Tutorial 1 – Answers

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 equations that are always valid:

Equation 1: $V_{in}(t) = V(t) + V_{out}(t) \Leftrightarrow V(t) = V_{in}(t) - V_{out}(t)$

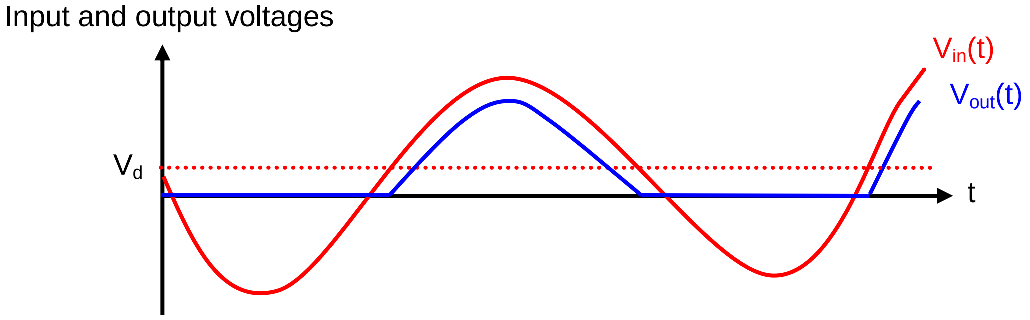
Equation 2: $V_{out}(t) = R \cdot i(t)$

The diode is off:

- If $V(t) < V_d$ => (equation 1) $V_{in}(t) - V_{out}(t) < V_d$ => $V_{in}(t) < V_{out}(t) + V_d$.
- Then, we have i(t) = 0, which yields, according to equation 2, $V_{out}(t) = R \cdot i(t) = 0$.
- Using equation 1 once again with this new result, we conclude that the diode is off if $V_{in}(t) < V_d$.

The diode is on:

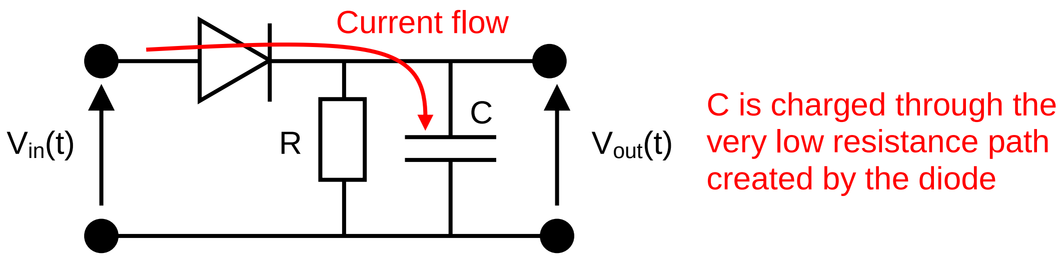
- If $V(t) = V_d$ => (equation 1) $V_{in}(t) - V_{out}(t) = V_d$ => $V_{out}(t) = V_{in}(t) - V_d$.
- Then, we have i(t) > 0, which yields, according to equation 2, $V_{out}(t) > 0$.
- Using equation 1 once again with this new result, we obtain $V_{in}(t) - V_d > 0$ => $V_{in}(t) > V_d$.



Question 2

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.

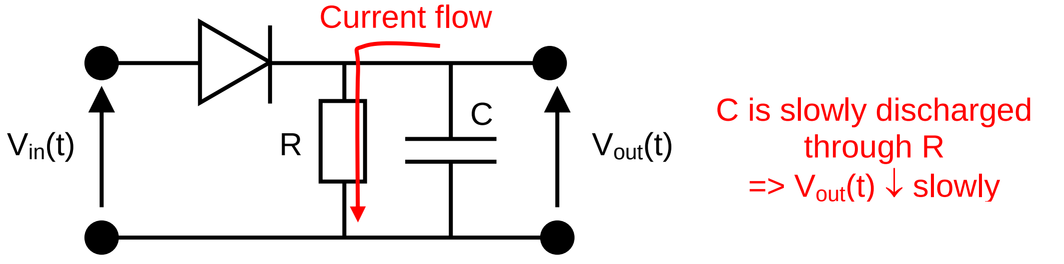
Assume that the input voltage $V_{in}(t)$ increases. As long as $V_{in}(t) < V_d$, the diode remain off and therefore nothing changes in the circuit. Once $V_{in}(t)$ reaches V_d, the diode turns on, as shown below, and we thus have $V_{out}(t) = V_{in}(t) - V_d$.



