Lab Notes

Using the LM 396 10A adjustable voltage regulator

Barry Davis

A new voltage regulator using a revolutionary IC fabrication technique has been introduced into the marketplace by National Semiconductor. It is the LM 196/396, a 10 ampere adjustable voltage regulator in a TO-3 package.

THIS NEW regulator has *all the protection features* that hobbyists have taken for granted in the lower power LM117/317 family. It is immune to blowout from excessive output current and all devices are 'burned-in' to guarantee the correct operation of the protection circuits under overload conditions.

The output voltage is adjustable over the range of 1.25 to 15 volts. *The maximum input-output voltage differential* (V_{in} - V_{out}) *is 20 volts,* and higher output voltages are possible providing that this parameter is not exceeded. A full load current of 10 amperes is available at all output voltages; however, the maximum power dissipation (70 watts) and the junction temperature must be watched closely. At a load current of 10 amperes, the maximum permissible V_{in} - V_{out} differential is 7 volts. Under these conditions the power dissipated is —

$V_{in} - V_{out} \times I_{max}$

$= 7 \times 10 = 70$ watts.

The features of the regulator are:

- 10 A guaranteed output current.
- 70 W maximum power dissipation.
- Adjustable output from 1.25 to 15 V.
- 100% burn-in thermal limit.
- Internal current power limiting.
- Input-output voltage differential is 20 V maximum.
- Dropout voltage is approximately 2.1 V.
- TO-3 Package.

The current limit and maximum power dissipation characteristics are shown in Figure 1a and 1b respectively.

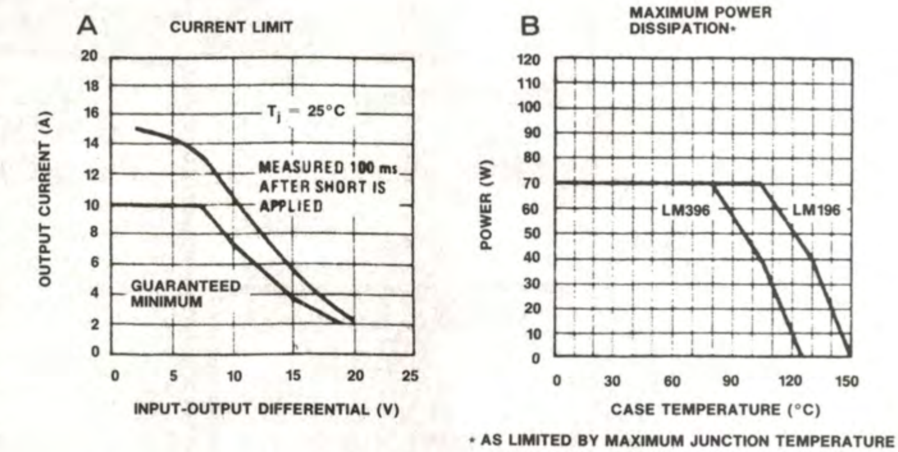

Figure 1. **Current limit and power dissipation**

Application precautions

1. Heatsinking

The major limitation in the output current capability of the regulator is heatsinking. The regulator has extremely high power dissipation, 70 watts continuously, providing that the maximum junction temperature limit is not exceeded. These limits are:

LM 196 -55°C to +150°C
LM 396 0°C to +125°C

Careful attention must be paid to *all* junction thermal resistances. A good heat-conductive paste *must* be used when mounting the regulator on the heatsink. The regulator must also be bolted down nice and tight. To ensure

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Barry Davis is also the author of a text book called 'Understanding dc power supplies', published by Prentice-Hall earlier this year. This book mentions the development of National Semiconductor's 'Moose-process' LM196/396 regulator which very recently became available — hence this article.

the selection of the correct heatsink, the procedure is as follows.

Calculate the *worst case continuous average power dissipation* in the regulator from the formula:

$P = (V_{in} - V_{out}) \times I_{out}$.

The voltage/current characteristics of the unregulated input must be accurate. A small change in input voltage can result in a large increase in the power dissipated by the regulator. For example, normal operating conditions are:

$V_{out} = 10$ V
$V_{in} = 14$ V
$I_{out} = 10$ A
$P = (14 - 10) \times 10$
$= 40$ watts.

If the input voltage increases by 10% to 15.4 volts:

$P = (15.4 - 10) \times 10$
$= 54$ watts

— an increase in power dissipation of 35%.

