ENG1004 - Electronics & Sensors

Tutorial 1 – Diode Circuits - Solutions

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Question 1

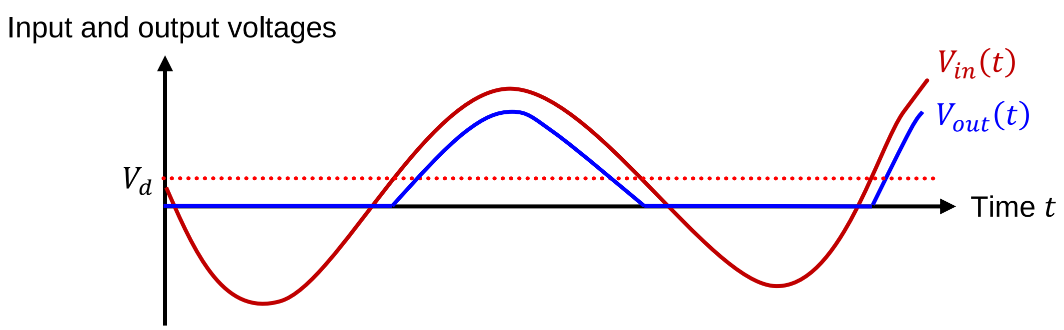
Let $V(t)$ designate the voltage across the diode and $I(t)$ the current flowing through the circuit. We start by writing two general equations that are always valid:

(1) $V(t) = V_{in}(t) - V_{out}(t)$;

(2) $V_{out}(t) = RI(t)$.

We need to take into account the two-state model of the diode by consider two possibilities considered in the table below.

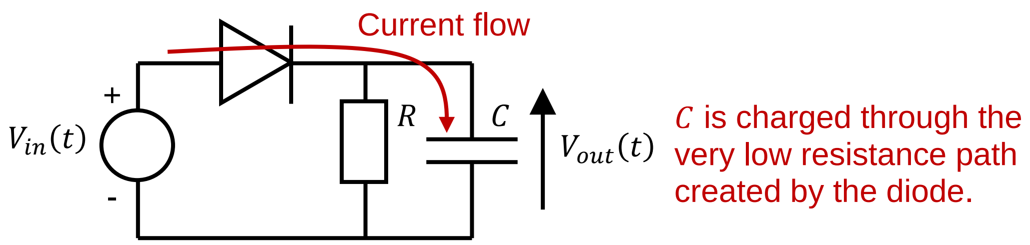
Diode On	**Diode Off**
With $V(t) = V_d$ and $I(t) > 0$, Equations (1) and (2) become • $V_{out}(t) = V_{in}(t) - V_d$; • $V_{out}(t) > 0$. This inequality implies that $V_{in}(t) - V_d > 0$, i.e., $V_{in}(t) > V_d$.	With $V(t) < V_d$ and $I(t) = 0$, Equations (1) and (2) become • $V_{in}(t) - V_{out}(t) < V_d$; • $V_{out}(t) = 0$. The above inequality implies that $V_{in}(t) < V_d$.



Question 2

We start from $V_{in}(t) = 0$. Assuming that the capacitance C is initially discharged, we can also write $V_{out}(t) = 0$.

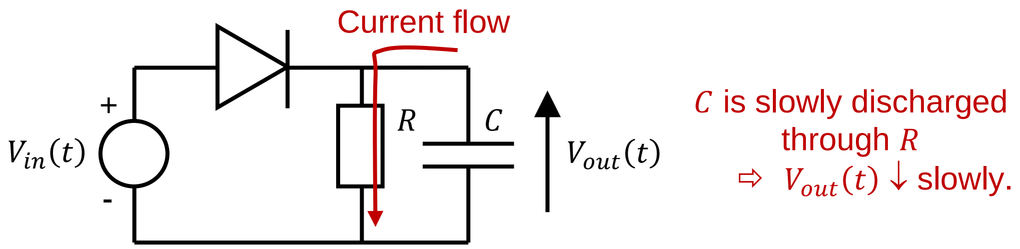
Assume that the input voltage $V_{in}(t)$ increases. As long as $V_{in}(t) < V_d$, the diode remains off and therefore nothing changes in the circuit. Once $V_{in}(t)$ reaches V_d, the diode turns on, and we thus have $V_{out}(t) = V_{in}(t) - V_d$.



