8.6: Extended Topic- Primary Switcher

The switching regulators examined earlier are referred to as secondary switchers because the switching elements are found on the secondary side of the power transformer. In contrast to this is the primary or forward switcher. The switching circuitry in these designs is placed prior to the primary of the power transformer. This positioning offers a distinct advantage over the secondary switcher. The power transformer and secondary rectifier will be handling much higher frequencies, thus they can be made much smaller. The result is a physically smaller and lighter design.

One possible configuration of a primary switcher is shown in Figure 8.35. This is known as a push-pull configuration. The two power transistors are alternately pulsed on and off. That is, when one device is conducting, the other is off. By doing this, opposite polarity pulses are fed into the primary of the transformer, creating a high frequency alternating current (as is the case with secondary switchers, primary switchers operate at frequencies well above the nominal 60 Hz power line). This high frequency waveform is then stepped up or down to the secondary, where it is again rectified and then filtered, producing a DC output signal.

Although the transformer and secondary rectifier/filter may be reduced in size, it is important to note that the main input rectifier and switching transistors are not isolated from the AC power source, as is the case in other power supply designs. These devices must handle high input potentials. For an ordinary 120 V AC line, that translates to over 170 V peak. Also, the power transistors will see an off-state potential of twice \(V_{\text{in}}\), or over 340 V in this case. Some form
of in-rush current limiting will also need to be added.

A somewhat more sophisticated approach is taken in Figure 8.36. This circuit is known as a full bridge switcher. In this configuration, diagonal pairs of devices are simultaneously conducting (i.e., \(Q_1/Q_4\) and \(Q_2/Q_3\)). By eliminating the center-tapped primary, each device sees a maximum potential of \(|V_{\text{in}}|\), or one-half that of the pushpull switcher. The obvious disadvantage is the need for four power devices instead of just two.

Primary switchers do offer a size and weight advantage over secondary switchers and linear regulators. They also maintain the high efficiency characteristics of the secondary switcher. They do tend to be somewhat more complex, though, and their application is therefore best suited to cases where circuit size, weight, and efficiency are paramount.

Summary

In this chapter you have examined the basic operation of voltage regulators. Their purpose is simple: to provide constant, non-varying output voltages despite changes in either the AC source, or in the load current demand. Voltage regulation circuits are an integral part of just about every piece of modern electronic equipment. Due to their wide use, a number of specialized voltage regulator ICs are available from a variety of manufacturers.

Voltage regulation may be achieved through two main methods. These methods are linear regulation and switching regulation. In both cases, a portion of the output voltage is compared to a stable internal reference. The result of this comparison is used to drive a control element, usually a power transistor. If the output voltage is too low, the control element allows more current to flow to the load from the rectified AC source. Conversely, if the output is too high, the control element constricts the current flow. In the case of the linear regulator, the control element is always in the active, or linear, state. Because of this, the linear regulator tends to dissipate quite a bit of power and, as a result, is rather inefficient. On the plus side, the linear regulator is able to quickly react to load variations, and thus exhibits good transient response.

In contrast to the linear regulator, the control device in the switching regulator is either fully on or fully off. As a result, its power dissipation tends to be reduced. For best performance, fast control devices are needed. The control device is driven by a pulse-width modulator. The output of this modulator is a rectangular pulse whose duty cycle is proportional to the load-current demand. As the control device produces current pulses instead of a constant current, some means of smoothing the pulses is necessary. This function is performed by an \((LC)\) filter. The main advantage of the switching regulator is its high efficiency. On the down side, switching regulators are somewhat more difficult to design, do not respond as fast to transient load conditions, and tend to radiate high frequency interference.

No matter what type of regulator is used, power dissipation can be rather large in the control device, so heat sinking is...
generally advisable. Heat sinks allow for a more efficient transferal of heat energy to the surrounding atmosphere than the control device exhibits on its own.

Review Questions

1. What is the function of a voltage regulator?
2. What is the difference between load regulation and line regulation?
3. Why do regulators need a reference voltage?
4. What is the functional difference between a linear regulator and a switching regulator?
5. What are the main advantages of using linear regulators versus switching regulators?
6. What are the main advantages of using switching regulators versus linear regulators?
7. What is the function of a pass transistor?
8. Describe two ways in which to increase the output current of an IC-based regulator.
9. How can fixed “three-pin” regulators be used to regulate at other than their rated voltage?
10. What is the purpose of the output inductor and capacitor in the switching regulator?
11. Explain the correlation between the output current demand and the pulsewidth modulator used in switching regulators.
12. What is the purpose of a heat sink?
13. What is meant by the term thermal resistance?
14. What are the thermal resistance elements that control heat flow in a typical power-device/heat-sink connection?
15. What are the general rules that should be considered when using heat sinks?

