Power Electronics for Actuators

Power Electronics

- Power Electronics drive all mechatronics devices – **Actuators**
- **Power Electronics devices are**
- **Diodes and**
- **Transistors**
- **that can carry large currents and**
- **sustain large voltages**

Electronics

- Classical / Standard Electronics
  - Electrical quantities carry information
  - Issues: Noise, BER (Bit Error Rate)…
- Power electronics
  - Electrical quantities carry power
  - Issue: Efficiency

Power Electronics

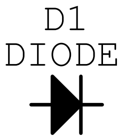
- Electric power
  - Conversion
  - Control and Applications
  - Conditioning

- Power range:
  - From few **mW (10^{-3})** to few 100s of **MW (10^{6}, 10^{8})**

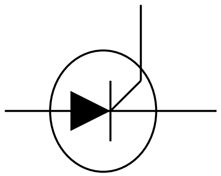
Power Electronics

1. Power diodes
2. Thyristors
3. Power Bipolar junction transistors (BJT)
4. Insulated-gate bipolar transistors (IGBT)
5. Static Induction Transistors (SIT)

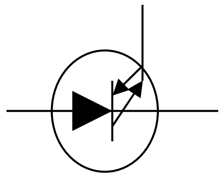
Power Electronics Devices



Diode

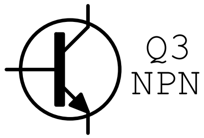


Thyristor



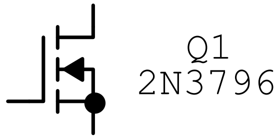
Gate Turnoff Thyristor (GTO)

Triac



npn BJT

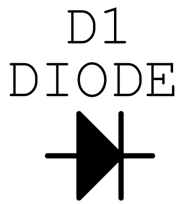
IGBT

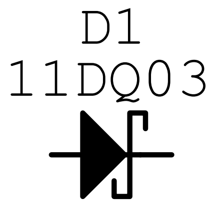


n-channel MOSFET

Power Diodes

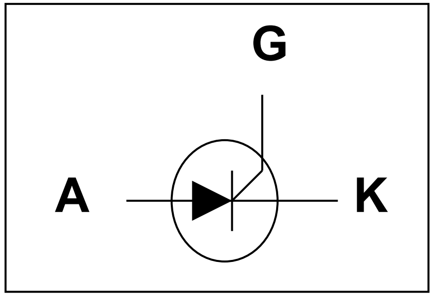
- General purpose
  - **3000V, 3500A**
- High-speed (fast-recovery)
  - **3000V, 1000A**
  - Switching time in **10^{-6} sec (μs)**
- Schottkey
  - **100V, 300A**
  - Switching time in **10^{-9} sec (ns)**
- V_D=0.5 to 1.2V, can be neglected comparing to 300V





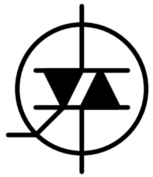
Thyristors

- **6000V and 3500A**
- Similar to power diodes, but with control
- Gate controls conducting start time
- Starts conducting when
  - gate current > 0, and $V_{AK} > 0$
  - Forward $V_{DROP} = 0.5$ to 2V
  - When conducting starts gate current has no control
- Conducting stops with reverse biasing, $V_{AK} \leq 0$

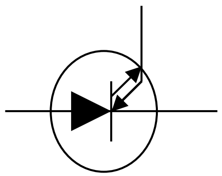


Thyristors

- There are many different types
- Two most popular are:
  - Triac,
    - Control current in either direction



  - GTO, Gate turnoff thyristor
    - Turned ON by a short positive pulse
    - Can be turned OFF by a short negative pulse



Power BJTs

- Operate like conventional BJTs, but
- Range **1200V, 400A**
- **Used in power converter applications**
- **Frequency up to 10kHZ**

