ITMO

Laboratory Work 1
Simple semiconductor device circuits design and simulation

Nikolai Poliakov (polyakov_n_a@itmo.ru)
Arina Arbuzina (arbyzina99@gmail.com)

Summary

1. LT Spice simulation for electronic device analysis
2. Diode parameters analysis
3. Rectifier scheme simulation
4. Capacitor parameter analysis
5. Overvoltage test
6. Starting current test
7. Uploading report to the

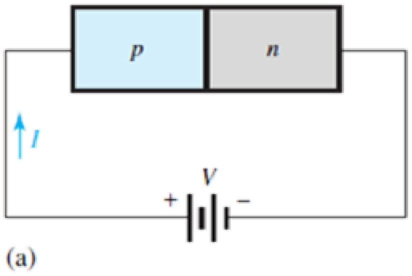
Goal and tasks

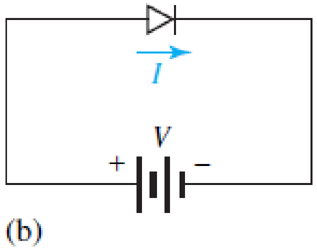
The goal of laboratory work «Simple semiconductor device circuits design and simulation» is to study rectifier scheme on the basis of proposed diode.

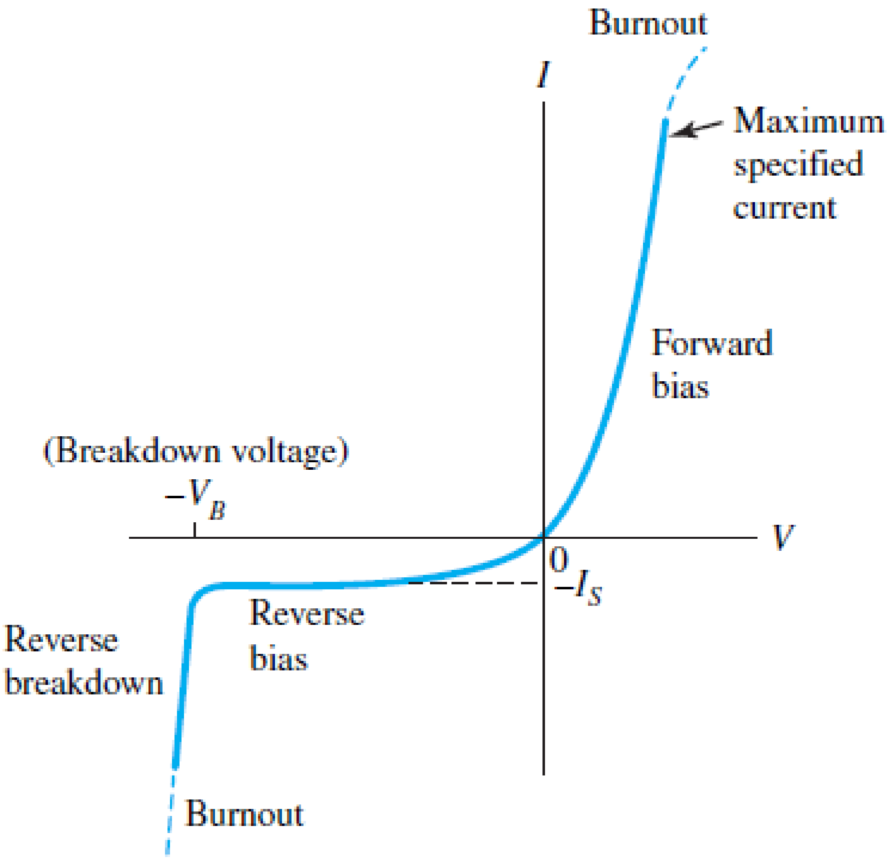
Laboratory work task are:

1. Rectifier scheme simulation
2. Diode parameters analysis
3. Capacitor parameter analysis
4. Overvoltage check
5. Starting current check