The diode turns on when $V_{in}(t)$ becomes greater than or equal to V_d.

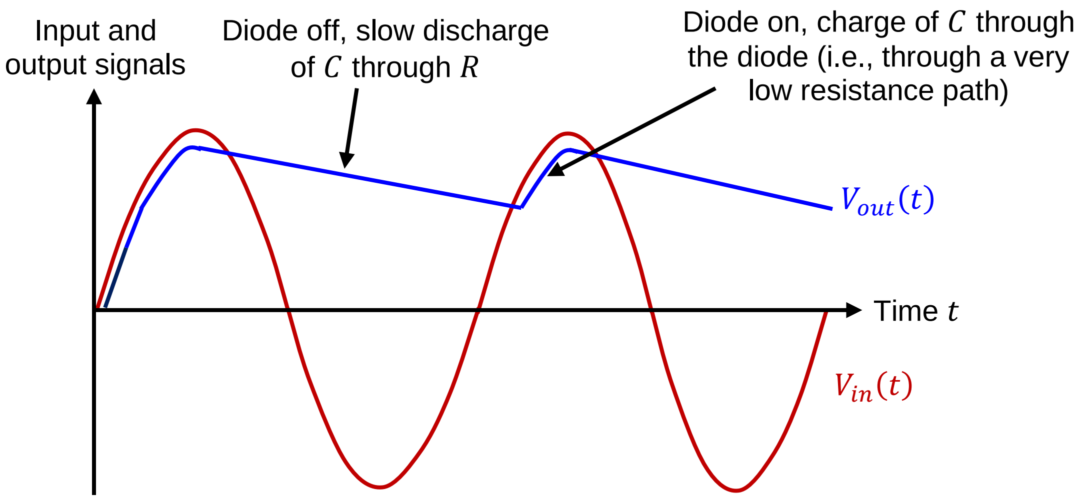
When $V_{in}(t)$ starts falling, $V_{out}(t)$ can no longer follow the change in $V_{in}(t)$ due to the presence of the capacitor-resistor circuit. In fact, the capacitance C cannot be discharged through the diode because the diode current cannot flow in the reverse direction. Instead, the capacitance is discharged through the resistance R because this is the only possible path.

Since this happens slowly (provided that the values of R and C are properly chosen), $V_{out}(t)$ falls more slowly than $V_{in}(t)$. Thus, as soon as $V_{in}(t)$ starts falling, $V_{out}(t) + V_d$ becomes suddenly greater than $V_{in}(t)$, which turns off the diode.



The diode turns off when $V_{in}(t)$ becomes smaller than $V_{out}(t) + V_d$.

At some stage, $V_{out}(t)$ has fallen enough and $V_{in}(t)$ has risen enough again. When that happens, $V_{in}(t)$ becomes once more equal to $V_{out}(t) + V_d$. As a result, the diode turns on again and we then have $V_{out}(t) = V_{in}(t) - V_d$.



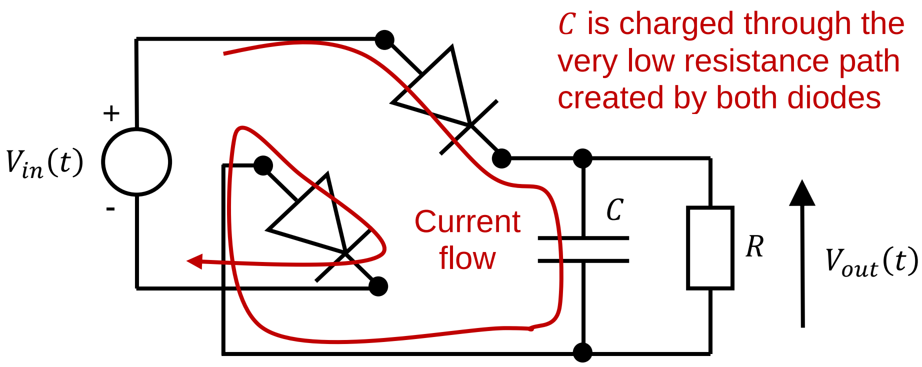
Typical applications of this circuit: power supply (conversion from AC to DC), amplitude demodulation (amplitude detector).

