Slide 7:

Since V = 10 V is applied, both diode D1 and D2 are on. They can be replaced by a battery of 0.7 V, respectively. Thus,

$V_o = V_{D,on} = 0.7$ V

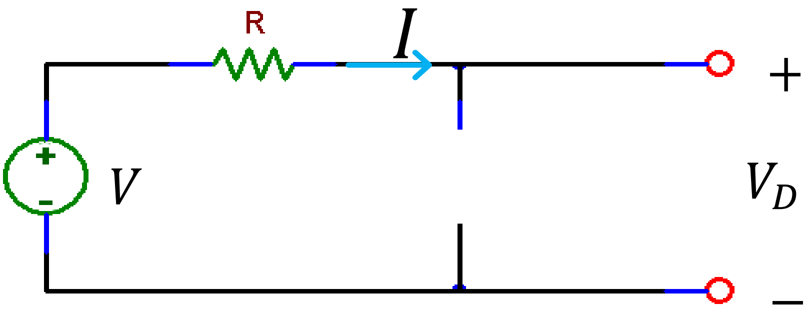
According to KVL,

$V = I_1 R + V_o$ => $I_1 = \frac{V - V_o}{R} = \frac{10 - 0.7}{0.33\ K} = 28.2$ mA => $I_{D1} = I_{D2} = \frac{I_1}{2} = 14.1$ mA

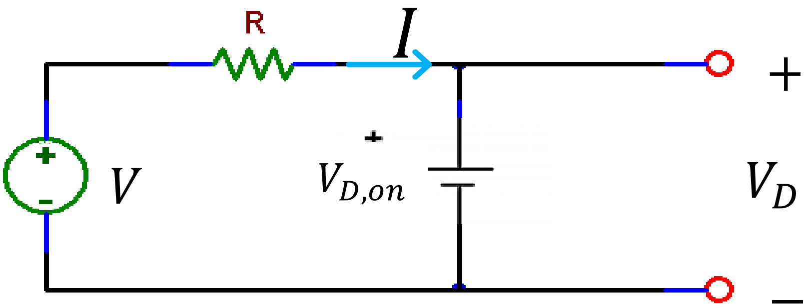
If the current rating of the diodes is only 20 mA, I_1 = 28.2 mA would damage the diode if only one is used, so we need to use two diodes to limit the current through the diodes.

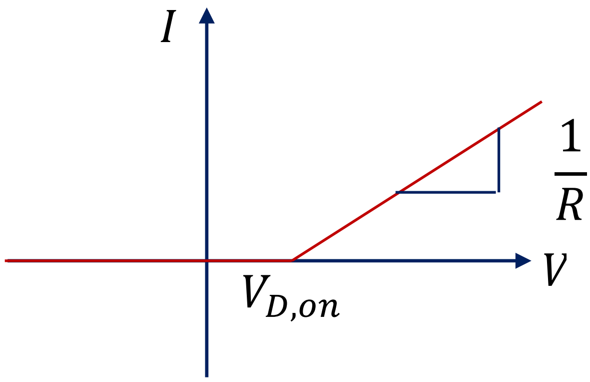
Slide 9:

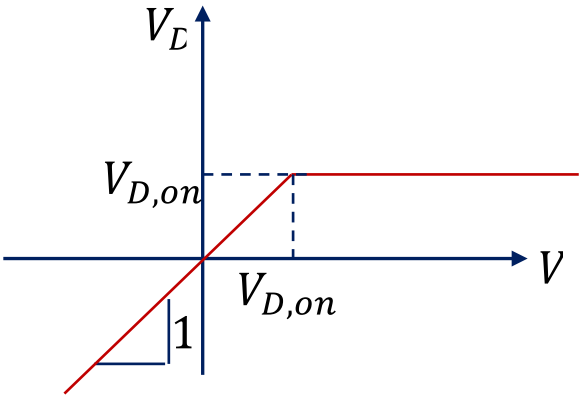
When $V < V_{D,on}$, the diode is off => replace the diode with an open circuit. So, $I = 0$ and $V_D = V$.



$V \geq V_{D,on}$, the diode is on => replace the diode with a battery of 0.7 V. So, $I = \frac{V - V_{D,on}}{R}$ and $V_D = V_{D,on}$.







