

A DESIGNER'S GUIDE TO THE L200 VOLTAGE REGULATOR

Delivering 2 A at a voltage variable from 2.85 V to 36 V, the L200 voltage regulator is a versatile device that simplifies the design of linear supplies. This design guide describes the operation of the device and its applications.

The introduction of integrated regulator circuits has greatly simplified the work involved in designing supplies. Regulation and protection circuits required for the supply, previously realized using discrete components, are now integrated in a single chip. This has led to significant cost and space saving as well as increased reliability. Today the designer has a wide range of fixed and adjustable, positive and negative series regulators to choose from as well as an increasing number of switching regulators.

The L200 is a positive variable voltage regulator which includes a current limiter and supplies up to 2 A at 2.85 to 36 V.

The output voltage is fixed with two resistors or, if a continuously variable output voltage is required, with one fixed and one variable resistor.

The maximum output current is fixed with a low value resistor. The device has all the characteristics common to normal fixed regulators and these are described in the datasheet. The L200 is particularly suitable for applications requiring output voltage variation or when a voltage not provided by the standard regulators is required or when a special limit must be placed on the output current.

The L200 is available in two packages :

Pentawatt - Offers easy assembly and good reliability. The guaranteed thermal resistance ($R_{th j-case}$) is 3 °C/W (typically 2 °C/W) while if the device is used without heatsink we can consider a guaranteed junction-ambient thermal resistance of 50 °C/W.

TO-3 - For professional and military use or where good hermeticity is required.

The guaranteed junction-case thermal resistance is 4 °C/W, while the junction-ambient thermal resistance is 35 °C/W.

The junction-case thermal resistance of this package, which is greater than that of the Pentawatt, is

partly compensated by the lower contact resistance with the heatsink, especially when an electrical insulator is used.

CIRCUIT OPERATION

As can be seen from the block diagram (fig. 1) the voltage regulation loop is almost identical to that of fixed regulators. The only difference is that the negative feedback network is external, so it can be varied (fig. 3). The output is linked to the reference by :

$$V_{out} = V_{ref} \left(1 + \frac{R2}{R1} \right) \quad (1)$$

Considering V_{out} as the output of an operational amplifier with gain equal to $G_v = 1 + R2/R1$ and input signal equal to V_{ref} , variability of the output voltage can be obtained by varying $R1$ or $R2$ (or both). It's best to vary $R1$ because in this way the current in resistors $R1$ and $R2$ remains constant (this current is in fact given by $V_{ref}/R1$).

Equation (1) can also be found in another way which is more useful in order to understand the descriptions of the applications discussed.

$$V_{out} = R1 i_1 + R2 i_2$$

and since in practice $i_1 \gg i_2$ (i_2 has a typical value of 10 nA) we can say that

$$V_{out} + R1 i_1 + R2 i_1 \text{ with } i_1 = \frac{V_{ref}}{R1}$$

Therefore

$$V_{out} = \frac{R2}{R1} V_{ref} + V_{ref} = V_{ref} \left(1 + \frac{R2}{R1} \right)$$

In other words $R1$ fixes the value of the current circulating in $R2$ so $R2$ is determined.

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Figure 1 : Block Diagram.

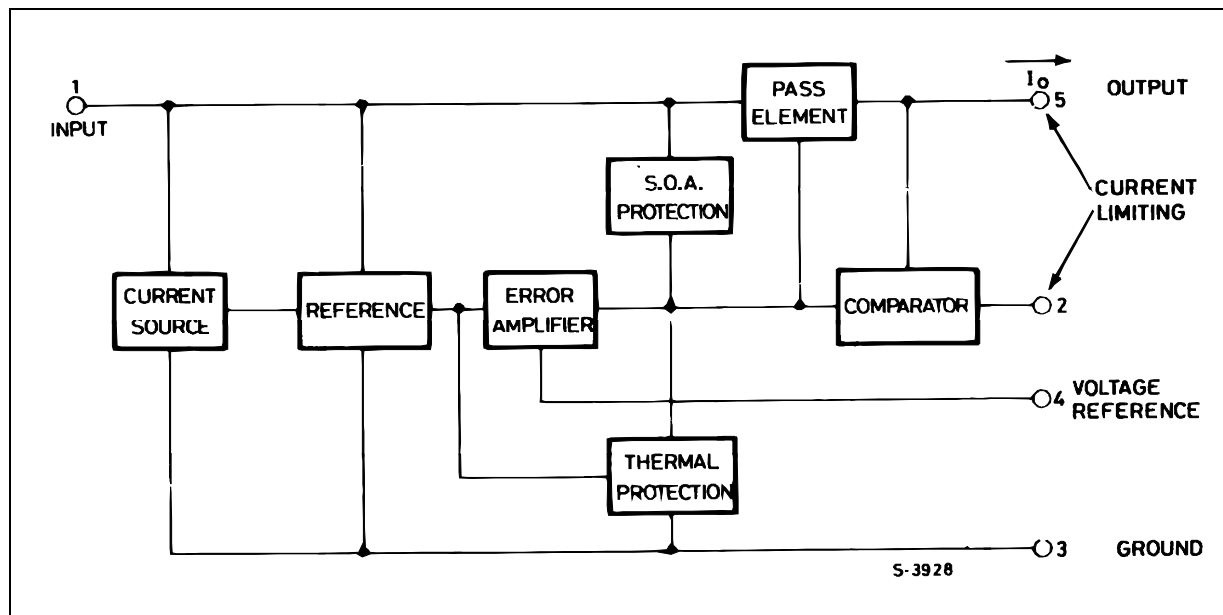


Figure 2 : Schematic Diagram.

