# Switching Regulator Topologies

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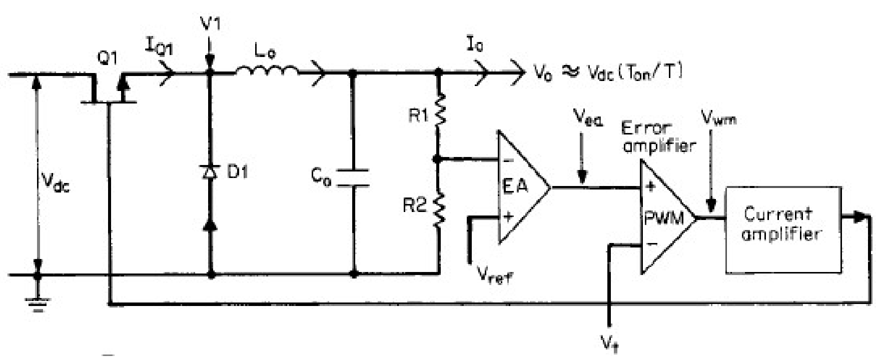
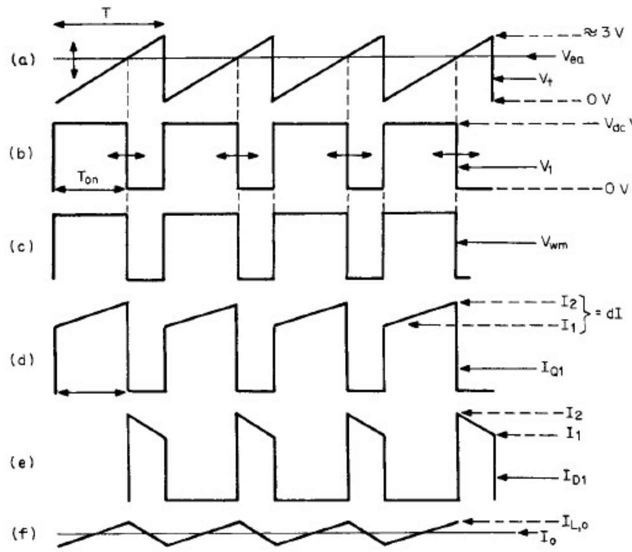
## The Buck Switching Regulator



# Waveforms




# Switching PS advantages

- 20 W/in$^3$ compared to 0.3 W/in$^3$ for linear PS.
- Multiple isolated output voltages from a single input.
- Low freq. Isolation Transformer not required.
- Efficiencies from 70% up to 95%.
- Some DC/DC converter designers are claiming load power densities of up to 50 W/in$^3$ for the actual switching elements.

# Conduction Loss and Efficiency

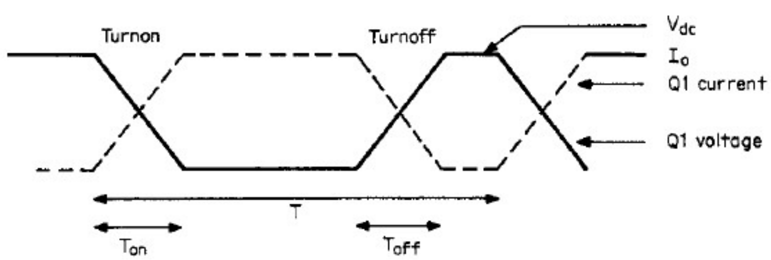
The average currents in *Q*1 and *D*1 is $I_o$ .
These currents flow at a forward voltage of about 1 V over a wide range of currents.
Thus conduction losses will be approximately

$$P_{\text{dc}} = L(Q1) + L(D1) = 1I_o\frac{T_{\text{on}}}{T} + 1I_o\frac{T_{\text{off}}}{T} = 1I_o$$

$$\text{Conduction Efficiency} = \frac{P_o}{P_o + \text{losses}} = \frac{V_oI_o}{V_oI_o + 1I_o} = \frac{V_o}{V_o + 1}$$