Slide 11:

If A= 0, B = 0 => diode A and diode B are off, i.e., open circuits, V_output = 0 => LED is off;

If A= 0, B = 1 => diode A is off (an open circuit) and diode B is on (a battery with 0.7 V), V_output = 5-0.7 = 4.3 V => LED is on;

If A= 1, B =0 => diode A is on (a battery with 0.7 V) and diode B is off (an open circuit), V_output = 5-0.7 = 4.3 V => LED is on;

If A= 1, B =0 => diode A is on (a battery with 0.7 V) and diode B is on (a battery with 0.7 V), V_output = 5-0.7 = 4.3 V => LED is on.

Slide 12:

If A= 0, B =0 => diode A is on (a battery with 0.7 V) and diode B is on (a battery with 0.7 V), V_output = 0.7 V => not enough to turn on the LED, so the LED is off;

If A= 0, B =1 => diode A is on (a battery with 0.7 V) and diode B is off (an open circuit), V_output = 0.7 V => not enough to turn on the LED, so the LED is off;

If A= 1, B =0 => diode A is off (an open circuit) and diode B is on (a battery with 0.7 V), V_output = 0.7 V => not enough to turn on the LED, so the LED is off;

If A= 1, B =1 => diode A is off (an open circuit) and diode B is off (an open circuit), V_output >= 2 V => the LED is on.

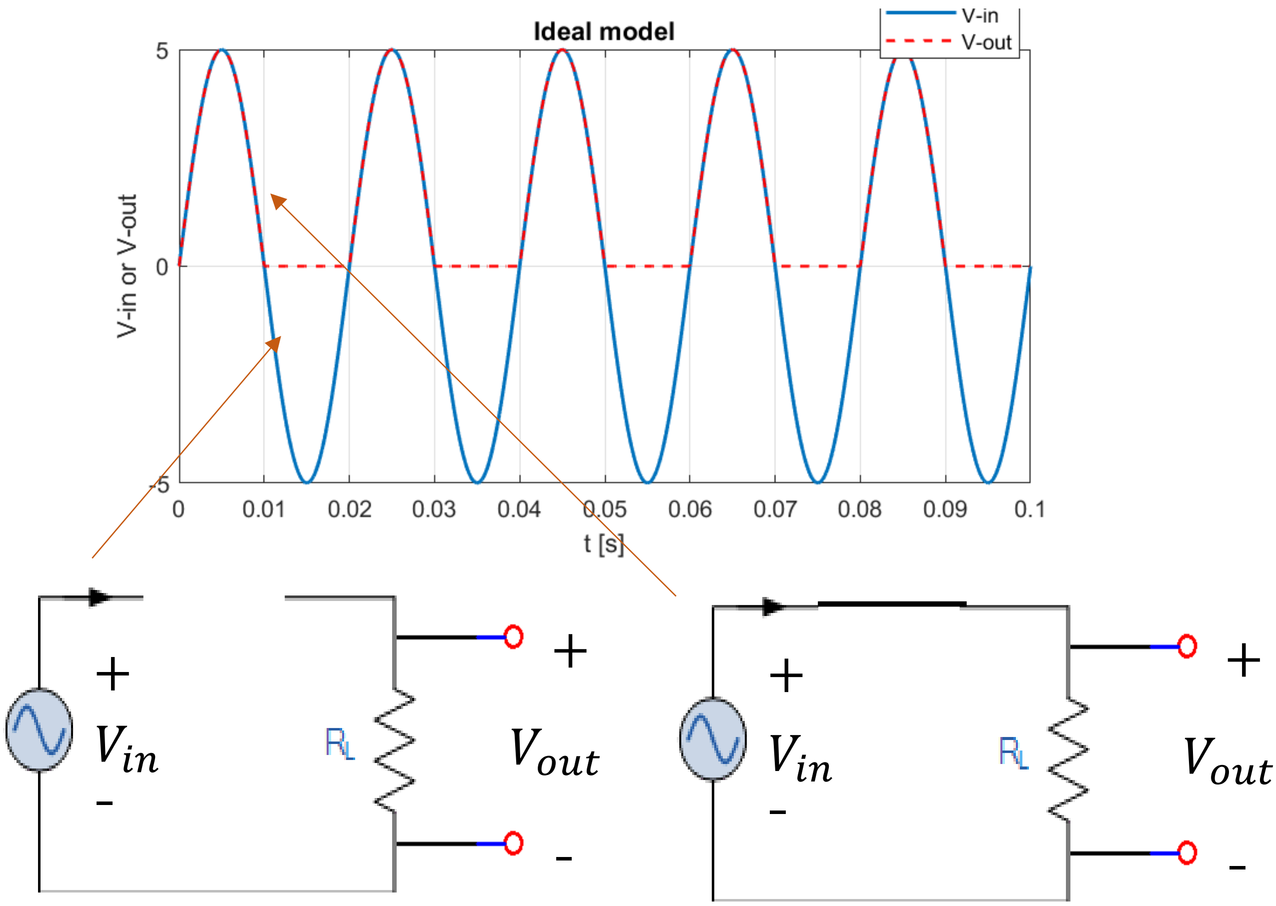
It is an AND logic gate.