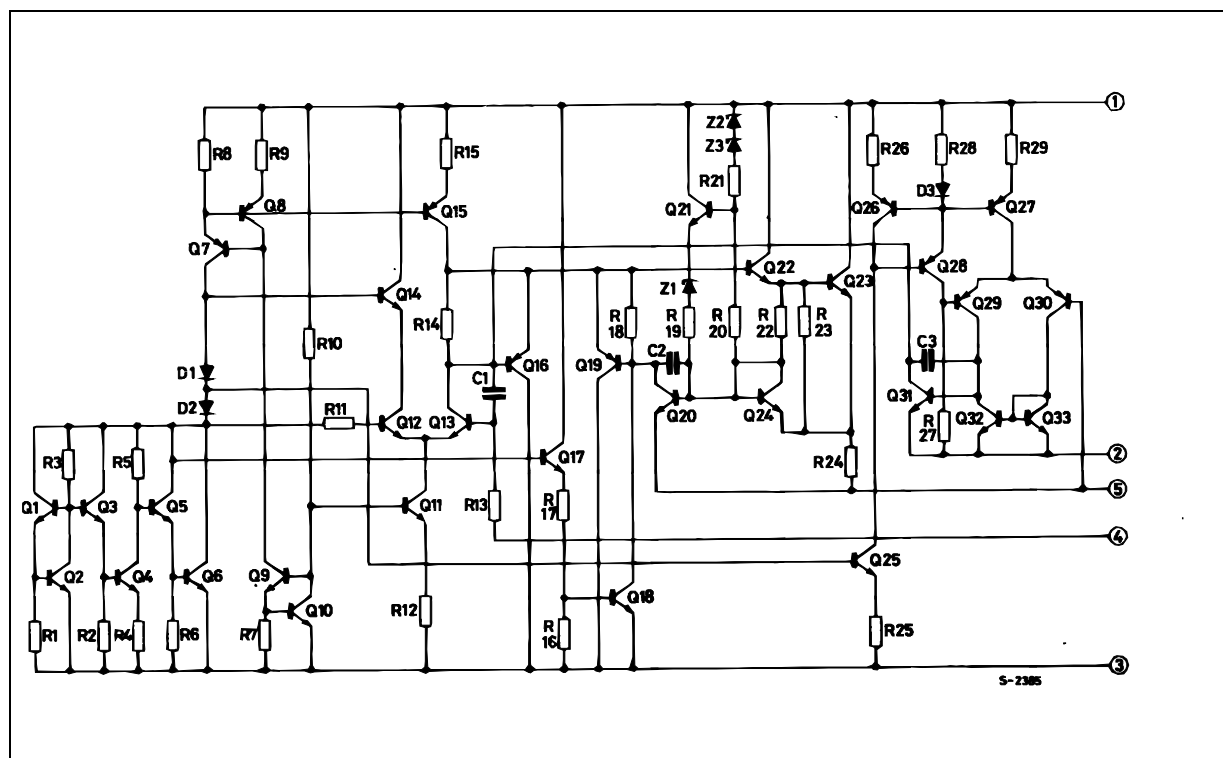
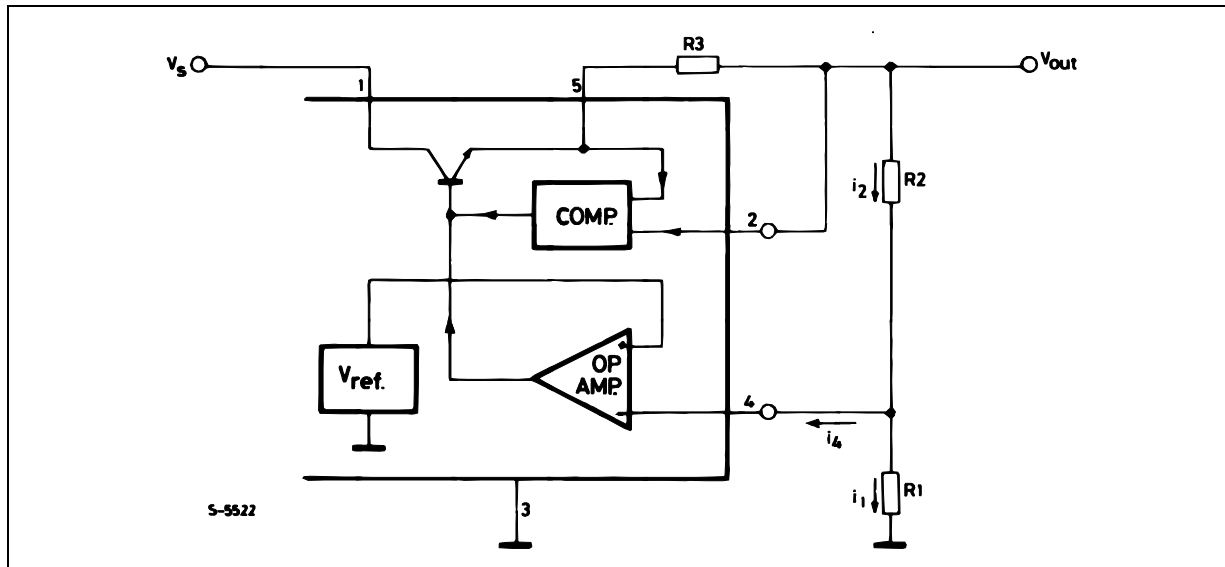


Figure 3.

