راهنمای استفاده از سنسورهای اندازه گیری دما با RTD

تهیه کننده: حمیدرضا صابری - کارشناس کنترل و ابزاردقیق

المان RTD مخفف Resistance Temperature Detector به معنی حسگرهای مقاومتی دما می‌باشد. این نوع سنسورها از سنسورهای خطی در اندازه گیری دما می باشد که سیگنال خروجی ما به صورت یک سیگنال مقاومتی می باشد. با قرار دادن RTD در یک بازوی پل وتستون می توان مقدار مقاومت را اندازه‌گیری نمود. سپس مقاومت RTD تعیین شده را به مقدار دمای متناظرش با استفاده از روش‌های استاندارد RTD (مثلا استاندارد IEC 751) یا معادله Callendar-Van Dusen تبدیل نمود. در شکل زیر بخشی از جدول تعیین دما از مقدار مقاومت RTD برای مدل Pt100 که در ادامه توضیح خواهیم داد، آورده شده است :

Technical Data Sheet TD-TV/PT1A

PT100 Resistance Table

°C	0	1	2	3	4	5	6	7	8	9	°C
-20.00	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62	-20.00
-10.00	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55	-10.00
0.00	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48	0.00
0.00	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51	0.00
10.00	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40	10.00
20.00	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29	20.00

شکل ۱- جدول PT100

انواع RTD ؟

ویژگی‌های ترمو مقاومتی المان حسگر RTD، بسته به فلز یا آلیاژی که از آن ساخته شده، متفاوت می‌باشد. سه نوع فلز مقاومتی که غالبا برای ساخت RTD استفاده می‌شود عبارتند از پلاتین (Platinum)، مس(Copper) و نیکل (Nickel).

المان های RTD از جنس پلاتین مرسوم‌ترین نوع RTD اند که دو نوع اصلی آن با عنوان PT100 و PT1000 وجود دارند (PT به معنی پلاتین و ۱۰۰ معرف مقاومت فلز بر حسب اهم در دمای صفر درجه سانتیگراد می باشد). المان های RTD مس و نیکل برای مواردی که دقت موضوع حیاتی‌ای نیست کاربرد دارند.

پارامترهای انتخاب RTD :

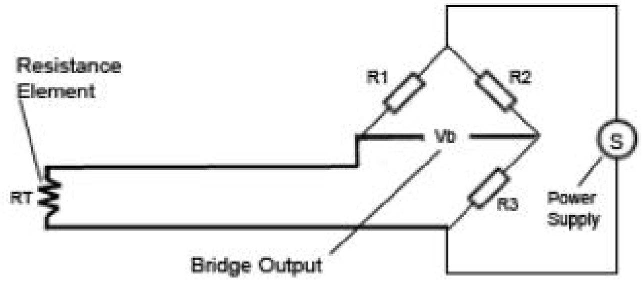
- نوع RTD : PT100 , PT1000 , CU , Ni
- تعداد سیم : ۲ سیمه، ۳سیمه، ۴ سیمه
- رنج دمایی : تا ۴۵۰ درجه یا ۶۰۰ درجه سانتیگراد

- خروجی : جریان(4-20 mA) یا ولتاژ (0-10 V) یا خروجی اهمی (بدون ترانسمیتر)
- متراژ کابل، ابعاد، طول و قطر سنسور : مثال : طول ۵ سانتیمتر، به قطر ۸ میلیمتر، متراژ کابل ۳ متر

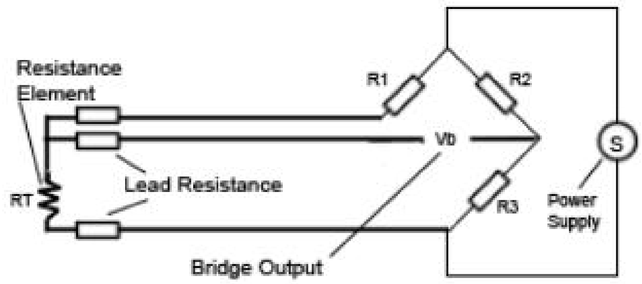
انواع پیکربندی RTD :

پیکربندی با پل وتستون :

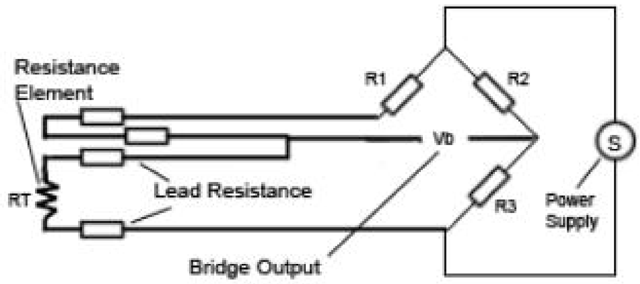
سنسورهای RTD به صورت دو سیمه، سه سیمه و چهار سیمه در بازار موجود می باشد. نوع دو سیمه به دلیل مقاومت مسیر (مقاوت ناشی از سیم) دارای خطای بالایی است (شکل ۲)؛ نوع سه سیمه دارای خطای کمتری است(شکل ۳) ولی نوع چهار سیمه به کلی مقاومت مسیر انتقال را حذف کرده است(شکل ۴).



شکل ۲ : پیکره بندی دوسیمه



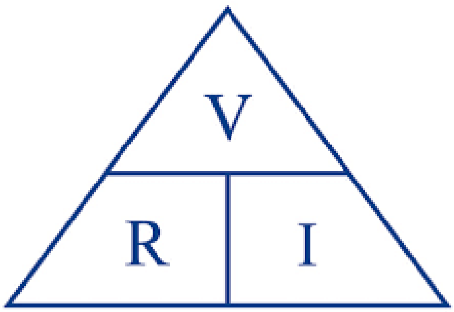
شکل ۳ : پیکره بندی سه سیمه



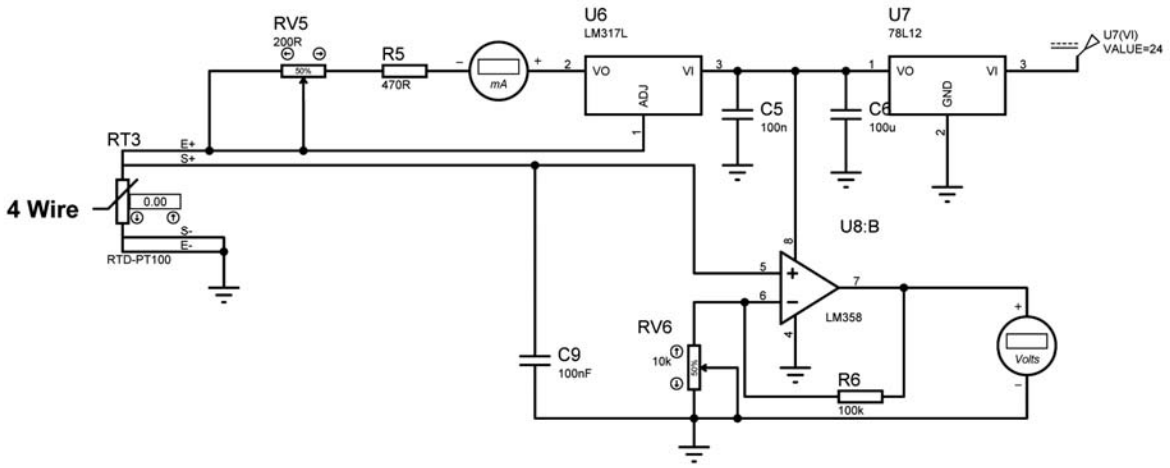
شکل ٤ : پیکره بندی چهار سیمه

ساخت ترانسمیتر برای RTD با خروجی ولتاژی :

برای ساخت این ترانسمیتر، نیاز است که ابتدا نگاهی به قانون اهم داشته باشیم:



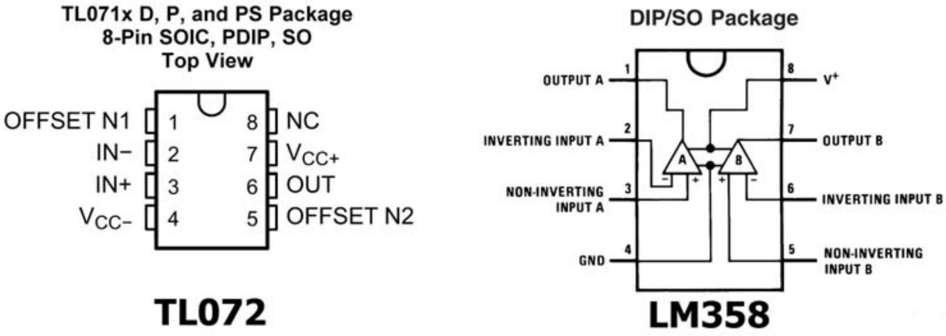
اگر جریان الکتریکی را ثابت (CT = Constant) در نظر بگیریم؛ با افزایش و یا کاهش مقدار مقاومت، میزان ولتاژ تغییر خواهد نمود. از این قانون برای ساخت ترانسمیتر RTD که قابلیت اتصال به هرنوع کنترلری را داراست استفاده می‌کنیم. مدار شکل زیر را در نظر بگیرید.



شکل ۵ – ترانسمیتر PT100 با خروجی ولتاژی

ابتدا ولتاژ ۲۴ ولت را توسط رگولاتور ولتاژ 78L12 به ولتاژ ۱۲ ولت تبدیل می‌کنیم. خازن‌های C5,C6,C9 خازن‌های صافی هستند. رگولاتور LM317L، رگولاتور ولتاژ می‌باشد که با پیکربندی مناسب می‌تواند بعنوان یک منبع جریان عمل نماید. (به دیتاشیت LM317 مراجعه نمائید) . خروجی LM317L بصورت جریانی بوده که توسط پتانسیومتر مولتی‌ترن (potentiometer multiturn) میزان جریان خروجی از منبع قابل تنظیم می‌باشد. در این پروژه خروجی را بر روی ۲ میلی‌آمپر تنظیم می نمائیم.

توسط تقویت کننده عملیاتی TL072 و یا LM358 مدار یک تقویت کننده را با گین قابل تنظیم مطابق با شکل فوق، پیاده‌سازی می‌نمائیم. شایان ذکر است در صورتیکه از TL072 استفاده می‌کنید، نیاز به تغذیه متقارنV ۱۲+/- دارید ولی برای LM358 نیاز به تغذیه ۱۲V+ دارید. با تغییر پتانسیومتر 10کیلواهمی، گین مدار قابل تنظیم می‌شود. توسط تقویت کننده عملیاتی AD620 خیلی راحتتر می‌توان این تقویت کننده را ساخت.



شکل۶ – شماتیک OPAMPهای پیشنهاد شده

محاسبه دما با RTD (PT100) :

1) Temperature $_{(pt100)}$ = (RTD-100) / 0.385 = RTD / 0.00385

2) $R= R_0 (1+\alpha\ \Delta t)$

در دو فرمول فوق :

Temperature : مقدار دمای اندازه‌گیری شده

RTD : مقاومت PT100 در دمای مورد اندازه‌گیری شده (۱۰۰ مقاومت RTD در دمای صفر درجه سانتیگراد)

α : ضریب RTD که برای PT100 برابر 0.385

R_0 : مقاومت RTD در دمای صفر درجه سانتیگراد

R : مقاومت RTD در دمای مورد اندازه‌گیری شده

Δt : میزان تغییرات دمای مورد اندازه‌گیری شده

مثال:

برای اندازه‌گیری ماکزیمم دمای ۲۰۰ درجه سانتیگراد را به ازای جریان ۲ میلی آمپر، ترانسمیتر مربوطه را طراحی نمائید.

حال به محاسبه گین مدار می‌رسیم:

حال با توجه به پارامترهای مدار، موارد زیر را محاسبه می‌کنیم:

$\text{Gain} = (V_o / V_i)=(1+(R_2/R_1)$

$I = \text{Constant} = 2mA$

R_{pt100} (in 200°C) = 177Ω

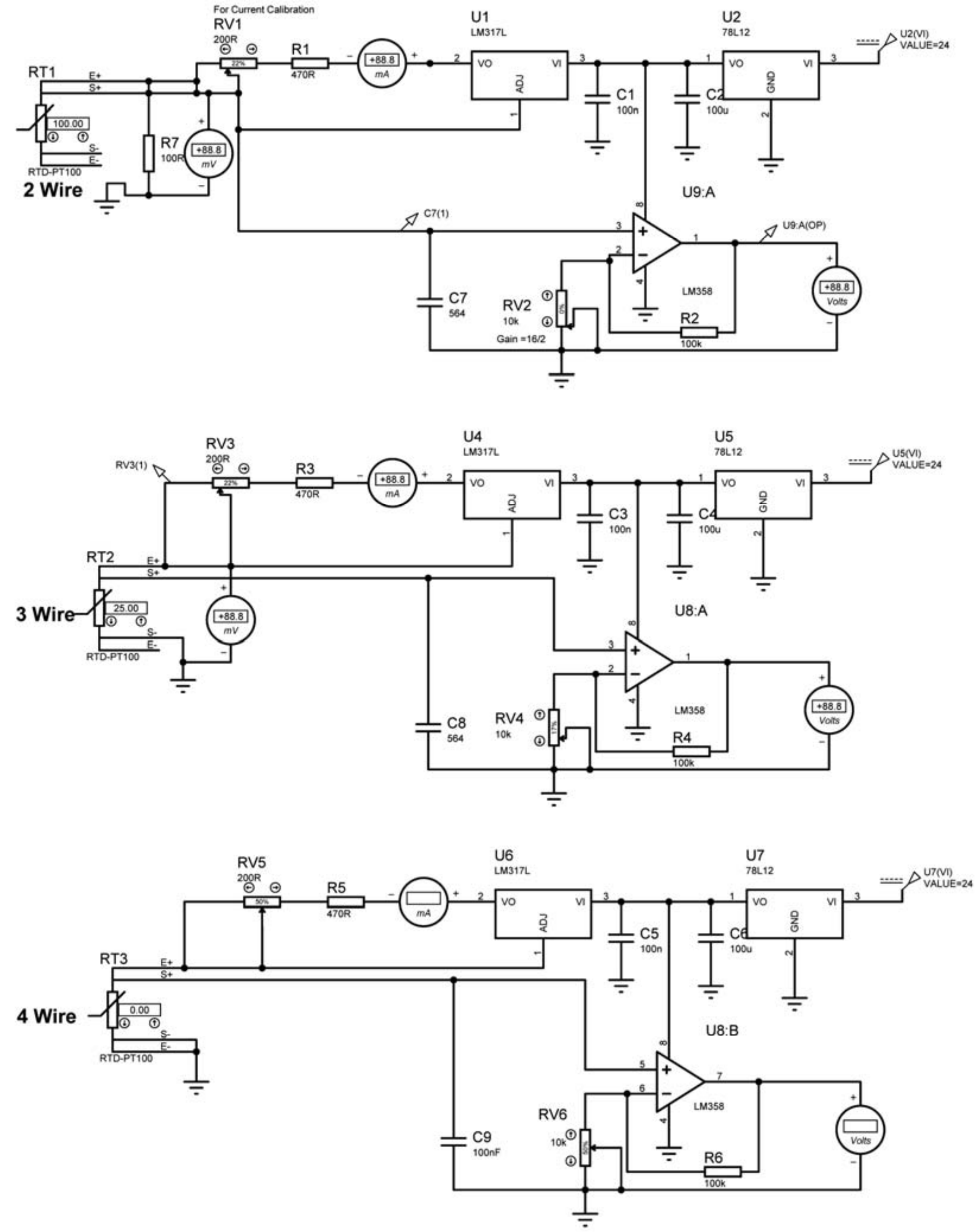
I. $V=(177\Omega)*(2mA) = 0.354$ Volt

II. $\text{Gain} = (10\ \text{volt}_{in\ 200°C}) / 0.354\text{Volt} = 28.24$

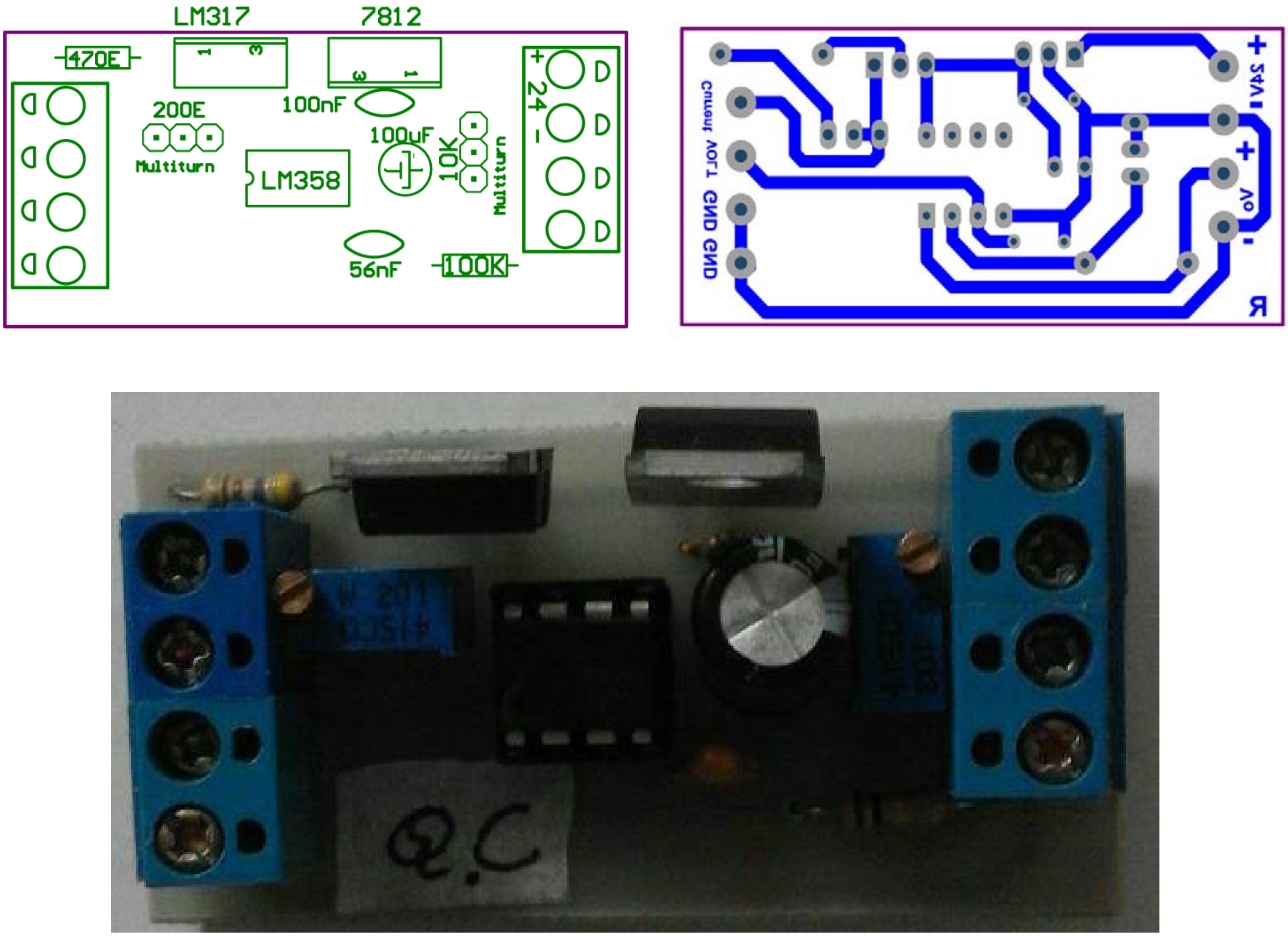
III. $\text{Gain}=1+(R_2/R_1) \Longrightarrow 28.24 = 1+ (100K\Omega / R_1) \Longrightarrow R_1= 3.671\ K\Omega$

چون مقاومت 3.671 KΩ وجود ندارد ، از یک potentiometer multiturn با مقدار ۱۰ کیلو اهم استفاده می‌کنیم. این ترانسمیتر این قابلیت را داراست که انواع RTD را از نوع ۲ و ۳ و۴ سیمه پشتیبانی کند. شکل زیر آرایش انواع RTD را برای مدار فوق نمایش می‌دهد. **شایان ذکر است که حتما از کابل شیلددار جهت اتصال PT به ترانسمیتر یا کنترلر خود استفاده کنید و شیلد آنرا حتما به کابل ارت ابزاردقیق متصل نمائید.** **ابعاد فیبر طراحی شده : ۳*۶ سانتیمتر می‌باشد.**

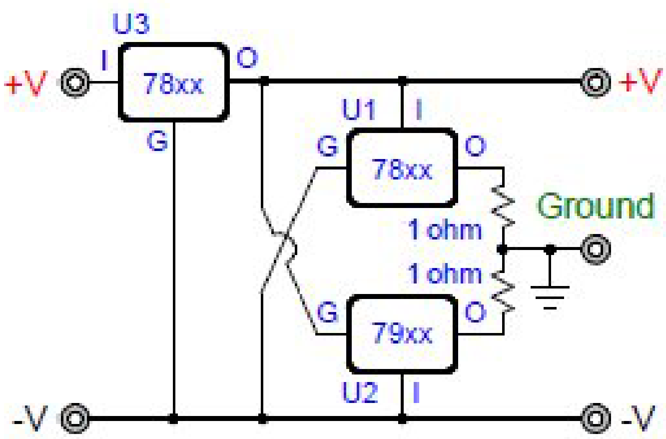
فایل PCB در قسمت Attachment فایل PDF موجود می‌باشد.



شکل ۷ – اتصال انواع RTD به ترانسمیتر



شکل۸- شماتیک ، PCB و برد طراحی شده توسط Altium Designer



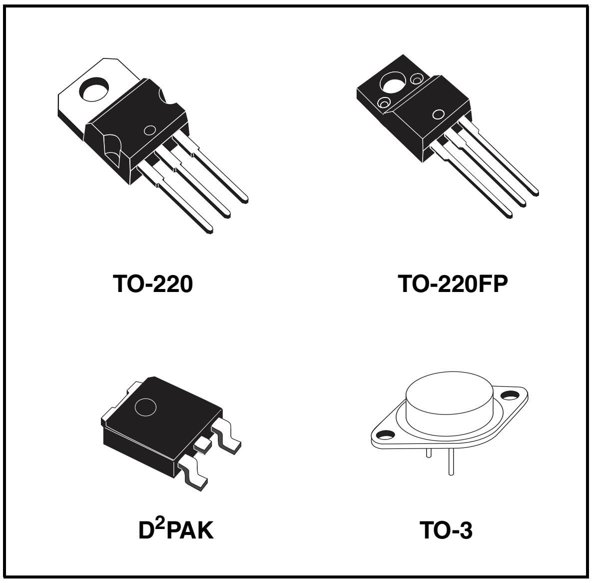
شکل ۹- مدار تغذیه جهت استفاده از TL072

L7800 series

Positive voltage regulators

Feature summary

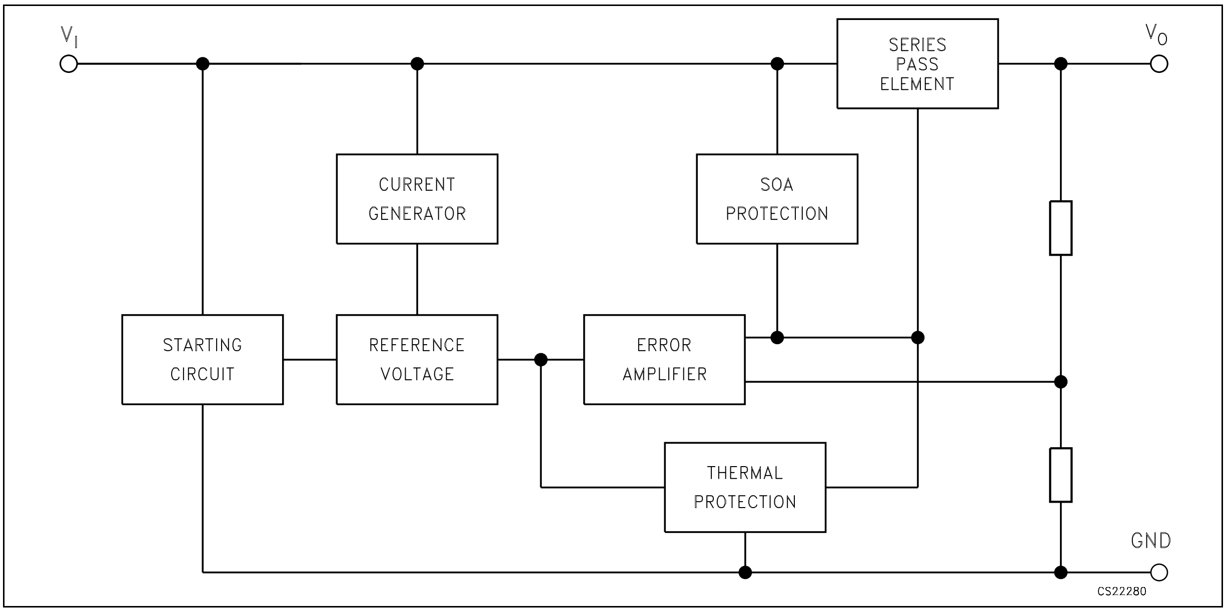
- Output current to 1.5A
- Output voltages of 5; 5.2; 6; 8; 8.5; 9; 10; 12; 15; 18; 24V
- Thermal overload protection
- Short circuit protection
- Output transition SOA protection



Description

The L7800 series of three-terminal positive regulators is available in TO-220, TO-220FP, TO-3 and D^2PAK packages and several fixed output voltages, making it useful in a wide range of applications. These regulators can provide local on-card regulation, eliminating the distribution problems associated with single point regulation. Each type employs internal current limiting, thermal shut-down and safe area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltage and currents.

Schematic diagram



Contents

1 Pin configuration

Figure 1. Pin connections (top view)

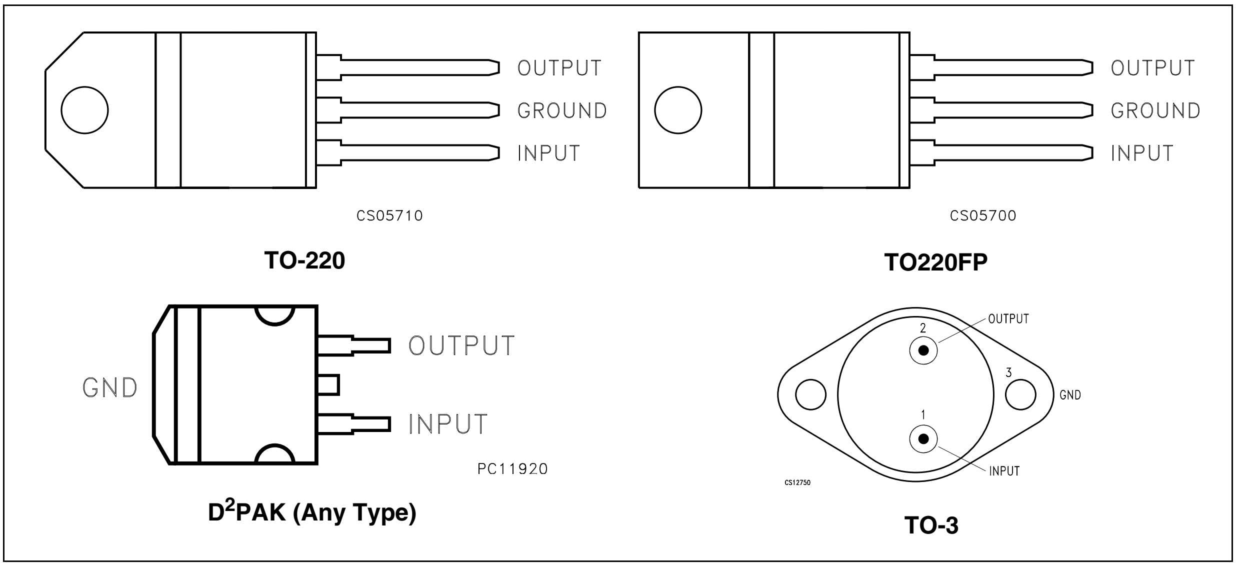
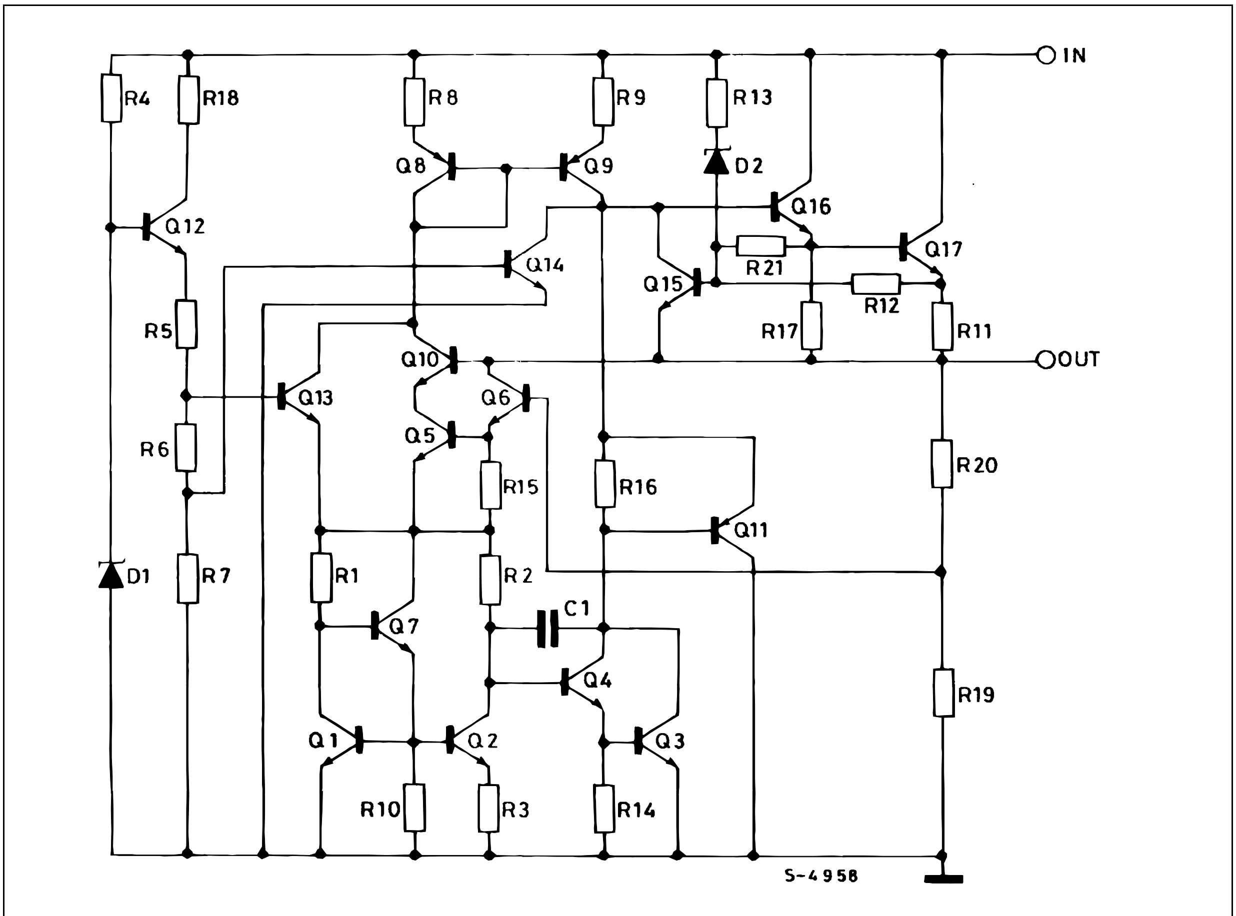


Figure 2. Schematic diagram



2 Maximum ratings

Table 1. Absolute maximum ratings

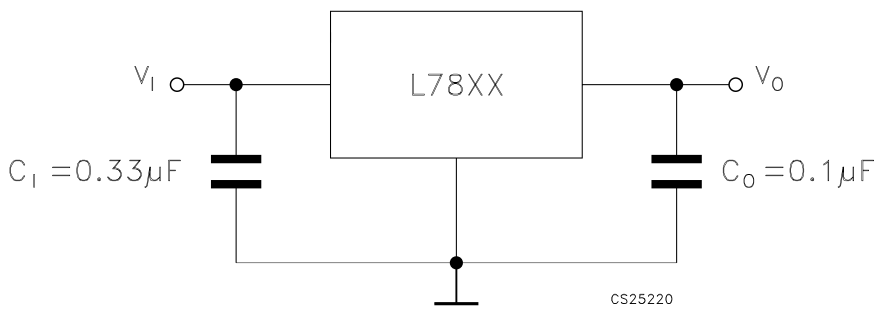
Symbol	Parameter		Value	Unit
V_I	DC Input voltage	for V_O= 5 to 18V	35	V
		for V_O= 20, 24V	40	
I_O	Output current		Internally Limited	
P_D	Power dissipation		Internally Limited	
T_{STG}	Storage temperature range		-65 to 150	°C
T_{OP}	Operating junction temperature range	for L7800	-55 to 150	°C
		for L7800C	0 to 150	

Note: Absolute Maximum Ratings are those values beyond which damage to the device may occur. Functional operation under these condition is not implied

Table 2. Thermal Data

Symbol	Parameter	D²PAK	TO-220	TO-220FP	TO-3	Unit
R_{thJC}	Thermal resistance junction-case	3	5	5	4	°C/W
R_{thJA}	Thermal resistance junction-ambient	62.5	50	60	35	°C/W