Power MOSFETs

- Range **1000V, 50A**
- **Frequency up to few 10kHZ**

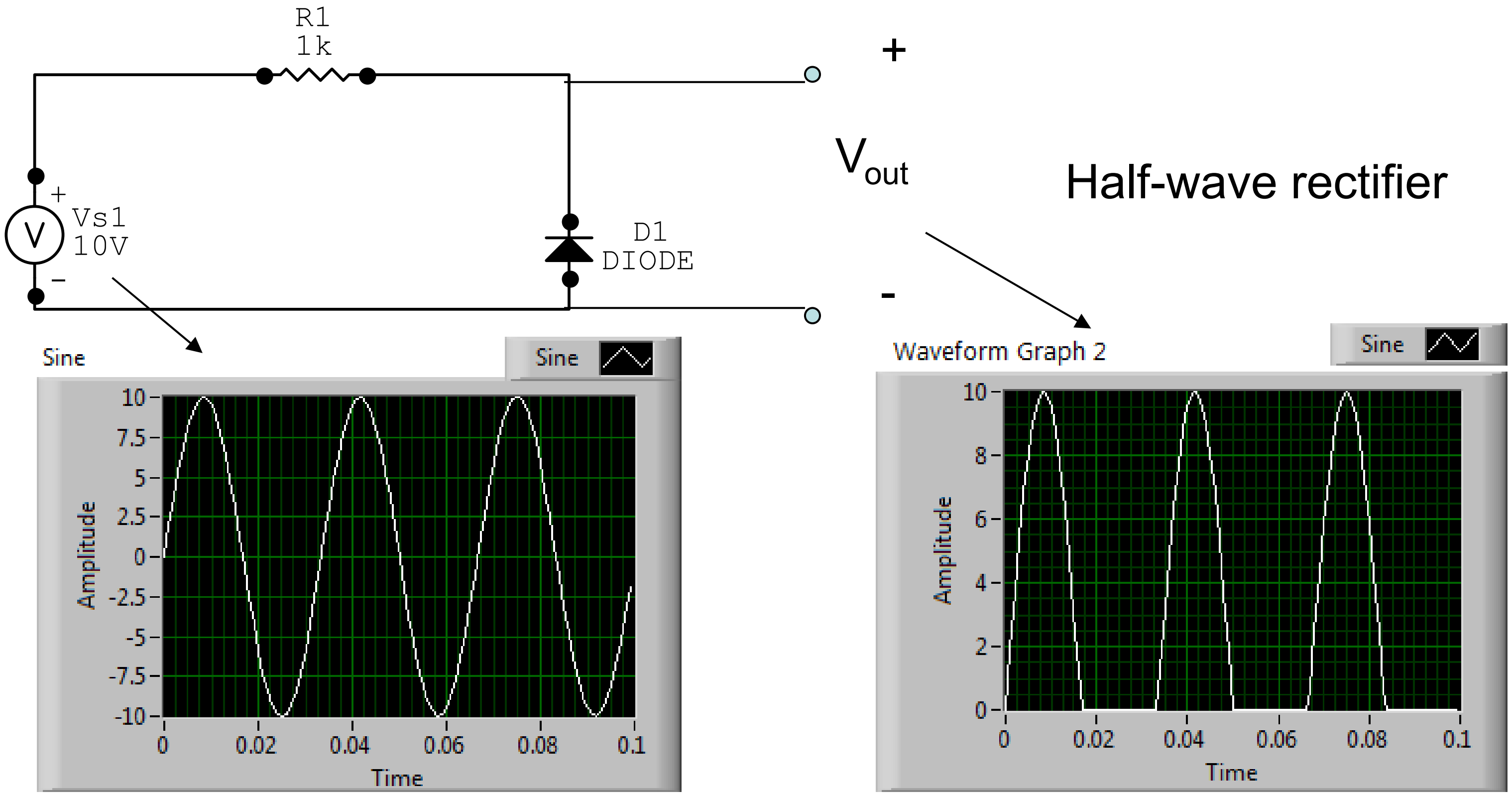
Power Electronic Circuits

- Voltage regulators
- Power amplifiers
- Switches
- Diode rectifier
- **Power conversion**

Power Conversion

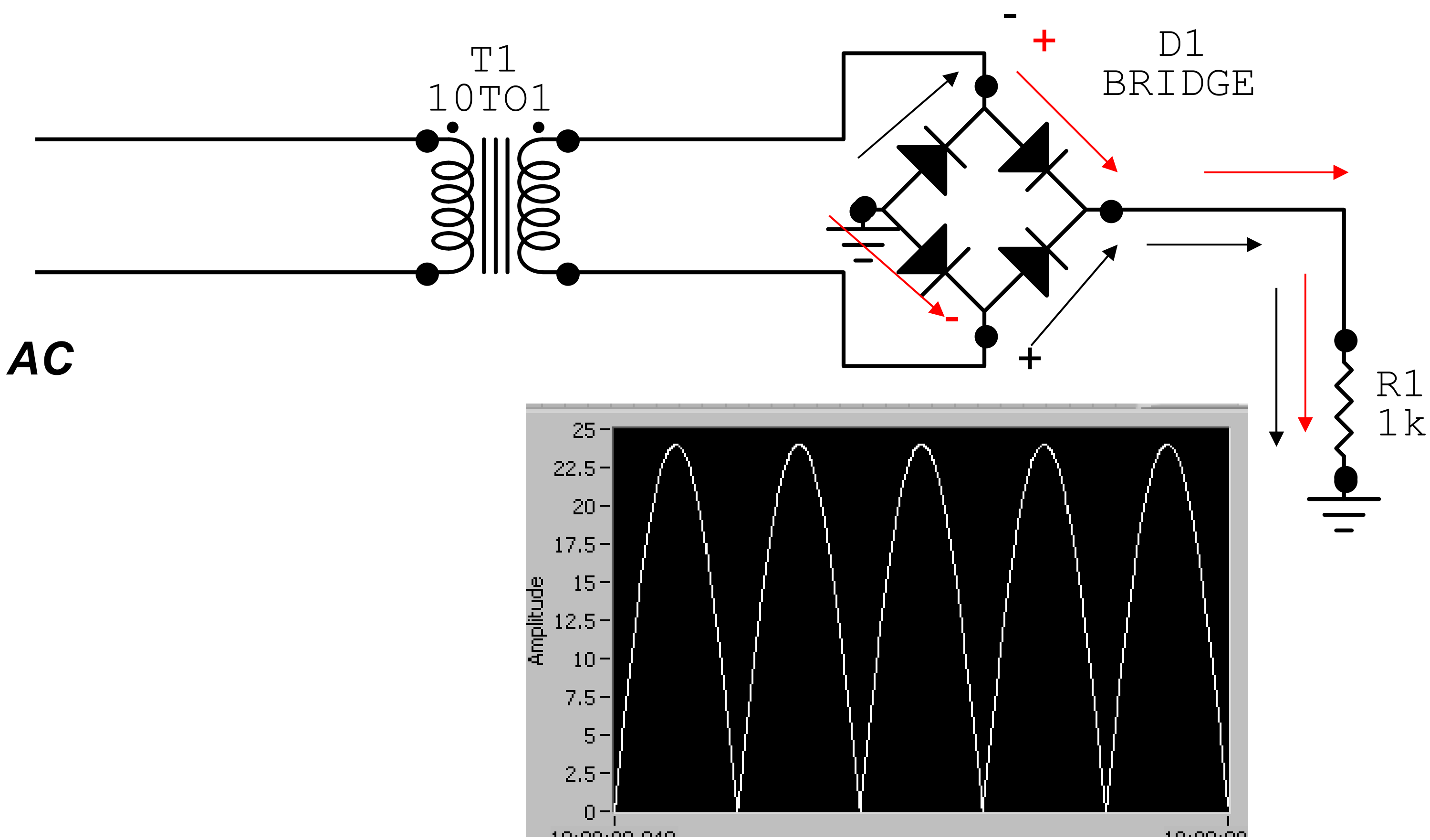
- AC → DC   Converters – Rectification
- DC → AC   Inversion
- DC → DC   Chopping
- AC → AC   AC voltage controller

