FUNDAMENTALS OF ELECTRONICS

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1. RECTIFIERS

Electronic circuits require a DC voltage supply. There are two basic types of power supplies: linear power supply (base on classic 50/60 Hz transformer) and switch mode power supply (switching occurs at a very high frequency, typically 10 kHz — 1 MHz).

The main elements of a linear (transformer) power supply (Fig. 1) are:

- **Transformer** – a step-down transformer converts the 230V_{AC} into low voltage (in most cases 5 - 24 V_{AC});
- **Rectifier** – is used to change AC to DC;
- **Filter** – (in the form of energy storage capacitors) is used to filter the AC ripples and gives to the voltage regulator;
- **Voltage regulator** – regulates the voltage to commanded low voltage value, additionally reduces the level of ripple.

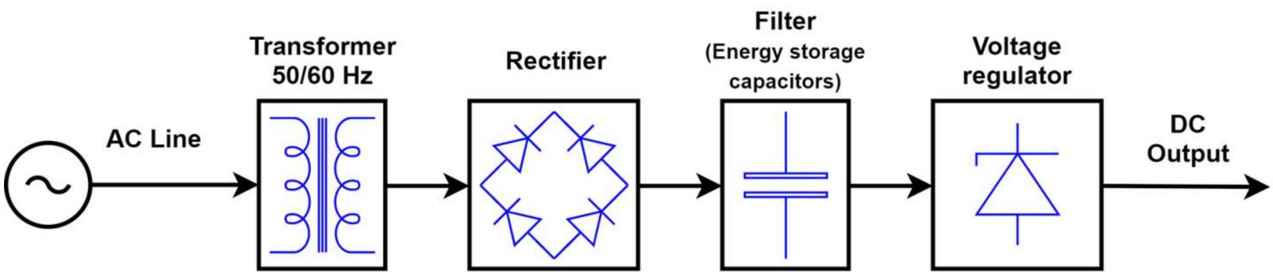

Fig. 1: Linear power supply block diagram

Advantages:

- simpler and more robust construction;
- easier to design;
- low ripple and noise – suited to sensitive applications;
- typically faster transient response times – therefore may be better suited to more dynamic loads;
- cheap for low power applications.

Disadvantages:

- less efficient;
- larger and heavier;
- can be more expensive (for high power applications).

The second basic type of power supplies are switching power supplies. The biggest advantage of switching power supplies is their high efficiency and small dimensions. The main elements of the switching power supplies (Fig. 2) are:

- **Input rectifier** – is used to change AC to high DC voltage (about 320 V_{DC});
- **Filter** – (in the form of energy storage capacitors) is used to filter the AC ripples;
- **Power switches** – are used to generate pulses in the primary winding of the transformer, based on the duty cycle commanded from the control circuit;
- **Pulse transformer** – is used to convert high voltage to low voltage, due to high switching frequency (most often 10 - 100 kHz) the transformer can have small dimensions;
- **Rectifier** – is used to change AC voltage (from secondary transformer winding) to low DC voltage;
- **Output filter** – high-frequency interference filtering from Pulse Width Modulation;
- **Control circuit** – main element in the feedback loop, is used to determine the duty cycle for the PWM signal (semiconductor switching control).

