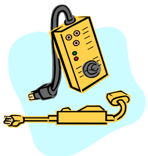
VOLTAGE DOUBLER AND RECTIFIERS WITH CAPACITIVE FILTER

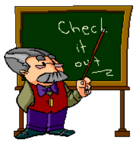
I. OBJECTIVES

a) To understand how voltage multipliers (doubler) can be built using simple DC circuits.
b) To determine how the frequency of the input voltage influences the rectified output voltage.



II. COMPONENTS AND INSTRUMENTATION

You will use a breadboard, semiconductor diodes of 1N4184 type (the stripe indicates the cathode), 330 nF capacitors and a 10 kΩ resistor. Because you will apply and measure ac voltages, you will need a signal generator and a dual channel oscilloscope.



III. THEORETICAL ASPECTS

1. Voltage doubler

Think of it as a cascading connection between an upward translation two-port network (from v_I to v_{O1}) and a positive peak detector (from v_{O1} *to* v_O).

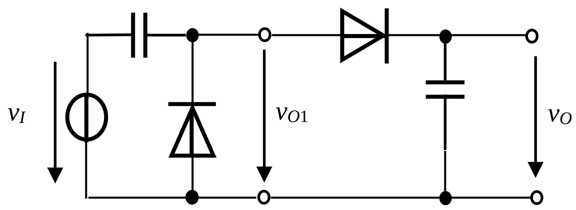


Fig. 1. Voltage doubler using a translation circuit and a peak detector.

The waveforms in steady-state regime, in the case of a sinusoidal input signal with $\hat{V}_I$ amplitude are plotted in Fig. 2.

2. Half-wave rectifiers with capacitive filter

Rectifiers with D and R generate an output voltage of a single sign, but it has a considerable variation, equal to the amplitude of the input signal. To obtain a continuous voltage, we must smoothen these variations by adding a filtering capacitor (see Fig. 3).

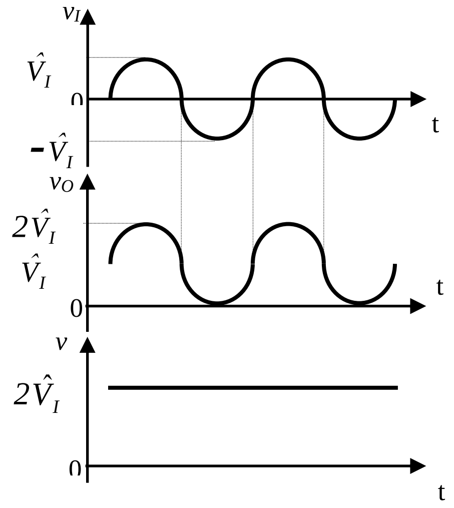


Fig. 2. Waveforms in steady-state for the doubler in Fig. 1

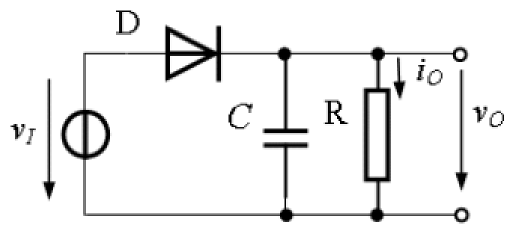


Fig. 3. Half-wave rectifier with capacitive filter

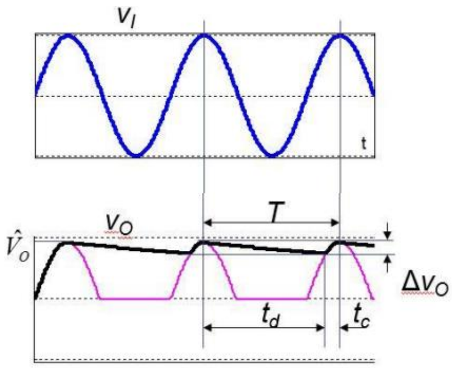


Fig. 4. Waveforms for half-wave rectifier with capacitive filter

The circuit can be seen also as a positive peak detector loaded with *R*. In actual practical situations, such as the design of power supplies a load resistance will be inherently present. If the input voltage is an alternative sinusoidal one, between two consecutive peaks of v_I, the capacitor will discharge through *R* and v_O will go down, unlike the situation without *R* when v_O was constant. The waveforms in steady-state for the circuit in Fig. 3 are plotted in Fig. 4. The time constant of the circuit, *RC*, should be much greater than the period *T* of the signal, *RC* >> *T*. Note that the output is no longer a constant dc voltage but it may be considered as being composed on a dc voltage on which an ac component, called *ripple*, is superimposed.