Diode as a Rectifier of AC current

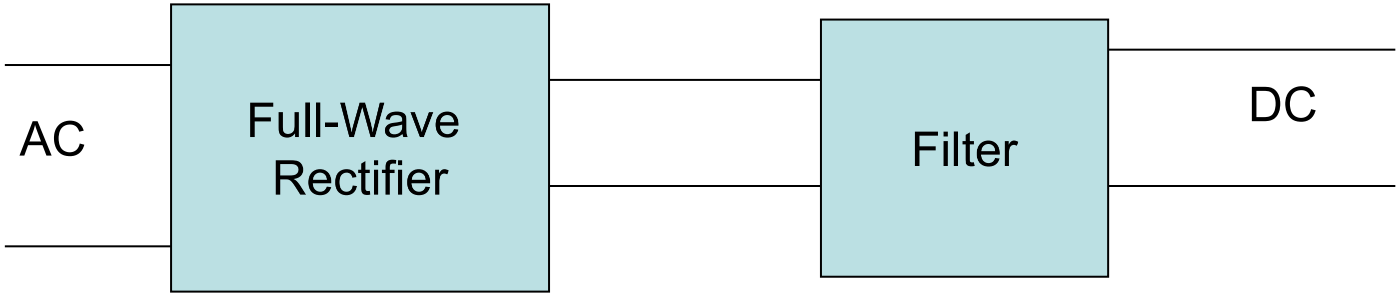


Half-wave rectifier

Full-Wave Bridge Rectifier



DC Filtering



$Vin = A\sin(wt+\theta)$

$Vout = Const$

AC DC Converter With Thyristor

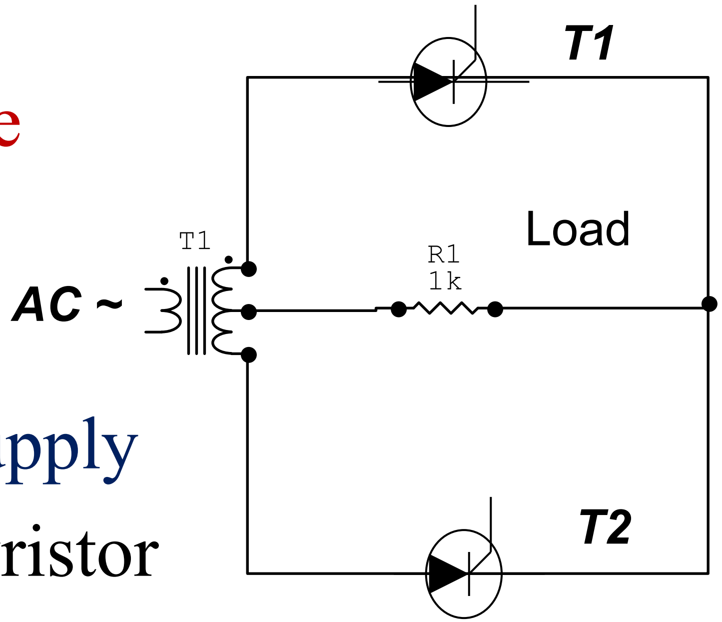
Thyristor can open at any time

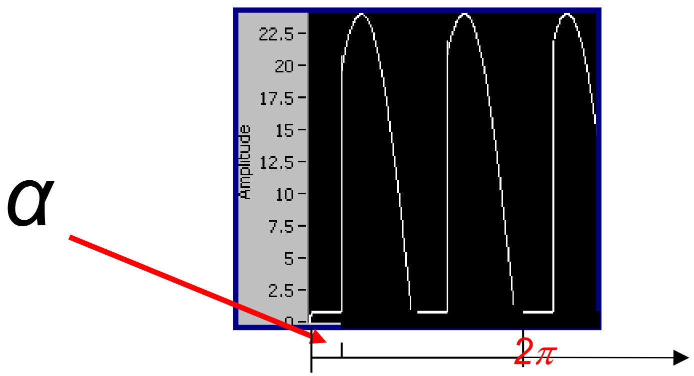
t=[0-T/2]&[T/2-T]

Variable DC output

Used for DC motors power supply

Angle α is firing angle of Thyristor





AC DC Converter With Thyristor

$$
\begin{aligned}
&\boldsymbol{v}_{\boldsymbol{s}}(\boldsymbol{wt}) = 0, && 0 \le \boldsymbol{wt} \le \alpha \\
&\boldsymbol{v}_{\boldsymbol{s}}(\boldsymbol{wt}) = \mathrm{V}_{\mathrm{m}} \sin(\boldsymbol{wt}) && \alpha \le \boldsymbol{wt} \le \pi \\
&\boldsymbol{v}_{\boldsymbol{s}}(\boldsymbol{wt}) = 0, && \pi \le \boldsymbol{wt} \le \pi + \alpha \\
&\boldsymbol{v}_{\boldsymbol{s}}(\boldsymbol{wt}) = -\mathrm{V}_{\mathrm{m}} \sin(\boldsymbol{wt}) && \pi + \alpha \le \boldsymbol{wt} \le 2\pi
\end{aligned}
$$