Figure 3. Application circuits



3 Test circuits

Figure 4. DC Parameter

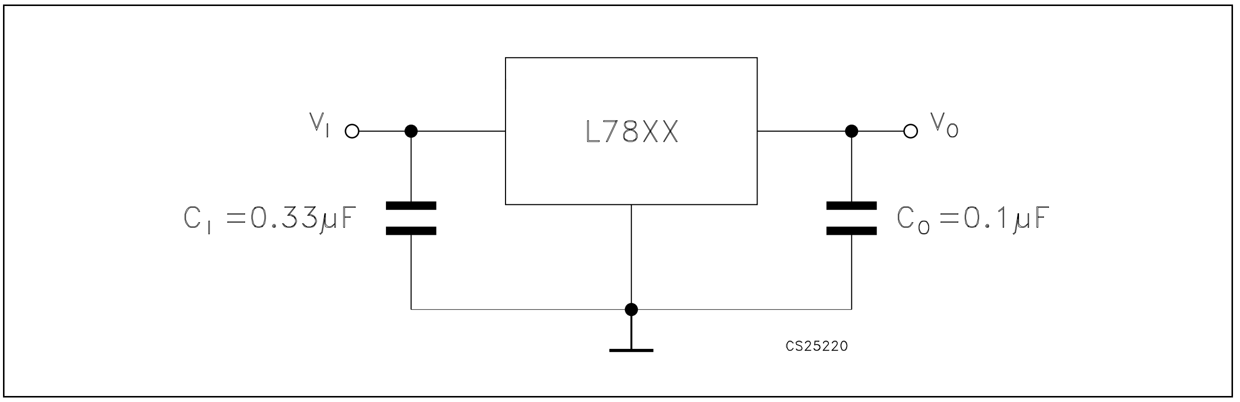


Figure 5. Load regulation

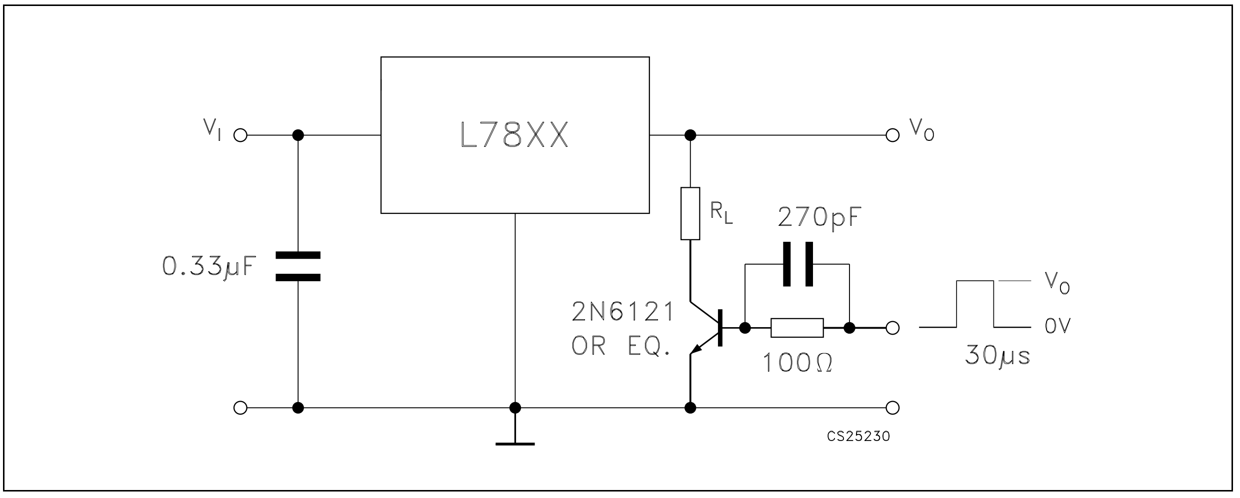
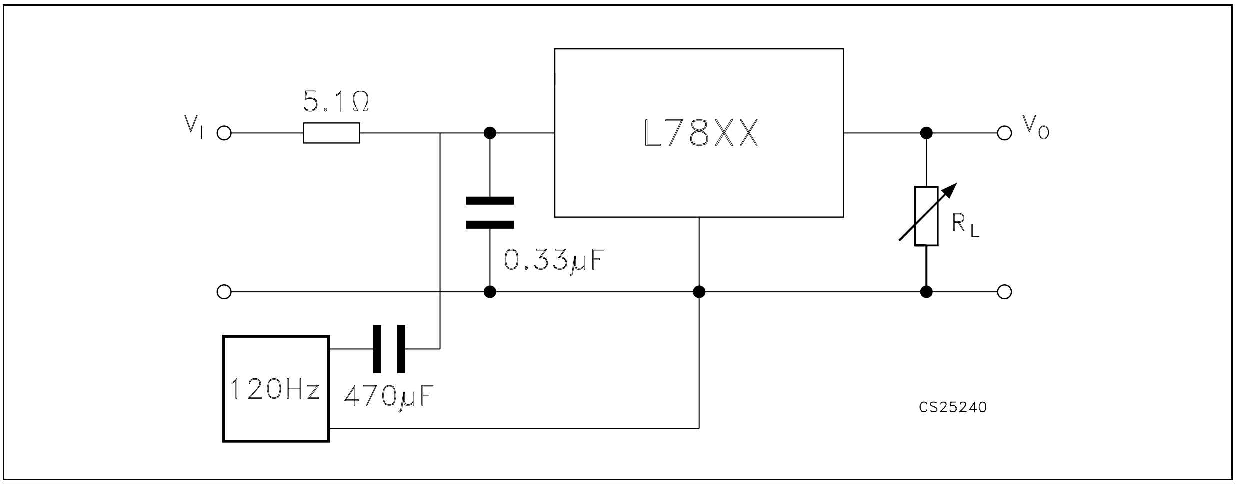


Figure 6. Ripple rejection



4 Electrical characteristics

Table 3. Electrical characteristics of L7805 (refer to the test circuits, T_J = -55 to 150°C, V_I = 10V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	4.8	5	5.2	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 8 to 20V	4.65	5	5.35	V
ΔV_O(1)	Line regulation	V_I = 7 to 25V, T_J = 25°C		3	50	mV
		V_I = 8 to 12V, T_J = 25°C		1	25	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			100	mV
		I_O = 250 to 750mA, T_J = 25°C			25	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 8 to 25 V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		0.6		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 8 to 18V, f = 120Hz	68			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		17		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 4. Electrical characteristics of L7806 (refer to the test circuits, T_J = -55 to 150°C, V_I = 11V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	5.75	6	6.25	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 9 to 21V	5.65	6	6.35	V
ΔV_O(1)	Line regulation	V_I = 8 to 25V, T_J = 25°C			60	mV
		V_I = 9 to 13V, T_J = 25°C			30	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			100	mV
		I_O = 250 to 750mA, T_J = 25°C			30	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 9 to 25V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		0.7		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 9 to 19V, f = 120Hz	65			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		19		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 5. Electrical characteristics of L7808 (refer to the test circuits, T_J = -55 to 150°C, V_I = 14V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	7.7	8	8.3	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 11.5 to 23V	7.6	8	8.4	V
ΔV_O(1)	Line regulation	V_I = 10.5 to 25V, T_J = 25°C			80	mV
		V_I = 11 to 17V, T_J = 25°C			40	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			100	mV
		I_O = 250 to 750mA, T_J = 25°C			40	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 11.5 to 25V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 11.5 to 21.5V, f = 120Hz	62			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		16		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 6. Electrical characteristics of L7812 (refer to the test circuits, T_J = -55 to 150°C, V_I = 19V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	11.5	12	12.5	V
V_O	Output voltage	I_O = 5mA to 1A, $P_O \leq$15W V_I = 15.5 to 27V	11.4	12	12.6	V
ΔV_O(1)	Line regulation	V_I = 14.5 to 30V, T_J = 25°C			120	mV
		V_I = 16 to 22V, T_J = 25°C			60	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			100	mV
		I_O = 250 to 750mA, T_J = 25°C			60	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 15 to 30V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		1.5		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 15 to 25V, f = 120Hz	61			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		18		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 7. Electrical characteristics of L7815 (refer to the test circuits, T_J = -55 to 150°C, V_I = 23V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	14.4	15	15.6	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 18.5 to 30V	14.25	15	15.75	V
ΔV_O(1)	Line regulation	V_I = 17.5 to 30V, T_J = 25°C			150	mV
		V_I = 20 to 26V, T_J = 25°C			75	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			150	mV
		I_O = 250 to 750mA, T_J = 25°C			75	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 18.5 to 30V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		1.8		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 18.5 to 28.5V, f = 120Hz	60			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		19		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 8. Electrical characteristics of L7818 (refer to the test circuits, T_J = -55 to 150°C, V_I = 26V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	17.3	18	18.7	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 22 to 33V	17.1	18	18.9	V
ΔV_O(1)	Line regulation	V_I = 21 to 33V, T_J = 25°C			180	mV
		V_I = 24 to 30V, T_J = 25°C			90	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			180	mV
		I_O = 250 to 750mA, T_J = 25°C			90	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 22 to 33V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		2.3		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 22 to 32V, f = 120Hz	59			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		22		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 9. Electrical characteristics of L7820 (refer to the test circuits, T_J = -55 to 150°C, V_I = 28V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	19.2	20	20.8	V
V_O	Output voltage	I_O = 5mA to 1A, $P_O \leq$15W V_I = 24 to 35V	19	20	21	V
ΔV_O(1)	Line regulation	V_I = 22.5 to 35V, T_J = 25°C			200	mV
		V_I = 26 to 32V, T_J = 25°C			100	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			200	mV
		I_O = 250 to 750mA, T_J = 25°C			100	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 24 to 35V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		2.5		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 24 to 35V, f = 120Hz	58			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		24		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 10. Electrical characteristics of L7824 (refer to the test circuits, T_J = -55 to 150°C, V_I = 33V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	23	24	25	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 28 to 38V	22.8	24	25.2	V
ΔV_O(1)	Line regulation	V_I = 27 to 38V, T_J = 25°C			240	mV
		V_I = 30 to 36V, T_J = 25°C			120	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			240	mV
		I_O = 250 to 750mA, T_J = 25°C			120	
I_d	Quiescent current	T_J = 25°C			6	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 28 to 38V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		3		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C			40	µV/V_O
SVR	Supply voltage rejection	V_I = 28 to 38V, f = 120Hz	56			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2	2.5	V
R_O	Output resistance	f = 1 KHz		28		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75	1.2	A
I_{scp}	Short circuit peak current	T_J = 25°C	1.3	2.2	3.3	A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 11. Electrical characteristics of L7805C (refer to the test circuits, T_J = -55 to 150°C, V_I = 10V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	4.8	5	5.2	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 7 to 20V	4.75	5	5.25	V
ΔV_O(1)	Line regulation	V_I = 7 to 25V, T_J = 25°C		3	100	mV
		V_I = 8 to 12V, T_J = 25°C		1	50	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			100	mV
		I_O = 250 to 750mA, T_J = 25°C			50	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 7 to 25 V			0.8	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1.1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		40		µV/V_O
SVR	Supply voltage rejection	V_I = 8 to 18V, f = 120Hz	62			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		17		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 12. Electrical characteristics of L7852C (refer to the test circuits, T_J = -55 to 150°C, V_I = 10V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	5.0	5.2	5.4	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 8 to 20V	4.95	5.2	5.45	V
ΔV_O(1)	Line regulation	V_I = 7 to 25V, T_J = 25°C		3	105	mV
		V_I = 8 to 12V, T_J = 25°C		1	52	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			105	mV
		I_O = 250 to 750mA, T_J = 25°C			52	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 7 to 25 V			1.3	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		42		µV/V_O
SVR	Supply voltage rejection	V_I = 8 to 18V, f = 120Hz	61			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		17		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.75		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 13. Electrical characteristics of L7806C (refer to the test circuits, T_J = -55 to 150°C, V_I = 11V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	5.75	6	6.25	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 8 to 21V	5.7	6	6.3	V
ΔV_O(1)	Line regulation	V_I = 8 to 25V, T_J = 25°C			120	mV
		V_I = 9 to 13V, T_J = 25°C			60	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			120	mV
		I_O = 250 to 750mA, T_J = 25°C			60	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 8 to 25V			1.3	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-0.8		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		45		µV/V_O
SVR	Supply voltage rejection	V_I = 9 to 19V, f = 120Hz	59			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		19		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.55		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 14. Electrical characteristics of L7808C (refer to the test circuits, T_J = -55 to 150°C, V_I = 14V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	7.7	8	8.3	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 10.5 to 25V	7.6	8	8.4	V
ΔV_O(1)	Line regulation	V_I = 10.5 to 25V, T_J = 25°C			160	mV
		V_I = 11 to 17V, T_J = 25°C			80	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			160	mV
		I_O = 250 to 750mA, T_J = 25°C			80	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 10.5 to 25V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-0.8		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		52		µV/V_O
SVR	Supply voltage rejection	V_I = 11.5 to 21.5V, f = 120Hz	56			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		16		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.45		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 15. Electrical characteristics of L7885C (refer to the test circuits, T_J = -55 to 150°C, V_I = 14.5V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	8.2	8.5	8.8	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 11 to 26V	8.1	8.5	8.9	V
ΔV_O(1)	Line regulation	V_I = 11 to 27V, T_J = 25°C			160	mV
		V_I = 11.5 to 17.5V, T_J = 25°C			80	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			160	mV
		I_O = 250 to 750mA, T_J = 25°C			80	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 11 to 27V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-0.8		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		55		µV/V_O
SVR	Supply voltage rejection	V_I = 12 to 22V, f = 120Hz	56			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		16		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.45		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 16. Electrical characteristics of L7809C (refer to the test circuits, T_J = -55 to 150°C, V_I = 15V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	8.64	9	9.36	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 11.5 to 26V	8.55	9	9.45	V
ΔV_O (1)	Line regulation	V_I = 11.5 to 26V, T_J = 25°C			180	mV
		V_I = 12 to 18V, T_J = 25°C			90	
ΔV_O (1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			180	mV
		I_O = 250 to 750mA, T_J = 25°C			90	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 11.5 to 26V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		70		µV/V_O
SVR	Supply voltage rejection	V_I = 12 to 23V, f = 120Hz	55			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		17		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.40		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 17. Electrical characteristics of L7810C (refer to the test circuits, T_J = -55 to 150°C, V_I = 15V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	9.6	10	10.4	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 12.5 to 26V	9.5	10	10.5	V
ΔV_O(1)	Line regulation	V_I = 12.5 to 26V, T_J = 25°C			200	mV
		V_I = 13.5 to 19V, T_J = 25°C			100	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			200	mV
		I_O = 250 to 750mA, T_J = 25°C			100	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 12.5 to 26V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		70		µV/V_O
SVR	Supply voltage rejection	V_I = 13 to 23V, f = 120Hz	55			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		17		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.40		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 18. Electrical characteristics of L7812C (refer to the test circuits, T_J = -55 to 150°C, V_I = 19V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	11.5	12	12.5	V
V_O	Output voltage	I_O = 5mA to 1A, $P_O \leq$15W V_I = 14.5 to 27V	11.4	12	12.6	V
ΔV_O(1)	Line regulation	V_I = 14.5 to 30V, T_J = 25°C			240	mV
		V_I = 16 to 22V, T_J = 25°C			120	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			240	mV
		I_O = 250 to 750mA, T_J = 25°C			120	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 14.5 to 30V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		75		µV/V_O
SVR	Supply voltage rejection	V_I = 15 to 25V, f = 120Hz	55			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		18		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.35		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 19. Electrical characteristics of L7815C (refer to the test circuits, T_J = -55 to 150°C, V_I = 23V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	14.5	15	15.6	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 17.5 to 30V	14.25	15	15.75	V
ΔV_O(1)	Line regulation	V_I = 17.5 to 30V, T_J = 25°C			300	mV
		V_I = 20 to 26V, T_J = 25°C			150	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			300	mV
		I_O = 250 to 750mA, T_J = 25°C			150	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 17.5 to 30V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		90		µV/V_O
SVR	Supply voltage rejection	V_I = 18.5 to 28.5V, f = 120Hz	54			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		19		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.23		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.2		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 20. Electrical characteristics of L7818C (refer to the test circuits, T_J = -55 to 150°C, V_I = 26V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	17.3	18	18.7	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 21 to 33V	17.1	18	18.9	V
ΔV_O(1)	Line regulation	V_I = 21 to 33V, T_J = 25°C			360	mV
		V_I = 24 to 30V, T_J = 25°C			180	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			360	mV
		I_O = 250 to 750mA, T_J = 25°C			180	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 21 to 33V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		110		µV/V_O
SVR	Supply voltage rejection	V_I = 22 to 32V, f = 120Hz	53			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		22		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.20		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.1		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 21. Electrical characteristics of L7820C (refer to the test circuits, T_J = -55 to 150°C, V_I = 28V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	19.2	20	20.8	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 23 to 35V	19	20	21	V
ΔV_O(1)	Line regulation	V_I = 22.5 to 35V, T_J = 25°C			400	mV
		V_I = 26 to 32V, T_J = 25°C			200	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			400	mV
		I_O = 250 to 750mA, T_J = 25°C			200	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 23 to 35V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		150		µV/V_O
SVR	Supply voltage rejection	V_I = 24 to 35V, f = 120Hz	52			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		24		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.18		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.1		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

Table 22. Electrical characteristics of L7824C (refer to the test circuits, T_J = -55 to 150°C, V_I = 33V, I_O = 500 mA, C_I = 0.33 µF, C_O = 0.1 µF unless otherwise specified)

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
V_O	Output voltage	T_J = 25°C	23	24	25	V
V_O	Output voltage	I_O = 5mA to 1A, P_O ≤15W V_I = 27 to 38V	22.8	24	25.2	V
ΔV_O(1)	Line regulation	V_I = 27 to 38V, T_J = 25°C			480	mV
		V_I = 30 to 36V, T_J = 25°C			240	
ΔV_O(1)	Load regulation	I_O = 5 mA to 1.5A, T_J = 25°C			480	mV
		I_O = 250 to 750mA, T_J = 25°C			240	
I_d	Quiescent current	T_J = 25°C			8	mA
ΔI_d	Quiescent current change	I_O = 5mA to 1A			0.5	mA
		V_I = 27 to 38V			1	
$\Delta V_O/\Delta T$	Output voltage drift	I_O = 5mA		-1.5		mV/°C
eN	Output noise voltage	B =10Hz to 100KHz, T_J = 25°C		170		µV/V_O
SVR	Supply voltage rejection	V_I = 28 to 38V, f = 120Hz	50			dB
V_d	Dropout voltage	I_O = 1A, T_J = 25°C		2		V
R_O	Output resistance	f = 1 KHz		28		mΩ
I_{sc}	Short circuit current	V_I = 35V, T_J = 25°C		0.15		A
I_{scp}	Short circuit peak current	T_J = 25°C		2.1		A

1. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

5 Typical performance

Figure 7. Dropout voltage vs junction temperature

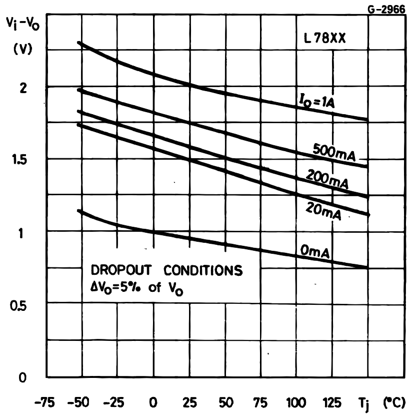


Figure 8. Peak output current vs input/output differential voltage

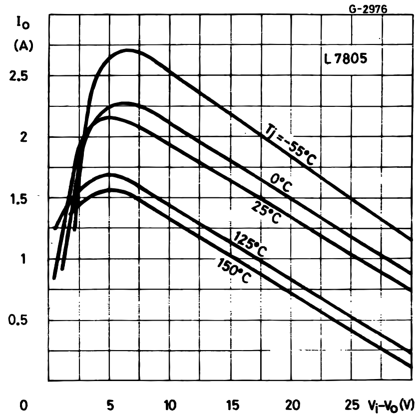


Figure 9. Supply voltage rejection vs frequency

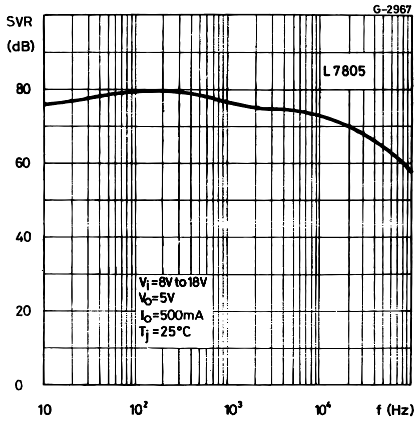


Figure 10. Output voltage vs junction temperature

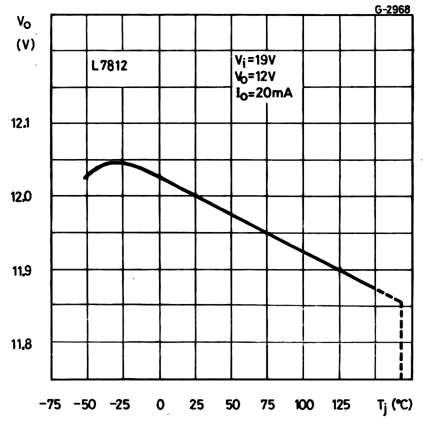


Figure 11. Output impedance vs frequency

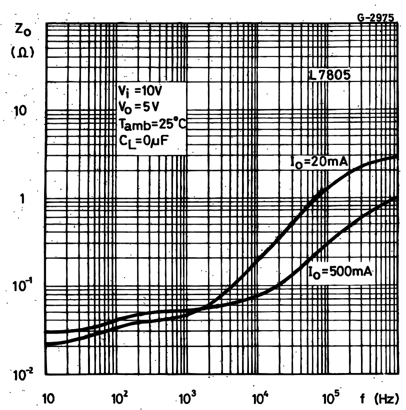


Figure 12. Quiescent current vs junction temperature

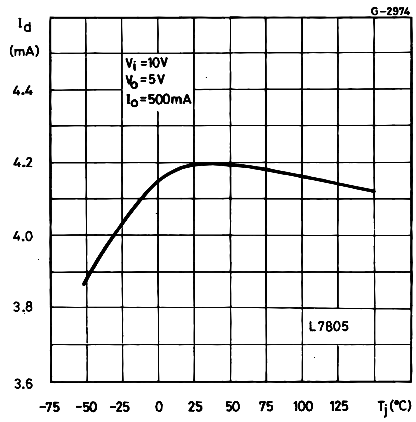


Figure 13. Load transient response

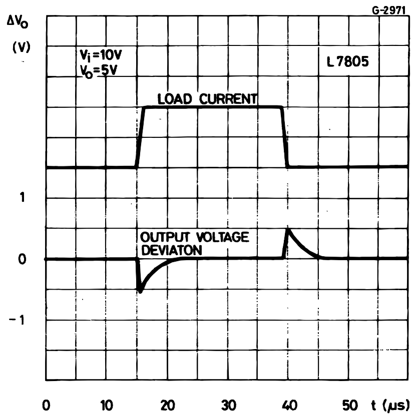


Figure 14. Line transient response

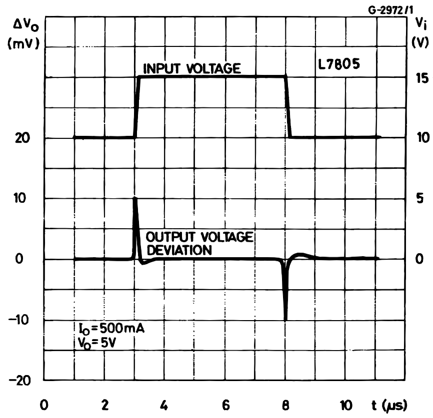


Figure 15. Quiescent current vs input voltage

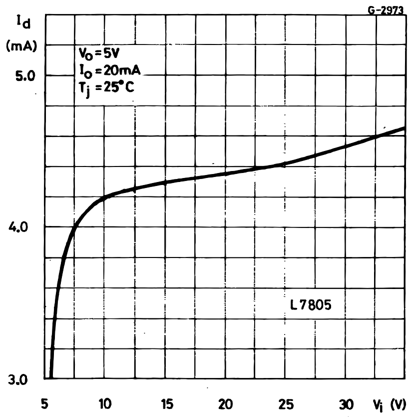
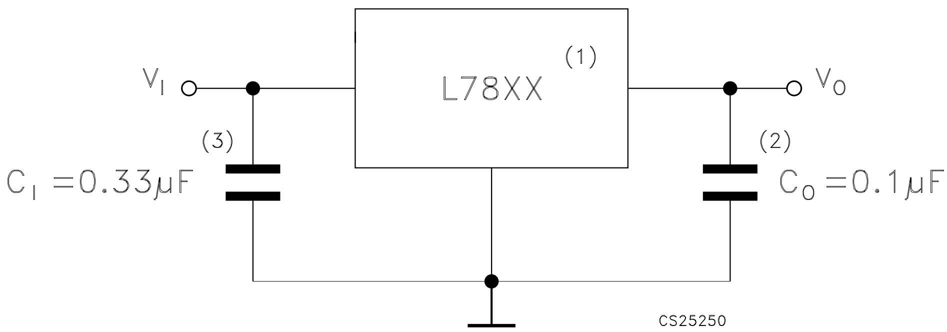


Figure 16. Fixed output regulator



1. To specify an output voltage, substitute voltage value for "XX".
2. Although no output capacitor is need for stability, it does improve transient response.
3. Required if regulator is locate an appreciable distance from power supply filter.

Figure 17. Current regulator

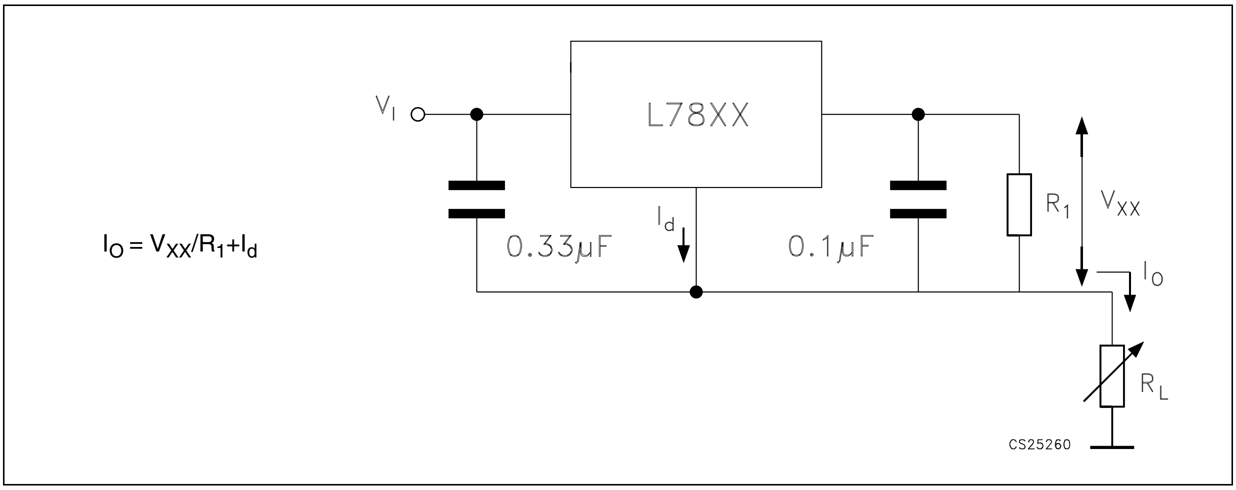


Figure 18. Circuit for increasing output voltage

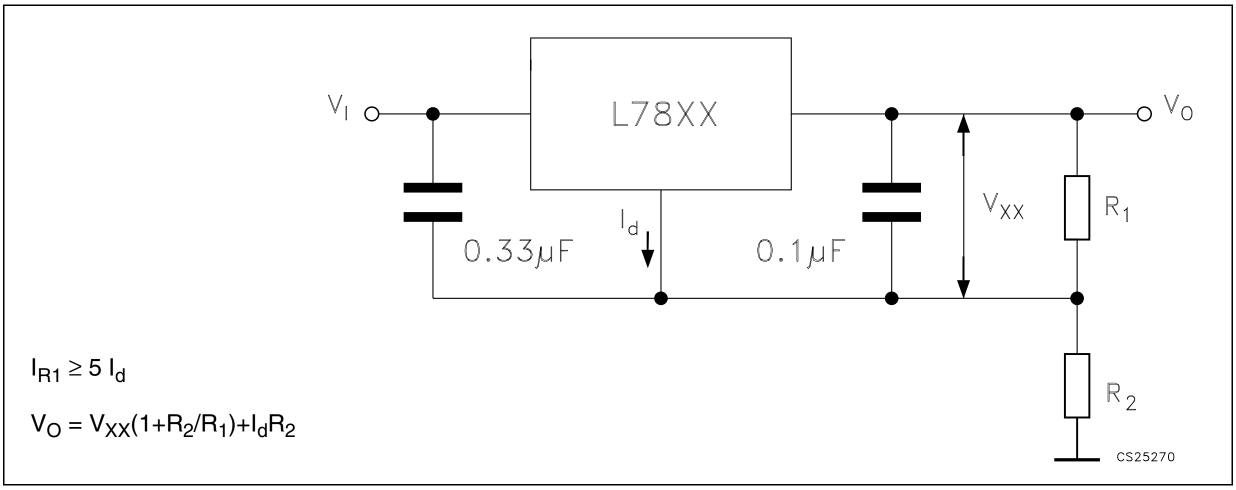


Figure 19. Adjustable output regulator (7 to 30V)

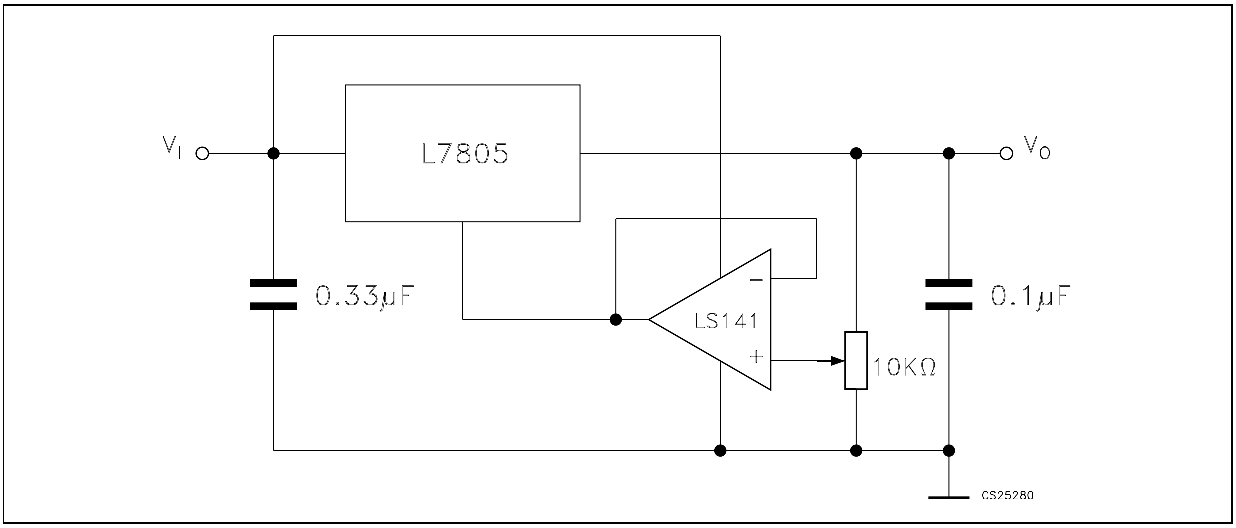


Figure 20. 0.5 to 10V Regulator

$V_O = V_{XX} R_4 / R_1$

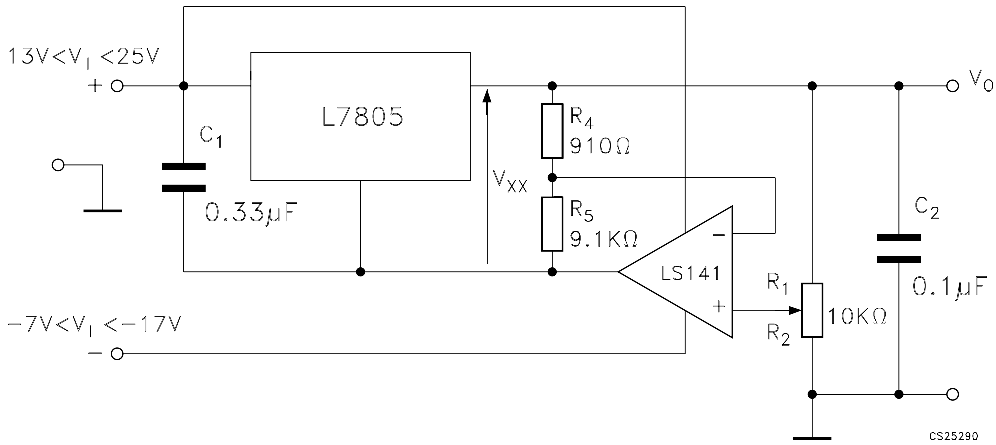


Figure 21. High current voltage regulator

$$R_1 = \frac{V_{BEQ1}}{I_{REQ} - (I_{Q1}/\beta_{Q1})}$$

$$I_O = I_{REG} + Q_1 \left(I_{REG} \frac{V_{BEQ1}}{R_1}\right)$$

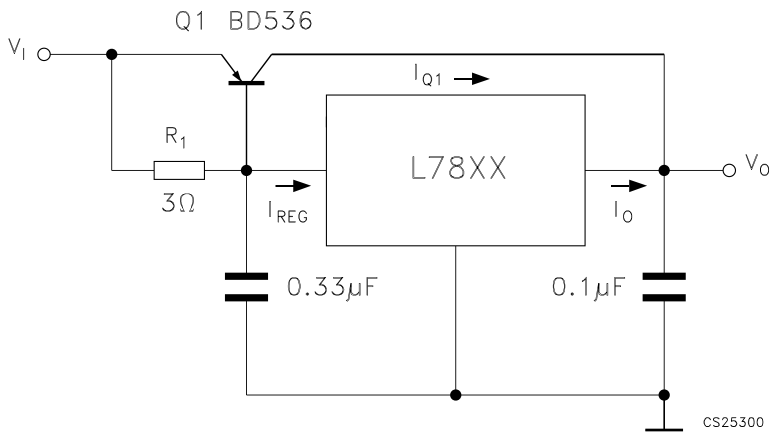


Figure 22. High output current with short circuit protection

$R_{SC} = V_{BEQ2} / I_{SC}$

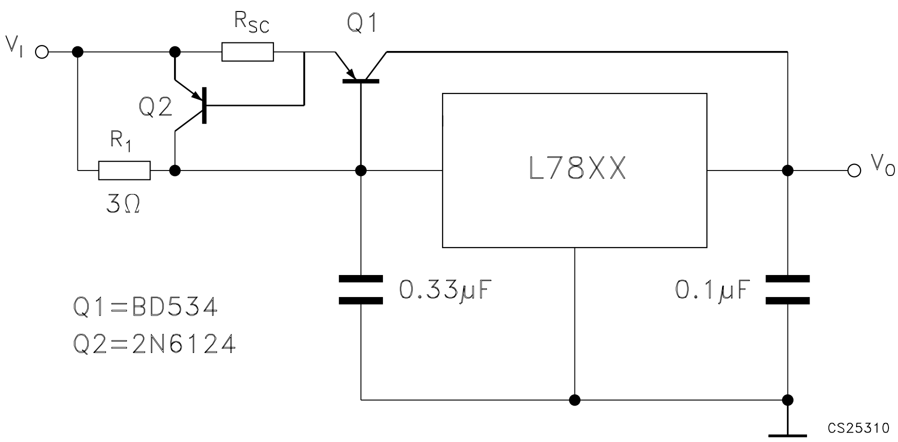


Figure 23. Tracking voltage regulator

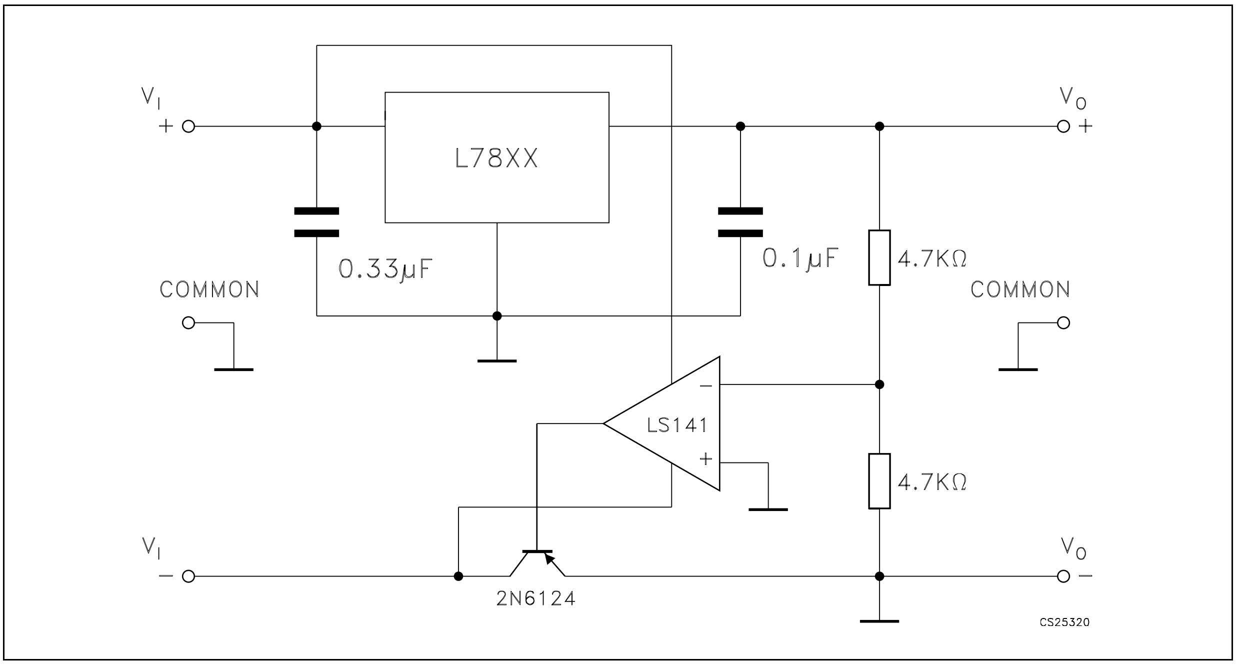
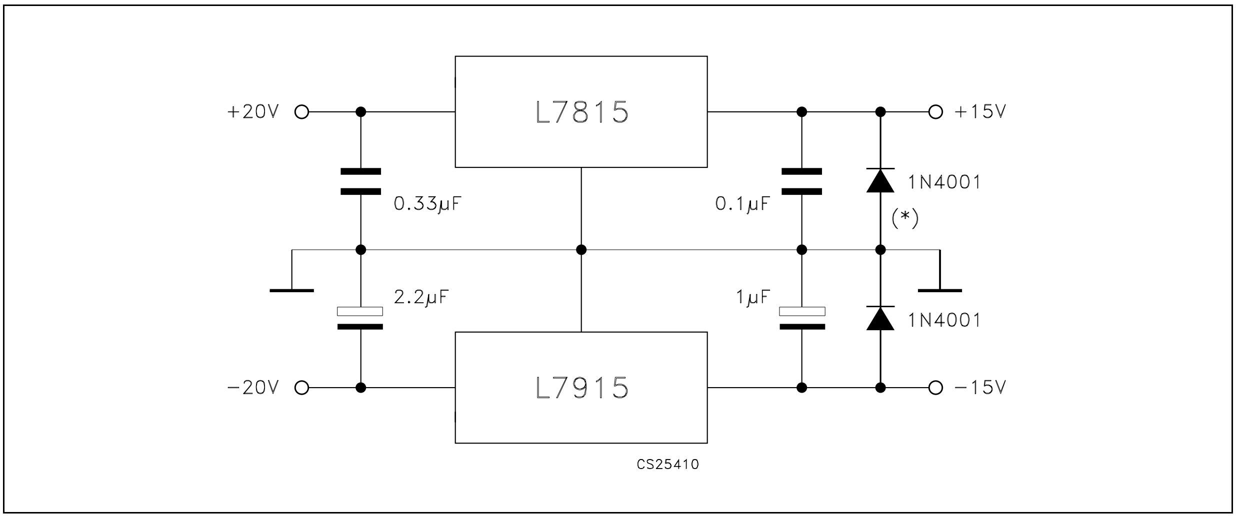


Figure 24. Split power supply (± 15V - 1 A)



* Against potential latch-up problems.

