bias Current		●		250	1200	pA
I_{OS}	Input Offset Current		●		20	120	pA
A_{VOL}	Large-Signal Voltage Gain	V_O = ±10V, R_L = 100k	●	60	240		V/mV
	Input Voltage Range		●	–15		21	V
CMRR	Common Mode Rejection Ratio	V_{CM} = –14.8V to 14V	●	98	120		dB
PSRR	Power Supply Rejection Ratio	V_S = ±5V to ±15V	●	94	120		dB
V_{OL}	Output Voltage Swing LOW	R_L = 1M	●		–14.84	–14.67	V
		R_L = 100k	●		–14.73	–14.46	V
V_{OH}	Output Voltage Swing HIGH	R_L = 1M	●	14.76	14.88		V
		R_L = 100k	●	14.58	14.79		mV
I_{SC}	Short-Circuit Current		●	0.6	1.3		mA
I_S	Supply Current per Amplifier		●		1.6	2.4	µA

ELECTRICAL CHARACTERISTICS

–40°C ≤ T_A ≤ 85°C, V_S = ±15V, V_{CM} = V_O = 0V, unless otherwise noted. (Note 1)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage		●		250	675	μV
I_B	Input Bias Current		●		250	1700	pA
I_{OS}	Input Offset Current		●		20	170	pA
A_{VOL}	Large-Signal Voltage Gain	V_O = ±10V, R_L = 100k	●	50	200		V/mV
	Input Voltage Range		●	–15		21	V
CMRR	Common Mode Rejection Ratio	V_{CM} = –14.8V to 14V	●	96	114		dB
PSRR	Power Supply Rejection Ratio	V_S = ±5V to ±15V	●	92	120		dB
V_{OL}	Output Voltage Swing LOW	R_L = 1M R_L = 100k	● ●		–14.83 –14.72	–14.66 –14.44	V V
V_{OH}	Output Voltage Swing HIGH	R_L = 1M R_L = 100k	● ●	14.74 14.54	14.87 14.77		V V
I_{SC}	Short-Circuit Current		●	0.4	1.1		mA
I_S	Supply Current per Amplifier		●		2.0	3.0	μA

The ● denotes specifications which apply over the full operating temperature range.

Note 1: The LT1495/LT1496 are designed, characterized and expected to meet these extended temperature limits, but are not tested at –40°C and 85°C. Guaranteed I grade parts are available; consult factory.

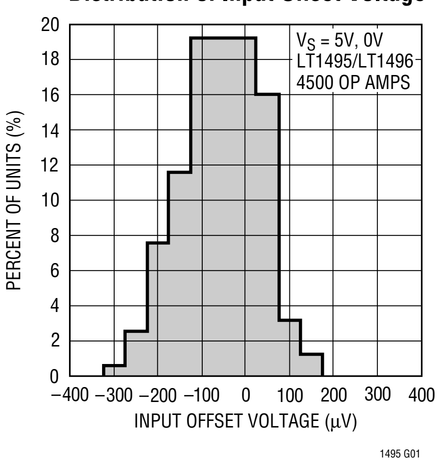
Note 2: This parameter is not 100% tested.

Note 3: V_S = 5V limit guaranteed by correlation to V_S = 3V and V_S = ±15V tests.

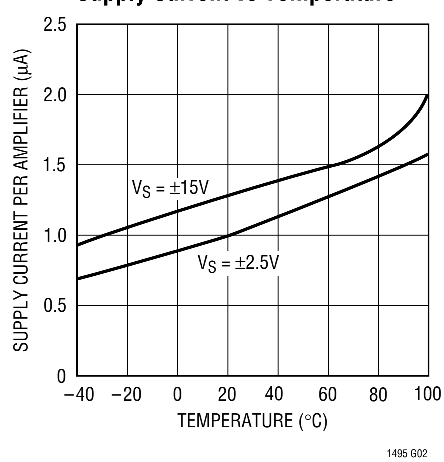
Note 4: V_S = 3V limit guaranteed by correlation to V_S = 5V and V_S = ±15V tests.

