第二章 线性电源及开关电源的提出

2.1 线性电源（Linear Regulators）

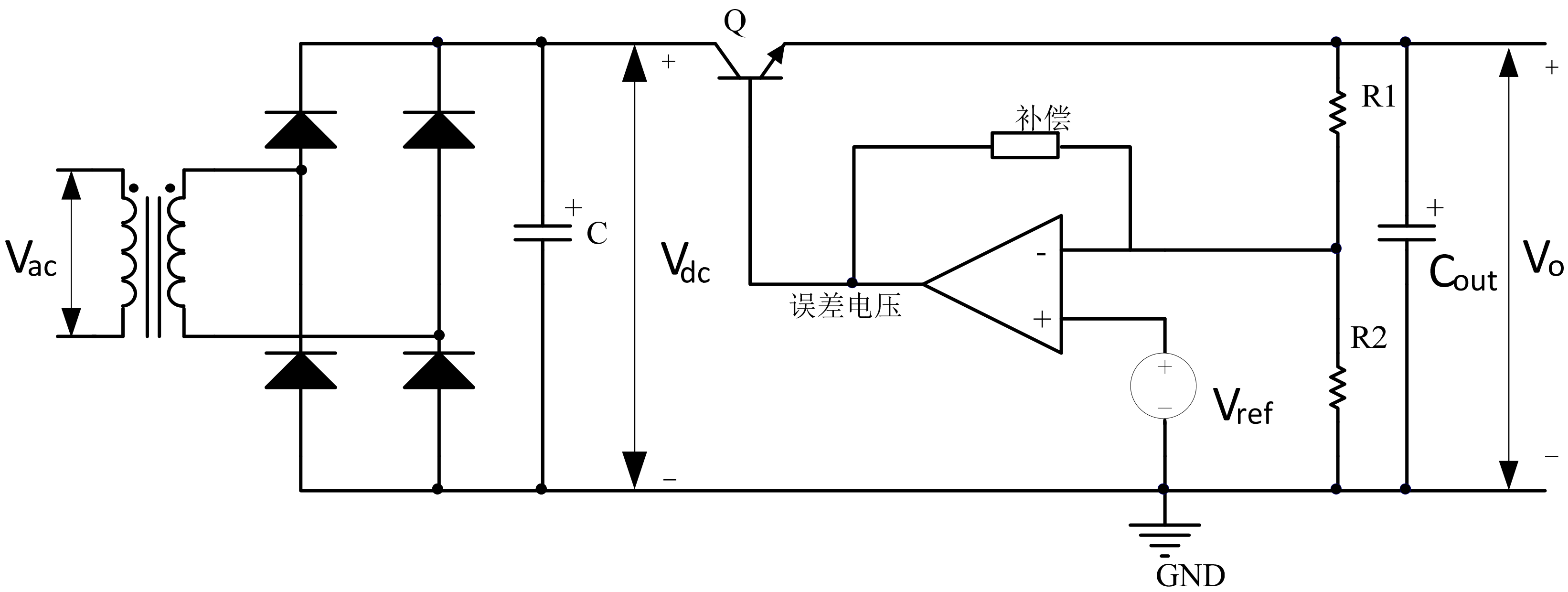
2.2 开关电源的提出

2.3 开关电源的稳态分析原理

2.1 线性调整器

基本工作（控制）原理：

如果电网电压降低或负载增加，输出电压会下降，则放大器的输出将增加（串接晶体管基极电压升高），等效串联电阻减小，使更多的电流流向负载，直流输出电压升高；同样地，如果电网电压升高或负载减少，输出电压升高，则放大器的输出将减小（串接晶体管基极电压减小），等效电阻阻值加大，流向负载的电流减小，直流输出电压降低，使得输出电压Vo恒定。



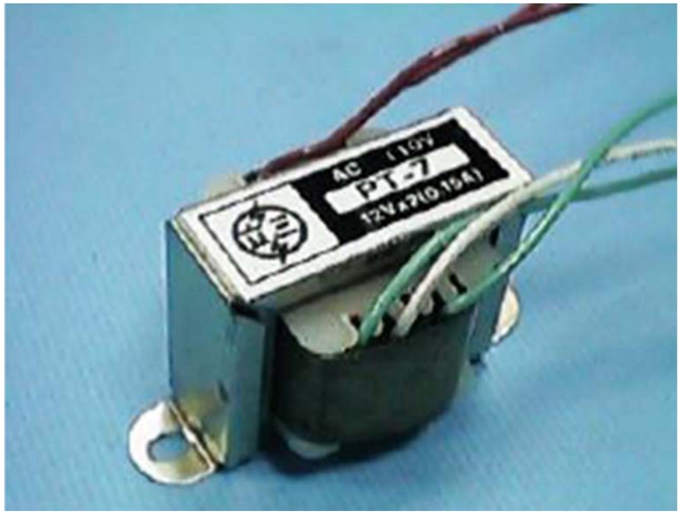
2.1 线性调整器

优点：

- 反馈回路是直流耦合，回路各点的直流电压都可以预测和计算；
- 电路中没有变压器并且不存在引起**RFI**噪声的瞬态尖峰电压和电流；

缺点：

- 只能降压；
- 制作高效率的线性变换器时，电路非常复杂。
- 体积和重量大。
- 效率低，工作时产生热量大。



2.1 线性调整器

晶体管功耗： $(V_{\mathrm{dc}}-V_{\mathrm{o}})\,I_{\mathrm{o}}$

注意：串接NPN晶体管的最小压差（V_{dc}-V_o）为2.5V

设次级滤波电容足够大，输入电压纹波忽略。次级整流获得的电压波动范围与交流网压波动范围对应，均为±15%。若网压输入最低（－15% ）时，变压器次级电压为（**Vo+2.5**），则网压输入最高（＋ 15% ）时，最大直流输入电压为**1.35** （**Vo+2.5**）。

$$V_{dc(\max)}=\frac{1+0.01T}{1-0.01T}(V_o+2.5+V_r/2)$$

V_o (V)	I_o (A)	$V_{dc(\min)}$ (V)	$V_{dc(\max)}$ (V)	最大压差 (V)	$P_{in(\max)}$ (W)	$P_{o(\max)}$ (W)	Q 最大损耗 (W)	P_o / $P_{in(\max)}$ 效率(%)
5.0	10	7.5	10.1	5.1	101	50.0	51	50
15.0	10	17.5	23.7	8.7	237	150	87	63
30.0	10	32.5	44.0	14	440	300	140	68