pn-junction under external voltage







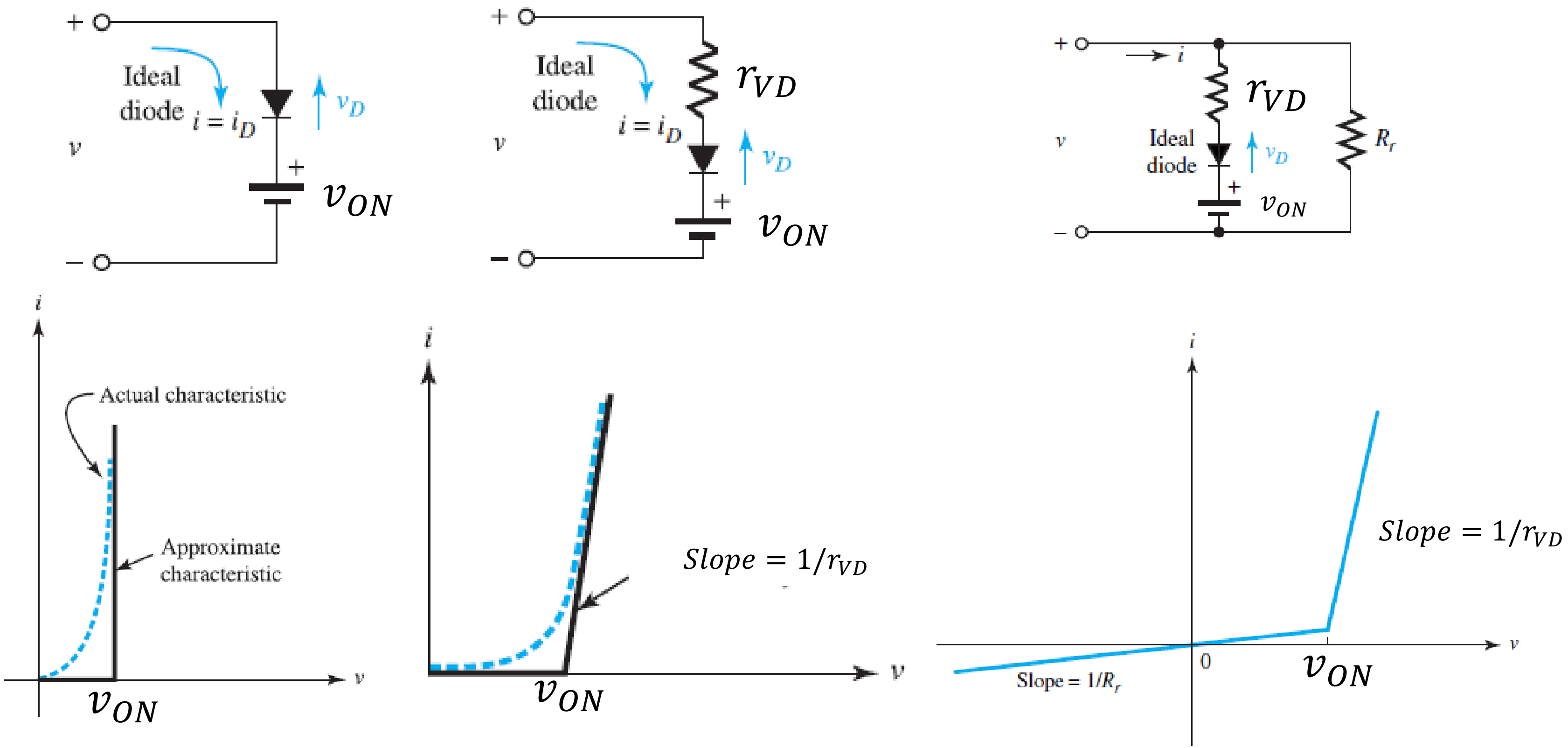
the *Boltzmann diode equation*

$$I = I_S(e^{V/\eta V_T} - 1)$$

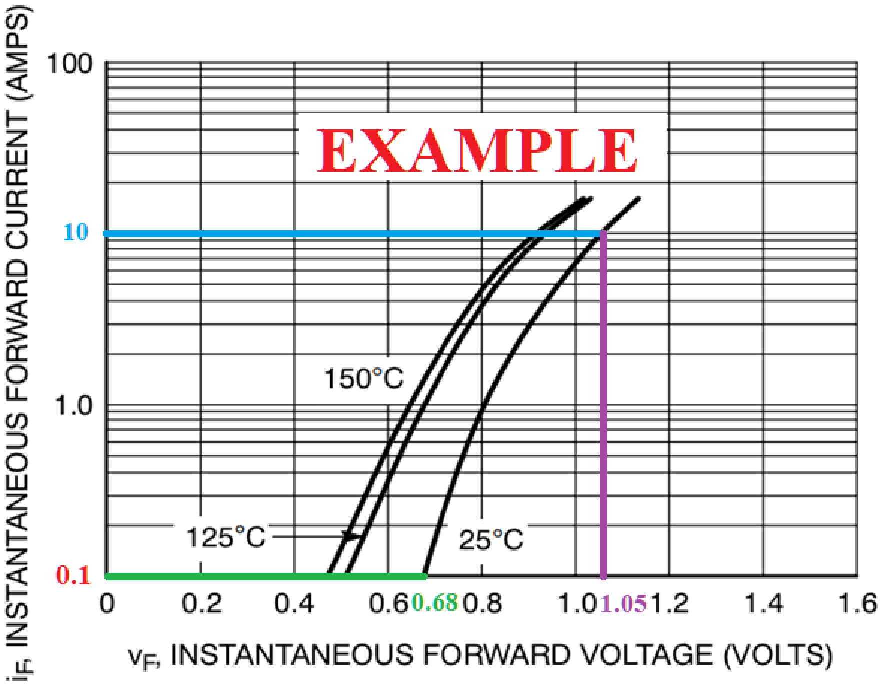
$$V_T = \frac{kT}{q}$$

$$\eta = \begin{cases} 1, \text{for Si} \\ 2, \text{for Ge} \end{cases}$$

Forward-biased diode models



Diode active resistance



Maximum repetitive peak surge forward current

$$I_{fwd\_imp} = 10 \quad \text{(A)}$$

Diode forward bias voltage

$$V_{fwd\_max}\left(I_{fwd\_imp}\right) = 1.05 \quad \text{(V)}$$

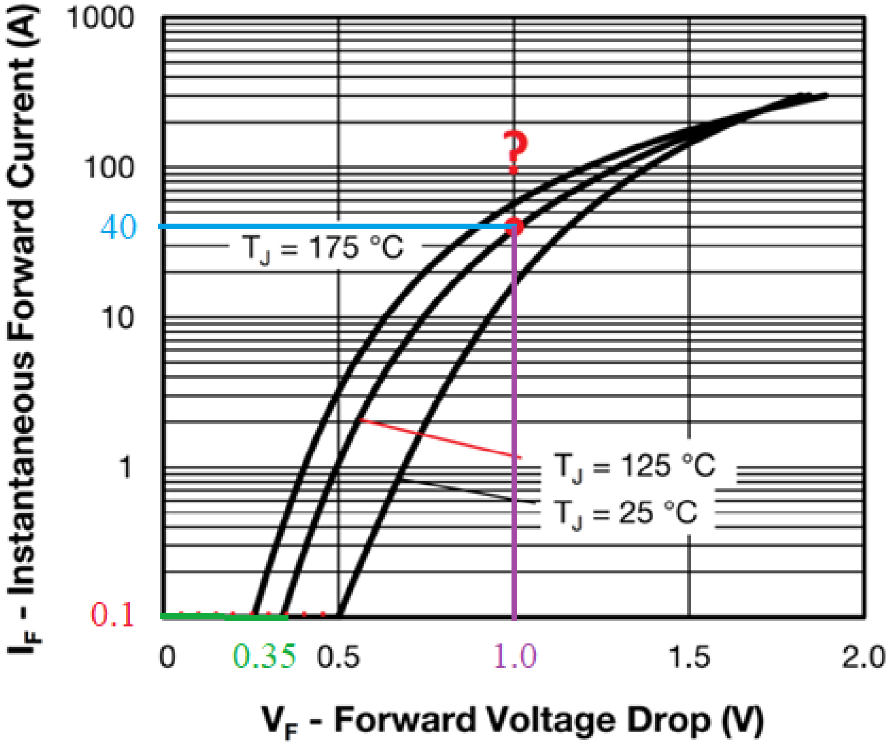
Diode threshold voltage:

$$v_{ON} = 0.68 \quad \text{(V)}$$

Diode active resistance:

$$r_{VD} = \frac{V_{fwd\_max} - v_{ON}}{I_{fwd_{imp}} - I_{fwd}(v_{ON})} = \quad (\Omega)$$

Diode active resistance



Maximum repetitive peak surge forward current

$$I_{fwd\_imp} = 40 \quad \text{(A)}$$

Diode forward bias voltage

$$V_{fwd\_max}\left(I_{fwd\_imp}\right) = 1.0 \quad \text{(V)}$$

Diode threshold voltage:

$$v_{ON} = 0.35 \quad \text{(V)}$$

Diode active resistance:

$$r_{VD} = \frac{V_{fwd\_max} - v_{ON}}{I_{fwd_{imp}} - I_{fwd}(v_{ON})} \quad (\Omega)$$

Diode breakdown

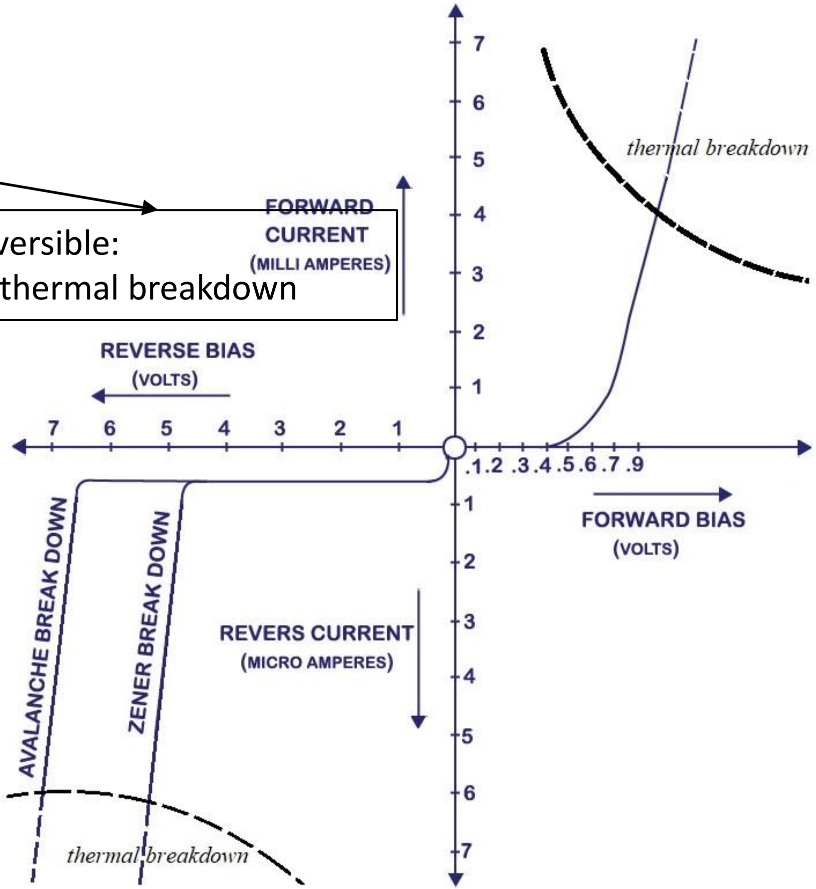
Diode breakdown

Reversible:

- *Zener breakdown* (at low voltages)
- *Avalanche breakdown* (at higher voltages)

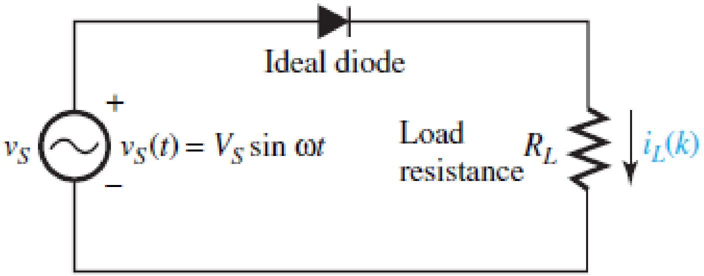
Irreversible:

- thermal breakdown



Zener and Avalanche breakdown find application in stabilitrons.

Half-Wave Rectifier (HWR)



Source voltage $v_s(t)$

$$v_s(t) = V_s \cdot \sin(\mathrm{f} \cdot 2\pi \cdot t) = V_s \cdot \sin(\omega \cdot t)$$

Voltage on the load resistance $\mathrm{R_L}$

$$v_{R_L}(t) = \begin{cases} 0, & if \quad v_s(t) \le 0 \\ v_s(t), & if \quad v_s(t) > 0 \end{cases}$$

Load parameters:

$$V_{R_{L_{AVG}}} = \frac{V_s}{\pi} = \frac{\sqrt{2}V_{S_{RMS}}}{\pi} \approx 0.45 V_{S_{RMS}}$$

$$V_{R_{L\ RMS}} = \frac{V_s}{2} = \frac{V_{S_{RMS}}}{\sqrt{2}} \approx 0.707 V_{S_{RMS}}$$

Average load current

$$I_{L_{AVG}} = \frac{V_{R_{L_{AVG}}}}{\mathrm{R_L}} = \frac{\sqrt{2}V_{S_{RMS}}}{\pi \mathrm{R_L}} \approx 0.45 \frac{V_{S_{RMS}}}{\mathrm{R_L}}$$

RMS load current through diode

$$I_{L_{RMS}} = \frac{V_s}{2\mathrm{R_L}} = \frac{V_{S_{RMS}}}{\sqrt{2}\mathrm{R_L}} \approx 0.707 \frac{V_{R_{L\ RMS}}}{\mathrm{R_L}}$$

Diode parameters:

Average diode current

$$I_{VD_{AVG}} = I_{L_{AVG}} = \frac{\sqrt{2}V_{S_{RMS}}}{\pi \mathrm{R_L}} \approx 0.45 \frac{V_{S_{RMS}}}{\mathrm{R_L}}$$

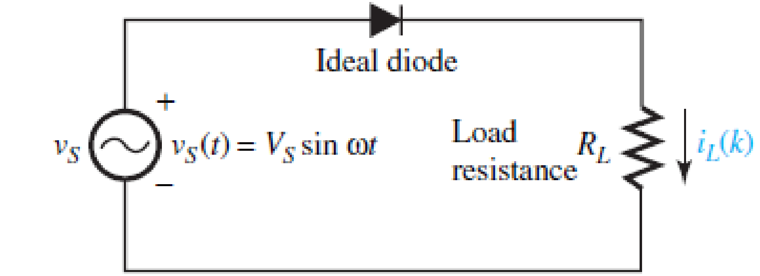
MAX diode current

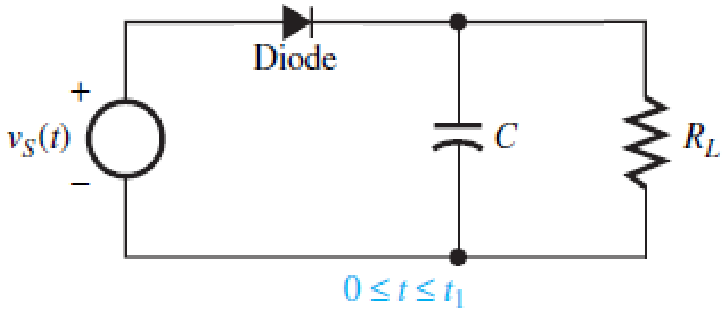
$$I_{VD_{max}} = \frac{V_s}{\mathrm{R_L}}$$

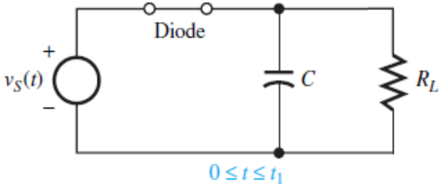
MAX diode reverse voltage

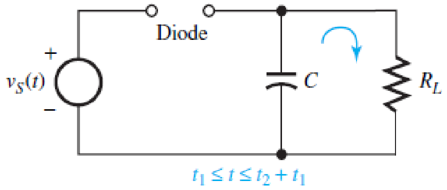
$$V_{VD_{max}} = V_s$$

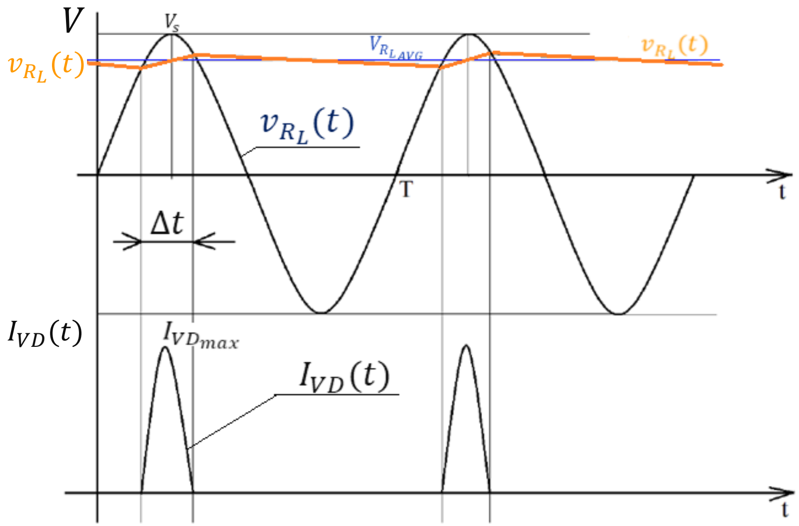
Half-Wave Rectifier with DC filter capacitor

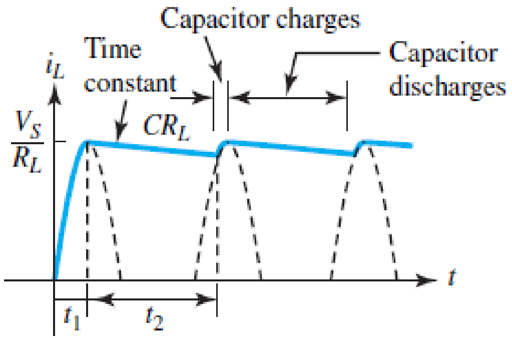












Half-Wave Rectifier with DC filter capacitor

$$v_{R_L}(t) = V_{R_{L\,AVG}} + v_{R_{L\sim}}(t) \approx V_{R_L} = \text{const}$$

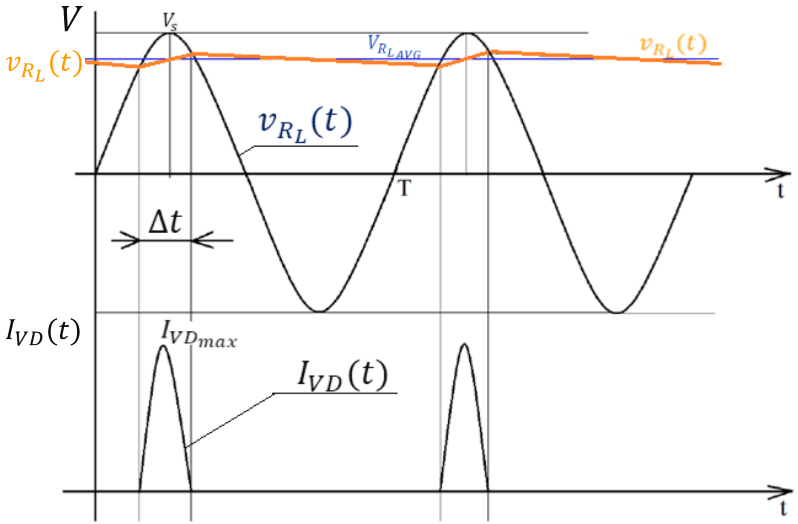
Diode voltage:

$$v_{VD}(t) = v_s(t) - V_{R_{L\,AVG}}$$

Average diode current:

$$I_{L\,AVG} = I_{VD\,AVG} = \frac{1}{T}\sqrt{\int_0^T I_{VD}(t)dt}$$

$$I_{L\,AVG} = \frac{1}{T}\sqrt{\int_{\frac{T}{4}-\theta/(2\cdot\omega)}^{\frac{T}{4}+\theta/(2\cdot\omega)} \frac{1}{r_{IN}}\left(V_s \cdot \sin(\omega \cdot t) - V_{R_{L\,AVG}}\right))dt} = \frac{V_{R_{L\,AVG}}}{\mathrm{R_L}}$$



Where

$r_{IN} = r_{VD} + r_{V_S}$ — input resistance of the rectifier

r_{VD} — diode resistance

r_{V_S} — voltage source resistance

$\theta = \omega \cdot \Delta t = \frac{2\pi}{T} \cdot \Delta t$ — angle of diode open state

Δt — diode open state time interval

$$\frac{V_{R_{L\,AVG}}}{V_S} = \frac{\mathrm{R_L}}{\pi r_{IN}}\left(\sin\left(\frac{\theta}{2}\right) - \frac{V_{R_{L\,AVG}}}{V_S}\frac{\theta}{2}\right)$$

$$V_{VD}\left(\frac{T}{4} \pm \frac{\theta}{2\cdot\omega}\right) = V_S \sin\left(\omega\left(\frac{T}{4} \pm \frac{\theta}{2\cdot\omega}\right)\right) - V_{R_{L\,AVG}} = 0 \Rightarrow V_{R_{L\,AVG}} = V_S\left(\omega\left(\frac{T}{4} \pm \frac{\theta}{2\cdot\omega}\right)\right) = V_S \sin\left(\frac{\pi}{2} \pm \frac{\theta}{2}\right)$$

Half-Wave Rectifier with DC filter capacitor

Average diode current:

$$I_{L_{AVG}} = \frac{1}{T}\sqrt{\int_{\frac{T}{4}-\boldsymbol{\theta}/(2\cdot\omega)}^{\frac{T}{4}+\boldsymbol{\theta}/(2\cdot\omega)} \frac{1}{\boldsymbol{r_{IN}}}(V_s \cdot \sin(\omega\cdot t) - V_{R_{L_{AVG}}}))dt} = \frac{V_{R_{L_{AVG}}}}{\mathrm{R_L}}$$

Where

$\boldsymbol{r_{IN}} = \boldsymbol{r_{VD}} + \boldsymbol{r_{V_S}}$ – input resistance of the rectifier