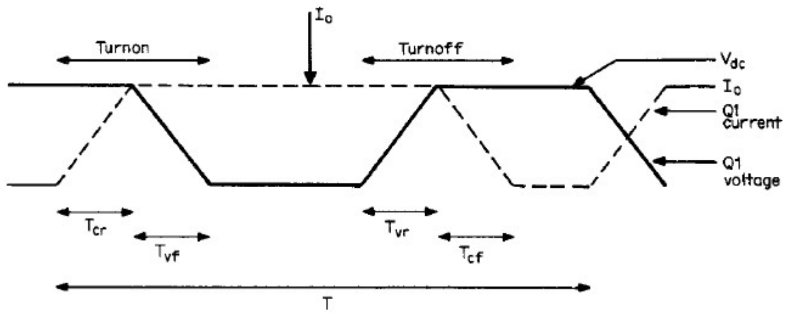
# AC Switching Losses

Waveforms show the Best-case scenario



# AC Switching Losses

Waveforms show the worst-case scenario




# AC Switching Losses

For best-case scenario

$$P(T_{\text{on}}) = \int_0^{T_{\text{on}}} IV\,dt = I_o V_{\text{dc}}/6$$

The power averaged over one complete period is

$$(I_o V_{\text{dc}}/6)(T_{\text{on}}/T)$$

$$P(T_{\text{off}}) = \int_0^{T_{\text{off}}} IV\;dt = I_o V_{\text{dc}}/6$$

## AC Switching Losses

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The power averaged over one complete period is

$$(I_o V_{\text{dc}}/6)(T_{\text{off}}/T)$$

Assuming

$$T_{\text{on}} = T_{\text{off}} = T_s$$

$$P_{\text{ac}} = (V_{\text{dc}} I_o T_s)/3T,$$

## Efficiency

***For Best-Case Scenario***

$$\begin{aligned}\text{Efficiency} &= \frac{P_o}{P_o + \text{DC losses} + \text{AC losses}} \\ &= \frac{V_o I_o}{V_o I_o + 1 I_o + V_{\text{dc}} I_o T_s/3T} \\ &= \frac{V_o}{V_o + 1 + V_{\text{dc}} T_s/3T}\end{aligned}$$

# Efficiency

Assume the buck regulator provides 5 V from a 48-V DC input at 50-kHz switching frequency ($T$ = 20μs) for $Ts$ = 0.3 μs and $T$ = 20 μs

The switching-related efficiency is

$$\begin{aligned}\text{Efficiency} &= \frac{5}{5+1+48\times 0.3/3\times 20}\\ &= \frac{5}{5+1+0.24} = \frac{5}{5+1.24}\\ &= 80.1\%\end{aligned}$$

# AC Switching Losses

***For Worst-Case Scenario***

$$P(T_{\text{on}}) = \frac{V_{\text{de}} I_o}{2}\frac{T_{\text{cr}}}{T} + \frac{I_o V_{\text{dc}}}{2}\frac{T_{\text{vf}}}{T}$$

The power averaged over one complete period is

Assuming

$$T_{\text{cr}} = T_{\text{vf}} = T_s,\ P(T_{\text{on}}) = V_{\text{dc}} I_o (T_s/T)$$

$$P_{\text{ac}} = 2V_{\text{dc}} I_o \frac{T_s}{T}$$

# AC Switching Losses

For Worst-case scenario

The power averaged over one complete period is

Assuming

$$T_{cr} = T_{vf} = T_s,\ P(T_{on}) = V_{dc} I_o (T_s / T)$$

$$P_{ac} = 2 V_{dc} I_o \frac{T_s}{T}$$

# AC Switching Losses

For Worst-case scenario

and the total losses (the sum of DC plus AC losses) will be

$$P_t = P_{dc} + P_{ac} = 1 I_o + 2 V_{dc} I_o \frac{T_s}{T}$$

# Efficiency

For Worst-case scenario

$$\text{Efficiency} = \frac{P_o}{P_o + P_t} = \frac{V_o I_o}{V_o I_o + 1 I_o + 2V_{\text{dc}} I_o T_s / T}$$
$$= \frac{V_o}{V_o + 1 + 2V_{\text{dc}} T_s / T}$$

$$\text{Efficiency} = \frac{5}{5 + 1 + 2 \times 48 \times 0.3/20} = \frac{5}{5 + 1 + 1.44}$$
$$= \frac{5}{5 + 1 + 2.44}$$
$$= 67.2\%$$

# Conclusion

*Comparing this with a linear regulator doing the same job (bringing 48 V down to 5 V), its efficiency would be $V_o/V_{dc}$(max), or 5/48; this is only 10.4% and is clearly unacceptable.*