2.1 线性调整器

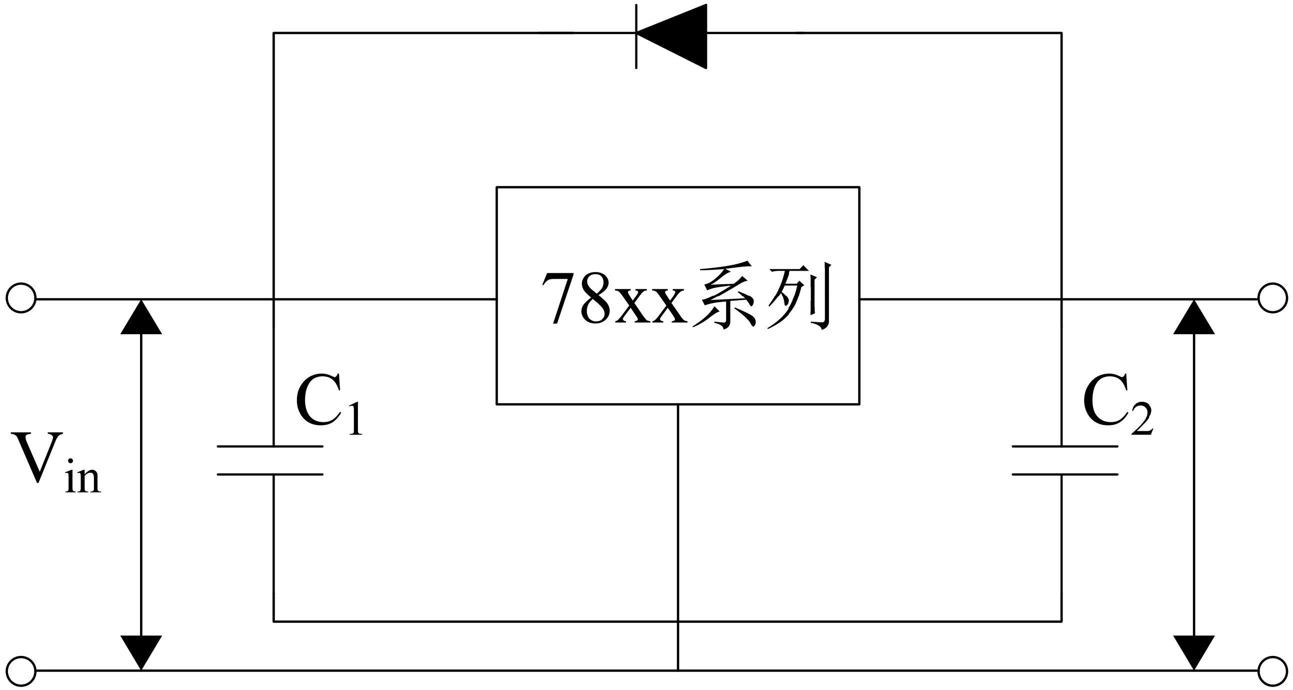
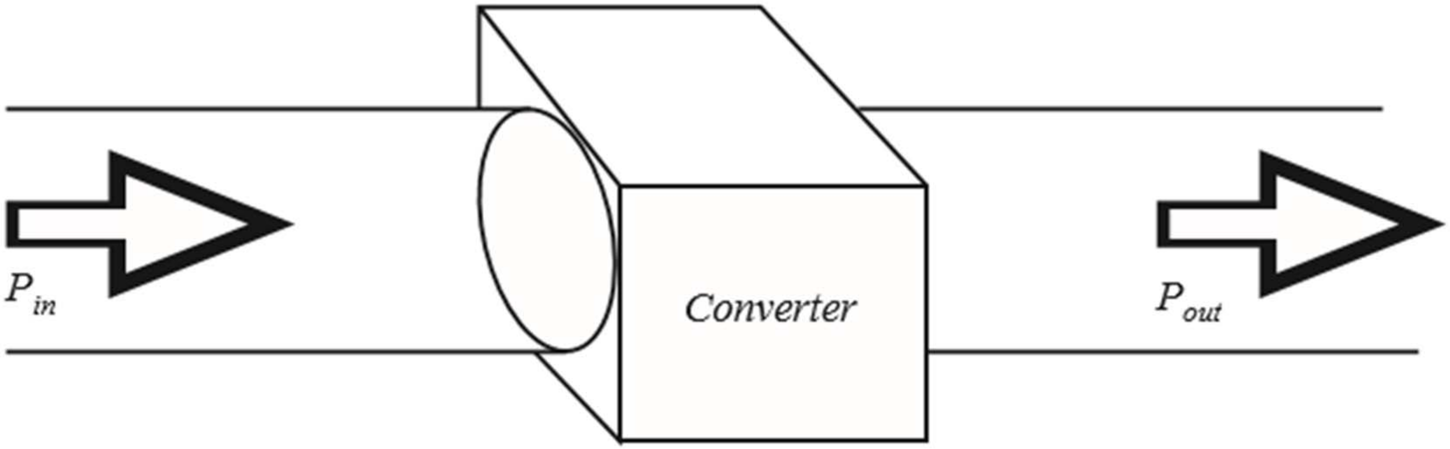