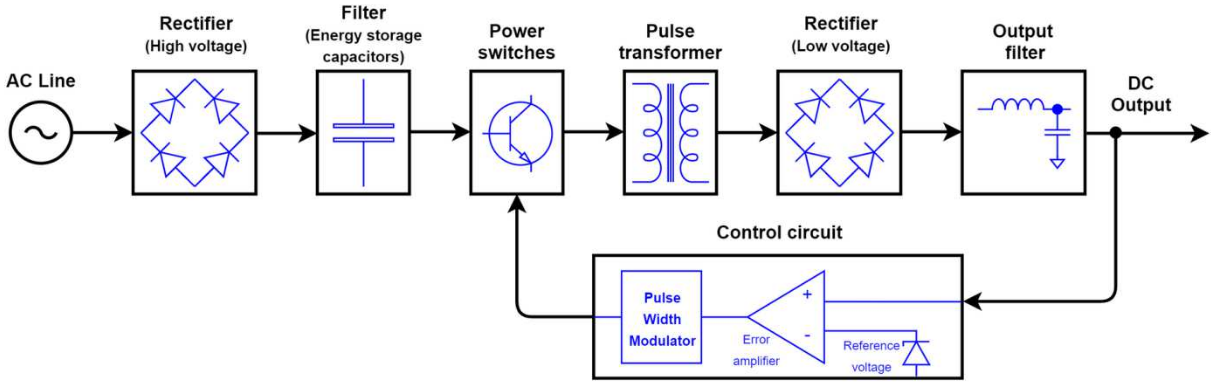

Fig. 2: Switch mode power supply block diagram

Advantages:
- more efficient than linear power supplies;
- typically much smaller and lighter;
- often lower cost due to much smaller transformers used.

Disadvantages:
- more complex construction;
- can be a potential source of EMI and RFI (electromagnetic interferences);
- typically slower transient response times.

Both types of power supplies require the rectifiers at some stage of energy conversion.

1.1 Half-wave rectifier without capacitor

A half-wave rectifier is shown in Fig. 3a. The name half-wave rectifier suggests that the rectification is done only for half of the cycle. The AC voltage is given through an input transformer to reduce the voltage value. The input signal given to the transformer is passed through a diode which acts as a rectifier. This diode converts the AC voltage into pulsating dc for only the positive half cycles of the input. A load resistor is connected at the end of the circuit. Input voltage (V_{AC}) and output voltage (V_{DC}) are shown in Figure 3b.

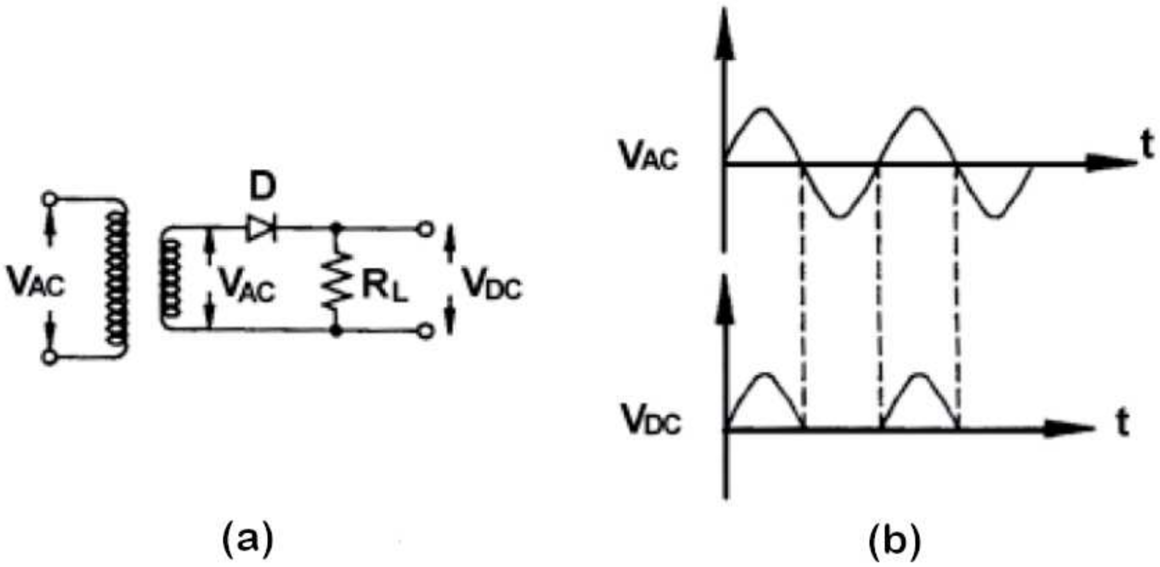

Fig. 3: Half-wave rectifier [1]:
a) electrical circuit;
b) input (V_{AC}) and output (V_{DC}) voltage waveform

1.2 Half-wave rectifier with capacitor

Fig. 4a and 4b show a half-wave rectifier with a filtering capacitor during charging and discharging. Fig. 4c and 4d show the output voltage waveforms for the load resistance RL = 1kΩ (case c) and without load, i.e. RL = ꝏ (case d). The greater the value of the load resistance, the longer the discharge time. This causes smaller fluctuations in the output voltage.