Question 3

We start from $V_{in}(t) = 0$. Assume that the capacitance C is initially discharged and we therefore have $V_{out}(t) = 0$ at the start.

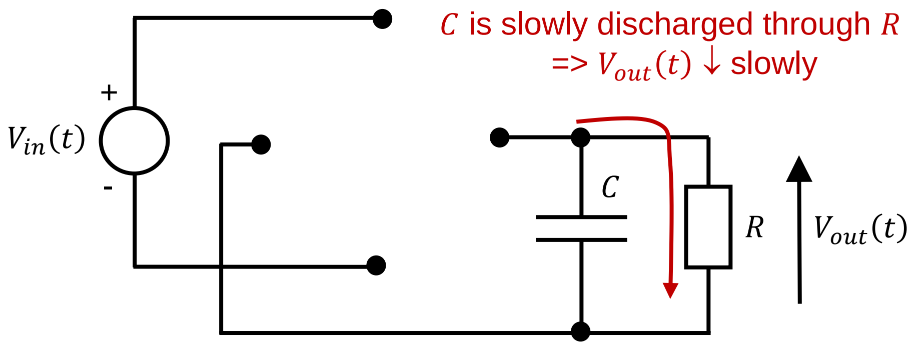
Assume that the input voltage $V_{in}(t)$ increases. As long as $V_{in}(t) < 2V_d$, all diodes remain off and therefore nothing changes in the circuit. Once $V_{in}(t)$ reaches $2V_d$, two diodes turn on, as shown below, and we thus have $V_{out}(t) = V_{in}(t) - 2V_d$.

When $V_{in}(t)$ starts falling, the output voltage $V_{out}(t)$ cannot follow the change in $V_{in}(t)$ due to the presence of the capacitor-resistor circuit. In fact, the capacitance C cannot be discharged through the diodes. Instead, it has to be discharged through the resistance R.



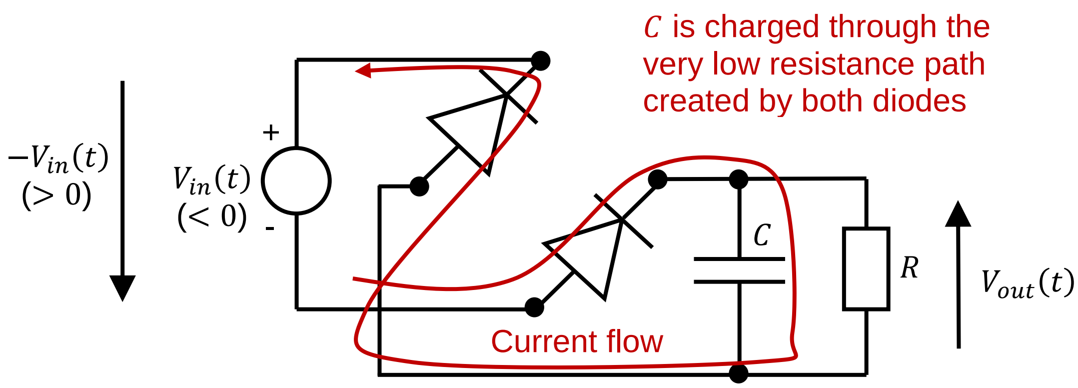
Both diodes turn on when $V_{in}(t)$ becomes greater than or equal to $V_{out}(t) + 2V_d$.

Since this happens slowly, $V_{out}(t)$ falls more slowly than $V_{in}(t)$. Thus, as soon as $V_{out}(t)$ starts falling, $V_{out}(t) + 2V_d$ becomes greater than $V_{in}(t)$, which turns off both diodes.



Both diodes turn off when $V_{in}(t)$ becomes smaller than $V_{out}(t) + 2V_d$.