Therefore, the power supply circuit up to the regulator input (i.e: transformer, rectifier diodes, filter capacitor) plays an important role in the successful operation of the regulator itself. It should be built and tested to determine its average dc output voltage under full load with maximum input voltage. This circuit is shown in Figure 2.

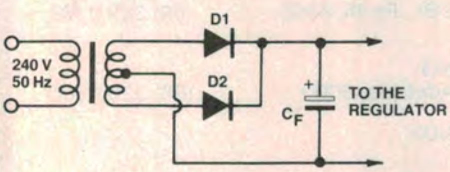

Figure 2. **Circuit prior to the regulator.**

The choice of C_F is also very important. At *high* current levels the capacitor ripple current (RMS) is two to three times the dc output current. If the capacitor has an equivalent series resistance (ESR) of 0.05 ohms, this can cause internal power dissipation (I^2R) of 20 to 45 watts at an output current of 10 amperes.

The life of the capacitor 'derates' with increase in operating temperature, and the choice of a small-value capacitor is asking for trouble (about 2000 µF is used for the LM 317 circuit). A value of some *2000 µF per ampere of load current* is the minimum recommended value. Large values of capacitor will have longer life and will also reduce the ripple

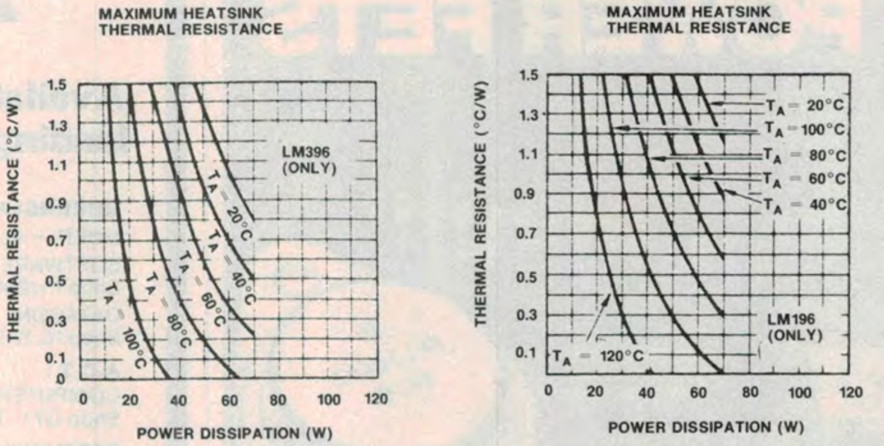

Figure 3. **Heatsink thermal resistance graphs (T_A = Ambient temperature)**

level. This allows a lower dc input voltage to the regulator, which will result in savings in transformer and heatsink costs.

A further idea is to place several capacitors in parallel. This increases the capacitance, reduces the net series resistance and increases the heat dissipating area (i.e: shares it among the capacitors). Once the circuit in Figure 2 has been finalised and the average dc output voltage determined, the thermal resistance of the heatsink can be determined from the graphs in Figure 3, in degrees centigrade per watt (°C/W).

For conservative heatsinking it is recommended that you choose T_A to be 35°C higher than anticipated.

The heatsink resistance generally falls into the range of 0.2°C/W - 1.5°C/W at a $T_A = 60$°C. These are *large* heatsinks such as the Philips 45D6CB, 55D6CB, and the large Minifin. These must be mounted for best convection cooling and could also be cooled by a fan.

2. Transformers

Correct transformer ratings are extremely important in high current supplies. If the secondary voltage is too high, power will be wasted and cause unnecessary power dissipation in the regulator. However, if the secondary voltage is too low it may cause loss of regulation if the input voltage (i.e: mains) fluctuates excessively.

The following formula can be used to calculate the secondary voltage required using the circuit in Figure 2 (full wave centre tap).

$$V_{(RMS)} = \frac{V_{out} + V_{reg} + V_{Rect} + V_{Ripple}}{\sqrt{2}} \times \frac{V_{Nom}}{V_{Low}} \times (1.1) \qquad (1)$$

Where:
1.1 is the factor accounting for load regulation of the transformer.
V_{out} = dc regulated output voltage.
V_{Reg} = Minimum $V_{in} - V_{out}$.
V_{Rect} = Voltage drop (forward) across the diode at $3 \times I_{out}$.
V_{Ripple} = Peak capacitor ripple voltage (½ p-p).

i.e: $\frac{(5.3 \times 10^{-3})\, I_{out}}{2C}$

C is the capacitor value in farads.
V_{Nom} = Normal ac input (RMS).
V_{Low} = Minimum ac input (RMS).