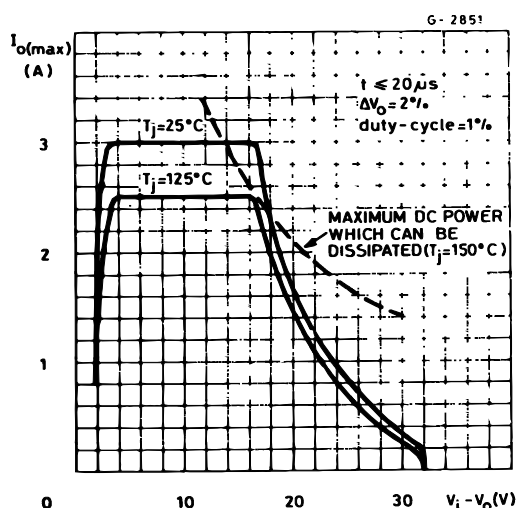


OVERLOAD PROTECTION

The device has an overload protection circuit which limits the current available.

Referring to fig. 2, R24 operates as a current sensor. When at the terminals of R24 there is a voltage drop sufficient to make Q20 conduct, Q19 begins to draw current from the base of the power transistor (darlington formed by Q22 and Q23) and the output current is limited. The limit depends on the current which Q21 injects into the base of Q20. This current depends on the drop-out and the temperature which explains the trend of the curves in fig. 4.

Figure 4.



THERMAL PROTECTION

The junction temperature of the device may reach destructive levels during a short circuit at the output or due to an abnormal increase in the ambient temperature. To avoid having to use heatsinks which are costly and bulky, a thermal protection circuit has been introduced to limit the output current so that the dissipated power does not bring the junction temperature above the values allowed. The operation of this circuit can be summarized as follows.

In Q17 there is a constant current equal to :

$$\frac{V_{ref} - V_{BE17}}{R17 + R16} \quad (V_{ref} = 2.75 \text{ V typ})$$

The base of Q18 is therefore biased at :

$$V_{BE18} = \frac{V_{ref} - V_{BE17}}{R16 + R17} \quad \bullet R16 \cong 350 \text{ mV}$$

Therefore at $T_j = 25^\circ\text{C}$ Q18 is off (since 600 mV is needed for it to start conducting). Since the V_{BE} of a silicon transistor decreases by about 2 mV/ $^\circ\text{C}$, Q18 starts conducting at the junction temperature :

$$T_j = \frac{600 - 350}{2} + 25 = 150^\circ\text{C}$$

CURRENT LIMITATION

The innovative feature of this device is the possibility of acting on the current regulation loop, i.e. of limiting the maximum current that can be supplied to the desired value by using a simple resistor (R3 in fig. 2). Obviously if $R3 = 0$ the maximum output current is

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also the maximum current that the device can supply because of its internal limitation.

The current loop consists of a comparator circuit with fixed threshold whose value is V_{sc} . This comparator intervenes when $I_o \cdot R3 = V_{sc}$, hence

$$I_o = \frac{V_{sc}}{R3} \quad (V_{sc} \text{ is the voltage between pin 5 and 2 with typical value of } 0.45 \text{ V}).$$

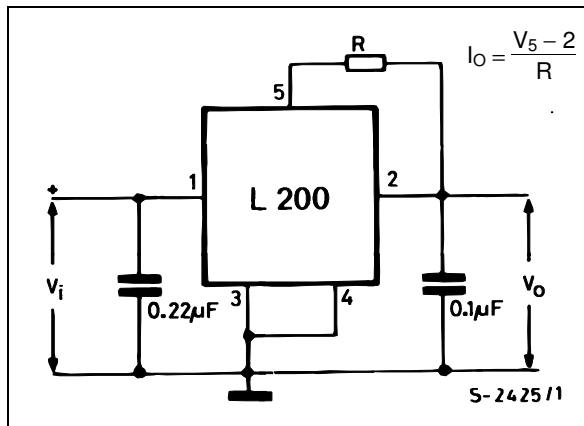
Special attention has been given to the comparator circuit in order to ensure that the device behaves as a current generator with high output impedance.

TYPICAL APPLICATIONS

PROGRAMMABLE CURRENT REGULATOR

Fig. 5 shows the device used as current generator. In this case the error amplifier is disabled by short-circuiting pin 4 to ground.

Figure 5.



The output current I_o is fixed by means of R :

$$I_o = \frac{V_{5-2}}{R}$$

The output voltage can reach a maximum value $V_i - V_{drop} \approx V_i - 2 \text{ V}$ (V_{drop} depends on I_o).

PROGRAMMABLE VOLTAGE REGULATOR

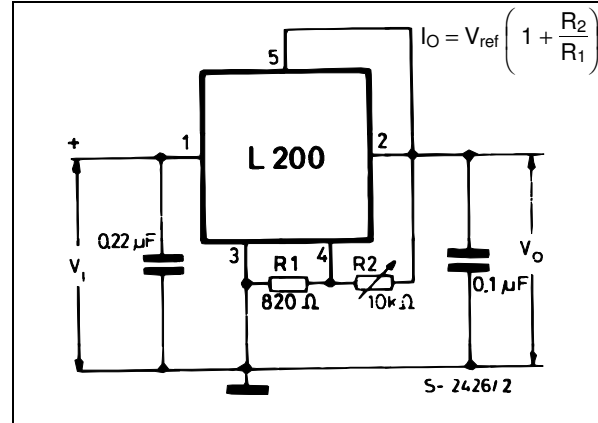
Fig. 6 shows the device connected as a voltage regulator and the maximum output current is the maximum current that the device can supply. The output voltage V_o is fixed using potentiometer $R2$. The equation which gives the output voltage is as follows :

$$V_o = V_{ref} \left(1 + \frac{R2}{R1} \right)$$

By substituting the potentiometer with a fixed resistor and choosing suitable values for $R1$ and $R2$, it is

possible to obtain a wide range of fixed output voltages.