图2.3 三端稳压电源

输出电流100mA (max)	78LXX、79LXX
输出电流0.5A (max)	78MXX、79MXX
输出电流1A (max)	78XX、79XX

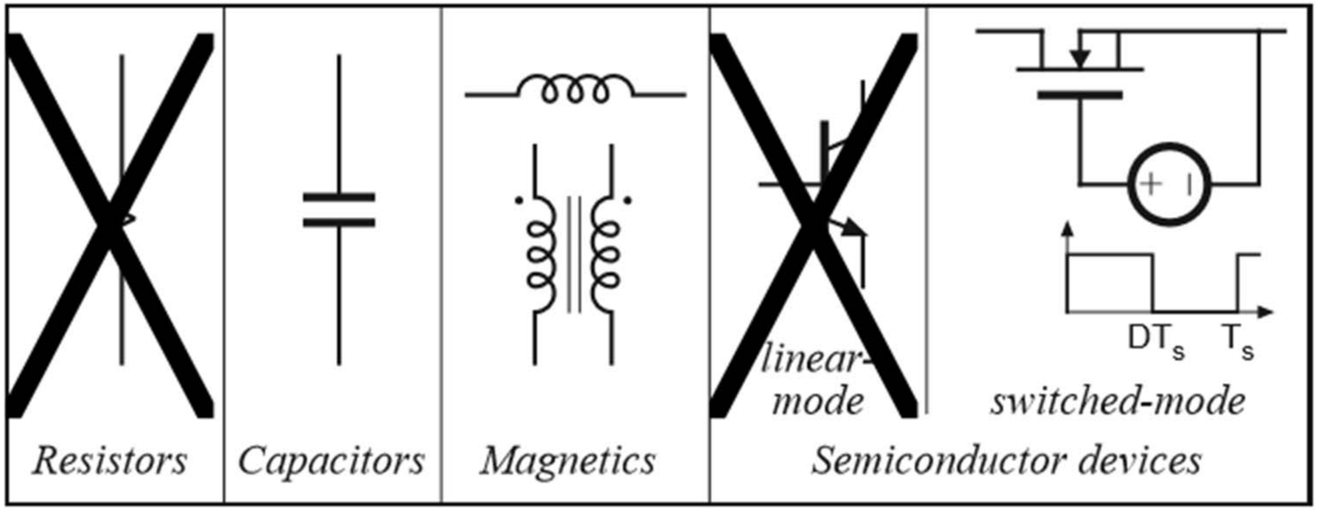
2.2 开关电源的提出

A high efficiency power converter



A goal of current converter technology is to construct converters of small size and weight, which process substantial power at high efficiency

Devices available to the circuit designer



Power processing: avoid lossy elements

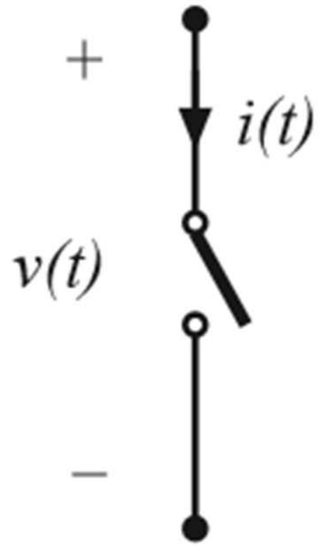
Power loss in an ideal switch

Switch closed: $v(t) = 0$

Switch open: $i(t) = 0$

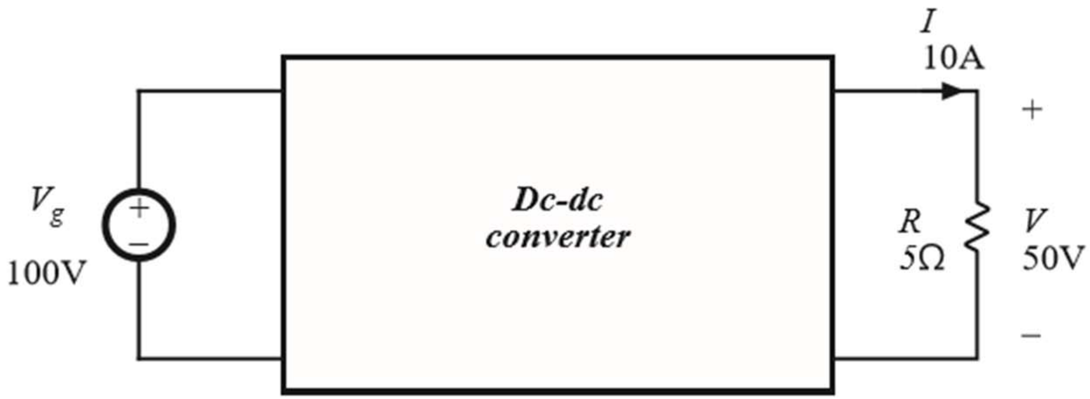
In either event: $p(t) = v(t)\, i(t) = 0$

