Lecture 29 ADC, DAC, & 直流电源

ANALOG DEVICES

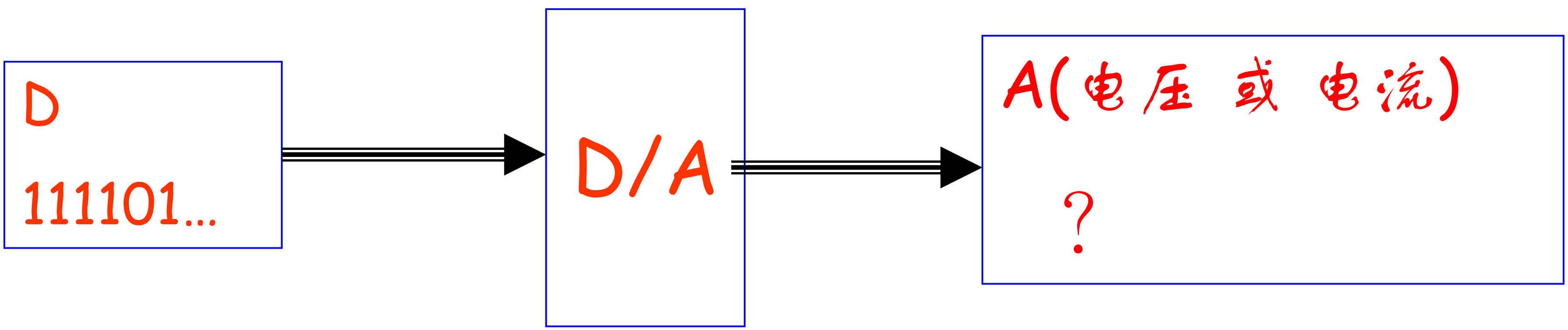
数模转换（DAC）的工作原理和实现方法

模数转换（ADC）的工作原理和实现方法

15.1 数模转换的工作原理和实现方法

15.1.1 D/A转换器的概念和基本原理

将数字信号转换成模拟信号的过程称为数/模转换（Digital to Analog），实现的电路称为D/A转换器，简写成DAC（Digital - Analog Converter）



15.1 数模转换的工作原理和实现方法

15.1.1 D/A转换器的概念基本原理

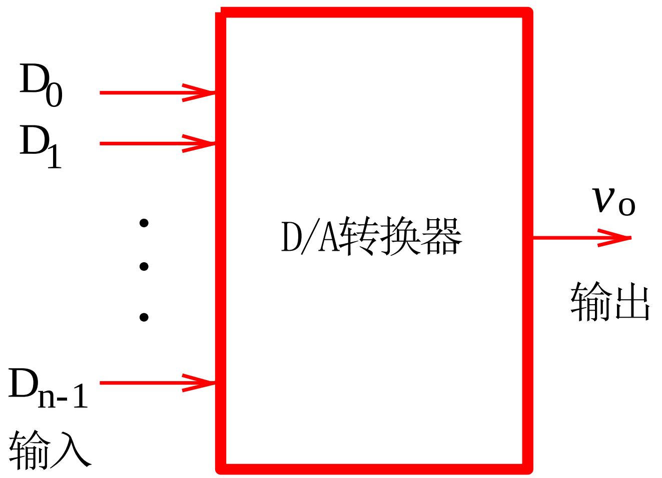
$$
\boxed{\begin{aligned} D_n &= d_{n-1}d_{n-2}\bullet\bullet\bullet d_1 d_0 \\ &= 2^{n-1}d_{n-1} + 2^{n-2}d_{n-2} + \bullet\bullet\bullet + 2^1 d_1 + 2^0 d_0 \end{aligned}}
$$

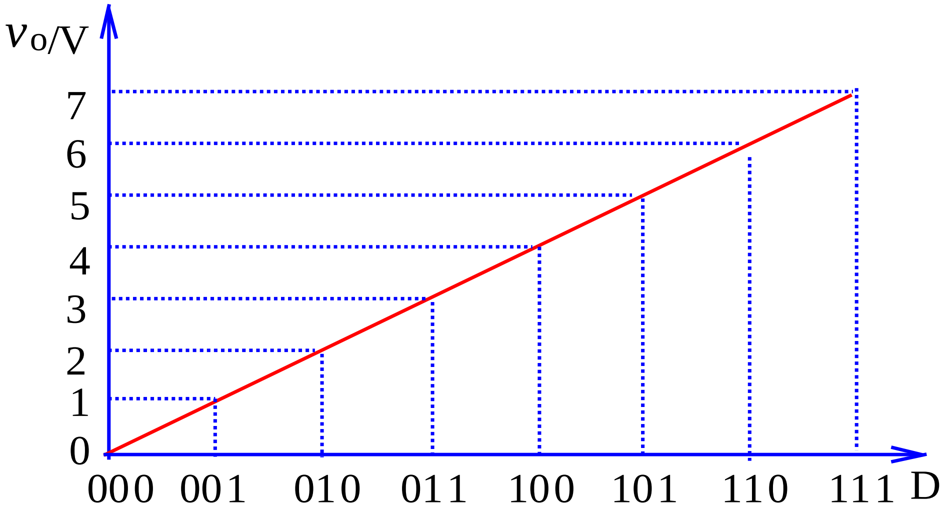
其中：2^{n-1}、2^{n-2}． ． ． 2^1、2^0称为最高位（Most Significant Bit，简称MSB）到最低位（Least Significant Bit，简称LSB）的权。

数字量是用代码按位数组合起来表示的，对于有权码，每位代码都有一定的权。为了将数字量转换成模拟量，必须将每一位的代码按其权的大小转换成相应的模拟量，然后相加，即可得与数字量成正比的总模拟量，从而实现数字－模拟的转换。

15.1 数模转换的工作原理和实现方法

15.1.1 D/A转换器的概念和基本原理





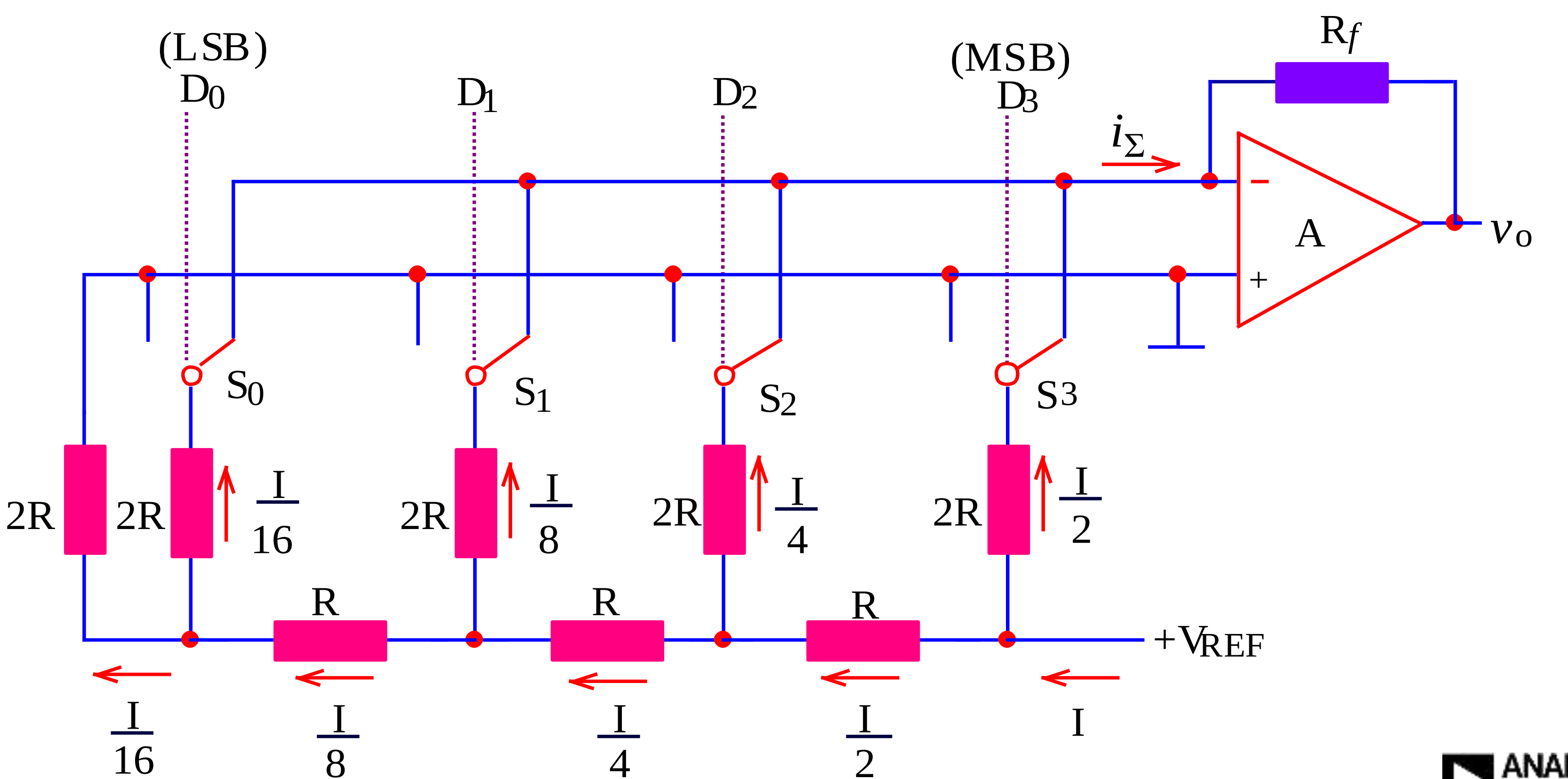
15.1.2　倒T形电阻网络D/A转换器

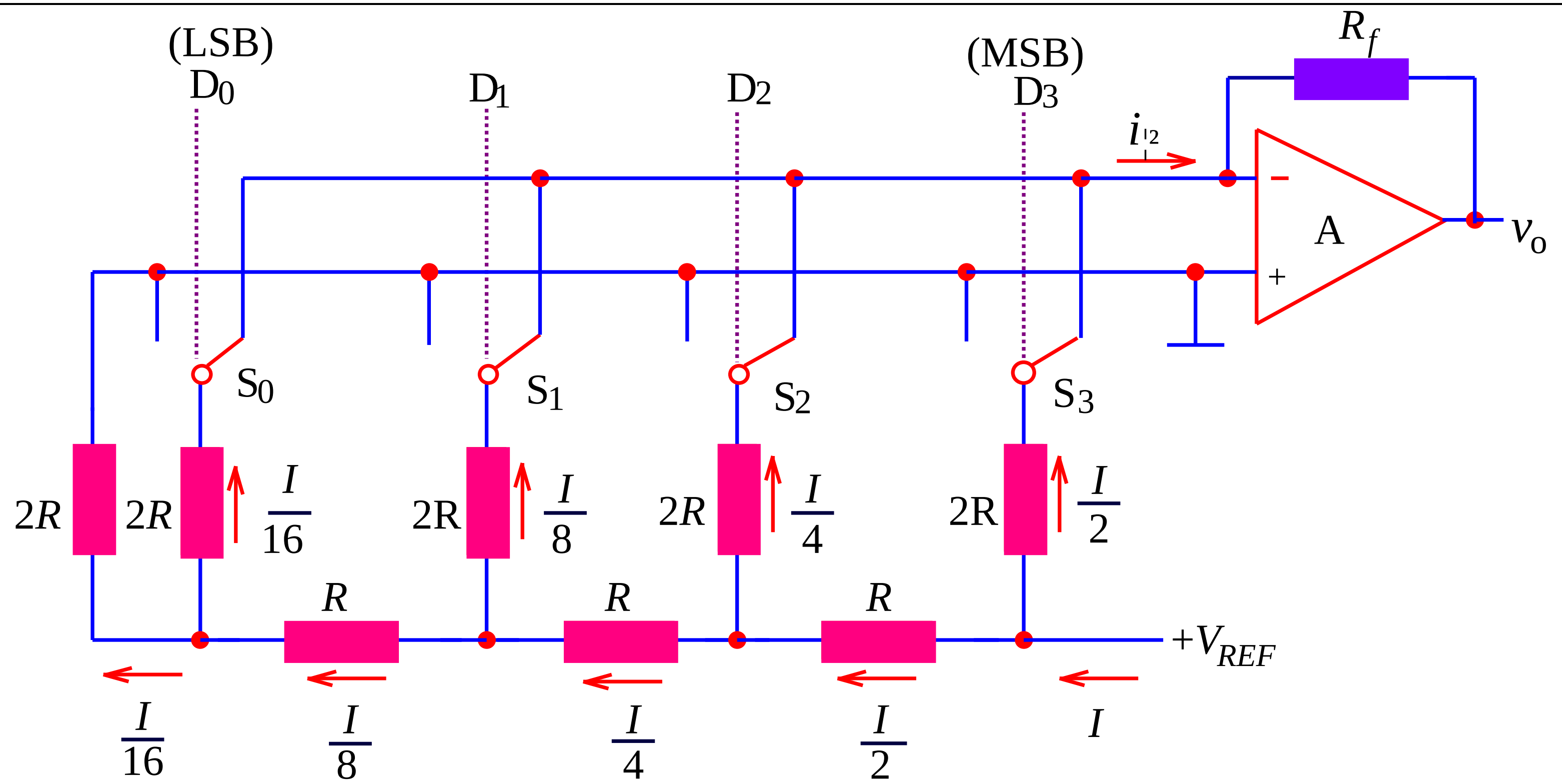
当D_i=1时，S_i接运算放大器反相输入端（虚地），电流I_i流入求和电路；

图中S_0～S_3为模拟开关，由输入数码D_i控制，

当D_i=0时，S_i将电阻2R接地。

因此，无论S_i处于何种位置，与S_i相连的2R电阻均接"地"（地或虚地）。





分析计算：

基准电流： $I=V_{REF}/R$，

流过各开关支路（从右到左）的电流分别为 $I/2$、$I/4$、$I/8$、$I/16$。

总电流： $$i_{\Sigma}=\frac{V_{REF}}{R}\left(\frac{D_0}{2^4}+\frac{D_1}{2^3}+\frac{D_2}{2^2}+\frac{D_3}{2^1}\right)=\frac{V_{REF}/R}{2^4}\sum_{i=0}^{3}(D_i\cdot 2^i)$$

输出电压： $$v_O=-i_{\Sigma}R_f=-\frac{R_f}{R}\cdot\frac{V_{REF}}{2^4}\sum_{i=0}^{3}(D_i\cdot 2^i)$$

4位D/A输出电压： $v_O = -i_\Sigma R_f = -\frac{R_f}{R} \cdot \frac{V_{REF}}{2^4} \sum_{i=0}^{3} (D_i \cdot 2^i)$

将输入数字量扩展到 n 位，则有：

$$v_O = -\frac{R_f}{R} \cdot \frac{V_{REF}}{2^n} \sum_{i=0}^{n-1} (D_i \cdot 2^i)$$