Figure 25. Negative output voltage circuit

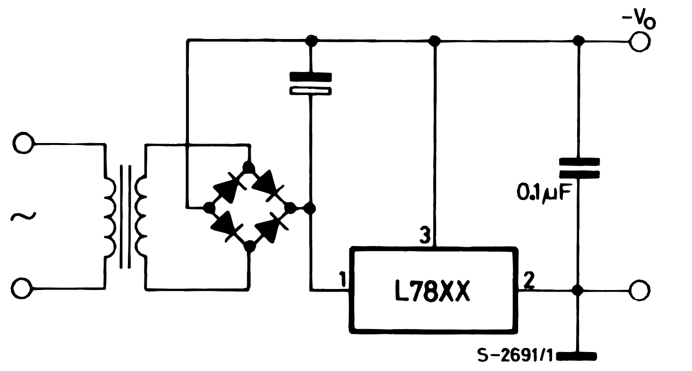


Figure 26. Switching regulator

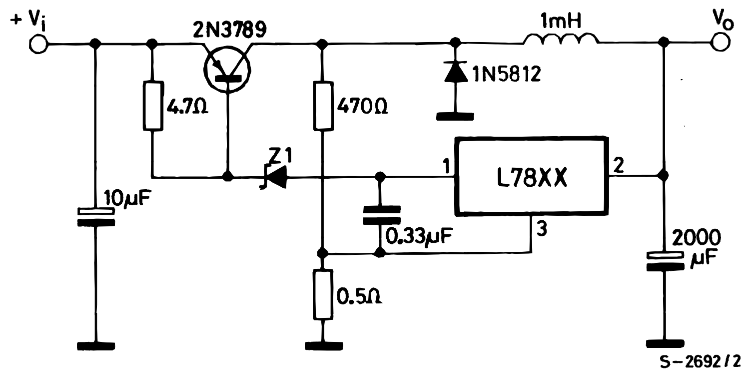
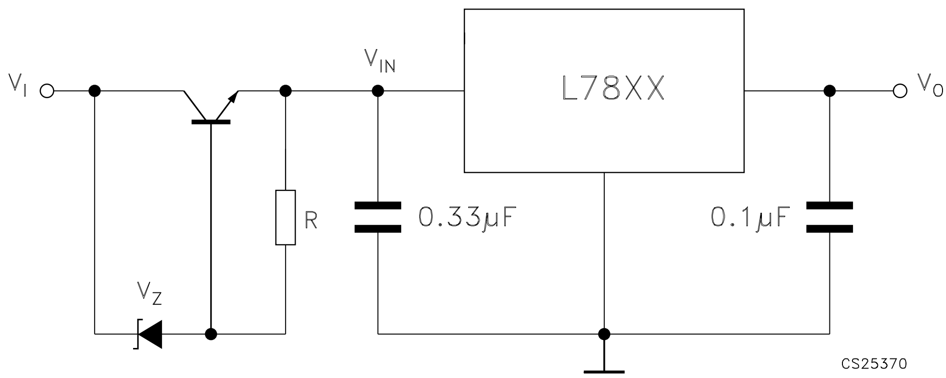


Figure 27. High input voltage circuit



$V_{IN} = V_I - (V_Z + V_{BE})$

Figure 28. High input voltage circuit

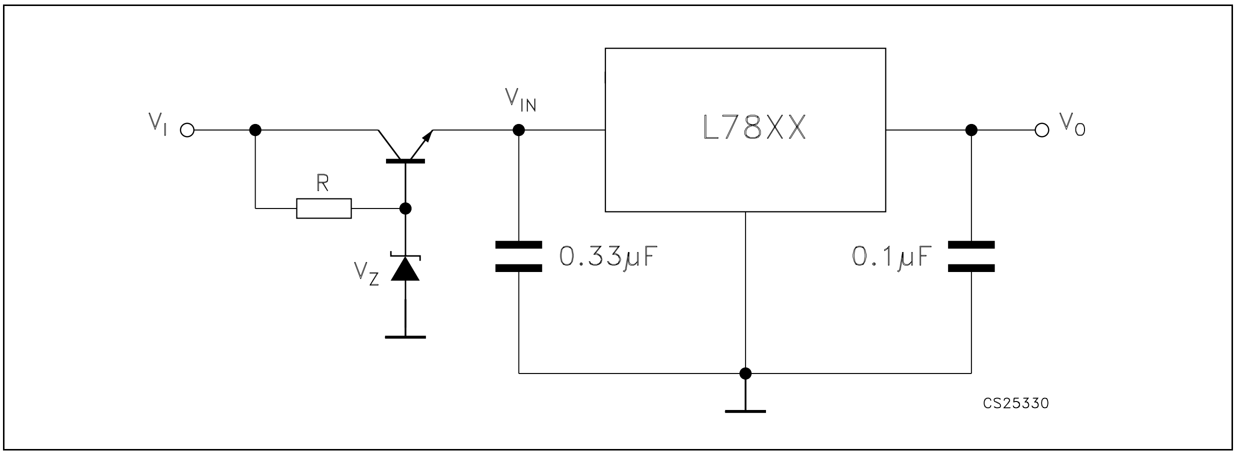


Figure 29. High output voltage regulator

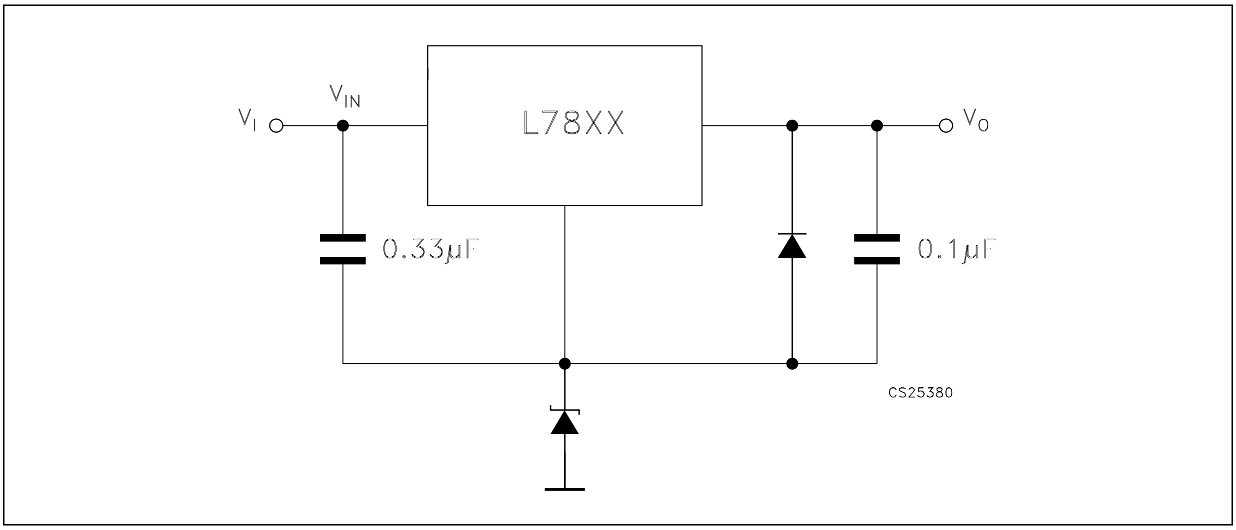


Figure 30. High input and output voltage

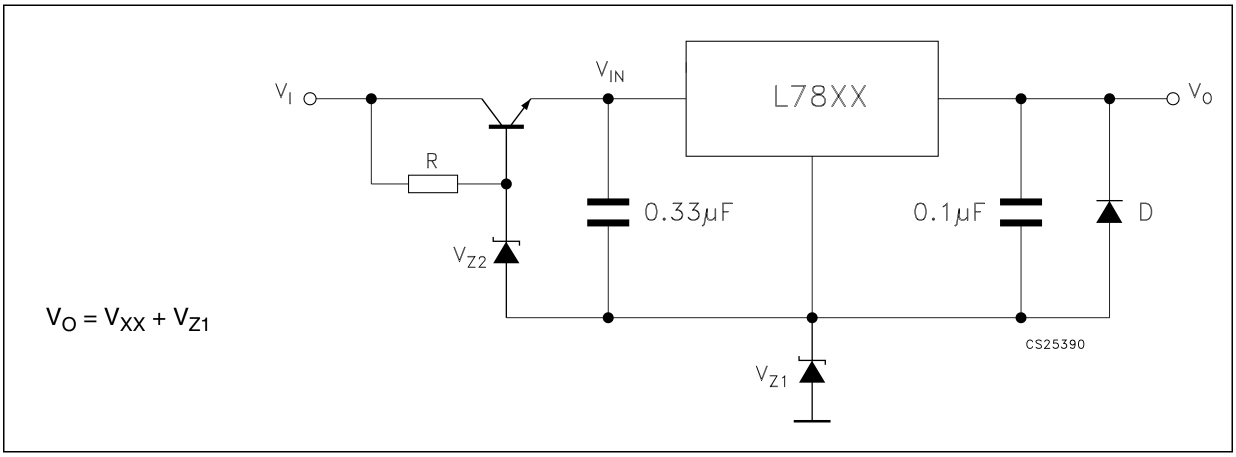
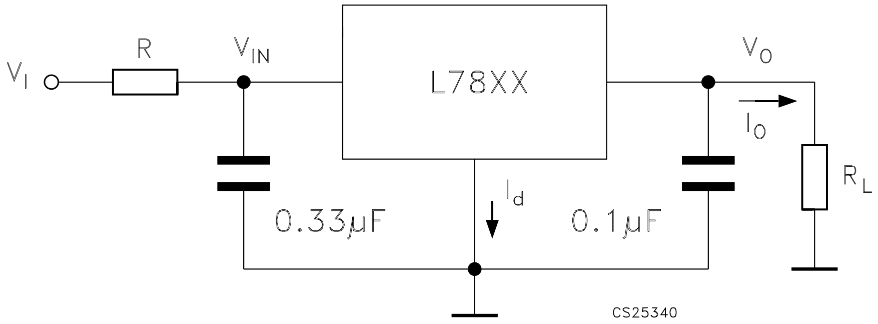


Figure 31. Reducing power dissipation with dropping resistor



$$R = \frac{V_{I(min)} - V_{XX} - V_{DROP(max)}}{I_{O(max)} + I_{d(max)}}$$

Figure 32. Remote shutdown

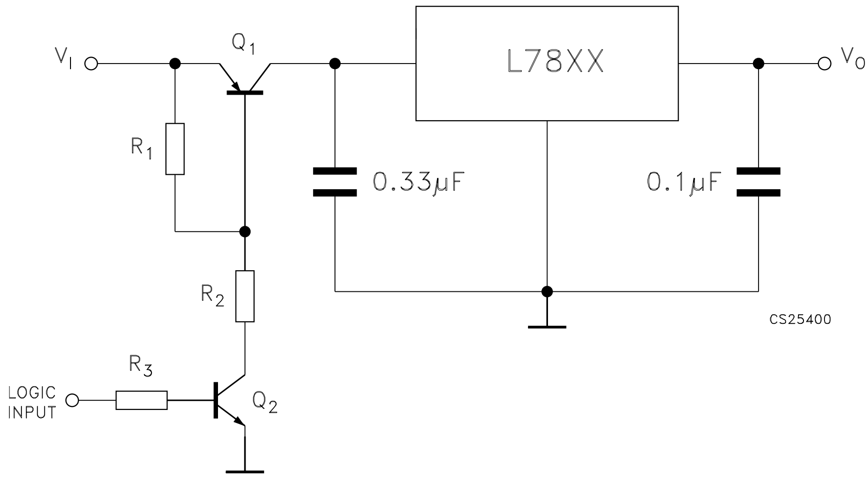
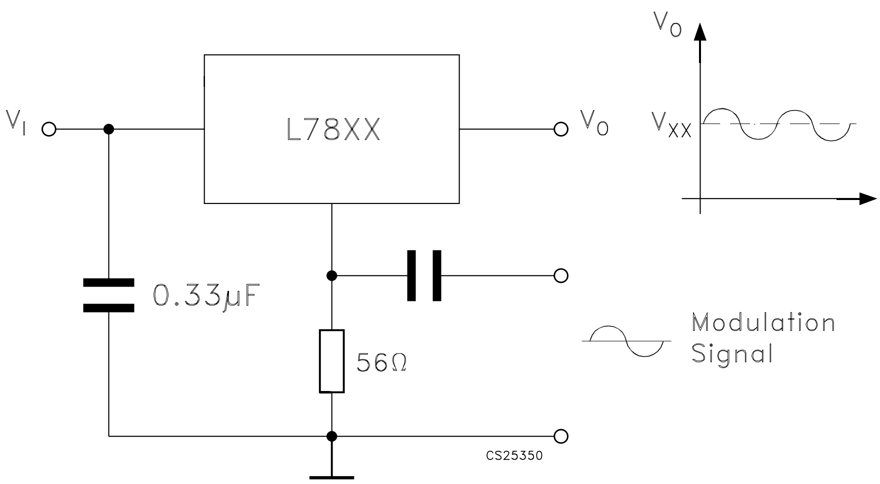


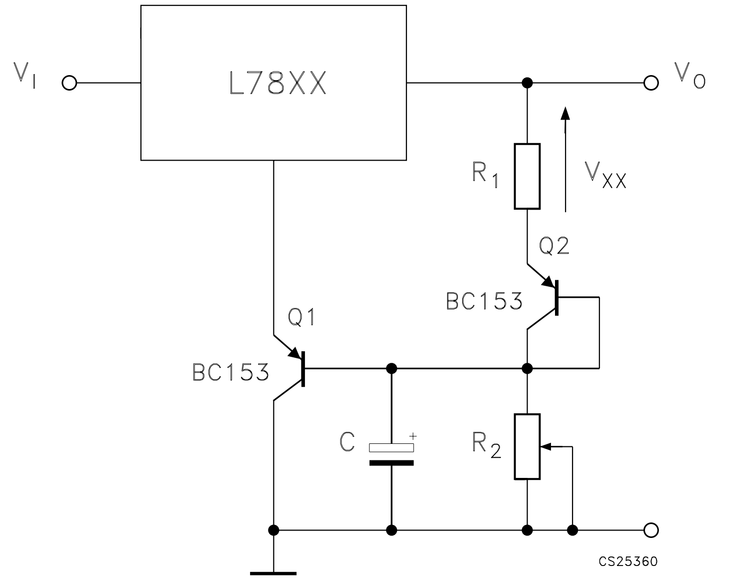
Figure 33. Power AM modulator (unity voltage gain, $I_O \leq 0.5$)



Note: The circuit performs well up to 100 KHz.

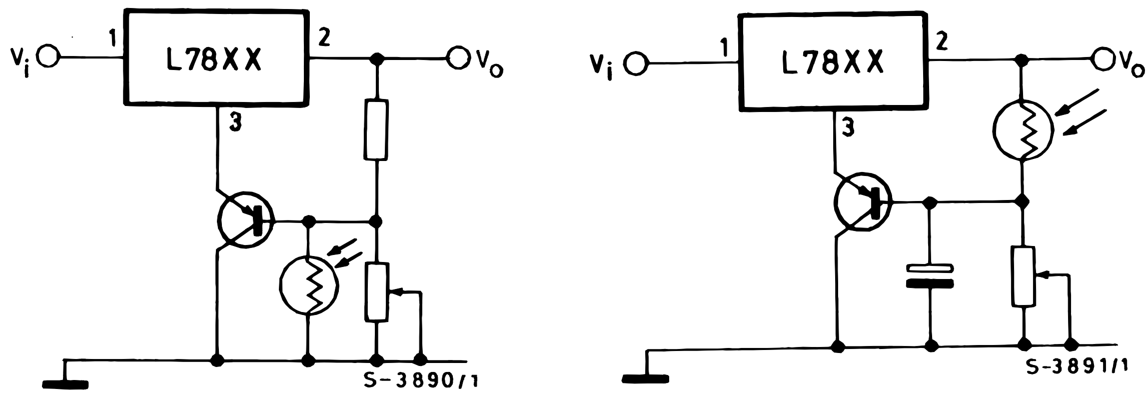
Figure 34. Adjustable output voltage with temperature compensation

$V_O = V_{XX} (1+R_2/R_1) + V_{BE}$



Note: *Q_2 is connected as a diode in order to compensate the variation of the Q_1 V_{BE} with the temperature. C allows a slow rise time of the V_O.*

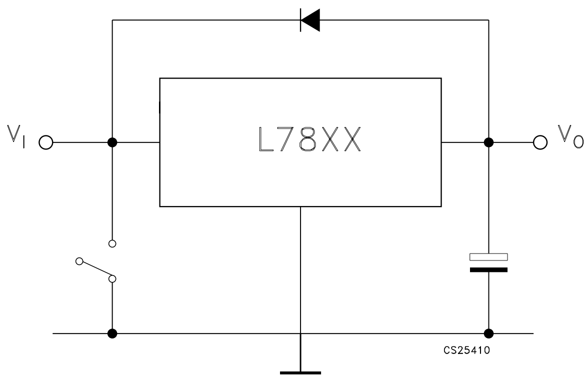
Figure 35. Light controllers ($V_{Omin} = V_{XX} + V_{BE}$)



V_O falls when the light goes up

V_O rises when the light goes up

Figure 36. Protection against input short-circuit with high capacitance loads



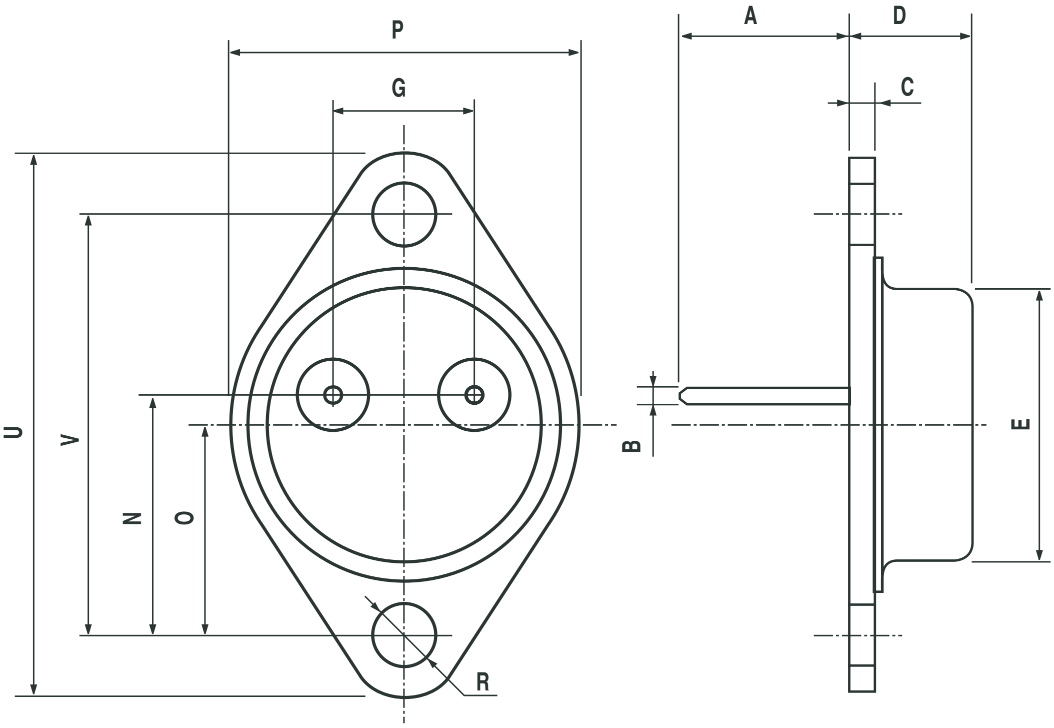
1. Application with high capacitance loads and an output voltage greater than 6 volts need an external diode (see fig. 32) to protect the device against input short circuit. In this case the input voltage falls rapidly while the output voltage decrease slowly. The capacitance discharges by means of the Base-Emitter junction of the series pass transistor in the regulator. If the energy is sufficiently high, the transistor may be destroyed. The external diode by-passes the current from the IC to ground.

6 Package mechanical data

In order to meet environmental requirements, ST offers these devices in ECOPACK® packages. These packages have a Lead-free second level interconnect. The category of second Level Interconnect is marked on the package and on the inner box label, in compliance with JEDEC Standard JESD97. The maximum ratings related to soldering conditions are also marked on the inner box label. ECOPACK is an ST trademark. ECOPACK specifications are available at: www.st.com.

TO-3 MECHANICAL DATA

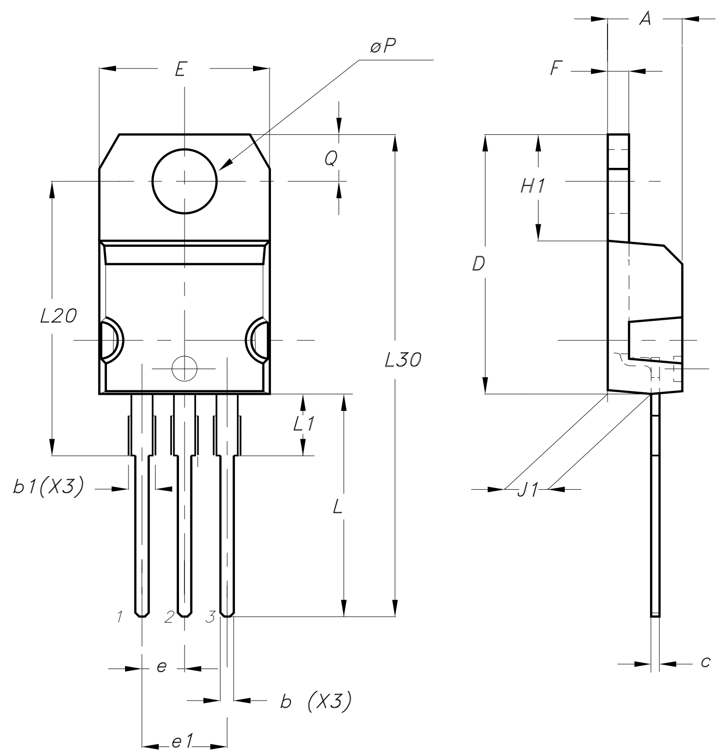
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A		11.85			0.466	
B	0.96	1.05	1.10	0.037	0.041	0.043
C			1.70			0.066
D			8.7			0.342
E			20.0			0.787
G		10.9			0.429	
N		16.9			0.665	
P			26.2			1.031
R	3.88		4.09	0.152		0.161
U			39.5			1.555
V		30.10			1.185	



P003C/C

TO-220 (A TYPE) MECHANICAL DATA

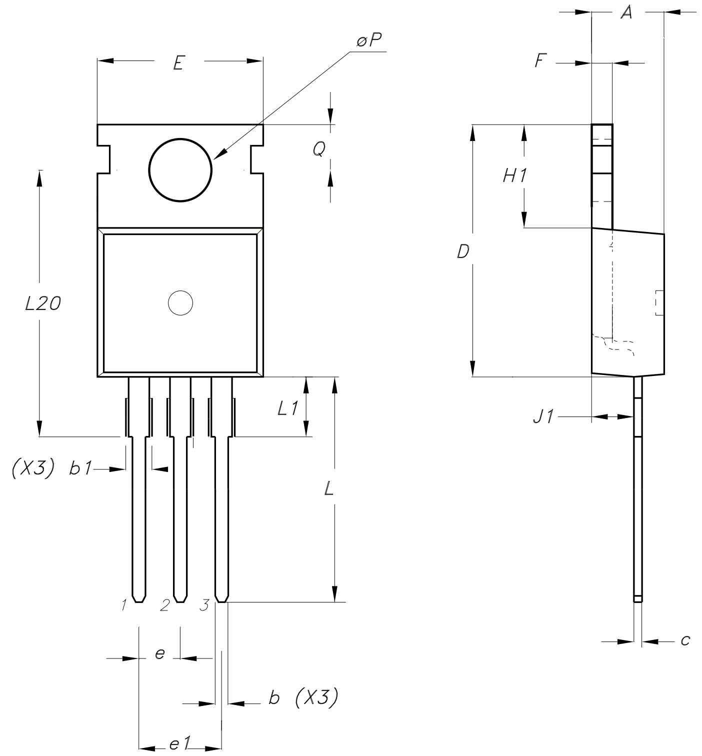
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A	4.40		4.60	0.173		0.181
b	0.61		0.88	0.024		0.034
b1	1.15		1.70	0.045		0.067
c	0.49		0.70	0.019		0.027
D	15.25		15.75	0.600		0.620
E	10.0		10.40	0.393		0.409
e	2.4		2.7	0.094		0.106
e1	4.95		5.15	0.194		0.203
F	1.23		1.32	0.048		0.051
H1	6.2		6.6	0.244		0.260
J1	2.40		2.72	0.094		0.107
L	13.0		14.0	0.511		0.551
L1	3.5		3.93	0.137		0.154
L20		16.4			0.645	
L30		28.9			1.138	
ϕP	3.75		3.85	0.147		0.151
Q	2.65		2.95	0.104		0.116



0015988/N

TO-220 (C TYPE) MECHANICAL DATA

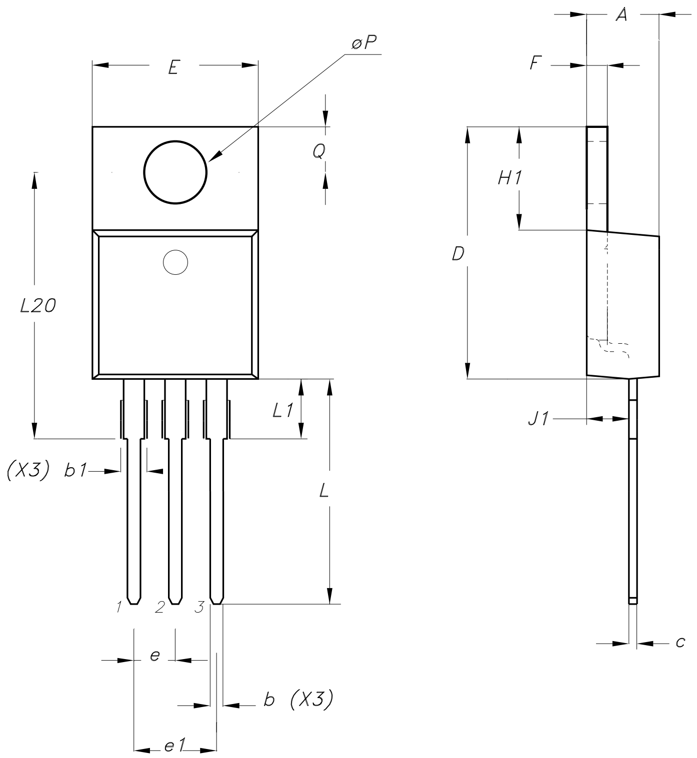
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A	4.30		4.70	0.169		0.185
b	0.70		0.90	0.028		0.035
b1	1.42		1.62	0.056		0.064
c	0.45		0.60	0.018		0.024
D		15.70			0.618	
E	9.80		10.20	0.386		0.402
e		2.54			0.100	
e1		5.08			0.200	
F	1.25		1.39	0.049		0.055
H1		6.5			0.256	
J1	2.20		2.60	0.087		0.202
L	12.88		13.28	0.507		0.523
L1		3			0.118	
L20	15.70		16.1	0.618		0.634
L30		28.9			1.138	
ϕP	3.50		3.70	0.138		0.146
Q	2.70		2.90	0.106		0.114



0015988/N

TO-220 (E TYPE) MECHANICAL DATA

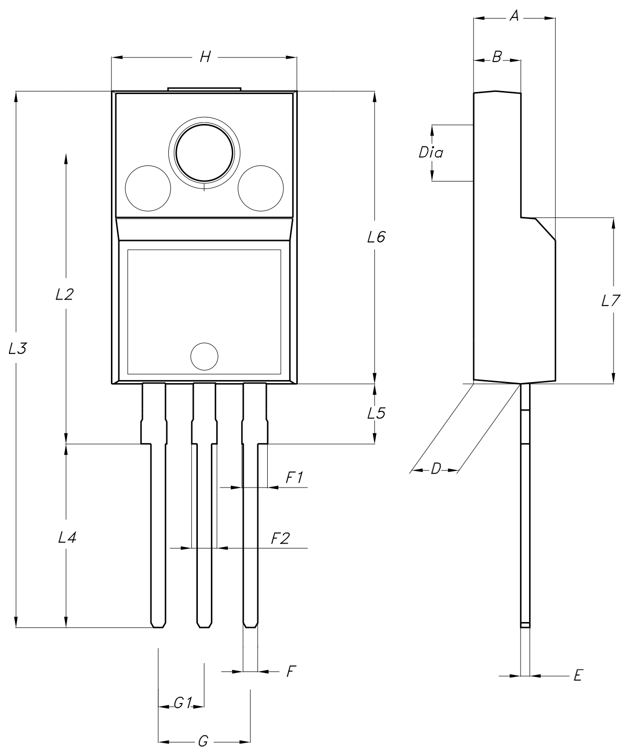
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A	4.47		4.67	0.176		0.184
b	0.70		0.91	0.028		0.036
b1	1.17		1.37	0.046		0.054
c	0.31		0.53	0.012		0.021
D	14.60		15.70	0.575		0.618
E	9.96		10.36	0.392		0.408
e		2.54			0.100	
e1		5.08			0.200	
F	1.17		1.37	0.046		0.054
H1	6.1		6.8	0.240		0.268
J1	2.52		2.82	0.099		0.111
L	12.70		13.80	0.500		0.543
L1	3.20		3.96	0.126		0.156
L20	15.21		16.77	0.599		0.660
ϕP	3.73		3.94	0.147		0.155
Q	2.59		2.89	0.102		0.114



7655923/A

TO-220FP MECHANICAL DATA

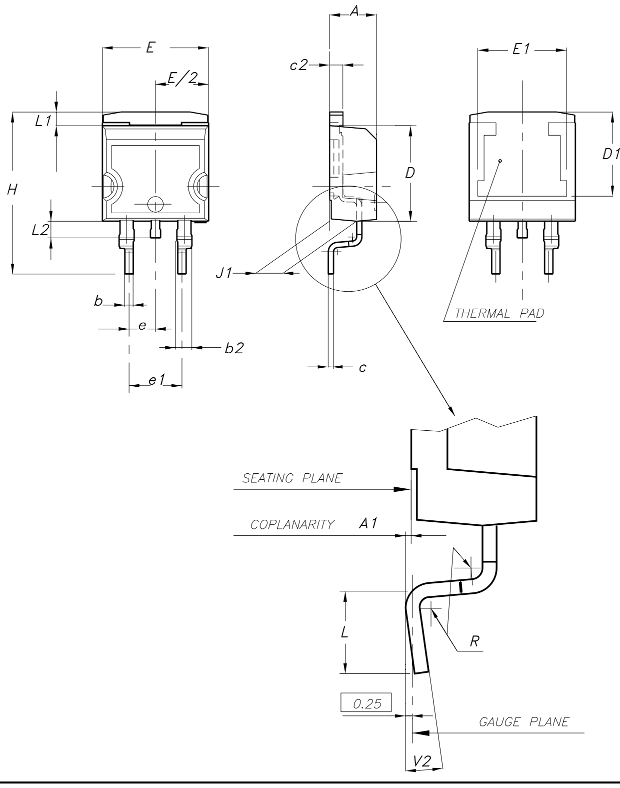
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A	4.40		4.60	0.173		0.181
B	2.5		2.7	0.098		0.106
D	2.5		2.75	0.098		0.108
E	0.45		0.70	0.017		0.027
F	0.75		1	0.030		0.039
F1	1.15		1.50	0.045		0.059
F2	1.15		1.50	0.045		0.059
G	4.95		5.2	0.194		0.204
G1	2.4		2.7	0.094		0.106
H	10.0		10.40	0.393		0.409
L2		16			0.630	
L3	28.6		30.6	1.126		1.204
L4	9.8		10.6	0.385		0.417
L5	2.9		3.6	0.114		0.142
L6	15.9		16.4	0.626		0.645
L7	9		9.3	0.354		0.366
DIA.	3		3.2	0.118		0.126



7012510A-H

D²PAK (A TYPE) MECHANICAL DATA

DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A	4.4		4.6	0.173		0.181
A1	0.03		0.23	0.001		0.009
b	0.7		0.93	0.027		0.036
b2	1.14		1.7	0.044		0.067
c	0.45		0.6	0.017		0.023
c2	1.23		1.36	0.048		0.053
D	8.95		9.35	0.352		0.368
D1	8			0.315		
E	10		10.4	0.393		0.409
E1	8.5			0.335		
e		2.54			0.100	
e1	4.88		5.28	0.192		0.208
H	15		15.85	0.590		0.624
J1	2.49		2.69	0.098		0.106
L	2.29		2.79	0.090		0.110
L1	1.27		1.4	0.050		0.055
L2	1.3		1.75	0.051		0.069
R		0.4			0.016	
V2	0°		8°	0°		8°



