New Design Techniques to Improve Shunt Regulated D. C. Power Supplies With Foldback Protection


Abstract

This article highlights hitherto unexplored circuit design & techniques, which could be harnessed to improve maximum output load current, efficiency and protection characteristics of a shunt regulated power supply. One advantage lies in achieving foldback protection and variable output characteristics within the framework of an extremely low cost circuit module. Another advantage is its adaptability to extra high current versions using current multiplier transistors whilst preserving the original module characteristics at a low incremental cost.

An optosensor device in a feedback loop could be incorporated to overcome the problem posed by the no load current, which discourages the use of shunt regulators for high currents. Such circuit design techniques as outlined in this article pave the way for a more versatile application of shunt regulators to high handling and variable type output characteristics, ultimately resulting in lower over-all cost of a regulated D. C. power supply.

1. Design of a variable shunt regulated power supply with fold back protection

1.1 Principal features of the resulting circuit:

(a) Variable output voltage and maximum current limit.

(b) Fold back type output protection.

(c) Automatic resetting when over load is removed.

1.2 Resulting characteristics of the prototype.

Regulated output voltage = 3.0 to 22 volts
Maximum Load current = 60 mA-600 mA
Unregulated input voltage necessary = 33 - 42 volts
% Load regulation = 0.3% maximum
Ripple Reduction factor > 70
Maximum ripple voltage < 30 mV p-p.

1.3 Design Method and Circuit Description: In this circuit of figure (1), Q₁ & Q₃ pair constitutes a carefully biased differential amplifier for comparing output voltage sample with the reference.

In this differential amplifier collector load (Iₑ₂) of Q₃ comprises two separate components.

(a) Base current Iₑ₆ of Q₄ via transistor Q₅.

(b) The zener diode current Iₑ₂ through Rₑ.

This condition results in one design equation,

\[ Iₑ₂ = Iₑ₂ + Iₑ₆ \] ........................................ (1)

The output voltage at the collector of Q₄ is applied to Darlington pair of Q₃ & Q₄, which constitutes the main shunt regulating element.

The preset maximum current \( I_{max} \) through Q₃ is controlled by Q₅, \( Z₂ \) & \( R_{v1} \), which forms a constant current generator. The collector current \( Iₑ₆ \) of Q₅ is set by \( Rₑ \) & \( R_{v1} \) where,

\[ Iₑ₆ = \frac{(Vₑ₂ - Vₑ₆)}{Rₑ + R_{v1}} \] ........................................ (2)

(Neglecting \( I_{CBO} \) of Q₄).

The collector load of Q₃ provides the necessary protection to the circuit. When the load current tends to exceed the preset value, the voltage at the base of Q₃ reduces to effectively cut off Q₃. Due to cut off of Q₅, \( Iₑ₂ \) & \( Iₑ₆ \) are eliminated. This combined effect reduces both load current and load voltage to zero simultaneously, giving a fold back type protection. This ensures the safety of the power supply as well as the load. \( C₁ \) and \( C₂ \) capacitors are added to prevent any possible high frequency oscillations. Capacitor \( C₃ \) is added to prevent any possible over-voltage spikes at the output during start up. This capacitor does not practically reduce operation speed and could be eliminated if external O.V. protection circuitry is added.

1.4 Measured output characteristics of the power supply is in Fig. 2. Short circuit current is less than 80 mA for a maximum load current of about 600 mA. Using standard techniques (i.e. Thyristor crowbar protection, etc.) over-voltage protection could be incorporated into the above circuits.
Ripple, Load and line regulations could be improved using standard techniques. Fold back protection in this particular design is achieved without any series resistors to monitor output current and hence could be used as a true three terminal voltage regulator with fold back.

2. Use of this shunt regulator module for high current versions

2.1 Use of an external power transistor is possible to multiply the maximum possible output current of the shunt regulator module, preserving the fold back type output protection.