Ideal switch consumes zero power



2.2 开关电源的提出

A simple dc-dc converter example



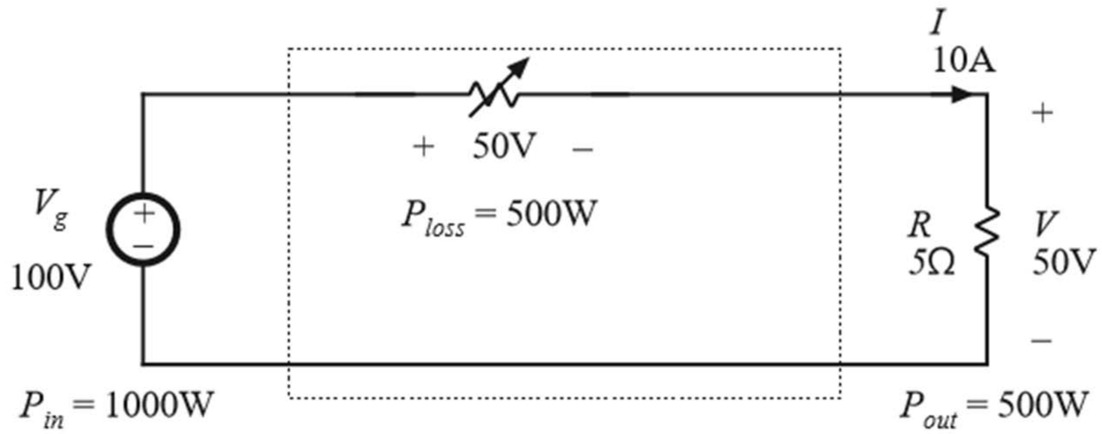
Input source: 100V

Output load: 50V, 10A, 500W

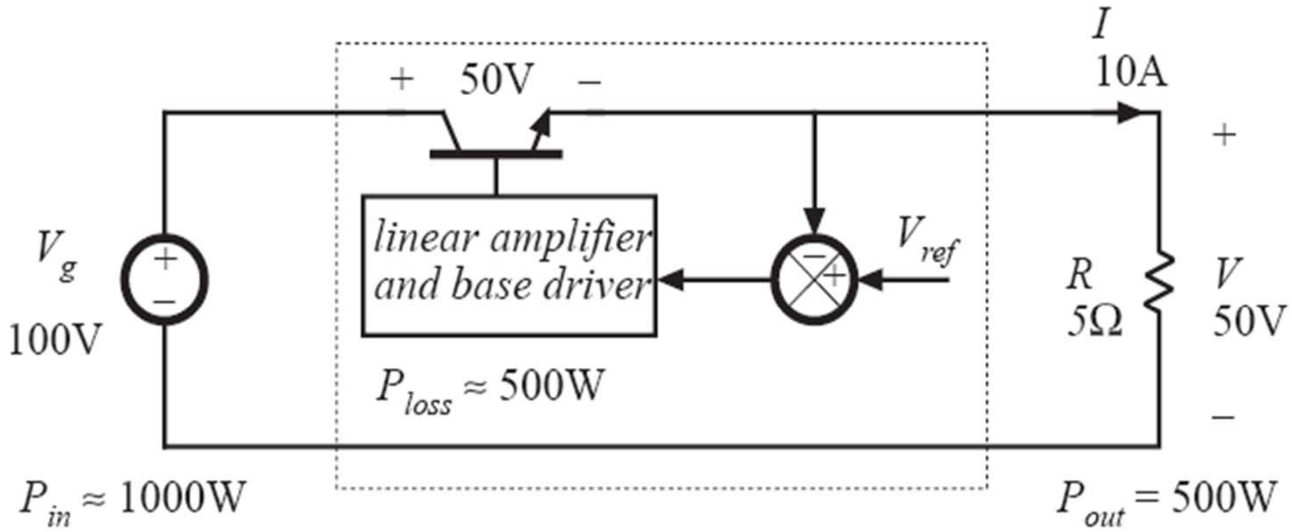
How can this converter be realized?