Calculate Average Voltage, RMS

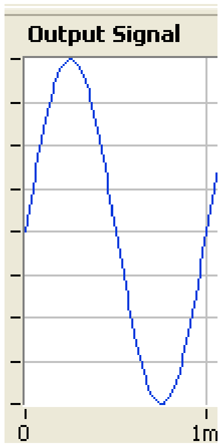
- RMS

$$V_{RMS}^2 = \frac{1}{T}\int_0^T v^2 dt$$

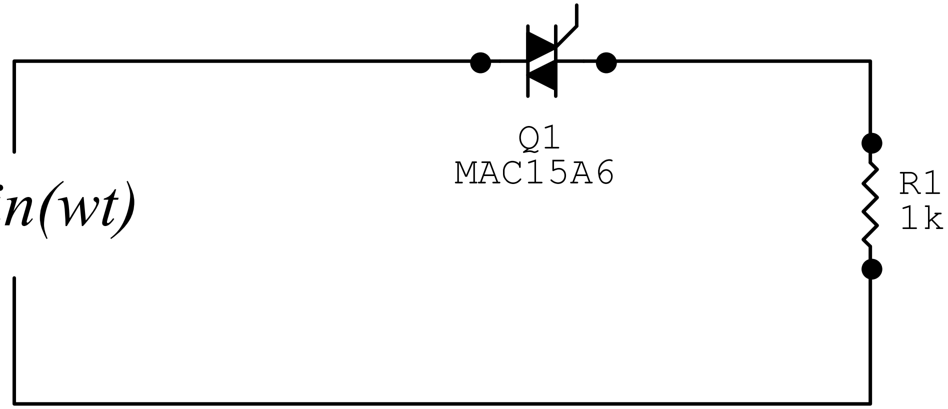
- Average value

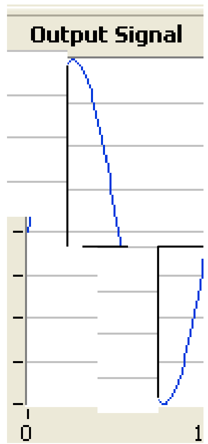
$$V_{av} = \frac{1}{T}\int_0^T v dt$$

AC AC Converter



$v=V_m sin(wt)$





Variable AC from fixed AC
Resulting AC is not pure sinusoid
Bidirectional control of RMS

Alternating Current (AC) Harmonic Waveform => *Alternating Current (AC) Non-harmonic Waveform*

AC AC Converter with Triac

$$\boldsymbol{v_s}(\boldsymbol{wt}) = 0, \qquad 0 \le \boldsymbol{wt} \le \alpha$$

$$\boldsymbol{v_s}(\boldsymbol{wt}) = \mathrm{V_m} \sin(\boldsymbol{wt}) \qquad \alpha \le \boldsymbol{wt} \le \pi$$

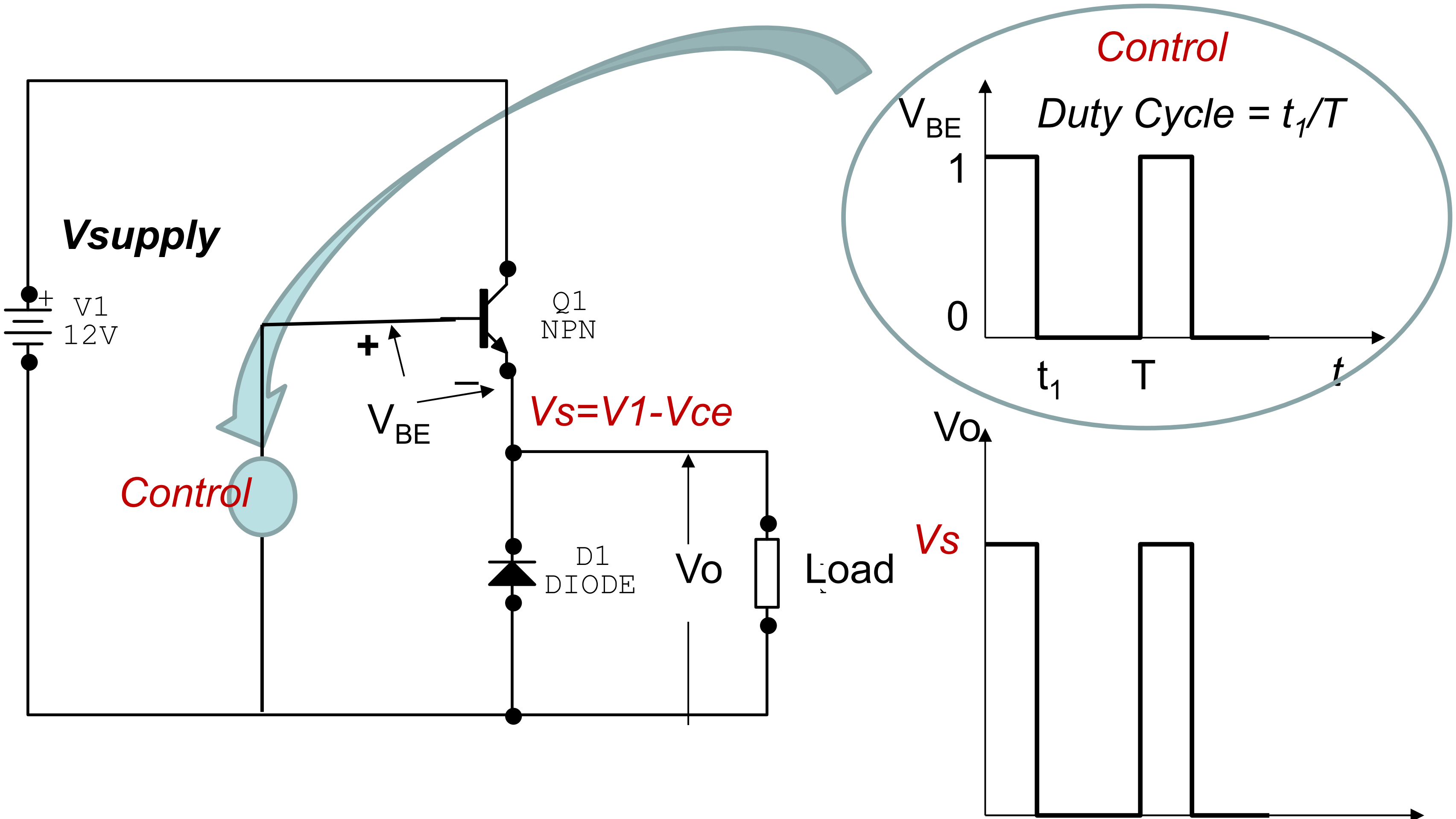
$$\boldsymbol{v_s}(\boldsymbol{wt}) = 0, \qquad \pi \le \boldsymbol{wt} \le \pi + \alpha$$

