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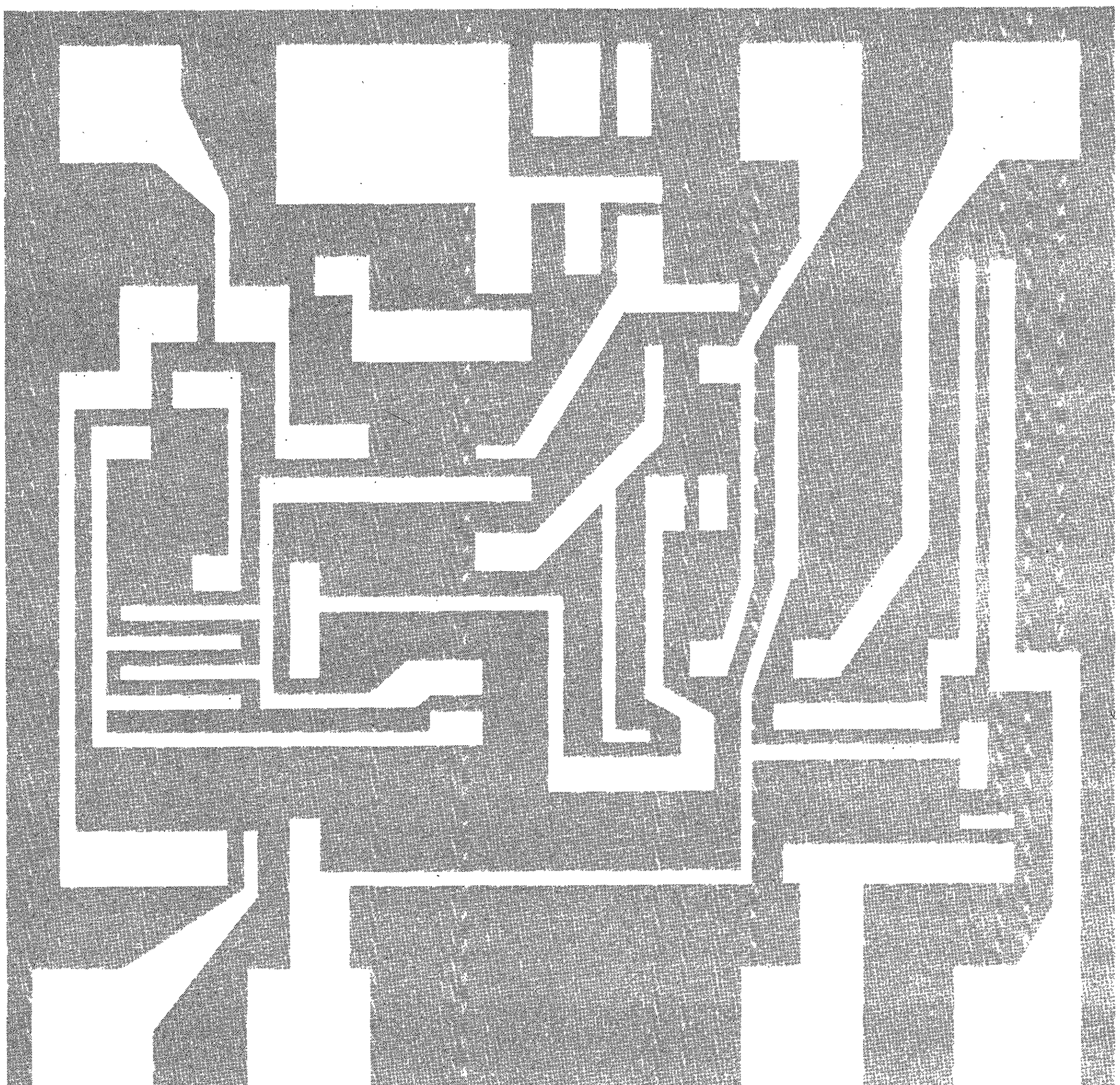
A VERSATILE, MONOLITHIC VOLTAGE REGULATOR



INTRODUCTION

The great majority of linear integrated circuits being produced today are DC amplifiers, particularly operational amplifiers. This has come about both because the DC operational amplifier is a basic analog building block and because this device makes good use of the well-matched characteristics of monolithic components, characteristics which are normally expensive to duplicate with discrete parts. A voltage regulator is a circuit which requires similar precision. As shown in the diagram of Figure 1, a basic regulator circuit employs an operational amplifier to compare a reference voltage with a fraction of the output voltage and control a series-pass element to regulate the output.

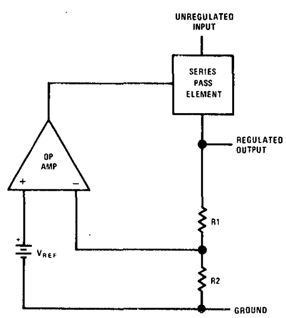


FIGURE 1. Basic Series-Regulator Circuit

Perhaps the reason that monolithic regulators have not appeared sooner is because it is difficult to make one design flexible enough to satisfy an appreciable percentage of the market. Different systems require vastly different output voltages and currents, as well as varying degrees of regulation. In addition, the current handling ability of monolithic circuits is limited because of the large physical die size of high-current transistors. Power dissipation is also a factor, since there are no readily available multi-lead power packages for integrated circuits.