We specify the following:

- The diode *D* conducts for short time intervals Δt_c, close to the positive peaks of v_I. We neglect the voltage drop across the conducting diode. The capacitor charges with an electric charge equal to the one lost on the longest duration of the discharge, Δt_d.

$$v_c(t) = (1 - e^{-\frac{t}{RC}})V_\infty + V(0) \cdot e^{-\frac{t}{RC}}$$

- When *D* –(*off*), *C* discharges through *R* and in this way v_O drops exponentially with the time constant *RC*. At the end of the discharge interval Δt_d, which is almost equal with $T, v_O = \hat{V}_I - \Delta v$, where Δv is the peak to peak value of the ripple of the output voltage. If *RC* >>*T*, Δv is small. A special attention will be paid to this ripple Δv.

We remind the expression of the voltage across the capacitor.

$$v_c(t) = (1 - e^{-\frac{t}{RC}})V_\infty + V(0)e^{-\frac{t}{RC}}$$

Let us assume the initial time moment, t=0 as being the moment when the discharge of the capacitor begins (v_I at the maximum value), therefore $V(0) = \hat{V}_I$. V_∞ is the value at which the voltage on the capacitor could finally reach, if the input signal will disappear, $V_\infty = 0\text{V}$. The time interval in which we are interested is the one of the capacitor's discharge $t = \Delta t_d$, when the value of the voltage is:

$$v(\Delta t_d) = \hat{V}_I - \Delta v$$

We obtain:

$$\hat{V}_I - \Delta v = \hat{V}_I e^{-\frac{\Delta t_d}{RC}} \approx \hat{V}_I e^{-\frac{T}{RC}}$$

Because $RC>>T$ we can use the approximation:

$$e^{-\frac{T}{RC}} \approx 1 - \frac{T}{RC}$$

$$\hat{V}_I - \Delta v = \hat{V}_I - \frac{T}{RC}\hat{V}_I$$

$$\Delta v = \frac{T}{RC}\hat{V}_I$$

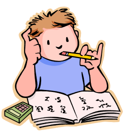
The higher the time constant RC (usually by choosing a large value for C), the smaller is the ripple, so v_O is closer to a smooth continuous voltage.

Remark: An alternative interpretation of the previous approximation is that, on the intervals Δt_d we consider that the discharge of the capacitor happens at a constant current $I_O = \frac{\hat{V}_I}{R}$. This interpretation holds as long as $\Delta v << \hat{V}_I$

$$\Delta v = \frac{T}{C}I_O = \frac{T}{RC}\hat{V}_I$$

If we want to use the frequency f of the voltage:

$$\Delta v = \frac{1}{fC}I_O = \frac{1}{fRC}\hat{V}_I$$



IV. PREPARATION

1.P. Voltage doubler

The questions address the circuit in Fig. 5.

- What is the function of the circuit consisting of D_1 and C_1, with the output $v_{O1}(t)$?
- Plot $v_I(t)$, $v_{O1}(t)$ and $v_{C1}(t)$ in steady state, if $v_I(t)$ is a sinusoidal voltage with 10 V amplitude.
- What is the function of the circuit consisting of D_2 and C_2, with the output $v_O(t)$?
- Plot $v_I(t)$, $v_O(t)$ and $v_{D2}(t)$ in steady state, if $v_I(t)$ is a sinusoidal voltage with 10 V amplitude.

2.P. Half-wave rectifier with capacitive filter

The questions address the circuit in Fig. 6.

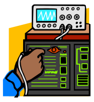
- Plot $v_I(t)$ and $v_O(t)$, if $v_I(t)$ is a sinusoidal voltage with 10 V amplitude.
- Compute the output voltage ripple Δv_O for f = 100 Hz and f = 1 kHz.
- What is the effect of the frequency on $v_O(t)$ and Δv_O ?

3.P. Spatial maximum circuit with capacitive filter

The questions address the circuit in Fig. 7.

- Plot $v_A(t)$, $v_B(t)$ and $v_O(t)$, if $v_A(t)$ is a sinusoidal voltage with 10 V amplitude, and $v_B(t)$ is a dc voltage, 5 V amplitude.
- Can the output voltage ripple Δv_O be computed using the same equation as for the previous circuit? Justify your answer.