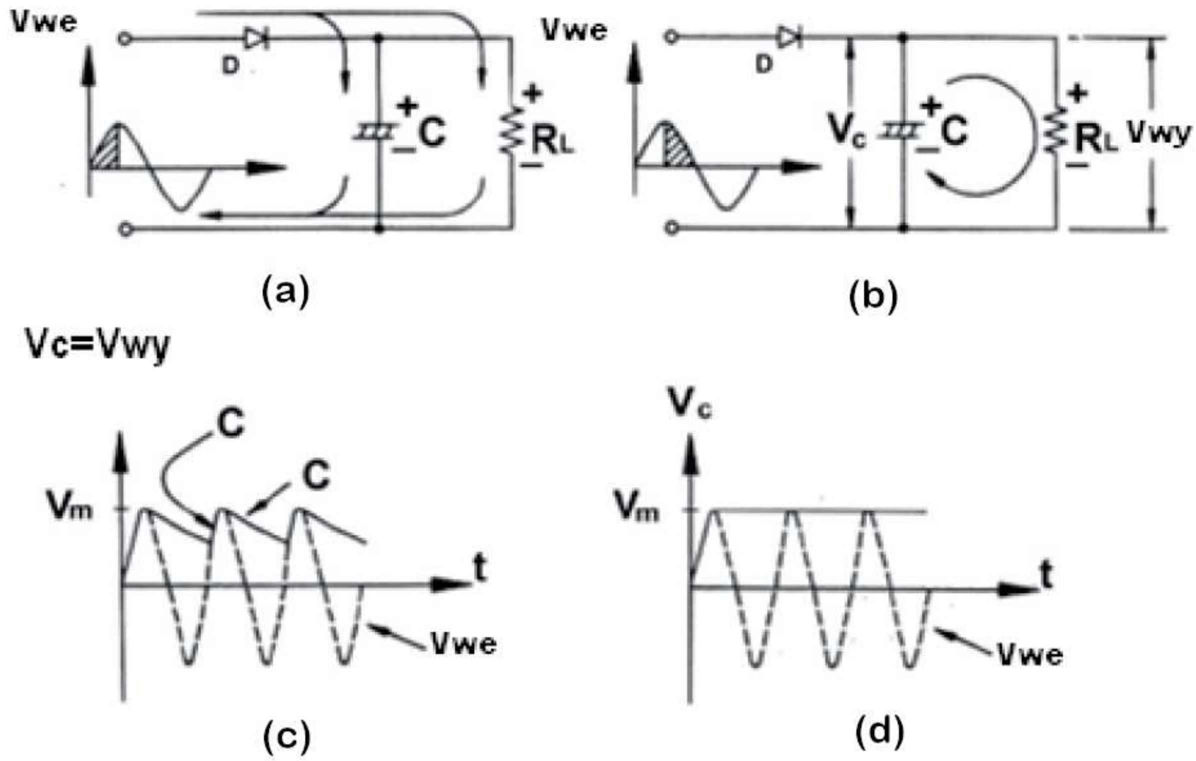

Fig. 4: Half-wave rectifier with capacitor [1]:
a) during charging
b) during discharging
c) output voltage for R_L = 1kΩ
d) output voltage for R_L = ꝏ

1.3 Full-wave bridge rectifier without capacitor

Full-wave bridge rectifier consist of four diodes (assigned as D1, D2, D3 and D4). Two of the diodes conduct for one half cycle, and two conduct for the other half cycle of the input supply. The circuit of a bridge full wave rectifier is as shown in the figure below (Fig. 5)..