A design is presented here which is versatile enough to overcome many of these problems. It is able to deliver regulated voltages which are externally adjustable from 2V to 30V, operating as either a linear, dissipating regulator or a high efficiency switching regulator. This covers the range from low-level logic circuits to the majority of solid-state linear systems. Although the output current of the integrated circuit is limited (12 mA), an external transistor can be added for currents to 250 mA. A second external power transistor will enable the regulator to deliver currents in excess of 2A.

The regulation is better than 1-percent for widely varying load and line conditions. The device also features 1-percent temperature stability over the full military temperature range, externally adjustable short-circuit-current limiting, fast response to both load and line transients, a small standby power dissipation, freedom from oscillations with varying resistive and reactive loads, and the ability to self start with any load.

VOLTAGE REFERENCE

The voltage reference of a regulator is normally a temperature compensated avalanche diode. Commercially available diodes have a breakdown voltage temperature coefficient of 0.01-percent/°C to 0.0005/°C, depending on selection. Normal integrated circuit processing yields an avalanche diode with acceptable characteristics for this application. The reversed-biased emitter-base junction of the transistors has a breakdown voltage of approximately 6.5V and an unusually uniform temperature coefficient of +2.3 mV/°C. Hence, the positive temperature coefficient of the avalanche diode can be very nearly balanced out by a forward biased, diode-connected transistor to produce a temperature compensated reference. However, exact compensation requires surface impurity concentrations in the transistor-base diffusion which are higher than desired to produce optimized transistors. One design objective of an integrated regulator is, then, to develop a reference element which permits nearly-exact compensation without requiring process alteration.

Another design objective is also centered around the reference. In the regulator circuit of Figure 1, the output voltage can be adjusted down to, but not lower than, the reference voltage. This means that, unless additional circuitry is incorporated, the reference restricts the use of the regulator to applications requiring output voltages above about 8V. It is therefore desirable to obtain as low as possible a reference voltage.

A circuit which provides a simple solution to the temperature compensation problem in addition to supplying a low reference voltage is shown in Figure 2. In this circuit, the breakdown diode is supplied by a current source from the unregulated supply. An emitter follower, Q_1, buffers the output voltage of the diode. The positive temperature coefficient of this buffered output is increased to approximately 7 mV/°C by the addition of the diode connected transistor, Q_2.

A resistor divider reduces this voltage as well as the temperature coefficient to exactly compensate for the negative temperature coefficient of Q_3, producing a temperature compensated output. With the integrated circuit process used, this output voltage is about 1.8V for optimum compensation.

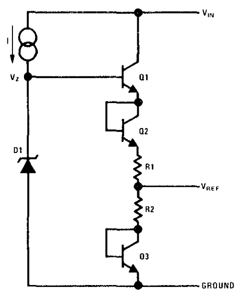


FIGURE 2. Voltage Reference Circuitry

One feature of this integrated reference is that the reverse emitter base breakdown, must have an extremely sharp knee (even in the 1 μA region) in order for the transistors in the circuit to be acceptable. Therefore, the diodes can be reliably operated at low currents where the noise is low and has a nearly uniform frequency spectrum. At higher currents (above about 100 μA for these particular devices) the noise becomes a sensitive function of current with low-repetition-rate pulsations. At even higher currents, the noise reduces in amplitude and loses its current sensitivity but still retains a heavy fluctuation component.

REGULATOR CIRCUIT

A simplified schematic of the regulator is shown in Figure 3. It is a single-stage differential amplifier with a Darlington, emitter-follower output.

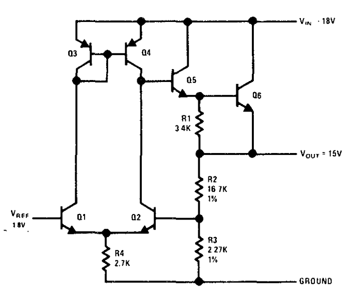


FIGURE 3. Simplified Schematic of the Regulator

The gain of this stage is made much higher than would normally be expected by the use of Q_3 and Q_4 as collector loads. If very large PNP current gain and good matching are assumed, the collector current of Q_4 will be equal to the collector current of Q_1. Therefore, the differential stage will be in balance independent of the magnitude of the collector currents of Q_1 and Q_2 and for the complete range of output voltage settings and input voltage variations. Even this simple circuit gives a no load to full load regulation of 0.2-percent and a line regulation of 0.05-percent per volt.