Slides 13:

Time response: input voltage varies over time, i.e., a function of time, $V_{in}(t)$ => How does the current $I(t)$ and output voltage V_{out} (t) change over time?

Slide 14:

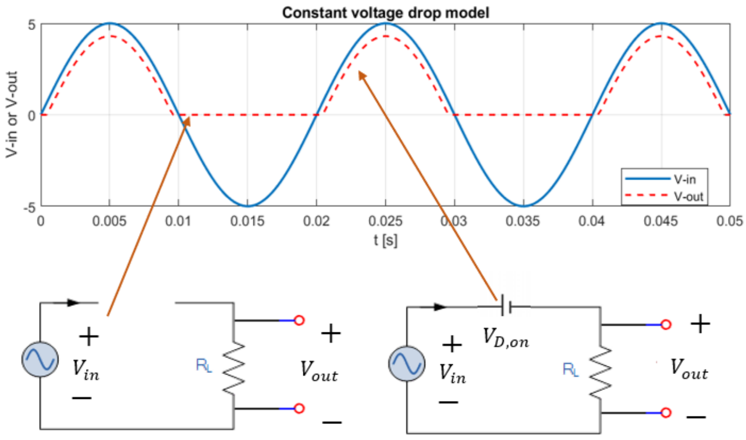
1. Ideal model:
   When $V_{in}(t) \geq 0$, the diode is on ➔ replace the diode with a short circuit➔$V_{out}(t) = V_{in}(t)$.
   When $V_{in}(t) < 0$, the diode is off ➔ replace the diode with an open circuit➔$V_{out}(t) = 0$.



2. Constant voltage drop model
   When $V_{in}(t) \geq V_{D,on}$, the diode is on ➔ replace the diode with a battery
   ➔$V_{out}(t) = V_{in}(t) - V_{D,on}$.

   When $V_{in}(t) < V_{D,on}$, the diode is off ➔ replace the diode with an open circuit

   ➔$V_{out}(t) = 0$.



Alternating current (AC) refers to the flow of electric charge that periodically reverses direction. In an AC circuit, the voltage and current alternate direction over time, typically following a sinusoidal waveform. This alternating flow of current is commonly used in household and industrial electrical systems for its ability to efficiently transmit electricity over long distances and its compatibility with transformers for voltage regulation.
Direct current (DC) refers to the flow of electric charge in a single direction. Unlike alternating current (AC), where the direction of current periodically reverses, DC flows steadily in one direction from the positive terminal of a voltage source to the negative terminal. DC is commonly used in electronic devices, such as computers, smartphones, and portable gadgets, as well as in specific applications like automotive systems, where a constant, unidirectional flow of electricity is required.
A **rectifier** is an electrical device used to convert AC into DC. It works by allowing current to flow in only one direction, effectively converting the alternating polarity of AC into a unidirectional flow. Rectifiers are essential components in many electronic devices and power supply systems, as they enable the use of DC power from AC sources such as mains electricity.

The above example shows that the circuit containing diodes can convert AC into DC.

Slide 15:
In Denmark, as in many other countries in Europe, the standard mains electricity supply typically has a voltage of 230 volts (V) and a frequency of 50 Hertz (Hz). However, most electronic devices require DC power supply, e.g., laptops require 20 V and cellphones require 5 V DC power.
To convert the AC power from the mains supply to the DC power required by electronic devices, chargers or adaptors are used. These chargers often contain rectifier circuits, where PN junction diodes play a crucial role.

Slide 16:

1. To lower the amplitude of the voltage, we can use a transformer to get an AC of proper magnitude.
2. And then Use the diode circuit in the previous slide → keep the positive voltages. The output signal of half-wave rectifier is not very useful, as the wave still fluctuates too much → cannot be used to devices.
3. From Fourier theory, a periodic waveform can be decomposed into a bunch of sines and cosine waves plus a DC quantity. Well, then we can use a low pass filter for the output waveform to get the DC voltage.