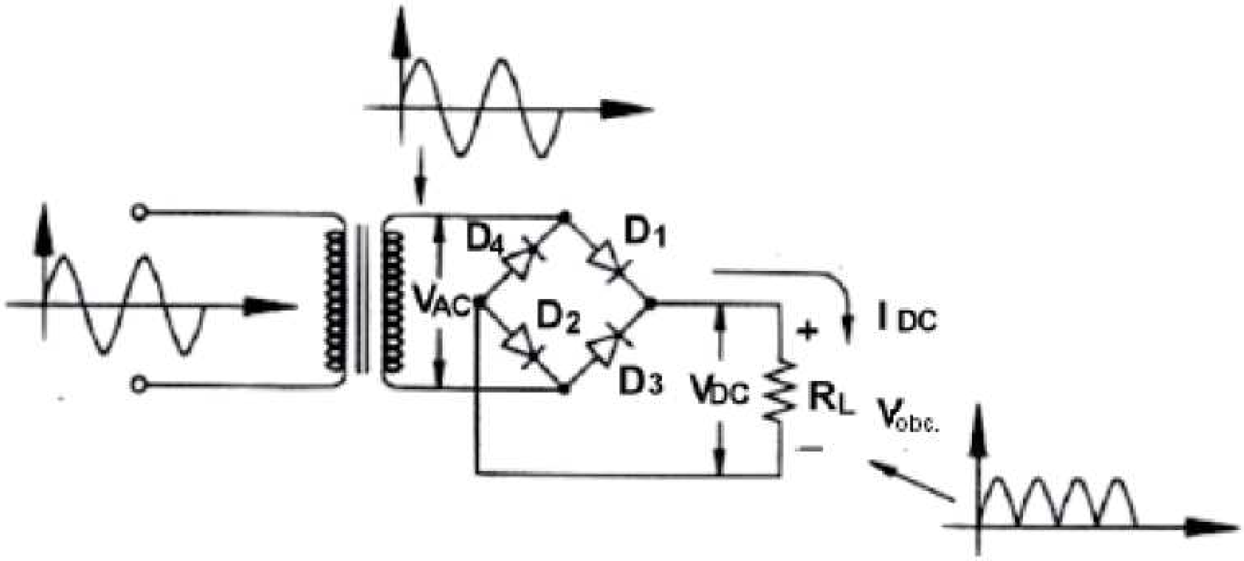

Fig. 5: Full-wave bridge rectifier circuit [1]

The full wave rectifier with four diodes connected in bridge circuit is employed to get a better full wave output response. When the positive half cycle of the input supply is given the diode D1 and D2 forward biased while D3 and D4 reverse biased. These two diodes will now be in series with the load resistor. The figure below (fig. 6) indicates this along with the conventional current flow in the circuit.

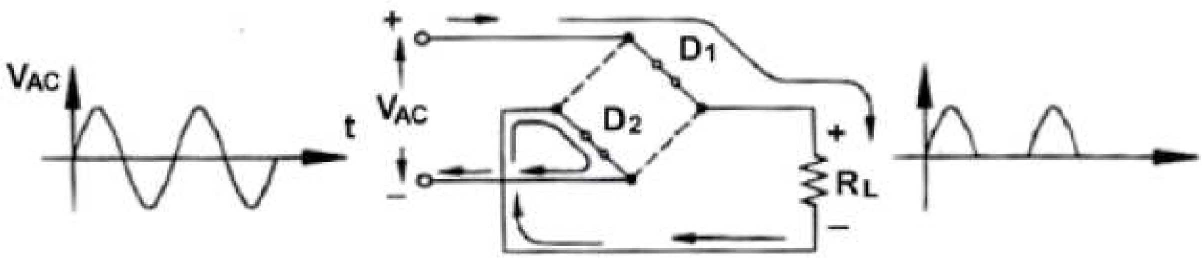

Fig. 6: Equivalent circuit of a bridge rectifier in the positive half-wave of the input voltage [1]

When the negative half cycle of the input supply is given the diode D1 and D2 reverse biased while D3 and D4 forward biased. These two diodes will now be in series with the load resistor. The following figure (fig. 7) indicates this along with the conventional current flow in the circuit.