The complete schematic of the regulator in Figure 4 shows several additions. First, an emitter follower,

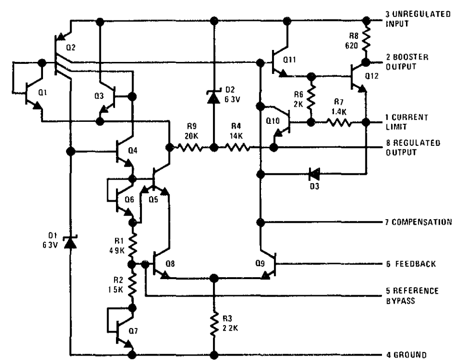


FIGURE 4. Complete Schematic of the LM100

Q_3, and a level-shifting diode, Q_1, have been added to increase the effective current gain of the PNP transistor, Q_2. This device is a lateral PNP which has a low current gain (0.5 to 5) but has the advantage that it can be made without adding any steps or process controls to the normal NPN integrated circuit process. One collector of the PNP serves as a collector load for the error-sensing transistor, Q_9. A second collector supplies current for the breakdown diode, D_1. A third collector, which determines the output current of the other two, maintains a current nearly equal to the collector current of Q_4 by means of negative feedback to the PNP base through Q_3 and Q_1.

The collector current of Q_4 is established at a known fraction of the resistive divider current through R_1 and R_2 by the second emitter on Q_5. This emitter-base junction of Q_5, which is five times larger than that of Q_6, bypasses most of the divider current, at a ratio determined by the relative geometries, to the collector of Q_5. This current, combined with the collector current of Q_8 through the other emitter of Q_5, supplies current for the emitter of Q_3 to drive the base of Q_2.

R_4 and R_9 serve the sole purpose of starting the regulator. They only need to supply enough base current to Q_2 to bring the breakdown diode, D_1, up to voltage. Since it can supply many times the required current under worst-case conditions, starting is ensured.

The clamp diode, D_2, reduces the current variation seen by Q_3 with changes in input voltage, improving line regulation. R_9 is a pinch resistor[2] which has a sheet resistivity more than two orders of magnitude higher than diffused base resistors, so it can be made quite small physically. Pinch resistors do have the disadvantages of non-linear voltage-current characteristic, a large temperature coefficient, a low breakdown voltage and rather large production variations in sheet resistivity. However, as shown in Reference 3, these characteristics can be designed around and actually put to good use, as they are here.

The start-up network is connected to the regulator output terminal, rather than ground, so that the internal power dissipation is minimized without requiring large resistance values. Because of this, the load current of the regulator cannot drop below the current supplied from the unregulated input through R_4. If it does, the circuit will no longer regulate. This is not usually a problem, since the resistive divider which sets the output voltage will normally draw enough current. However, it should be kept in mind in applications where the regulator might be lightly loaded and the difference between the unregulated input voltage and the regulated output voltage is apt to be high.

The collector of the output transistor, Q_{12}, is brought out separately to permit the addition of an external PNP transistor for higher currents. An emitter-base resistor for the external PNP, R_8, is also included. This resistor is shorted out when the regulator is used without the external transistor.

The output of the voltage reference is brought out so that the inherent noise of the breakdown diode can be bypassed out. Since the low operating current of the diode minimizes low-frequency noise, adequate bypassing can be provided by a capacitor as small as 0.1 μF.

The purpose of the clamp diode, D_3, is to keep Q_9 from saturating when the circuit is used as a switching regulator. It plays no functional role in linear operation.

Output-current limiting is provided by Q_{10}. The value of current limit is determined by an external resistor between the current limit, and regulated output terminals. When the voltage drop across this resistor becomes high enough to turn on Q_{10}, it removes base drive from Q_{11} to prevent any further increase in output current. It can be seen from Figure 4 that the voltage turning on Q_{10} is the voltage drop across the external current limit resistor plus a fraction of the emitter-base voltage of the series pass transistor, Q_{12}. This arrangement was used for two reasons. First, less voltage is dropped across the current limit resistor, permitting the circuit to regulate with lower input voltages. Second, since in current limit Q_{12} is operated at a much higher emitter-current density than is Q_{10}, it has a lower negative temperature coefficient of emitter-base voltage. The negative temperature coefficient of the emitter-base voltage of Q_{10} along with this difference in temperature coefficients causes the current limit to decrease by a factor of 2 as the chip temperature increases from 25°C to 150°C. This enables the regulator to deliver maximum current to room temperature but still be protected when the output is shorted and the dissipation increases: the current will decrease as the chip heats, holding the dissipation to a safe level.

It is interesting to note that this current limit scheme will only work when the two transistors are in close thermal contact, as they are in a monolithic integrated circuit.

Since a regulator is an operational amplifier with a large amount of feedback, frequency compensation is required to prevent oscillations. However, a voltage regulator has compensation problems in addition to those encountered in an operational amplifier. For one, the compensation method must provide a high degree of rejection to input voltage transients. Secondly, it must be stable with reactive loads which are far heavier than those normally encountered with operational amplifiers. Thirdly, it must minimize the overshoot caused by large load and line transients.