Dissipative realization

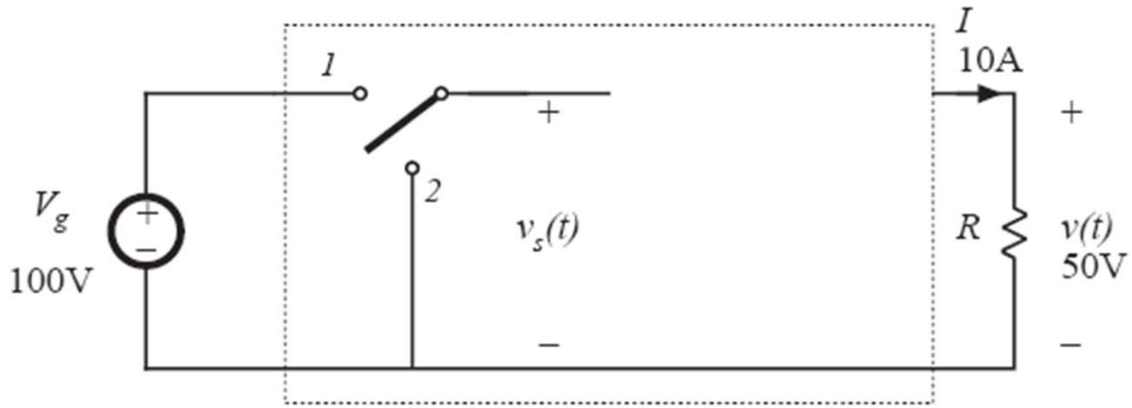
Resistive voltage divider

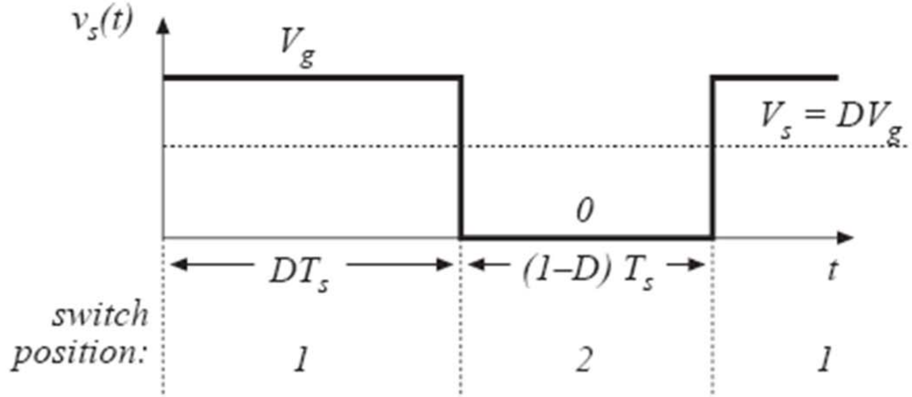


Series pass regulator: transistor operates in active region

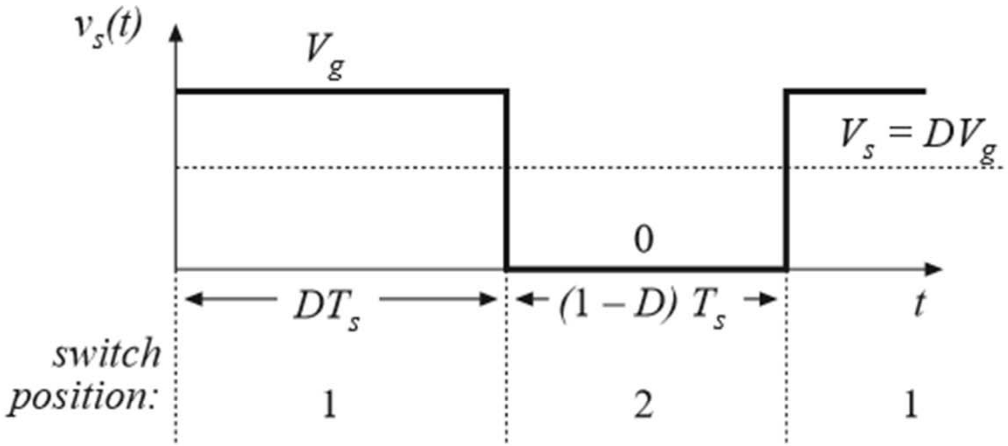


Use of a SPDT switch





The switch changes the dc voltage level



D = switch duty cycle

$0 \le D \le 1$

T_s = switching period

f_s = switching frequency

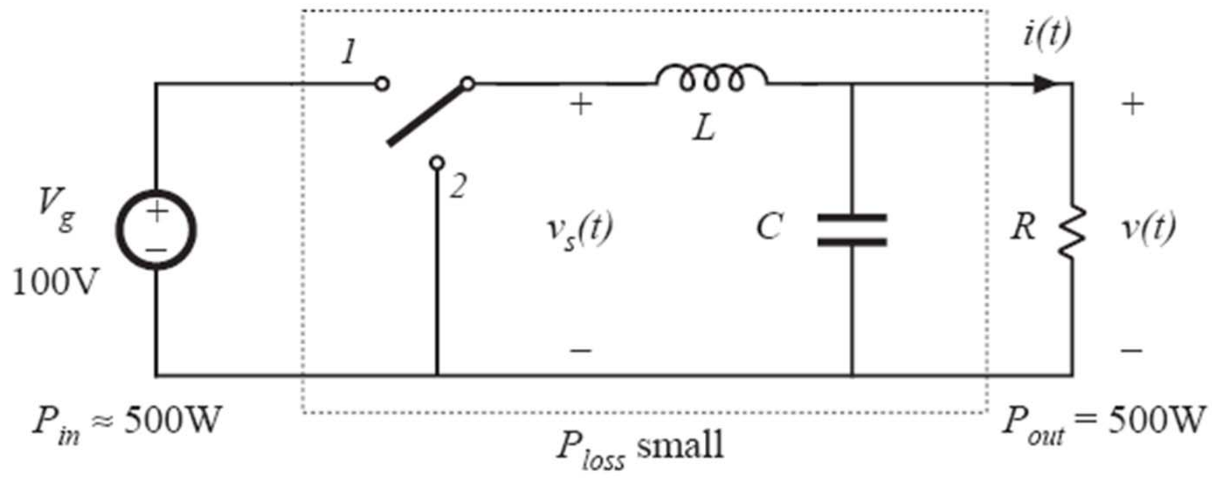
$= 1 / T_s$

DC component of $v_s(t)$ = average value:

$$V_s = \frac{1}{T_s} \int_0^{T_s} v_s(t)\, dt = DV_g$$

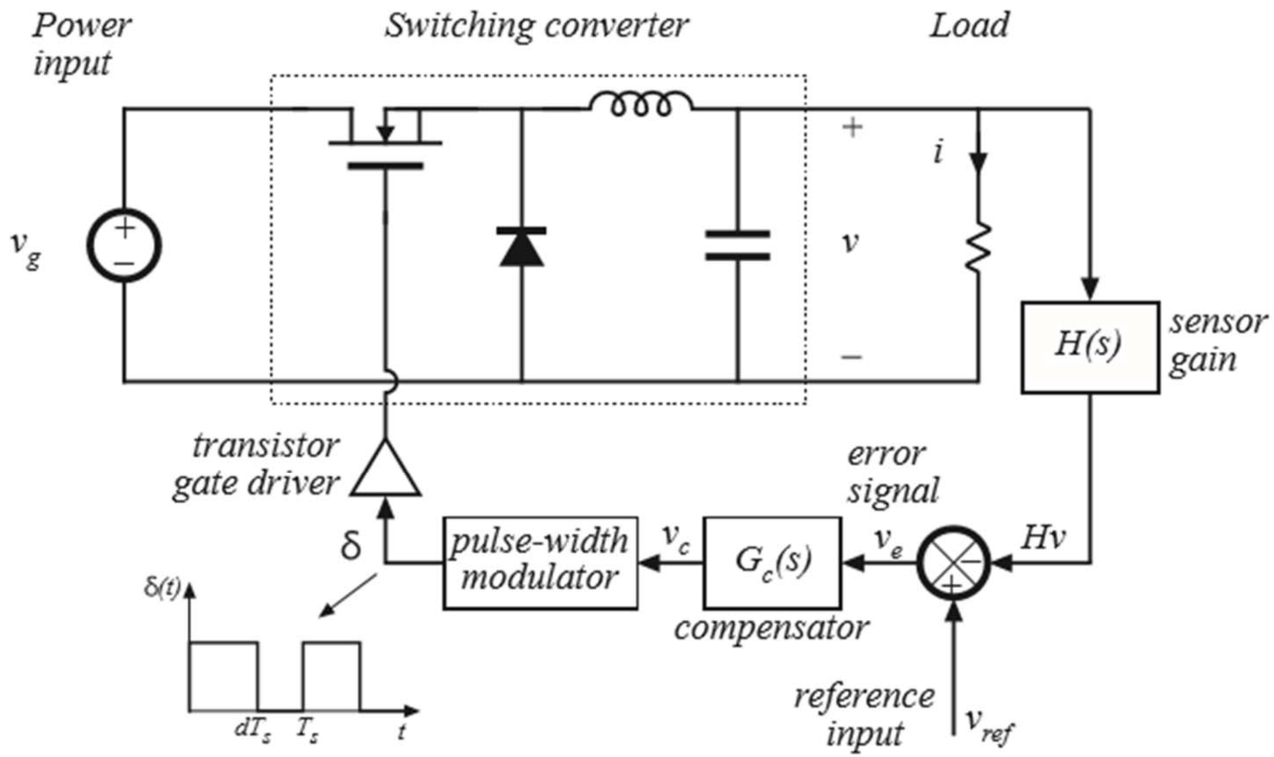
Addition of low pass filter

Addition of (ideally lossless) L-C low-pass filter, for removal of switching harmonics:



- Choose filter cutoff frequency f_0 much smaller than switching frequency f_s
- This circuit is known as the "buck converter"

Addition of control system for regulation of output voltage



2.3 开关电源的稳态分析原理

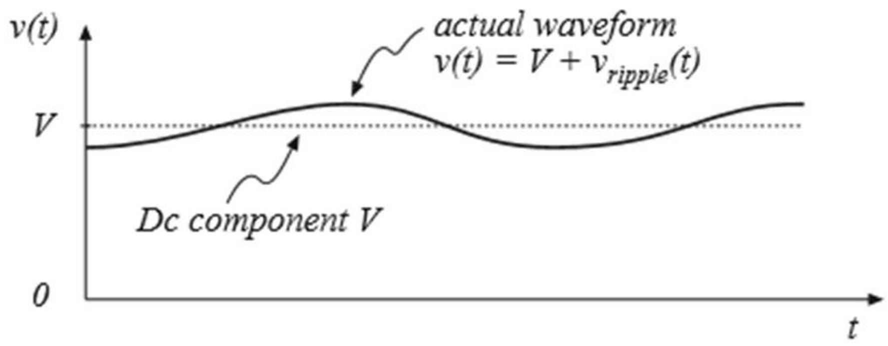
1、小纹波近似（small ripple approximation）

2、电感伏秒平衡（Inductor volt-second balance）

3、电容电荷平衡（ capacitor charge balance）

The small ripple approximation

$$v(t) = V + v_{ripple}(t)$$



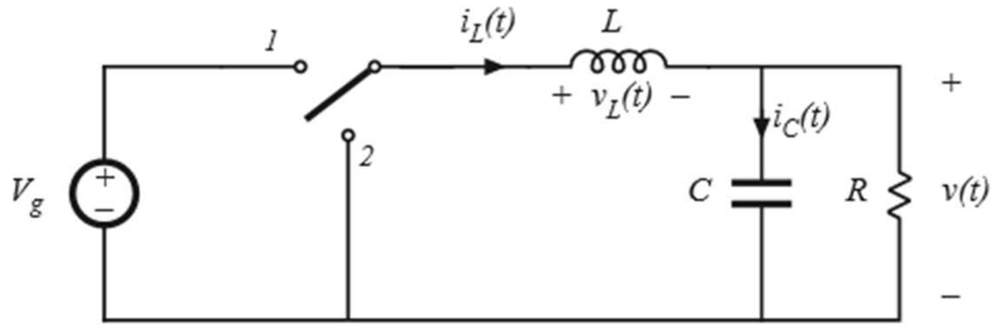
In a well-designed converter, the output voltage ripple is small. Hence, the waveforms can be easily determined by ignoring the ripple:

$$\| v_{ripple} \| << V$$

$$v(t) \approx V$$

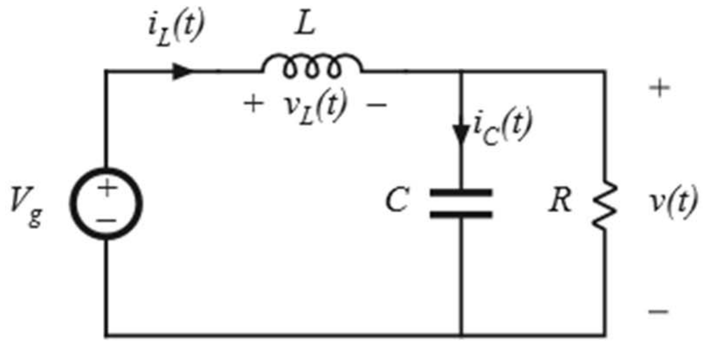
Buck converter analysis: inductor current waveform