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

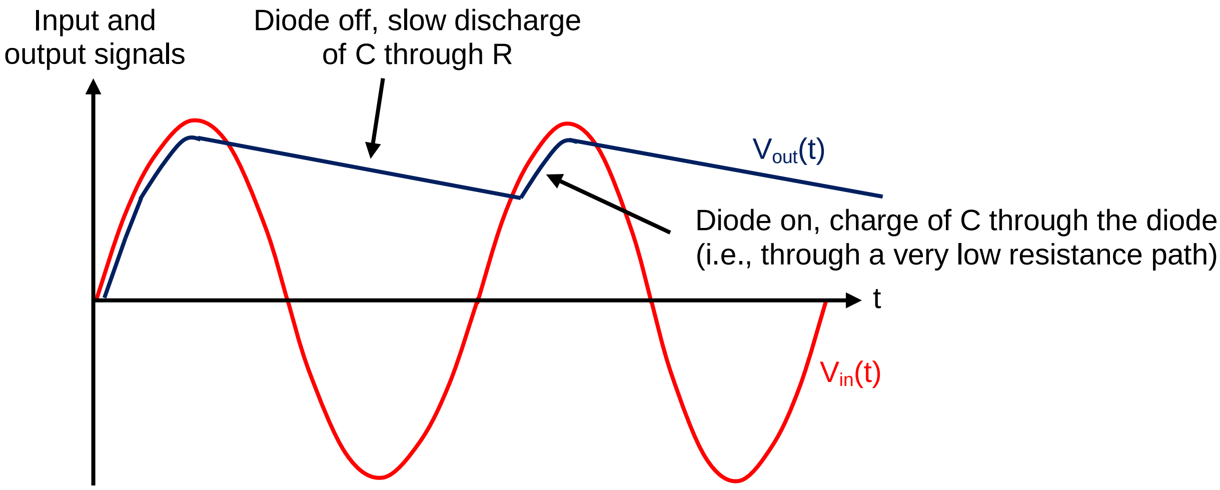
When $V_{in}(t)$ starts falling, $V_{out}(t)$ cannot follow the change in $V_{in}(t)$ due to the presence of the capacitor-resistor circuit. In fact, the capacitance C cannot be discharged through the diode. Instead, it has to be discharged through the resistance R.

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 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 so that $V_{in}(t)$ becomes once more equal to $V_{out}(t) + V_d$. As a result, the diode turns on again. In this case, $V_{out}(t) = V_{in}(t) - V_d$.



Applications of this circuit: AM demodulator (amplitude detector), power supply (conversion from AC to DC).

Question 3

Let $V_{D1}(t)$ and $V_{D2}(t)$ designate the voltages across diodes D1 and D2, respectively. Also, let $i_1(t)$ and $i_2(t)$ be the currents flowing through diodes D1 and D2, respectively. Finally, let i(t) denote the current flowing through the resistor R.

We start by writing four equations that are always valid:

Equation 1: $V_{out}(t) = V_1 + V_{D1}(t) \Leftrightarrow V_{D1}(t) = V_{out}(t) - V_1$

Equation 2: $V_{out}(t) = -(V_2 + V_{D2}(t)) \Leftrightarrow V_{D2}(t) = -V_2 - V_{out}(t)$

Equation 3: $V_{in}(t) = R \cdot i(t) + V_{out}(t)$

Equation 4: $i(t) + i_2(t) = i_1(t)$

Diode D1 is off & diode D2 is off:

- If $V_{D1}(t) < V_d$ and $V_{D2}(t) < V_d$ => (equations 1 and 2) $V_{out}(t) - V_1 < V_d$ and $-V_2 - V_{out}(t) < V_d$ => $V_{out}(t) < V_1 + V_d$ and $V_{out}(t) > -(V_2 + V_d)$.
- Then, we have $i_1(t) = i_2(t) = 0$, which yields, according to equation 4, $i(t) = 0$ => (equation 3) $\underline{V_{out}(t) = V_{in}(t)}$.
- Using equations 1 and 2 once again with this new result, we conclude that both diodes are off if $\underline{-(V_2 + V_d) < V_{in}(t) < V_1 + V_d}$.