Figure 6.



The following formulas and tables can be used to calculate some of the most common output voltages.

Having fixed a certain V_o , using the previous formula, the maximum value is :

$$V_{O \max} = V_{ref \max} \left(1 + \frac{R2_{\max}}{R1_{\min}} \right) \text{ and the}$$

minimum value is :

$$V_{O \min} = V_{ref \min} \left(1 + \frac{R2_{\min}}{R1_{\max}} \right)$$

The table below indicates resistor values for typical output voltages :

$V_o \pm 4\%$	$R1 \pm 1\%$	$R2 \pm 1\%$
5V	1.5kΩ	1.2kΩ
12V	1kΩ	3.3kΩ
15V	750Ω	3.3kΩ
18V	330Ω	1.8kΩ
24V	510Ω	3.9kΩ

PROGRAMMABLE CURRENT AND VOLTAGE REGULATOR

The typical configuration used by the device as a voltage regulator with external current limitation is shown in fig. 7. The fixed voltage of 2.77 V at the terminals of $R1$ makes it possible to force a constant current across variable resistor $R2$. If $R2$ is varied, the voltage at pin 2 is varied and so is the output voltage.

The output voltage is given by :

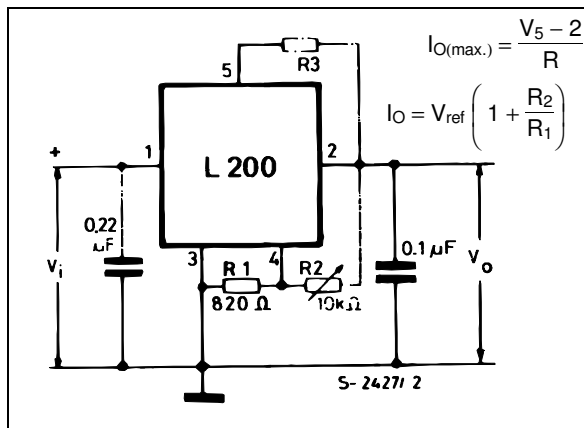
$$V_O = V_{ref} \cdot \left(1 + \frac{R_2}{R_1}\right), \text{ with } V_{ref} = 2.77 \text{ V typ}$$

and the maximum output current is given by :

$$I_{O \max} = \frac{V_{5-2}}{R_3} \text{ with } V_{5-2} = 0.45 \text{ V typ.}$$

To maintain a sufficient current for good regulation the value of R_1 should be kept low. When there is no load, the output current is V_{ref}/R_1 . Suitable values of R_1 are between 500Ω and $1.5 \text{ k}\Omega$. If the load is always present the maximum value for R_1 is limited by the current value (10 A) at the input of the error amplifier (pin 4).

Figure 7.



DIGITALLY SELECTED REGULATOR WITH INHIBIT

The output voltage of the device can be regulated digitally as shown in fig. 8. The output voltage depends on the divider formed by R_5 and a combination of R_1 , R_2 , R_3 and P_2 . The device can be switched off with a transistor.

When the inhibit transistor is saturated, pin 2 is brought to ground potential and the output voltage does not exceed 0.45 V .

REDUCING POWER DISSIPATION WITH DROPPING RESISTOR

It may sometimes be advisable to reduce the power dissipated by the device. A simple and economic method of doing this is to use a resistor connected in series to the input as shown in fig. 9. The input-output differential voltage on the device is thus reduced.

The formula for calculating R is as follows :

$$R = \frac{V_{i \min} - (V_O + V_{drop})}{I_O}$$

Figure 8.

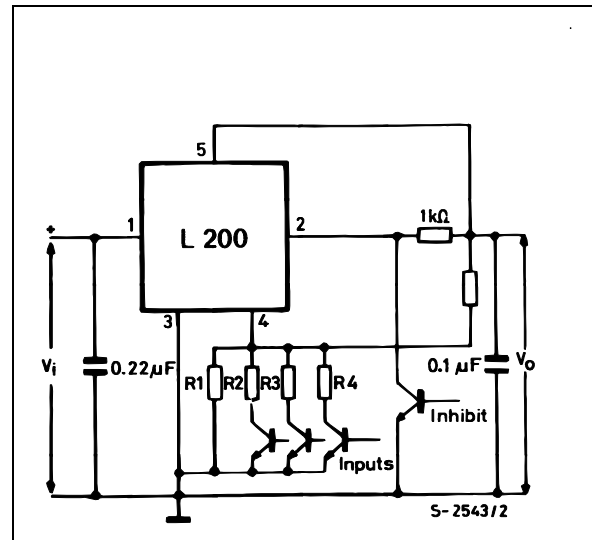
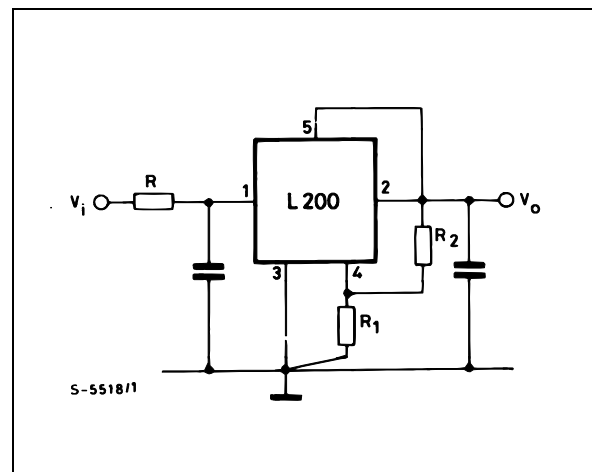


Figure 9.