Although the real circuit is not exactly like this one, but the idea is very similar.

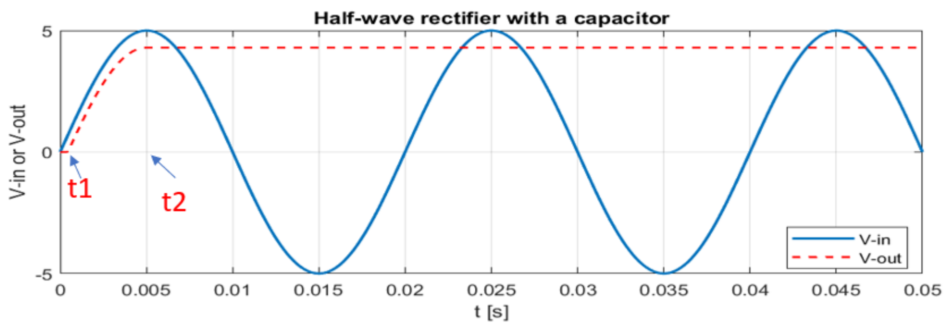
Slide 17:

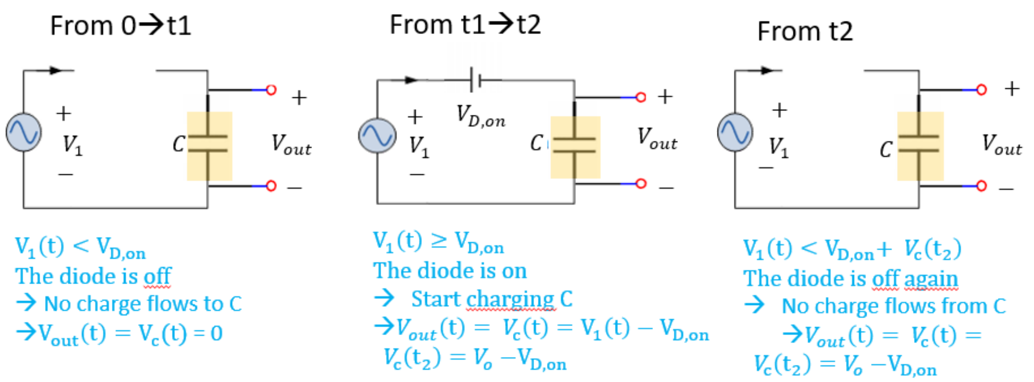
Below, we focus on how to convert the AC after the transformer to the required DC. Thus, we omit the transformer circuit for simplicity.

Here, we introduce a capacitor to filter out the high frequency components after the half-wave rectifier.

When we replace the resistor with a capacitor, what waveform will be output?

We assume the initial voltage of the capacitor is 0.

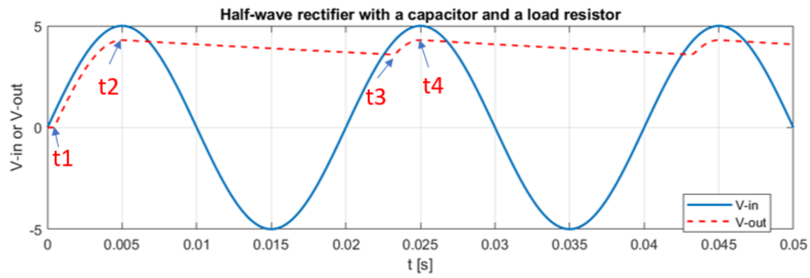


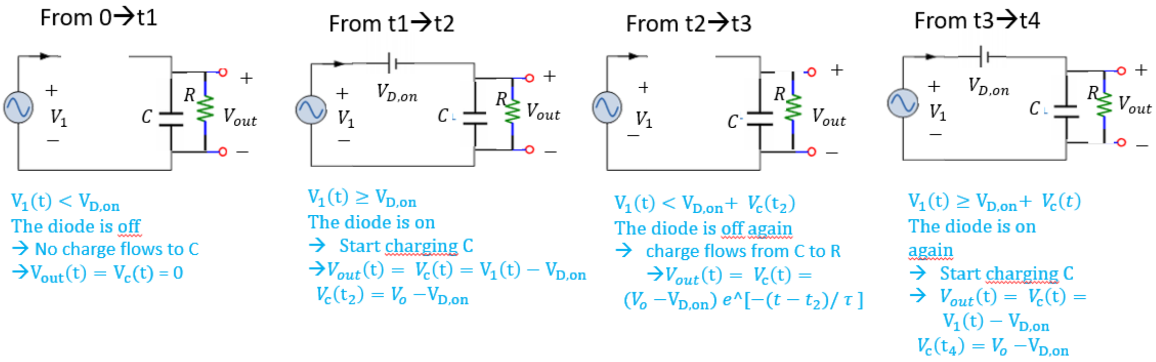


Slide 18:

In practice, the circuit will be connected to a device and the device will draw current from supplier. The device can be represented by a load resistor, as shown in slide 18. So what waveform will be output after adding the load resistor to the circuit?

