Power Supply Auxiliary Circuits

In addition to the power circuit a commercial power supply will require:

- Voltage feedback circuits to feed a signal back to the error amplifier which is proportional to the output voltage. This will need to be isolated (optocoupler) if the power supply is transformer coupled.

- Error Amplifier to compare the actual output voltage with the desired output voltage

- Pulse Width modulator

- Gate drive circuits to amplify and possible isolate the gate drive pulses

- Protection Circuits
  - Current limiting Circuit
  - Output Overvoltage (Usually a Crowbar)
  - Input Overvoltage (Usually a Voltage dependent resistor)
  - Input fuse
  - Thermal Cutout

- Additional Filtering to reduce high frequency ripple and noise at input and output.

**Note:** Power Supply Control IC’s are available which contain Voltage reference, Error amplifier, pulse width modulator, current limit and gate drive all in one IC.
Generating the duty cycle

In a modern switch mode power supply all of the control functions are combined in a readily available power supply control integrated circuit. Every switch mode power supply will have some form of error amplifier which looks at the difference between the actual output voltage and the desired output voltage (the error). The error amplifier multiplies the error by a control gain to generate a control voltage $V_{\text{control}}$ which is then used to set the duty cycle of the switch.

\[ V_v(\text{desired}) \]
\[ V_v(\text{actual}) \]
\[ \text{Error Amplifier} \]
\[ V_{\text{control}} \]
\[ \text{Power Stage} \]
\[ V_v \]

The simplest approach sometimes called Voltage mode control is to use a comparator and a triangle wave to generate a square wave whose duty cycle is directly proportional to $V_{\text{control}}$.

\[ \text{Switch control signal} \]

![Diagram](image)

**Figure 7-3** Pulse-width modulator: (a) block diagram; (b) comparator signals.
Current Mode Control

Instead of generating the duty cycle directly from $V_{control}$, many modern power supplies use $V_{control}$ to set the peak or average level of inductor current. This inner current loop has two main advantages:
- It simplifies the control transfer function by effectively removing the inductor from the loop. This in turn allows for better regulation.
- In buck and flyback topologies it provides inherent pulse-by-pulse current limiting.

Peak current mode control is particularly suited to discontinuous mode flyback converters because the circuit acts like an energy pump – the energy pumped into the output on each cycle is $\frac{1}{2}L_I p^2$ where $I_p$ is the peak inductor current.

Peak Current mode control:

**Note:** The peak inductor current during the on time of the switch is usually sensed by a small resistor in series with the switch.
Parasitic Inductance and Capacitance in Power Electronic Circuits:

There will always be parasitic inductances and capacitances in a real life switching power supply which impact significantly on the performance of the circuit.

Parasitic inductance:
In circuits with transformers the transformer leakage inductance does not contribute to energy transfer and is usually the dominant parasitic inductance element. Even where no transformer is present every wire or circuit board loop has a parasitic inductance of the order of 1uH per metre length. The bigger the loop area the bigger the stray inductance. It is vital to keep the loop area of any loop where current is changing rapidly as small as possible.

Parasitic capacitance:
Drain source Capacitance is significant for Mosfets. Collector emitter capacitance for IGBTs or bipolars. Cathode Anode capacitance is significant for diodes. Transformers can also have significant interwinding capacitance.

The diagram below shows the dominant power circuit parasitics for a buck converter. Please note that the loop inductance is actually distributed around the loop but is shown as a lumped inductance (L\textsubscript{stray}) for convenience.
**Impacts of parasitics**

1. **Current and voltage overshoots.**
   When a switch opens the stray loop inductance will attempt to keep the current flowing causing a voltage overshoot. When a switch closes any parasitic capacitance that was charged up during the off time of the switch will discharge into the switch causing a current overshoot. If large enough these overshoots could damage the device.

2. **Ringing.**
   When a switch opens the stray inductance and the switch capacitance form an LC resonant circuit which will ring at its resonant frequency \( \frac{1}{2\pi \sqrt{LC}} \). In addition to causing over voltages and overcurrents this ringing generates electromagnetic noise which may interfere with other electronic circuits. This also happens when a diode becomes reverse biased.

3. **Increased switching losses.**
   The energy stored in stray inductance \( \frac{1}{2}LI^2 \) must be dissipated when a switch opens. Similarly the energy stored in stray capacitance \( \frac{1}{2}CV^2 \) must be dissipated when a switch closes. Unless steps are taken to deal with this energy it will appear as increased switching losses in the switching device.