A compensation method satisfying those requirements is shown in Figure 5. The operational amplifier is connected as an integrator and isolated

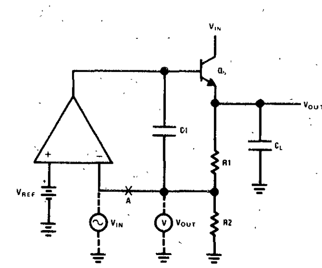


FIGURE 5. Simplified Schematic Showing Regulator Frequency Compensation

from the load with an emitter follower, which serves as a series pass transistor. If the feedback loop is opened at point A and the frequency response measured, it can be seen that the feedback at high frequencies where the loop response must be controlled is through C_F. Reactive loads have little effect since they are isolated from the high frequency feedback path by Q_5.

This compensation method provides excellent response to load transients. That part of a load transient which is not absorbed by the output capacitor, C_L, sees the output impedance of Q_5 which is quite low since it is driven by an operational amplifier with a low AC output impedance.

In the actual regulator (Figure 4) the operational amplifier is a single stage amplifier (Q_9). Hence, it is stable in the integrator connection, with a collector base capacitor on Q_9, without additional compensation which might degrade either the load or line transient response. The series pass transistor is a compound emitter follower to insure isolation from reactive loads. In addition, the stability of the circuit is not dependent on the output impedance of the unregulated supply. It is also stable with no bypass capacitance on the output (if external booster transistors are not used) so it is possible to obtain extremely rapid current limiting as might be required with sensitive transistor loads.

A photomicrograph of the monolithic regulator die is shown in Figure 6. Since the design requires a minimum of resistance, substituting active devices where possible, the entire circuit has been constructed on a 38-mil-square die. This die size is comparable to that of a single silicon transistor.

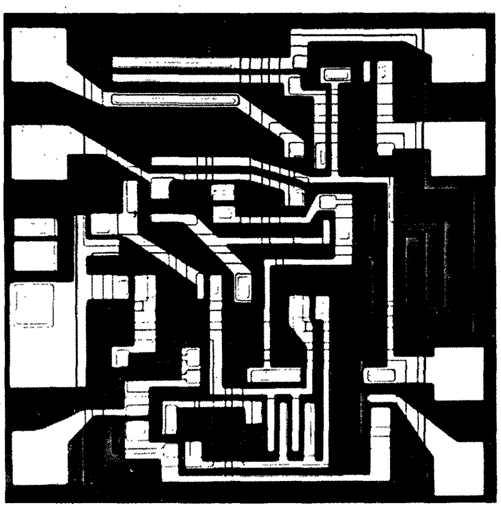


FIGURE 6. Photomicrograph of the LM100 Regulator

APPLICATIONS

The basic regulator circuit for the LM100 is shown in Figure 7. The output voltage is set by R_1 and

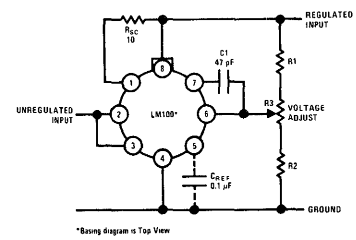


FIGURE 7. Basic Regulator Circuit

R_2, with a fine adjustment provided by the potentiometer, R_3. The resistance seen by the feedback terminal should be approximately 2.2k to minimize drift caused by the bias current on this terminal. Figure 8 is based on this and gives the optimum

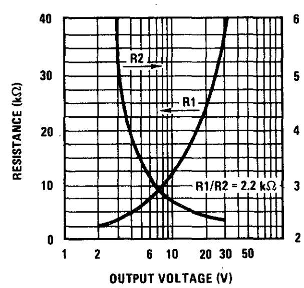


FIGURE 8. Optimum Divider Resistance Values as a Function of Output Voltage

values for R_1 and R_2 as a function of design-center output voltage. The potentiometer should be least 1/4 of R_2 to insure that the output can be set to the desired voltage.

It is possible to operate the regulator with or without internal current limiting. If current limiting is not needed, improved load regulation can be realized by shorting together the current limit terminals ($R_{SC} = 0$). Figure 9 gives the load regulation for this condition. Short circuit protection is obtained by connecting a resistor between the current limit terminals. The resistor value is determined from the current limit sense voltage which is plotted as a function of temperature in Figure 10, for low output currents which corresponds to the case where external booster transistors are used. The current limit sense voltage is the voltage across the current limit terminals when the regulator is current limiting with the output shorted. The regulation and current limit characteristics with a 10Ω current limit resistor are given in Figures 11 and 12, respectively.