TYPICAL PERFORMANCE CHARACTERISTICS

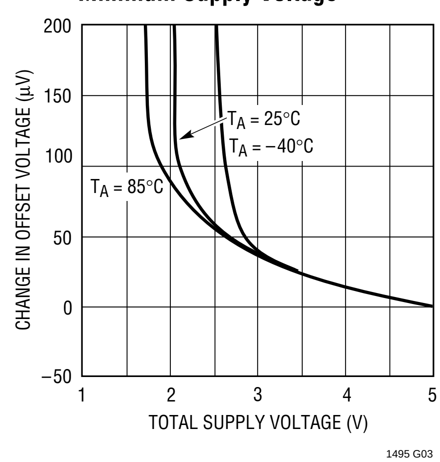
Distribution of Input Offset Voltage



Supply Current vs Temperature

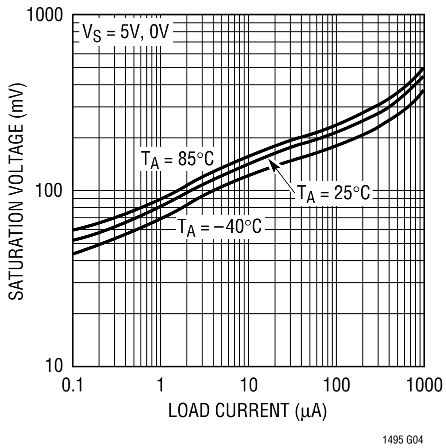


Minimum Supply Voltage

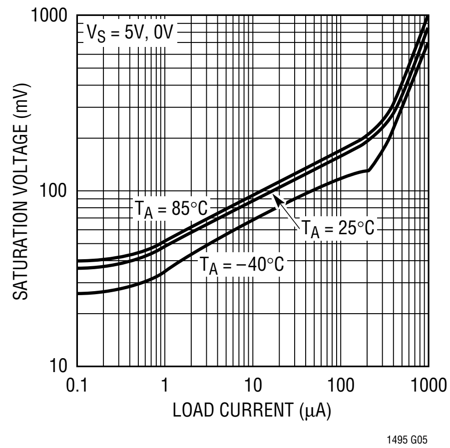


TYPICAL PERFORMANCE CHARACTERISTICS

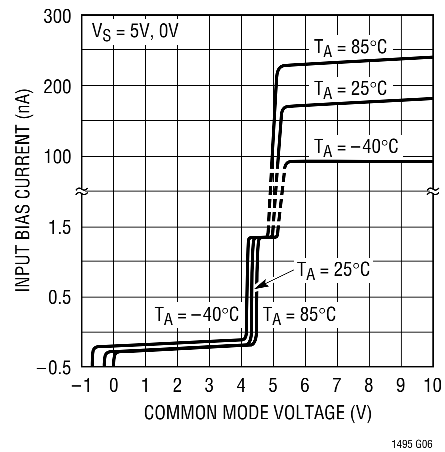
Output Saturation Voltage vs Load Current (Output Low)



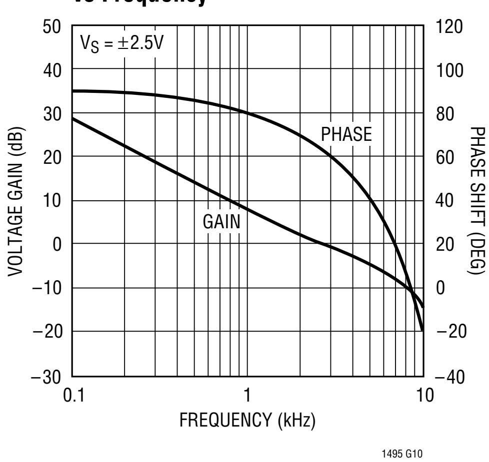
Output Saturation Voltage vs Load Current (Output High)



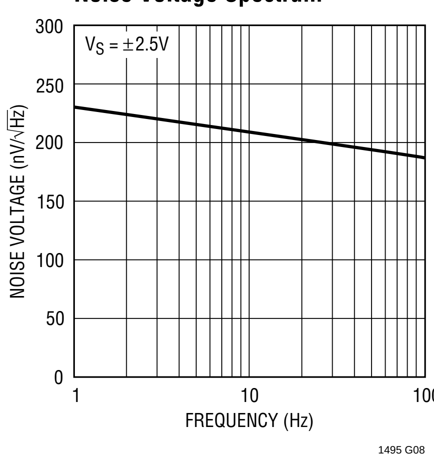
Input Bias Current vs Common Mode Voltage