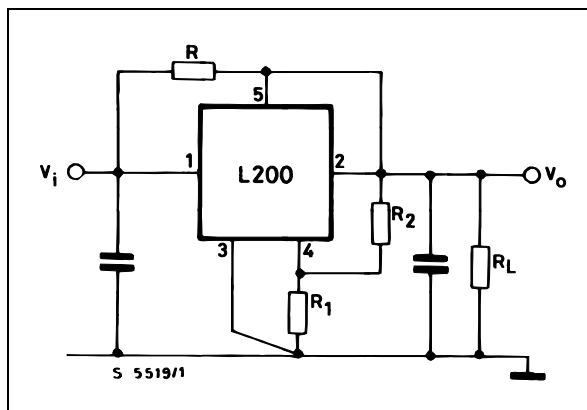
Where V_{drop} is the minimum differential voltage between the input and the output of the device at current I_O . $V_{i \min}$ is the minimum voltage. V_O is the output voltage and I_O the output current.

With constant load, resistor R can be connected between pins 1 and 2 of the IC instead of in series with the input (fig. 10). In this way, part of the load current flows through the device and part through the resistor. This configuration can be used when the minimum current by the load is :

$$I_{O \min} = \frac{V_{drop}}{R} \quad (\text{instant by instant})$$

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Figure 10.



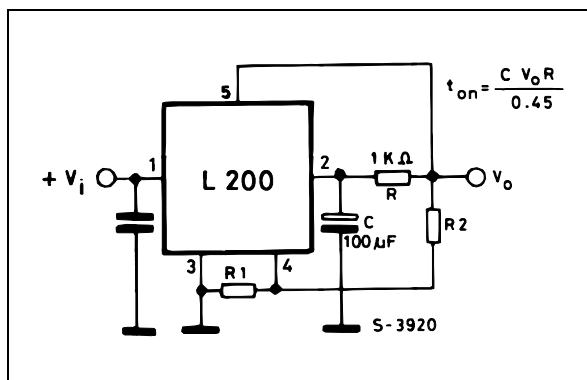
SOFT START

When a slow rise time of the output voltage is required, the configuration in fig. 11 can be used. The rise time can be found using the following formula :

$$t_{on} = \frac{CV_o R}{0.45}$$

At switch on capacitor C is discharged and it keeps the voltage at pin 2 low ; or rather, since a voltage of more than 0.45 V cannot be generated between pins 5 and 2, the V_o follows the voltage at pin 2 at less than 0.45 V.

Figure 11.



Capacitor C is charged by the constant current i_c .

$$i_c = \frac{V_{sc}}{R}$$

Therefore the output reaches its nominal value after the time t_{on} :

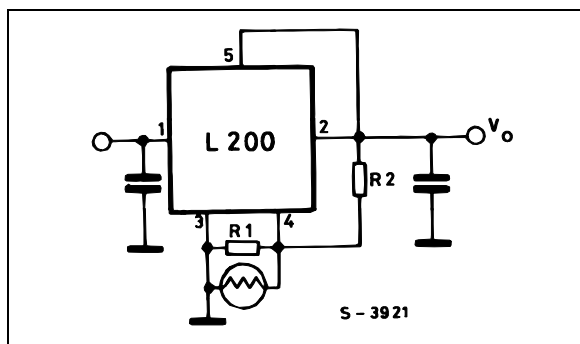
$$V_o - V_{sc} = \frac{I_c \cdot t_{on}}{C}$$

$$t_{on} = C \cdot \frac{V_o - 0.45}{0.45} \cdot R \cong \frac{CV_o R}{0.45}$$

LIGHT CONTROLLER

Fig. 12 shows a circuit in which the output voltage is controlled by the brightness of the surrounding environment. Regulation is by means of a photo resistor in parallel with R1. In this case, the output voltage increases as the brightness increases. The opposite effect, i.e. dimming the light as the ambient light increases, can be obtained by connecting the photoresistor in parallel with R2.

Figure 12.



LIGHT DIMMER FOR CAR DISPLAY

Although digital displays in cars are often more aesthetically pleasing and frequently more easily read they do have a problem. Under varying ambient light conditions they are either lost in the background or alternatively appear so bright as to distract the driver. With the system proposed here, this problem is overcome by automatically adjusting the display brightness during daylight conditions and by giving the driver control over the brightness during dusk and darkness conditions.