Diode D1 is on & diode D2 is off:

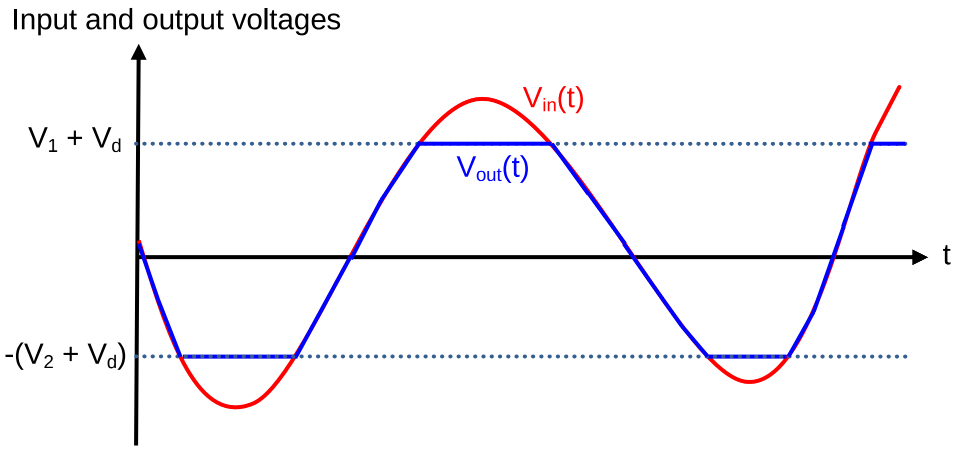
- If $V_{D1}(t) = V_d$ and $V_{D2}(t) < V_d$ => (equations 1 and 2) $V_{out}(t) - V_1 = V_d$ and $-V_2 - V_{out}(t) < V_d$ => $\underline{V_{out}(t) = V_1 + V_d}$ and $V_{out}(t) > -(V_2 + V_d)$.
- Then, we have $i_1(t) > 0$ and $i_2(t) = 0$, which yields, according to equation 4, $i(t) > 0$ => (equation 3) $V_{in}(t) > V_{out}(t)$ => $\underline{V_{in}(t) > V_1 + V_d}$.

Diode D1 is off & diode D2 is on:

- If $V_{D1}(t) < V_d$ and $V_{D2}(t) = V_d$ => (equations 1 and 2) $V_{out}(t) - V_1 < V_d$ and $-V_2 - V_{out}(t) = V_d$ => $V_{out}(t) < V_1 + V_d$ and $\underline{V_{out}(t) = -(V_2 + V_d)}$.
- Then, we have $i_1(t) = 0$ and $i_2(t) > 0$, which yields, according to equation 4, $i(t) < 0$ => (equation 3) $V_{in}(t) < V_{out}(t)$ => $\underline{V_{in}(t) < -(V_2 + V_d)}$.

Diode D1 is on & diode D2 is on:

- If $V_{D1}(t) = V_d$ and $V_{D2}(t) = V_d$ => (equations 1 and 2) $V_{out}(t) - V_1 = V_d$ and $-V_2 - V_{out}(t) = V_d$ => $V_{out}(t) = V_1 + V_d$ and $V_{out}(t) = -(V_2 + V_d)$, which can never happen. Thus, this case can be discarded.

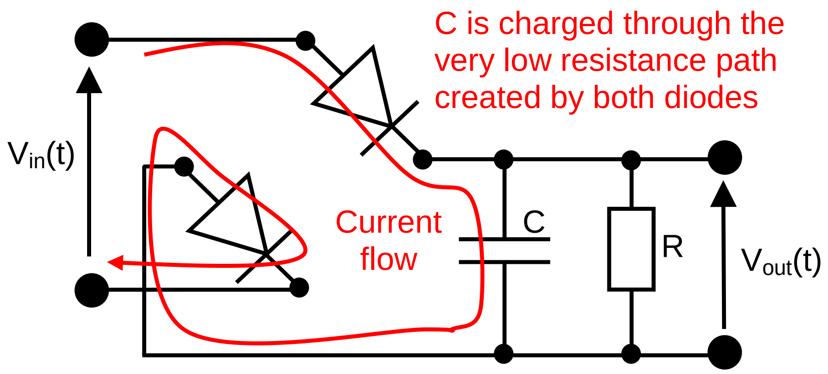


We conclude that this circuit performs a clipping function.