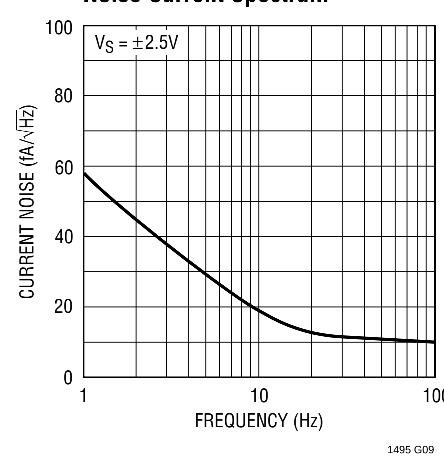
Gain and Phase Shift vs Frequency



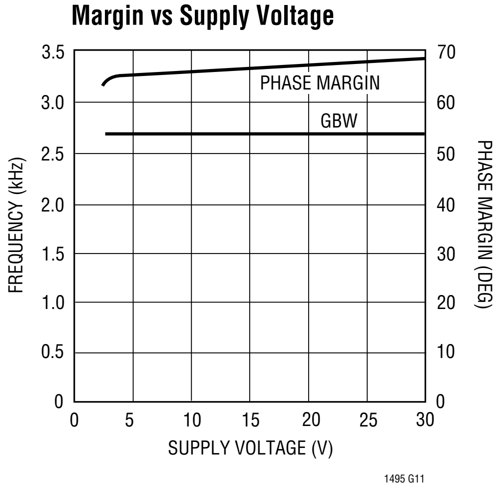
Noise Voltage Spectrum



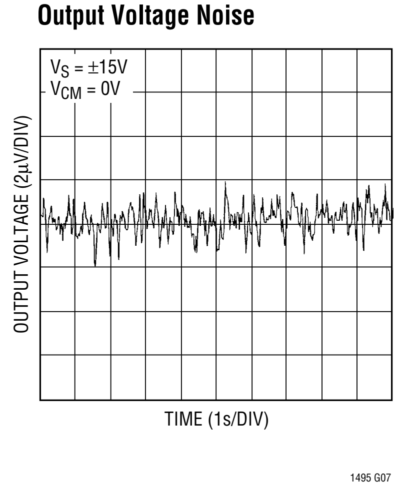
Noise Current Spectrum



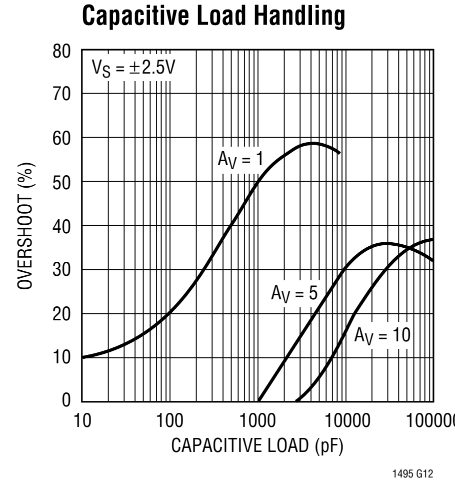
Gain Bandwidth and Phase Margin vs Supply Voltage



0.1Hz to 10Hz Output Voltage Noise

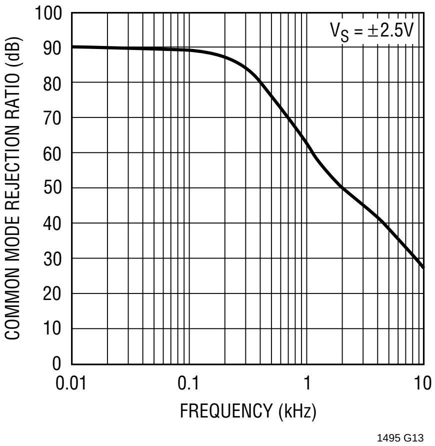


Capacitive Load Handling

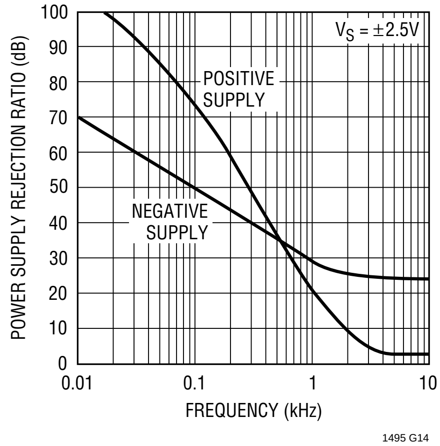


TYPICAL PERFORMANCE CHARACTERISTICS

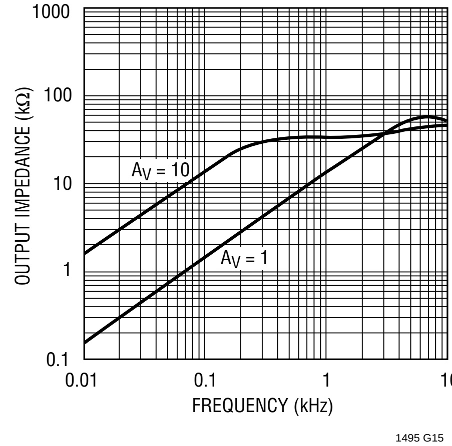
Common Mode Rejection Ratio vs Frequency



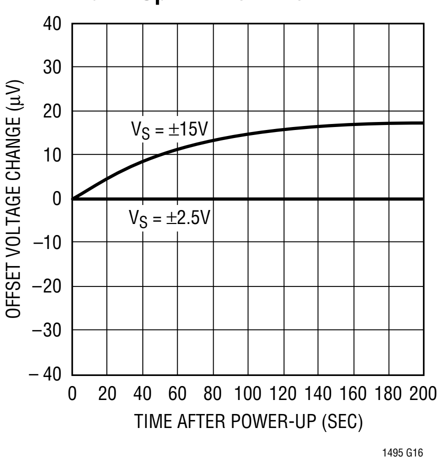
Power Supply Rejection Ratio vs Frequency