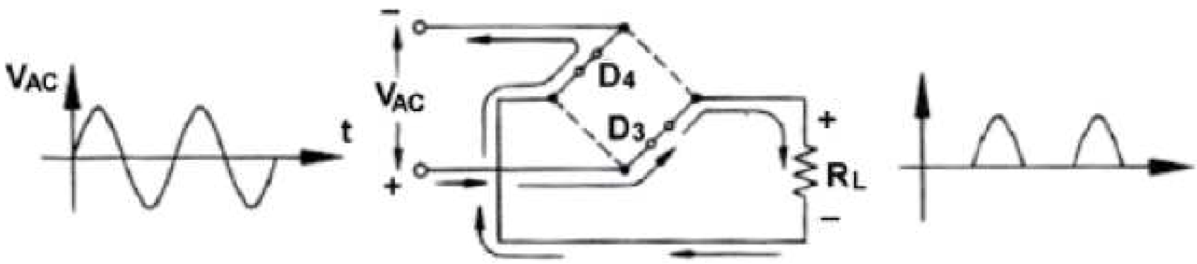

Fig. 7: Equivalent circuit of a bridge rectifier in the negative half-wave of the input voltage [1]

1.4 Full-wave bridge rectifier with capacitor

Fig. 8 shows a bridge rectifier (Graetz) circuit with a filter in the form of a high-capacity capacitor. As a result, the ripple of the output voltage was significantly reduced.

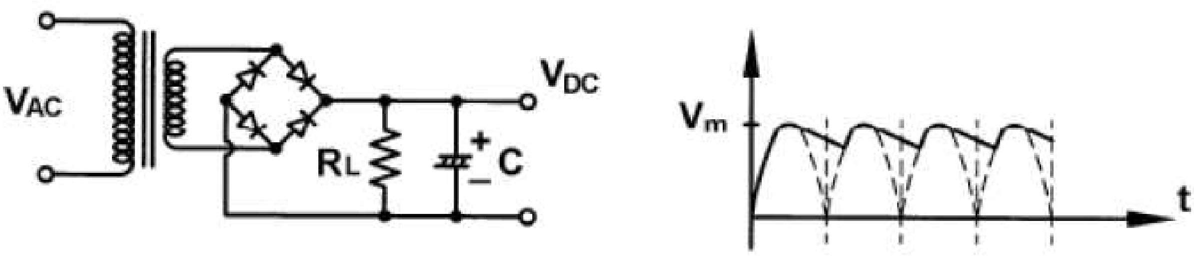

Fig. 8: Full-wave bridge rectifier with capacitor [1]

2. VOLTAGE MULTIPLIER

Generally, the DC output voltage of a rectifier circuit is limited by the peak value of its sinusoidal input voltage. But by using combinations of diodes and capacitors we can effectively multiply this input peak voltage to give a DC output equal to some odd or even multiple of the peak voltage value of the AC input voltage.

A voltage multiplier is an electrical circuit that converts AC electrical power from a lower voltage to a higher DC voltage, typically in the form of a network of capacitors and diodes. The voltage multiplier can be found in many electrical and electronic circuit applications such as in microwave ovens, strong electric field coils for cathode-ray tubes, electrostatic and high voltage test equipment, cathode ray tubes, cathode ray tubes in oscilloscope, television receivers, computer display, X-ray systems, lasers, copy machines, electrostatic systems, photomultiplier tubes, etc (where it is necessary to have a very high DC voltage generated from a relatively low AC supply).

Fig. 9 shows a schematic of a Voltage doubler. During the negative half cycle of the sinusoidal input voltage, diode D1 is forward biased and conducts charging up the pump capacitor, C1 to the peak value of the input voltage. Because there is no return path for capacitor C1 to discharge into, it remains fully charged acting as a storage device. At the same time, diode D2 conducts via D1 charging up capacitor, C2.

During the positive half cycle, diode D1 is reverse biased blocking the discharging of C1 while diode D2 is forward biased charging up capacitor C2. But because there is a voltage across capacitor C1 already equal to the peak input voltage, capacitor C2 charges to twice the peak voltage value of the input signal.