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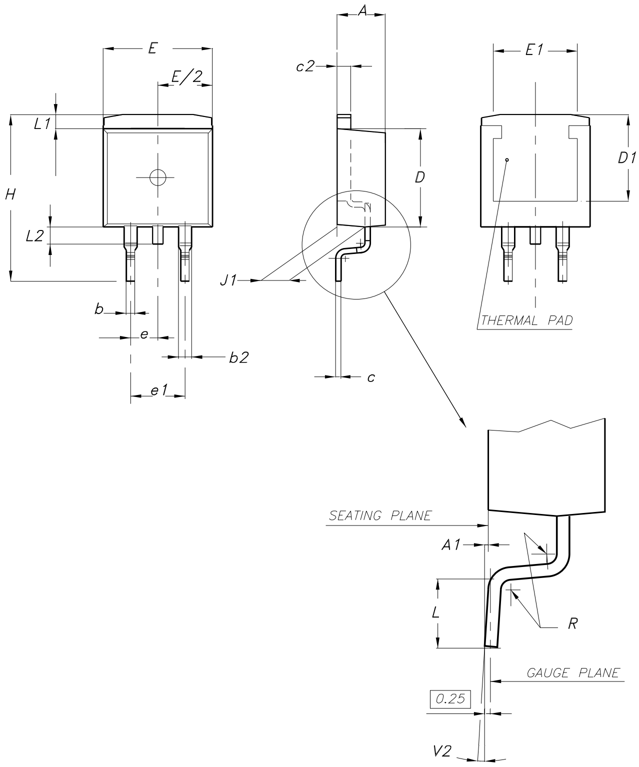
D²PAK (C TYPE) MECHANICAL DATA

DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A	4.3		4.7	0.169		0.185
A1	0		0.20	0.000		0.008
b	0.70		0.90	0.028		0.035
b2	1.17		1.37	0.046		0.054
c	0.45	0.50	0.6	0.018	0.020	0.024
c2	1.25	1.30	1.40	0.049	0.051	0.055
D	9.0	9.2	9.4	0.354	0.362	0.370
D1	7.5			0.295		
E	9.8		10.2	0.386		0.402
E1	7.5			0.295		
e		2.54			0.100	
e1		5.08			0.200	
H	15	15.30	15.60	0.591	0.602	0.614
J1	2.20		2.60	0.087		0.102
L	1.79		2.79	0.070		0.110
L1	1.0		1.4	0.039		0.055
L2	1.2		1.6	0.047		0.063
R		0.3			0.012	
V2	0°		3°	0°		3°



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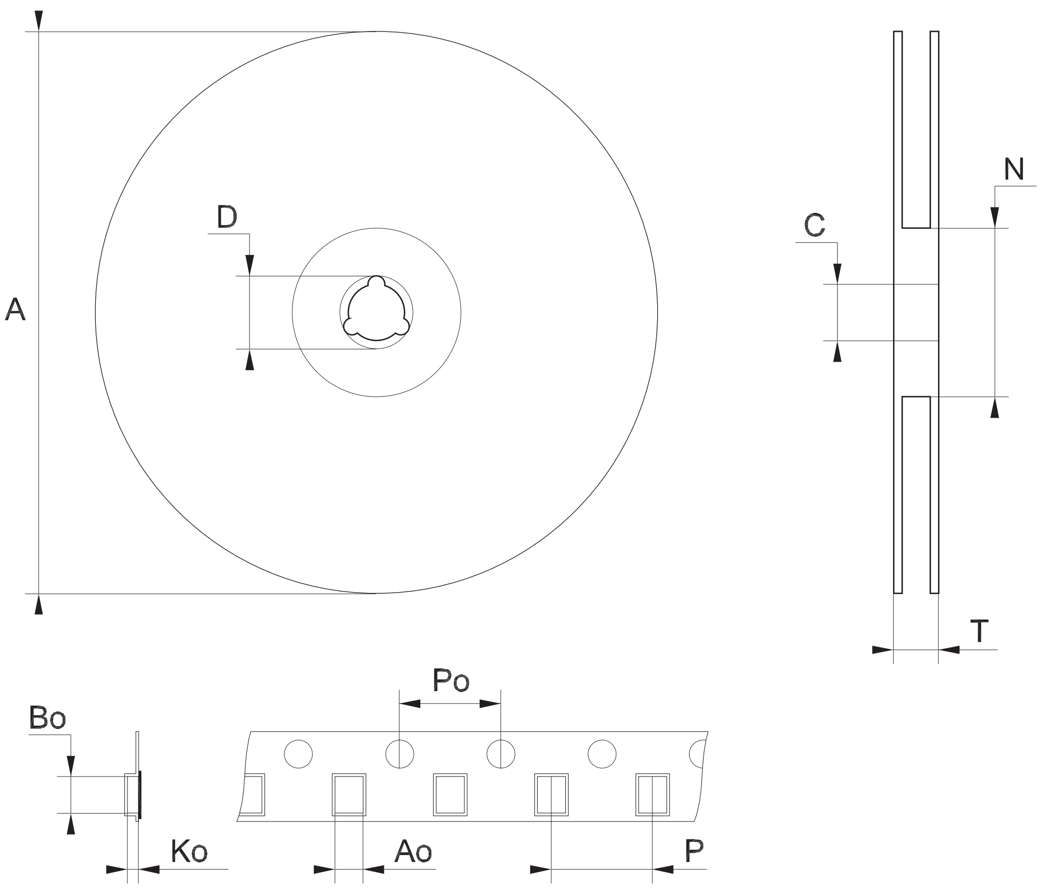
Tape & Reel $D^2PAK-P^2PAK-D^2PAK/A-P^2PAK/A$ MECHANICAL DATA						
DIM.	mm.			inch		
	MIN.	TYP	MAX.	MIN.	TYP.	MAX.
A			180			7.086
C	12.8	13.0	13.2	0.504	0.512	0.519
D	20.2			0.795		
N	60			2.362		
T			14.4			0.567
Ao	10.50	10.6	10.70	0.413	0.417	0.421
Bo	15.70	15.80	15.90	0.618	0.622	0.626
Ko	4.80	4.90	5.00	0.189	0.193	0.197
Po	3.9	4.0	4.1	0.153	0.157	0.161
P	11.9	12.0	12.1	0.468	0.472	0.476



Note: Drawing not in scale

7 Order code

Table 23. Order code

Part numbers	Packaging					
	TO-220 (A Type)	TO-220 (C Type)	D^2PAK (A Type)	D^2PAK (C Type)	TO-220FP	TO-3
L7805						L7805T
L7805C	L7805CV	L7805C-V	L7805CD2T-TR	L7805C-D2TR	L7805CP	L7805CT
L7852C	L7852CV		L7852CD2T-TR(1)		L7852CP(1)	L7852CT(1)
L7806C	L7806CV	L7806C-V	L7806CD2T-TR		L7806CP	L7806CT
L7808C	L7808CV	L7808C-V	L7808CD2T-TR		L7808CP	L7808CT
L7885C	L7885CV		L7885CD2T-TR(1)		L7885CP(1)	L7885CT(1)
L7809C	L7809CV	L7809C-V	L7809CD2T-TR		L7809CP	L7809CT
L7810C	L7810CV		L7810CD2T-TR(1)		L7810CP	
L7812C	L7812CV	L7812C-V	L7812CD2T-TR		L7812CP	L7812CT
L7815C	L7815CV	L7815C-V	L7815CD2T-TR		L7815CP	L7815CT
L7818C	L7818CV		L7818CD2T-TR(1)		L7818CP	L7818CT
L7820C	L7820CV		L7820CD2T-TR(1)		L7820CP(1)	L7820CT(1)
L7824C	L7824CV		L7824CD2T-TR		L7824CP	L7824CT

1. Available on request.

8 Revision history

Table 24. Revision history

Date	Revision	Changes
21-Jun-2004	12	Document updating.
03-Aug-2006	13	Order Codes has been updated and new template.

LM317, NCV317

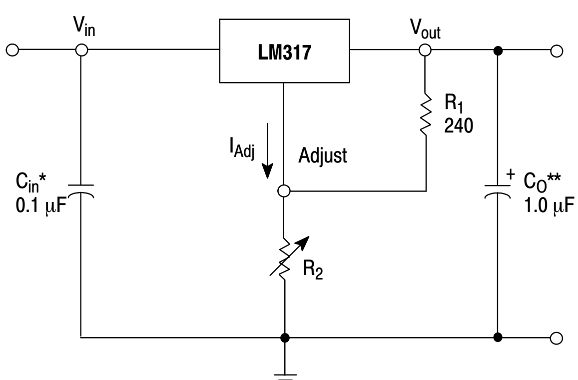
1.5 A Adjustable Output, Positive Voltage Regulator

The LM317 is an adjustable 3−terminal positive voltage regulator capable of supplying in excess of 1.5 A over an output voltage range of 1.2 V to 37 V. This voltage regulator is exceptionally easy to use and requires only two external resistors to set the output voltage. Further, it employs internal current limiting, thermal shutdown and safe area compensation, making it essentially blow−out proof.

The LM317 serves a wide variety of applications including local, on card regulation. This device can also be used to make a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM317 can be used as a precision current regulator.

Features

- Output Current in Excess of 1.5 A
- Output Adjustable between 1.2 V and 37 V
- Internal Thermal Overload Protection
- Internal Short Circuit Current Limiting Constant with Temperature
- Output Transistor Safe−Area Compensation
- Floating Operation for High Voltage Applications
- Eliminates Stocking many Fixed Voltages
- Available in Surface Mount D^2PAK−3, and Standard 3−Lead Transistor Package
- NCV Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC−Q100 Qualified and PPAP Capable
- These are Pb−Free Devices



* C_{in} is required if regulator is located an appreciable distance from power supply filter.
** C_O is not needed for stability, however, it does improve transient response.

$$V_{out} = 1.25\,V\left(1 + \frac{R_2}{R_1}\right) + I_{Adj}R_2$$

Since I_{Adj} is controlled to less than 100 µA, the error associated with this term is negligible in most applications.

Figure 1. Standard Application

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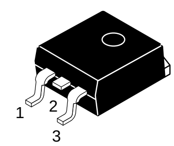
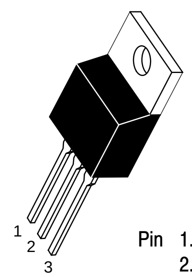


D^2PAK−3
D2T SUFFIX
CASE 936

Heatsink surface (shown as terminal 4 in case outline drawing) is connected to Pin 2.



TO−220
T SUFFIX
CASE 221AB

Pin 1. Adjust
2. V_{out}
3. V_{in}

Heatsink surface connected to Pin 2.

ORDERING INFORMATION

See detailed ordering and shipping information in the package dimensions section on page 10 of this data sheet.

DEVICE MARKING INFORMATION

See general marking information in the device marking section on page 10 of this data sheet.

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Input−Output Voltage Differential	V_I−V_O	−0.3 to 40	Vdc
Power Dissipation			
Case 221A			
T_A = +25°C	P_D	Internally Limited	W
Thermal Resistance, Junction−to−Ambient	θ_{JA}	65	°C/W
Thermal Resistance, Junction−to−Case	θ_{JC}	5.0	°C/W
Case 936 (D^2PAK−3)			
T_A = +25°C	P_D	Internally Limited	W
Thermal Resistance, Junction−to−Ambient	θ_{JA}	70	°C/W
Thermal Resistance, Junction−to−Case	θ_{JC}	5.0	°C/W
Operating Junction Temperature Range	T_J	−55 to +150	°C
Storage Temperature Range	T_{stg}	−65 to +150	°C

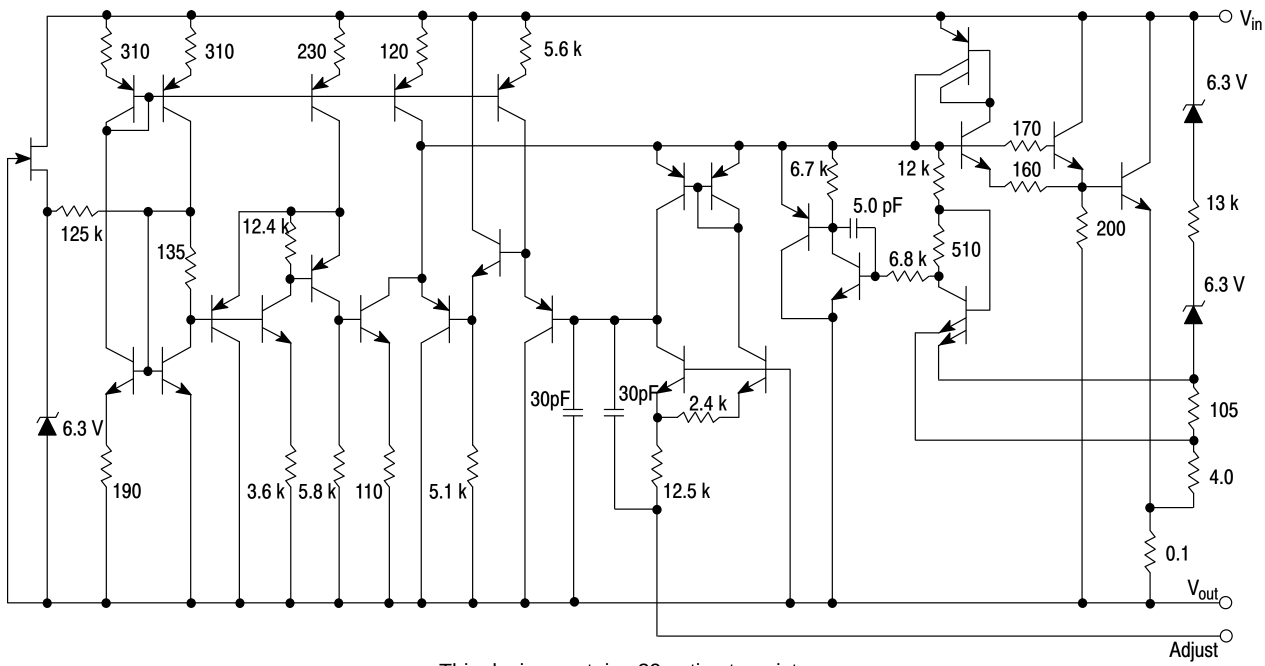
Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

ELECTRICAL CHARACTERISTICS

(V_I−V_O = 5.0 V; I_O = 0.5 A for D2T and T packages; T_J = T_{low} to T_{high} (Note 1); I_{max} and P_{max} (Note 2); unless otherwise noted.)

Characteristics	Figure	Symbol	Min	Typ	Max	Unit
Line Regulation (Note 3), T_A = +25°C, 3.0 V ≤ V_I−V_O ≤ 40 V	1	Reg_{line}	−	0.01	0.04	%/V
Load Regulation (Note 3), T_A = +25°C, 10 mA ≤ I_O ≤ I_{max}	2	Reg_{load}				
V_O ≤ 5.0 V			−	5.0	25	mV
V_O ≥ 5.0 V			−	0.1	0.5	% V_O
Thermal Regulation, T_A = +25°C (Note 4), 20 ms Pulse	−	Reg_{therm}	−	0.03	0.07	% V_O/W
Adjustment Pin Current	3	I_{Adj}	−	50	100	μA
Adjustment Pin Current Change, 2.5 V ≤ V_I−V_O ≤ 40 V, 10 mA ≤ I_L ≤ I_{max}, P_D ≤ P_{max}	1, 2	ΔI_{Adj}	−	0.2	5.0	μA
Reference Voltage, 3.0 V ≤ V_I−V_O ≤ 40 V, 10 mA ≤ I_O ≤ I_{max}, P_D ≤ P_{max}	3	V_{ref}	1.2	1.25	1.3	V
Line Regulation (Note 3), 3.0 V ≤ V_I−V_O ≤ 40 V	1	Reg_{line}	−	0.02	0.07	% V
Load Regulation (Note 3), 10 mA ≤ I_O ≤ I_{max}	2	Reg_{load}				
V_O ≤ 5.0 V			−	20	70	mV
V_O ≥ 5.0 V			−	0.3	1.5	% V_O
Temperature Stability (T_{low} ≤ T_J ≤ T_{high})	3	T_S	−	0.7	−	% V_O
Minimum Load Current to Maintain Regulation (V_I−V_O = 40 V)	3	I_{Lmin}	−	3.5	10	mA
Maximum Output Current	3	I_{max}				A
V_I−V_O ≤ 15 V, P_D ≤ $P_{max,}$ T Package			1.5	2.2	−	
V_I−V_O = 40 V, P_D ≤ P_{max}, T_A = +25°C, T Package			0.15	0.4	−	
RMS Noise, % of V_O, T_A = +25°C, 10 Hz ≤ f ≤ 10 kHz	−	N	−	0.003	−	% V_O
Ripple Rejection, V_O = 10 V, f = 120 Hz (Note 5)	4	RR				dB
Without C_{Adj}			−	65	−	
C_{Adj} = 10 μF			66	80	−	
Thermal Shutdown (Note 6)	−	−	−	180	−	°C
Long−Term Stability, T_J = T_{high} (Note 7), T_A = +25°C for Endpoint Measurements	3	S	−	0.3	1.0	%/1.0 kHrs.
Thermal Resistance Junction−to−Case, T Package	−	$R_{\theta JC}$	−	5.0	−	°C/W

1. T_{low} to T_{high} = 0° to +125°C, for LM317T, D2T. T_{low} to T_{high} = −40° to +125°C, for LM317BT, BD2T, T_{low} to T_{high} = −55° to +150°C, for NCV317BT, BD2T.
2. I_{max} = 1.5 A, P_{max} = 20 W
3. Load and line regulation are specified at constant junction temperature. Changes in V_O due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.
4. Power dissipation within an IC voltage regulator produces a temperature gradient on the die, affecting individual IC components on the die. These effects can be minimized by proper integrated circuit design and layout techniques. Thermal Regulation is the effect of these temperature gradients on the output voltage and is expressed in percentage of output change per watt of power change in a specified time.
5. C_{Adj}, when used, is connected between the adjustment pin and ground.
6. Thermal characteristics are not subject to production test.
7. Since Long−Term Stability cannot be measured on each device before shipment, this specification is an engineering estimate of average stability from lot to lot.



This device contains 29 active transistors.

Figure 2. Representative Schematic Diagram

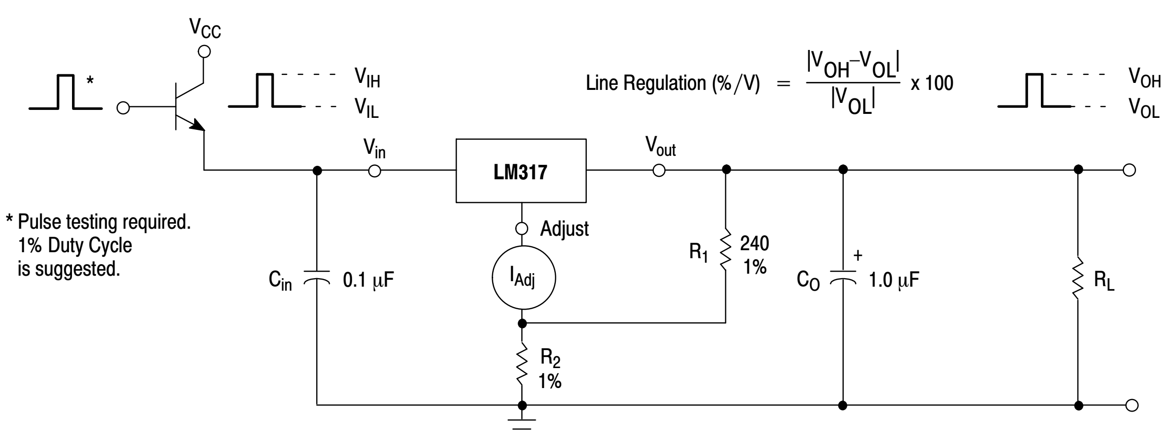
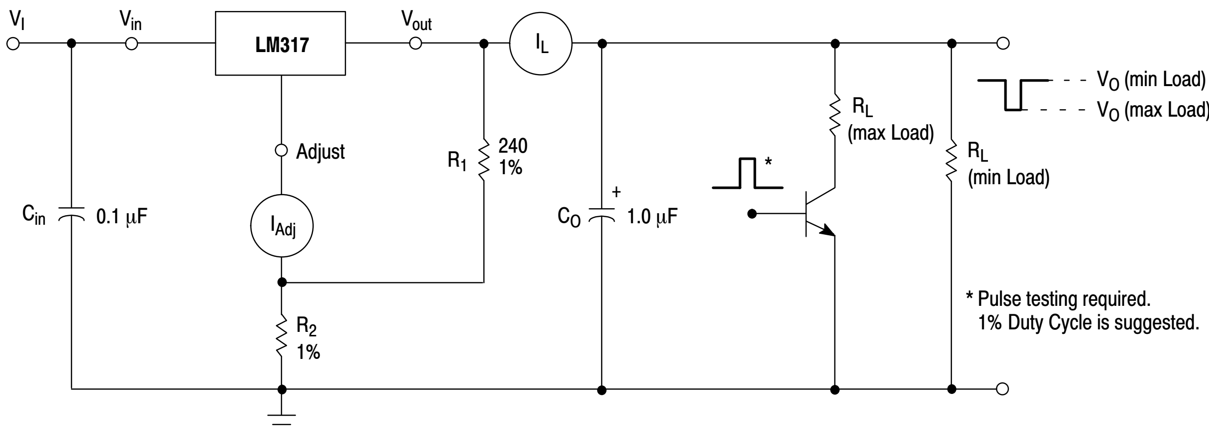


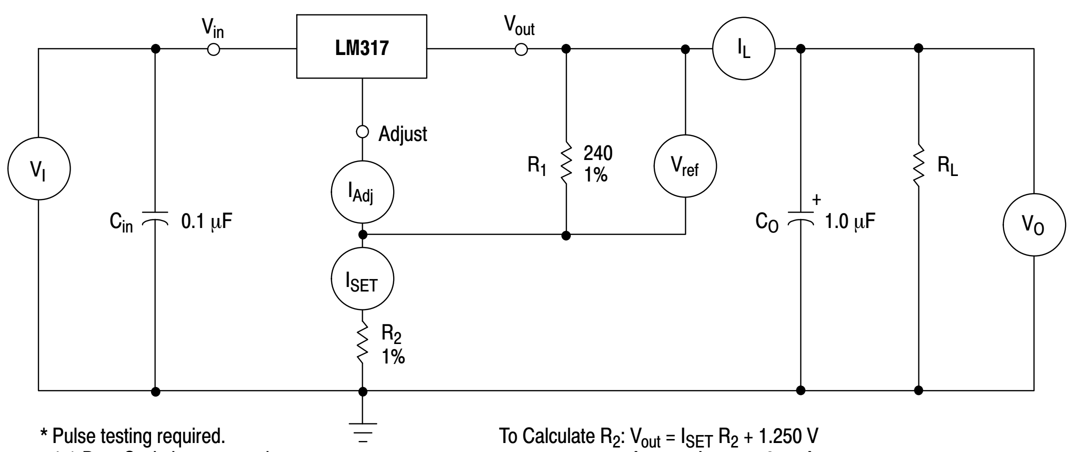
Figure 3. Line Regulation and ΔI_{Adj}/Line Test Circuit



Load Regulation (mV) = V_O (min Load) − V_O (max Load)

$$\text{Load Regulation } (\%\ V_O) = \frac{V_O \text{ (min Load)} - V_O \text{ (max Load)}}{V_O \text{ (min Load)}} \times 100$$

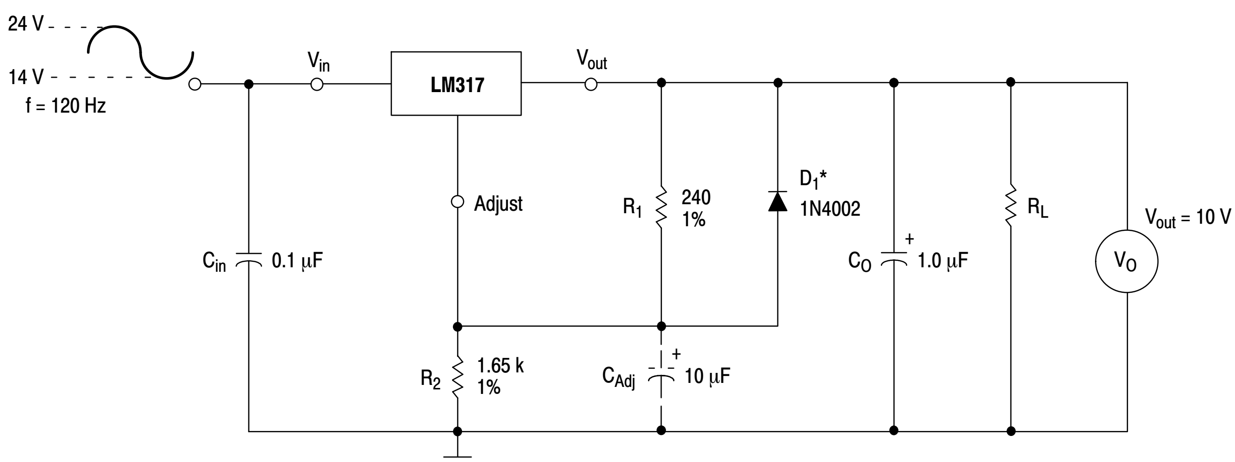
Figure 4. Load Regulation and ΔI_{Adj}/Load Test Circuit



* Pulse testing required.
1% Duty Cycle is suggested.

To Calculate R_2: $V_{out} = I_{SET} R_2 + 1.250$ V
Assume $I_{SET} = 5.25$ mA

Figure 5. Standard Test Circuit



* D_1 Discharges C_{Adj} if output is shorted to Ground.

Figure 6. Ripple Rejection Test Circuit

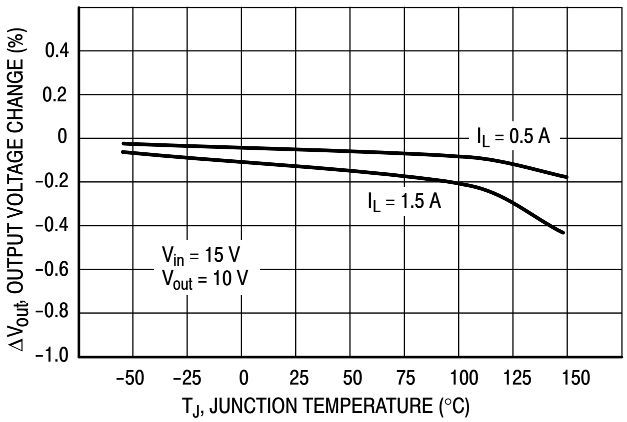


Figure 7. Load Regulation

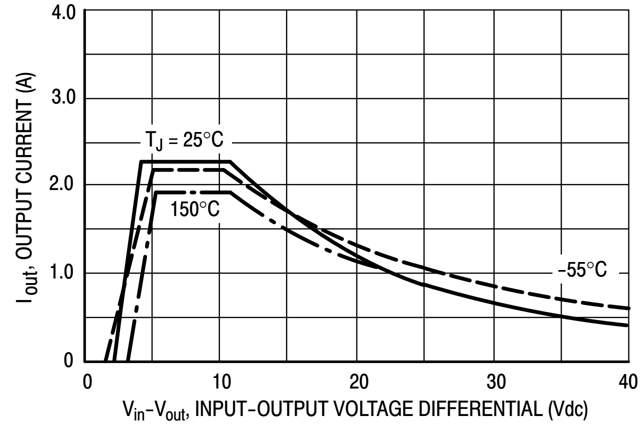


Figure 8. Current Limit

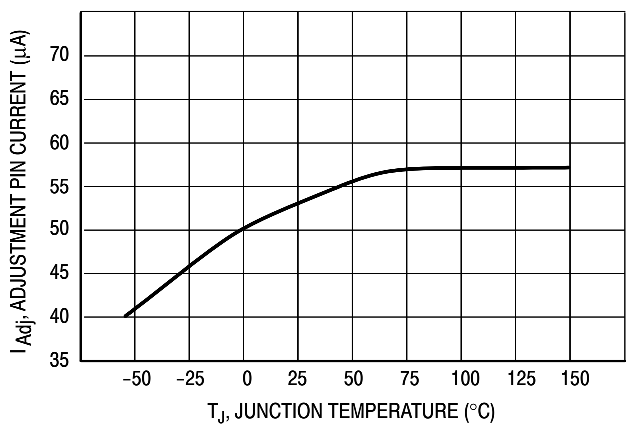


Figure 9. Adjustment Pin Current

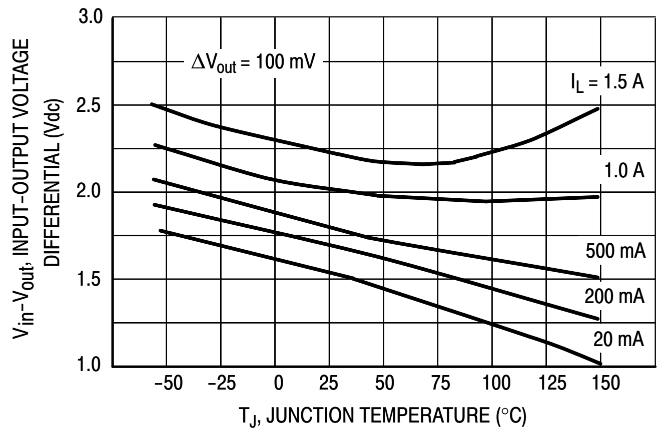


Figure 10. Dropout Voltage

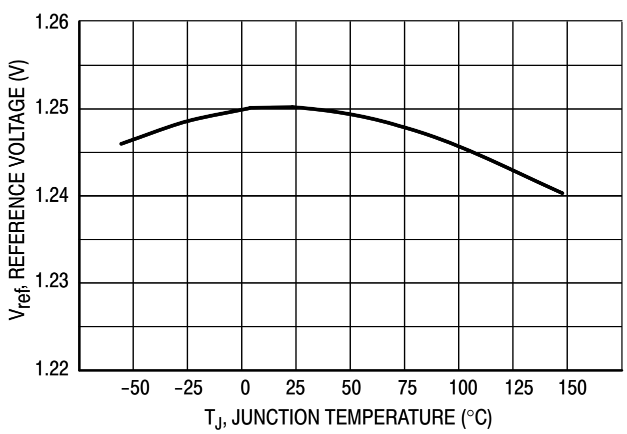


Figure 11. Temperature Stability

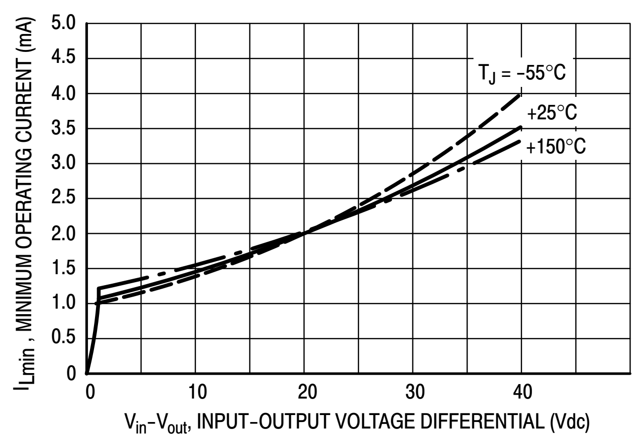


Figure 12. Minimum Operating Current

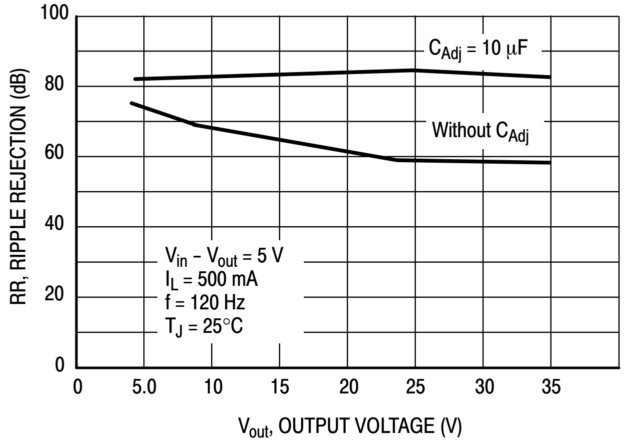


Figure 13. Ripple Rejection versus Output Voltage

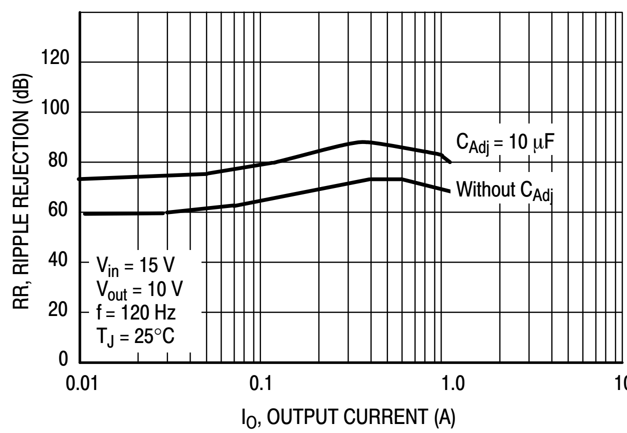


Figure 14. Ripple Rejection versus Output Current

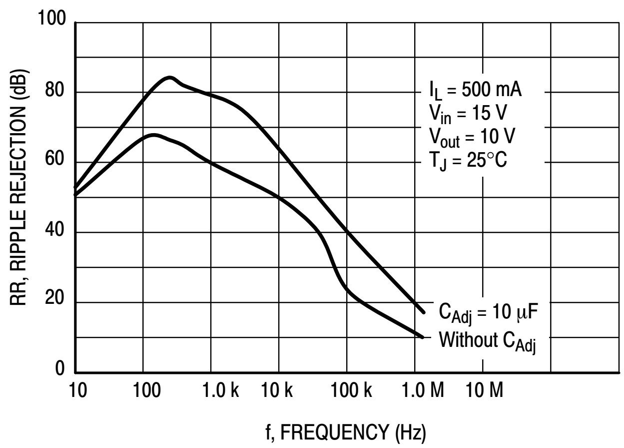


Figure 15. Ripple Rejection versus Frequency

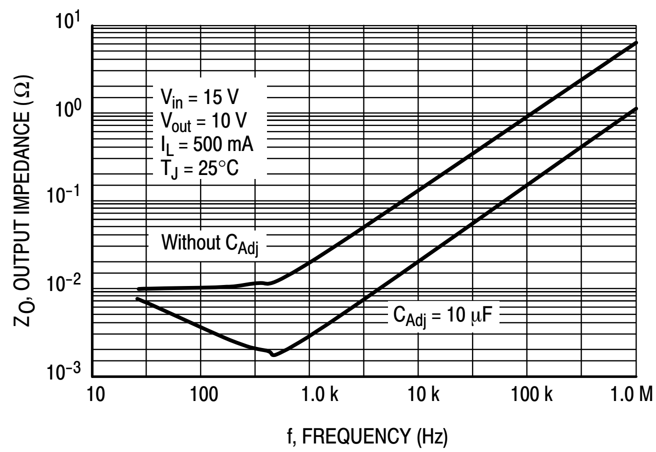


Figure 16. Output Impedance

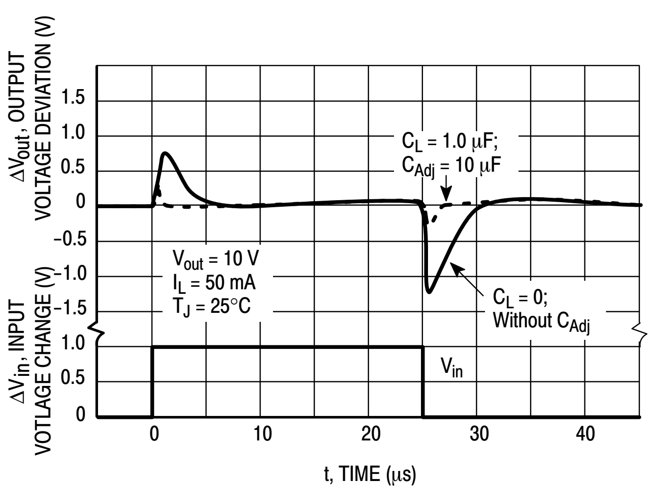


Figure 17. Line Transient Response

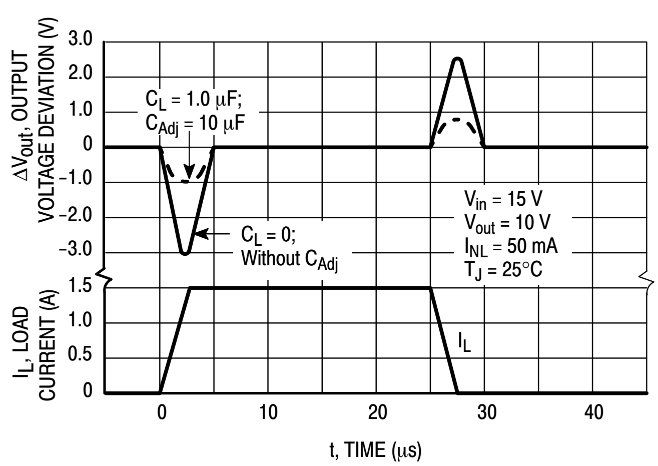


Figure 18. Load Transient Response

APPLICATIONS INFORMATION

Basic Circuit Operation

The LM317 is a 3−terminal floating regulator. In operation, the LM317 develops and maintains a nominal 1.25 V reference (V_{ref}) between its output and adjustment terminals. This reference voltage is converted to a programming current (I_{PROG}) by R_1 (see Figure 17), and this constant current flows through R_2 to ground.