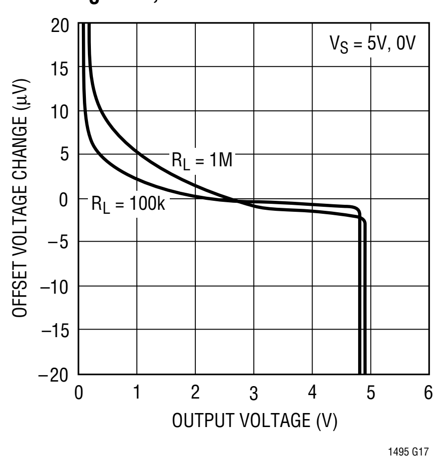
Output Impedance vs Frequency



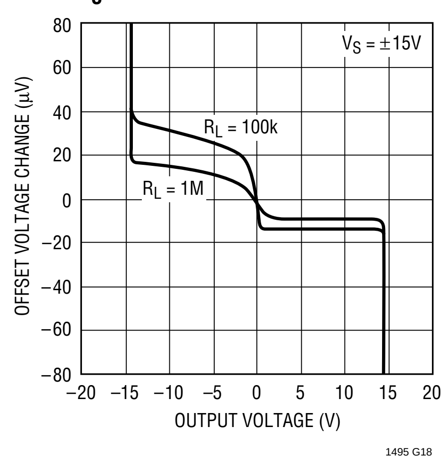
Warm-Up Drift vs Time



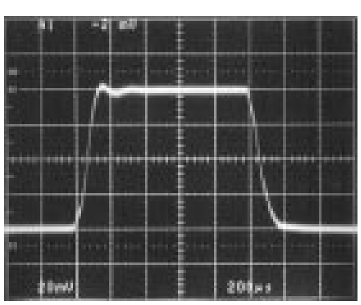
Open-Loop Gain V_S = 5V, 0V



Open-Loop Gain $V_S = \pm 15V$

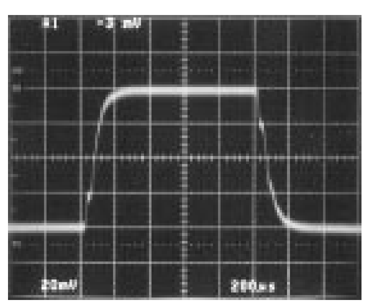


Small-Signal Response $V_S = \pm 15V$



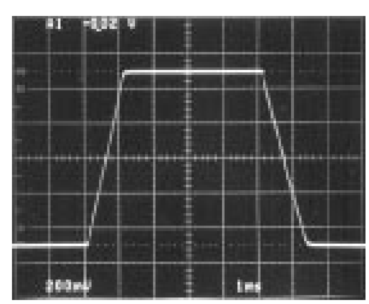
$V_S = \pm 15V$
R_L = 1M
C_L = 100pF

Small-Signal Response V_S = 5V, 0V



V_S = 5V, 0V
R_L = 1M
C_L = 100pF

Large-Signal Response V_S = 5V, 0V



V_S = 5V, 0V
R_L = 1M
C_L = 100pF

APPLICATIONS INFORMATION

Start-Up Characteristics

Micropower op amps are sometimes not micropower during start-up, wreaking havoc on low current supplies. In the worst case, there may not be enough supply current available to take the system up to nominal voltages. Figure 1 is a graph of LT1495 supply current vs supply voltage for the three limit cases of input offset that could occur during start-up. The circuits are shown in Figure 2. One circuit creates a positive offset, forcing the output to come up saturated high. Another circuit creates a negative offset, forcing the output to come up saturated low, while the last brings up the output at half supply. In all cases, the supply current is well behaved. Supply current is highest with the output forced high, so if one amplifier is unused, it is best to force the output low or at half supply.

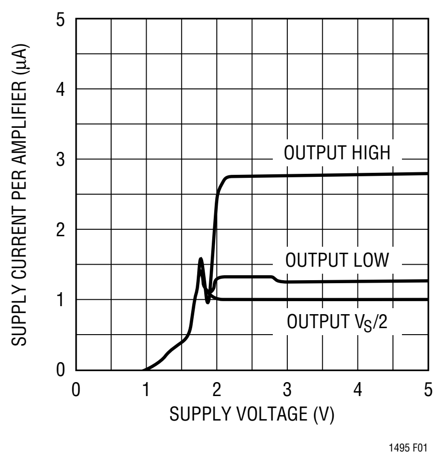


Figure 1. Start-Up Characteristics

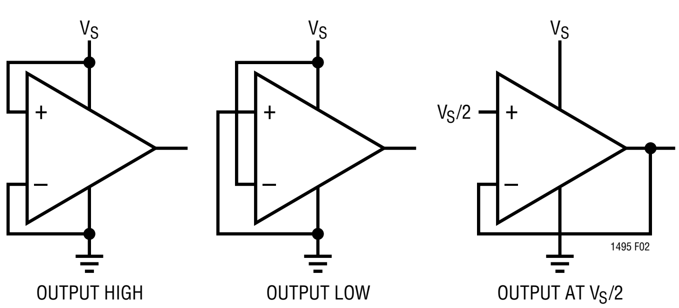


Figure 2. Circuits for Start-Up Characteristics

Reverse Battery

The LT1495/LT1496 are protected against reverse battery voltages up to 18V. In the event a reverse battery condition occurs, the supply current is typically less than 100nA (inputs grounded and outputs open). For typical single supply applications with ground referred loads and feedback networks, no other precautions are required. If the reverse battery condition results in a negative voltage at either the input pins or output pin, the current into the pin should be limited by an external resistor to less than 10mA.

Inputs

While the LT1495/LT1496 will function normally with its inputs taken above the positive supply, the common mode range does not extend beyond approximately 300mV below the negative supply at room temperature. The device will not be damaged if the inputs are taken lower than 300mV below the negative supply as long as the current out of the pin is limited to less than 10mA. However, the output phase is not guaranteed and the supply current will increase.