We assume the initial voltage of the capacitor is 0 and the capacitor discharges very slowly.





From t4, the waveform from t2 to t4 will be repeated.

With a load, V_{out} has ripples, the ripples should be as small as possible in practical application. For instance, the circuit is used to charge an audio device, we will hear humming noise in the background of music due to the supplied voltage is not constant.

<u>How to calculate the ripple amplitude?</u>

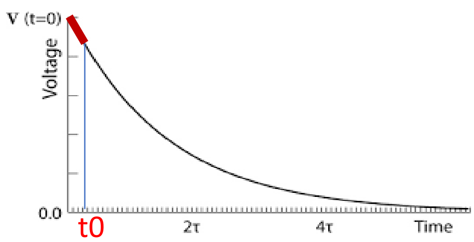
Assuming the V_{out}decays very slow from t2 to t3, comparing to the period of the ripple is about T_{in}, the period of the input signal.

When diode is off, the initial voltage on C is V_o , the amplitude of V1, $V_{out}(t) = V_o * \exp\,[-\frac{t-t_2}{\tau}]$

$$\tau = RC$$

If T_{in} is much small than tau, for an observation time window t_o, $V_{out}(t_o) = V_o * \exp\,[-\frac{t-t_2}{\tau}]$

$\approx V_o(1 - t_o/\tau)$, i.e., can be approximated by a straight line.



$$V_{out}(t_2) = V_o - V_{D,on}$$

$$V_{out}(t_3) = (V_o - V_{D,on}) * (1 - \frac{t_3 - t_2}{\tau})$$

$$t_3 - t_2 \approx T_{in}$$

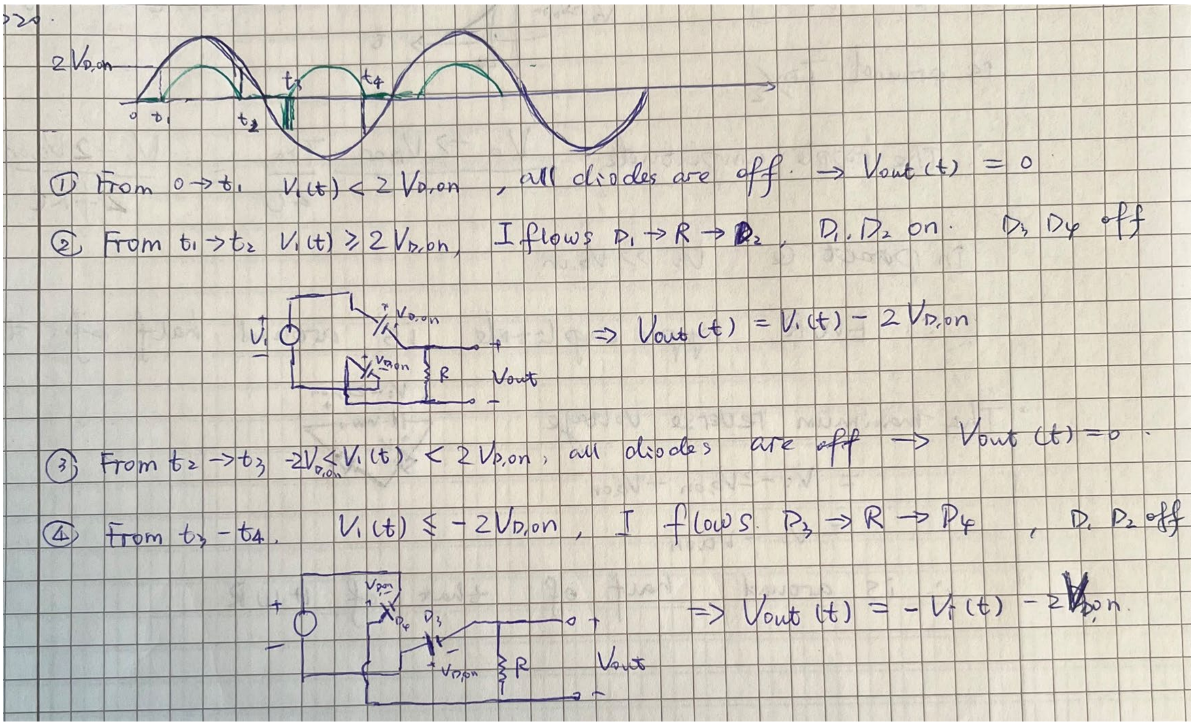
➔ *ripple amplitude* = $V_{out}(t_2)$-$V_{out}(t_3) = (V_o - V_{D,on})\ \frac{t_3 - t_2}{\tau} = (V_o - V_{D,on})\ \frac{T_{in}}{\tau} = \frac{V_o - V_{D,on}}{fRC}$