The current rating required can be calculated from the formula:

$$I_{RMS} = I_{out} \times 1.2 \qquad (2)$$

Where I_{out} = dc output current.

Transposing formula (2) we can calculate the value of filter capacitor required:

$$C = \frac{(5.3 \times 10^{-3})\, I_{out}}{2 \times V_{Ripple}} \qquad (3)$$

The best way to appreciate these formulas in use is to calculate the values required for a power supply circuit. If we design a good mobile radio power supply, 13.8 volts at 10 amperes: ▶

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$V_{out} = 13.8$ V
$I_{out} = 10$ A
Assume $V_{Reg} = 2.2$ V, $V_{Rect} = 1.2$ V
$V_{Ripple} = 2$ V p-p, $V_{Nom} = 240$ V
$V_{Low} = 220$ V

Using formula (1)

$$V_{(RMS)} = \left(\frac{13.8 + 2.2 + 1.2 + 1}{\sqrt{2}}\right) \left(\frac{240}{220}\right) 1.1$$

$$= \frac{18.2}{\sqrt{2}} \times 1.09 \times 1.1$$

$$= 12.869 \times 1.09 \times 1.1$$

$$= \underline{15.4 \text{ volts (RMS)}}$$

Using formula (2)

$$I_{(RMS)} = 10 \times 1.2$$

$$= 12 \text{ amperes (RMS)}$$

The transformer must therefore be 240: 30 CT at 12 amperes. The centre tap (CT) will provide 15 volts secondary voltage for each diode.

The size of the filter capacitor required can be calculated using formula (3)

$$C = \frac{(5.3 \times 10^{-3})\ 10}{2 \times 1}$$

$$= 26500\ \mu F$$

The transformer, rectifier and filter circuit is now shown in Figure 4.

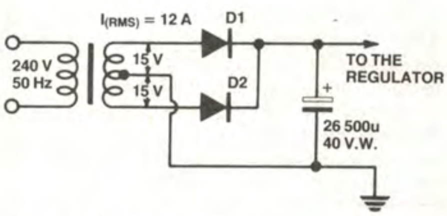

Figure 4. **Rectifier and filter circuit**

3. Diodes

The diodes used in the circuit must have a high dc current rating. The capacitor input filter draws high peak current pulses that are considerably higher than the average dc current. With a 10 amperes supply the average current is 5 amperes. The current pulse's duration and amplitude result in a long-term diode heating of approximately 10 amperes dc. Therefore the diodes should have a rating of at least 10-15 amperes. Also, the power supply may have to survive a short circuit and average current could rise to 15 amperes (see Figure 1a).

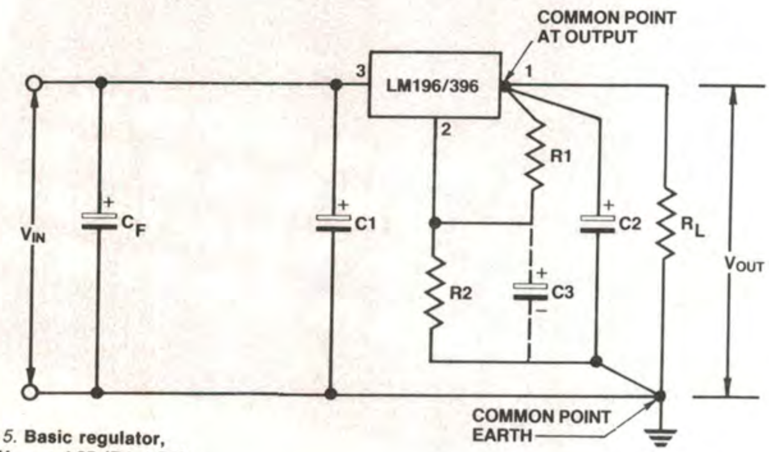

Figure 5. **Basic regulator,** $V_{out} = 1.25 \frac{(R1 + R2)}{R1}$

Another important factor in the choice of diode is the surge current at switch on. The peak *surge current* is about *10-20 times the dc output current* (i.e: 100-200 A for a 10 A supply). (Note: smaller transformers and filter capacitors may be used in lower current supplies. This will reduce the surge current; unless you are sure of the worst case surges, do not economise on diodes.)