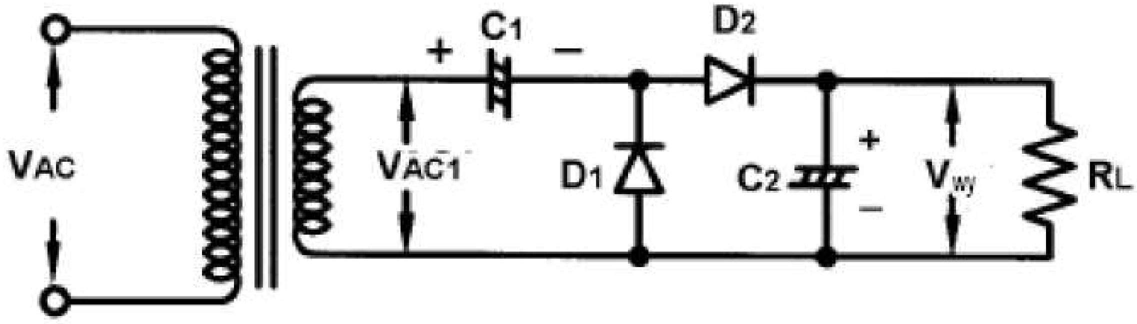

Fig. 9: Voltage doubler circuit [1]

Fig. 10 shows the voltage multiplier. This circuit is an extension of the half-wave rectifier with voltage doubling and works on the same principle. Using this topology, it is possible to obtain a direct voltage at the output with a value many times higher than the amplitude of the input voltage (some odd or even multiple of the peak voltage value of the AC input voltage).

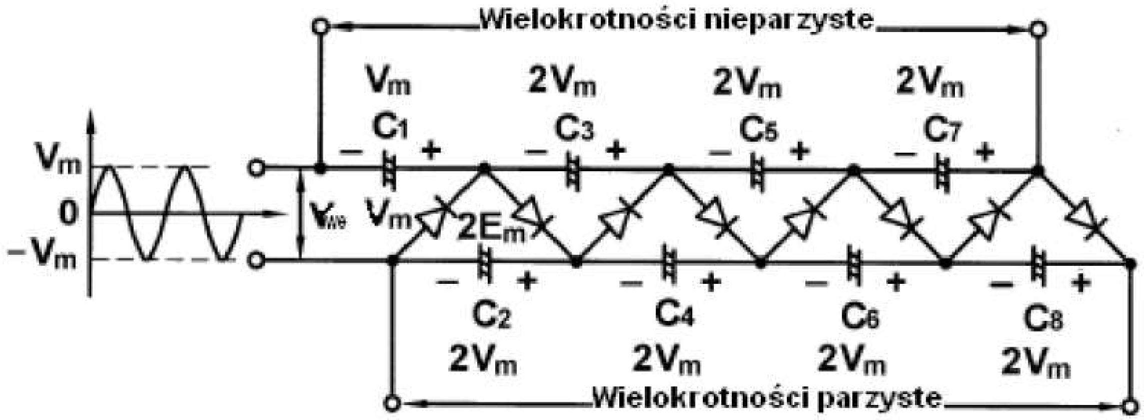

Fig. 10: Voltage multiplier [1]

3. RC FILTERS

3.1 RC Low-Pass Filter (LPF)

The amplitude-frequency characteristic of the RC integrator is shown in Fig. 11. As you can see, it can be divided into two parts: the part with a gain of 0 dB (k = 1 V / V) and the part where the signal is damped with a gain less than one (k <1 V / V). Due to such frequency response, the RC integrator is used as a passive (first order) low-pass filter. The consequence is also the occurrence of a phase shift for higher frequencies, according to Fig. 12.