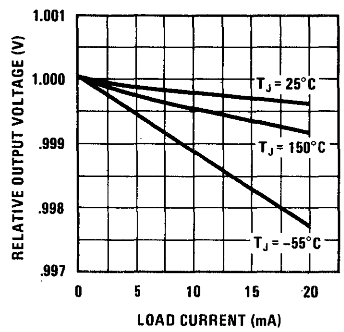


FIGURE 9. Regulation Characteristics Without Current Limiting

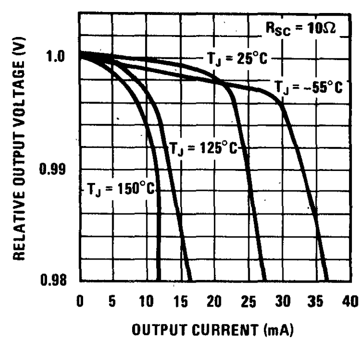


FIGURE 11. Regulation Characteristics with Current Limiting

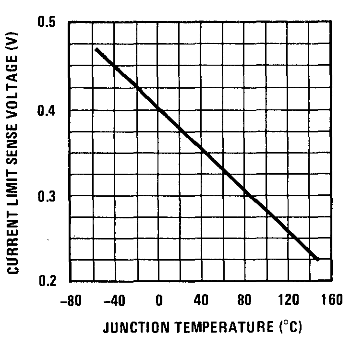


FIGURE 10. Current Limit Sense Voltage as a Function of Junction Temperature

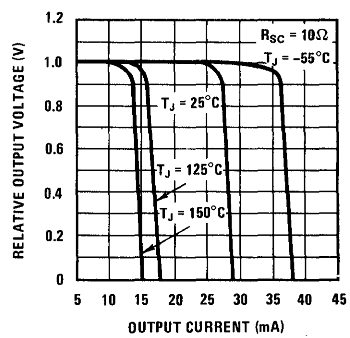


FIGURE 12. Current Limiting Characteristics

A bypass capacitor is not required on the regulator output in the circuit of Figure 7. This permits extremely fast current limiting. The output impedance as a function of frequency is plotted in Figure 13 for this condition. The output impedance at high frequencies can be reduced somewhat by the addition of a bypass, as shown in Figure 13. However, it is necessary to use a low-inductance capacitor (such as a solid-tantalum capacitor) to gain any real advantage. Similarly, bypassing on the unregulated input is not normally needed, although it may be advisable to use a small (0.01 μF) ceramic capacitor when the regulator is fed through long leads which can look like a high-Q resonant circuit.

A reduction in the output noise can be realized by the addition of a 0.1 μF capacitor on the reference bypass terminal. This reduces the noise inherent in the reference diode.

The transient response of the regulator is shown in Figures 14 and 15. Figure 14 shows the response to a current step from 3 mA to 15 mA, without any output bypass capacitor and with a 10Ω current limit resistor. The overshoot can be reduced both by the addition of an output bypass capacitor and by the removal of the current limit resistor since the overshoot is developed across the resistor. The response to a line voltage transient is shown in Figure 15. Neither the line transient response nor the load transient response is affected by the output voltage setting. Therefore, the overshoot becomes a smaller percentage of the output voltage as this voltage is increased.

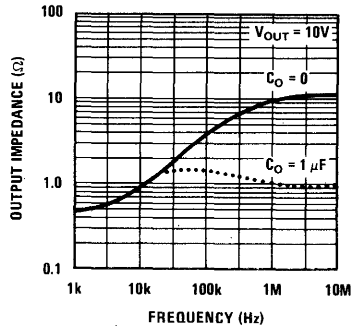


FIGURE 13. Output Impedance as a Function of Frequency

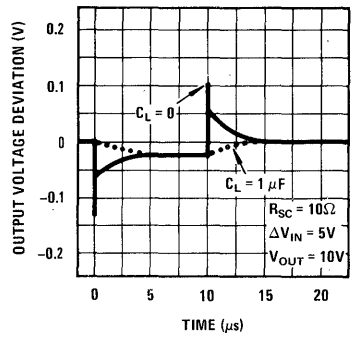


FIGURE 15. Line Transient Response

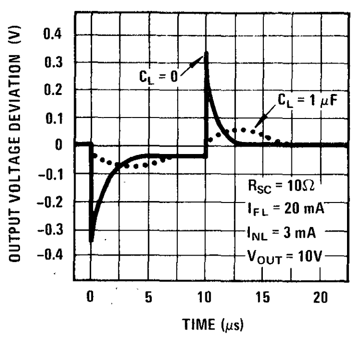


FIGURE 14. Load Transient Response

The regulator provides a line regulation of 0.1-percent per volt change in input voltage. The full-load regulation is better than 0.5-percent. The output voltage drift is less than 1-percent for a temperature change from +25°C to either the −55°C or +125°C temperature extreme. The regulator will operate within specifications for output voltages between 2V and 30V, for input voltages between 8.5V and 40V, for a difference between the input and output voltage between 3V and 30V and over −55°C to +125°C temperature range. This applies whether the regulator is used alone or with external current-boosting transistors.

The load and line regulation given above is for a constant chip temperature on the integrated circuit. Temperature drift effects caused by internal heating must be taken into account separately when the device is operated under conditions of high dissipation.

HIGH POWER REGULATORS

Increased output current capability and improved load regulation can be obtained by the addition of external transistors. The output currents achievable are in fact limited only by the power dissipating and current handling capabilities of the external transistors. The use of these external transistors as the series pass elements also reduces internal dissipation in the integrated circuits and prevents the temperature drift mentioned above.

One circuit which is capable of up to 200 mA load current with 1-percent regulation is shown in Figure 16. The load characteristics are essentially the same as those given in Figures 11 and 12 except that the current scale is multiplied by a factor of 10.