Output

The graph, Capacitive Load Handling, shows amplifier stability with the output biased at half supply. If the output is to be operated within about 100mV of the positive rail, the allowable load capacitance is less. With this output voltage, the worst case occurs at $A_V = 1$ and light loads, where the load capacitance should be less than 500pF with a 5V supply and less than 100pF with a 30V supply.

Rail-to-Rail Operation

The simplified schematic, Figure 3, details the circuit design approach of the LT1495/LT1496. The amplifier topology is a three-stage design consisting of a rail-to-rail input stage, that continues to operate with the inputs above the positive rail, a folded cascode second stage that develops most of the voltage gain, and a rail-to-rail common emitter stage that provides the current gain.

APPLICATIONS INFORMATION

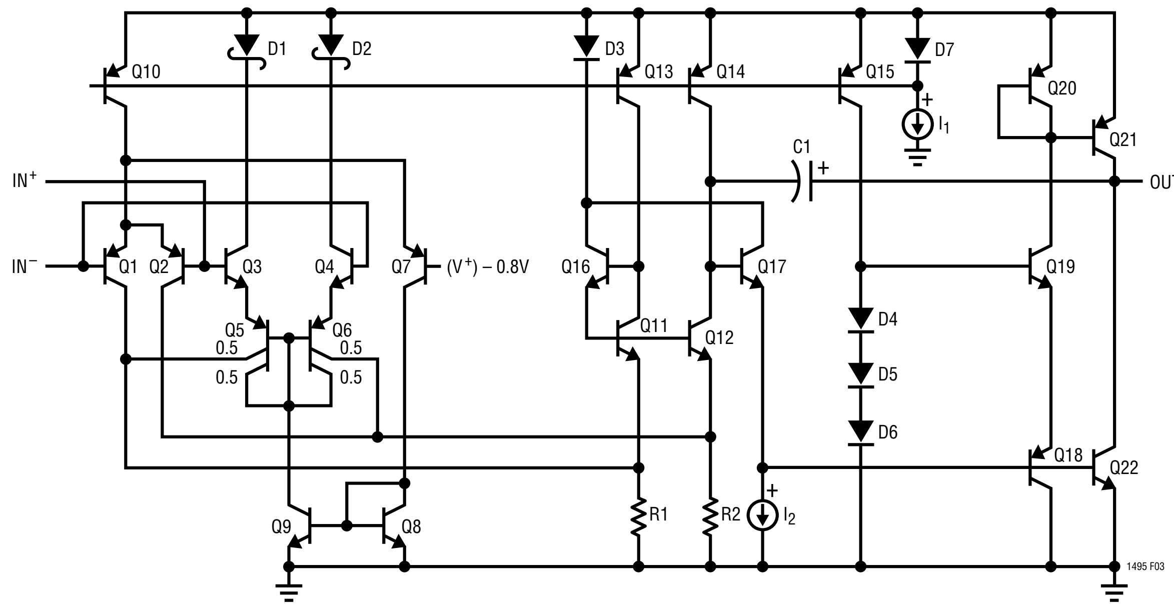


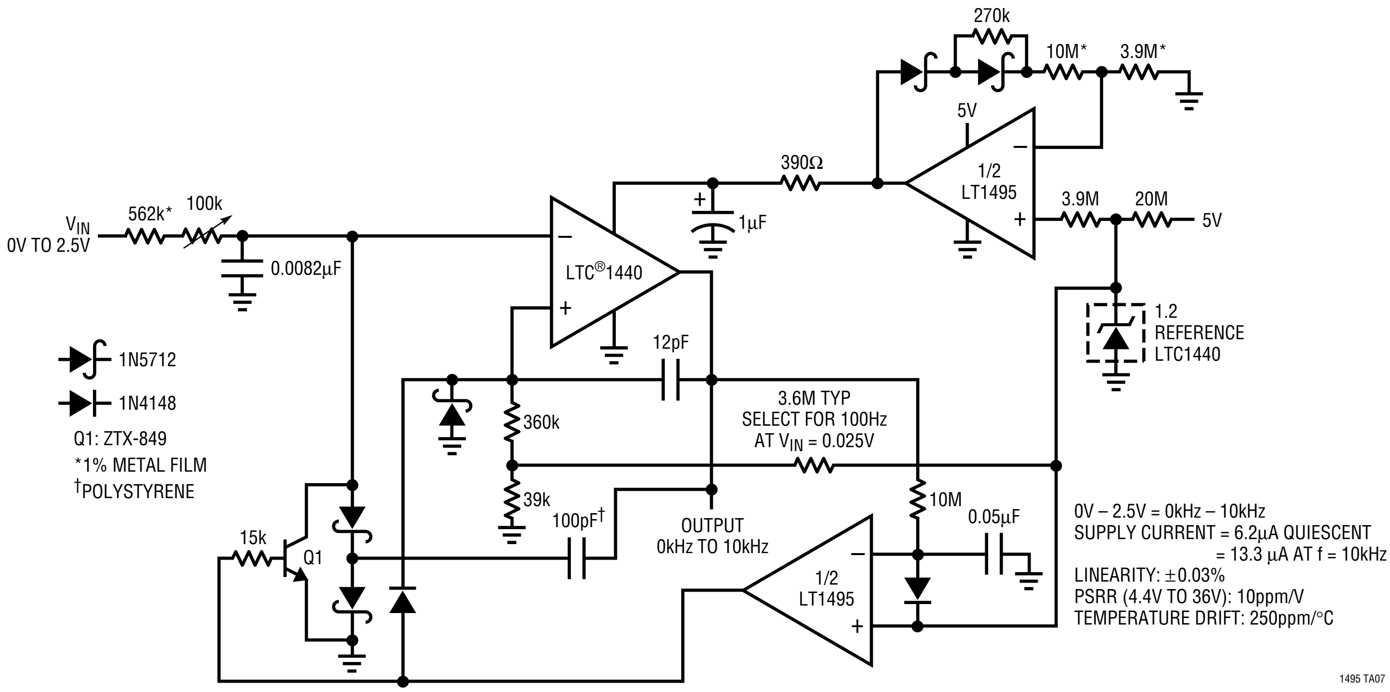
Figure 3. Simplified Schematic

The input stage is formed by two diff amps Q1-Q2 and Q3-Q6. For signals with a common mode voltage between V_{EE} and (V_{CC} – 0.8V), Q1 and Q2 are active. When the input common mode exceeds (V_{CC} – 0.8V), Q7 turns on, diverting the current from diff amp Q1-Q2 to current