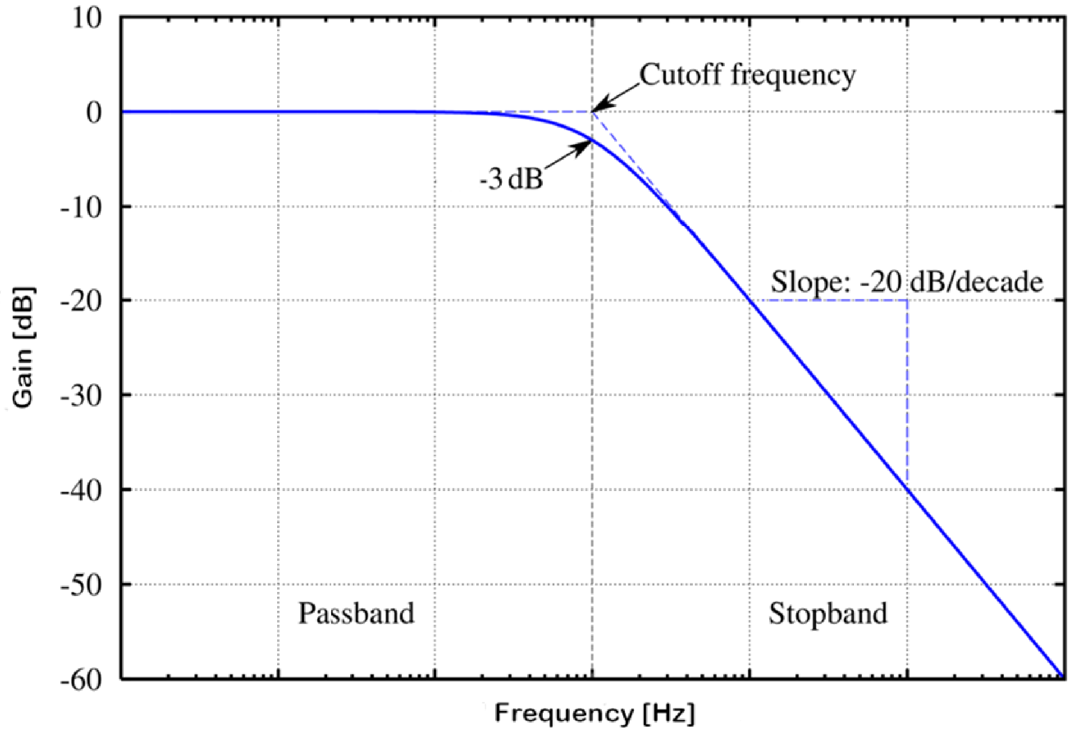

Fig. 11: Amplitude-frequency characteristic of the RC low-pass filter

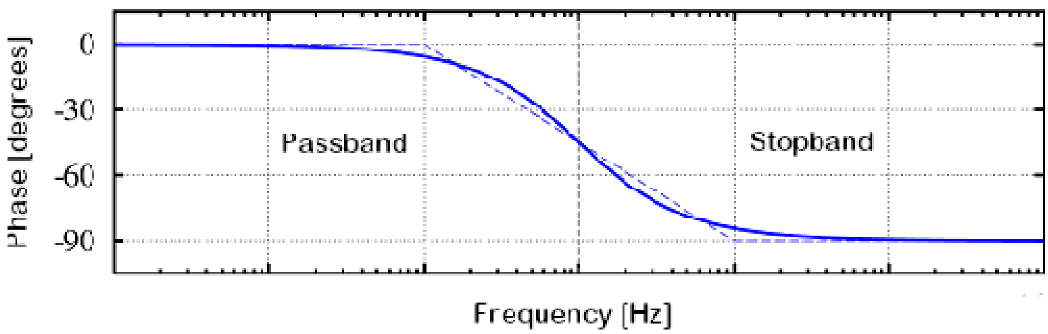

Fig. 12: Phase-frequency characteristics of the RC low-pass filter

The point that connect this two areas (with different gain) is called the cut-off frequency. It is determined for the point where the damping is -3 dB (√2 ≈ 0.71). The relationship of the RC time constant with the cutoff frequency is as follows:

$$\omega_{-3dB} = \frac{1}{\tau}$$

$$2\pi f_{-3dB} = \frac{1}{\tau}$$

$$f_{-3dB} = \frac{1}{2\pi\tau}$$

3.2 RC High-Pass Filter (HPF)

The amplitude-frequency characteristic of the RC differentiator is shown in Fig. 13. the part with a gain of 0 dB (k = 1 V / V) and the part in which the signal is damped with a gain lower than unity (k <1 V / V). Due to such frequency response, the RC differentiator is used as a passive (first order) high-pass filter. The point that connect this two areas (with different gain) is called the cut-off frequency. It is determined for the point where the damping is -3 dB (√2 ≈ 0.71). The relationship of the RC time constant with the cutoff frequency is the same as for the RC low-pass filter.