$$\boldsymbol{v_s}(\boldsymbol{wt}) = \mathrm{V_m} \sin(\boldsymbol{wt}) \qquad \pi + \alpha \le \boldsymbol{wt} \le 2\pi$$

DC DC Converter

- Known as **Chopper**, or **Switching regulator**
- Converts fixed DC source voltage to a variable DC supply, i.e.
- Converts DC source to a variable-duty-cycle output voltage
- Application: **Run DC electric motors used in electric vehicles**

DC DC Converter

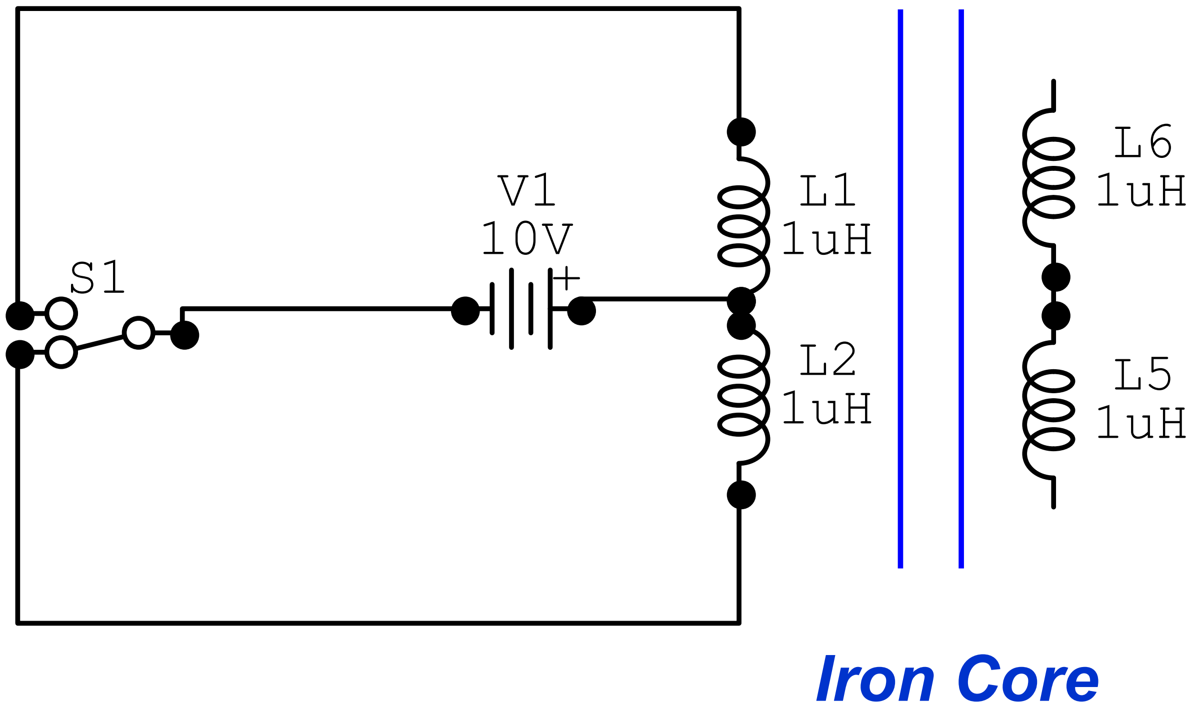