可简写为：$v_O = K N_B$

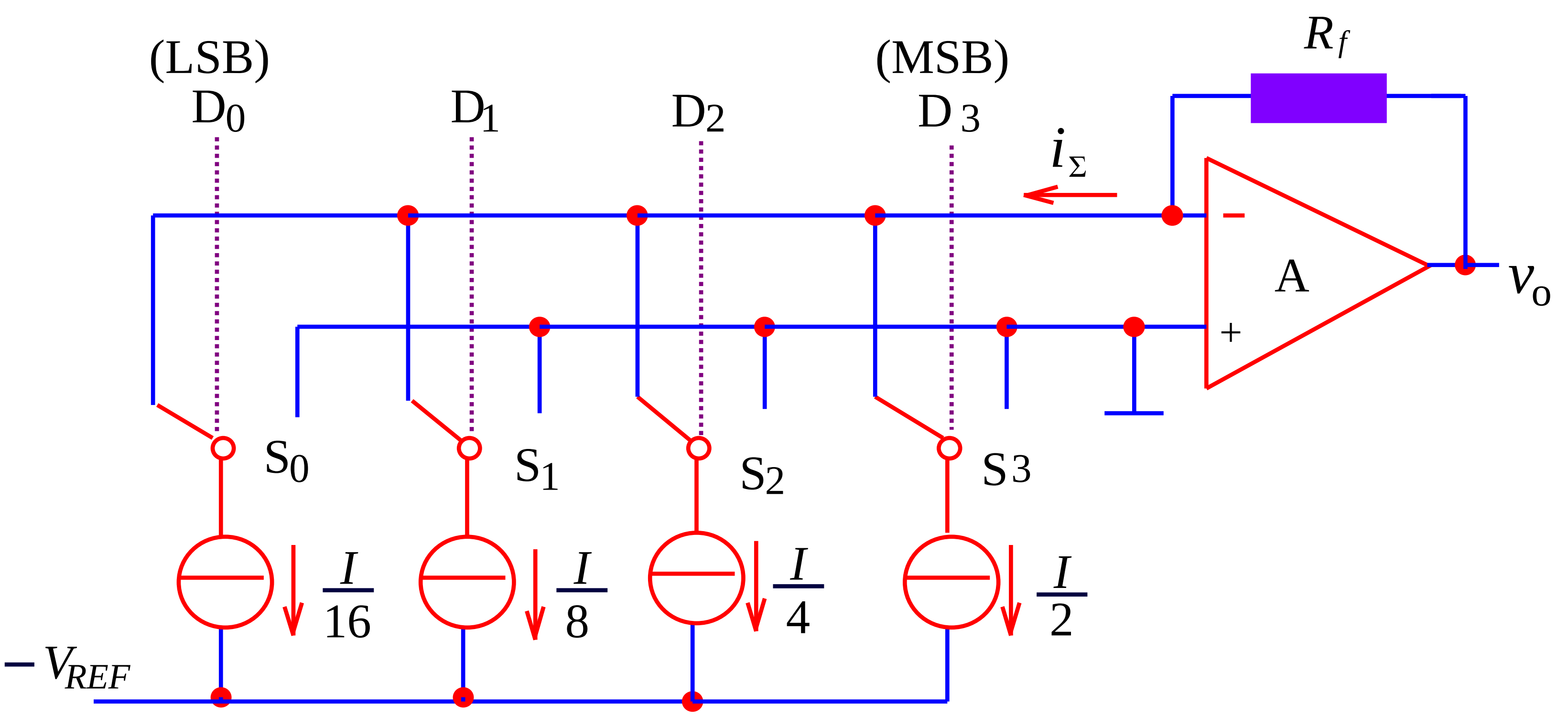
其中： $K = -\frac{R_f}{R} \cdot \frac{V_{REF}}{2^n}$ **最小单位量化电压**

$$N_B = \sum_{i=0}^{n-1} (D_i \cdot 2^i)$$

15.1.3 权电流型D/A转换器

为进一步提高D/A转换器的转换精度，可采用权电流型D/A转换器。

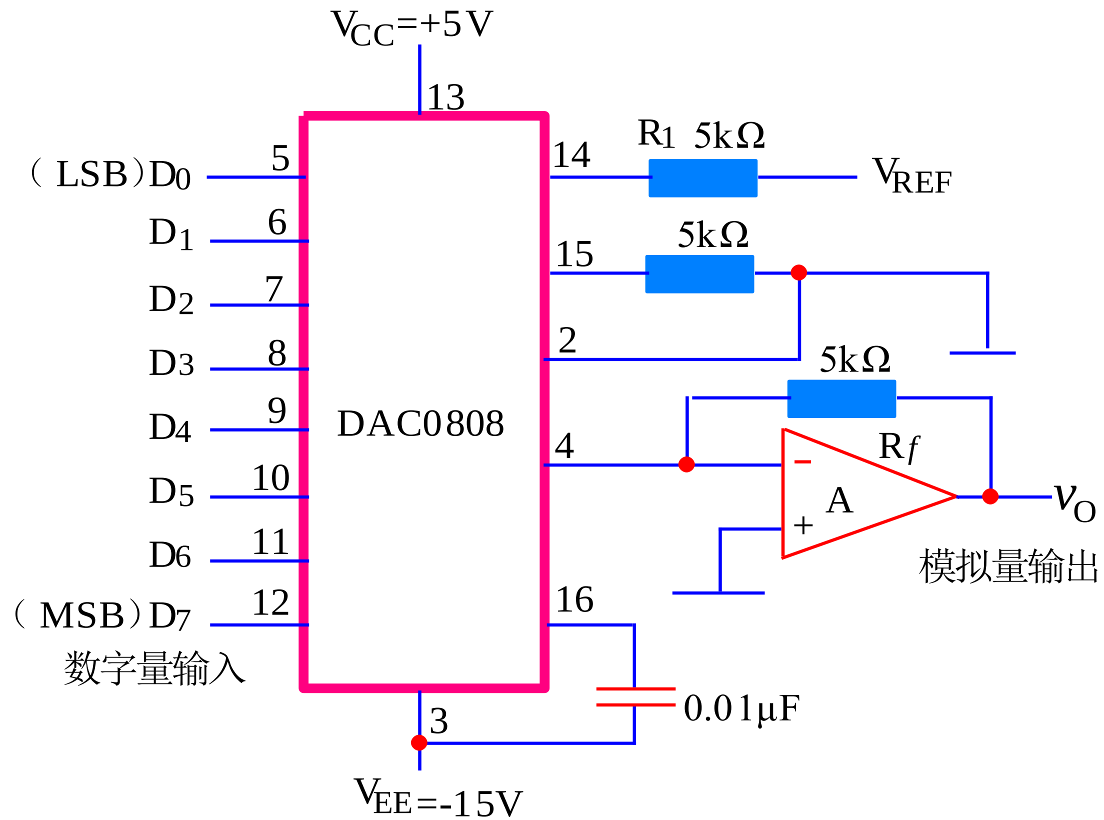
图示为一4位权电流D/A转换器原理电路。这组恒流源从高位到低位电流的大小依次为 $I/2$、$I/4$、$I/8$、$I/16$。



15.1.4 D/A转换器应用举例

DAC0808是8位权电流型D/A转换器，其中D_0～D_7是数字量输入端。

使用时，需要外接运算放大器和产生基准电流用的电阻 R_1。



当V_{REF} = 10V、

R_1 = 5 kΩ、

R_f = 5 kΩ 时，

输出电压为：

$$v_O = \frac{R_f V_{REF}}{2^8 R_1} \sum_{i=0}^{7} D_i \cdot 2^i = \frac{10}{2^8} \sum_{i=0}^{7} D_i \cdot 2^i$$

DAC0808 D/A转换器输出与输入的关系（设V_{REF}=10V）

数字输入								模拟输出	
D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	v_O	
0	0	0	0	0	0	0	0	$V_{REF}\left(\frac{0}{256}\right)$	0V
0	0	0	0	0	0	0	1	$V_{REF}\left(\frac{1}{256}\right)$	0.039V
⋮								⋮	
0	1	1	1	1	1	1	1	$V_{REF}\left(\frac{127}{256}\right)$	4.96V
1	0	0	0	0	0	0	0	$V_{REF}\left(\frac{128}{256}\right)$	5V
1	0	0	0	0	0	0	1	$V_{REF}\left(\frac{129}{256}\right)$	5.039V
⋮								⋮	
1	1	1	1	1	1	1	1	$V_{REF}\left(\frac{255}{256}\right)$	9.96V

最小单位量化电压

15.1.5 D/A转换器的主要技术指标

1、转换精度

（1）分辨率——D/A转换器模拟输出电压可能被分离的等级数。

输入数字量位数越多，分辨率越高。因此，在实际应用中，常用数字量的位数表示D/A转换器的分辨率。

此外，也可用D/A转换器的最小输出电压(数字量：00000001)与最大输出电压(数字量：全1）之比来表示分辨率，*n*位D/A转换器的分辨率可表示为 $1/(2^n-1)$。

$$v_O = -KN_B$$

$$N_B = \sum_{i=0}^{n-1}(D_i \cdot 2^i)$$

最小 $v_O = -KN_B = -K\times 1$

最大 $v_O = -KN_B = -K\times(2^n-1)$

（2）转换误差——比例系数误差、失调误差、非线性误差。

2、转换速度

（1）建立时间（t_{set}）——当输入的数字量发生变化时，输出电压变化到相应稳定电压值所需时间。最短可达0.1 μs。

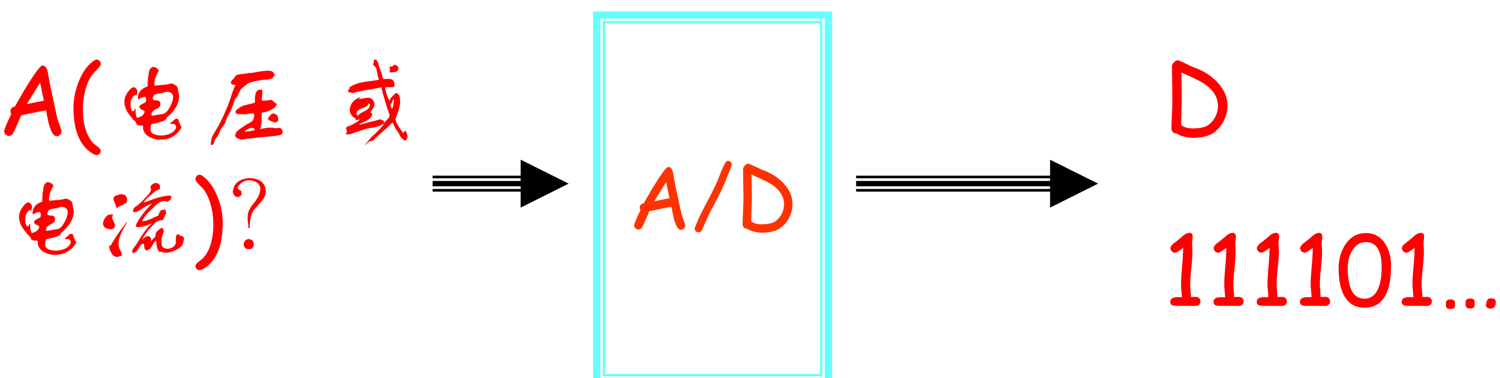
（2）转换速率（*SR*）——在大信号工作状态下模拟电压的变化率。

3、温度系数——在输入不变的情况下，输出模拟电压随温度变化产生的变化量。一般用满刻度输出条件下温度每升高1℃，输出电压变化的百分数作为温度系数。

15.2 模数转换的工作原理和实现方法

15.2.1 A/D转换器的概念和基本原理

将模拟信号转换成数字信号的过程称为模/数转换（Analog to Digital），实现的电路称为A/D转换器，简写为ADC（Analog - Digital Converter）。