Question 4

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.

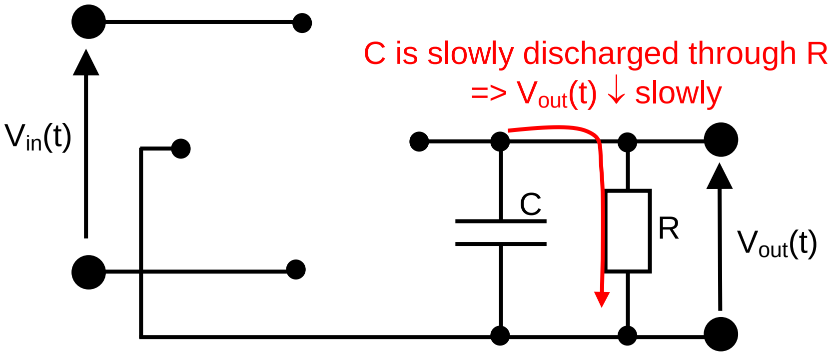
Assume that the input voltage $V_{in}(t)$ increases. As long as $V_{in}(t) < 2V_d$, all diodes remain off and therefore nothing changes in the circuit. Once $V_{in}(t)$ reaches $2V_d$, two diodes turn on, as shown below, and we thus have $V_{out}(t) = V_{in}(t) - 2V_d$.



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

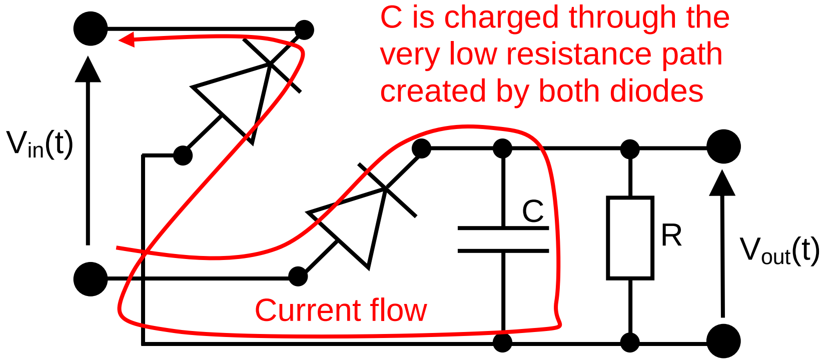
When $V_{in}(t)$ starts falling, the output voltage $V_{out}(t)$ cannot follow the change in $V_{in}(t)$ due to the presence of the capacitor-resistor circuit. In fact, the capacitance C cannot be discharged through the diodes. Instead, it has to be discharged through the resistance R.

Since this happens slowly, $V_{out}(t)$ falls more slowly than $V_{in}(t)$. Thus, as soon as $V_{in}(t)$ 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 $V_{out}(t) + 2V_d$.

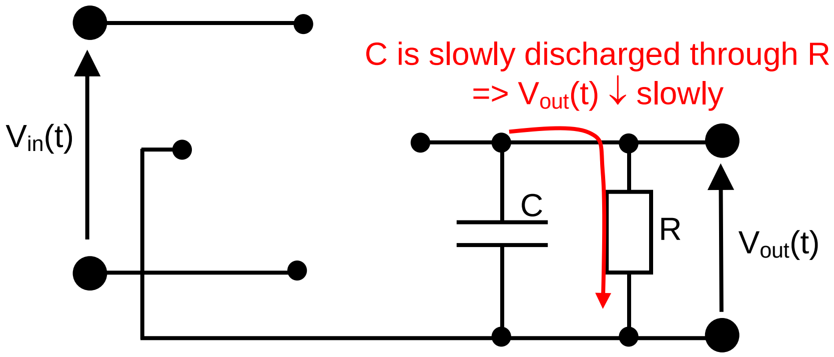
At some stage, $V_{out}(t)$ has fallen enough and $V_{in}(t)$ has also become sufficiently negative so that two diodes turn on, as shown below, and we thus have $V_{out}(t) = -V_{in}(t) - 2V_d$



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

When $V_{in}(t)$ starts rising again, 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 $-V_{in}(t)$. 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 when $-V_{in}(t)$ becomes smaller than $V_{out}(t) + 2V_d$.