Problems

Analysis Problems

1. If the average input voltage to the circuit of Problem 9 is 22 V, determine the maximum device dissipation for a 900 mA output.
2. If the average input voltage is 25 V for the circuit of Problem 11, determine the maximum output current for each output voltage. Use the TO-220 case style \((P_D) = 15W, \,(I_{\text{limit}}) = 1.5A)\).
3. Draw a block diagram of a complete ±12 V regulated power supply using LM78XX and LM79XX series parts.

4. Determine the maximum allowable thermal resistance for a heat sink given the following: Ambient temperature = 50°C, maximum operating temperature = 150°C, TO-3 case style with thermal grease and Thermalfilm isolator, power dissipation is 30 W, and the device's thermal resistance is 1.1°C/W, junction to case.

5. A pass transistor has the following specifications: maximum junction temperature = 125°C, TO-220 case, junction to case thermal resistance = 1.5°C/W. Determine the maximum power dissipation allowed if this device is connected to a 20°C/W heat sink with thermal grease, using a 0.003 mica insulator. The ambient temperature is 35°C.

6. The thermal resistance of the LM723 is 25°C/W, junction to case. Its maximum operating temperature is 150°C. For a maximum dissipation of 500 mW and an ambient temperature of 30°C, determine the maximum allowable thermal resistance for the heat-sink/insulator-interface combination.

Design Problems

7. Using Figure 8.4, design a 15 V regulator using a 3.3 V Zener. The Zener bias current should be 2 mA, the output should be capable of 500 mA.

8. Using Figure 8.4 as a guide, design a variable power supply regulator with a 5 to 15 V output range using a 3.9 V Zener. \(I_{\text{zener}}\) = 3 mA.

9. Design a +12 V regulator using the LM317. The output current capability should be at least 900 mA.

10. Design a +3 to +15 V regulator using the LM317. The output should be continuously variable.

11. Using the LM317, configure a regulator to produce either +5V, +12V, or +15V.

12. Design a +12 V regulator using the LM7805.

13. Design a +9 V regulator using the LM723. Use a current limit of 100 mA.

14. Design a +5 V regulator with 100 mA current limiting using the LM723.

15. Configure a ±12 V regulator with 70 mA current limiting. Use the LM326

16. Reconfigure the circuit of Problem 15 for ±15 V.

17. Using the LM3578A, design a 5 V, 400 mA, regulator. The input voltage is 15 V. Use a discontinuity factor of 0.2, and an oscillator frequency of 75 kHz. No more than 10 mV of ripple is allowed.

18. Repeat Problem 17 for a 9 V output.

Challenge Problems

19. Based on the LM723 adjustable regulator example, design a regulator that will produce a continuously variable...
output from 5 V to 12 V.

20. The LM317 has a maximum operating temperature of 125°C. The TO-220 case version shows a thermal resistance of 4°C/W, junction to case. It also shows 50°C/W, junction to ambient (no heat sink used). Assuming an ambient temperature of 50°C. What is the maximum allowable power dissipation for each setup? Assume that the first version uses a 15°C/W heat sink with a 2°C/W case to heat sink interconnection.

21. Forced air cooling of a heat-sink/power-device can significantly aid in removing heat energy. As a rule of thumb, forced air cooling at a velocity of 1000 feet per minute will effectively increase the efficiency of a heat sink by a factor of 5. Assuming such a system is applied to the circuit of Problem 17, calculate the new power dissipation.

22. An LM317 (TO-3) is used for a 5 V, 1 A power supply. The average voltage into the regulator is 12 V. Assume a maximum operating temperature of 125°C, and an ambient temperature of 25°C. First, determine whether or not a heat sink is required. If it is, determine the maximum acceptable thermal resistance for the heat-sink/insulator combination. For the LM317, thermal resistance = 2.3°C/W, junction to case, and 35°C/W, junction to ambient.

**Computer Simulation Problems**

23. Using a simulator, plot the time-domain response of the circuit of Figure 8.13, assuming an input of 22 V with 3 V peak ripple. How does the simulation change if the ripple is increased to 8 V peak?

24. Verify the output waveform for the circuit of Figure 8.17 using a simulator. Use various loads in order to test the current limit operation. The source is 18 V DC, with 2 V peak ripple.

25. Verify the adjustment range for the regulator designed in Example 8.5 in the text using a simulator. Use a load of 200 Ω, and a source equal to 10 V, with 1 V peak ripple.

26. Use several different loads with a simulator in order to test the current limit portion of the regulator designed in Example 8.5 in the text.