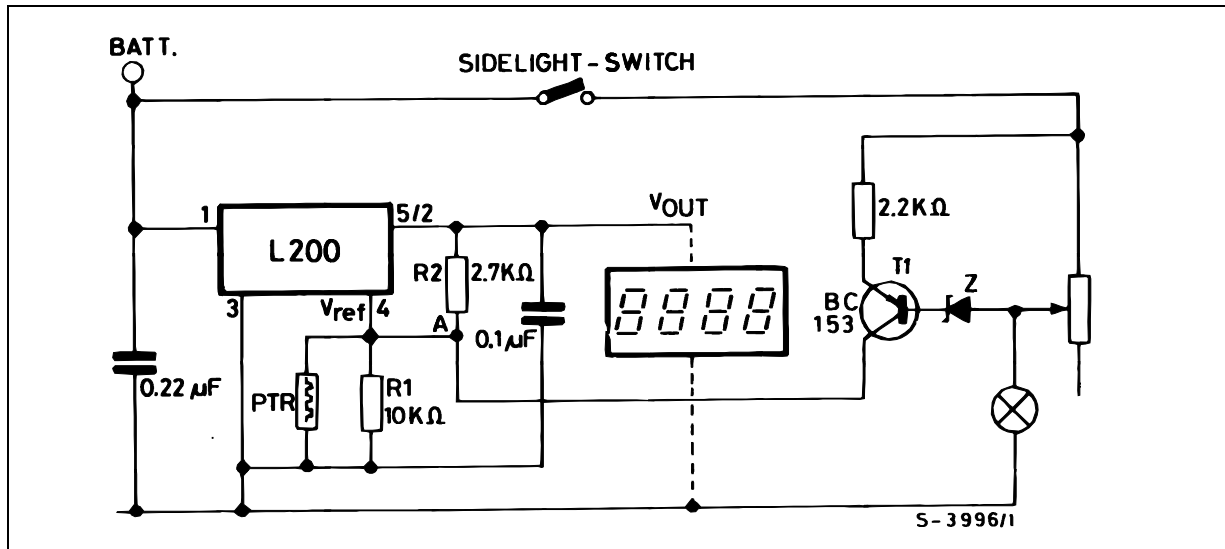
The circuit is shown in fig. 13. The primary supply is shown taken straight from the car battery however it is worth noting that in a car there is always the risk of dump voltages up to 120 V and it is recommended that some form of protection is included against this.

Under daylight conditions i.e. with sidelights off and T1 not conducting the output of the device is determined by the values of R1, R2 and the photoresistor (PTR). The output voltage is given by

$$V_{out} = V_{ref} \left(1 + \frac{R2}{PTR/R1} \right)$$

If the ambient light intensity is high, the resistance of the photoresistor will be low and therefore V_{out} will be high. As the light decreases, so V_{out} decreases dimming the display to a suitable level.

Figure 13.



In dusk conditions, when the sidelights are switched on, T1 starts to conduct with its conduction set by the potentiometer wiper at its uppermost position the sidelights are at their brightest and current through T1 would be a minimum. With the wiper at its lowest position obviously the opposite conditions apply.

The current through T1 is felt at the summing node A along with the currents through R2 and the parallel network R1, PTR. Since V_{ref} is constant the current flowing through R1, PTR must also be constant. Therefore any change in the current through T1 causes an equal and opposite change in the current through R2. Therefore as I_{T1} increases, V_{out} decreases i.e. as the brightness of the side-lights is increased or decreased so is the brightness of the display.

The values of R2 and PTR should be selected to give the desired minimum and maximum brightness levels desired under both automatic and manual conditions although the minimum brightness under manual conditions can also be set by the maximum current flowing through T1 and, in any case, this should not exceed the maximum current through R2 under automatic operation.

The circuit shown with a small modification can also be used for dimmers other than in a car. Fig. 15 shows the modification needed. The zener diode should have a $V_F \geq 2.5$ V at $I = 10$ A.

HIGHER INPUT OR OUTPUT VOLTAGES

Certain applications may require higher input or output voltages than the device can produce. The problem can be solved by bringing the regulator back into

Figure 14.

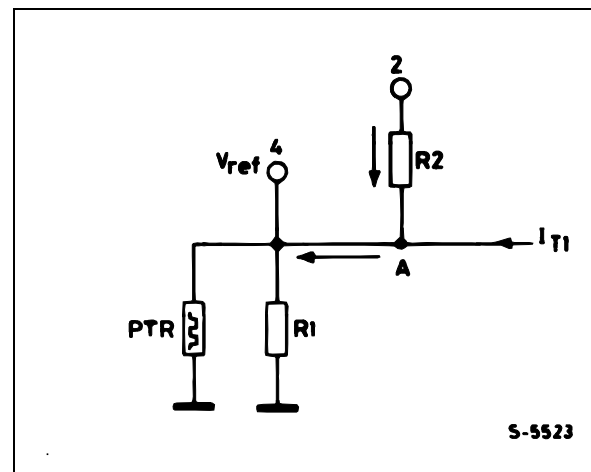
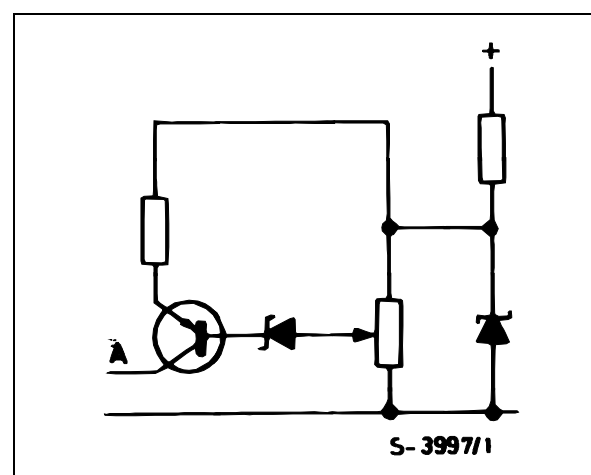


Figure 15.



APPLICATION NOTE

the normal operating units with the help of external components.

When there are high input voltages, the excess voltage must be absorbed with a transistor. Figs. 16 and 17 show the two circuits :

Figure 16.