$\boldsymbol{r_{VD}}$ – diode resistance

$\boldsymbol{r_{V_S}}$ – voltage source resistance

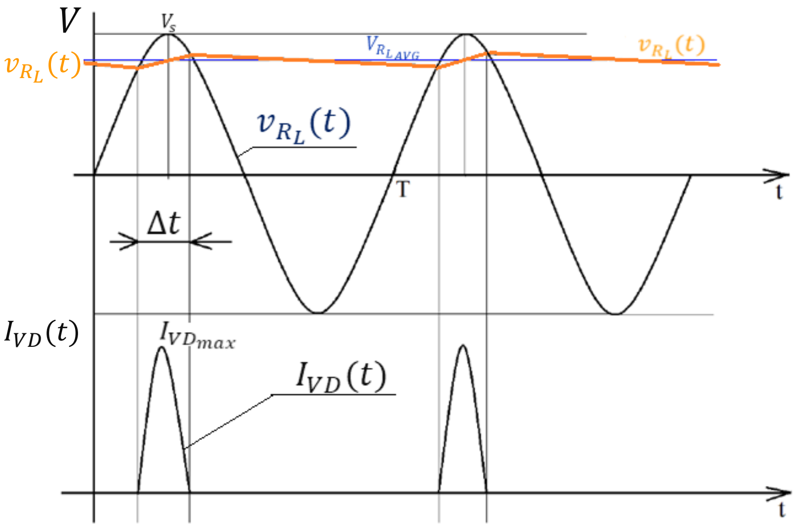
$\boldsymbol{\theta} = \omega\cdot\Delta t = \frac{2\pi}{T}\cdot\Delta t$ – angle of diode open state

Δt – diode open state time interval

$$\frac{V_{R_{L_{AVG}}}}{V_S} = \frac{\mathrm{R_L}}{\pi r_{IN}}\left(\sin\left(\frac{\boldsymbol{\theta}}{2}\right) - \frac{V_{R_{L_{AVG}}}}{V_S}\frac{\boldsymbol{\theta}}{2}\right)$$

$$V_{VD}\left(\frac{T}{4}\pm\frac{\boldsymbol{\theta}}{2\cdot\omega}\right) = V_S\sin\left(\omega\left(\frac{T}{4}\pm\frac{\boldsymbol{\theta}}{2\cdot\omega}\right)\right) - V_{R_{L_{AVG}}} = 0 \Rightarrow V_{R_{L_{AVG}}} = V_S\left(\omega\left(\frac{T}{4}\pm\frac{\boldsymbol{\theta}}{2\cdot\omega}\right)\right) = V_S\sin\left(\frac{\pi}{2}\pm\frac{\boldsymbol{\theta}}{2}\right)$$

$$\frac{V_{R_{L_{AVG}}}}{V_S} = \cos\left(\frac{\boldsymbol{\theta}}{2}\right) \Rightarrow \cos\left(\frac{\boldsymbol{\theta}}{2}\right) = \frac{\mathrm{R_L}}{\pi r_{IN}}\left(\sin\left(\frac{\boldsymbol{\theta}}{2}\right) - \cos\left(\frac{\boldsymbol{\theta}}{2}\right)\cdot\frac{\boldsymbol{\theta}}{2}\right) \Rightarrow \frac{r_{IN}}{\mathrm{R_L}} = \frac{1}{\pi}\left(\tan\left(\frac{\boldsymbol{\theta}}{2}\right) - \frac{\boldsymbol{\theta}}{2}\right)$$



From $\frac{r_{IN}}{\mathrm{R_L}} = \frac{1}{\pi}\left(\tan\left(\frac{\theta}{2}\right) - \frac{\theta}{2}\right)$
angle of diode open state θ can be evaluated:

$$\tan\left(\frac{\theta}{2}\right) \approx \frac{\theta}{2} + \frac{1}{3}\left(\frac{\theta}{2}\right)^3 \Rightarrow \theta = 2 \cdot \sqrt[3]{3\pi \frac{r_{IN}}{\mathrm{R_L}}}$$

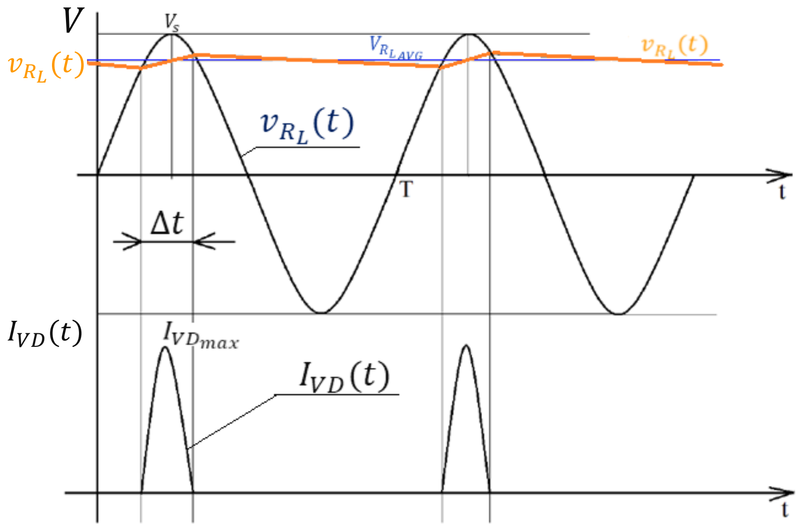
Average load voltage: $V_{R_{L\,AVG}} = V_S \cos\left(\frac{\theta}{2}\right)$

Average load (diode) current: $I_{VD} = \frac{V_S}{\mathrm{R_L}} \cos\left(\frac{\theta}{2}\right)$

Peak (repetitive) diode current: $I_{VD_{max}} = \frac{V_S - V_{R_{L\,AVG}}}{r_{IN}}$

Peak (turn on) diode current: $I_{VD_{ON}} = \frac{V_S}{r_{IN}}$

Diode reverse voltage: $V_{VD_{max}} = V_S + V_{R_{L\,AVG}} \approx 2 \cdot V_S$

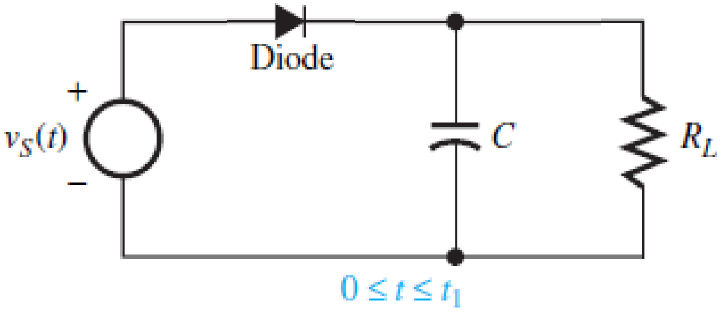


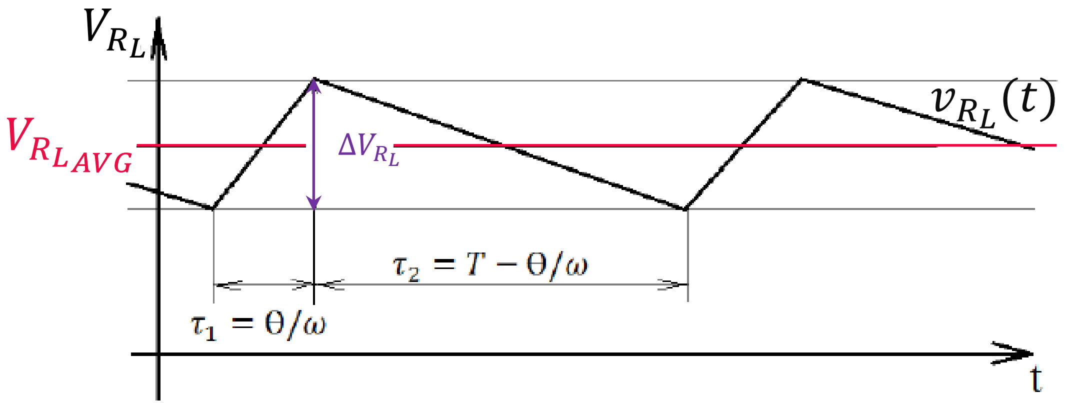
From equation of capacitor charge on the interval of $\tau_1 < t < \tau_2 = T - \frac{\theta}{\omega}$

$$\Delta Q = C \cdot \Delta V_{R_L} = I_{L_{AVG}}\left(T - \frac{\theta}{\omega}\right) \quad \text{(C)}$$

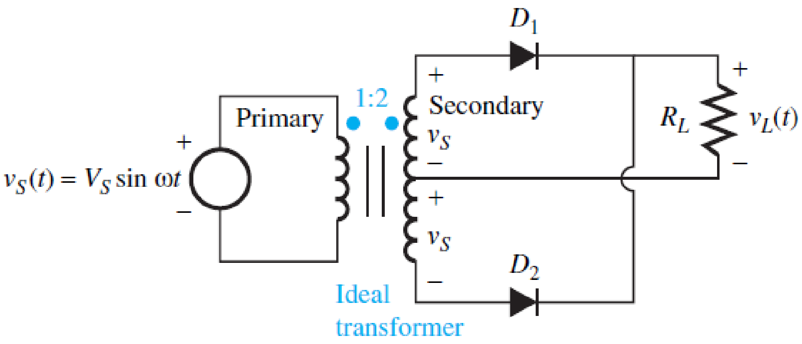
Power filter capacitor evaluation to provide required ripple factor