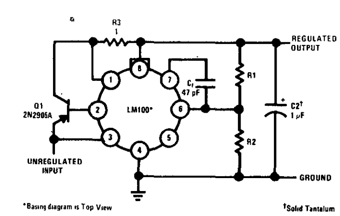


FIGURE 16. Regulator Connected for 200 mA Output Current

When external transistors are used, it is necessary to bypass the output terminal close to the integrated circuit. This is required to suppress oscillations in the minor feedback loop around the external transistor and the output transistor of the integrated circuit (Q_{12} in Figure 4). Since the instability is inclined to occur at high frequencies, a low inductance (solid tantalum) capacitor must be used. Electrolytic capacitors which have a high equivalent series resistance at high frequencies are not effective.

It is not always necessary to bypass the input of the regulator in Figure 16, although it would be advisable if the regulator were being operated from long supply leads or from a source with unknown output impedance characteristics. Again, if a bypass is used, it should be of the low-inductance variety and located close to the regulator.

If output currents much greater than about 200 mA are required, it becomes necessary to add a second external transistor to provide more current gain. The method of accomplishing this is shown in Figure 17. The PNP transistor, Q_2, is used to drive

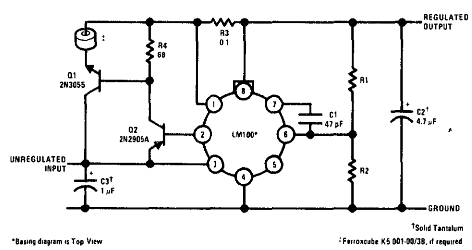


FIGURE 17. Regulator Connected for 2A Output Current

a NPN power transistor, Q_1. With this circuit it is necessary to bypass both the input and output terminals of the regulator, as indicated, with low inductance capacitors to prevent oscillation in the minor feedback loop through Q_2, Q_1 and the output transistor of the integrated circuit. In addition, with certain types of NPN power transistors, it may be necessary to install a ferrite bead[4] in the emitter lead of the device to suppress parasitic oscillations in the power transistor.

The load characteristics of the circuit are again essentially the same as those given in Figures 11 and 12 except that the current scale is multiplied by a factor of 100. As before, the line regulation, temperature drift, etc., are all the same as for the basic regulator.

Another high-power regulator is shown in Figure 18. This circuit is a minor variation of that described previously and is useful when low output voltages

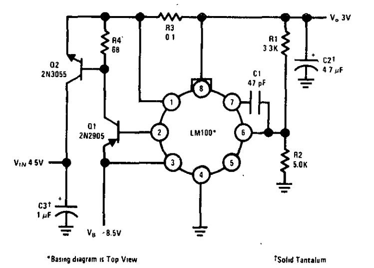


FIGURE 18. Circuit for Obtaining Higher Efficiency Operation with Low Output Voltages

are required. Here, the series pass transistor, Q_2, and the regulator are operated from separate supplies. The series pass transistor is run off of a low voltage main supply which minimizes the input-output differential for increased efficiency. The regulator, on the other hand, operates from a low power bias supply with an output greater than 8.5V.

With this circuit, care must be taken that Q_2 never saturates. Otherwise, Q_1 will try to supply the entire load current and destroy itself, unless the bias supply is current limited.

SWITCHBACK CURRENT LIMITING

With high power regulators it is possible to run into excessive power dissipation when the output is shorted, even though the regulator has current limiting. This happens, with normal current limiting, because the series pass transistor must dissipate the power generated by the full input voltage at a current slightly above the full load current. This dissipation can easily be three times the worst case dissipation in normal operation at full load.

This problem can be overcome by reducing the short circuit current to a value substantially less than the full load current. A circuit for doing this with the LM100 is shown in Figure 19, along with the current limit characteristics obtained. As can be seen from the schematic, two components are added to achieve this — R_4 and R_5. These resistors supply a voltage which bucks out the voltage drop across the current limit sense resistor, R_3, thereby increasing the maximum load current from 0.5A to 2.0A. When the output is shorted, however, this bucking voltage is no longer generated so the short circuit current is only 0.5A.

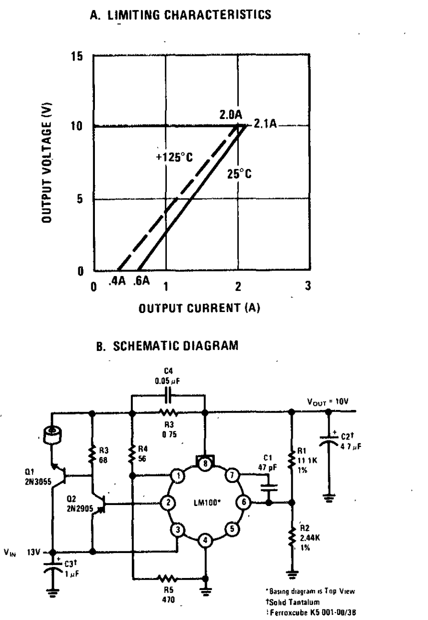


FIGURE 19. Circuit for Obtaining Switchback Current Limiting with the LM100

In this circuit, the voltage drop across the current-sense resistor at full load is 1.5V as compared to about 0.37V when the bucking arrangement is not used. However, this does not increase the minimum input-output voltage differential since the output of the LM100 does not see this increased voltage. With a 10V output and a 2A load, the circuit will still work with input voltages down to 13V, worst case.