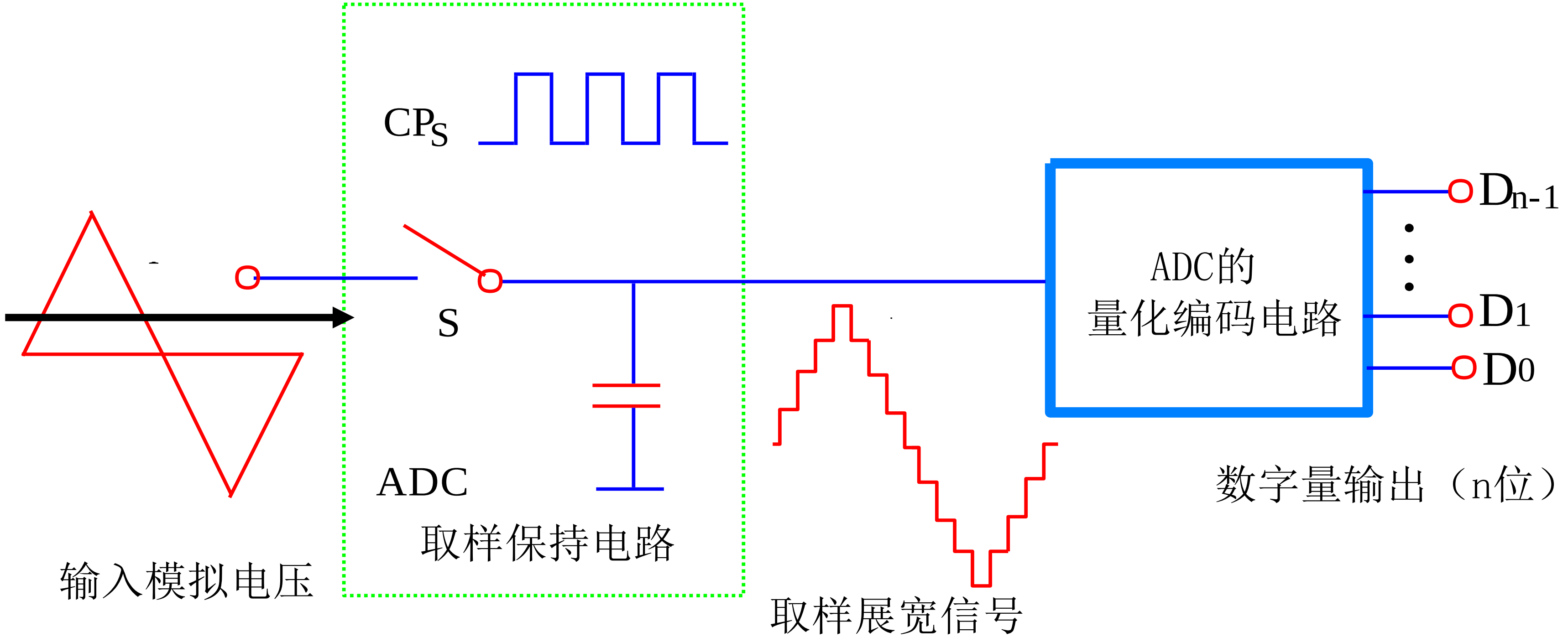


15.2 模数转换的工作原理和实现方法

15.2.1 A/D转换的一般步骤

因为输入的模拟信号在时间上是连续量，所以一般的A/D转换过程包括：取样、保持、量化和编码四个过程。

【时间离散——取样、保持；幅度离散——量化、编码】

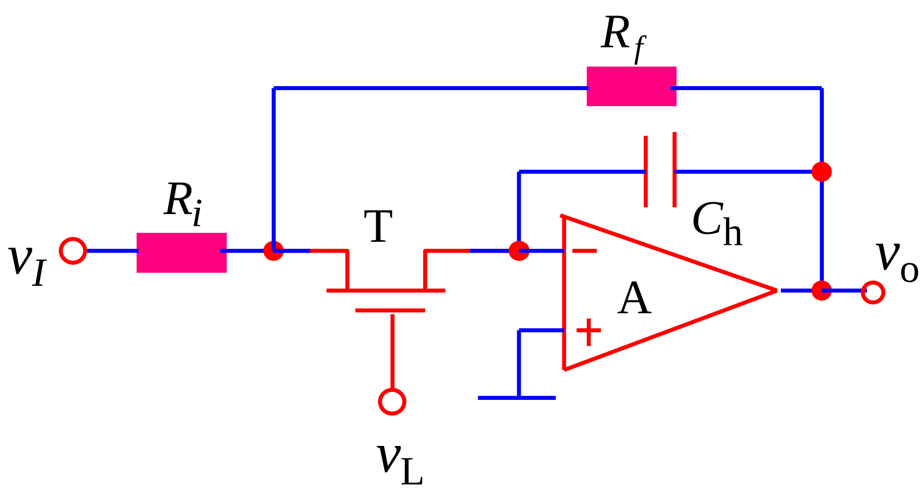


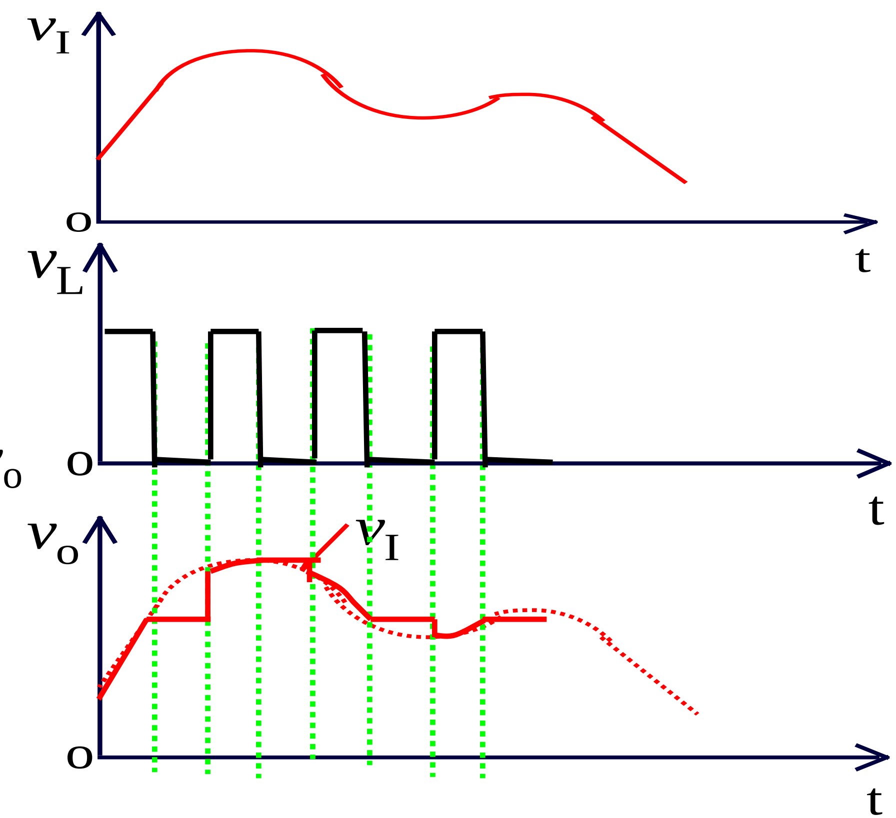
15.2.2 取样—保持电路

电路组成及工作原理（取$R_i = R_f$）：

当v_L为高电平时，T导通，v_I 经 R_i 和 T 向电容 C_h 充电。v_O=－v_I=v_C。

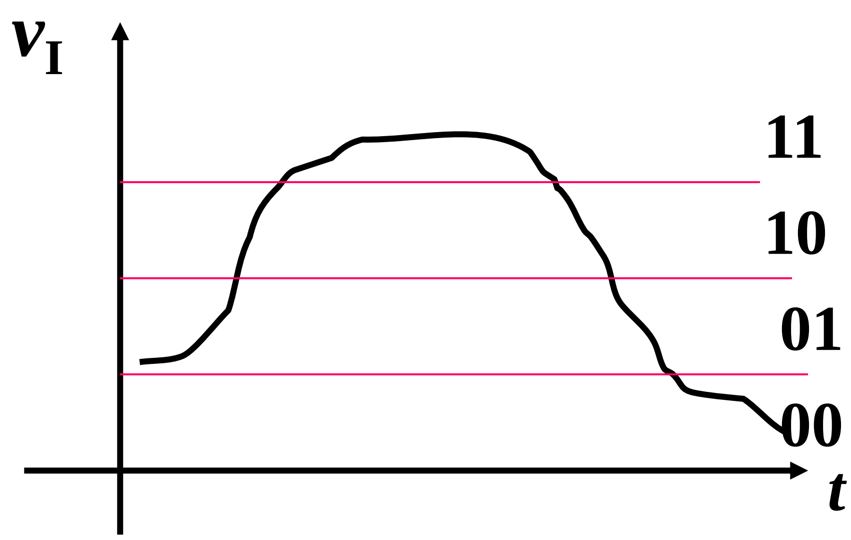
当v_L返回低电平后，T截止。C_h无放电回路，因此v_O的数值可被保存下来。



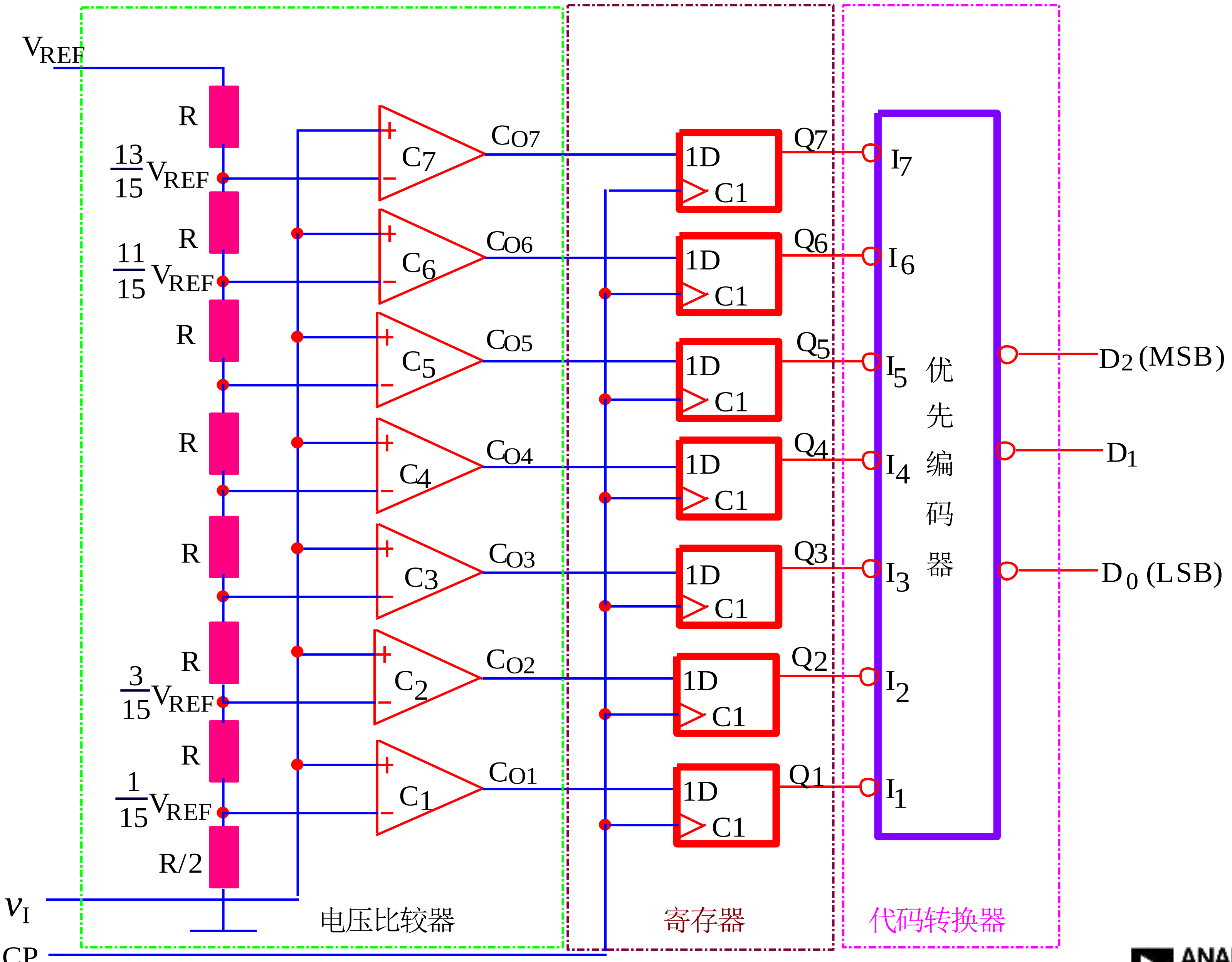


15.2.3 并行比较型A/D转换器

基本原理：



3位并行比较型A/D转换器

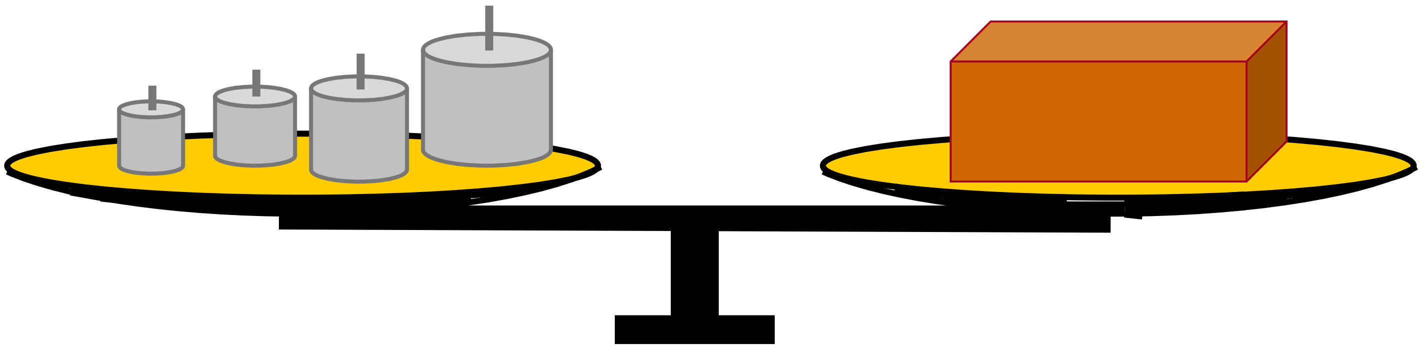


并行比较型A/D转换器真值表

输入模拟电压	寄存器状态							数字量输出		
	Q_7	Q_6	Q_5	Q_4	Q_3	Q_2	Q_1	D_2	D_1	D_0
（0～1/15）V_{REF}	0	0	0	0	0	0	0	0	0	0
（1/15～3/15）V_{REF}	0	0	0	0	0	0	1	0	0	1
（3/15～5/15）V_{REF}	0	0	0	0	0	1	1	0	1	0
（5/15～7/15）V_{REF}	0	0	0	0	1	1	1	0	1	1
（7/15～9/15）V_{REF}	0	0	0	1	1	1	1	1	0	0
（9/15～11/15）V_{REF}	0	0	1	1	1	1	1	1	0	1
（11/15～13/15）V_{REF}	0	1	1	1	1	1	1	1	1	0
（13/15～1）V_{REF}	1	1	1	1	1	1	1	1	1	1

15.2.4 逐次比较型A/D转换器

转换原理



有效砝码的总重量逐次逼近重物的重量：

$$G \approx d_3 g_3 + d_2 g_2 + d_1 g_1 + d_0 g_0$$

$$d_i \begin{cases} 1 & \text{有效} \\ 0 & \text{无效} \end{cases}$$

15.2.5 A/D转换器的主要技术指标

$$分辨率=\frac{V_{LSB}}{V_m}=\frac{1}{2^n-1}$$

一、转换精度

（1）分辨率——说明A/D转换器对输入信号的分辨能力。

一般以输出二进制（或十进制）数的位数表示。因为，在最大输入电压一定时，输出位数愈多，量化单位愈小，分辨率愈高。

（2）转换误差——它表示A/D转换器实际输出的数字量和理论上的输出数字量之间的差别。常用最低有效位的倍数表示。

例如，相对误差≤±LSB/2，就表明实际输出的数字量和理论上应得到的输出数字量之间的误差小于最低位的半个字。

二、转换时间

——指从转换控制信号到来开始，到输出端得到稳定的数字信号所经过的时间。

并行比较A/D转换器转换速度最高；逐次比较型A/D转换器次之；间接A/D转换器的速度最慢。

Arduino boards contain a multichannel, **10-bit** analog to digital converter. This means that it will map input voltages between **0** and the **operating voltage**(5V or 3.3V) into integer values between **0** and **1023**. On an Arduino UNO, for example, this yields a resolution between readings of: 5 volts / 1023 units or, 0.0049 volts (4.9 mV) per unit.

```
/*
  ReadAnalogVoltage

  Reads an analog input on pin 0, converts it to voltage, and prints the result to the Serial Monitor.
  Graphical representation is available using Serial Plotter (Tools > Serial Plotter menu).
  Attach the center pin of a potentiometer to pin A0, and the outside pins to +5V and ground.

  This example code is in the public domain.

  http://www.arduino.cc/en/Tutorial/ReadAnalogVoltage
*/

// the setup routine runs once when you press reset:
void setup() {
  // initialize serial communication at 9600 bits per second:
  Serial.begin(9600);
}

// the loop routine runs over and over again forever:
void loop() {
  // read the input on analog pin 0:
  int sensorValue = analogRead(A0);
  // Convert the analog reading (which goes from 0 - 1023) to a voltage (0 - 5V):
  float voltage = sensorValue * (5.0 / 1023.0);
  // print out the value you read:
  Serial.println(voltage);
}
```

从 ADC code 反推出输入模拟电压的幅度

直流电源

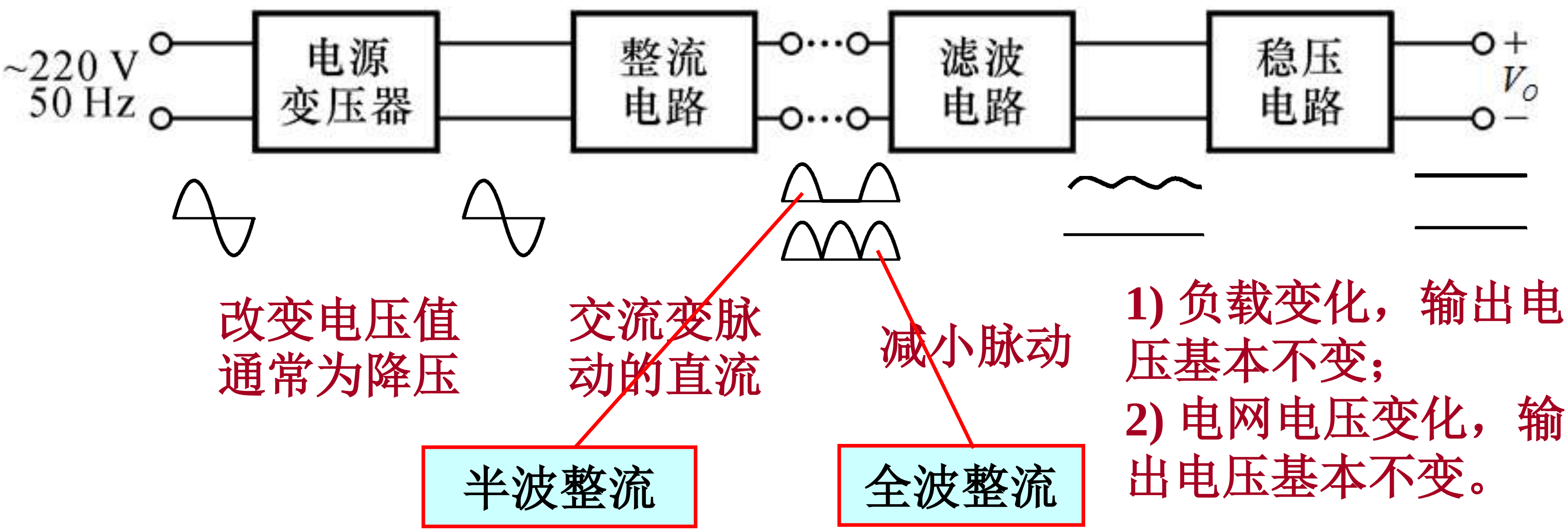
滤波电路

串联型稳压电路

开关型稳压电路

直流电源的组成

直流电源是能量转换电路，将220V 50Hz的交流电转换为直流电



1) 负载变化，输出电压基本不变；
2) 电网电压变化，输出电压基本不变。

分析电源电路时要特别考虑的两个问题：

- 允许电网电压波动±10%
- 负载有一定的变化范围

4.5. Rectifier Circuits
整流电路

- One important application of diode is the rectifier –
  - Electrical device which converts alternating current (AC) to direct current (DC)
- One important application of rectifier is dc power supply.