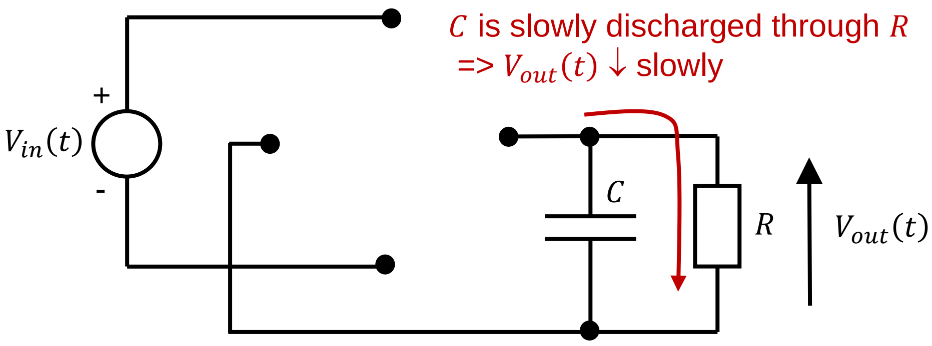
At some stage, $V_{out}(t)$ has fallen enough and $V_{in}(t)$ has also become sufficiently negative. That allows two diodes to turn on, as shown below, and we have $V_{out}(t) = -V_{in}(t) - 2V_d$.



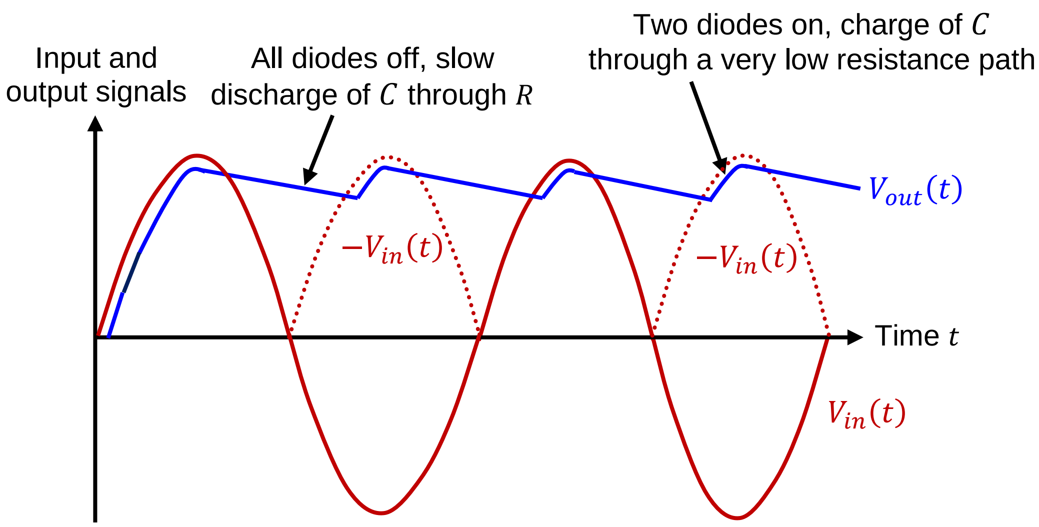
Both diodes turn on when $V_{in}(t)$ becomes sufficiently negative, i.e., when $-V_{in}(t)$ becomes equal to $V_{out}(t) + 2V_d$. When that happens, KVL tells us that $-V_{in}(t) = V_{out}(t) + 2V_d$, i.e., $V_{out}(t) = -V_{in}(t) - 2V_d$.

When $V_{in}(t)$ starts rising again, i.e., becoming less negative, the output voltage $V_{out}(t)$ cannot follow the change in $V_{in}(t)$ due to the presence of the capacitor-resistor circuit.

Once again, the capacitance C is discharged through the resistance R. Since this happens slowly, $V_{out}(t)$ falls more slowly than $-V_{in}(t)$ does. Thus, as soon as $V_{in}(t)$ starts rising, $V_{out}(t) + 2V_d$ becomes greater than $-V_{in}(t)$, which turns off both diodes.