In addition to providing the switchback characteristics, R_4 and R_5 also give a 20 mA preload on the regulator so that it can be operated without a load.

NEGATIVE VOLTAGE REGULATORS

A schematic diagram for using the LM100 as both a positive and a negative regulator is shown in Figure 20. With this circuit, the inputs and outputs of both regulators have a common ground.

The positive regulator is identical to those described previously. For the negative regulator, the normal output terminal (pin 8) of the LM100 is grounded, and the ground terminal (pin 4) is connected to the regulated negative output. Hence, as in the usual mode of operation, it regulates the voltage between the output and ground terminals. A PNP booster transistor, Q_2, is connected in the normal manner; and it drives a NPN series-pass transistor, Q_3. The additional components (R_7, R_8, R_9, R_{10} and Q_4) are included to provide current limiting.

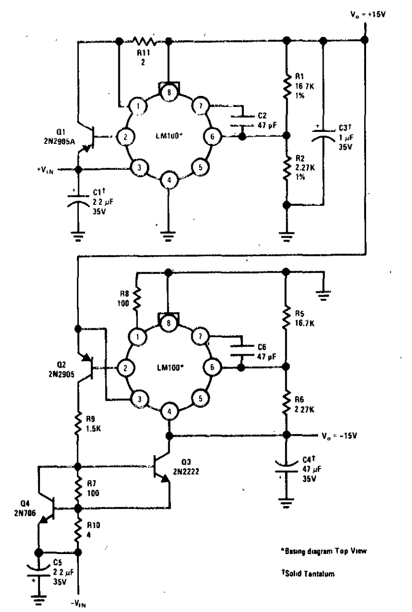


FIGURE 20. Positive and Negative Regulators using the LM100

Figure 21 shows a somewhat simpler circuit. Split secondaries are used on a power transformer to create a floating voltage source for the negative regulator. With this floating source, the conventional regulator is used, except that the output is grounded.

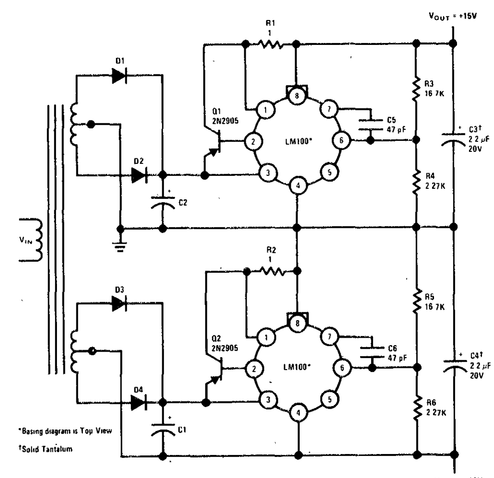


FIGURE 21. Circuit for using the LM100 as Both a Positive and a Negative Regulator

TEMPERATURE COMPENSATING REGULATORS

In the majority of applications, it is desired that the output voltage of the regulator be constant over the operating temperature range of equipment. However, in some applications, improved performance can be realized if the output voltage of the regulator changes with temperature in such a way as to operate the load at its optimum voltage.

An example of this in integrated logic circuitry. Optimum performance can be realized by powering the devices with a voltage that decreases with increasing temperature. A circuit which does this is shown in Figure 22. Silicon diodes are used in

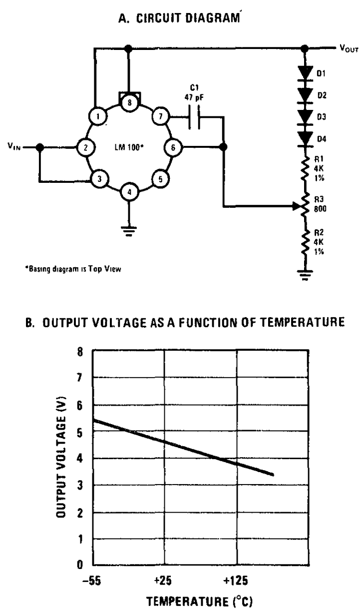


FIGURE 22. Temperature Compensating Voltage Regulator with Negative Temperature Coefficient

the feedback divider to give the required negative temperature coefficient. The advantage of using diodes, rather than thermistors or other temperature sensitive resistors, is that their temperature coefficient is quite predictable so it is not necessary to make cut-and-try adjustments in temperature testing. Reference 6 gives a method of predicting the voltage change in the emitter base voltage of a transistor within 5 mV over a 100°C temperature change. Diodes are not quite this predictable, but diode connected transistors (base shorted to collector) can be used if greater accuracy is required.