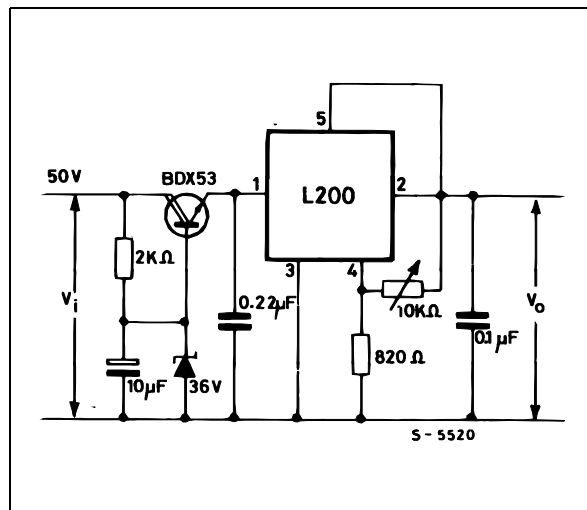
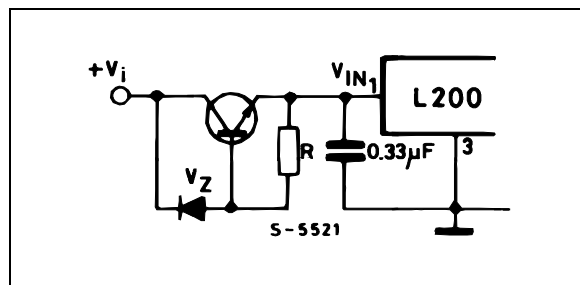


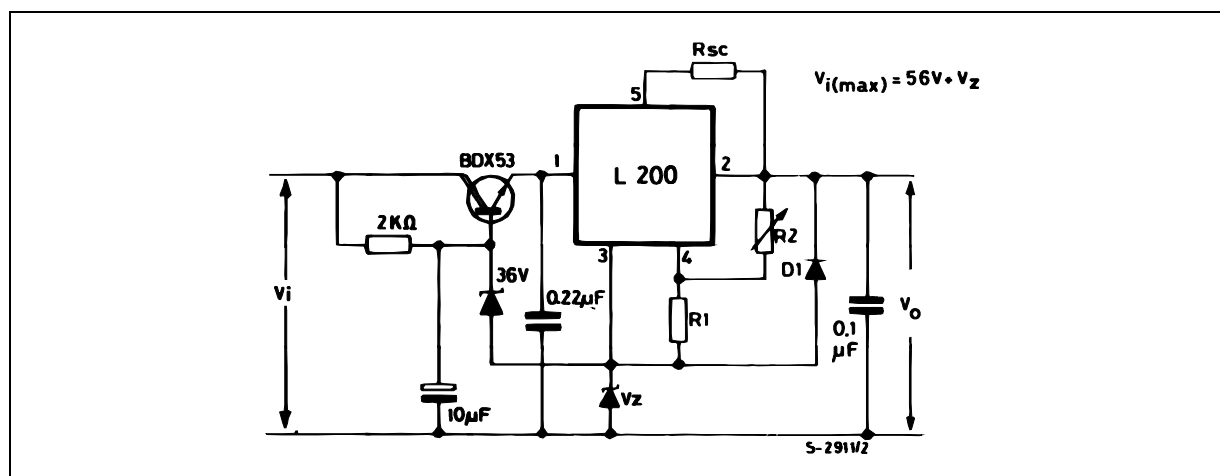
Figure 17.



The designer must take into account the dissipated power and the SOA of the preregulation transistor. For example, using the BDX53, the maximum input voltage can reach 56 V (fig. 16). In these conditions we have 20 V of V_{CEon} on the transistor and with a load current of 2 A the operation point remains inside the SOA. The preregulation used in fig. 16 reduces the ripple at the input of the device, making it possible to obtain an output voltage with negligible ripple.

If high output voltages are also required, a second zener, V_Z , is used to refer the ground pin of an IC to a potential other than zero ; diode D1 provides output shortcircuit protection (fig. 18).

Figure 18.



POSITIVE AND NEGATIVE VOLTAGE REGULATORS

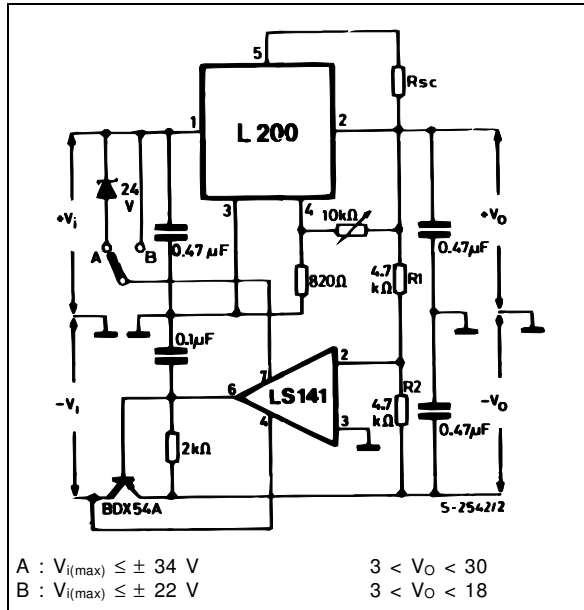
The circuit in fig. 19 provides positive and negative balanced, stabilized voltages simultaneously. The L200 regulator supplies the positive voltage while the negative is obtained using an operational amplifier connected as follower with output current booster.

Tracking of the positive voltage is achieved by putting the non-inverting input to ground and using the inverting input to measure the feedback voltage coming from divider R1-R2.

The system is balanced when the inputs of the operational amplifier are at the same voltage, or, since one input is at fixed ground potential, when the voltage of the intermediate point of the divider goes to 0 Volts. This is only possible if the negative voltage, on command of the op-amp, goes to a value which will make a current equal to that in R1 flows in R2. The ratio which expresses the negative output voltage is :

$$V^- = V^+ \cdot \frac{R_2}{R_1} \quad (\text{If } R_2 = R_1, \text{ we'll get } V^- = V^+)$$

Figure 19.