mirror Q8-Q9. The current from Q8 biases on the other diff amp consisting of PNP's Q5-Q6 and NPN's Q3-Q4. Though Q5-Q6 are driven from the emitters rather than the base, the basic diff amp action is the same. When the common mode voltage is between (V_{CC} – 0.8V) and V_{CC}, devices Q3 and Q4 act as followers, forming a buffer between the amplifier inputs and the emitters of the Q5-Q6. If the common mode voltage is taken above V_{CC}, Schottky diodes D1 and D2 reverse bias and devices Q3 and Q4 then act as diodes. The diff amp formed by Q5-Q6 operates normally, however, the input bias current increases to the emitter current of Q5-Q6, which is typically 180nA. The graph, Input Bias Current vs Common Mode Voltage found in the Typical Performance Characteristics section, shows these transitions at three temperatures.

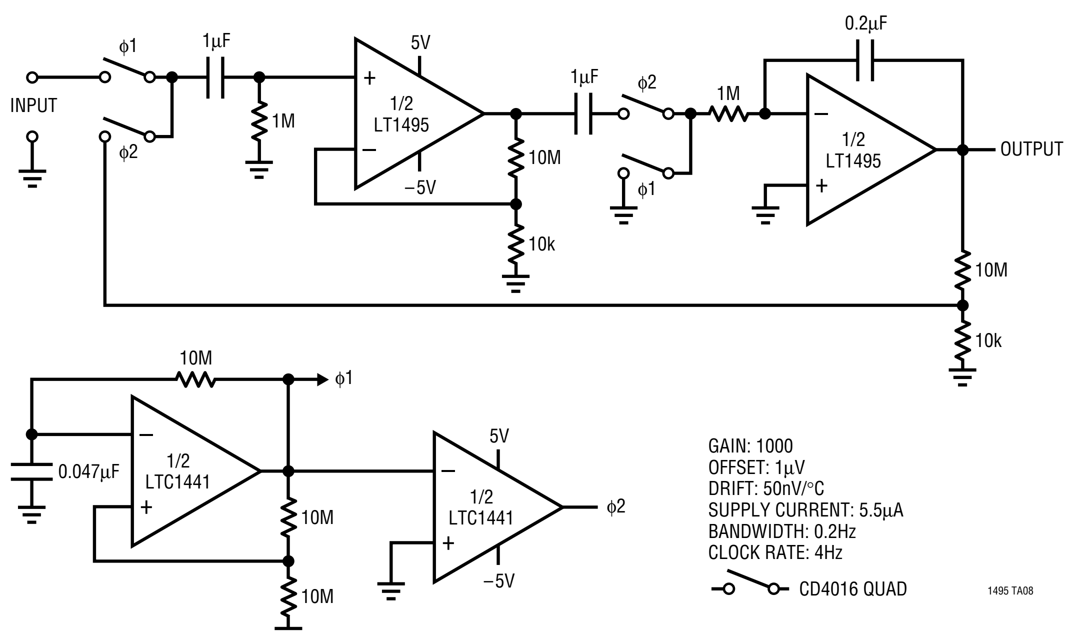
The collector currents of the two-input pairs are combined in the second stage consisting of Q11 to Q16, which furnishes most of the voltage gain. Capacitor C1 sets the amplifier bandwidth. The output stage is configured for maximum swing by the use of common emitter output devices Q21 and Q22. Diodes D4 to D6 and current source Q15 set the output quiescent current.