Stud-mounted diodes in a DO-4 or DO-5 package are recommended, such as IR 12F10B, IN3209 or 16F10 silicon rectifiers. Remember to choose the correct PIV for the type of transformer in use (PIV = $\sqrt{2}\ V_{Secondary}$).

4. Wiring

High load currents produce higher than normal voltage drops across the resistance of the wiring. It is suggested that 16-18 gauge wire is used for input and output connections, and the *length is kept to a minimum.*

The two resistors used to set the output voltage level are connected:

1. directly to a common point earth and
2. directly to the output of the regulator as shown in Figure 5.

Components in Figure 5.

C_F = Main filter capacitor 26 500 μF.

C1 = 4μ7 tantalum. It is only necessary if the main filter capacitor is more than 150 mm away from the regulator. Connecting wire is 18 gauge or larger.

C2 = 4μ7 tantalum. It is not absolutely necessary, but is recommended to maintain low output impedance at high frequencies.

C3 = 25 μF. Improves ripple rejection, output impedance, and noise. (Capacitor C2 should be close to the regulator if C3 is used).

R1 = 120 ohms. It should be a wirewound or metal film resistor, tolerance 1% or better.

R2 = calculated to set V_{out}; the same type of resistor as R1.

The value of R2 can be calculated from the formula:

$$R_2 = \left(\frac{V_{out}}{1.25}\right) \times R1 - R1$$

Example:

$V_{out} = 13.8$ V
R1 = 120 ohms

$$R2 = \left(\frac{13.8}{1.25}\right) \times 120 - 120$$

$$= (11.04 \times 120) - 120$$

$$= 1324.8 - 120$$

$$= 1204.8 \text{ ohms.}$$

As stated earlier, the package is a TO-3 and the connections are shown in Figure 6. ▶

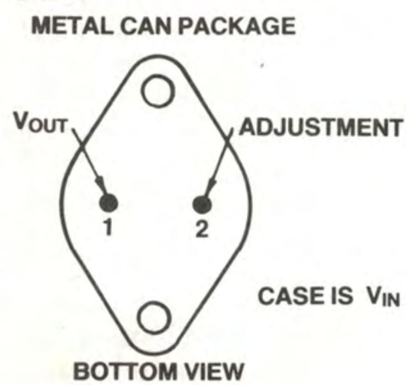

Figure 6. **Connection diagram**

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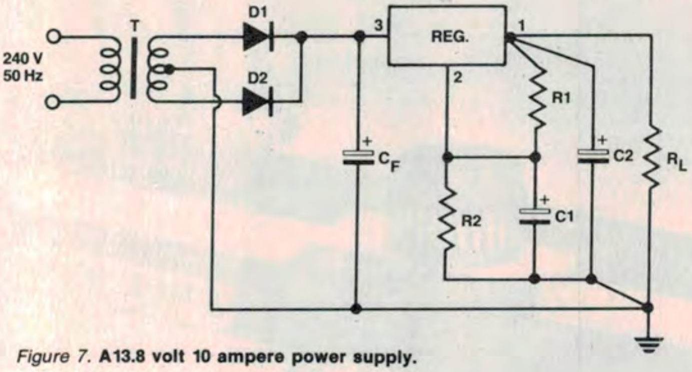

Figure 7. **A13.8 volt 10 ampere power supply.**

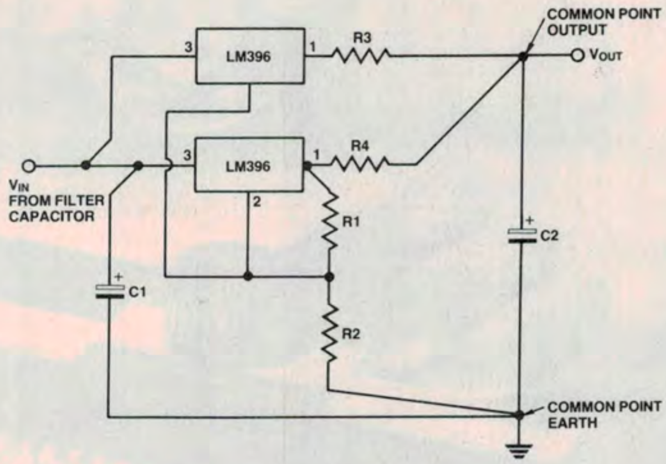

Figure 9. **Quasi-parallel regulators**
R1 = 120 ohms
R2 chosen to set V_{out}
R3, R4 = 0.015 ohms
C1 = 4μ7 tantalum
C2 = 100μF

The complete circuit can now be built, incorporating Figures 4 and 5. The circuit diagram of the final 13.8 V 10 A power supply is shown in Figure 7.