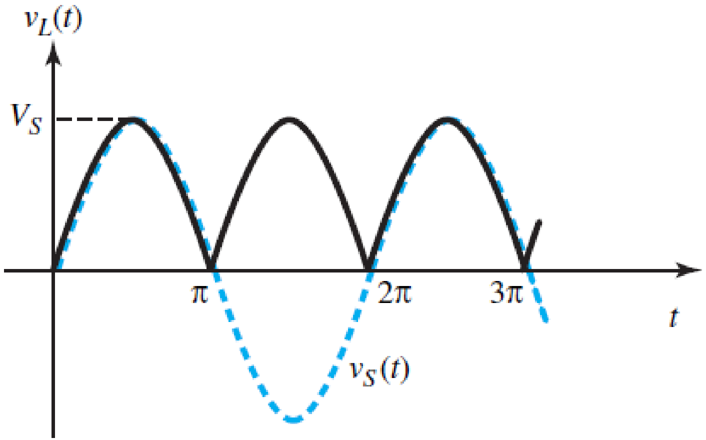
$$C = \frac{I_{L_{AVG}}}{2\pi f \cdot \Delta V_{R_L}}(2\pi - \theta) = \frac{I_{L_{AVG}}}{\omega \cdot \Delta V_{R_L}}(2\pi - \theta) \quad \text{(F)}$$

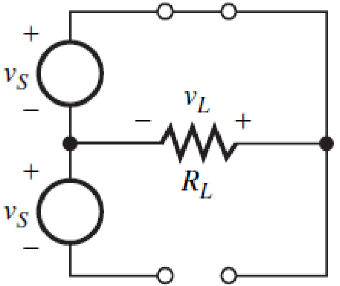




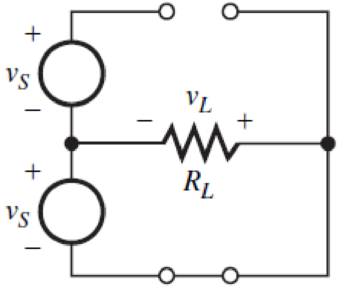
Center-Tap Full Wave Rectifier



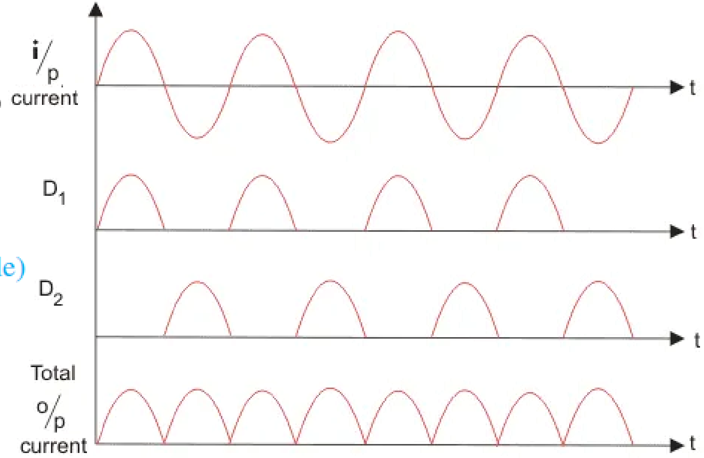




$v_S > 0$ (positive half-cycle)



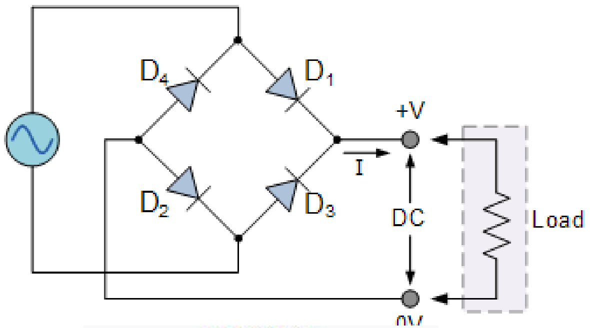
$v_S < 0$ (negative half-cycle)

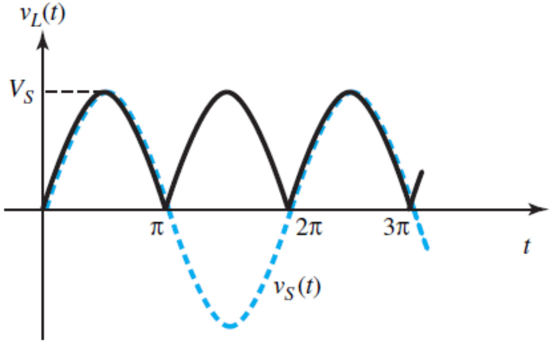


Vladimir Mitkevich

BORN: 22/06/1872 (03. 08. 1872)
in MINSK, (Russian Empire,
now it's the capital of BELARUS)
Death: 01/06/1951
Moscow, Soviet Russia
Worked in Peter the Great
St.Petersburg Polytechnic University

Full Wave Bridge Rectifier

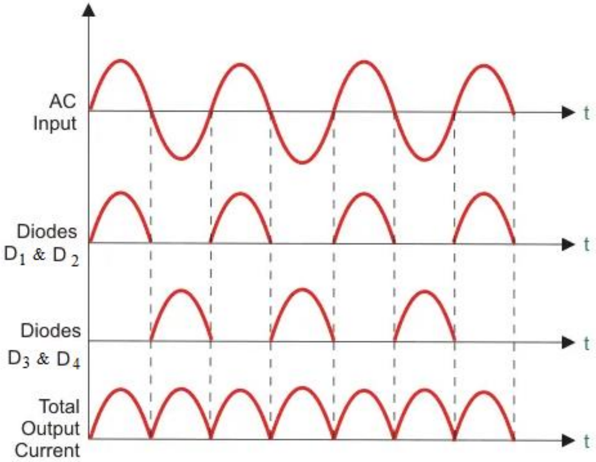


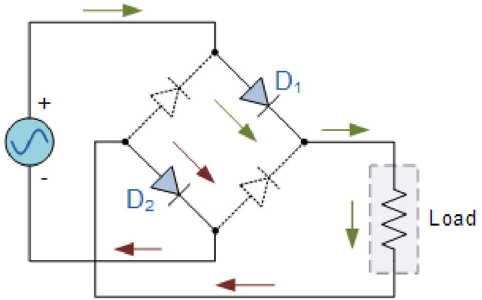


Leo Graetz

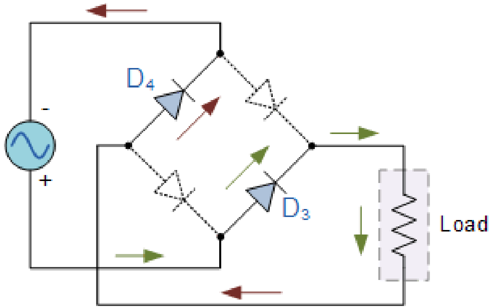
Leo Graetz, painted by Franz von Stuck (1906)

Born	26 September 1856 Breslau, Prussia
Died	12 November 1941 (aged 85) Munich, Nazi Germany
Known for	Graetz number, Diode bridge





The Positive Half-cycle



The Negative Half-cycle

Full-Wave rectifiers (without C-filter)

- **Average load voltage:** $V_{R_{L\,AVG}} = \begin{cases} \frac{V_S}{\pi}, & \text{for } \textbf{HWR} \text{ schemes} \\ \frac{2 \cdot V_S}{\pi}, & \text{for } \textbf{FBR} \text{ or } \textbf{CTR} \text{ schemes} \end{cases}$ (V)

- **RMS load voltage:** $V_{R_{L\,RMS}} = \begin{cases} \frac{V_S}{2}, & \text{for } \textbf{HWR} \text{ schemes} \\ \frac{V_S}{\sqrt{2}}, & \text{for } \textbf{FBR} \text{ or } \textbf{CTR} \text{ schemes} \end{cases}$ (V)

- **Max peak diode reverse voltage:** $V_{VD_{max}} = V_{VD_{max}} = \begin{cases} 2V_S & \text{for CTR scheme} \\ V_S, & \text{for HWR and FBR schemes} \end{cases}$ (V)

- **Average load current:** $I_{L\,AVG} = \frac{V_{R_{L\,AVG}}}{R_L} = \begin{cases} \frac{V_S}{\pi R_L}, & \text{for } \textbf{HWR} \text{ schemes} \\ \frac{2 \cdot V_S}{\pi R_L}, & \text{for } \textbf{FBR} \text{ or } \textbf{CTR} \text{ schemes} \end{cases}$ (A)

- **RMS load current:** $I_{L\,RMS} = \frac{V_{R_{L\,RMS}}}{R_L} = \begin{cases} \frac{V_S}{2R_L}, & \text{for } \textbf{HWR} \text{ schemes} \\ \frac{V_S}{\sqrt{2}R_L}, & \text{for } \textbf{FBR} \text{ or } \textbf{CTR} \text{ schemes} \end{cases}$ (A)