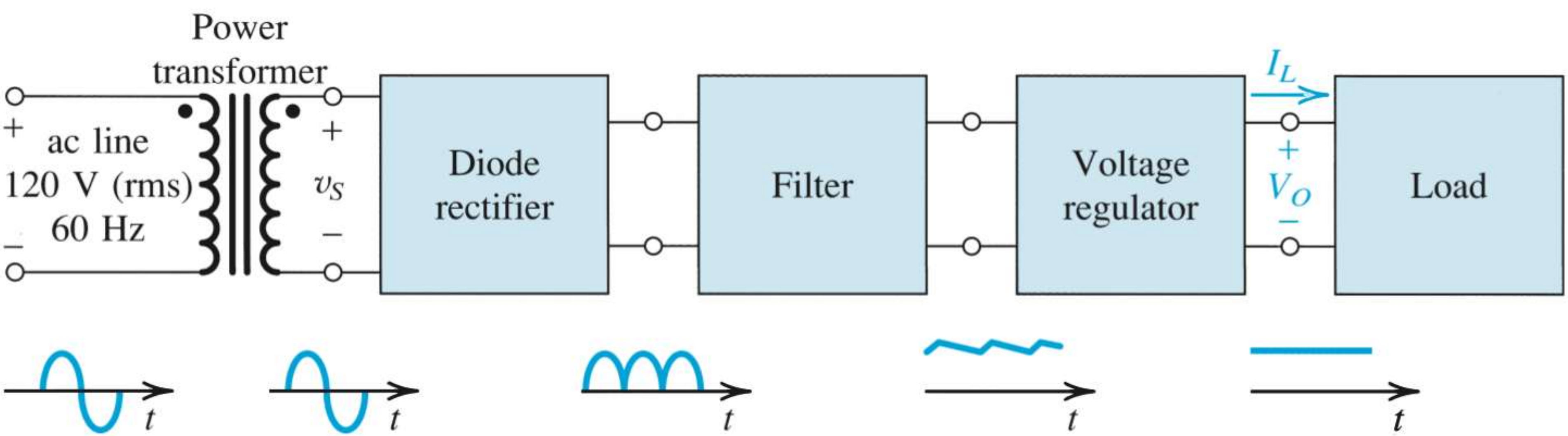


Figure 4.22 Block diagram of a dc power supply.

step #1: increase / decrease rms magnitude of AC wave via power transformer

step #2: convert full-wave AC to half-wave DC (still time-varying and periodic)

step #3: 滤去高频分量，使曲线更光滑

step #4: employ voltage regulator to eliminate ripple

step #5: supply dc load

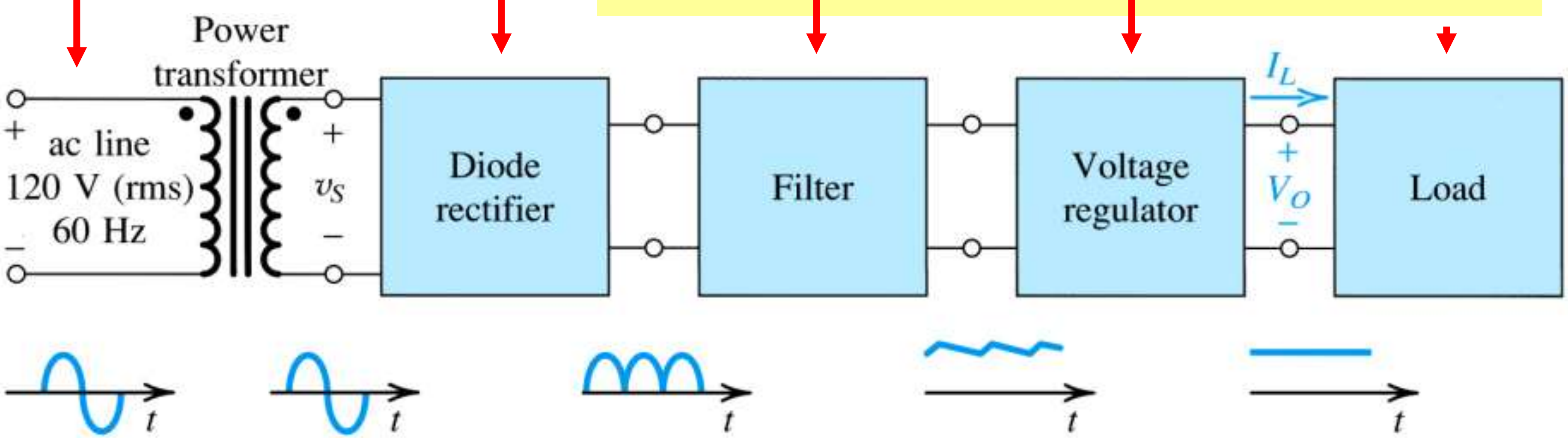


Figure 4.20: Block diagram of a dc power supply

4.5.1. The Half-Wave Rectifier
半波整流

◆ half-wave rectifier
– utilizes only alternate half-cycles of the input sinusoid
- Constant voltage drop diode model is employed.

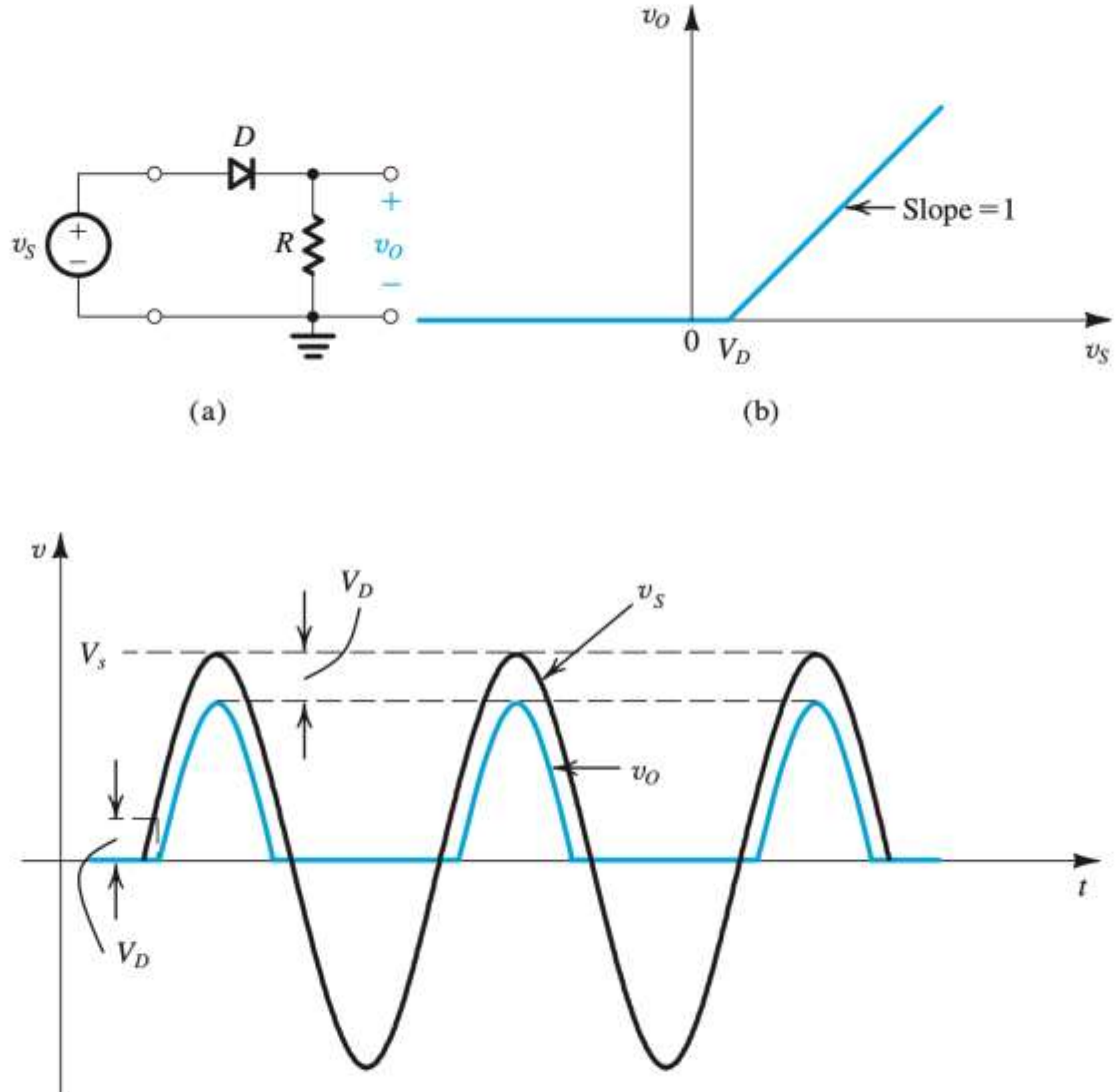


Figure 4.21: (a) Half-wave rectifier **(b)** Transfer characteristic of the rectifier circuit **(c)** Input and output waveforms

4.5.1. The Half-Wave Rectifier

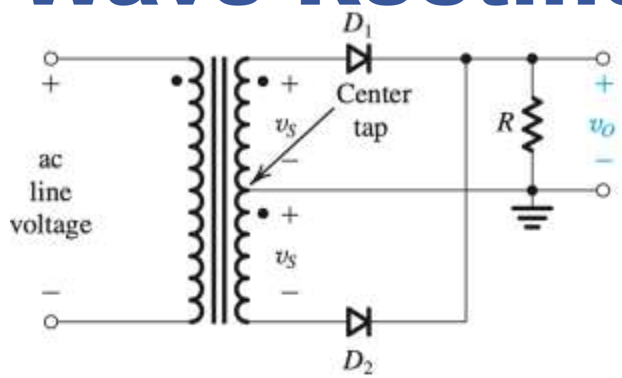
- **current-handling capability – what is maximum forward current diode is expected to conduct?**
- **peak inverse voltage (PIV) – what is maximum reverse voltage it is expected to block w/o breakdown?**
- 需关注两个参数：最大正向电流、最大反向电压

4.5.1. The Half-Wave Rectifier

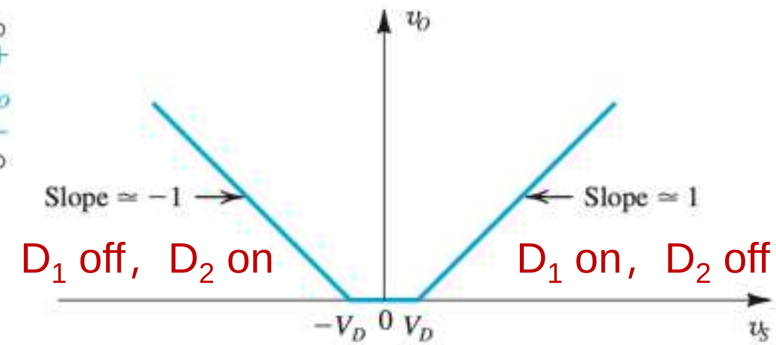
- **exponential model?** **It is possible to use the diode exponential model in describing rectifier operation; however, this requires too much work.**
- **small inputs?** **Regardless of the model employed, one should note that the rectifier will not operate properly when input voltage is small (< 1*V*).**
  - **Those cases require a precision rectifier.**
  - 半波整流电路只适合于输入较大的信号（要远大于V_D才近似半波整流）

4.5.2. The Full-Wave Rectifier

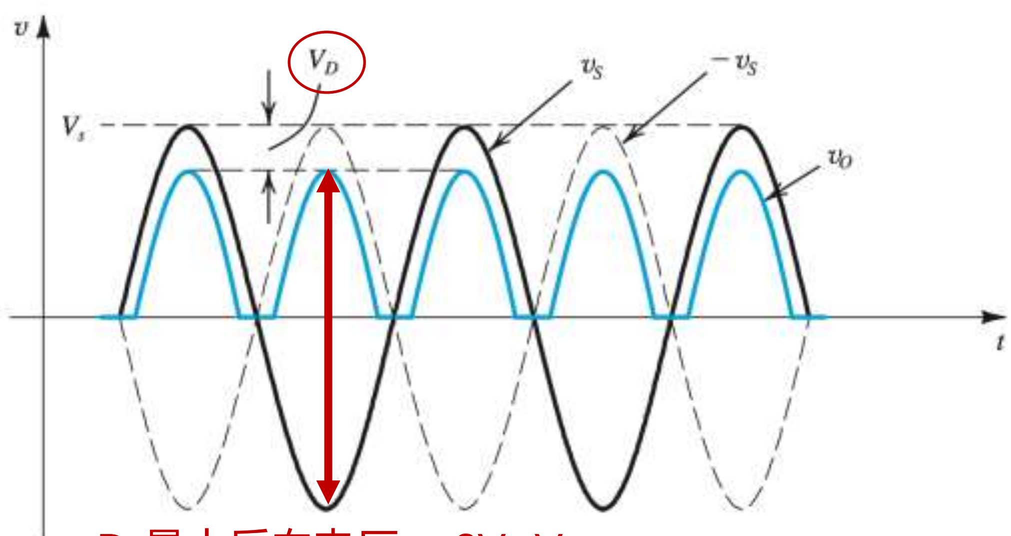
全波整流的实现方法之一



(a)



(b)



D_1最大反向电压： $2V_s$-V_D

(c)

4.5.2. The Full-Wave Rectifier

1. 流经负载的电流方向不变
2. 相比半波整流利用率更高
3. 最大反向电压较大

- **Q: What are most important observation(s) from this operation?**
  - **A: The direction of current flowing across load never changes (both halves of AC wave are rectified). The full-wave rectifier produces a more “energetic” waveform than half-wave.**
    - **PIV for full-wave = $2V_S - V_D$**

4.5.3. The Bridge Rectifier

全波整流的实现方法之二：
桥式整流

- An alternative implementation of the full-wave rectifier is bridge rectifier.
  - Shown to right.