V. EXPLORATIONS AND RESULTS



1. Voltage doubler

Exploration

Build the circuit shown in Fig. 5.

• At the input of the circuit apply a sinusoidal voltage with 500 Hz frequency and 10 V amplitude obtained from the signal generator.

• $v_I(t)$, $v_{O1}(t)$ and $v_O(t)$ are visualized on the oscilloscope. Because you can visualize only two signals simultaneously you will visualize first $v_I(t)$ and $v_{O1}(t)$ and then $v_I(t)$ and $v_O(t)$, using the DC setting for both channels.

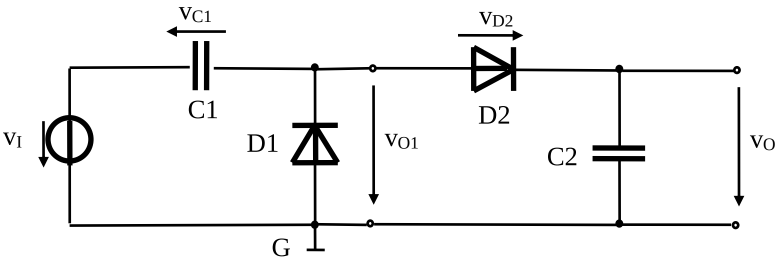


Fig. 5. Voltage doubler

Results

• Draw the waveforms for $v_I(t)$, $v_{O1}(t)$, $v_O(t)$, $v_{C1}(t)$ and $v_{D2}(t)$ for 10 V amplitude of the input voltage.

2. Half-wave rectifier with capacitive filter

Exploration

Build the circuit shown in Fig. 6.

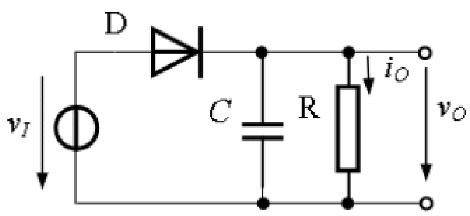


Fig. 6. Half-wave rectifier with capacitive filter

- At the input of the circuit apply a sinusoidal voltage with 100 Hz frequency and 10 V amplitude obtained from the signal generator.
- Visualize v_I and v_O on the oscilloscope, using the DC setting for both channels.
- Compute the output voltage ripple, by reading the values from the oscilloscope.
- Change the frequency of the input voltage to f = 1 kHz. Recompute the output voltage ripple, by reading the values from the oscilloscope.

Results

- Plot of $v_I(t)$, $v_O(t)$.
- Computed output voltage ripple for f = 100 Hz and f = 1 kHz.
- How does the frequency influence $v_O(t)$ and Δv_O ?

3. Spatial maximum circuit with capacitive filter

Exploration

Build the circuit shown in Fig. 7

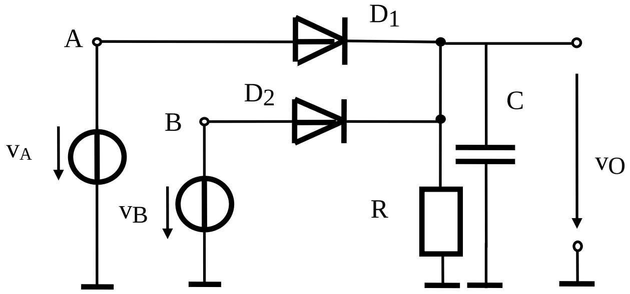


Fig. 7. Spatial maximum circuit with capacitive filter

- At the input of the circuit apply v_A - sinusoidal voltage with 100 Hz frequency and 10 V amplitude obtained from the signal generator, and V_B = 5 V from the power supply.
- Visualize v_A and v_O on the oscilloscope, using the DC setting for both channels.
- Compute the output voltage ripple, by reading the values from the oscilloscope.
- Change the frequency of the input voltage to f = 1 kHz. Recompute the output voltage ripple, by reading the values from the oscilloscope.

Results

- Plot of $v_A(t)$, $v_O(t)$.
- Computed output voltage ripple for f = 100 Hz and f = 1 kHz.
- How does the frequency influence $v_O(t)$ and Δv_O ?
- How does Δv_O change, compared to the previous circuit?

REFERENCES

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