Full-Wave rectifiers (without C-filter)

- **Average diode rectified output current:** $I_{VD} = \begin{cases} I_{L_{AVG}}, & \text{for } \mathbf{HWR} \text{ schemes} \\ \dfrac{I_{L_{AVG}}}{2}, & \text{for } \mathbf{FBR} \text{ or } \mathbf{CTR} \text{ schemes} \end{cases}$ (A)

- **Peak repetitive forward output current:** $I_{VD_{max}} = \begin{cases} \dfrac{V_S}{R_L}, & \text{for } \mathbf{HWR} \text{ schemes} \\ \dfrac{V_S}{2R_L}, & \text{for } \mathbf{FBR} \text{ or } \mathbf{CTR} \text{ schemes} \end{cases}$ (A)

- **Voltage ripple factor:** $K_p = \sqrt{\left(\dfrac{V_{R_{LRMS}}}{V_{R_{LAVG}}}\right)^2 - 1} = \begin{cases} \sqrt{\left(\dfrac{\pi}{2}\right)^2 - 1} \approx 1.21, & \text{for } \mathbf{HWR} \text{ schemes} \\ \sqrt{\left(\dfrac{\pi}{2\cdot\sqrt{2}}\right)^2 - 1} \approx 0.48 & \text{for } \mathbf{FBR} \text{ or } \mathbf{CTR} \text{ schemes} \end{cases}$

Full-Wave rectifiers (with C-filter)

- **Source output resistance (overcurrent protection):** $r_{on} = \frac{V_S}{I_{FSM}}$ (Ω)

- **Input rectifier resistance:** $r_{IN} = \begin{cases} r_{vd} + r_{V_S}, & \text{for HWR } \textit{or} \text{ CTR schemes} \\ 2 \cdot r_{vd} + r_{V_S}, & \text{for FBR schemes} \end{cases}$ (Ω)

- **Diode opening state angle:** $\theta = \begin{cases} 2 \cdot \sqrt[3]{3 \cdot \pi \cdot \frac{r_{IN}}{R_L}}, & \text{for HWR schemes} \\ 2 \cdot \sqrt[3]{\frac{3}{2} \cdot \pi \cdot \frac{r_{IN}}{R_L}}, & \text{for FBR or CTR schemes} \end{cases}$ (rad)

- **Average load voltage** $V_{R_{LAVG}} = V_S \cdot \cos\left(\frac{\theta}{2}\right) = \begin{cases} V_S \cdot \cos\left(\sqrt[3]{3 \cdot \pi \cdot \frac{r_{IN}}{R_L}}\right), & \text{for HWR schemes} \\ V_S \cdot \cos\left(\sqrt[3]{\frac{3}{2} \cdot \pi \cdot \frac{r_{IN}}{R_L}}\right), & \text{for FBR or CTR schemes} \end{cases}$ (V)

- **Average load current:** $I_{L_{AVG}} = \begin{cases} \frac{1}{\pi \cdot r_{IN}} \left(V_S \cdot \sin\left(\frac{\theta}{2}\right) - V_{R_{LAVG}} \cdot \frac{\theta}{2}\right), & \text{for HWR schemes} \\ \frac{2}{\pi \cdot r_{IN}} \left(V_S \cdot \sin\left(\frac{\theta}{2}\right) - V_{R_{LAVG}} \cdot \frac{\theta}{2}\right), & \text{for FBR or CTR schemes} \end{cases}$ (A)

Full-Wave rectifiers (with C-filter)

- **Average diode current:** $$I_{VD} = \begin{cases} \frac{V_S}{R_L} \cdot \cos\left(\frac{\theta}{2}\right) = \frac{V_S}{R_L} \cdot \cos\left(\sqrt[3]{3 \cdot \pi \cdot \frac{r_{IN}}{R_L}}\right), & \text{for HWR schemes} \\ \frac{V_S}{2 \cdot R_L} \cdot \cos\left(\frac{\theta}{2}\right) = \frac{V_S}{2 \cdot R_L} \cdot \cos\left(\sqrt[3]{\frac{3}{2} \cdot \pi \cdot \frac{r_{IN}}{R_L}}\right), & \text{for FBR or CTR schemes} \end{cases}$$ (A)

- **Maximum repetitive rectifier scheme diode current:** $$I_{VD_{max}} = \frac{V_S - V_{R_{LAVG}}}{r_{IN}}$$ (A)

- **Starting (Non-repetitive) maximum peak surge diode current in rectifier scheme:** $$I_{VD_{ON}} = \frac{V_S}{r_{IN}}$$ (A)

- **Peak repetitive reverse voltage:** $$V_{VD_{max}} = \begin{cases} V_S + V_{R_{LAVG}}, & \text{for HWR or CTR schemes} \\ \frac{V_S + V_{R_{LAVG}}}{2}, & \text{for FBR schemes} \end{cases}$$ (V)

- **Capacitance evaluation:** $$C = \begin{cases} \frac{I_{LAVG}}{2\pi f \cdot \Delta V_{R_L}} (2\pi - \theta), & \text{for HWR schemes} \\ \frac{I_{LAVG}}{2\pi f \cdot \Delta V_{R_L}} (\pi - \theta), & \text{for FBR or CTR schemes} \end{cases}$$ (F)

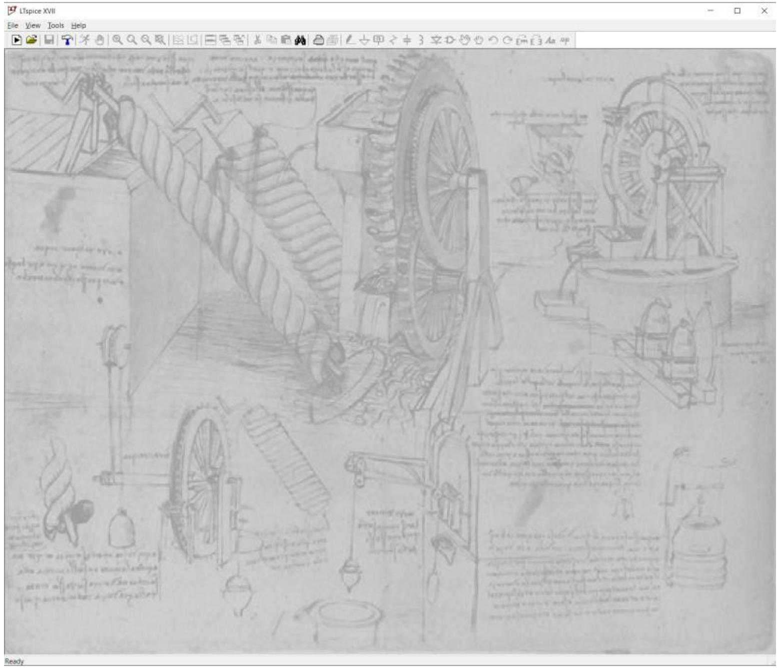
- **Voltage ripple:** $$\Delta V_{R_L} = \begin{cases} \frac{I_{LAVG}}{2\pi f \cdot C} (2\pi - \theta), & \text{for HWR schemes} \\ \frac{I_{LAVG}}{2\pi f \cdot C} (\pi - \theta), & \text{for FBR or CTR schemes} \end{cases}$$ (V)

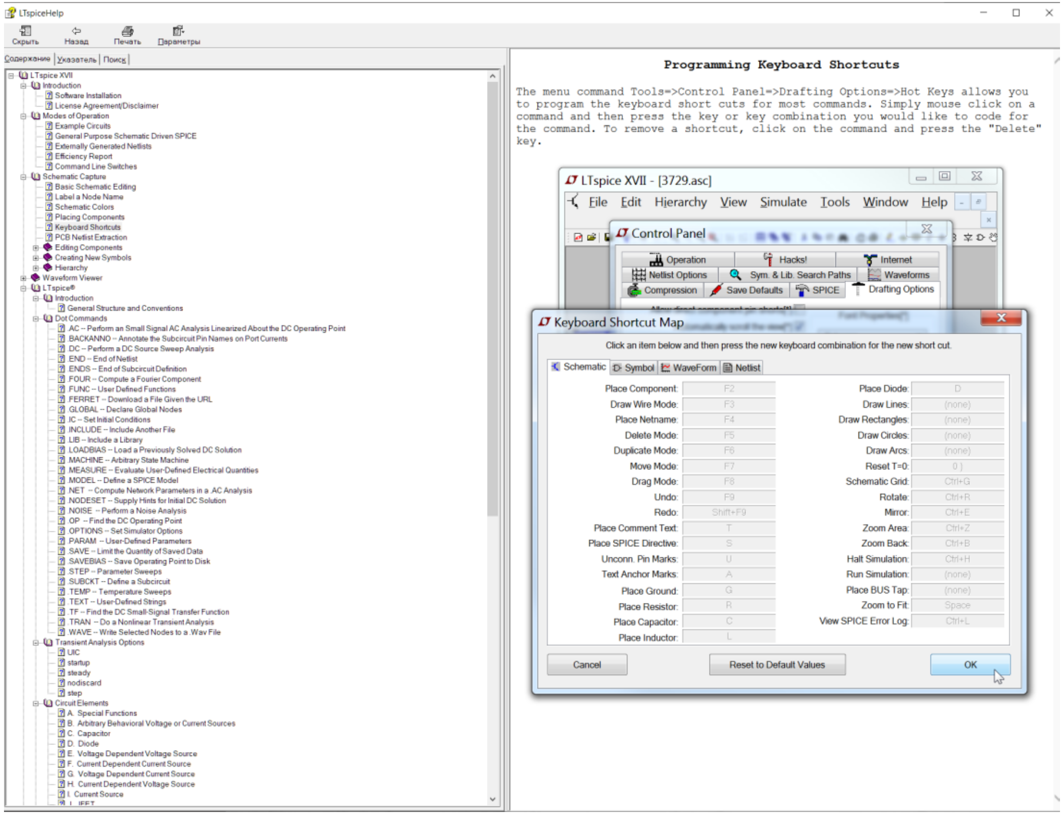
- **Voltage ripple factor** $$K_p = \sqrt{\left(\frac{V_{R_{LRMS}}}{V_{R_{LAVG}}}\right)^2 - 1}$$