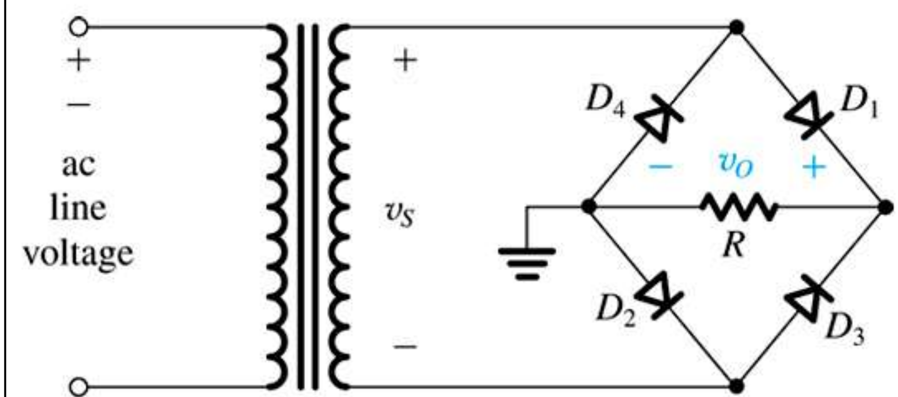


Figure 4.23: The bridge rectifier circuit.

when instantaneous source voltage is **positive**, D_1 and D_2 on while D_3 *and* D_4 off

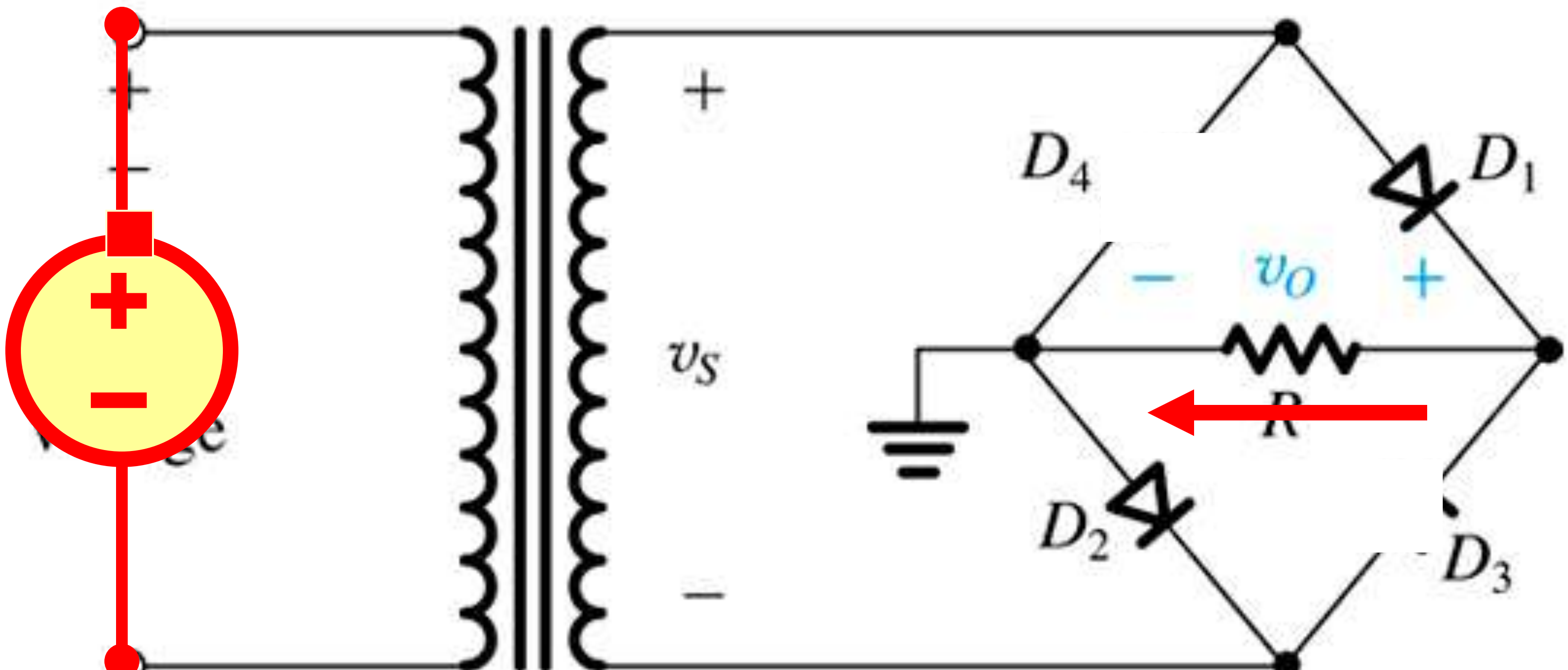


Figure 4.23: The bridge rectifier circuit.

when instantaneous source voltage is **negative**, D_1 and D_2 off while D_3 *and* D_4 on

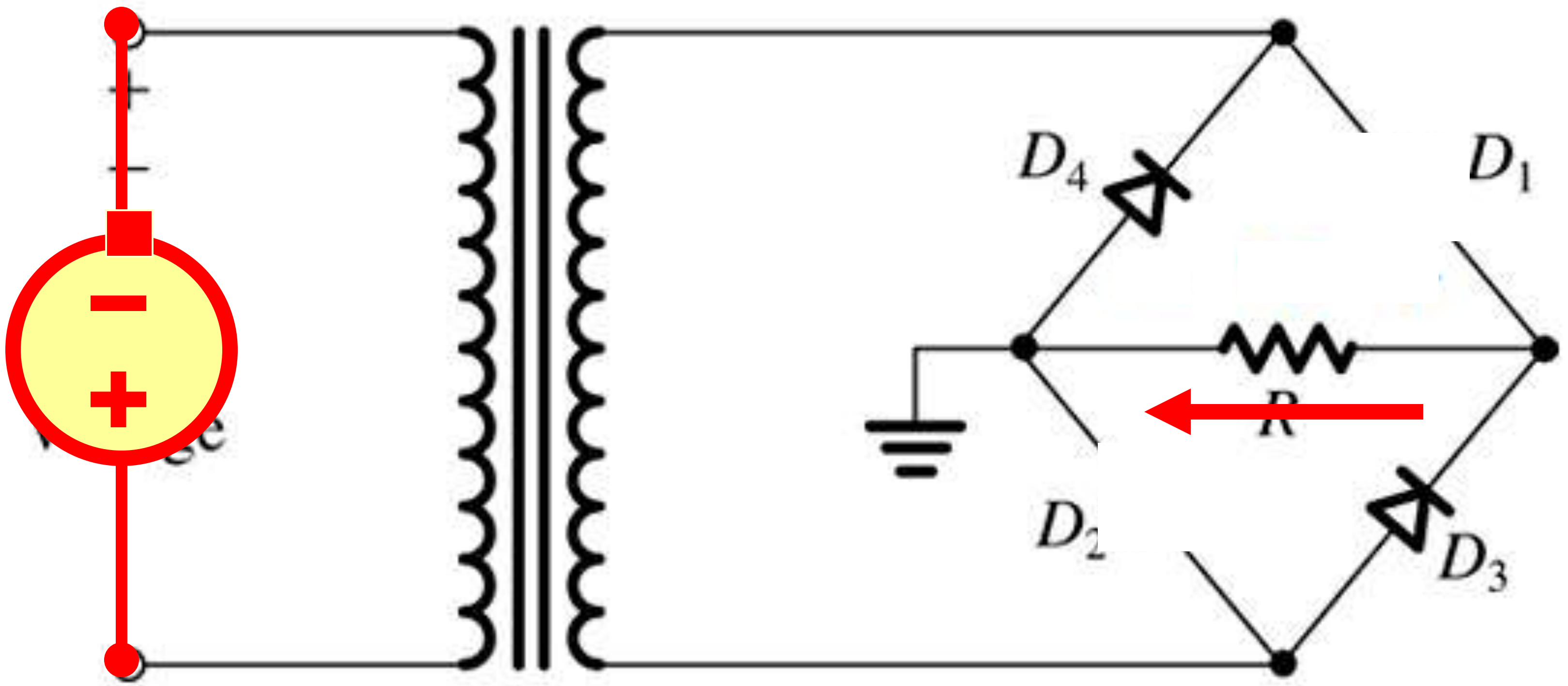
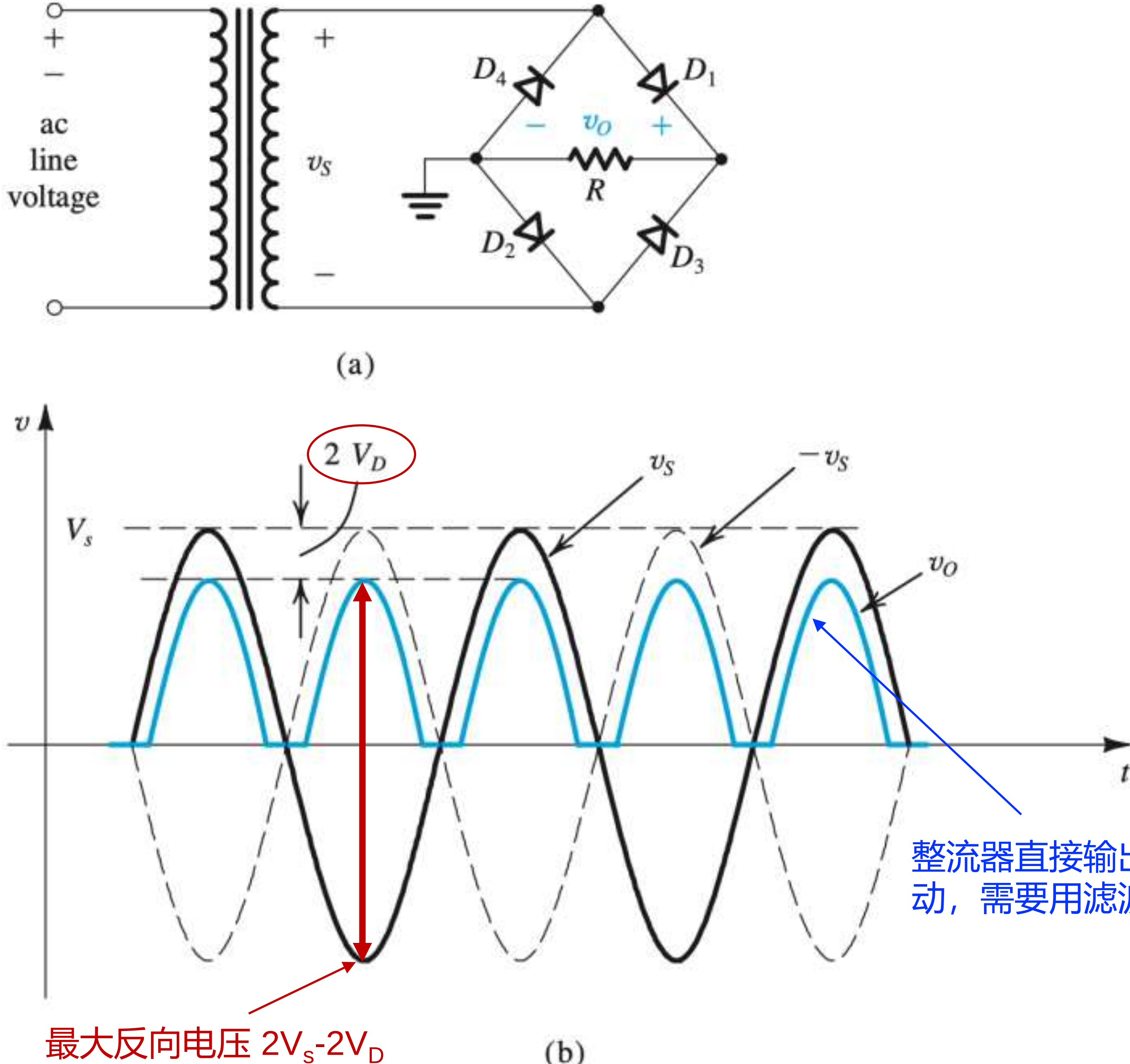


Figure 4.23: The bridge rectifier circuit.



整流器直接输出有较大波动，需要用滤波器滤除

最大反向电压 $2V_s$-$2V_D$
被两个二极管D_3D_4分摊

Figure 4.25 The bridge rectifier: **(a)** circuit; **(b)** input and output waveforms.

4.5.3: The Bridge Rectifier (BR)

- **Q: What is the main advantage of BR?**
  - **A: No need for center-tapped transformer.**
- **Q: What is main disadvantage?**
  - **A: Series connection of TWO diodes will reduce output voltage.**
- **PIV =** $V_S - V_D$

1. 无需变压器中间抽头
2. 最大反向电压较小；

- 但，输出电压有两个$V_{D,on}$的压差

4.5.4. The Rectifier with a Filter Capacitor 滤波电容

- Pulsating nature of rectifier output makes **unreliable dc supply.**
- As such, a **filter capacitor** is employed to remove ripple.

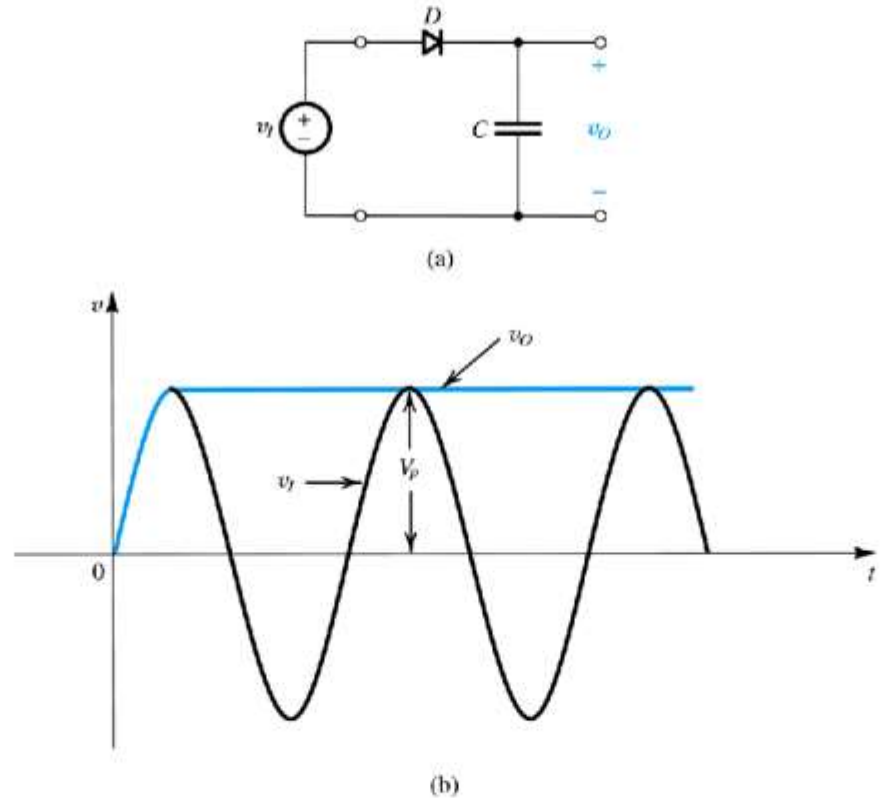


Figure 4.24: (a) A simple circuit used to illustrate the effect of a filter capacitor. **(b)** input and output waveforms assuming an ideal diode.

4.5.4. The Rectifier with a Filter Capacitor

- step #1: source voltage is positive, diode is forward biased, capacitor charges.
- step #2: source voltage is reverse, diode is reverse-biased (blocking), capacitor cannot discharge.