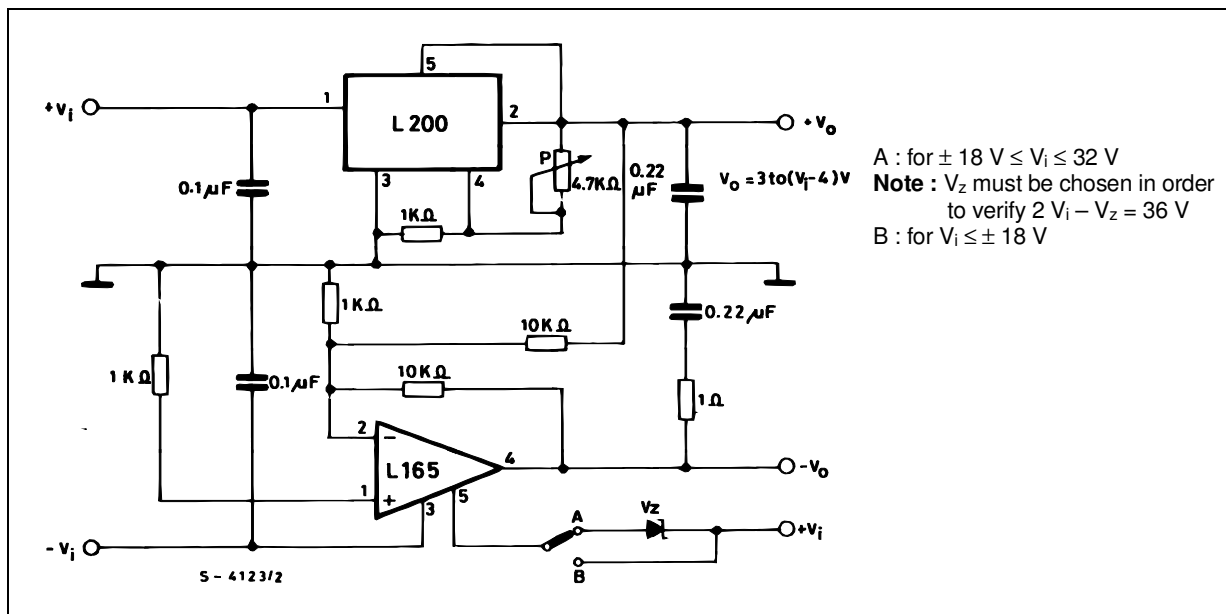


Since the maximum supply voltage of the op amp used is $\pm 22 \text{ V}$, when pin 7 is connected to point B output voltages up to about 18 V can be obtained. If on the other hand pin 7 is connected to point A, much higher output voltages, up to about 30 V , be obtained since in this case the input voltage can rise to 34 V .

Fig. 20 shows a diagram in which the L165 power op amp is used to produce the negative voltage. In this case (as in fig. 19) the output voltage is limited by the absolute maximum rating of the supply voltage of the L165 which is $\pm 18 \text{ V}$. Therefore to get a higher V_{out} we must use a zener to keep the device supply within the safety limits.

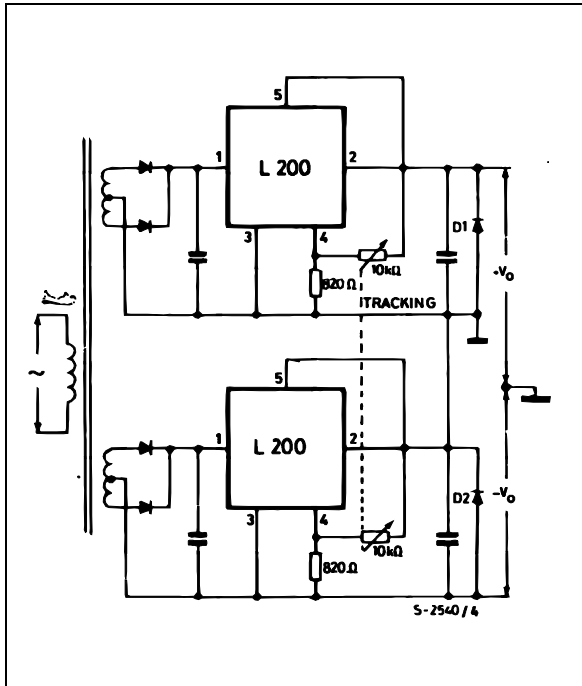
If we have a transformer with two separate secondaries, the diagram of fig. 21 can be used to obtain independent positive and negative voltages. The two output diodes, D1 and D2, protect the devices from shortcircuits between the positive and negative outputs.

Figure 20.



APPLICATION NOTE

Figure 21.



COMPENSATION OF VOLTAGE DROP ALONG THE WIRES

The diagram in fig. 22 is particularly suitable when a load situated far from the output of the regulator has to be supplied and when we want to avoid the use of two sensing wires. In fact, it is possible to compensate the voltage drop on the line caused by the load current (see the two curves in fig. 23 and 24). R_K transforms the load current I_L into a proportional voltage in series to the reference of the L200. $R_K I_L$ is then amplified by the factor

$$\frac{R_2 + R_1}{R_1}$$

With the values of R_Z , R_2 and R_1 known, we get :

$$R_K = R_Z \frac{R_1}{R_1 + R_2}$$

R_Z , R_1 and R_2 are assumed to be constant.

If R_K is higher than 10Ω , the output voltage should be calculated as follows :

$$V_O = I_d R_K + V_{ref} \frac{R_2 + R_1}{R_1}$$

Figure 22.