DC to AC, Inversion

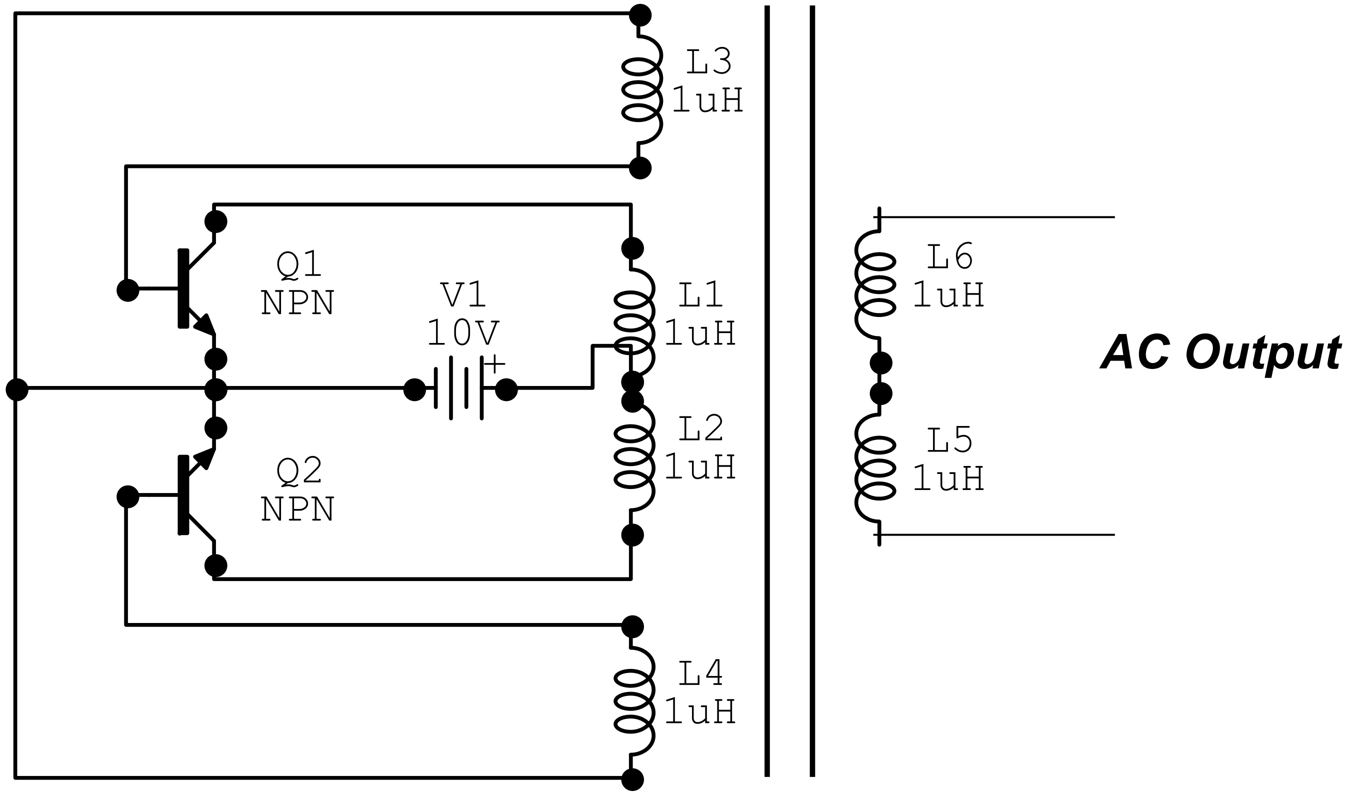
- Battery 12V to 240, 50Hz
- Solar panels
- Fuel cells

- Applications: AC motor control

Inverter
With Electromechanical Switch



Inverter
With an Electronic Switch



Basic Revision 1

Ohm’s law:

Kirchhoff's current law:

Kirchhoff's voltage law:

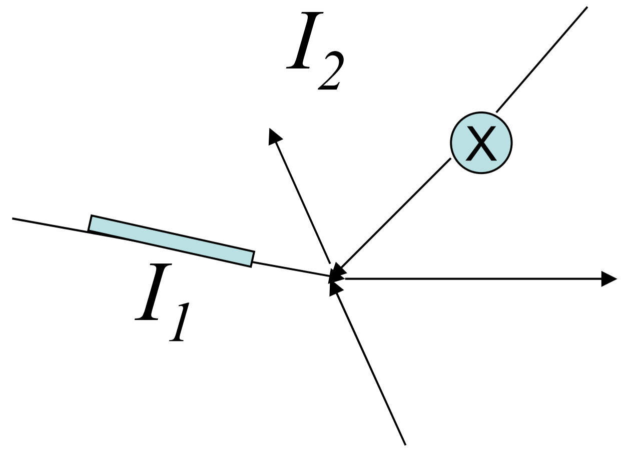
Basic Revision 1

Ohm’s law: $V=R*I$

Basic Revision 1

Kirchhoff's current law:

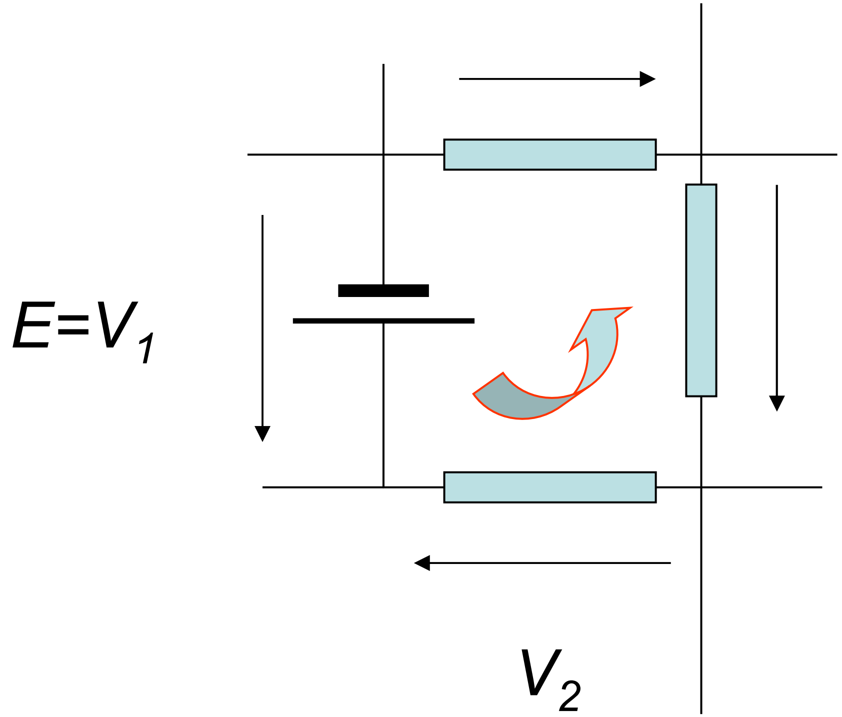
$$\sum_{k=1}^{n} I_k = 0$$



Basic Revision 1

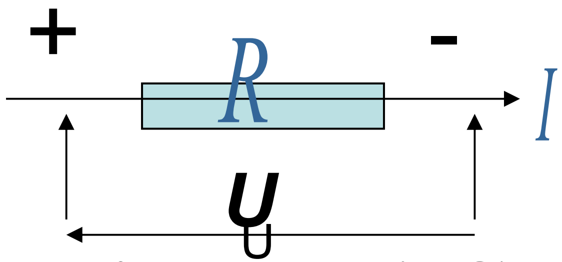
Kirchhoff's voltage law:

$$\sum_{k=1}^{n} V_k = 0$$



Basic Revision 1

Ohm’s law:



Voltage = Resistance * Current

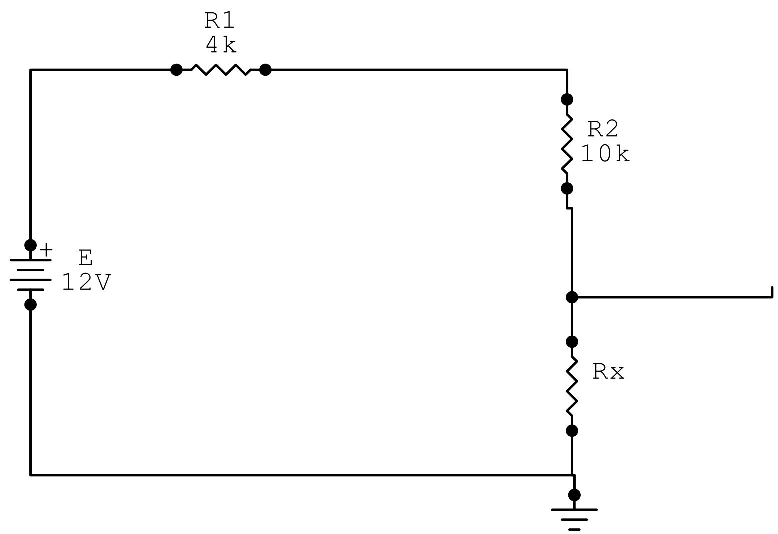
Across Variable = Proportional Element * Through Variable

Find the voltage if I=14mA and R =1kΩ

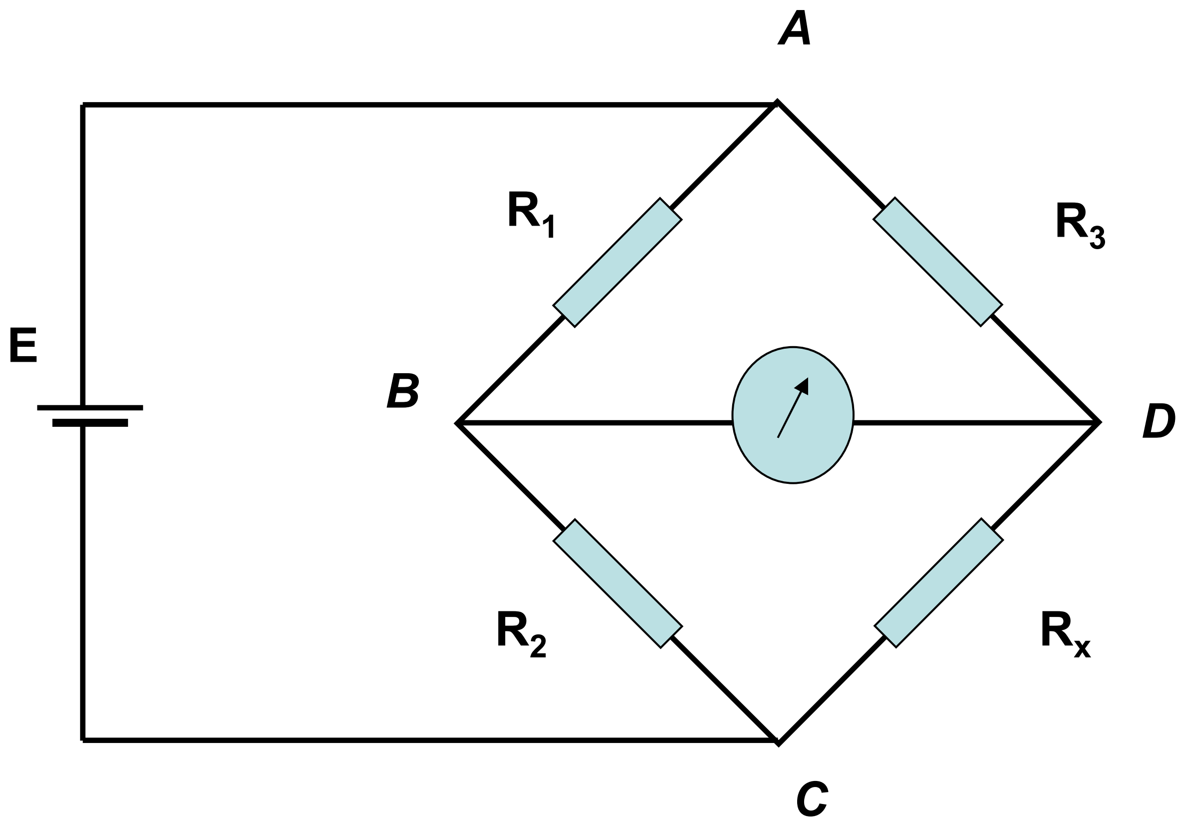
Our resistance is = ?