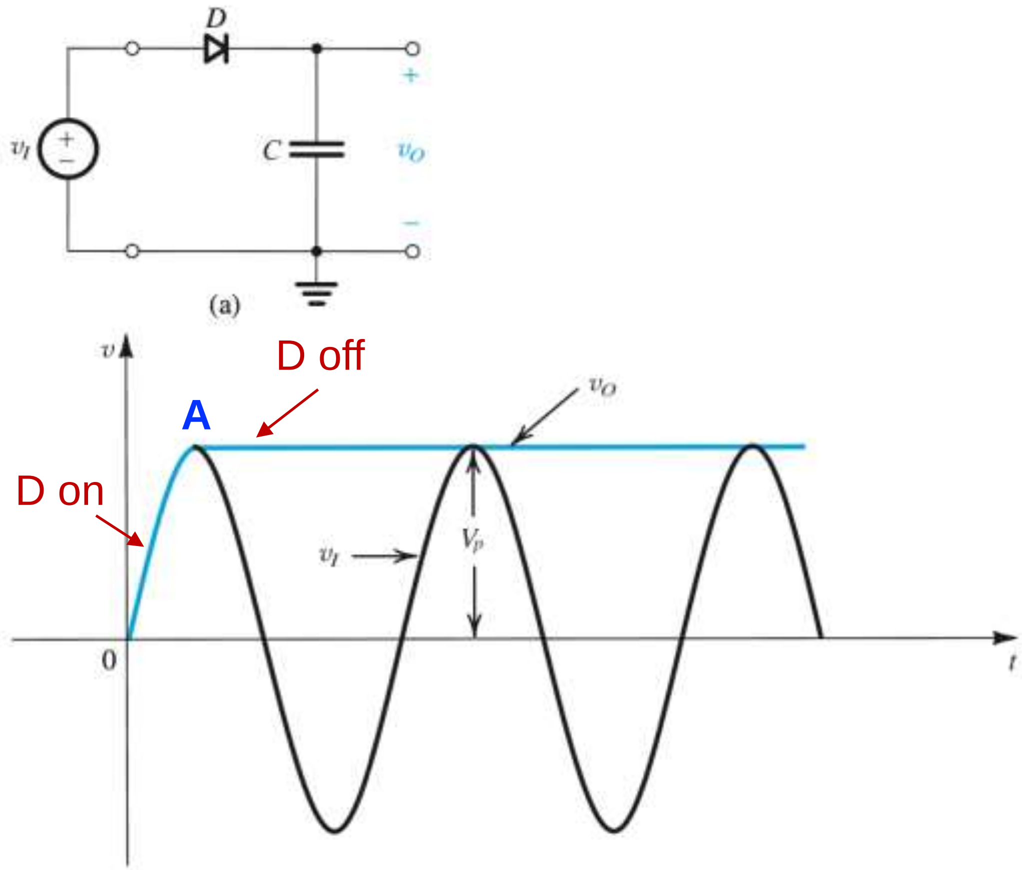


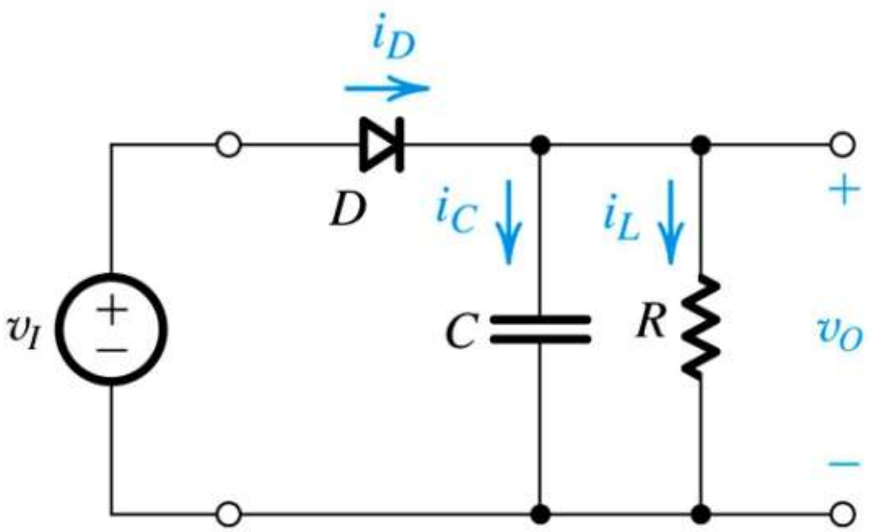
Figure 4.24 (a) A simple circuit used to illustrate the effect…

4.5.4. The Rectifier with a Filter Capacitor

- **Q:** Why is this example unrealistic?
  - **A:** Because for any practical application, the converter would supply a load (which in turn provides a path for capacitor discharging).

4.5.4. The Rectifier with a Filter Capacitor

- **Q:** What happens when load resistor is placed in parallel with capacitor?
  - **A:** One must now consider the discharging of capacitor across load.

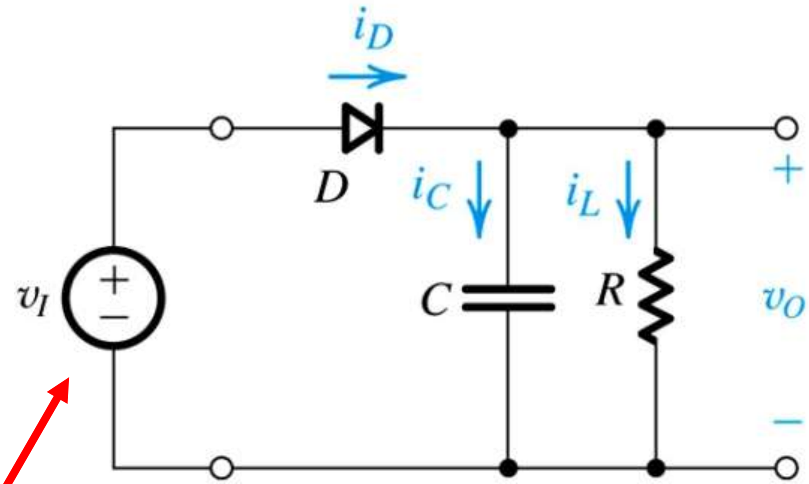


4.5.4. The Rectifier with a Filter Capacitor

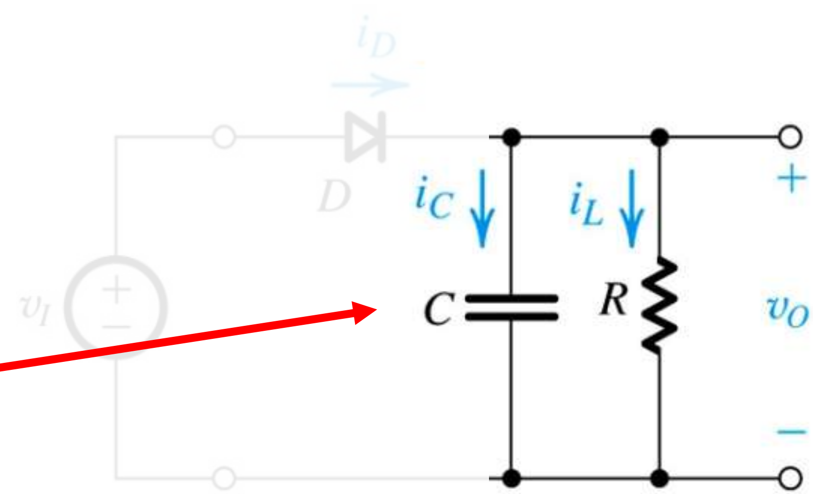
- The textbook outlines how **Laplace Transform** may be used to define behavior below.

$$\overbrace{v_O(t) = v_I(t) - v_D}^{\text{output voltage for state \#1}}$$

$$\underbrace{v_O(t) = V_{peak} e^{-\frac{t}{RC}}}_{\text{output voltage for state \#2}}$$



D ON, circuit state #1



D OFF, circuit state #2

ANALOG DEVICES

$$\underbrace{v_O(t)=v_I(t)}^{\text{output voltage for state \#1}}$$

$$\underbrace{v_O(t)=V_{peak}e^{-\frac{t}{RC}}}_{\text{output voltage for state \#2}}$$

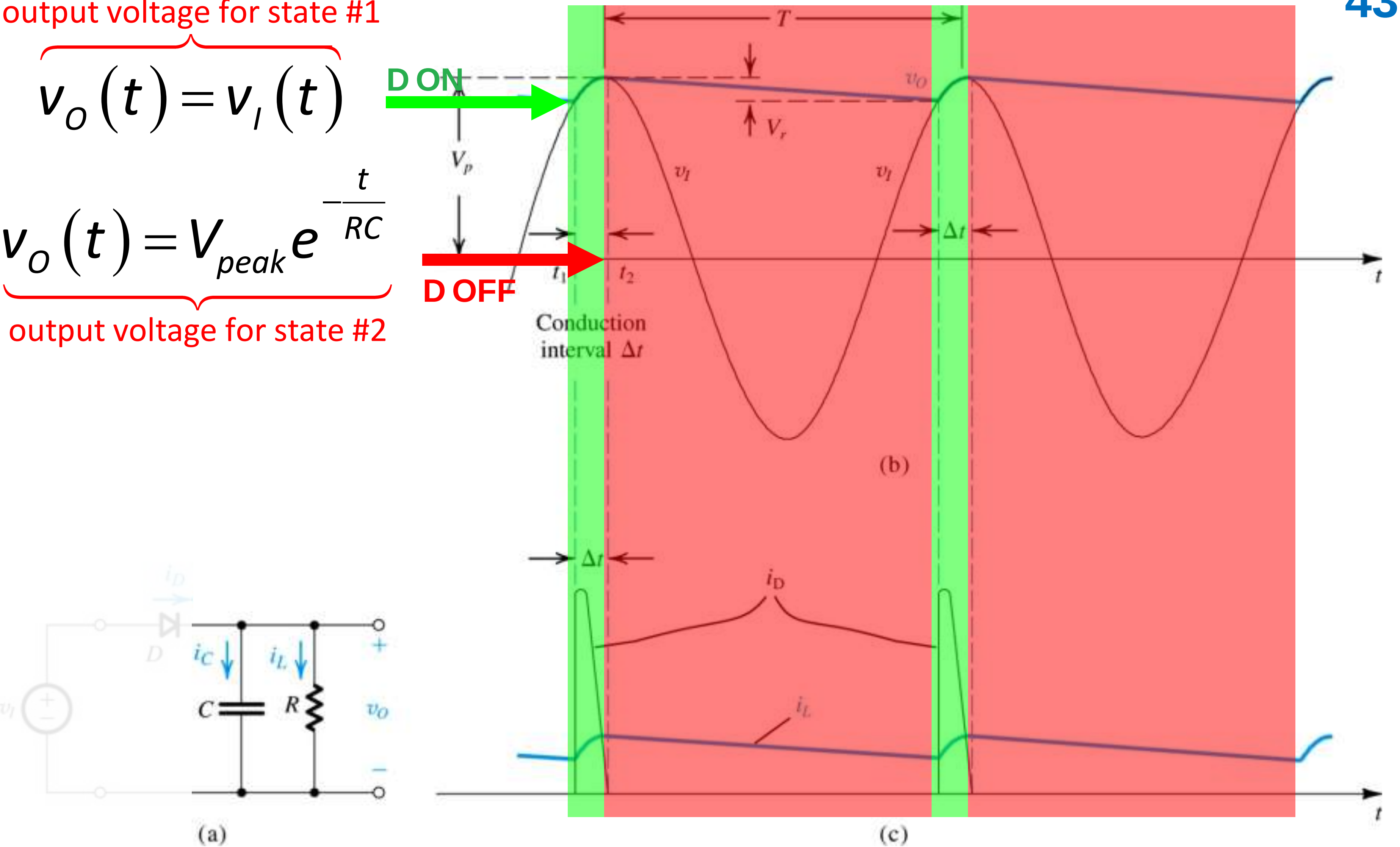


Figure 4.25: Voltage and Current Waveforms in the Peak Rectifier Circuit WITH *RC* >> *T*. The diode is assumed ideal.

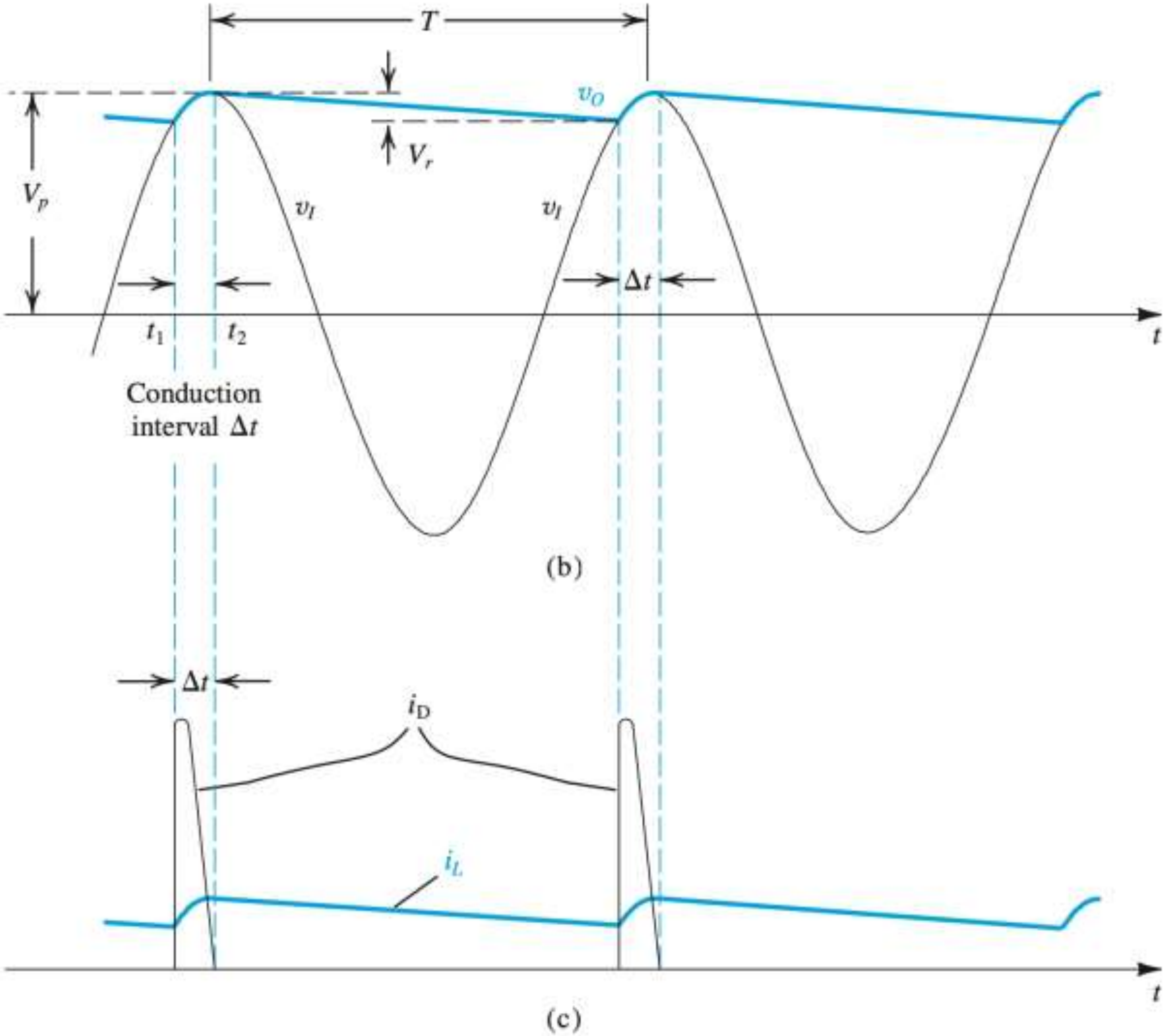


Figure 4.27 Voltage and current waveforms in the peak-rectifier circuit with $CR \gg T$. The diode is assumed ideal.

