Section F7: Switching Regulators

In the previous section, we discussed discrete and selected IC regulators. Although these regulators are easily set up and extremely useful, they suffer from several limitations. The most serious limitation has to do with the efficiency of the regulator. Since these series regulators all rely on the variable voltage dropped across the series resistor of the power transistor, the input voltage must be greater than the regulated output voltage. The difference between input and output voltages is dropped across an internal component and the greater the difference, the greater the power dissipated (and heat generated) within the regulator. Because of the inefficiency of the series regulator, power supplies that generate high current output (> 2A) rely on the switching regulator. The block diagram of a switching regulator is shown in Figure 8.26 of your text and is reproduced below.

The feedback system of the switching regulator compares the regulated output voltage, \( V_{\text{REG}} \), with a fraction (defined by \( R_A/(R_A+R_F) \)) of a reference voltage, \( V_{\text{REF}} \) by the error amplifier. \( V_{\text{REF}} \) is obtained from a low-current output series regulator, as presented in the previous section. Since little current is required from this reference series generator, it dissipates little internal power and provides an accurate reference voltage. The error amplifier in this circuit is an operational amplifier, and its output, \( v_e \), is applied to a pulse width modulator (i.e., a circuit that generates output pulses with widths proportional to the input amplitude). The output of the pulse width modulator is the control voltage, \( v_c \), which is used to control the high current switch. The control voltage is a square wave of period \( T \) with a duty cycle, \( \sigma \), given by

\[
\sigma = kv_e, \quad \text{(Equation 8.59)}
\]

where \( k \) is the proportionality constant of the pulse width modulator circuitry. The high current switch alternately supplies either the unregulated
voltage, \( v_{in} \), or zero volts to the low pass filter. Therefore, the voltage at the filter input, \( v_s \), is a square wave with a period \( T \) and a duty cycle \( \sigma \) (just like the control voltage \( v_c \)), but with a low value of zero and a high value of \( v_{in} \). The voltage \( v_s \) is then passed through the low pass filter to reduce the fundamental frequency \((2\pi/T)\) and higher harmonics that are present in \( V_{REG} \). A simple low pass filter is shown in Figure 8.27 and is given to the right. Note that, to be effective, \( \sqrt{LC} \) must be much larger than \( T/2\pi \). The value of \( V_{REG} \) is then a constant and is equal to the average value of \( v_s \).

Using a property of an ideal operational amplifier; i.e., \( v_+=v_- \), we may define the regulated output voltage in terms of the reference voltage as

\[
V_{REG} = V_{REF} \left(1 + \frac{R_F}{R_A}\right). \tag{Equation 8.62}
\]

Therefore, if all the multiple pieces of the puzzle come together – good filtering, constant resistors, stable reference voltage, etc., the regulated output voltage does not vary with the unregulated input voltage or the load current.

The output current of a switching regulator comes directly from the unregulated input voltage, \( v_{in} \), through the high current switch and the filter inductor \( L \). Therefore, if we use a transistor switch with low “ON” voltage drop in addition to a low-loss inductor, conversion efficiency of this regulator can be high (greater than 90%). The significant savings in this regulator is based upon switching, or modulating, the input voltage with the high current switch. This is in contrast with the dissipation of power across a series resistor or pass transistor as is the case with the other regulators we discussed.