Component values for Figure 7.

T = 240 : 30 CT at 12 amperes.
D1 = 16F10 DO-4 case.
D2 = 16F10 DO-4 case.
CF = 26500 μF 40 VW (ideally, capacitors in parallel).
C1 = 25 μF 16 VW.
C2 = 4μ7 tantalum 16 VW.
R1 = 120 ohms 1% metal film.
R2 = 1k2 1% metal film.
Reg = LM396 on a 6" 55 or 65D heatsink.

$$V_{out} = 1.25\left(\frac{R1 + R2}{R1}\right) = 1.25\left(\frac{120 + 1200}{120}\right) = 1.25 \times 11 = \underline{13.75 \text{ volts}}$$

A highly desirable situation would be to *reduce* the power dissipated by the regulator. This can be achieved by supplying part of the output current around the regulator as shown in Figure 8.

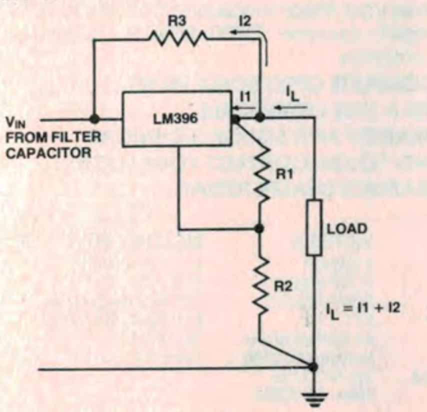

Figure 8. **Reducing regulator power dissipation**

Resistor R3 is selected to supply a portion of the load current. In this case a *minimum load must always be maintained.* This prevents the regulated output from rising uncontrolled. The value of R3 must be greater than:

$$\frac{V_{max} - V_{out}}{I\ min} \text{ ohms}$$

Where: V_{max} is worst case high input voltage.
I_{min} is the minimum load current.
Power rating must also be considered and R3 must be rated at a minimum of:

$$\frac{(V_{in} - V_{out})^2}{R3} \text{ watts}$$

This circuit configuration will reduce the regulator power dissipation by a factor of 2 to 3, if the minimum load current is about 50% of the full load current.

Precautions when using R3

1. The power rating of R3 must be *increased* to $\frac{(V_{max})^2}{R3}$ watts if continuous output short circuits are at all likely.
2. Under short circuit conditions the *overall circuit* power dissipation increases by $\frac{(V_{in})^2}{R3}$ watts.

The regulator and R3 will not be harmed (if R3 is the correct wattage), but the circuit components prior to the regulator (diodes, transformer) must be able to withstand the overload condition (i.e: the power rating is sufficient to handle the excess current).

The only problem with this technique is the large power rating required for resistor R3. If $V_{in} - V_{out} = 7$ volts and R3 = 2 ohms, the power dissipated by the resistor is:

$$\frac{(7)^2}{2} = 24.5 \text{ watts}$$

with 3.5 A of current passing through it.

High Current Output

Placing regulators in parallel is not recommended because they may not share the current equally. The regulator with the highest reference voltage will handle the highest current up to the time it current limits. Therefore, one regulator may be flat out handling 16 A while the other is cool and calm passing only 2 A. Reliability cannot be guaranteed under these conditions because of the high junction temperature of regulator one.

However, if load regulation is not critical, the regulators may be connected quasi-parallel, as shown in Figure 9. This circuit will share current to within 1 ampere, and in the worst case 3 amperes. However, the payoff is in the load regulation. It is degraded by 150 mV at 20 ampere loads compared to about 20 mV with 10 ampere loads. This should not cause too much of a problem in higher voltage power supplies. ●

Acknowledgement

This article was made possible by the courtesy of National Semiconductor. Data and basic circuits were taken from their publication 'LM196/LM396 10 Amp Moose Adjustable Voltage Regulator'.