电容放电时：

$$v_O = V_p e^{-t/CR}$$

假设 $CR \gg T$ ，指数衰减变直线

$$V_r \simeq V_p \frac{T}{CR}$$

电容充电时间

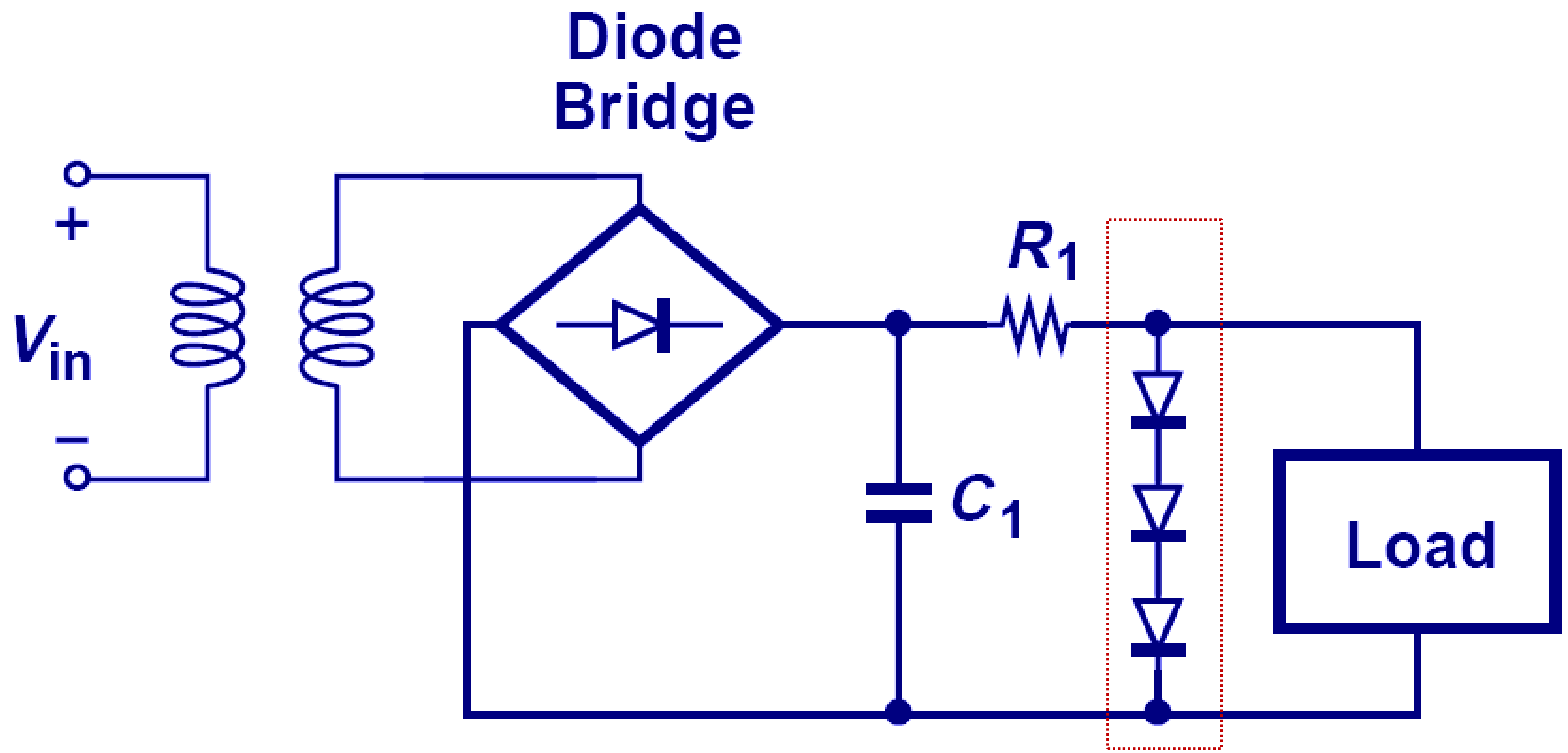
$$V_p \cos(\omega\Delta t) = V_p - V_r$$

近似 $\cos(\omega\Delta t) \simeq 1 - \frac{1}{2}(\omega\Delta t)^2$

$$\Rightarrow \quad \omega\Delta t \simeq \sqrt{2V_r/V_p}$$

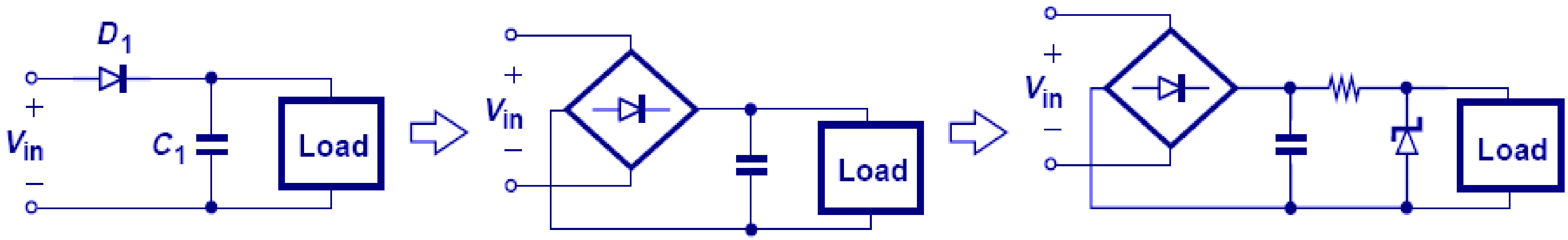
这一电路也可以用来检测波形的峰值，可用作**峰值检波电路**

滤波之后加稳压电路



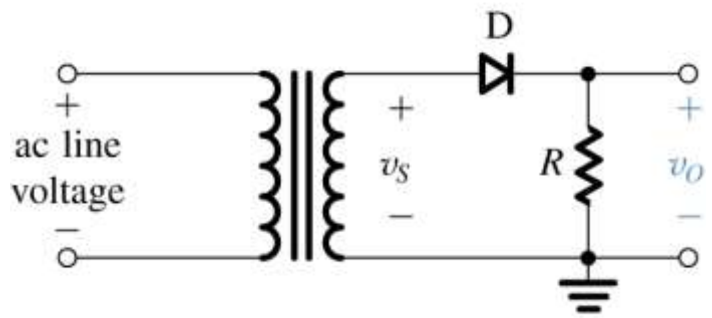
- The ripple created by the rectifier can be unacceptable to sensitive load; therefore, a regulator is required to obtain a very stable output.
- Three diodes operate as a primitive regulator.

Evolution of AC-DC Converter

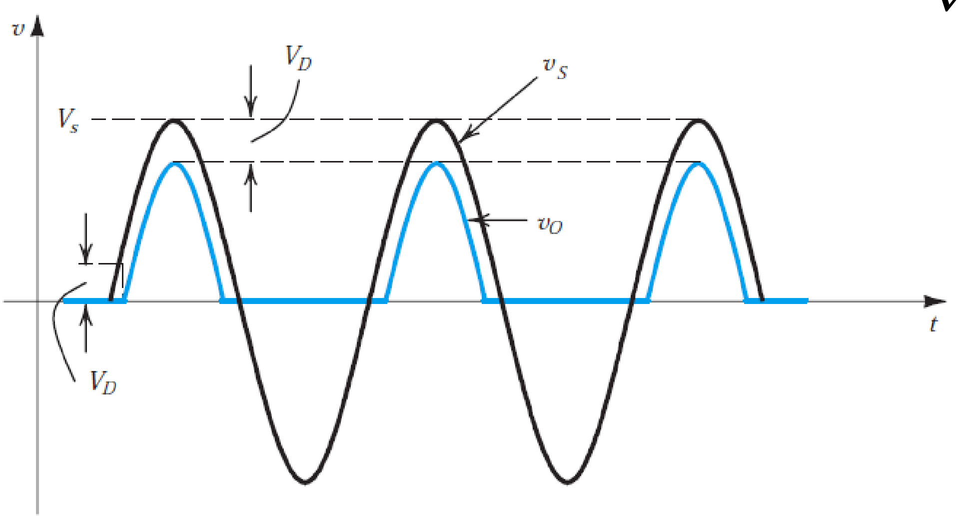


半波整流 + 滤波　　　全波整流 + 滤波　　　全波整流 + 滤波 + 稳压

半波整流的输出直流分量



(a)



输出电压在一个周期内，是正半周导电，在负载上得到的是半个正弦波。

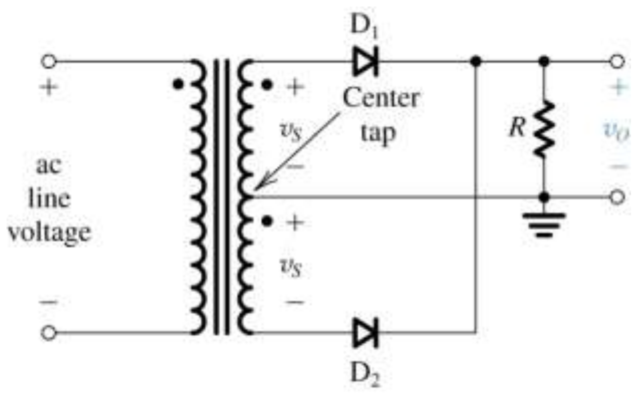
负载上输出平均电压（直流分量）为：

$$V_O = V_L = \frac{1}{2\pi}\int_0^{\pi}\sqrt{2}V_2 \sin\omega t \, d(\omega t)$$

$$= \frac{\sqrt{2}}{\pi}V_2 = 0.45V_2$$

V_2：变压器次级电压的有效值（忽略二极管压降）

全波整流的输出直流分量

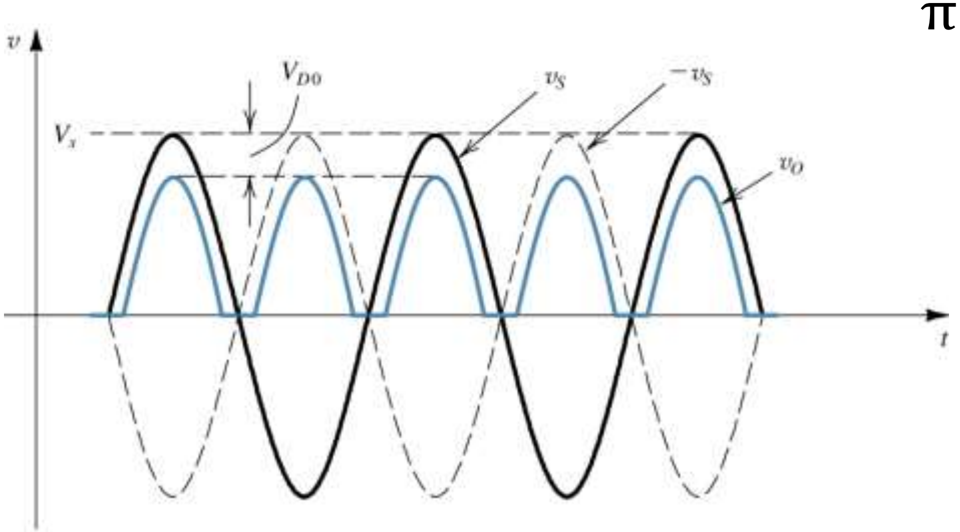


(a)

D1、D2分别在正负半周导通，负载上得到的是两个半个正弦波的叠加。

负载上输出平均电压（直流分量）为：

$$V_O = V_L = \frac{1}{\pi}\int_0^{\pi}\sqrt{2}V_2 \sin\omega t \mathrm{d}(\omega t) = \frac{2\sqrt{2}}{\pi}V_2 = 0.9V_2$$

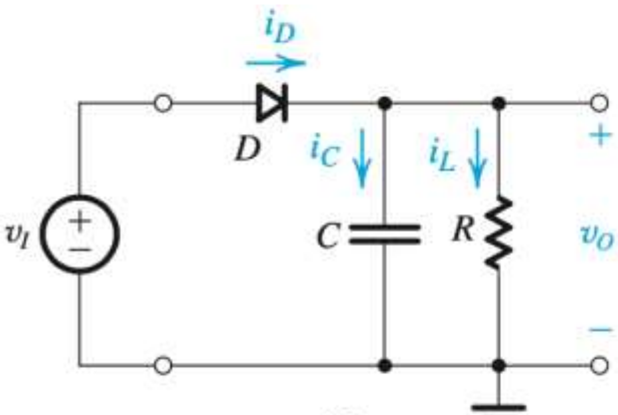


(c)

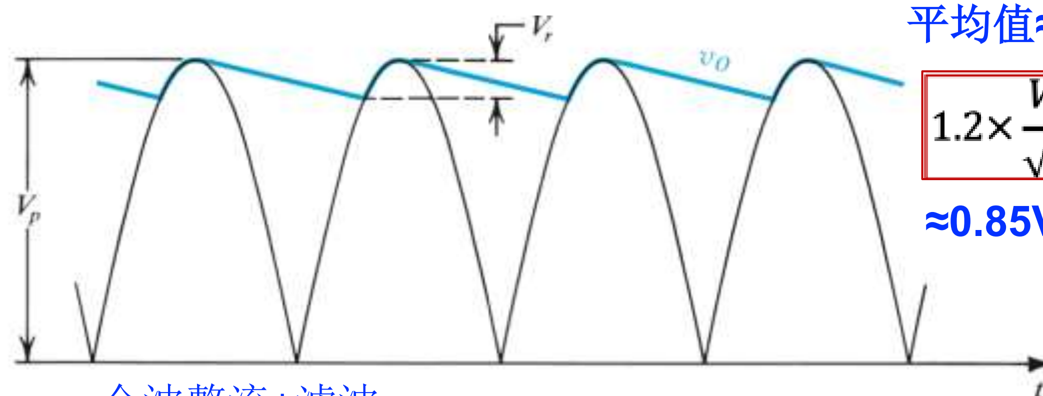
V_2：变压器次级电压的有效值

（忽略二极管压降）

滤波后的输出直流分量



(a)

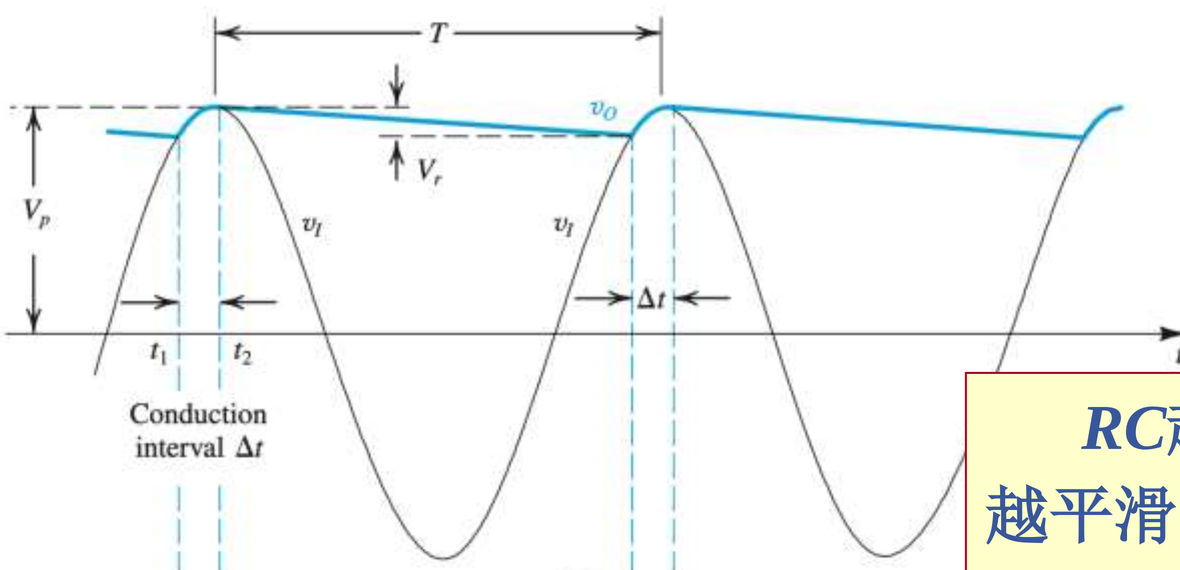


全波整流+滤波

平均值≈

$$\boxed{1.2\times\frac{V_p}{\sqrt{2}}}$$

≈0.85Vp



半波整流+滤波 (b)