TYPICAL APPLICATIONS

13µA, 0kHz to 10kHz Voltage to Frequency Converter

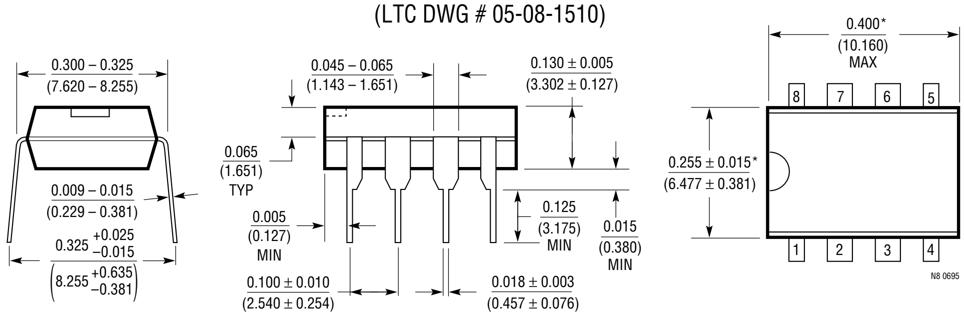


6µA, A_V = 1000, Chopper Stabilized Amplifier



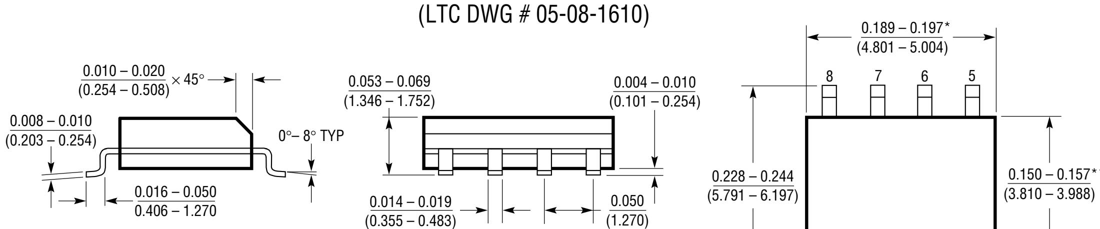
PACKAGE DESCRIPTION Dimensions in inches (millimeters) unless otherwise noted.

N8 Package
8-Lead PDIP (Narrow 0.300)
(LTC DWG # 05-08-1510)



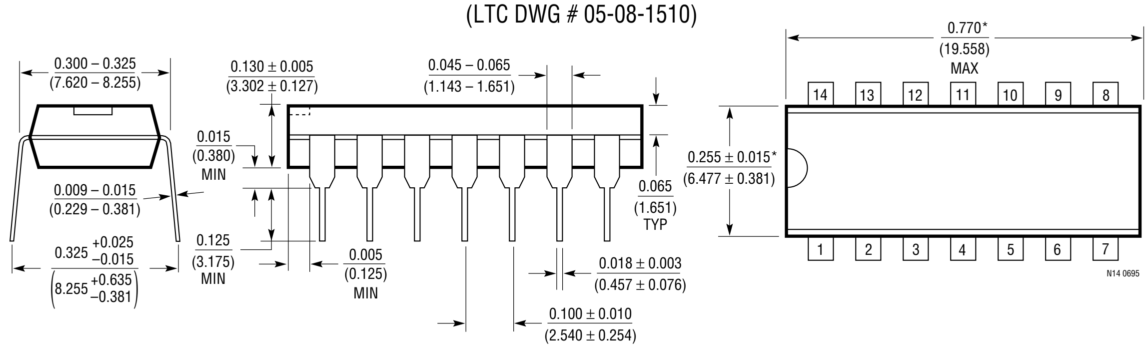
*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 INCH (0.254mm)

S8 Package
8-Lead Plastic Small Outline (Narrow 0.150)
(LTC DWG # 05-08-1610)



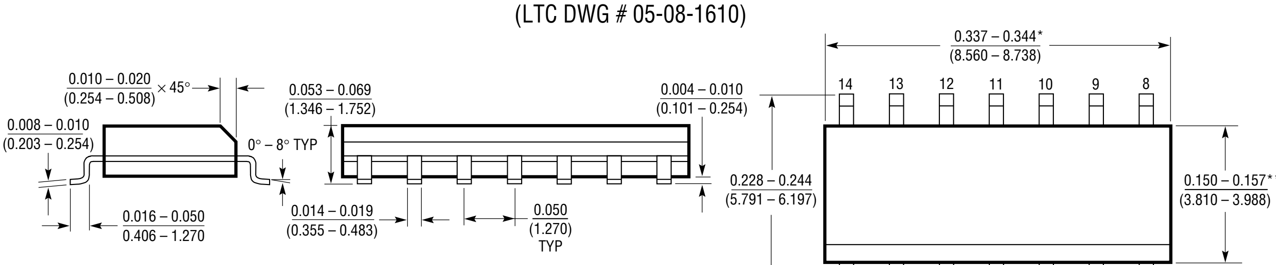
*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE
**DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

N Package
14-Lead PDIP (Narrow 0.300)
(LTC DWG # 05-08-1510)



*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.010 INCH (0.254mm)