2.2 A prototype was designed for a maximum current of 4 Amp. at 12 V. output voltage. In this design (ref. Fig. 3a) a series transistor is fed at its base with the shunt control module of the above type and a voltage sampling chain is used at the output to monitor the output voltage to drive the base of \( Q_3 \) of the shunt module.

In the prototype (Fig. 3b) the \( Q_3 - Q_4 \) current source is set for \( I_L/hfe \) for proper tracking.

\[
I = \frac{I_L}{hfe} = \frac{hfe Q_3 (V_{Z3} - V_{be Q_4})}{R_7} \quad \text{(1)}
\]

so that current is most easily set by adjusting resistor \( R_7 \).

The value of this constant current,

\[
I_L = \frac{hfe Q_4 (V_{Z3} - V_{be Q_4})}{R_7}
\]

The shunt module is designed for about 70 - 80mA for maximum load current. In this case short circuit current at output is less than 200 mA. Zener diodes \( Z_1 - Z_3 \) were added as a pre-regulator for improving the ripple characteristics of supply. Prototype has an output ripple of 6 mV peak to peak.
As the shunt module can be easily configured for any output voltage, a high current variable power supply with fold back protection is feasible.

3. Use of a photocoupler to limit no load current in the shunt element

3.1 The basic shunt modules no load current could be reduced easily using a photocoupler in the supply's feedback loop to monitor current drain. This method removes a serious restriction on shunt regulators for high output currents. Thus the need for large heat sinks for the supply's shunt transistor element is eliminated, as is the need for a high power device having the same power handling specifications as would be required in an uncompensated supply.

3.2 Design method and circuit description: This new design technique is applied to the general purpose power supply shown in Fig. 1 and the final circuit is shown in Fig. 4a.

The special feedback arrangement that includes the light dependent resistor and the LED light source reduces the supply’s shunt current, which normally would be 600 mA under no load conditions, to only 120 mA (Fig. 4c).
For this configuration in Fig. 4A, 
\[ V_{out} = V_{ref} \left(1 + \frac{(R_{i2})}{(R_{i3} + R_{V2} + R_{V3})}\right) \] 
with \( R_{V2}, R_{V3} \) used to set the desired output voltage.

LED and the light dependent resistor (LDR) are placed in close proximity in the feedback network, ensuring that 
\[ I_{5} = \frac{(V_{Z2} - V_{be3})}{R_{V1} + R_{7} + (R_{0}/b_{fe5})} \] 
where \( R_{0} \) is the resistance of LDR.

When there is high illumination on LDR (due to high current through LED) \( R \) tends to be very small and 
\[ I_{5} = \frac{(V_{Z2} - V_{be3})}{R_{V1} + R_{7}} \] 
with this circuit arrangement the voltage across LED2, 
\[ V_{LED2} = (V_{X} - I_{4} \cdot R_{11}) \] 
where \( I_{4} \) is the current flowing through \( Q_{8}, Q_{4} \).

When the load is disconnected current through \( Q_{4} \) tends to increase and the voltage across LED2 decreases. This decrease reduces the amount of light emitted from LED2, which in turn causes the resistance of LDR to increase and limit \( I_{5} \) & \( I_{6} \). On the other hand, the voltage across LED2 increases and the resistance of LDR decreases when load current is demanded. With this arrangement to reduce no load current does not affect fold back protection.

Graph in Fig. 4c shows the shunt element current Vs load current in the prototype.

This effect facilitates the replacement of a large capacity power transistor with a smaller and cheaper version at the place of main shunt element (Q4).

**Conclusion**

The design techniques described above were used by the author to develop prototypes which yielded the special characteristics illustrated in the graphs herein. There is room for improvement of these techniques as well as for development of similar techniques to enhance the versatility of shunt regulator applications to DC power supplies and harness the consequent cost benefits. The simpler configuration of components herein facilitates miniaturisation to integrated circuits, which possibility, unfortunately cannot be exploited at present here.

**References**


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