一般选择合适RC值（3-5倍的半周期），使得滤波后的直流分量约为**1.2 V_2**，其中V_2为变压器次级电压的有效值，忽略整流二极管的压降

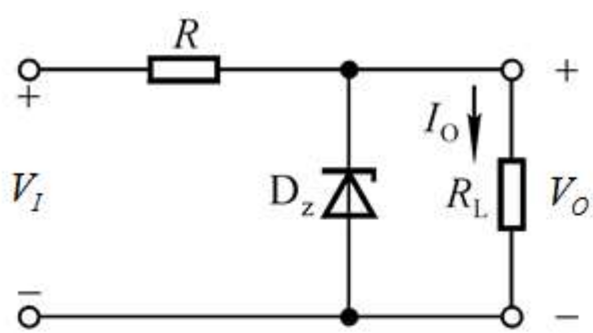
***RC*越大，放电越慢，曲线越平滑，脉动越小，直流分量越大**

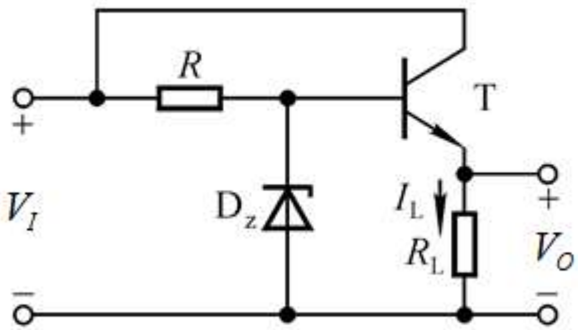
15.2 串联型稳压电路

15.2.1 串联型稳压电路工作原理

一、基本调整管稳压电路

为了使稳压管稳压电路输出大电流，需要加晶体管放大。



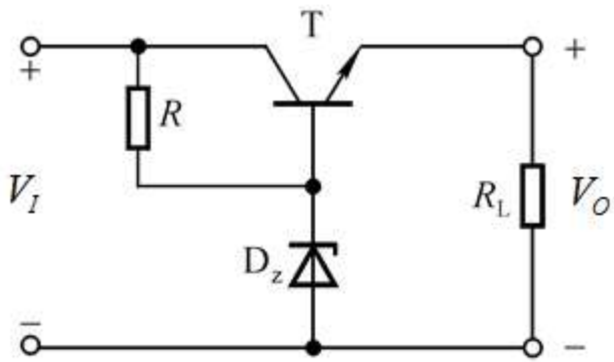


$$I_L = (1+\beta) I_O$$

$$V_O = V_Z - V_{BE}$$

稳压原理：电路引入负反馈，稳定输出电压。

稳压原理：电路引入负反馈，稳定输出电压。



$$V_O = V_I - V_{CE}$$

通过V_{CE}的调节使V_O稳定，故称晶体管为调整管。V_O如果因某种原因突然增大，则流过R_L的电流（晶体管的I_c）增大 → V_{be}增大 → V_O减小

若要提高电路的稳压性能，则应加深电路的负反馈，即提高放大电路的放大倍数。

TPS799 200-mA, Low-Quiescent Current, Ultralow Noise, High-PSRR Low-Dropout Linear Regulator

稳压器 输出电压比输入电压略降低

1 Features

- 200-mA Low-Dropout Regulator With EN
- Multiple Output Voltage Versions Available:
  - Fixed Outputs of 1.2 V to 4.5 V Using Innovative Factory EEPROM Programming
  - Adjustable Outputs from 1.20 V to 6.5 V
- Inrush Current Protection with EN Toggle
- Low I_Q: 40 μA
- High PSRR: 66 dB at 1 kHz
- Stable with a Low-ESR, 2-μF Typical Output Capacitance
- Excellent Load and Line Transient Response
- 2% Overall Accuracy (Load, Line, and Temperature)
- Very Low Dropout: 100 mV
- Package: 5-Bump, Thin, 1-mm × 1.37-mm DSBGA

即使负载、供电、温度等有波动
输出电压也稳定在2%的准确度范围

2 Applications

- Cellular Phones
- Wireless LAN, *Bluetooth*®
- VCOs, RF
- Handheld Organizers, PDAs

3 Description

The TPS799 family of low-dropout (LDO), low-power linear regulators offers excellent ac performance with very low ground current. High power-supply rejection ratio (PSRR), low noise, fast start-up, and excellent line and load transient response are provided while consuming a very low 40-μA (typical) ground current.

The TPS799 is stable with ceramic capacitors and uses an advanced BiCMOS fabrication process to yield a dropout voltage of typically 100 mV at a 200-mA output. The TPS799 uses a precision voltage reference and feedback loop to achieve an overall accuracy of 2% over all load, line, process, and temperature variations. The TPS799 features inrush current protection when the EN toggle is used to start the device, immediately clamping the current.

All devices are fully specified over the temperature range of T_J = –40°C to 125°C, and offered in a low-profile, die-sized ball grid array (DSBGA) package, ideal for wireless handsets and WLAN cards.

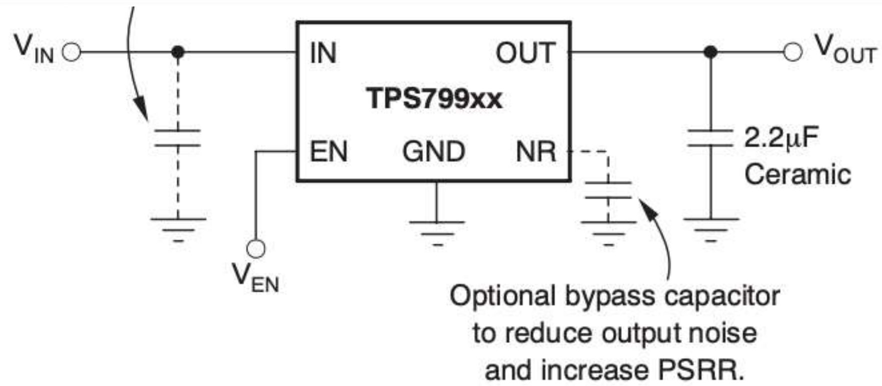
Device Information(1)

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TPS799	SOT (5)	2.90 mm x 1.60 mm
	SON (6)	2.00 x 2.00 mm
	DSBGA (5)	1.57 mm x 1.20 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.

Table 1. Device Nomenclature(1)

PRODUCT	V_{OUT}
TPS799**xx(x)** ***yyy z***	**xx(x)** is nominal output voltage (for example, 28 = 2.8 V, 285 = 2.85 V, 01 = Adjustable). **yyy** is package designator. **z** is package quantity.



6.5 Electrical Characteristics

Over operating temperature range (T_J = –40°C to 125°C), $V_{IN} = V_{OUT(nom)}$ + 0.
$V_{EN} = V_{IN}$, C_{OUT} = 2.2 µF, C_{NR} = 0.01 µF, unless otherwise noted. For TPS79
25°C.

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{IN}	Input voltage range(1)			2.7		6.5	V
V_{FB}	Internal reference (TPS79901)			1.169	1.193	1.217	V
V_{OUT}	Output voltage range (TPS79901)			V_{FB}		6.5 – V_{DO}	V
V_{OUT}	Output accuracy, nominal	T_J = 25°C		–1%		1%	
	Output accuracy(1) Over V_{IN}, I_{OUT}, temperature	V_{OUT} + 0.3 V ≤ V_{IN} ≤ 6.5 V 500 µA ≤ I_{OUT} ≤ 200 mA		–2%	±1%	2%	
$\Delta V_{O(\Delta VI)}$	Line regulation(1)	$V_{OUT(NOM)}$ + 0.3 V ≤ V_{IN} ≤ 6.5 V			0.02		%/V
$\Delta V_{O(\Delta IO)}$	Load regulation	500 µA ≤ I_{OUT} ≤ 200 mA			0.002		%/mA
V_{DO}	Dropout voltage(2) ($V_{IN} = V_{OUT(nom)}$ – 0.1 V)	I_{OUT} = 200 mA	$V_{OUT(nom)}$ ≤ 3.3 V		100	175	mV
			$V_{OUT(nom)}$ ≥ 3.3 V		90	160	mV
I_{CL}	Output current limit	V_{OUT} = 0.9 × $V_{OUT(nom)}$		220	400	600	mA
I_{GND}	Ground pin current	500 µA ≤ I_{OUT} ≤ 200 mA			40	60	µA
I_{SHDN}	Shutdown current (I_{GND})	V_{EN} ≤ 0.4 V, 2.7 V ≤ V_{IN} ≤ 6.5 V			0.15	1	µA
I_{FB}	Feedback pin current (TPS79901)			–0.5		0.5	µA
PSRR	Power-supply rejection ratio	V_{IN} = 3.85 V, V_{OUT} = 2.85 V, C_{NR} = 0.01 µF, I_{OUT} = 100 mA	f = 100 Hz		70		dB
			f = 1 kHz		66		dB
			f = 10 kHz		51		dB
			f = 100 kHz		38		dB

MAX6126

Ultra-High-Precision, Ultra-Low-Noise, Series Voltage Reference

General Description

The MAX6126 is an ultra-low-noise, high-precision, low-dropout voltage reference. This family of voltage references feature curvature-correction circuitry and high-stability, laser-trimmed, thin-film resistors that result in 3ppm/°C (max) temperature coefficients and an excellent ±0.02% (max) initial accuracy. The proprietary low-noise reference architecture produces a low flicker noise of $1.3\mu V_{P-P}$ and wideband noise as low as $60nV/\sqrt{Hz}$ (2.048V output) without the increased supply current usually found in low-noise references. Improve wideband noise to $35nV/\sqrt{Hz}$ and AC power-supply rejection by adding a 0.1µF capacitor at the noise reduction pin. The MAX6126 series mode reference operates from a wide 2.7V to 12.6V supply voltage range and load-regulation specifications are guaranteed to be less than 0.025Ω for sink and source currents up to 10mA. These devices are available over the automotive temperature range of -40°C to +125°C.

The MAX6126 typically draws 380µA of supply current

Benefits and Features

- Ultra-Low $1.3\mu V_{P-P}$ Noise (0.1Hz to 10Hz, 2.048V Output)
- Ultra-Low 3ppm/°C (max) Temperature Coefficient
- ±0.02% (max) Initial Accuracy
- Wide (V_{OUT} + 200mV) to 12.6V Supply Voltage Range
- Low 200mV (max) Dropout Voltage
- 380µA Quiescent Supply Current
- 10mA Sink/Source-Current Capability
- Stable with C_{LOAD} = 0.1µF to 10µF
- Low 20ppm/1000hr Long-Term Stability
- 0.025Ω (max) Load Regulation
- 20µV/V (max) Line Regulation
- Force and Sense Outputs for Remote Sensing

ANALOG DEVICES

Electrical Characteristics—MAX6126_21 (V_{OUT} = 2.048V)

(V_{IN} = 5V, C_{LOAD} = 0.1µF, I_{OUT} = 0, T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°C.)

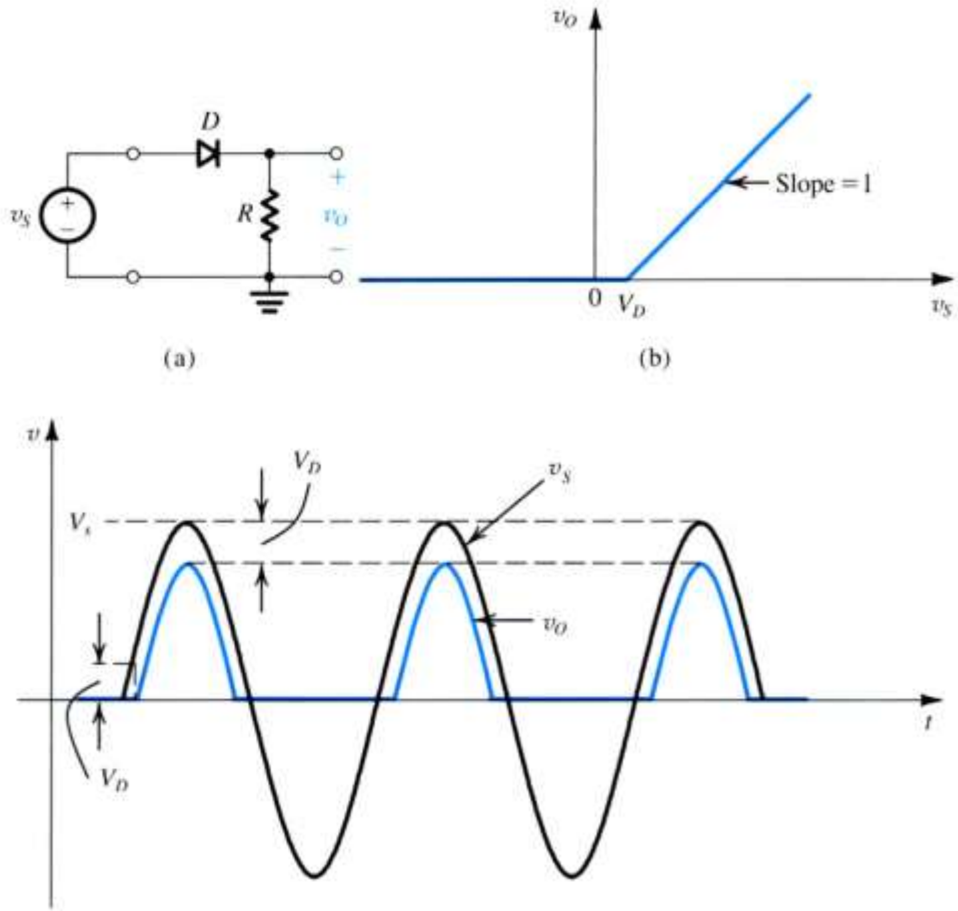
PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
OUTPUT							
Output Voltage	V_{OUT}	T_A = +25°C			2.048		V
Output Voltage Accuracy		Referred to V_{OUT}, T_A = +25°C	A grade SO	-0.02		+0.02	%
			B grade SO	-0.06		+0.06	
			A grade µMAX	-0.06		+0.06	
			B grade µMAX	-0.1		+0.1	
Output Voltage Temperature Coefficient (Note 1)	TCV_{OUT}	T_A = -40°C to +85°C	A grade SO		0.5	3	ppm/°C
			B grade SO		1	5	
			A grade µMAX		1	3	
			B grade µMAX		2	7	
		T_A = -40°C to +125°C	A grade SO		1	5	
			B grade SO		2	10	
			A grade µMAX		2	5	
			B grade µMAX		3	12	
Line Regulation	$\Delta V_{OUT}/\Delta V_{IN}$	2.7V ≤ V_{IN} ≤ 12.6V	T_A = +25°C		2	20	µV/V
			T_A = -40°C to +125°C			40	
Load Regulation	$\Delta V_{OUT}/\Delta I_{OUT}$	Sourcing: 0 ≤ I_{OUT} ≤ 10mA			0.7	25	µV/mA
		Sinking: -10mA ≤ I_{OUT} ≤ 0			1.3	25	
OUT Short-Circuit Current	I_{SC}	Short to GND			160		mA
		Short to IN			20		
Thermal Hysteresis (Note 2)	ΔV_{OUT}/cycle	SO			25		ppm
		µMAX			80		
Long-Term Stability	ΔV_{OUT}/time	1000hr at T_A = +25°C	SO		20		ppm/1000hr
			µMAX		100		

ANALOG DEVICES

4.21 For the half-wave rectifier circuit in Fig. 4.21(a), show the following: (a) For the half-cycles during which the diode conducts, conduction begins at an angle $\theta = \sin^{-1}(V_D/V_s)$ and terminates at $(\pi - \theta)$, for a total conduction angle of $(\pi - 2\theta)$. (b) The average value (dc component) of v_O is $V_O \simeq (1/\pi)V_s - V_D/2$. (c) The peak diode current is $(V_s - V_D)/R$.

Find numerical values for these quantities for the case of 12-V (rms) sinusoidal input, $V_D \simeq 0.7$ V, and $R = 100\ \Omega$. Also, give the value for PIV.

Ans. (a) $\theta = 2.4°$, conduction angle $= 175°$; (b) 5.05 V; (c) 163 mA; 17 V



4.23 For the bridge-rectifier circuit of Fig. 4.23(a), use the constant-voltage-drop diode model to show that (a) the average (or dc component) of the output voltage is $V_O \simeq (2/\pi)V_s - 2V_D$ and (b) the peak diode current is $(V_s - 2V_D)/R$. Find numerical values for the quantities in (a) and (b) and the PIV for the case in which v_S is a 12-V (rms) sinusoid, $V_D \simeq 0.7$ V, and $R = 100\ \Omega$.

Ans. 9.4 V; 156 mA; 16.3 V