4. **Zero voltage or zero current switching.**
   If a switch has significant parasitic capacitance across it then the voltage will rise slowly when the switch opens. This means that the voltage at the moment of switching is zero and there are no turn off losses. Of course the energy in the capacitance will be dissipated in the switch at turn on so there is not net benefit unless steps are taken to recycle the capacitor energy. Similarly if a switch has significant inductance in series with it the current will be zero at turn on giving rise to zero turn on losses. Again the inductor stores energy will be dissipated in the switch at turn off unless steps are taken to recycle it.

   It is possible to construct circuits which use these effects to advantage, recycling the energy stored in stray Ls and Cs and effectively eliminating switching losses.

**A note on diodes**

When a diode becomes reverse biased the junction capacitance will normally resonate with stray circuit inductance to give a ring on the cathode anode voltage. This problem is exacerbated in a normal PN diode where stored charge means that the diode conducts in the reverse direction for a time before the diode switches off very suddenly (diode reverse recovery) – giving a sharp kick to the LC resonant circuit. At low voltages we can use schottky diodes which do not have stored charge (but still have junction capacitance). At higher voltages it is important to choose soft recovery diodes, which will not snap off. In any case an RC snubber is likely to be required to damp the ring.
**Snubbing**

A snubber may be used to damp the overshoot and ringing caused by parasitic Ls and Cs. There are many designs of snubber available. Lossless snubbers attempt to recycle the energy stored in the parasitic elements. We will look more closely at the design of the simplest lossy RC snubber. In general we will not know the exact value of the parasitics (they cannot be discretely measured) so we will need to rely on circuit measurements to estimate their values.

The switch in the circuit above is turning off 10Amps and must block a voltage of 100V. Design an appropriate RC snubber.

1. Test the circuit at low voltage and current without any snubber. There will be a ring on the edge of the switch waveform but if the voltage is kept low enough it shouldn’t damage the switch. Observe the voltage across the switch. In particular note the ringing frequency of the turn off ring. We will call this \( f_{nr} \) the natural resonance.

\[
f_{nr} = \frac{1}{2\pi \sqrt{L_{stray} C_{stray}}}
\]

2. Still operating at low voltage put various values of capacitor across the switch. These capacitors are in parallel with \( C_{stray} \) and will lower the resonant frequency. Find the value of capacitor (\( C_{snubber} \)) which halves the resonant frequency.

The resonant frequency \( f_r = \frac{1}{2\pi \sqrt{L_{stray} C_{total}}} \) where \( C_{total} = C_{snubber} + C_{stray} \)

When \( f_r = \frac{1}{2} f_{nr} \) \( \Rightarrow C_{total} = 4 C_{stray} \Rightarrow C_{snubber} = 3 C_{stray} \)

3. Now use \( f_{nr} \) and \( C_{stray} \) to work out the value of \( L_{stray} \)
4. Now choose the resistor required to give critical damping. This is achieved when
\[ R_{\text{snubber}} = \frac{L_{\text{stray}}}{\sqrt{C_{\text{stray}}}} \]

Note that because the snubber capacitor is in series with \( R_{\text{snubber}} \) perfect damping cannot be achieved. Nevertheless this circuit gives very good results.

5. At each turn off the capacitor \( C_{\text{snubber}} \) charges up through \( R_{\text{snubber}} \) and at each turn on the capacitor discharges through \( R_{\text{snubber}} \).

It may be seen that every time a capacitor charges up to a voltage \( V \) through a resistor the energy dissipated in the resistor equals the stored charge on the capacitor = \( \frac{1}{2}CV^2 \). Also every time a capacitor discharges to 0V through a resistor the energy dissipated in the resistor = \( \frac{1}{2}CV^2 \) also.

If we assume that the time constant \( R_{\text{snubber}}C_{\text{snubber}} \) is much longer then the turn on or off time of the switch but much shorter than the period of the switching cycle then the total energy dissipated in the resistor every cycle = \( C_{\text{snubber}}V^2 \).

The power dissipation in the resistor is therefore: \( f_sC_{\text{snubber}}V^2 \)

Where \( V \) = blocking voltage of the switch and \( f_s \) is the switching frequency.
Block Diagram of UC3842 a common power supply control IC used for peak current mode control of discontinuous mode flyback power supplies.

Note 1: A/B  A = DIL-8 Pin Number, B = SO-14 and CFP-14 Pin Number.
Note 2: Toggle flip flop used only in 1844 and 1845.

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