The regulated output voltage is given by:

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{Adj} R_2$$

Since the current from the adjustment terminal (I_{Adj}) represents an error term in the equation, the LM317 was designed to control I_{Adj} to less than 100 μA and keep it constant. To do this, all quiescent operating current is returned to the output terminal. This imposes the requirement for a minimum load current. If the load current is less than this minimum, the output voltage will rise.

Since the LM317 is a floating regulator, it is only the voltage differential across the circuit which is important to performance, and operation at high voltages with respect to ground is possible.

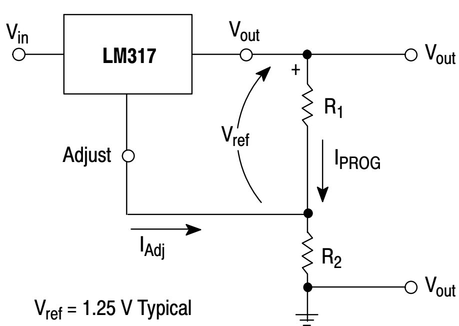


Figure 19. Basic Circuit Configuration

Load Regulation

The LM317 is capable of providing extremely good load regulation, but a few precautions are needed to obtain maximum performance. For best performance, the programming resistor (R_1) should be connected as close to the regulator as possible to minimize line drops which effectively appear in series with the reference, thereby degrading regulation. The ground end of R_2 can be returned near the load ground to provide remote ground sensing and improve load regulation.

External Capacitors

A 0.1 μF disc or 1.0 μF tantalum input bypass capacitor (C_{in}) is recommended to reduce the sensitivity to input line impedance.

The adjustment terminal may be bypassed to ground to improve ripple rejection. This capacitor (C_{Adj}) prevents ripple from being amplified as the output voltage is increased. A 10 μF capacitor should improve ripple rejection about 15 dB at 120 Hz in a 10 V application.

Although the LM317 is stable with no output capacitance, like any feedback circuit, certain values of external capacitance can cause excessive ringing. An output capacitance (C_O) in the form of a 1.0 μF tantalum or 25 μF aluminum electrolytic capacitor on the output swamps this effect and insures stability.

Protection Diodes

When external capacitors are used with any IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator.

Figure 18 shows the LM317 with the recommended protection diodes for output voltages in excess of 25 V or high capacitance values (C_O > 25 μF, C_{Adj} > 10 μF). Diode D_1 prevents C_O from discharging thru the IC during an input short circuit. Diode D_2 protects against capacitor C_{Adj} discharging through the IC during an output short circuit. The combination of diodes D_1 and D_2 prevents C_{Adj} from discharging through the IC during an input short circuit.

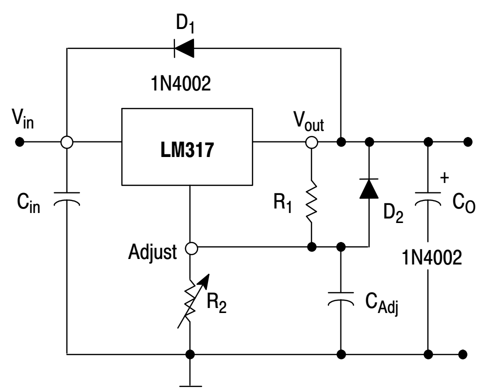


Figure 20. Voltage Regulator with Protection Diodes

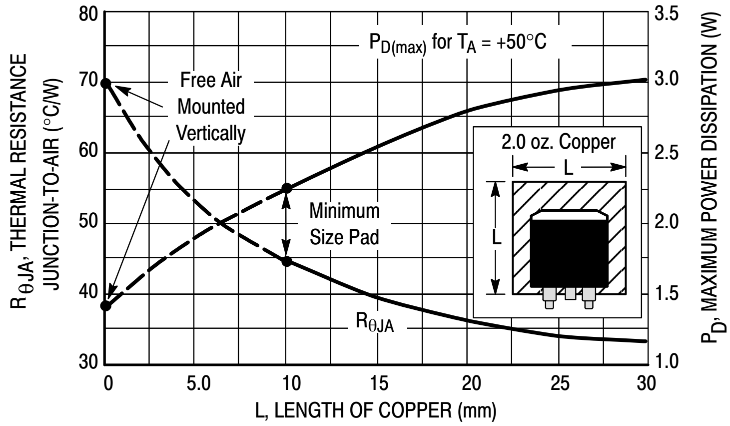


Figure 21. D²PAK Thermal Resistance and Maximum Power Dissipation versus P.C.B. Copper Length

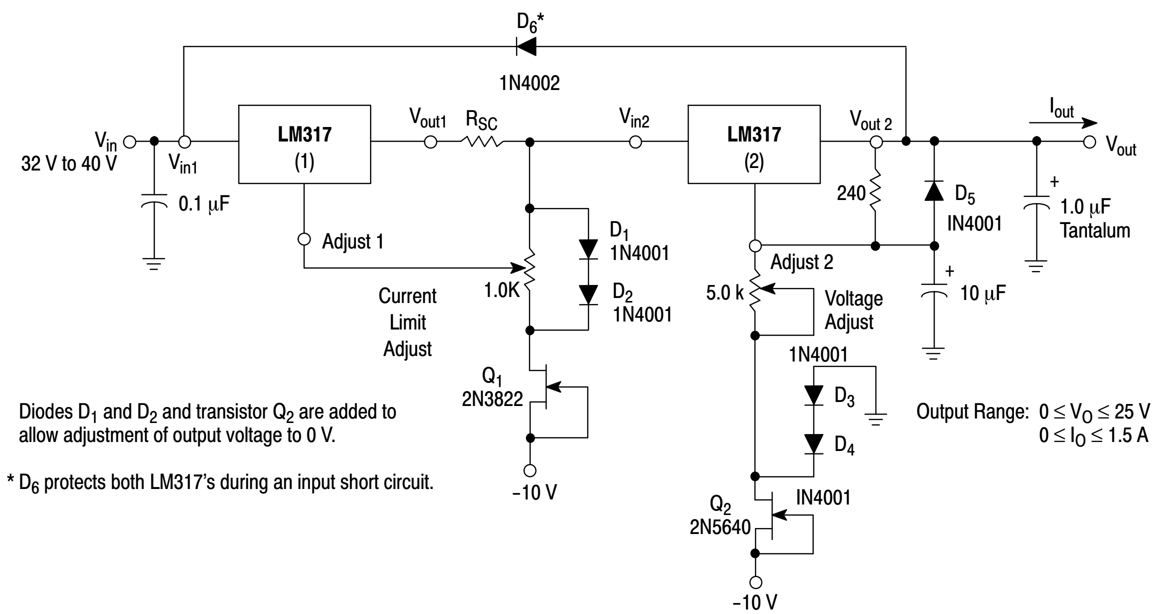


Figure 22. "Laboratory" Power Supply with Adjustable Current Limit and Output Voltage

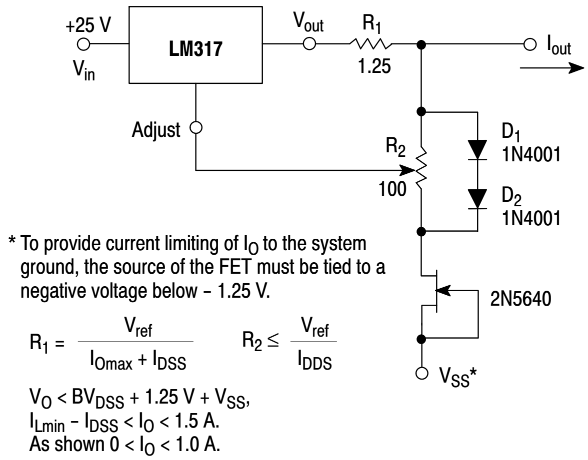


Figure 23. Adjustable Current Limiter

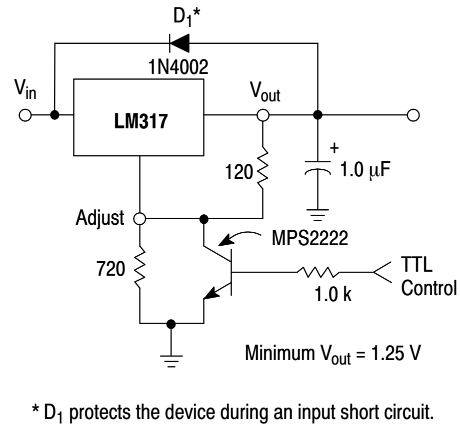


Figure 24. 5.0 V Electronic Shutdown Regulator

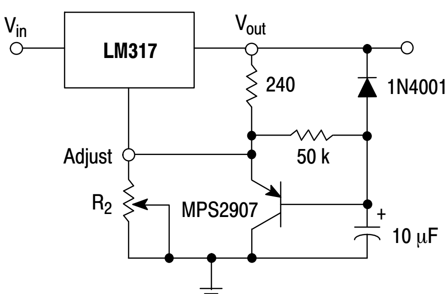


Figure 25. Slow Turn−On Regulator

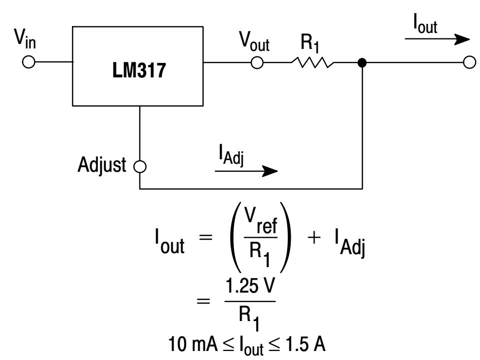


Figure 26. Current Regulator

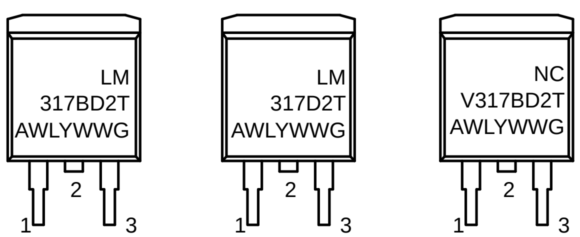
ORDERING INFORMATION

Device	Operating Temperature Range	Package	Shipping†
LM317BD2TG	T_J = −40° to +125°C	D^2PAK−3 (Pb−Free)	50 Units / Rail
LM317BD2TR4G		D^2PAK−3 (Pb−Free)	800 Tape & Reel
LM317BTG		TO−220 (Pb−Free)	50 Units / Rail
LM317D2TG	T_J = 0° to +125°C	D^2PAK−3 (Pb−Free)	50 Units / Rail
LM317D2TR4G		D^2PAK−3 (Pb−Free)	800 Tape & Reel
LM317TG		TO−220 (Pb−Free)	50 Units / Rail
NCV317BD2TG*	T_J = −55° to +150°C	D^2PAK−3 (Pb−Free)	50 Units / Rail
NCV317BD2TR4G*		D^2PAK−3 (Pb−Free)	800 Tape & Reel
NCV317BTG*		TO−220 (Pb−Free)	50 Units / Rail

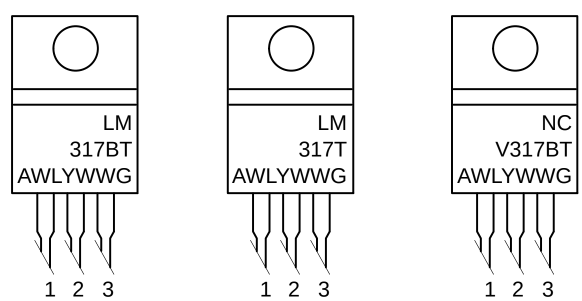
†For information on tape and reel specifications, including part orientation and tape sizes, please refer to our Tape and Reel Packaging Specifications Brochure, BRD8011/D.
*NCV Prefix for Automotive and Other Applications Requiring Unique Site and Control Change Requirements; AEC−Q100 Qualified and PPAP Capable.

MARKING DIAGRAMS

D^2PAK−3
D2T SUFFIX
CASE 936



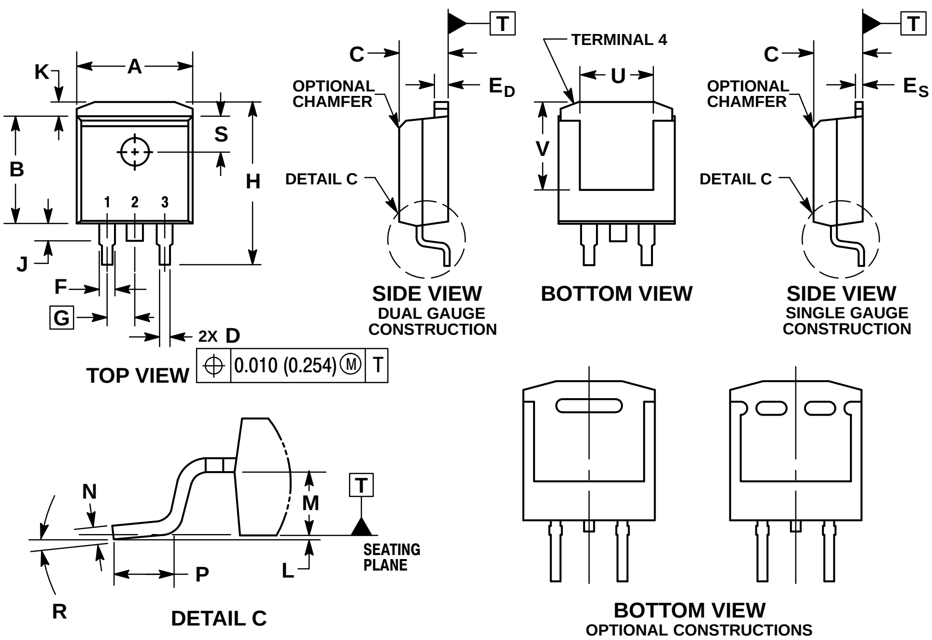
TO−220
T SUFFIX
CASE 221A



A = Assembly Location
WL = Wafer Lot
Y = Year
WW = Work Week
G = Pb−Free Package

PACKAGE DIMENSIONS

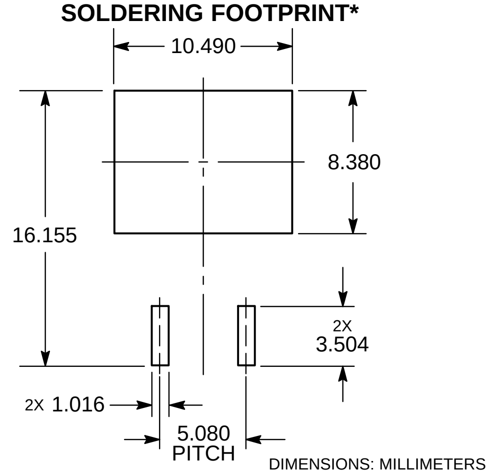
D2PAK−3
D2T SUFFIX
CASE 936−03
ISSUE E



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCHES.
3. TAB CONTOUR OPTIONAL WITHIN DIMENSIONS A AND K.
4. DIMENSIONS U AND V ESTABLISH A MINIMUM MOUNTING SURFACE FOR TERMINAL 4.
5. DIMENSIONS A AND B DO NOT INCLUDE MOLD FLASH OR GATE PROTRUSIONS. MOLD FLASH AND GATE PROTRUSIONS NOT TO EXCEED 0.025 (0.635) MAXIMUM.
6. SINGLE GAUGE DESIGN WILL BE SHIPPED AFTER FPCN EXPIRATION IN OCTOBER 2011.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.386	0.403	9.804	10.236
B	0.356	0.368	9.042	9.347
C	0.170	0.180	4.318	4.572
D	0.026	0.036	0.660	0.914
E_D	0.045	0.055	1.143	1.397
E_S	0.018	0.026	0.457	0.660
F	0.051 REF		1.295 REF	
G	0.100 BSC		2.540 BSC	
H	0.539	0.579	13.691	14.707
J	0.125 MAX		3.175 MAX	
K	0.050 REF		1.270 REF	
L	0.000	0.010	0.000	0.254
M	0.088	0.102	2.235	2.591
N	0.018	0.026	0.457	0.660
P	0.058	0.078	1.473	1.981
R	0°	8°	0°	8°
S	0.116 REF		2.946 REF	
U	0.200 MIN		5.080 MIN	
V	0.250 MIN		6.350 MIN	

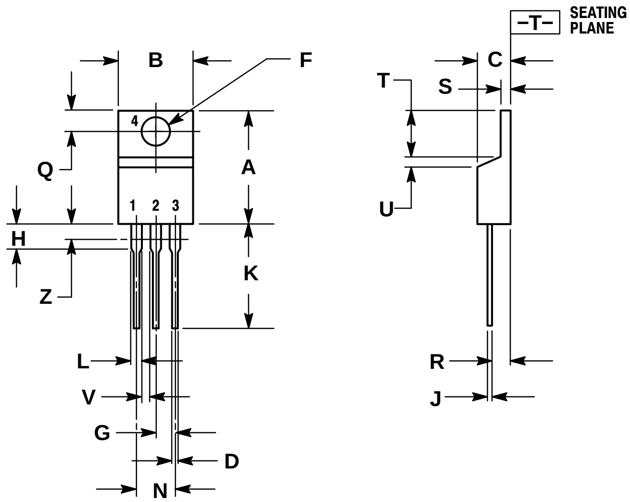
SOLDERING FOOTPRINT*



*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

PACKAGE DIMENSIONS

TO−220, SINGLE GAUGE
T SUFFIX
CASE 221AB
ISSUE A



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCHES.
3. DIMENSION Z DEFINES A ZONE WHERE ALL BODY AND LEAD IRREGULARITIES ARE ALLOWED.
4. PRODUCT SHIPPED PRIOR TO 2008 HAD DIMENSIONS S = 0.045 − 0.055 INCHES (1.143 − 1.397 MM)

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.570	0.620	14.48	15.75
B	0.380	0.405	9.66	10.28
C	0.160	0.190	4.07	4.82
D	0.025	0.035	0.64	0.88
F	0.142	0.147	3.61	3.73
G	0.095	0.105	2.42	2.66
H	0.110	0.155	2.80	3.93
J	0.018	0.025	0.46	0.64
K	0.500	0.562	12.70	14.27
L	0.045	0.060	1.15	1.52
N	0.190	0.210	4.83	5.33
Q	0.100	0.120	2.54	3.04
R	0.080	0.110	2.04	2.79
S	0.020	0.024	0.508	0.61
T	0.235	0.255	5.97	6.47
U	0.000	0.050	0.00	1.27
V	0.045	---	1.15	---
Z	---	0.080	---	2.04

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
P.O. Box 5163, Denver, Colorado 80217 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5817−1050

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative

National Semiconductor

October 2005

LM158/LM258/LM358/LM2904
Low Power Dual Operational Amplifiers

General Description

The LM158 series consists of two independent, high gain, internally frequency compensated operational amplifiers which were designed specifically to operate from a single power supply over a wide range of voltages. Operation from split power supplies is also possible and the low power supply current drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, dc gain blocks and all the conventional op amp circuits which now can be more easily implemented in single power supply systems. For example, the LM158 series can be directly operated off of the standard +5V power supply voltage which is used in digital systems and will easily provide the required interface electronics without requiring the additional ±15V power supplies.

The LM358 and LM2904 are available in a chip sized package (8-Bump micro SMD) using National's micro SMD package technology.

Unique Characteristics

- In the linear mode the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.
- The unity gain cross frequency is temperature compensated.
- The input bias current is also temperature compensated.

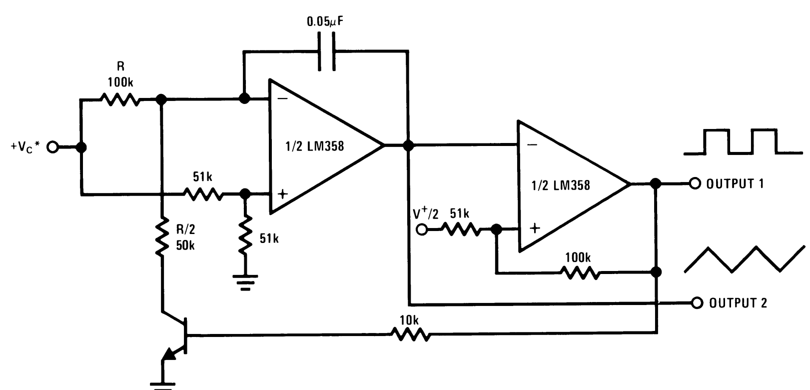
Advantages

- Two internally compensated op amps
- Eliminates need for dual supplies
- Allows direct sensing near GND and V_{OUT} also goes to GND
- Compatible with all forms of logic
- Power drain suitable for battery operation

Features

- Available in 8-Bump micro SMD chip sized package, (See AN-1112)
- Internally frequency compensated for unity gain
- Large dc voltage gain: 100 dB
- Wide bandwidth (unity gain): 1 MHz (temperature compensated)
- Wide power supply range:
  — Single supply: 3V to 32V
  — or dual supplies: ±1.5V to ±16V
- Very low supply current drain (500 µA) — essentially independent of supply voltage
- Low input offset voltage: 2 mV
- Input common-mode voltage range includes ground
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing

Voltage Controlled Oscillator (VCO)



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Absolute Maximum Ratings (Note 9)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

	LM158/LM258/LM358 LM158A/LM258A/LM358A	LM2904
Supply Voltage, V^+	32V	26V
Differential Input Voltage	32V	26V
Input Voltage	−0.3V to +32V	−0.3V to +26V
Power Dissipation (Note 1)		
Molded DIP	830 mW	830 mW
Metal Can	550 mW	
Small Outline Package (M)	530 mW	530 mW
micro SMD	435mW	
Output Short-Circuit to GND		
(One Amplifier) (Note 2)		
$V^+ \leq 15V$ and $T_A = 25°C$	Continuous	Continuous
Input Current ($V_{IN} < -0.3V$) (Note 3)	50 mA	50 mA
Operating Temperature Range		
LM358	0˚C to +70˚C	−40˚C to +85˚C
LM258	−25˚C to +85˚C	
LM158	−55˚C to +125˚C	
Storage Temperature Range	−65˚C to +150˚C	−65˚C to +150˚C
Lead Temperature, DIP		
(Soldering, 10 seconds)	260˚C	260˚C
Lead Temperature, Metal Can		
(Soldering, 10 seconds)	300˚C	300˚C
Soldering Information		
Dual-In-Line Package		
Soldering (10 seconds)	260˚C	260˚C
Small Outline Package		
Vapor Phase (60 seconds)	215˚C	215˚C
Infrared (15 seconds)	220˚C	220˚C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

ESD Tolerance (Note 10)	250V	250V

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM158A			LM358A			LM158/LM258			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 5), $T_A = 25°C$		1	2		2	3		2	5	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25°C$, $V_{CM} = 0V$, (Note 6)		20	50		45	100		45	150	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25°C$		2	10		5	30		3	30	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 7) (LM2904, $V^+ = 26V$), $T_A = 25°C$	0		$V^+-1.5$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps										
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2		0.5	1.2	mA

Electrical Characteristics

$V^+ = +5.0V$, unless otherwise stated

Parameter	Conditions	LM358			LM2904			Units
		Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	(Note 5) , $T_A = 25^\circ C$		2	7		2	7	mV
Input Bias Current	$I_{IN(+)}$ or $I_{IN(-)}$, $T_A = 25^\circ C$, $V_{CM} = 0V$, (Note 6)		45	250		45	250	nA
Input Offset Current	$I_{IN(+)} - I_{IN(-)}$, $V_{CM} = 0V$, $T_A = 25^\circ C$		5	50		5	50	nA
Input Common-Mode Voltage Range	$V^+ = 30V$, (Note 7) (LM2904, $V^+ = 26V$), $T_A = 25^\circ C$	0		$V^+-1.5$	0		$V^+-1.5$	V
Supply Current	Over Full Temperature Range $R_L = \infty$ on All Op Amps							
	$V^+ = 30V$ (LM2904 $V^+ = 26V$)		1	2		1	2	mA
	$V^+ = 5V$		0.5	1.2		0.5	1.2	mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions	LM158A			LM358A			LM158/LM258			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25^\circ C$, $R_L \geq 2\ k\Omega$, (For $V_O = 1V$ to 11V)	50	100		25	100		50	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25^\circ C$, $V_{CM} = 0V$ to $V^+-1.5V$	70	85		65	85		70	85		dB
Power Supply Rejection Ratio		$V^+ = 5V$ to 30V (LM2904, $V^+ = 5V$ to 26V), $T_A = 25^\circ C$	65	100		65	100		65	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25^\circ C$ (Input Referred), (Note 8)		−120			−120			−120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25^\circ C$	20	40		20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25^\circ C$, $V_O = 2V$	10	20		10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25^\circ C$, $V_O = 200\ mV$, $V^+ = 15V$	12	50		12	50		12	50		μA
Short Circuit to Ground		$T_A = 25^\circ C$, (Note 2), $V^+ = 15V$		40	60		40	60		40	60	mA
Input Offset Voltage		(Note 5)			4			5			7	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7	15		7	20		7		μV/˚C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			30			75			100	nA
Input Offset Current Drift		$R_S = 0\Omega$		10	200		10	300		10		pA/˚C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	100		40	200		40	300	nA
Input Common-Mode Voltage Range		$V^+ = 30\ V$, (Note 7) (LM2904, $V^+ = 26V$)	0		V^+-2	0		V^+-2	0		V^+-2	V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions		LM158A			LM358A			LM158/LM258			Units
				Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = +15V$ (V_O = 1V to 11V) $R_L \geq 2\ k\Omega$		25			15			25			V/mV
Output Voltage Swing	V_{OH}	$V^+ = +30V$ (LM2904, $V^+ = 26V$)	$R_L = 2\ k\Omega$	26			26			26			V
			$R_L = 10\ k\Omega$	27	28		27	28		27	28		V
	V_{OL}	$V^+ = 5V$, $R_L = 10\ k\Omega$			5	20		5	20		5	20	mV
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$		10	20		10	20		10	20		mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$		10	15		5	8		5	8		mA

Electrical Characteristics

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions	LM358			LM2904			Units
			Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain		$V^+ = 15V$, $T_A = 25°C$, $R_L \geq 2\ k\Omega$, (For V_O = 1V to 11V)	25	100		25	100		V/mV
Common-Mode Rejection Ratio		$T_A = 25°C$, V_{CM} = 0V to V^+–1.5V	65	85		50	70		dB
Power Supply Rejection Ratio		V^+ = 5V to 30V (LM2904, V^+ = 5V to 26V), $T_A = 25°C$	65	100		50	100		dB
Amplifier-to-Amplifier Coupling		f = 1 kHz to 20 kHz, $T_A = 25°C$ (Input Referred), (Note 8)		–120			–120		dB
Output Current	Source	$V_{IN}^+ = 1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$, $T_A = 25°C$	20	40		20	40		mA
	Sink	$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $V^+ = 15V$, $T_A = 25°C$, $V_O = 2V$	10	20		10	20		mA
		$V_{IN}^- = 1V$, $V_{IN}^+ = 0V$ $T_A = 25°C$, $V_O = 200\ mV$, $V^+ = 15V$	12	50		12	50		μA
Short Circuit to Ground		$T_A = 25°C$, (Note 2), $V^+ = 15V$		40	60		40	60	mA
Input Offset Voltage		(Note 5)			9			10	mV
Input Offset Voltage Drift		$R_S = 0\Omega$		7			7		μV/˚C
Input Offset Current		$I_{IN(+)} - I_{IN(-)}$			150		45	200	nA
Input Offset Current Drift		$R_S = 0\Omega$		10			10		pA/˚C
Input Bias Current		$I_{IN(+)}$ or $I_{IN(-)}$		40	500		40	500	nA
Input Common-Mode Voltage Range		$V^+ = 30\ V$, (Note 7) (LM2904, $V^+ = 26V$)	0		V^+–2	0		V^+ –2	V

Electrical Characteristics (Continued)

$V^+ = +5.0V$, (Note 4), unless otherwise stated

Parameter		Conditions		LM358 Min	LM358 Typ	LM358 Max	LM2904 Min	LM2904 Typ	LM2904 Max	Units
Large Signal Voltage Gain		$V^+ = +15V$ (V_O = 1V to 11V) $R_L \geq 2$ kΩ		15			15			V/mV
Output Voltage Swing	V_{OH}	$V^+ = +30V$ (LM2904, $V^+ = 26V$)	R_L = 2 kΩ	26			22			V
			R_L = 10 kΩ	27	28		23	24		V
	V_{OL}	$V^+ = 5V$, R_L = 10 kΩ			5	20		5	100	mV
Output Current	Source	$V_{IN}^+ = +1V$, $V_{IN}^- = 0V$, $V^+ = 15V$, $V_O = 2V$		10	20		10	20		mA
	Sink	$V_{IN}^- = +1V$, $V_{IN}^+ = 0V$, $V^+ = 15V$, $V_O = 2V$		5	8		5	8		mA

Note 1: For operating at high temperatures, the LM358/LM358A, LM2904 must be derated based on a +125˚C maximum junction temperature and a thermal resistance of 120˚C/W for MDIP, 182˚C/W for Metal Can, 189˚C/W for Small Outline package, and 230˚C/W for micro SMD, which applies for the device soldered in a printed circuit board, operating in a still air ambient. The LM258/LM258A and LM158/LM158A can be derated based on a +150˚C maximum junction temperature. The dissipation is the total of both amplifiers — use external resistors, where possible, to allow the amplifier to saturate or to reduce the power which is dissipated in the integrated circuit.

Note 2: Short circuits from the output to V^+ can cause excessive heating and eventual destruction. When considering short circucits to ground, the maximum output current is approximately 40 mA independent of the magnitude of V^+. At values of supply voltage in excess of +15V, continuous short-circuits can exceed the power dissipation ratings and cause eventual destruction. Destructive dissipation can result from simultaneous shorts on all amplifiers.

Note 3: This input current will only exist when the voltage at any of the input leads is driven negative. It is due to the collector-base junction of the input PNP transistors becoming forward biased and thereby acting as input diode clamps. In addition to this diode action, there is also lateral NPN parasitic transistor action on the IC chip. This transistor action can cause the output voltages of the op amps to go to the V^+voltage level (or to ground for a large overdrive) for the time duration that an input is driven negative. This is not destructive and normal output states will re-establish when the input voltage, which was negative, again returns to a value greater than −0.3V (at 25˚C).

Note 4: These specifications are limited to −55˚C ≤ T_A ≤ +125˚C for the LM158/LM158A. With the LM258/LM258A, all temperature specifications are limited to −25˚C ≤ T_A ≤ +85˚C, the LM358/LM358A temperature specifications are limited to 0˚C ≤ T_A ≤ +70˚C, and the LM2904 specifications are limited to −40˚C ≤ T_A ≤ +85˚C.

Note 5: $V_O \simeq 1.4V$, $R_S = 0\Omega$ with V^+ from 5V to 30V; and over the full input common-mode range (0V to V^+ −1.5V) at 25˚C. For LM2904, V^+ from 5V to 26V.

Note 6: The direction of the input current is out of the IC due to the PNP input stage. This current is essentially constant, independent of the state of the output so no loading change exists on the input lines.

Note 7: The input common-mode voltage of either input signal voltage should not be allowed to go negative by more than 0.3V (at 25˚C). The upper end of the common-mode voltage range is V^+ −1.5V (at 25˚C), but either or both inputs can go to +32V without damage (+26V for LM2904), independent of the magnitude of V^+.

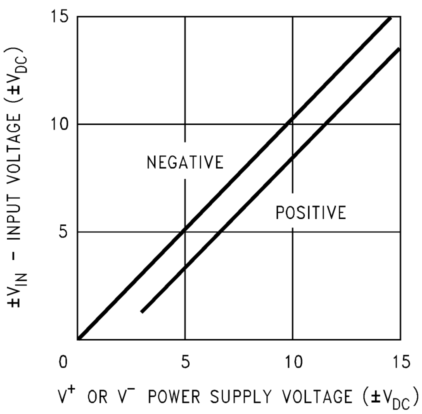
Note 8: Due to proximity of external components, insure that coupling is not originating via stray capacitance between these external parts. This typically can be detected as this type of capacitance increases at higher frequencies.

Note 9: Refer to RETS158AX for LM158A military specifications and to RETS158X for LM158 military specifications.

Note 10: Human body model, 1.5 kΩ in series with 100 pF.