Both diodes turn off as soon as $V_{in}(t)$ starts rising from its most negative value, i.e., $-V_{in}(t)$ becomes smaller than $V_{out}(t) + 2V_d$.



Question 4

Let v_{D1} and v_{D2} designate the voltages across diodes D1 and D2, respectively. Also, let i_1 and i_2 be the currents flowing through diodes D1 and D2, respectively. Finally, let i_{out} denote the current flowing through the resistance R.

We start by writing five general equations:

(1) $v_{out} = v_{in} - v_{D1}$;

(2) $v_{out} = v_{in} + v_{D2}$;

(3) $v_{out} = Ri_{out}$;

(4) $i_{in} = i_1 - i_2$;

(5) $i_{out} = (\beta + 1)(i_1 - i_2) = (\beta + 1)i_{in}$.

Combining (4) and (5) leads to $i_{out} = (\beta + 1)(i_1 - i_2) = (\beta + 1)i_{in}$.

Without even considering the two diodes, we have already found the link between input and output currents: $i_{out} = (\beta + 1)i_{in}$.

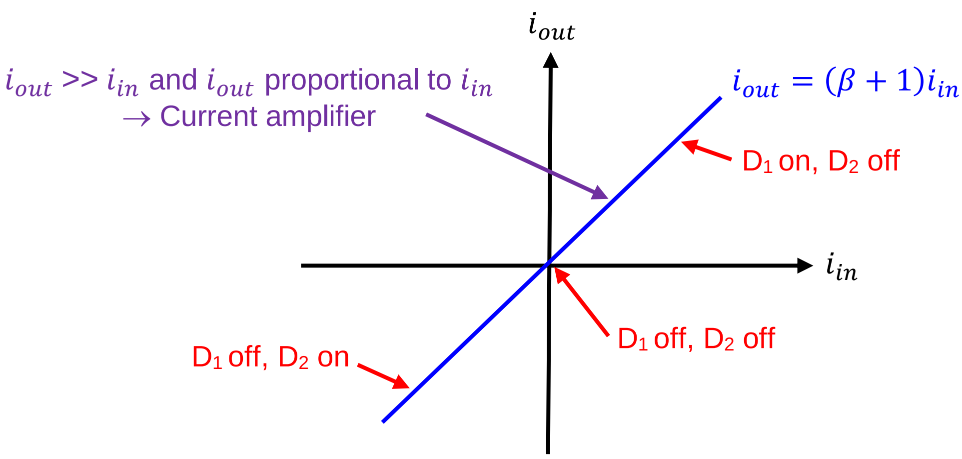
The circuit is a current amplifier with a current gain $A_i = \frac{i_{out}}{i_{in}} = \beta + 1 = 101$.

However, we are now going to consider the diodes in order to find the link between the input and output voltages.

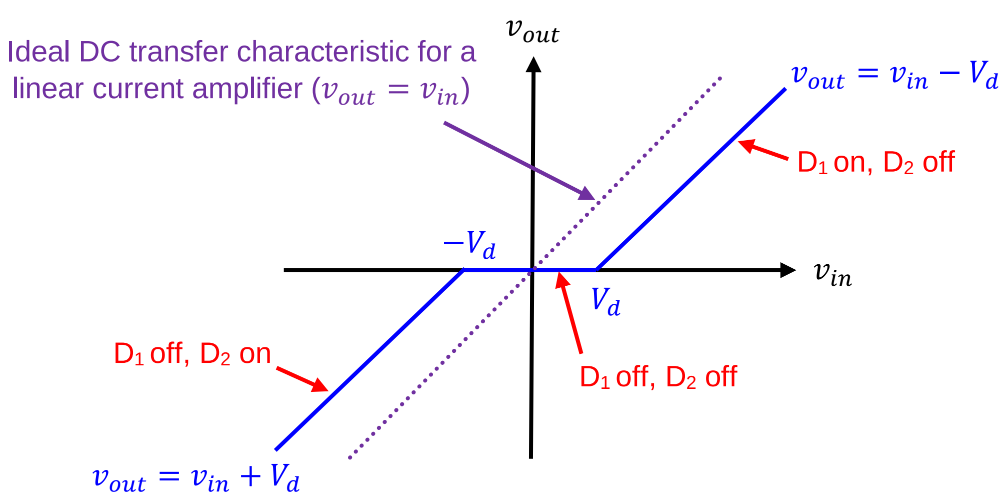
D1 and D2 are off	**D1 is on and D2 is off**
With $v_{D1} < V_d$, $v_{D2} < V_d$, and $i_1 = i_2 = 0$, the equations yield • $v_{out} > v_{in} - V_d$ • $v_{out} < v_{in} + V_d$ • $i_{in} = 0$, $i_{out} = 0$, and $v_{out} = 0$ => $v_{in} < V_d$ and $v_{in} > -V_d$	With $v_{D1} = V_d$, $v_{D2} < V_d$, $i_1 > 0$, and $i_2 = 0$, the equations yield • $v_{out} = v_{in} - V_d$ • $v_{out} < v_{in} + V_d$ • $i_{in} = i_1 > 0$, $i_{out} = (\beta + 1)i_1 > 0$, and $v_{out} > 0$ => $v_{in} > -V_d$ and $v_{in} > V_d$