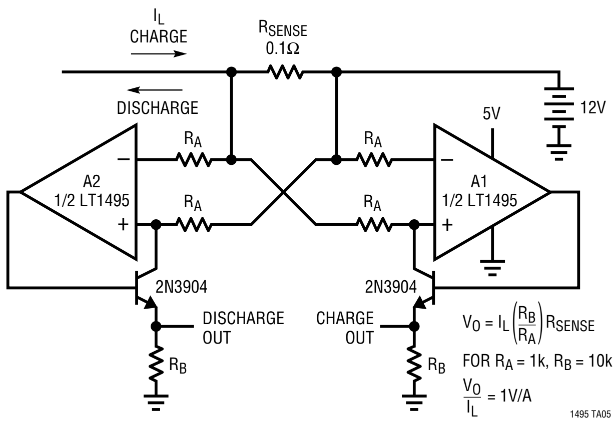
S Package
14-Lead Plastic Small Outline (Narrow 0.150)
(LTC DWG # 05-08-1610)



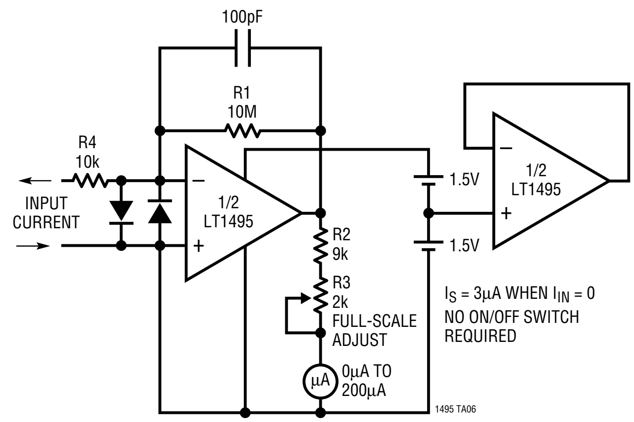
*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE
**DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

TYPICAL APPLICATIONS

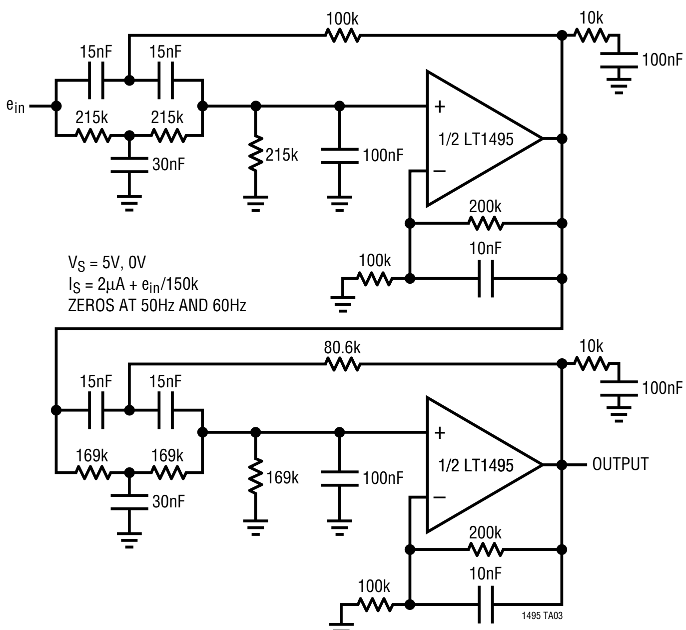
Battery Current Monitor



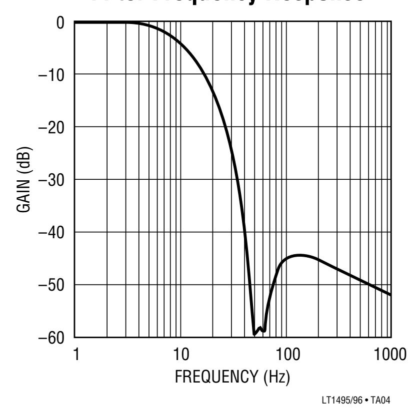
0nA to 200nA Current Meter



6th Order 10Hz Elliptic Lowpass Filter



Filter Frequency Response



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LTC1440/41/42	Micropower Single/Dual Comparators with 1% Reference	LTC1440: Single, LTC1441/42: Dual
LTC1443/44/45	Micropower Quad Comparators with 1% Reference	LTC1443: 1.182 Reference LTC1444/45: 1.221V Reference and Adjustable Hysteresis
LT1466/LT1467	75µA Dual/Quad Rail-to-Rail Input and Output Op Amps	390µV $V_{OS(MAX)}$, Gain Bandwidth = 120kHz
LT1490/LT1491	50µA Dual/Quad Rail-to-Rail Input and Output Op Amps	950µV $V_{OS(MAX)}$, Gain Bandwidth = 200kHz
LTC1540	Nanopower Single Comparator with 1% Reference	350nA Supply Current
LT2078/LT2079	55µA Dual/Quad Single Supply Op Amps	120µV $V_{OS(MAX)}$, Gain Bandwidth = 200kHz
LT2178/LT2179	17µA Dual/Quad Single Supply Op Amps	120µV $V_{OS(MAX)}$, Gain Bandwidth = 60kHz

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417 • (408) 432-1900
FAX: (408) 434-0507 • TELEX: 499-3977 • www.linear-tech.com
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