Typical Performance Characteristics

Input Voltage Range



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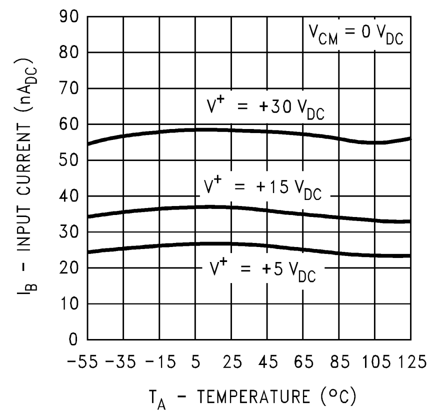
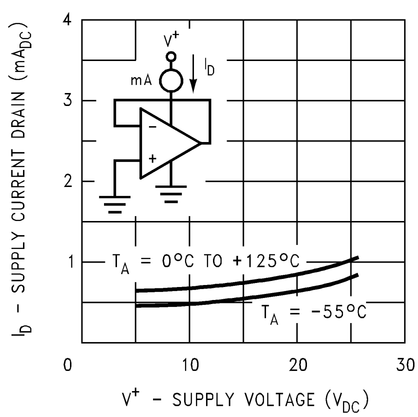
Input Current



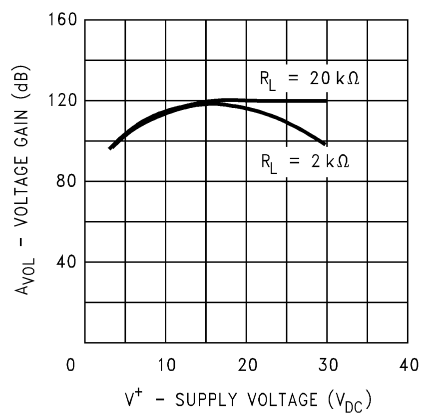
00778735

Supply Current



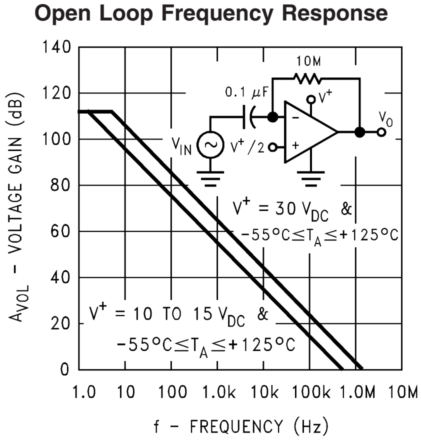
00778736

Voltage Gain



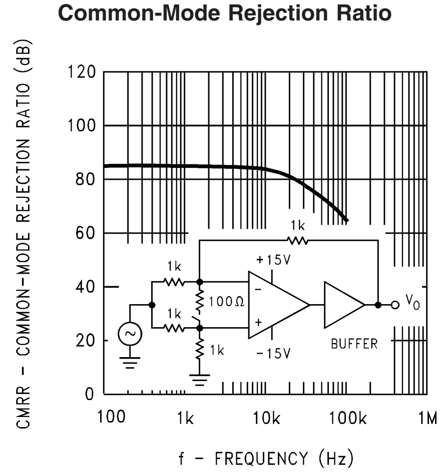
00778737

Open Loop Frequency Response



00778738

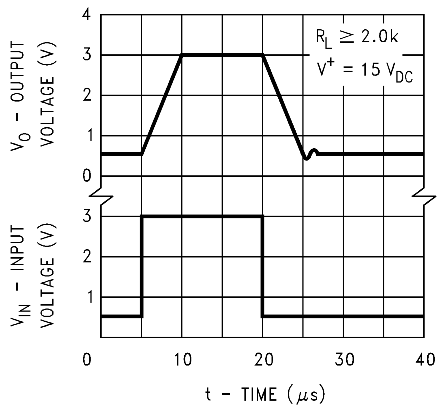
Common-Mode Rejection Ratio



00778739

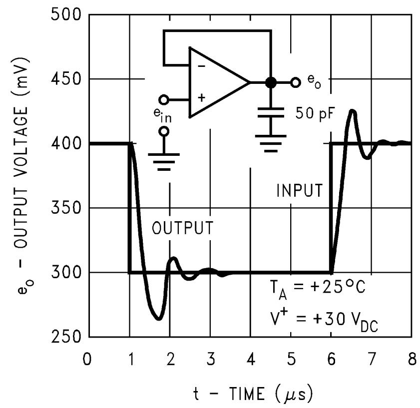
Typical Performance Characteristics (Continued)

Voltage Follower Pulse Response



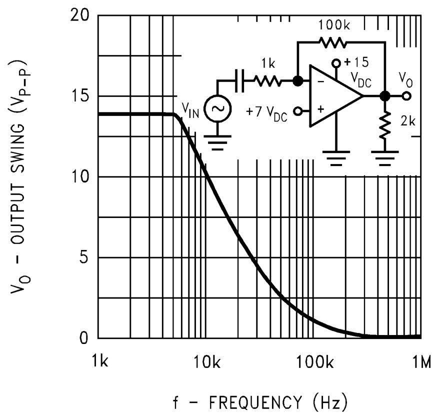
00778740

Voltage Follower Pulse Response (Small Signal)



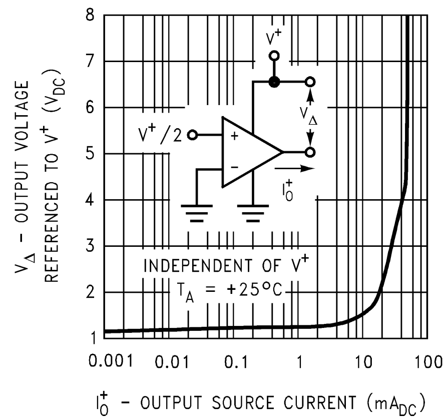
00778741

Large Signal Frequency Response



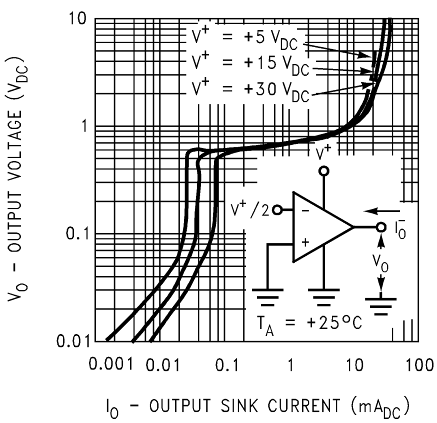
00778742

Output Characteristics Current Sourcing



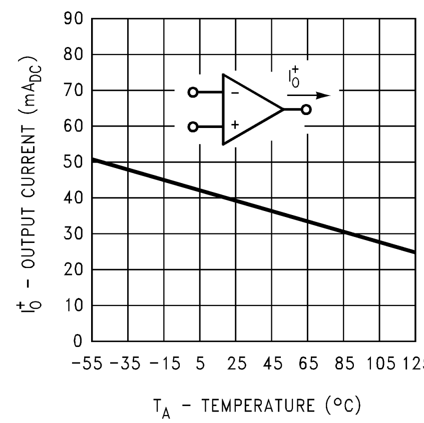
00778743

Output Characteristics Current Sinking



00778744

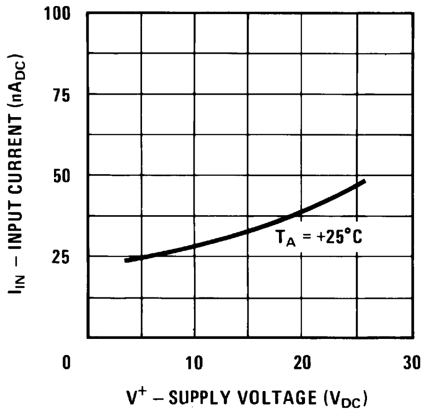
Current Limiting



00778745

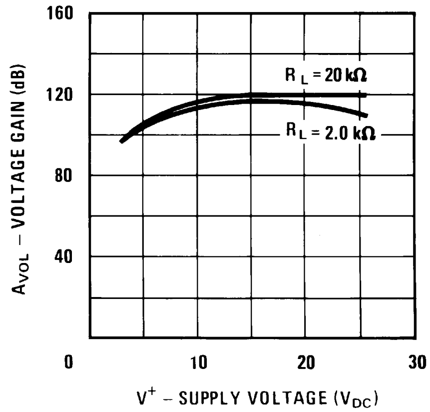
Typical Performance Characteristics (Continued)

Input Current (LM2902 only)



00778746

Voltage Gain (LM2902 only)



00778747

Application Hints

The LM158 series are op amps which operate with only a single power supply voltage, have true-differential inputs, and remain in the linear mode with an input common-mode voltage of 0 V_{DC}. These amplifiers operate over a wide range of power supply voltage with little change in performance characteristics. At 25˚C amplifier operation is possible down to a minimum supply voltage of 2.3 V_{DC}.

Precautions should be taken to insure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a test socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

Large differential input voltages can be easily accomodated and, as input differential voltage protection diodes are not needed, no large input currents result from large differential input voltages. The differential input voltage may be larger than V^+ without damaging the device. Protection should be provided to prevent the input voltages from going negative more than –0.3 V_{DC} (at 25˚C). An input clamp diode with a resistor to the IC input terminal can be used.

To reduce the power supply current drain, the amplifiers have a class A output stage for small signal levels which converts to class B in a large signal mode. This allows the amplifiers to both source and sink large output currents. Therefore both NPN and PNP external current boost transistors can be used to extend the power capability of the basic amplifiers. The output voltage needs to raise approximately 1 diode drop above ground to bias the on-chip vertical PNP transistor for output current sinking applications.

For ac applications, where the load is capacitively coupled to the output of the amplifier, a resistor should be used, from the output of the amplifier to ground to increase the class A bias current and prevent crossover distortion. Where the load is directly coupled, as in dc applications, there is no crossover distortion.

Capacitive loads which are applied directly to the output of the amplifier reduce the loop stability margin. Values of 50 pF can be accomodated using the worst-case non-inverting unity gain connection. Large closed loop gains or resistive isolation should be used if larger load capacitance must be driven by the amplifier.

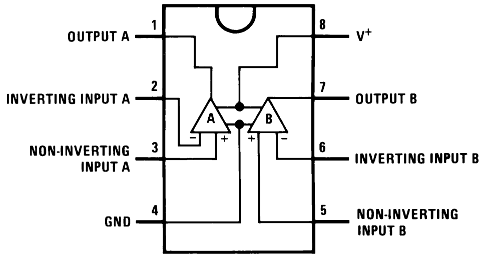
The bias network of the LM158 establishes a drain current which is independent of the magnitude of the power supply voltage over the range of 3 V_{DC} to 30 V_{DC}.

Output short circuits either to ground or to the positive power supply should be of short time duration. Units can be destroyed, not as a result of the short circuit current causing metal fusing, but rather due to the large increase in IC chip dissipation which will cause eventual failure due to excessive function temperatures. Putting direct short-circuits on more than one amplifier at a time will increase the total IC power dissipation to destructive levels, if not properly protected with external dissipation limiting resistors in series with the output leads of the amplifiers. The larger value of output source current which is available at 25˚C provides a larger output current capability at elevated temperatures (see typical performance characteristics) than a standard IC op amp.

The circuits presented in the section on typical applications emphasize operation on only a single power supply voltage. If complementary power supplies are available, all of the standard op amp circuits can be used. In general, introducing a pseudo-ground (a bias voltage reference of $V^+/2$) will allow operation above and below this value in single power supply systems. Many application circuits are shown which take advantage of the wide input common-mode voltage range which includes ground. In most cases, input biasing is not required and input voltages which range to ground can easily be accommodated.

Connection Diagrams

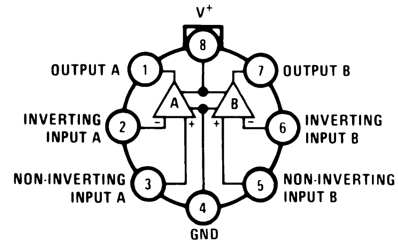
DIP/SO Package



00778702

Top View

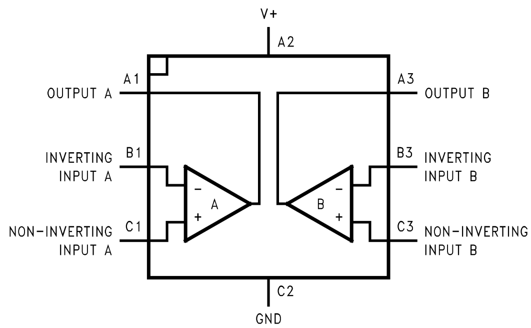
Metal Can Package



00778701

Top View

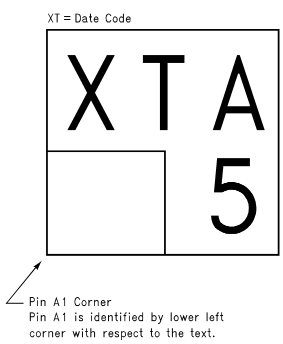
8-Bump micro SMD



00778755

Top View
(Bump Side Down)

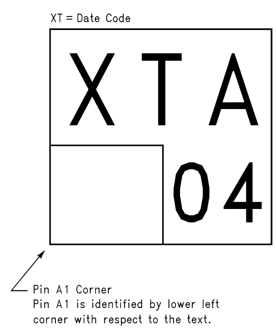
LM358BP micro SMD Marking Orientation



00778756

Top View

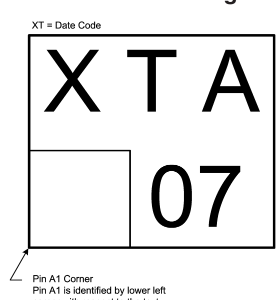
LM2904IBP micro SMD Marking Orientation



00778757

Top View

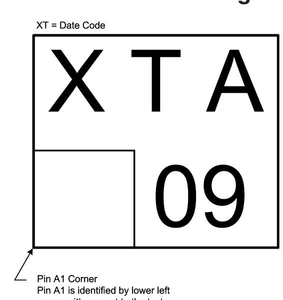
LM358TP micro SMD Marking Orientation



00778758

Top View

LM2904ITP micro SMD Marking Orientation



00778759

Top View

Ordering Information

Package	Temperature Range				NSC Drawing
	−55˚C to 125˚C	−25˚C to 85˚C	0˚C to 70˚C	−40˚C to 85˚C	
SO-8			LM358AM LM358AMX LM358M LM358MX	LM2904M LM2904MX	M08A
8-Pin Molded DIP			LM358AN LM358N	LM2904N	N08E
8-Pin Ceramic DIP	LM158AJ/883(Note 11) LM158J/883(Note 11) LM158J LM158AJLQML(Note 12) LM158AJQMLV(Note 12)				J08A
TO-5, 8-Pin Metal Can	LM158AH/883(Note 11) LM158H/883(Note 11) LM158AH LM158H LM158AHLQML(Note 12) LM158AHLQMLV(Note 12)	LM258H	LM358H		H08C
8-Bump micro SMD			LM358BP LM358BPX	LM2904IBP LM2904IBPX	BPA08AAB 0.85 mm Thick
8-Bump micro SMD Lead Free			LM358TP LM358TPX	LM2904ITP LM2904ITPX	TPA08AAA 0.50 mm Thick
14-Pin Ceramic SOIC	LM158AWG/883				WG10A

Note 11: LM158 is available per SMD #5962-8771001

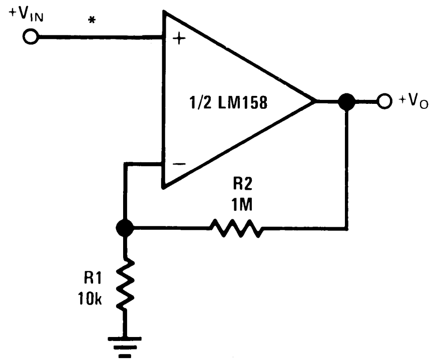
LM158A is available per SMD #5962-8771002

Note 12: See STD Mil DWG 5962L87710 for Radiation Tolerant Devices

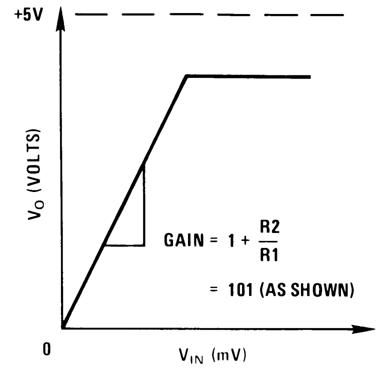
Typical Single-Supply Applications

($V^+ = 5.0\ V_{DC}$)

Non-Inverting DC Gain (0V Output)



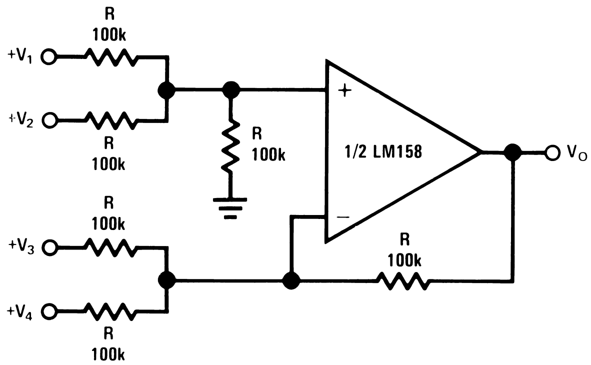
00778706



00778707

*R not needed due to temperature independent I_{IN}

DC Summing Amplifier ($V_{IN'S} \geq 0\ V_{DC}$ and $V_O \geq 0\ V_{DC}$)

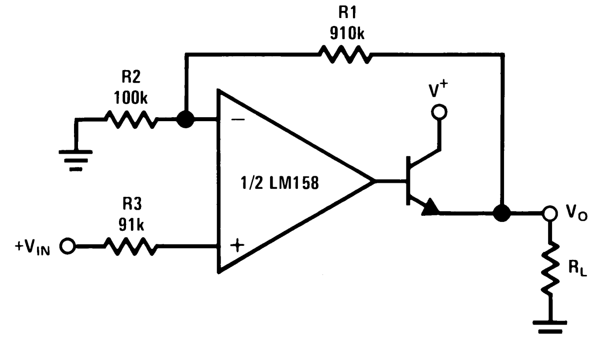


00778708

Where: $V_O = V_1 + V_2 - V_3 - V_4$

$(V_1 + V_2) \geq (V_3 + V_4)$ to keep $V_O > 0\ V_{DC}$

Power Amplifier



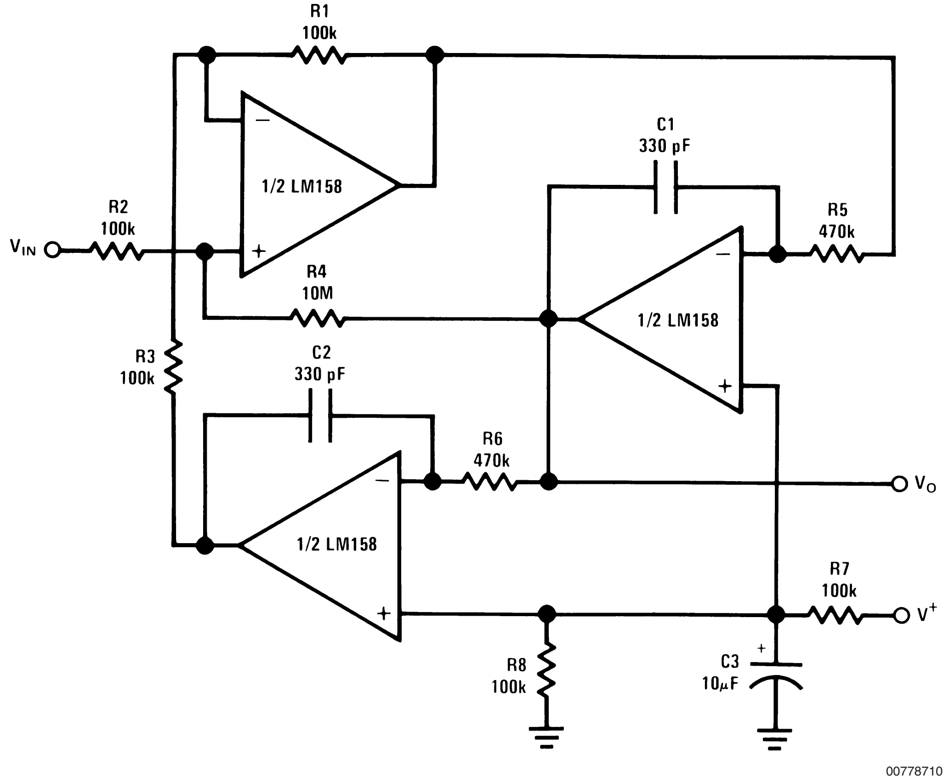
00778709

$V_O = 0\ V_{DC}$ for $V_{IN} = 0\ V_{DC}$

$A_V = 10$

Typical Single-Supply Applications (V^+ = 5.0 V_{DC}) (Continued)

"BI-QUAD" RC Active Bandpass Filter

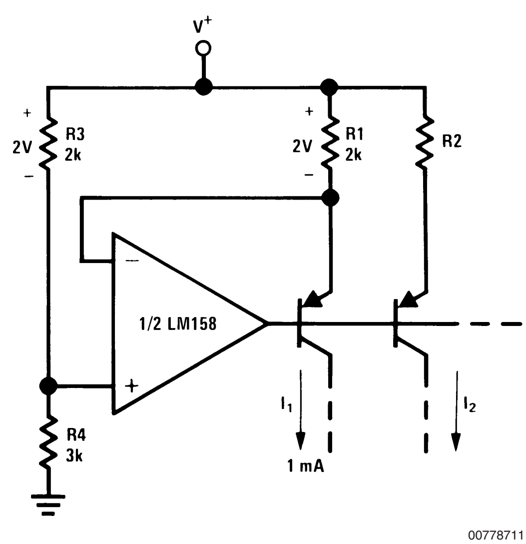


f_o = 1 kHz

Q = 50

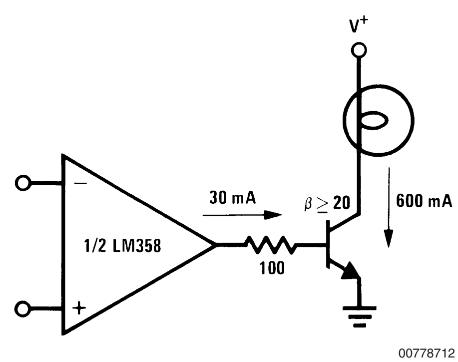
A_V = 100 (40 dB)

Fixed Current Sources



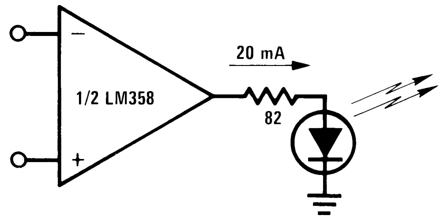
$$I_2 = \left(\frac{R1}{R2}\right) I_1$$

Lamp Driver



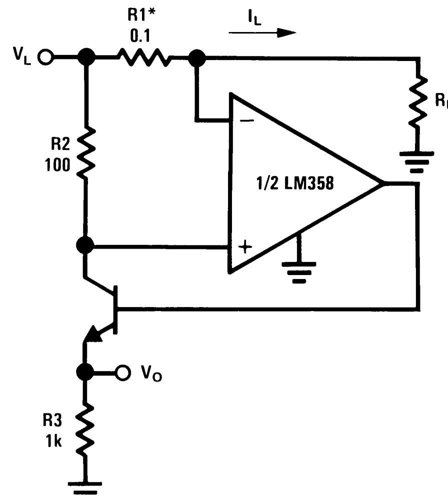
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

LED Driver



00778713

Current Monitor



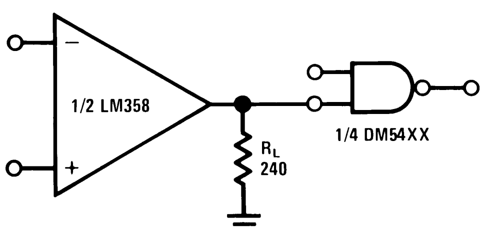
00778714

$$V_O = \frac{1V\,(I_L)}{1A}$$

*(Increase R1 for I_L small)

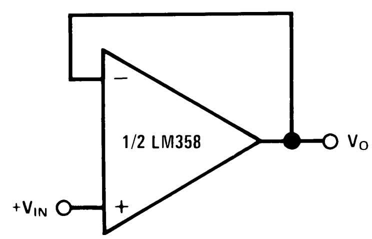
$V_L \leq V^+ - 2V$

Driving TTL



00778715

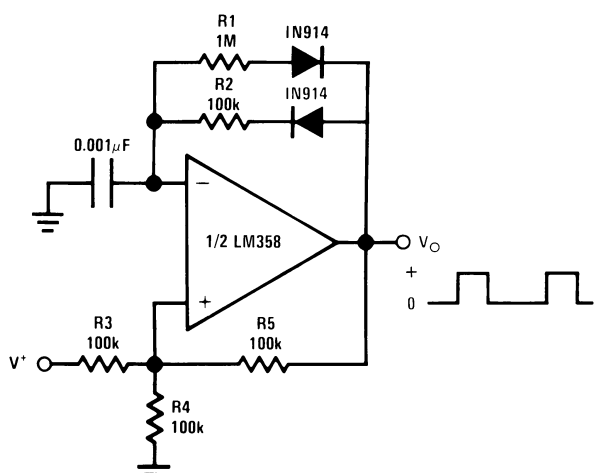
Voltage Follower



00778717

$V_O = V_{IN}$

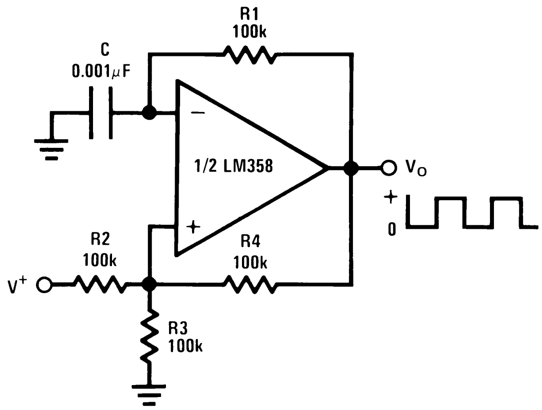
Pulse Generator



00778716

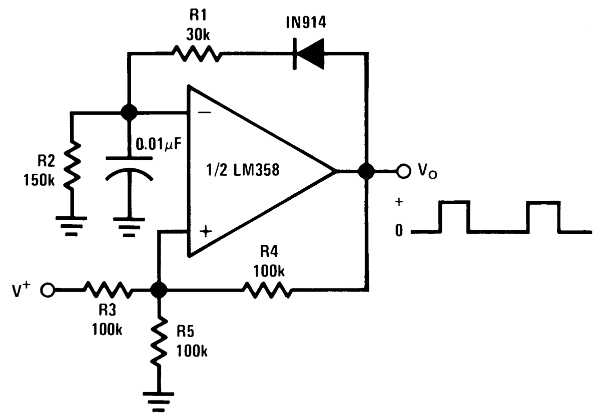
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Squarewave Oscillator



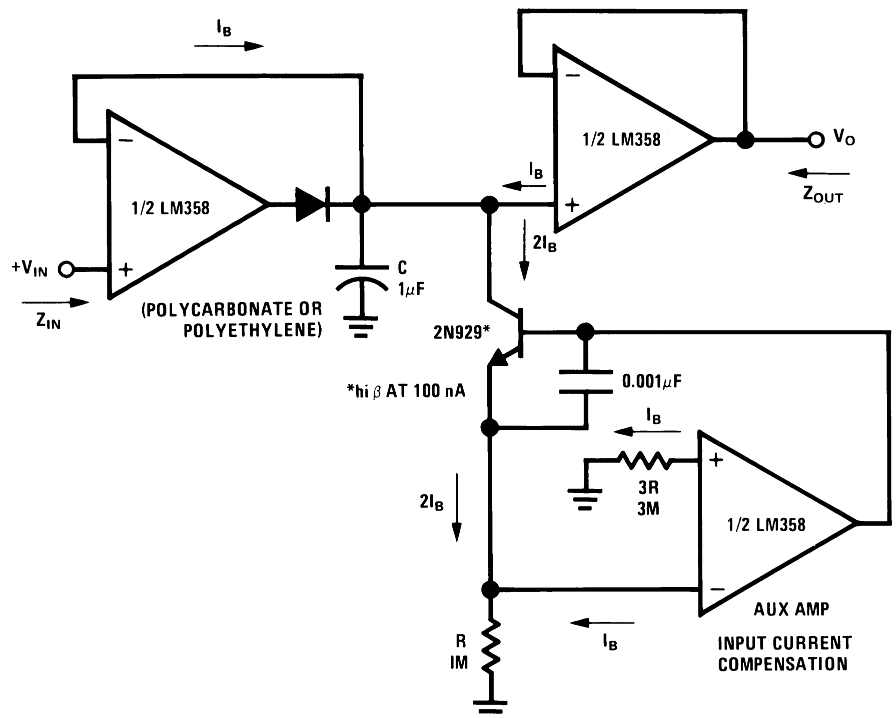
00778718

Pulse Generator



00778719

Low Drift Peak Detector

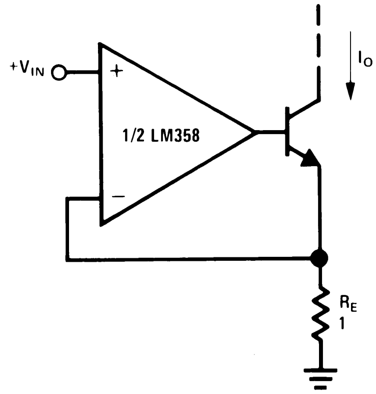


00778720

HIGH Z_{IN}
LOW Z_{OUT}

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

High Compliance Current Sink

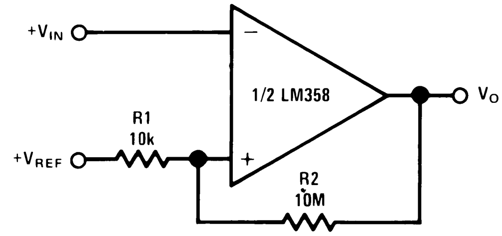


00778721

I_O = 1 amp/volt V_{IN}

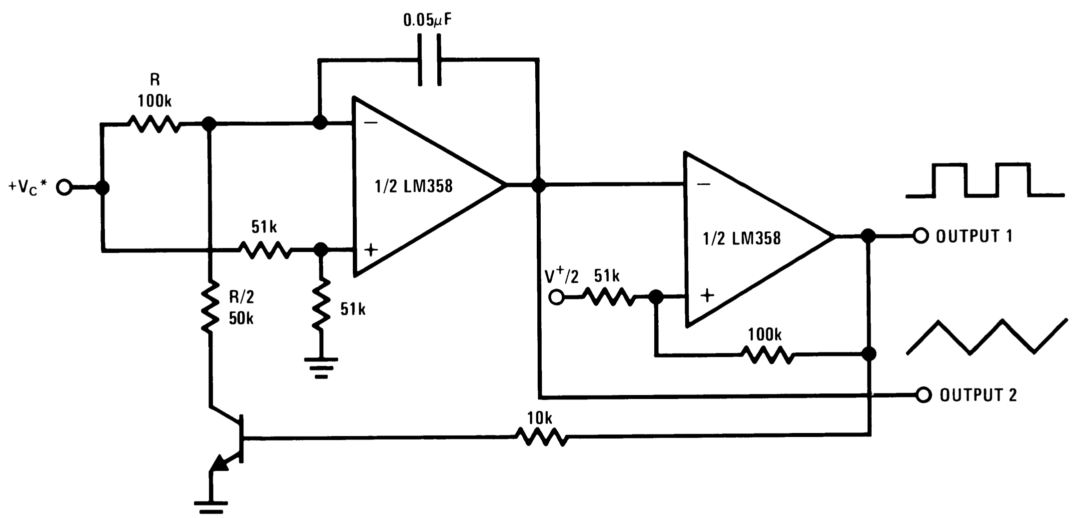
(Increase R_E for I_O small)

Comparator with Hysteresis



00778722

Voltage Controlled Oscillator (VCO)

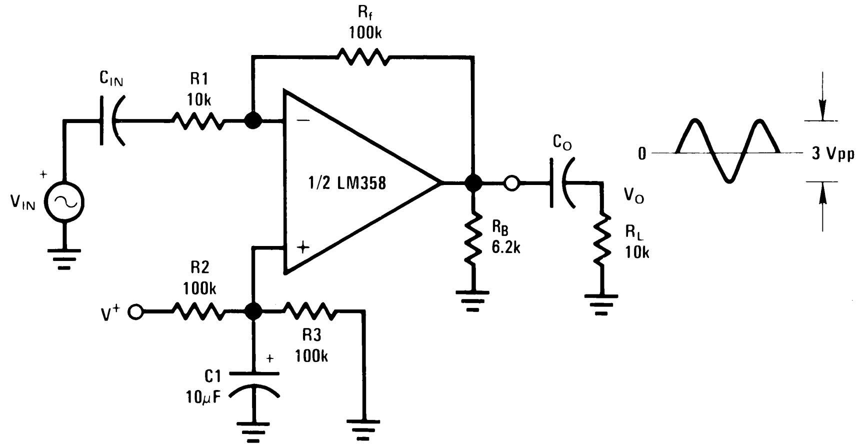


00778723

*WIDE CONTROL VOLTAGE RANGE: 0 $V_{DC} \leq V_C \leq 2\ (V^+ - 1.5V_{DC})$

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

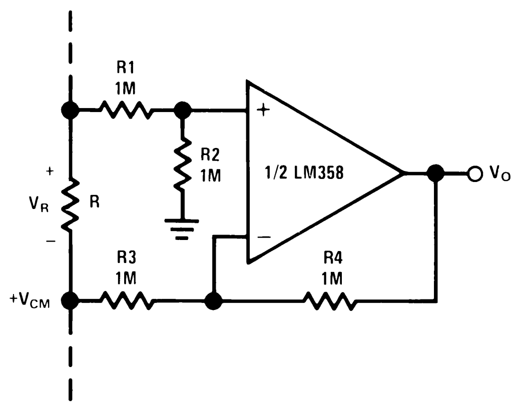
AC Coupled Inverting Amplifier



00778724

$$A_V = \frac{R_f}{R1} \quad \text{(As shown, } A_V = 10\text{)}$$

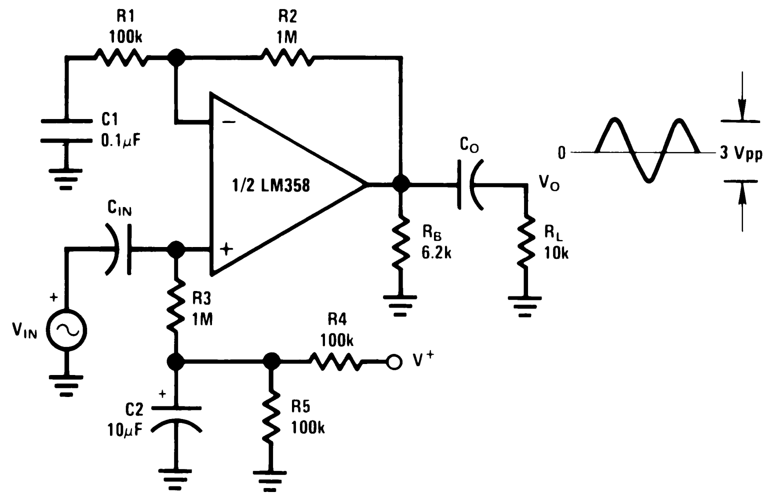
Ground Referencing a Differential Input Signal



00778725

Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

AC Coupled Non-Inverting Amplifier

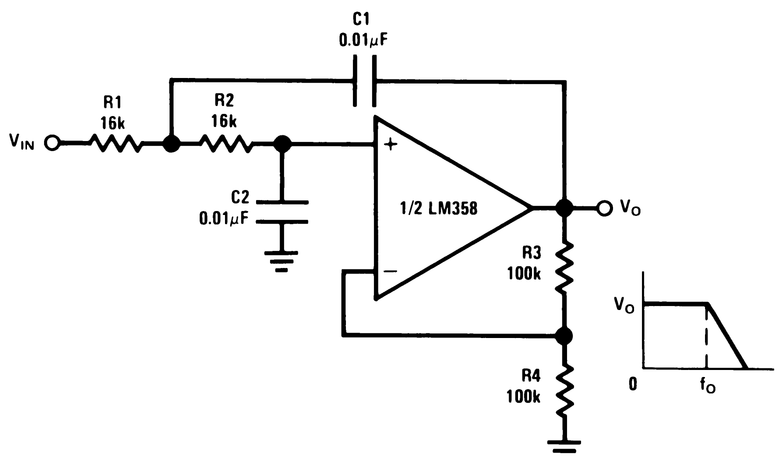


00778726

$$A_V = 1 + \frac{R2}{R1}$$

A_v = 11 (As Shown)