Evaluations

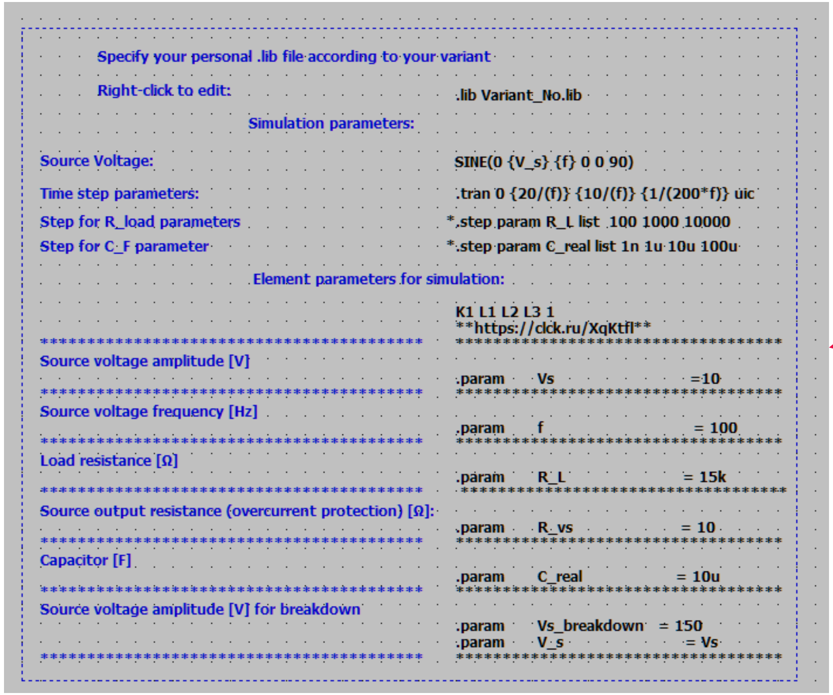
	$I_{VD_{AVG}}$	$I_{VD_{max}}$	$V_{VD_{max}}$	r_{IN}
Half - Wave rectifier (HWR)	$= I_{L_{AVG}}$	$\approx 7I_{L_{AVG}}$	$= V_S \cdot 2 \approx 3V_{R_{L_{AVG}}}$	$= r_{VD} + r_{V_s}$
Central Tap Rectifier (CTR)	$= \frac{I_{L_{AVG}}}{2}$	$\approx 3.5I_{L_{AVG}}$	$= V_S \cdot 2 \approx 3V_{R_{L_{AVG}}}$	$= r_{VD} + r_{V_s}$
Full bridge (Graetz) rectifier (FBR)	$= \frac{I_{L_{AVG}}}{2}$	$\approx 3.5I_{L_{AVG}}$	$= V_S \approx 1.5V_{R_{L_{AVG}}}$	$=2r_{VD} + r_{V_s}$

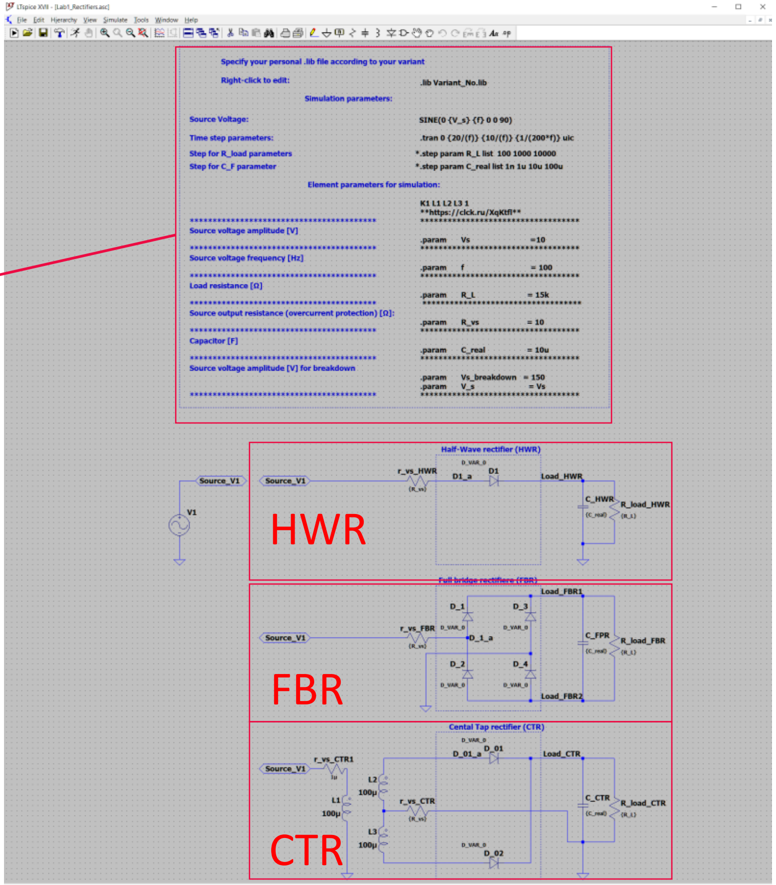
Step One: LT Spice XVII start





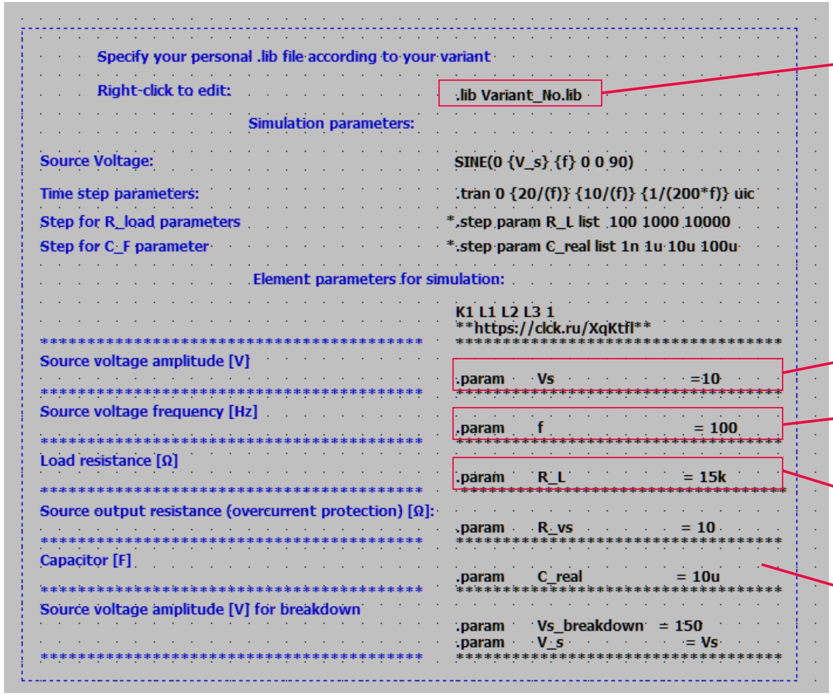
Step Two: Lab1_Rectifiers.asc





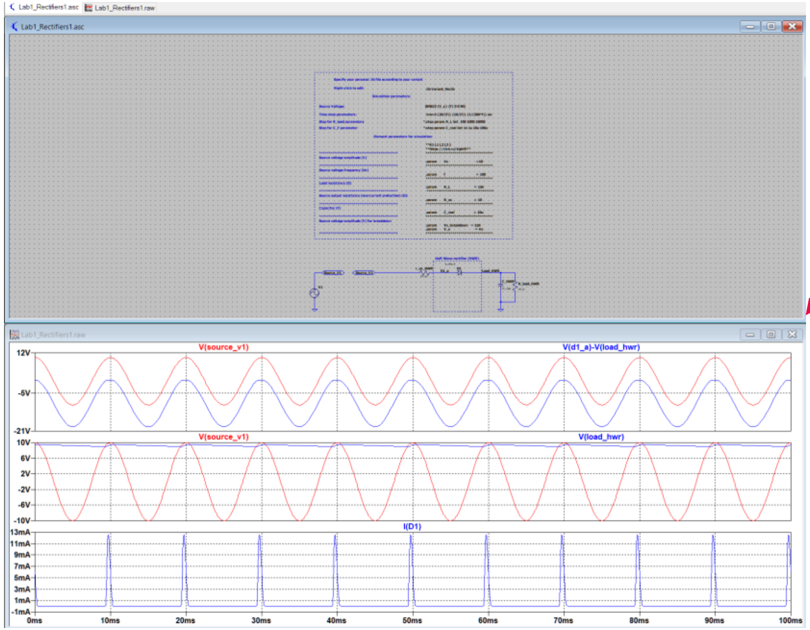
You should delete all rectifier schemes which are not your variant from template