D1 is off and D2 is on	D1 and D2 are on
With $v_{D1} < V_d$, $v_{D2} = V_d$, $i_1 = 0$, and $i_2 > 0$, the equations yield • $v_{out} > v_{in} - V_d$ • $v_{out} = v_{in} + V_d$ • $i_{in} = -i_2 < 0$, $i_{out} = -(\beta + 1)i_2 < 0$, and $v_{out} < 0$ => $v_{in} < -V_d$ and $v_{in} < V_d$	With $v_{D1} = V_d$, $v_{D2} = V_d$, $i_1 > 0$, and $i_2 > 0$, the equations yield • $v_{out} = v_{in} - V_d$ • $v_{out} = v_{in} + V_d$ => This is not possible. This case can be discarded.

The DC current transfer characteristic (i_{out} as a function of i_{in}) of the push-pull circuit is shown below.

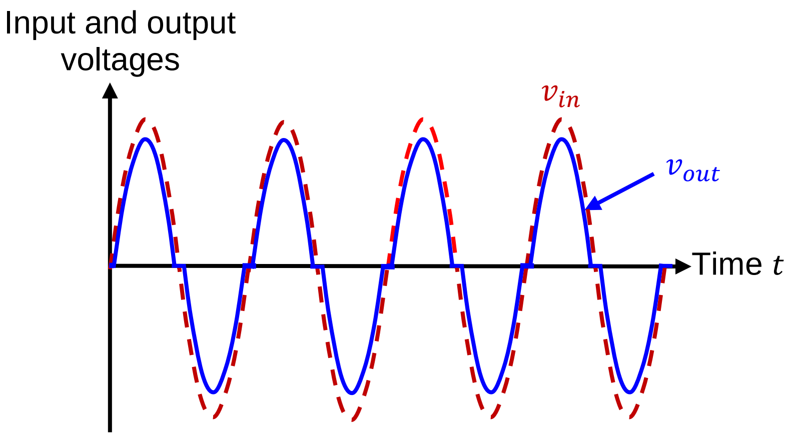


The DC voltage transfer characteristic (v_{out} as a function of v_{in}) of the push-pull circuit is shown below.



We conclude that the push-pull circuit is a current amplifier, but not a voltage amplifier (since v_{out} is not an amplified replica of v_{in}). We have also shown that this circuit is not linear as it introduces some unwanted distortion on the voltage (because $v_{out} \neq v_{in}$). Such distortion, referred to as cross-over distortion, is due to the fact that, for $-V_d < v_{in} < V_d$, both diodes are off, which results in $v_{out} = 0$.

To illustrate the effect of the cross-over distortion, we have plotted below the output voltage v_{out} obtained when the input voltage v_{in} is a sinusoidal signal. For large-amplitude signals, the effect of the cross-over distortion can often be ignored.



Finally, we conclude that this circuit, that can now be referred to as push-pull amplifier, is a non-linear current amplifier.

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