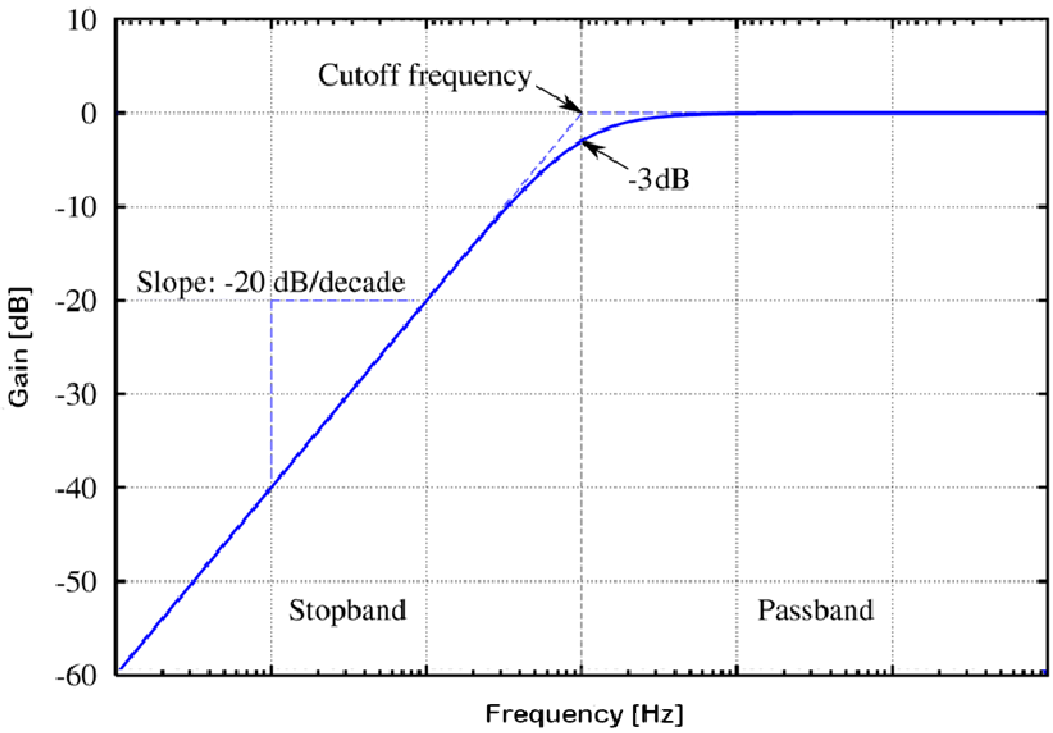

Fig. 13: Amplitude-frequency characteristic of the RC high-pass filter

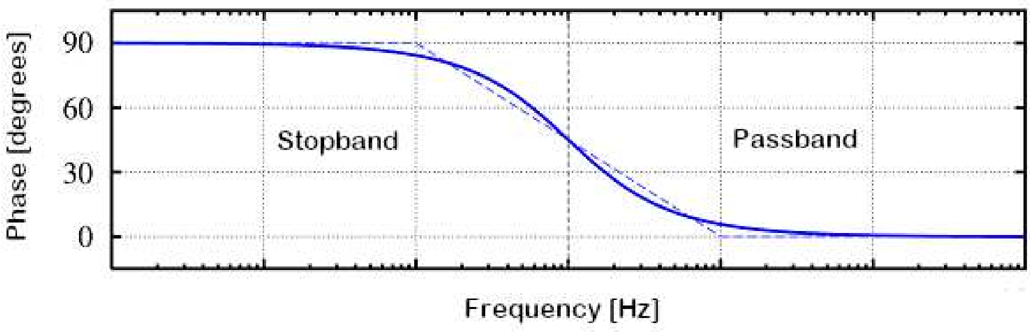

Fig. 14: Phase-frequency characteristics of the RC high-pass filter

4. REFERENCES

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