SWITCHING REGULATORS

The dissipating-type regulators described already have the advantages of fast response to load transients as well as low noise and ripple. However, since they must dissipate the difference between the unregulated supply power and the output power, they sometimes have a low efficiency. This is not always a problem with AC line-operated equipment because the power loss is easily afforded, because the input voltage is already fairly well regulated, and because losses can be minimized by adjustment of transformer ratios in the power supply. In systems operating from a fixed DC input voltage, the situation is often much different. It might be necessary to regulate a 28V input voltage down to 10V. In this case the power loss can quickly become excessive. This is true even if efficiency is not one of the more important criteria, since the high power dissipation requirements will necessitate expensive power transistors and elaborate heat sinking methods.

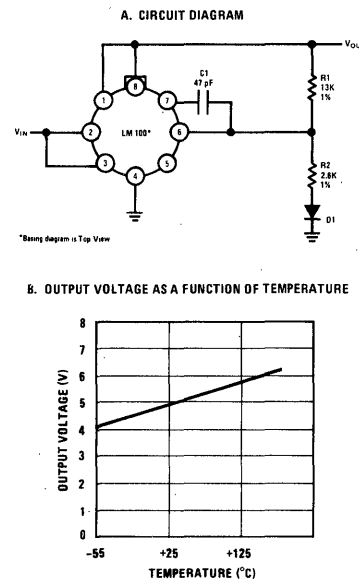


FIGURE 23. Temperature Compensating Voltage Regulator with Positive Temperature Coefficient

One way of overcoming this difficulty is to go to a switching regulator. With switching regulators, efficiencies approaching 90-percent can be realized even though the regulated output voltage is only a fraction of the input voltage. By proper design, transient response and ripple can also be made quite acceptable.

A circuit using the LM100 as a switching regulator is given in Figure 24. It is designed for an application where a 28V DC power source must supply a system operating at 10V.

As shown in Figure 24, the LM100 is connected in much the same way as a linear regulator when

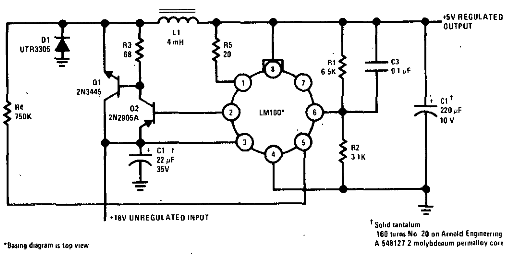


FIGURE 24. High Current Switching Regulator

it is used as a switching regulator. Two external transistors, a NPN and a PNP, are connected in cascade to handle the output current. The regulated output is fed back through a resistive divider which determines the output voltage in the normal manner. The regulator is made to oscillate by applying positive feedback to the reference terminal through R_4 (from Figure 4, the reference terminal is the non-inverting side of the input differential amplifier).

In operation, the switching transistors, Q_1 and Q_2, turn on when the voltage on the feedback terminal is less than that on the reference terminal. This action raises the reference voltage since current is fed into this point from the switch output through R_4. The switching transistors remain on until the voltage on the feedback terminal increases to the higher reference voltage. The regulator then switches off, lowering the reference voltage. It remains off until the voltage on the feedback terminal falls to the lower reference voltage.

When the switch transistors are on, power is delivered from the power source to the load through L_1. When the transistors turn off, the inductor continues to deliver current to the load with D_1 supplying a return path. Since fairly fast rise and fall times are involved, D_1 cannot be an ordinary silicon rectifier. A fast-switching diode must be used to prevent excessive switching transients and large power losses.

Additional details of the circuit are that R_5 limits the output current of the LM100, which drives the base of Q_2. C_3 causes the full output ripple to be delivered to the feedback terminal of the regulator. The bypass capacitor, C_1, is used on the input line both to minimize the voltage transients on this line and to reduce power losses in the line resistance.

A far more complete description of switching regulators is given in Reference 7.

CONCLUSIONS

A regulated power supply is required in practically every piece of electronic equipment. A monolithic integrated circuit was described here which covers an extremely wide voltage range and can supply virtually unlimited power by the addition of external transistors. As indicated in Table 1, its performance is more than adequate for the majority of applications. It is flexible enough to be used as either a linear dissipating regulator or as a high efficiency switching regulator without sacrificing performance in either application. The LM100 also has fast transient response in that overshoot and recovery time can be made vanishingly small in most applications. In addition, the frequency stability is indicated by the fact that it is virtually impossible to make the regulator oscillate in a properly designed circuit.

The suitability of the design to monolithic construction is demonstrated by the fact that it is built on a 38-mil-square silicon die – a size comparable to modern silicon transistors. This small size helps to achieve high yields which are necessary to realize low manufacturing costs and insure off-the-shelf availability.

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TABLE 1. Typical Performance of the National LM100 Voltage Regulator

PARAMETER	CONDITIONS	VALUE
Input Voltage Range		8.5 – 40V
Output Voltage Range		2.0 – 30V
Output-Input Voltage Differential		3.0 – 30V
Load Regulation	$R_{SC} = 0$, $I_O < 15$ mA	0.1%
Line Regulation		0.05%/V
Temperature Stability	$-55°C \leq T_A \leq +125°C$	0.3%
Output Noise Voltage		0.005%
Long Term Stability		0.1%
Standby Current Drain		1 mA
Minimum Load Current		1.5 mA