DC Coupled Low-Pass RC Active Filter



00778727

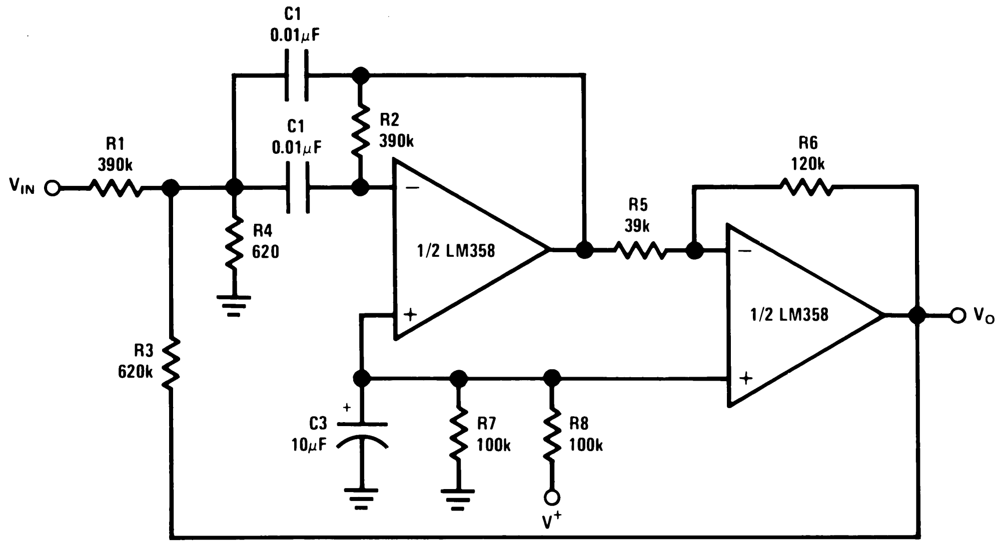
f_o = 1 kHz

Q = 1

A_V = 2

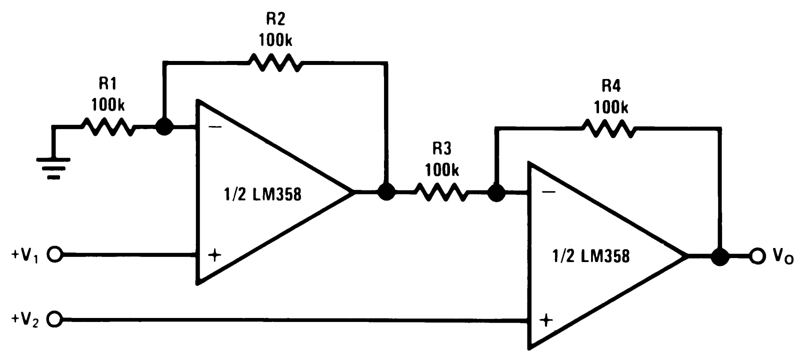
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Bandpass Active Filter



$f_O = 1$ kHz
Q = 25

High Input Z, DC Differential Amplifier



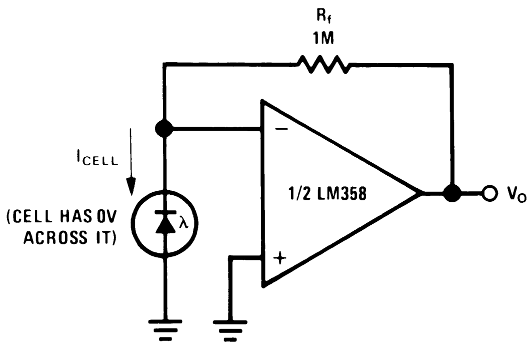
For $\frac{R1}{R2} = \frac{R4}{R3}$ (CMRR depends on this resistor ratio match)

$V_O = 1 + \frac{R4}{R3} (V_2 - V_1)$

As Shown: $V_O = 2 (V_2 - V_1)$

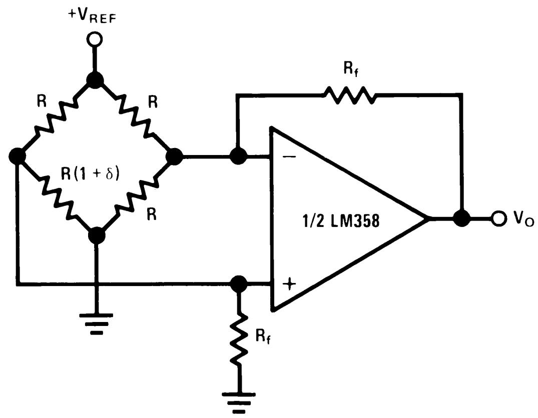
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Photo Voltaic-Cell Amplifier



00778730

Bridge Current Amplifier

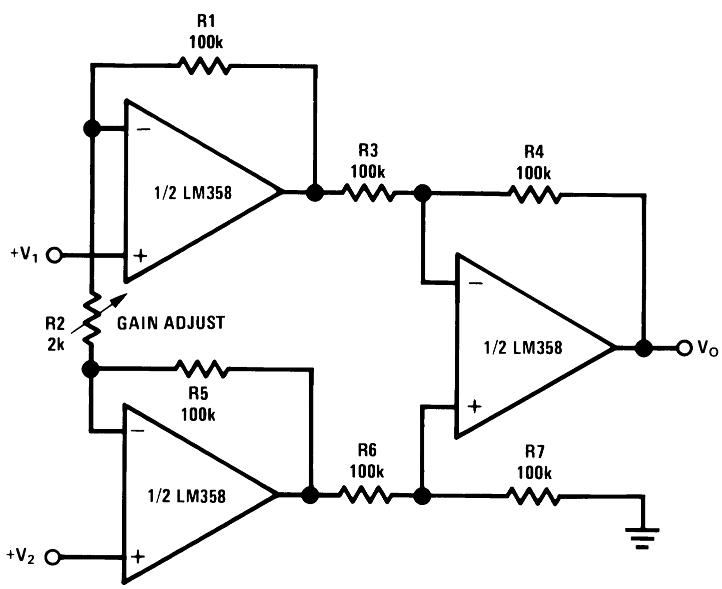


00778733

For $\delta << 1$ and $R_f >> R$

$$V_O \cong V_{REF}\left(\frac{\delta}{2}\right)\frac{R_f}{R}$$

High Input Z Adjustable-Gain DC Instrumentation Amplifier



00778731

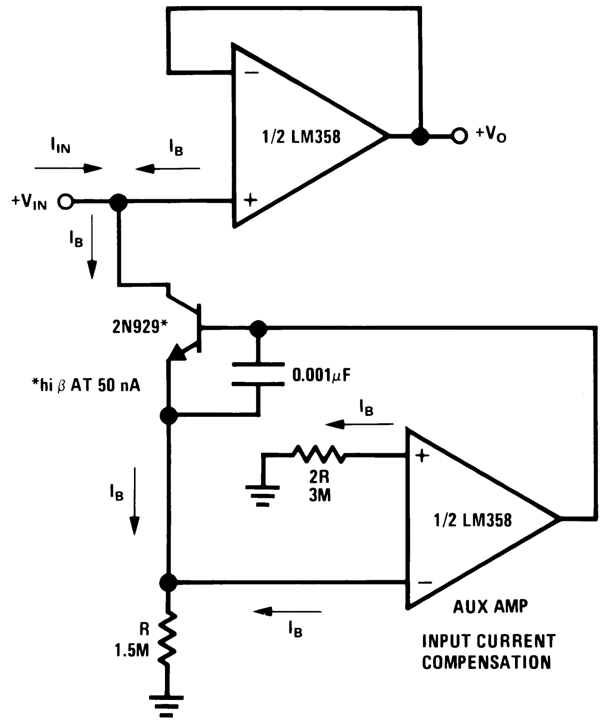
If R1 = R5 & R3 = R4 = R6 = R7 (CMRR depends on match)

$$V_O = 1 + \frac{2R1}{R2}(V_2 - V_1)$$

As shown $V_O = 101\ (V_2 - V_1)$

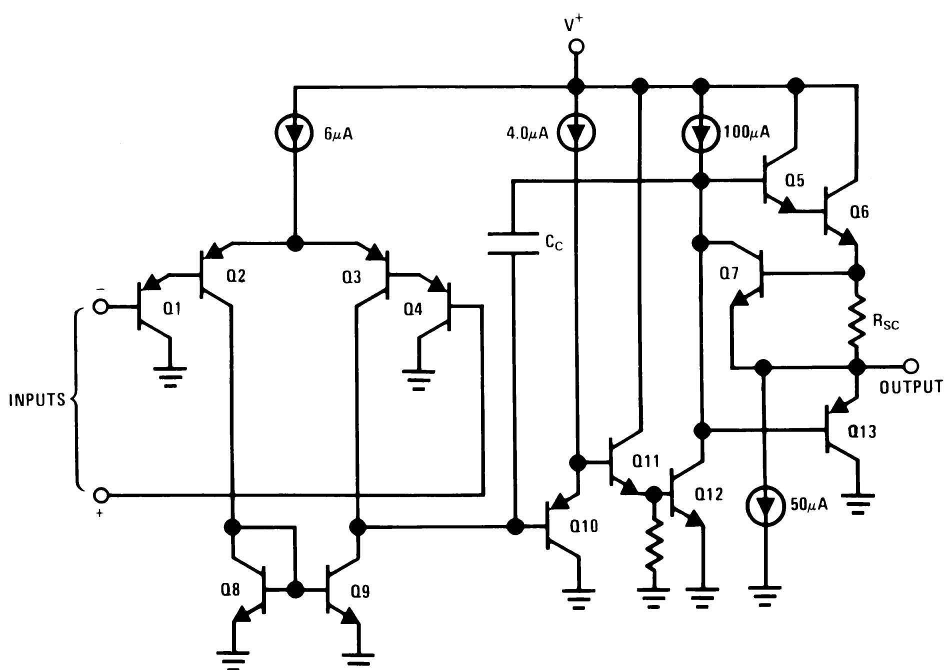
Typical Single-Supply Applications ($V^+ = 5.0\ V_{DC}$) (Continued)

Using Symmetrical Amplifiers to Reduce Input Current (General Concept)



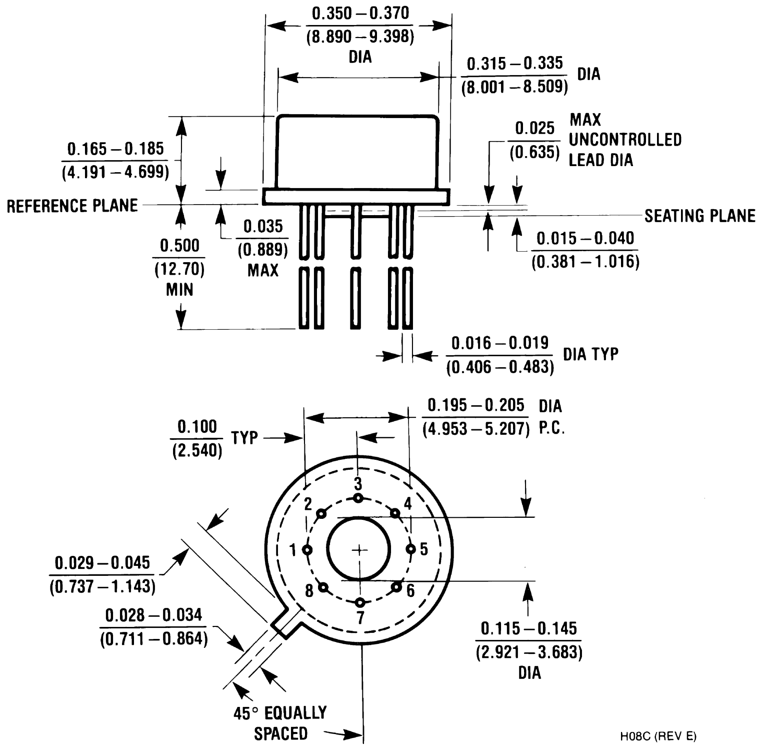
00778732

Schematic Diagram (Each Amplifier)

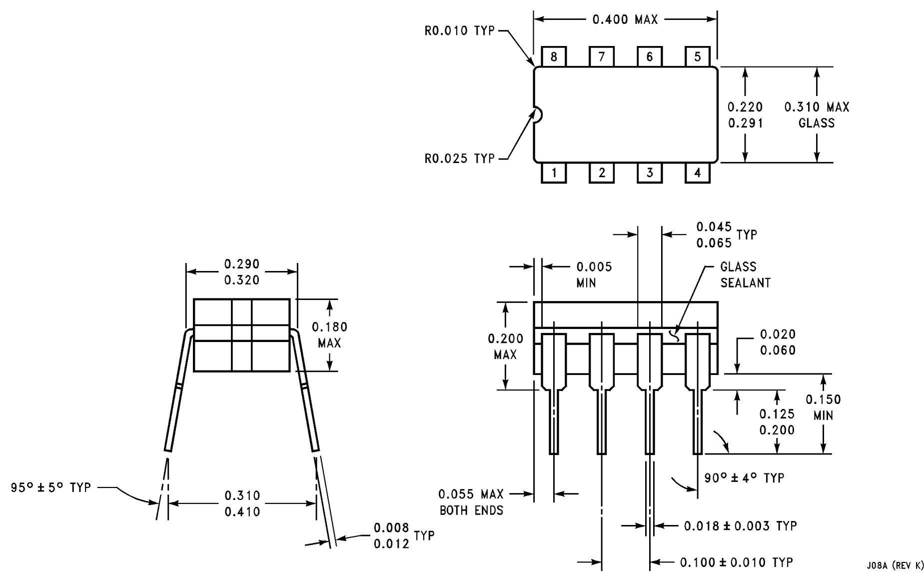


00778703

Physical Dimensions inches (millimeters) unless otherwise noted

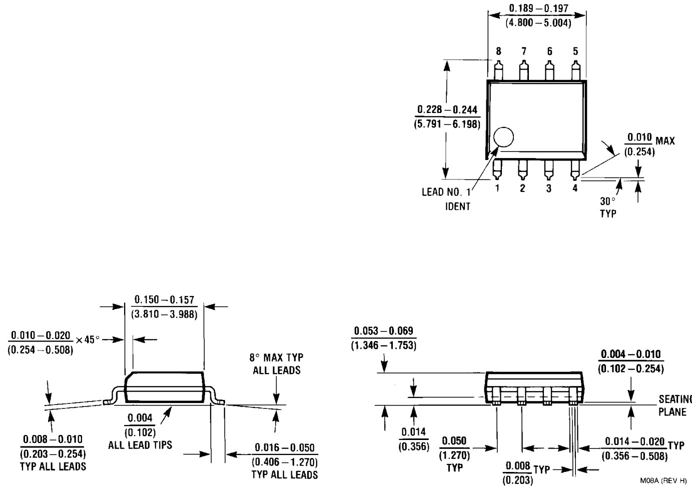


Metal Can Package (H)
NS Package Number H08C

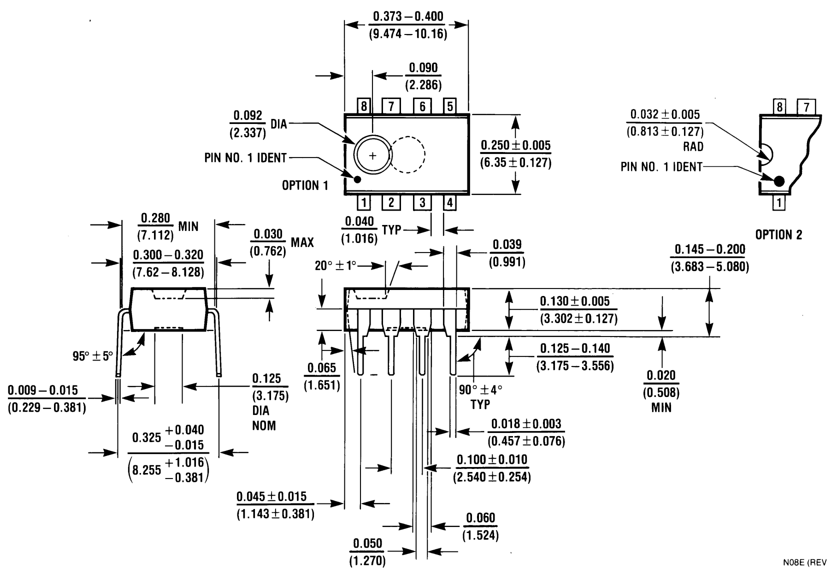


Cerdip Package (J)
NS Package Number J08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

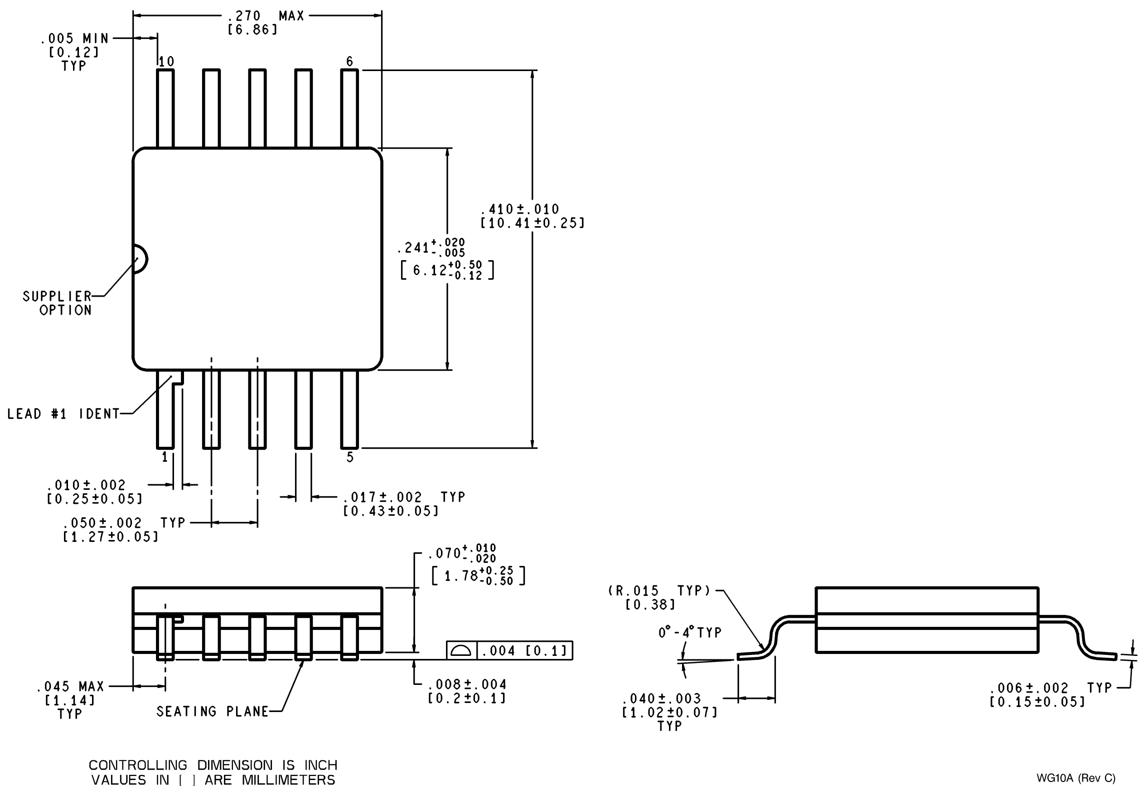


SOIC Package (M)
NS Package Number M08A



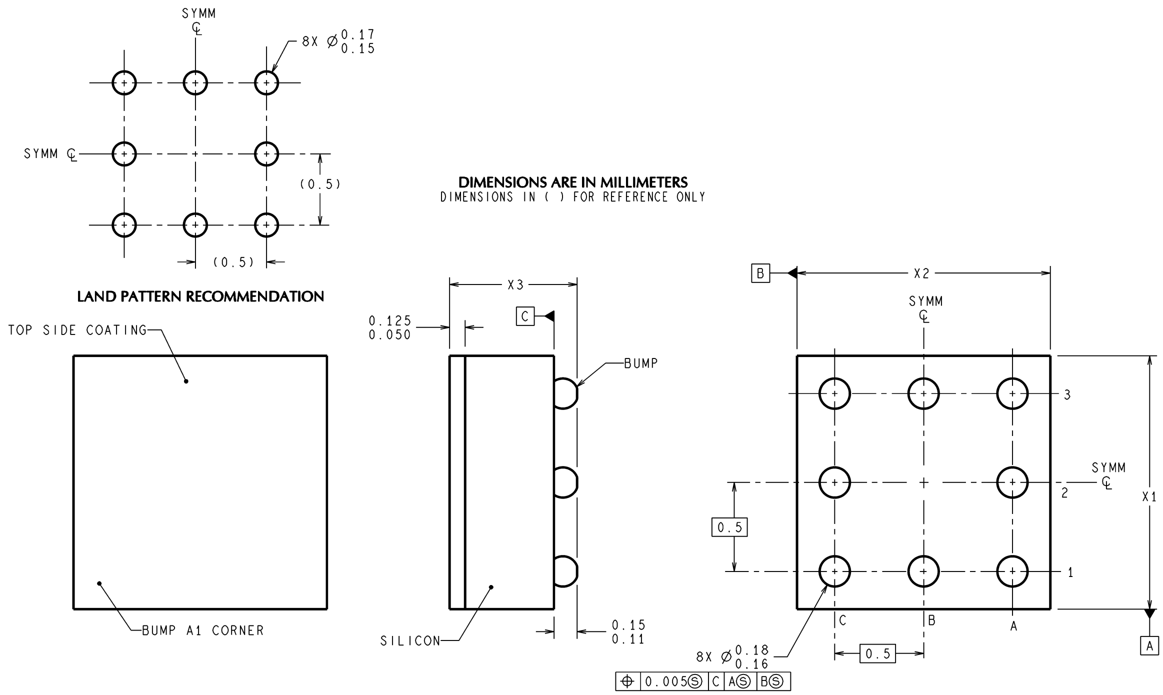
Molded Dip Package (N)
NS Package Number N08E

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Order Number LM158AWG/883
NS Package Number WG10A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



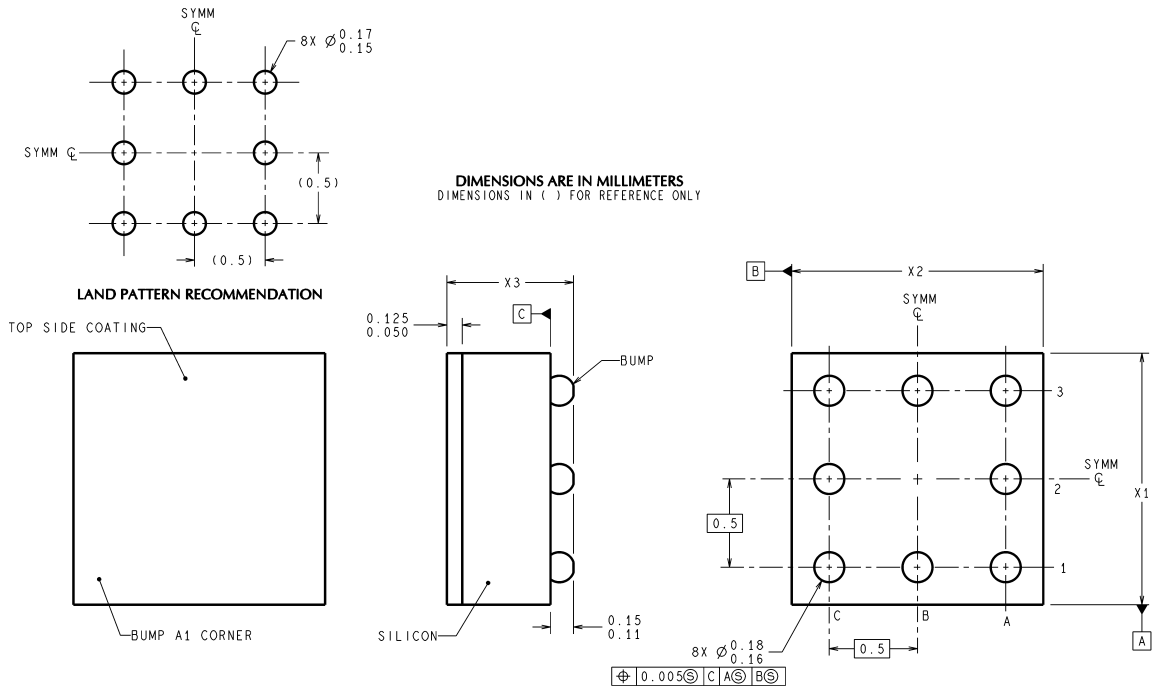
BPA08XXX (Rev D)

NOTES: UNLESS OTHERWISE SPECIFIED

1. EPOXY COATING
2. 63Sn/37Pb EUTECTIC BUMP
3. RECOMMEND NON-SOLDER MASK DEFINED LANDING PAD.
4. PIN A1 IS ESTABLISHED BY LOWER LEFT CORNER WITH RESPECT TO TEXT ORIENTATION REMAINING PINS ARE NUMBERED COUNTERCLOCKWISE.
5. XXX IN DRAWING NUMBER REPRESENTS PACKAGE SIZE VARIATION WHERE X_1 IS PACKAGE WIDTH, X_2 IS PACKAGE LENGTH AND X_3 IS PACKAGE HEIGHT.
6. REFERENCE JEDEC REGISTRATION MO-211, VARIATION BC.

8-Bump micro SMD
NS Package Number BPA08AAB
X_1 = 1.285 X_2 = 1.285 X_3 = 0.850

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TPA08XXX (Rev B)

NOTES: UNLESS OTHERWISE SPECIFIED

1. EPOXY COATING
2. RECOMMEND NON-SOLDER MASK DEFINED LANDING PAD.
3. PIN A1 IS ESTABLISHED BY LOWER LEFT CORNER WITH RESPECT TO TEXT ORIENTATION REMAINING PINS ARE NUMBERED COUNTERCLOCKWISE.
4. XXX IN DRAWING NUMBER REPRESENTS PACKAGE SIZE VARIATION WHERE X_1 IS PACKAGE WIDTH, X_2 IS PACKAGE LENGTH AND X_3 IS PACKAGE HEIGHT.
5. REFERENCE JEDEC REGISTRATION MO-211, VARIATION BC.

8-Bump micro SMD Lead Free
NS Package Number TPA08AAA
X_1 = 1.285 X_2 = 1.285 X_3 = 0.500

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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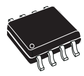
TL072, TL072A, TL072B

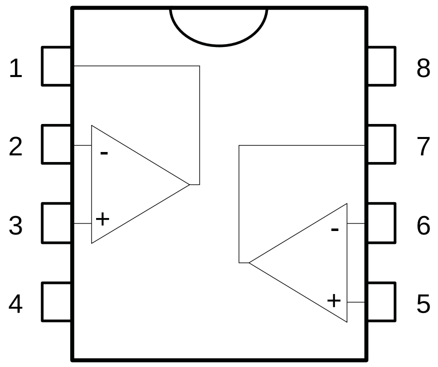
Low noise JFET dual operational amplifiers

Datasheet - production data



D
SO8

Pin connections (top view)



1 - Output 1
2 - Inverting input 1
3 - Non-inverting input 1
4 - V_{CC}^-
5 - Non-inverting input 2
6 -Inverting input 2
7 - Output 2
8 - V_{CC}^+

Features

- Wide common-mode (up to V_{CC}^+) and differential voltage range
- Low input bias and offset current
- Low noise e_n = 15 nV/√Hz (typ)
- Output short-circuit protection
- High input impedance JFET input stage
- Low harmonic distortion: 0.01 % (typical)
- Internal frequency compensation
- Latch-up free operation
- High slew rate: 16 V/µs (typ)

Related products

- See TL071 for single op amp version
- See TL074 for quad op amp version

Description

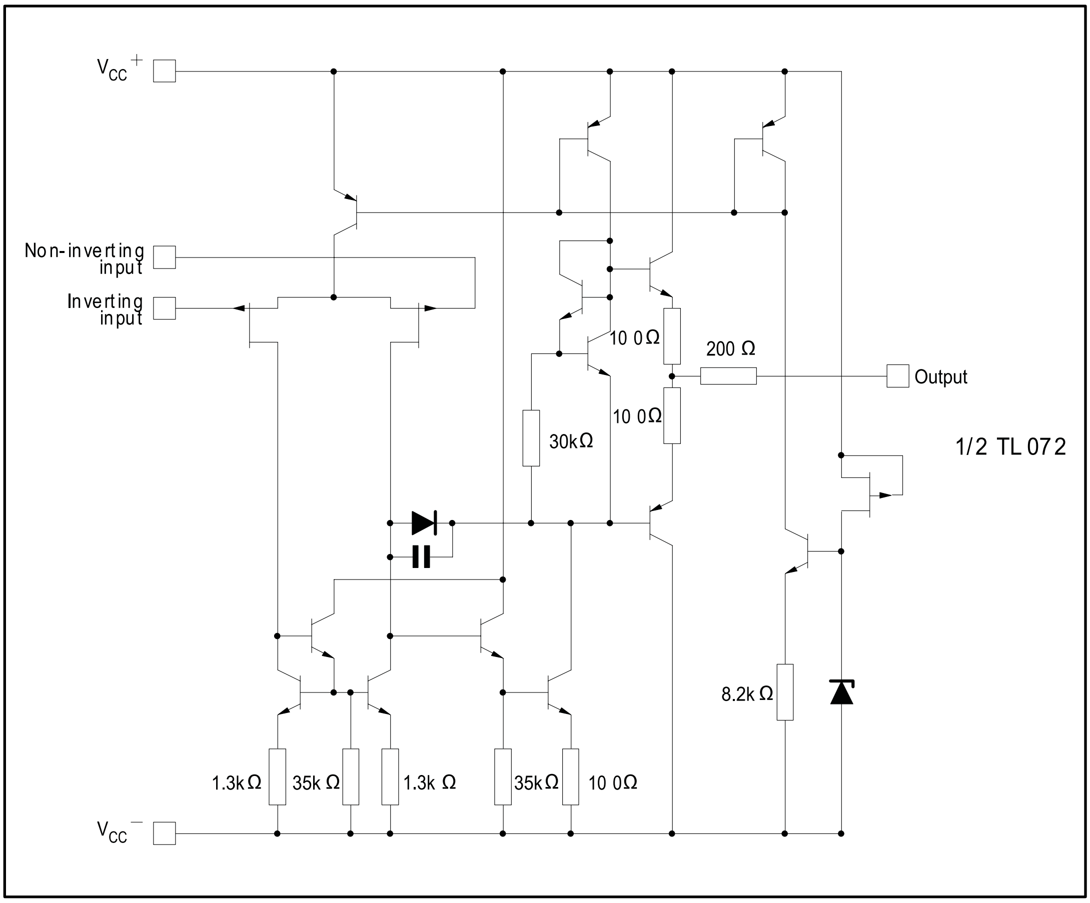
The TL072, TL072A, and TL072B are high speed JFET input dual operational amplifiers incorporating well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit.

The devices feature high slew rates, low input bias and offset current, and low offset voltage temperature coefficients.

Contents

1 Schematic diagram

Figure 1: Schematic diagram



2 Absolute maximum ratings and operating conditions

Table 1: Absolute maximum ratings

Symbol	Parameter	TL072I, AI, BI	TL072C, AC, BC	Unit
V_{CC}	Supply voltage [(1)]	±18		V
V_{in}	Input voltage [(2)]	±15		
V_{id}	Differential input voltage [(3)]	±30		
R_{thja}	Thermal resistance junction to ambient, SO8 [(4)]	125		°C/W
R_{thjc}	Thermal resistance junction to case, SO8 [(4)]	40		
	Output short-circuit duration [(5)]	Infinite		
T_{stg}	Storage temperature range	-65 to +150		°C
ESD	HBM: human body model [(6)]	1		kV
	MM: machine model [(7)]	200		V
	CDM: charged device model [(8)]	1.5		kV

Notes:

[(1)]All voltage values, except the differential voltage, are with respect to the zero reference level (ground) of the supply voltages where the zero reference level is the midpoint between V_{CC}^{+} and V_{CC}^{-}.

[(2)]The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 volts, whichever is less.

[(3)]Differential voltages are the non-inverting input terminal voltages with respect to the inverting input terminal.

[(4)]Short-circuits can cause excessive heating. Destructive dissipation can result from simultaneous short-circuits on all amplifiers.

[(5)]The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

[(6)]Human body model: 100 pF discharged through a 1.5 kΩ resistor between two pins of the device. This is done for all couples of pin combinations with other pins floating.

[(7)]Machine model: a 200 pF cap is charged to the specified voltage, then discharged directly between two pins of the device with no external series resistor (internal resistor < 5 W). This is done for all couples of pin combinations with other pins floating.

[(8)]Charged device model: all pins plus package are charged together to the specified voltage and then discharged directly to the ground.

Table 2: Operating conditions

Symbol	Parameter	TL072I, AI, BI	TL072C, AC, BC	Unit
V_{CC}	Supply voltage	6 to 36		V
T_{oper}	Operating free-air temperature range	-40 to +125	0 to +70	°C

3 Electrical characteristics

Table 3: Electrical characteristics at VCC = ±15 V, Tamb = +25 °C (unless otherwise specified).

Symbol	Parameter		TL072I, AC, AI, BC, BI			TL072C			Unit
			Min.	Typ.	Max.	Min.	Typ.	Max.	
V_{io}	Input offset voltage (R_s = 50 Ω) T_{amb} = +25 °C	TL072		3	10		3	10	mV
		TL072A		3	6				
		TL072B		1	3				
	Input offset voltage (R_s = 50 Ω) $T_{min} \leq T_{amb} \leq T_{max}$	TL072			13			13	
		TL072A			7				
		TL072B			5				
$\Delta V_{io}/\Delta T$	Input offset voltage drift			10			10		μV/°C
I_{io}	Input offset current, T_{amb} = +25 °C [1]			5	100		5	100	pA
	Input offset current, $T_{min} \leq T_{amb} \leq T_{max}$				4			10	nA
I_{ib}	Input bias current, T_{amb} = +25 °C [1]			20	200		20	200	pA
	Input bias current, $T_{min} \leq T_{amb} \leq T_{max}$ [1]				20			20	nA
A_{vd}	Large signal voltage gain (R_L = 2 kΩ, V_o = ±10 V), T_{amb} = +25 °C		50	200		25	200		V/mV
	Large signal voltage gain (R_L = 2 kΩ, V_o = ±10 V), $T_{min} \leq T_{amb} \leq T_{max}$		25			15			
SVR	Supply voltage rejection ratio (R_S = 50 Ω), T_{amb} = +25 °C		80	86		70	86		dB
	Supply voltage rejection ratio (R_S = 50 Ω), $T_{min} \leq T_{amb} \leq T_{max}$		80			70			
I_{CC}	Supply current, no load, T_{amb} = +25 °C			1.4	2.5		1.4	2.5	mA
	Supply current, no load, $T_{min} \leq T_{amb} \leq T_{max}$				2.5			2.5	
V_{icm}	Input common mode voltage range		±11	-12 to +15		±11	-12 to +15		V
CMR	Common mode rejection ratio (R_S = 50 Ω), T_{amb} = +25 °C		80	86		70	86		dB
	Common mode rejection ratio (R_S = 50 Ω), $T_{min} \leq T_{amb} \leq T_{max}$		80			70			
I_{os}	Output short-circuit current, T_{amb} = +25 °C		10	40	60	10	40	60	mA
	Output short-circuit current, $T_{min} \leq T_{amb} \leq T_{max}$		10		60	10		60	
$\pm V_{opp}$	Output voltage swing, T_{amb} = +25 °C	R_L = 2 kΩ	10	12		10	12		V
		R_L = 10 kΩ	12	13.5		12	13.5		
	Output voltage swing, $T_{min} \leq T_{amb} \leq T_{max}$	R_L = 2 kΩ	10			10			
		R_L = 10 kΩ	12			12			

Symbol	Parameter	TL072I, AC, AI, BC, BI			TL072C			Unit
		Min.	Typ.	Max.	Min.	Typ.	Max.	
SR	Slew rate, V_{in} = 10 V, R_L = 2 kΩ, C_L = 100 pF, unity gain	8	16		8	16		V/µs
t_r	Rise time, V_{in} = 20 mV, R_L = 2 kΩ, C_L = 100 pF, unity gain		0.1			0.1		µs
K_{ov}	Overshoot, V_{in} = 20 mV, R_L = 2 kΩ, C_L = 100 pF, unity gain		10			10		%
GBP	Gain bandwidth product, V_{in} = 10 mV, R_L = 2 kΩ, C_L = 100 pF, F= 100 kHz	2.5	4		2.5	4		MHz
R_i	Input resistance		10^{12}			10^{12}		Ω
THD	Total harmonic distortion, F= 1 kHz, R_L = 2 kΩ, C_L = 100 pF, A_v = 20 dB, V_o = 2 V_{pp}		0.01			0.01		%
e_n	Equivalent input noise voltage, R_S = 100 Ω, F= 1 kHz		15			15		$\frac{nV}{\sqrt{Hz}}$
Øm	Phase margin		45			45		degrees
V_{o1}/V_{o2}	Channel separation, A_v = 100		120			120		dB

Notes:

(1)The input bias currents are junction leakage currents which approximately double for every 10 °C increase in the junction temperature.