Maximum reverse voltage = $2V_o - V_{D,on}$

Slide 19:

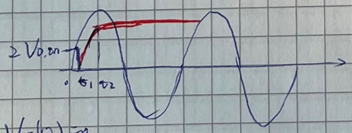
The performance of rectifier can be further improved by using full-wave rectifier circuit. However, the circuit is more complex.

Slide 20:



Slide 21:

e, S.21



Assume $V_c(0) = 0$

① From $0 \to t_1$ $V_i(t) < 2V_{D,on}$, all diodes off

$V_{out}(t) = 0$

② From $t_1 \to t_2$, $V_i(t) \geq 2V_{D,on}$

I flows $D_1 \to C \to D_2$, D_3 D_4 off

$V_{out}(t) = V_i(t) - 2V_{D,on}$.

$\cancel{V_{out}(t_2)} = V_c(t_2)$

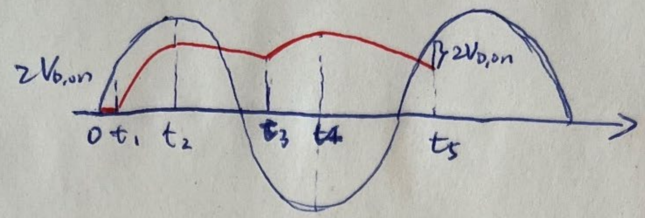
$= V_0 - 2V_{D,on}$

③ From t_2, all diodes off

$V_{out}(t) = V_0 - 2V_{D,on}$. Constant

Slide 22:

Assume $V_c(0) = 0$



① From $0 \to t_1$, all diodes are off, $V_{out}(t) = 0$

② From $t_1 \to t_2$, D_1, D_2 on, D_3, D_4 off, start charging C $\Rightarrow$ $V_{out}(t) = V_i(t) - 2V_{D,on}$

$V_c(t_2) = V_{out}(t_2) = V_0 - 2V_{D,on}$

③ From $t_2 \to t_3$, $-V_i(t) - V_{out}(t) < 2V_{D,on}$

$\Rightarrow$ all diodes are off

$\Rightarrow$ C discharges $\Rightarrow$ $V_c(t) = V_{out}(t) \downarrow$ decrease

④ From $t_3 - t_4$, $-V_i(t) - V_{out}(t) \geq 2V_{D,on}$

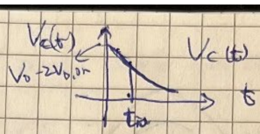
$\Rightarrow$ D_3, D_4 on, D_1, D_4 off $\Rightarrow$ C starts charging

$\cancel{V_c(t_4)}$ $V_c(t) = V_{out}(t) = V_i(t) - 2V_{D,on}$

$V_c(t_4) = V_{out}(t_4) = V_0 - 2V_{D,on}$

⑤ From t_4 $\cancel{t_5}$ the waveform from $t_2 \to t_4$ repeats.

So the decay is around $T_{in}/2$



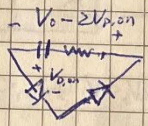
$V_c(t) = (V_0 - 2V_{D,on})\, e^{-t/\tau}$ $\quad \tau = RC$.

∴ The ripple amplitude $(V_0 - 2V_{D,on}) \dfrac{T_{in}}{2\tau} = \dfrac{V_0 - 2V_{D,on}}{2fRC}$

in practice $V_0 \gg V_{D,on}$

∴ FWR ripple amplitude is around half of that HWR

• The maximum reverse voltage



$= V_0 - 2V_{D,on} + V_{D,on}$

$= V_0 - V_{D,on}$.

∴ is around half of that of HWR.