Basic Revision 2

- What is the value of the resistance Rx, as shown in the Figure 3, if the output voltage is 5V?
- *What is the amount of Power dissipation on the resistor R1, R2, Rx ?*



Question 1



$E=12V$

$R_1=2k$

$R_2=4k$

$R_3=0.5k$

Find

$R_x=?$,

so that

$I_{BD}=0$

How do we call this circuit?

Where is it used?

Question 2

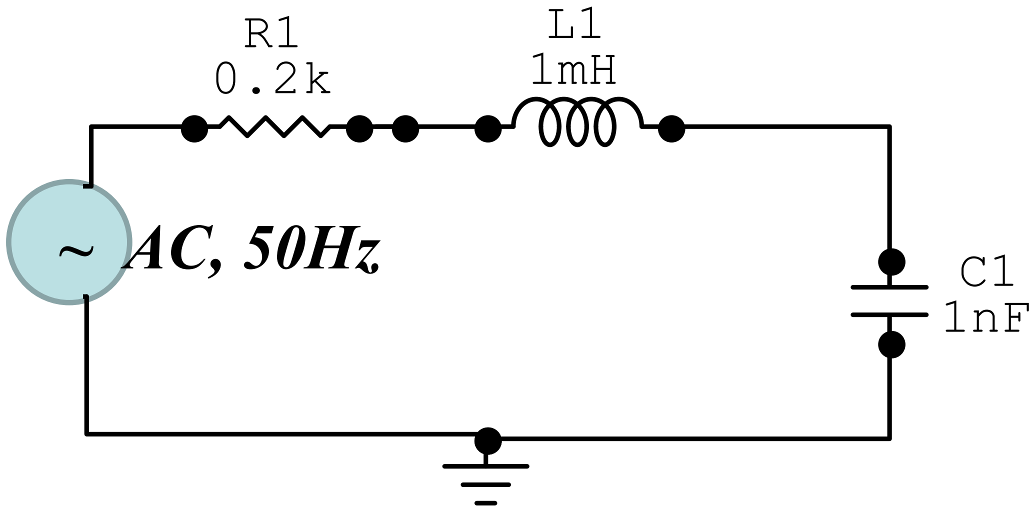
Calculate an AC Circuit Impedance:

Z=? R=200Ω, L=1mH, C=1nF

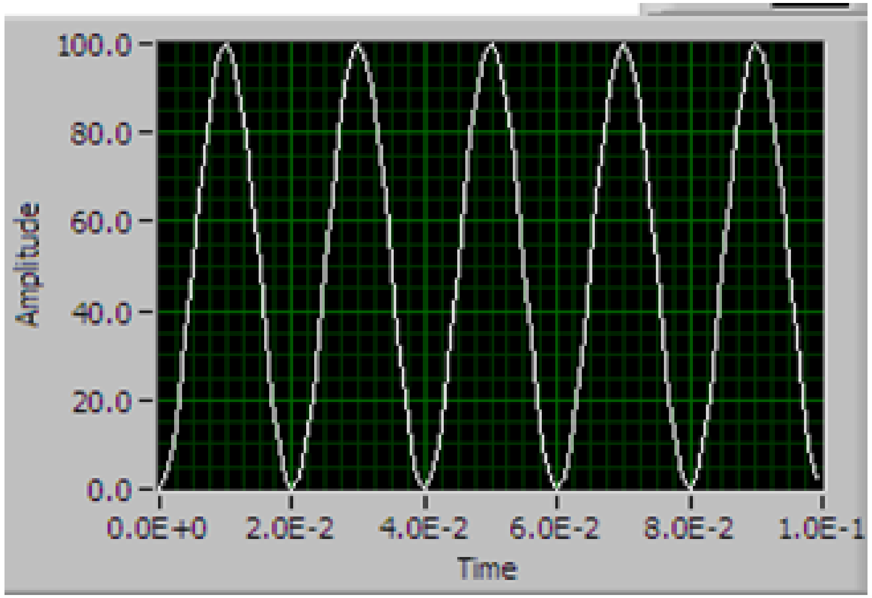
$$Z = R + jwL - j\frac{1}{wC}$$

$$Z = R + j2\pi fL - j\frac{1}{2\pi fC}$$

$$Z = R + j(2\pi fL - \frac{1}{2\pi fC})$$



Question 3



- What are the period and the frequency of the signal waveform?

- What is the average value of the voltage?
- What is RMS value of the voltage waveform?

Amplitude is shown in [V].

1. Write an analytical expression for the shown waveform.

Thank you, Questions