Figure 2: Maximum peak-to-peak output voltage versus frequency (RL = 2 kΩ)

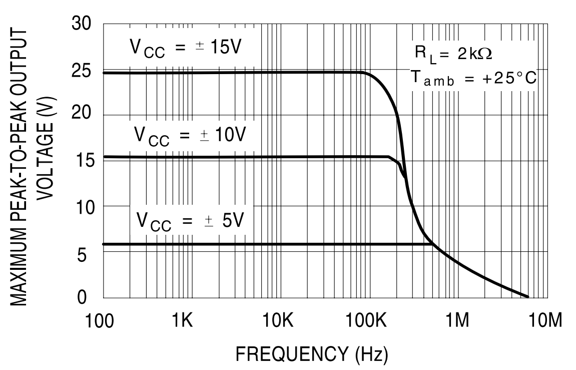


Figure 3: Maximum peak-to-peak output voltage versus frequency (RL = 10 kΩ)

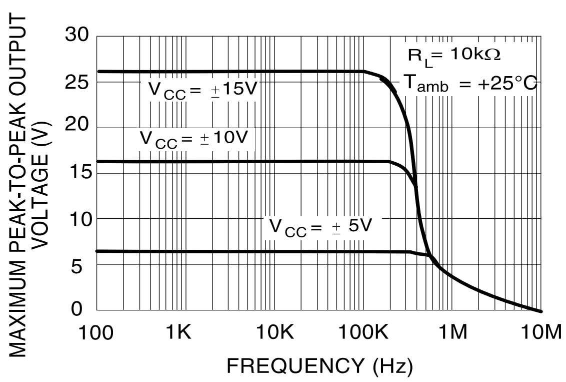


Figure 4: Maximum peak-to-peak output voltage versus frequency

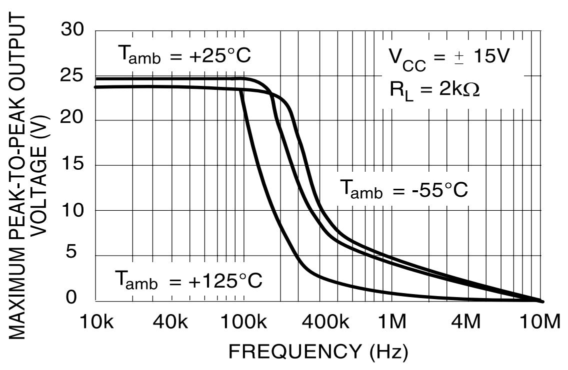


Figure 5: Maximum peak-to-peak output voltage versus free air temperature

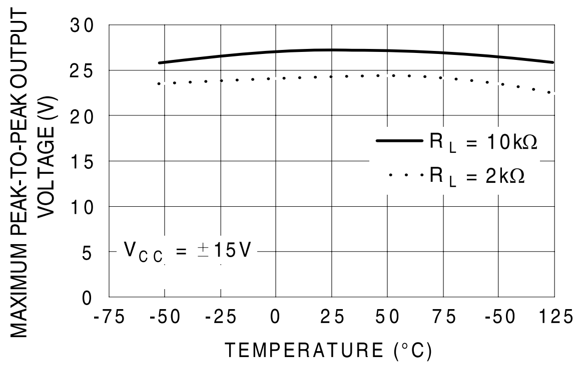


Figure 6: Maximum peak-to-peak output voltage versus load resistance

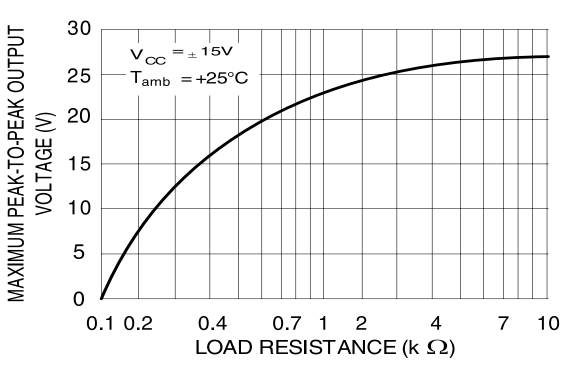


Figure 7: Maximum peak-to-peak output voltage versus supply voltage

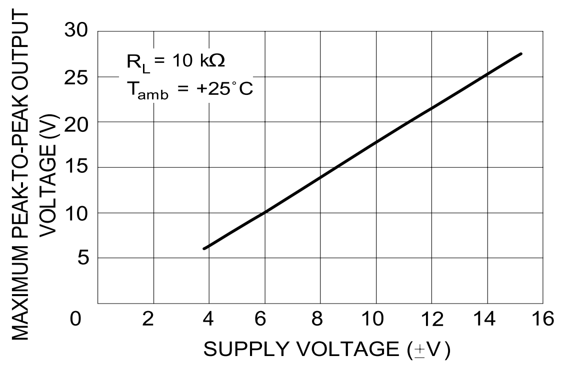


Figure 8: Input bias current versus free air temperature

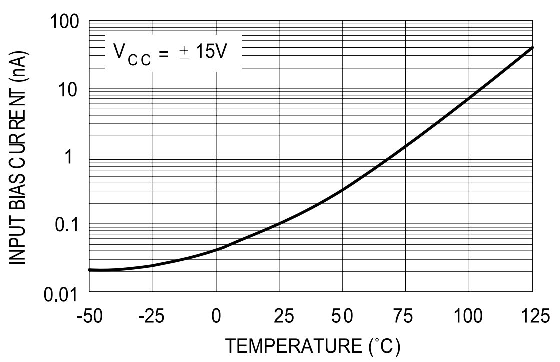


Figure 9: Large signal differential voltage amplification versus free air temperature

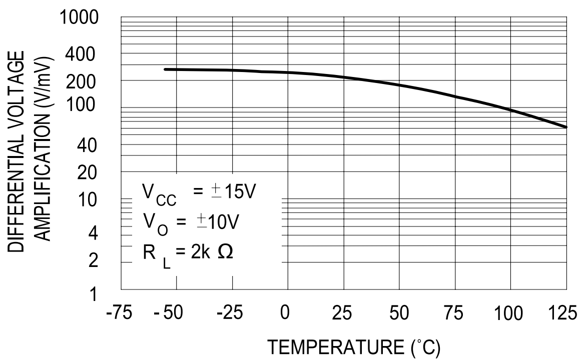


Figure 10: Large signal differential voltage amplification and phase shift versus frequency

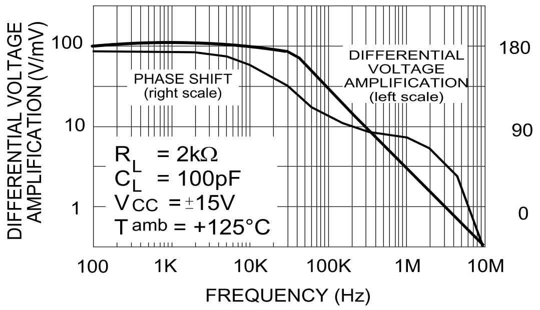


Figure 11: Total power dissipation versus free air temperature

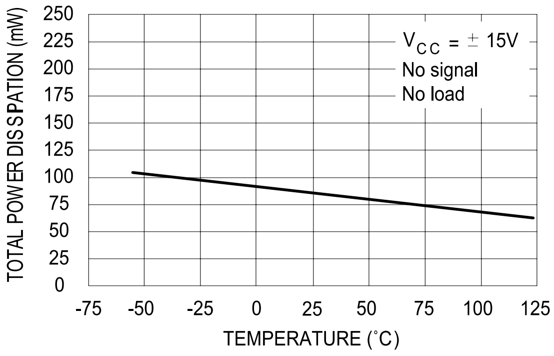


Figure 12: Supply current per amplifier versus free air temperature

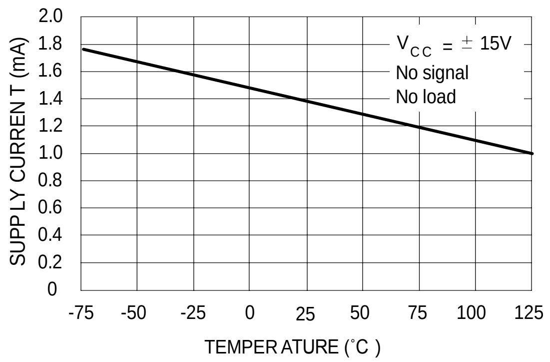


Figure 13: Common mode rejection ratio versus free air temperature

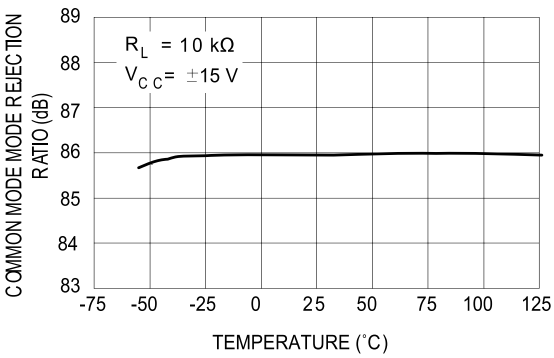


Figure 14: Voltage follower large signal pulse response

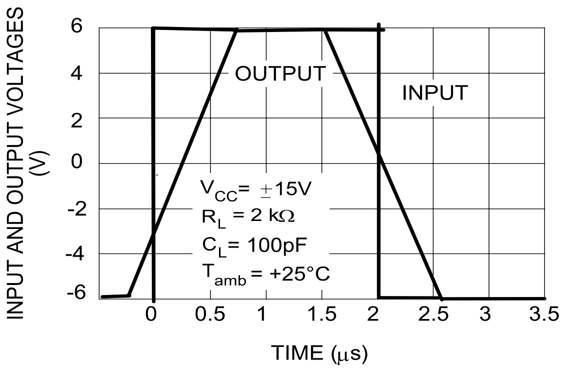


Figure 15: Output voltage versus elapsed time

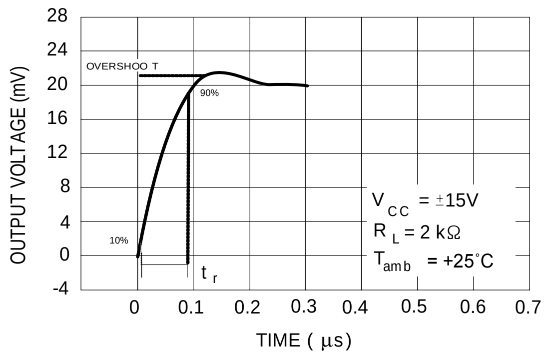


Figure 16: Equivalent input noise voltage versus frequency

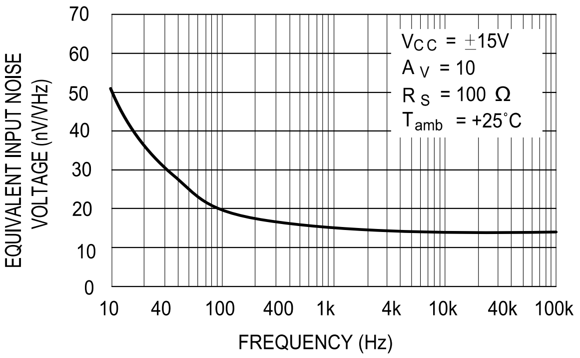
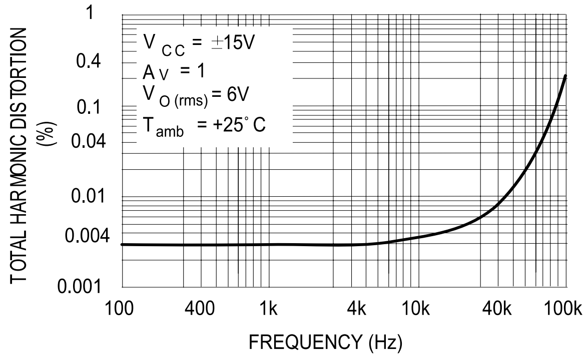


Figure 17: Total harmonic distortion versus frequency



4 Parameter measurement information

Figure 18: Voltage follower

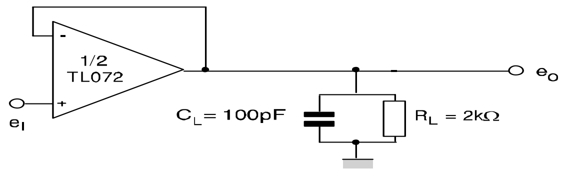
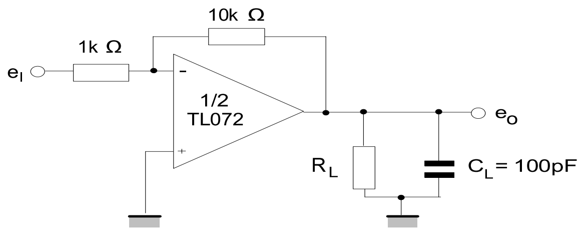
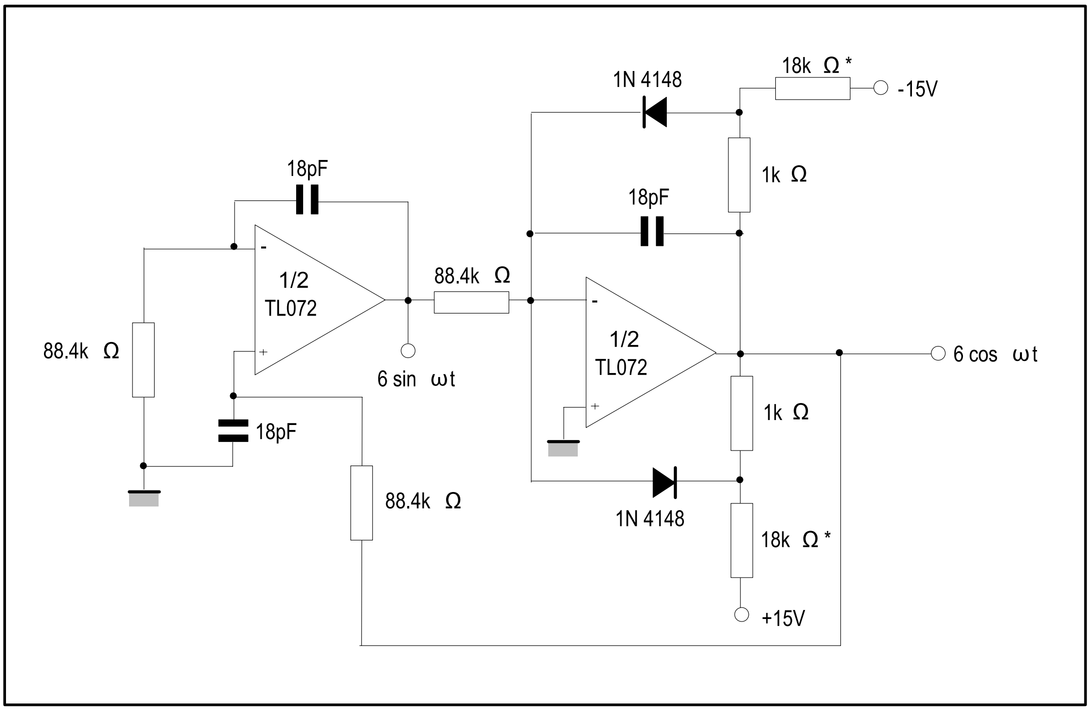


Figure 19: Gain-of-10 inverting amplifier



5 Typical application

Figure 20: 100 kHz quadruple oscillator



1. The resistor values of *Figure 20* may be adjusted for a symmetrical output

6 Package information

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK® packages, depending on their level of environmental compliance. ECOPACK® specifications, grade definitions and product status are available at: www.st.com. ECOPACK is an ST trademark.

6.1 SO8 package information

Figure 21: SO8 package mechanical drawing

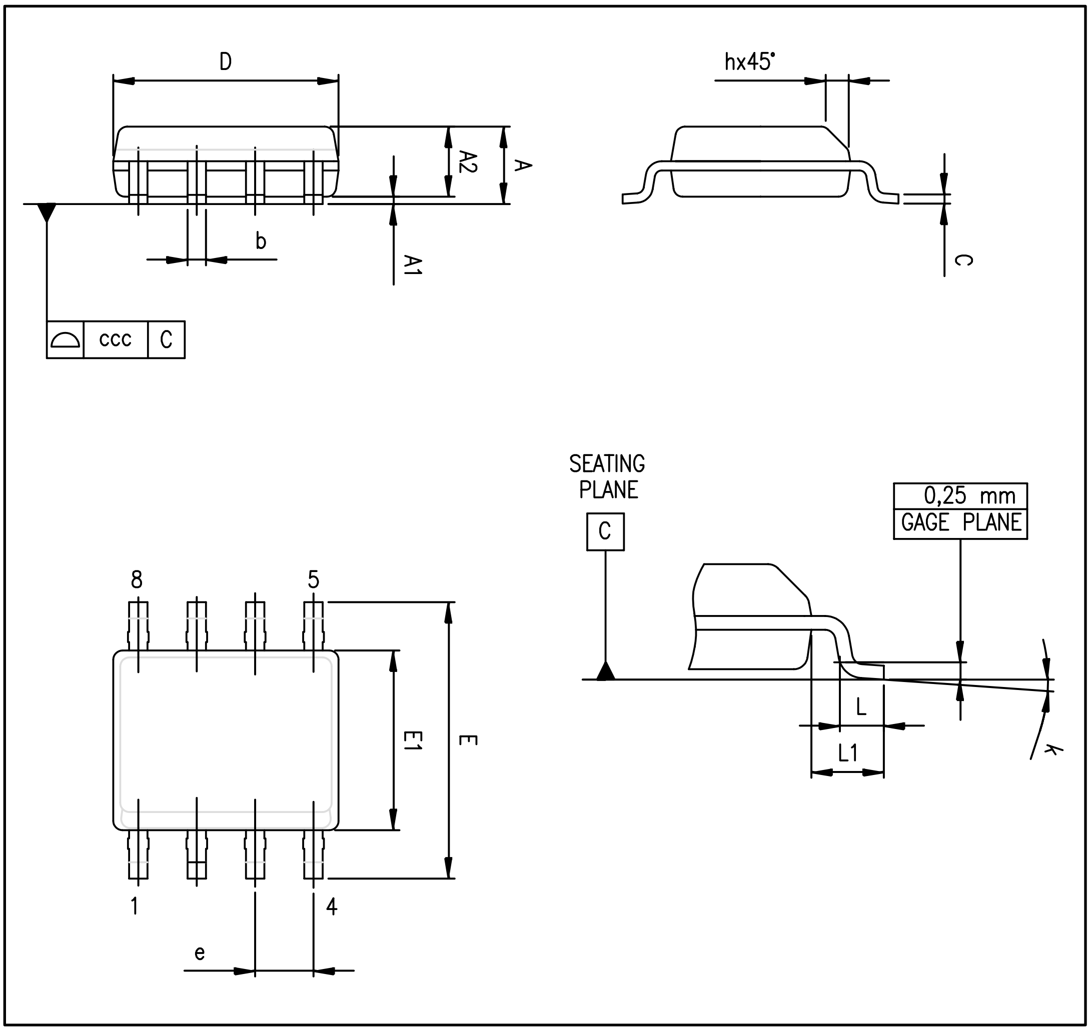


Table 4: SO8 package mechanical data

Ref.	Dimensions					
	Millimeters			Inches		
	Min.	Typ.	Max.	Min.	Typ.	Max.
A			1.75			0.069
A1	0.10		0.25	0.004		0.010
A2	1.25			0.049		
b	0.28		0.48	0.011		0.019
c	0.17		0.23	0.007		0.010
D	4.80	4.90	5.00	0.189	0.193	0.197
E	5.80	6.00	6.20	0.228	0.236	0.244
E1	3.80	3.90	4.00	0.150	0.154	0.157
e		1.27			0.050	
h	0.25		0.50	0.010		0.020
L	0.40		1.27	0.016		0.050
k	1°		8°	1°		8°
ccc			0.10			0.004

7 Ordering information

Table 5: Order codes

Order code	Temperature range	Package	Packing	Marking
TL072IDT	-40 °C, +125 °C	SO8	Tape and reel	072I
TL072AIDT				072AI
TL072BIDT				072BI
TL072CDT	0 °C, +70 °C			072C
TL072ACDT				072AC
TL072BCDT				072BC
TL072IYDT [(1)]	-40 °C, +125 °C	SO8 (automotive grade)		072IY
TL072AIYDT [(1)]				072AIY
TL072BIYDT [(1)]				072BIY

Notes:

[(1)]Qualified and characterized according to AEC Q100 and Q003 or equivalent, advanced screening according to AEC Q001 & Q 002 or equivalent.

8 Revision history

Table 6: Document revision history

Date	Revision	Changes
28-Mar-2001	1	Initial release.
02-Apr-2004	2	Correction to pin connection diagram on cover page. Unpublished.
04-Dec-2006	3	Modified graphics in package mechanical data.
06-Mar-2007	4	Expanded order codes table and added automotive grade order codes. See *Table 5: "Order codes"*. Added thermal resistance and ESD tolerance in *Table 1: "Absolute maximum ratings"*. Added *Table 2: "Operating conditions"*. Updated package mechanical data to make it compliant with the latest JEDEC standards.
13-Mar-2008	5	ESD HBM value modified in AMR table. Re-ordered order codes table. Removed TL072BIY and TL072AIY order codes from order code table. Corrected footnote for automotive grade order codes in order codes table.
15-Jul-2008	6	Removed information concerning military temperature range (TL072Mx, TL072AMx, TL072BMx). Added order codes for automotive grade products in *Table 5: "Order codes"*.
04-Jul-2012	7	Removed part numbers TL072IYD, TL072AIYD, TL072BIYD. Updated *Table 5: "Order codes"*.
19-Jun-2014	8	Removed DIP8 package Added *Related products* *Table 2: "Operating conditions"*: temperature range for “I” versions changed from “-40 °C, +105 °C” to “-40 °C, +125 °C”. *Table 3: Electrical characteristics at VCC = ±15 V, Tamb = +25 °C (unless otherwise specified)*: replaced DV_{io} with $\Delta V_{io}/\Delta T$. *Table 5: "Order codes"*: temperature range for “I” version order codes changed from “-40 °C, +105 °C” to “-40 °C, +125 °C”; removed tube packing and related order codes. Updated disclaimer

PT100 Resistance Table

°C	0	1	2	3	4	5	6	7	8	9	°C
-200.00	18.52										-200.00
-190.00	22.83	22.40	21.97	21.54	21.11	20.68	20.25	19.82	19.38	18.95	-190.00
-180.00	27.10	26.67	26.24	25.82	25.39	24.97	24.54	24.11	23.68	23.25	-180.00
-170.00	31.34	30.91	30.49	30.07	29.64	29.22	28.80	28.37	27.95	27.52	-170.00
-160.00	35.54	35.12	34.70	34.28	33.86	33.44	33.02	32.60	32.18	31.76	-160.00
-150.00	39.72	39.31	38.89	38.47	38.05	37.64	37.22	36.80	36.38	35.96	-150.00
-140.00	43.88	43.46	43.05	42.63	42.22	41.80	41.39	40.97	40.56	40.14	-140.00
-130.00	48.00	47.59	47.18	46.77	46.36	45.94	45.53	45.12	44.70	44.29	-130.00
-120.00	52.11	51.70	51.29	50.88	50.47	50.06	49.65	49.24	48.83	48.42	-120.00
-110.00	56.19	55.79	55.38	54.97	54.56	54.15	53.75	53.34	52.93	52.52	-110.00
-100.00	60.26	59.85	59.44	59.04	58.63	58.23	57.82	57.41	57.01	56.60	-100.00
-90.00	64.30	63.90	63.49	63.09	62.68	62.28	61.88	61.47	61.07	60.66	-90.00
-80.00	68.33	67.92	67.52	67.12	66.72	66.31	65.91	65.51	65.11	64.70	-80.00
-70.00	72.33	71.93	71.53	71.13	70.73	70.33	69.93	69.53	69.13	68.73	-70.00
-60.00	76.33	75.93	75.53	75.13	74.73	74.33	73.93	73.53	73.13	72.73	-60.00
-50.00	80.31	79.91	79.51	79.11	78.72	78.32	77.92	77.52	77.12	76.73	-50.00
-40.00	84.27	83.87	83.48	83.08	82.69	82.29	81.89	81.50	81.10	80.70	-40.00
-30.00	88.22	87.83	87.43	87.04	86.64	86.25	85.85	85.46	85.06	84.67	-30.00
-20.00	92.16	91.77	91.37	90.98	90.59	90.19	89.80	89.40	89.01	88.62	-20.00
-10.00	96.09	95.69	95.30	94.91	94.52	94.12	93.73	93.34	92.95	92.55	-10.00
0.00	100.00	99.61	99.22	98.83	98.44	98.04	97.65	97.26	96.87	96.48	0.00
0.00	100.00	100.39	100.78	101.17	101.56	101.95	102.34	102.73	103.12	103.51	0.00
10.00	103.90	104.29	104.68	105.07	105.46	105.85	106.24	106.63	107.02	107.40	10.00
20.00	107.79	108.18	108.57	108.96	109.35	109.73	110.12	110.51	110.90	111.29	20.00
30.00	111.67	112.06	112.45	112.83	113.22	113.61	114.00	114.38	114.77	115.15	30.00
40.00	115.54	115.93	116.31	116.70	117.08	117.47	117.86	118.24	118.63	119.01	40.00
50.00	119.40	119.78	120.17	120.55	120.94	121.32	121.71	122.09	122.47	122.86	50.00
60.00	123.24	123.63	124.01	124.39	124.78	125.16	125.54	125.93	126.31	126.69	60.00
70.00	127.08	127.46	127.84	128.22	128.61	128.99	129.37	129.75	130.13	130.52	70.00
80.00	130.90	131.28	131.66	132.04	132.42	132.80	133.18	133.57	133.95	134.33	80.00
90.00	134.71	135.09	135.47	135.85	136.23	136.61	136.99	137.37	137.75	138.13	90.00
100.00	138.51	138.88	139.26	139.64	140.02	140.40	140.78	141.16	141.54	141.91	100.00
110.00	142.29	142.67	143.05	143.43	143.80	144.18	144.56	144.94	145.31	145.69	110.00
120.00	146.07	146.44	146.82	147.20	147.57	147.95	148.33	148.70	149.08	149.46	120.00
130.00	149.83	150.21	150.58	150.96	151.33	151.71	152.08	152.46	152.83	153.21	130.00
140.00	153.58	153.96	154.33	154.71	155.08	155.46	155.83	156.20	156.58	156.95	140.00
150.00	157.33	157.70	158.07	158.45	158.82	159.19	159.56	159.94	160.31	160.68	150.00
160.00	161.05	161.43	161.80	162.17	162.54	162.91	163.29	163.66	164.03	164.40	160.00
170.00	164.77	165.14	165.51	165.89	166.26	166.63	167.00	167.37	167.74	168.11	170.00
180.00	168.48	168.85	169.22	169.59	169.96	170.33	170.70	171.07	171.43	171.80	180.00
190.00	172.17	172.54	172.91	173.28	173.65	174.02	174.38	174.75	175.12	175.49	190.00
200.00	175.86	176.22	176.59	176.96	177.33	177.69	178.06	178.43	178.79	179.16	200.00
210.00	179.53	179.89	180.26	180.63	180.99	181.36	181.72	182.09	182.46	182.82	210.00
220.00	183.19	183.55	183.92	184.28	184.65	185.01	185.38	185.74	186.11	186.47	220.00
230.00	186.84	187.20	187.56	187.93	188.29	188.66	189.02	189.38	189.75	190.11	230.00
240.00	190.47	190.84	191.20	191.56	191.92	192.29	192.65	193.01	193.37	193.74	240.00
250.00	194.10	194.46	194.82	195.18	195.55	195.91	196.27	196.63	196.99	197.35	250.00
260.00	197.71	198.07	198.43	198.79	199.15	199.51	199.87	200.23	200.59	200.95	260.00
270.00	201.31	201.67	202.03	202.39	202.75	203.11	203.47	203.83	204.19	204.55	270.00
280.00	204.90	205.26	205.62	205.98	206.34	206.70	207.05	207.41	207.77	208.13	280.00
290.00	208.48	208.84	209.20	209.56	209.91	210.27	210.63	210.98	211.34	211.70	290.00
300.00	212.05	212.41	212.76	213.12	213.48	213.83	214.19	214.54	214.90	215.25	300.00
310.00	215.61	215.96	216.32	216.67	217.03	217.38	217.74	218.09	218.44	218.80	310.00
320.00	219.15	219.51	219.86	220.21	220.57	220.92	221.27	221.63	221.98	222.33	320.00

°C	0	1	2	3	4	5	6	7	8	9	°C
330.00	222.68	223.04	223.39	223.74	224.09	224.45	224.80	225.15	225.50	225.85	**330.00**
340.00	226.21	226.56	226.91	227.26	227.61	227.96	228.31	228.66	229.02	229.37	**340.00**
350.00	229.72	230.07	230.42	230.77	231.12	231.47	231.82	232.17	232.52	232.87	**350.00**
360.00	233.21	233.56	233.91	234.26	234.61	234.96	235.31	235.66	236.00	236.35	**360.00**
370.00	236.70	237.05	237.40	237.74	238.09	238.44	238.79	239.13	239.48	239.83	**370.00**
380.00	240.18	240.52	240.87	241.22	241.56	241.91	242.26	242.60	242.95	243.29	**380.00**
390.00	243.64	243.99	244.33	244.68	245.02	245.37	245.71	246.06	246.40	246.75	**390.00**
400.00	247.09	247.44	247.78	248.13	248.47	248.81	249.16	249.50	249.85	250.19	**400.00**
410.00	250.53	250.88	251.22	251.56	251.91	252.25	252.59	252.93	253.28	253.62	**410.00**
420.00	253.96	254.30	254.65	254.99	255.33	255.67	256.01	256.35	256.70	257.04	**420.00**
430.00	257.38	257.72	258.06	258.40	258.74	259.08	259.42	259.76	260.10	260.44	**430.00**
440.00	260.78	261.12	261.46	261.80	262.14	262.48	262.82	263.16	263.50	263.84	**440.00**
450.00	264.18	264.52	264.86	265.20	265.53	265.87	266.21	266.55	266.89	267.22	**450.00**
460.00	267.56	267.90	268.24	268.57	268.91	269.25	269.59	269.92	270.26	270.60	**460.00**
470.00	270.93	271.27	271.61	271.94	272.28	272.61	272.95	273.29	273.62	273.96	**470.00**
480.00	274.29	274.63	274.96	275.30	275.63	275.97	276.30	276.64	276.97	277.31	**480.00**
490.00	277.64	277.98	278.31	278.64	278.98	279.31	279.64	279.98	280.31	280.64	**490.00**
500.00	280.98	281.31	281.64	281.98	282.31	282.64	282.97	283.31	283.64	283.97	**500.00**
510.00	284.30	284.63	284.97	285.30	285.63	285.96	286.29	286.62	286.95	287.29	**510.00**
520.00	287.62	287.95	288.28	288.61	288.94	289.27	289.60	289.93	290.26	290.59	**520.00**
530.00	290.92	291.25	291.58	291.91	292.24	292.56	292.89	293.22	293.55	293.88	**530.00**
540.00	294.21	294.54	294.86	295.19	295.52	295.85	296.18	296.50	296.83	297.16	**540.00**
550.00	297.49	297.81	298.14	298.47	298.80	299.12	299.45	299.78	300.10	300.43	**550.00**
560.00	300.75	301.08	301.41	301.73	302.06	302.38	302.71	303.03	303.36	303.69	**560.00**
570.00	304.01	304.34	304.66	304.98	305.31	305.63	305.96	306.28	306.61	306.93	**570.00**
580.00	307.25	307.58	307.90	308.23	308.55	308.87	309.20	309.52	309.84	310.16	**580.00**
590.00	310.49	310.81	311.13	311.45	311.78	312.10	312.42	312.74	313.06	313.39	**590.00**
600.00	313.71	314.03	314.35	314.67	314.99	315.31	315.64	315.96	316.28	316.60	**600.00**
610.00	316.92	317.24	317.56	317.88	318.20	318.52	318.84	319.16	319.48	319.80	**610.00**
620.00	320.12	320.43	320.75	321.07	321.39	321.71	322.03	322.35	322.67	322.98	**620.00**
630.00	323.30	323.62	323.94	324.26	324.57	324.89	325.21	325.53	325.84	326.16	**630.00**
640.00	326.48	326.79	327.11	327.43	327.74	328.06	328.38	328.69	329.01	329.32	**640.00**
650.00	329.64	329.96	330.27	330.59	330.90	331.22	331.53	331.85	332.16	332.48	**650.00**
660.00	332.79	333.11	333.42	333.74	334.05	334.36	334.68	334.99	335.31	335.62	**660.00**
670.00	335.93	336.25	336.56	336.87	337.18	337.50	337.81	338.12	338.44	338.75	**670.00**
680.00	339.06	339.37	339.69	340.00	340.31	340.62	340.93	341.24	341.56	341.87	**680.00**
690.00	342.18	342.49	342.80	343.11	343.42	343.73	344.04	344.35	344.66	344.97	**690.00**
700.00	345.28	345.59	345.90	346.21	346.52	346.83	347.14	347.45	347.76	348.07	**700.00**
710.00	348.38	348.69	348.99	349.30	349.61	349.92	350.23	350.54	350.84	351.15	**710.00**
720.00	351.46	351.77	352.08	352.38	352.69	353.00	353.30	353.61	353.92	354.22	**720.00**
730.00	354.53	354.84	355.14	355.45	355.76	356.06	356.37	356.67	356.98	357.28	**730.00**
740.00	357.59	357.90	358.20	358.51	358.81	359.12	359.42	359.72	360.03	360.33	**740.00**
750.00	360.64	360.94	361.25	361.55	361.85	362.16	362.46	362.76	363.07	363.37	**750.00**
760.00	363.67	363.98	364.28	364.58	364.89	365.19	365.49	365.79	366.10	366.40	**760.00**
770.00	366.70	367.00	367.30	367.60	367.91	368.21	368.51	368.81	369.11	369.41	**770.00**
780.00	369.71	370.01	370.31	370.61	370.91	371.21	371.51	371.81	372.11	372.41	**780.00**
790.00	372.71	373.01	373.31	373.61	373.91	374.21	374.51	374.81	375.11	375.41	**790.00**
800.00	375.70	376.00	376.30	376.60	376.90	377.19	377.49	377.79	378.09	378.39	**800.00**
810.00	378.68	378.98	379.28	379.57	379.87	380.17	380.46	380.76	381.06	381.35	**810.00**
820.00	381.65	381.95	382.24	382.54	382.83	383.13	383.42	383.72	384.01	384.31	**820.00**
830.00	384.60	384.90	385.19	385.49	385.78	386.08	386.37	386.67	386.96	387.25	**830.00**
840.00	387.55	387.84	388.14	388.43	388.72	389.02	389.31	389.60	389.90	390.19	**840.00**
850.00	390.48										**850.00**

Thermocouple Instruments Limited
Pontygwindy Road, Caerphilly, CF83 2WJ, UK
Tel: (+44) 029 20807400 Fax: (+44) 029 20807410
Internet: http://www.thermocouple.co.uk
E-mail: enquiries@thermocouple.co.uk

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