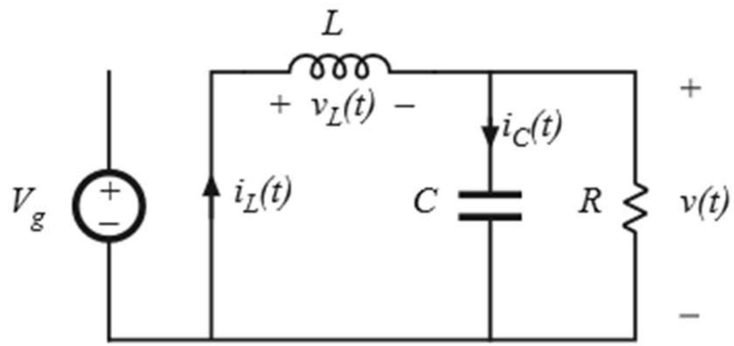
original converter



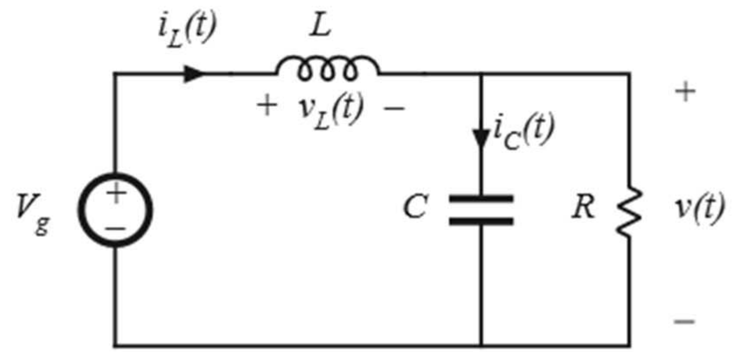
switch in position 1

switch in position 2





Inductor voltage and current
Subinterval 1: switch in position 1



Inductor voltage

$$v_L = V_g - v(t)$$

Small ripple approximation:

$$v_L \approx V_g - V$$

Knowing the inductor voltage, we can now find the inductor current via

$$v_L(t) = L\,\frac{di_L(t)}{dt}$$

Solve for the slope:

$$\frac{di_L(t)}{dt} = \frac{v_L(t)}{L} \approx \frac{V_g - V}{L}$$

⇒ *The inductor current changes with an essentially constant slope*

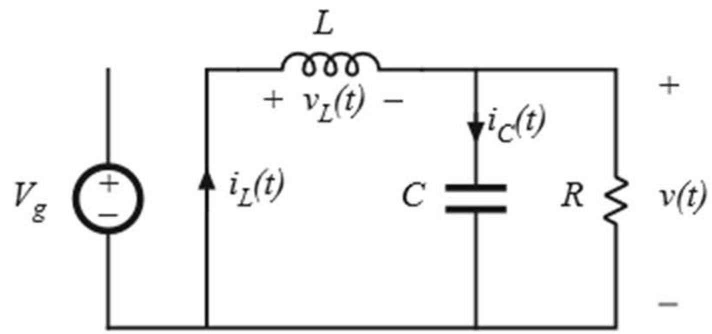
Inductor voltage and current
Subinterval 2: switch in position 2

Inductor voltage

$$v_L(t) = -v(t)$$

Small ripple approximation:

$$v_L(t) \approx -V$$



Knowing the inductor voltage, we can again find the inductor current via

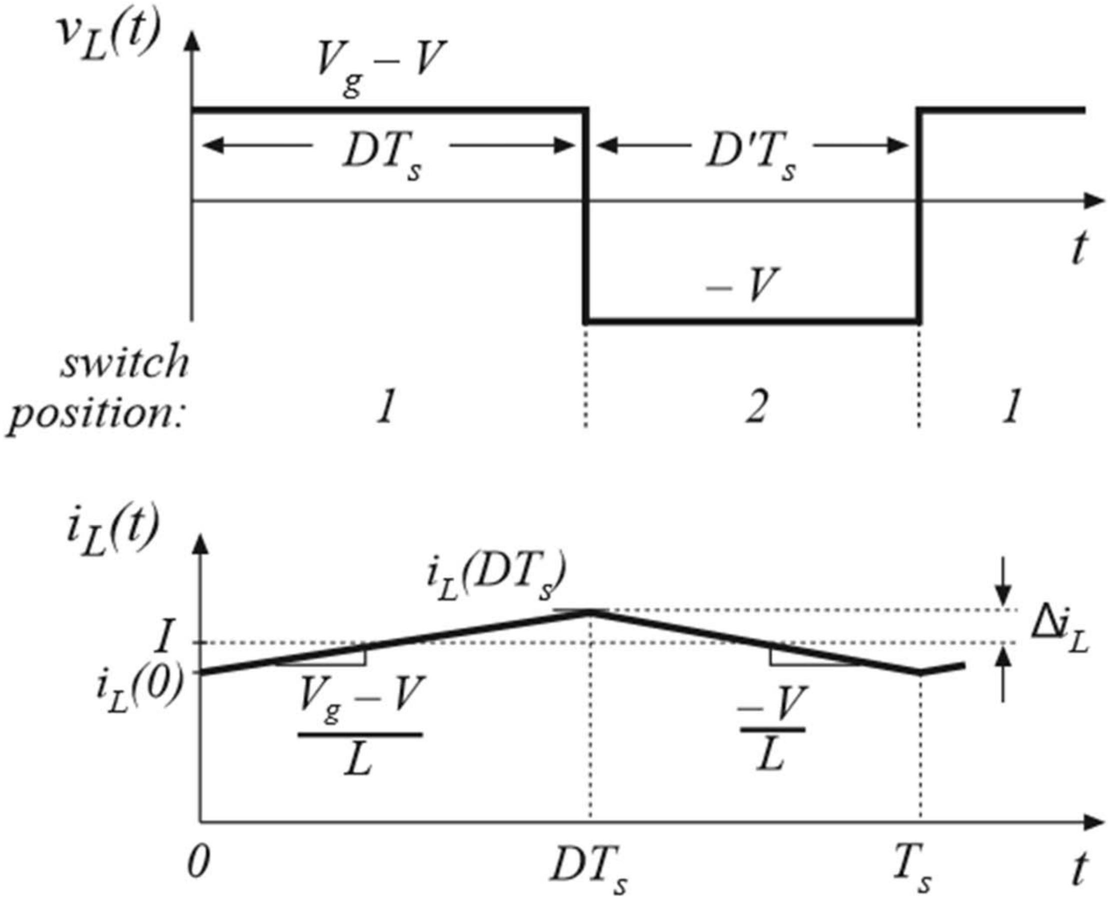
$$v_L(t) = L\,\frac{di_L(t)}{dt}$$

Solve for the slope:

$$\frac{di_L(t)}{dt} \approx -\frac{V}{L}$$

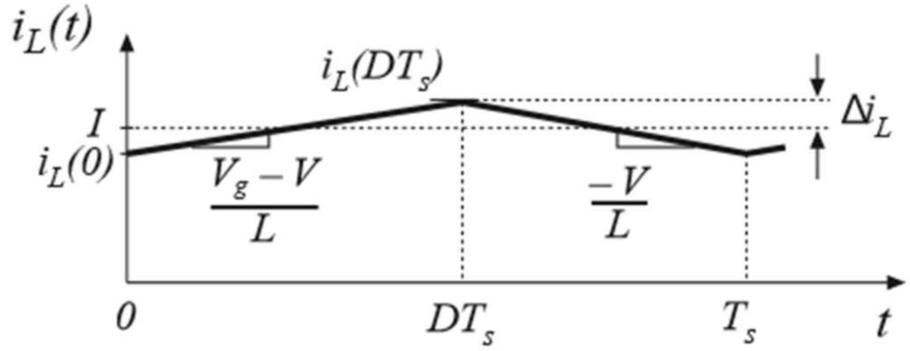
⇒ *The inductor current changes with an essentially constant slope*

Inductor voltage and current waveforms



$$v_L(t) = L\,\frac{di_L(t)}{dt}$$

Determination of inductor current ripple magnitude



$$(\textit{change in } i_L) = (\textit{slope})(\textit{length of subinterval})$$

$$\left(2\,\Delta i_L\right) = \left(\frac{V_g - V}{L}\right)\left(DT_s\right)$$

$$\Rightarrow \qquad \Delta i_L = \frac{V_g - V}{2L}\,DT_s \qquad\qquad L = \frac{V_g - V}{2\,\Delta i_L}\,DT_s$$

The principle of inductor volt-second balance: Derivation

Inductor defining relation:

$$v_L(t) = L\,\frac{di_L(t)}{dt}$$

Integrate over one complete switching period:

$$i_L(T_s) - i_L(0) = \frac{1}{L}\int_0^{T_s} v_L(t)\,dt$$

In periodic steady state, the net change in inductor current is zero:

$$0 = \int_0^{T_s} v_L(t)\,dt$$

Hence, the total area (or volt-seconds) under the inductor voltage waveform is zero whenever the converter operates in steady state.

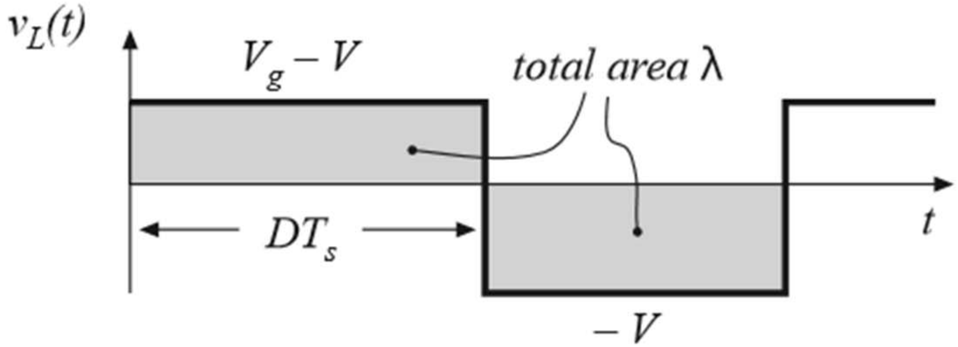
An equivalent form:

$$0 = \frac{1}{T_s}\int_0^{T_s} v_L(t)\,dt = \left\langle v_L \right\rangle$$

The average inductor voltage is zero in steady state.

Inductor volt-second balance: Buck converter example

Inductor voltage waveform, previously derived:



Integral of voltage waveform is area of rectangles:

$$\lambda = \int_0^{T_s} v_L(t)\, dt = (V_g - V)(DT_s) + (-V)(D'T_s)$$

Average voltage is

$$\langle v_L \rangle = \frac{\lambda}{T_s} = D(V_g - V) + D'(-V)$$

Equate to zero and solve for *V:*

$$0 = DV_g - (D + D')V = DV_g - V \qquad \Rightarrow \qquad V = DV_g$$

The principle of capacitor charge balance: Derivation

Capacitor defining relation:

$$i_C(t) = C\,\frac{dv_C(t)}{dt}$$

Integrate over one complete switching period:

$$v_C(T_s) - v_C(0) = \frac{1}{C}\int_0^{T_s} i_C(t)\,dt$$

In periodic steady state, the net change in capacitor voltage is zero:

$$0 = \frac{1}{T_s}\int_0^{T_s} i_C(t)\,dt = \left\langle i_C \right\rangle$$

Hence, the total area (or charge) under the capacitor current waveform is zero whenever the converter operates in steady state. The average capacitor current is then zero.