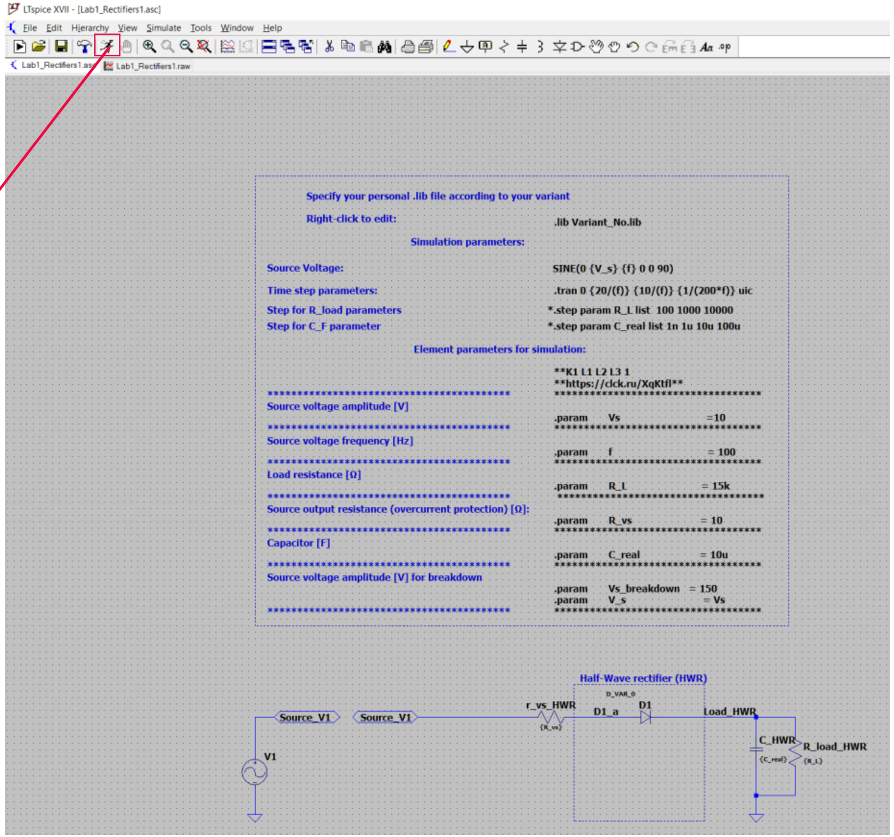
Step Three: Variant data



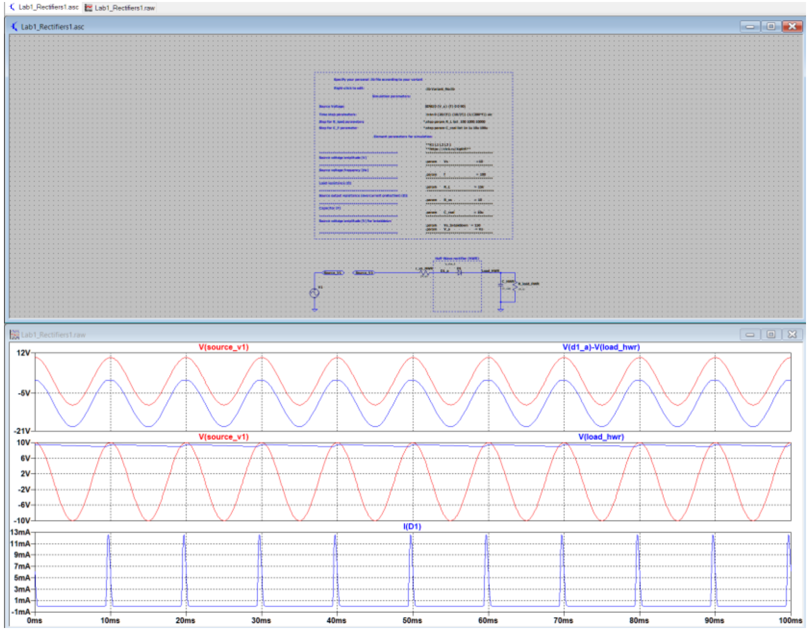
	Rectifier scheme	Source voltage amplitude, [V]	Load resistance, [Ω]	Capacitor value [μF]	Source voltage frequency, [Hz]
Variant #	HWR-half-wave rectifier, CTR-centrtal tap rectifier, FBR - full bridge rectifier	V_s	R_L	C_{real}	f

Step Four: Simulation





Step Five: Results



LABORATORY WORK REPORT №1 2

1. Work purpose: to study parameters of semiconductor elements and basis of the semiconductor device design

Goals:
1) Design rectifier model on the basis of diode «diode name»
2) Simulate rectifier scheme and analyze dependencies of DC voltage ripple from load and filter capacitor values variation
3) Simulate overvoltage and overcurrent states (optional)

2. Starting data

2.1.1. Parameters of the voltage source:

- One-phase sine voltage source
- Rectifier scheme: Half-Wave Rectifier (HWR) /Central tap rectifier (CTR) /Full -Bridge rectifier (FBR)
- Source voltage amplitude

$V_s =$ (V)

- Source voltage frequency

f= (Hz)

2.1.2. Diode: (copy the 1stand the second line of .lib file of your variant)

2.1.3. Required parameters of DC output:

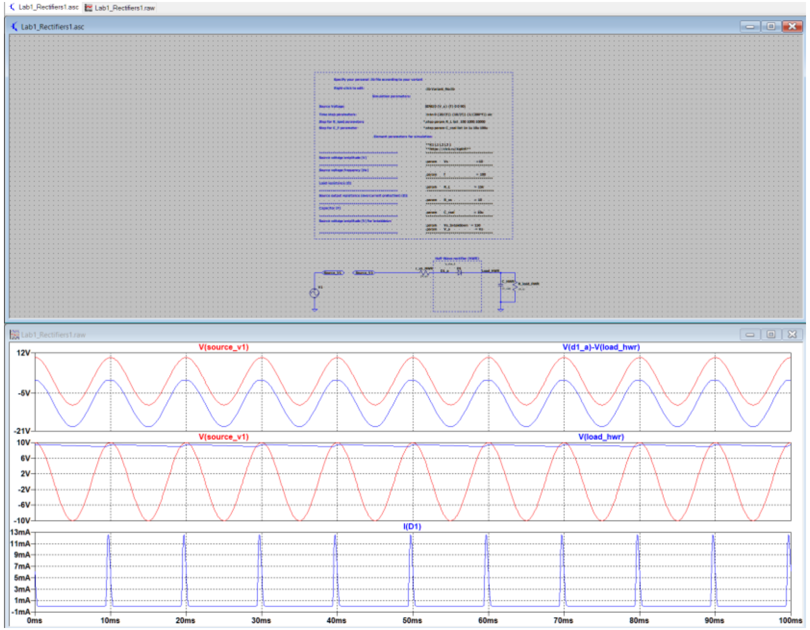
- Load resistance:

$R_L = R_{LOAD\_HWR/CTR/FBR} =$ (V)

- Desired DC voltage ripple factor:

$K_n =$.

Step Five: Results



3. Simulation report

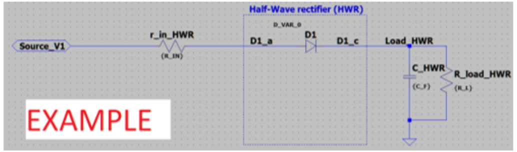


Fig. 3.1 – Rectifier scheme model

3.1.1. Filter parameters:

— C_{real} = 470____________________(uF)

3.1.2. Load parameters:

— $R_L = R_{LOAD\_HWR}$ = 667____________________(Ω)

— $V_{R_{L_{AVG}}}$ = 23.676V____________________(V)

— $V_{R_{L_{RMS}}}$ = 23.679V____________________(V)

— $K_p = K_p = \frac{\Delta V_{R_L}}{2V_{R_{L\,AVG}}} =$ ____________________

— $I_{VD_{ON}}$ = ____________________(A)

— $I_{VD_{max}}$ = ____________________(A)

— ΔV_{R_L} = ____________________(V)

3.2. Simulation results

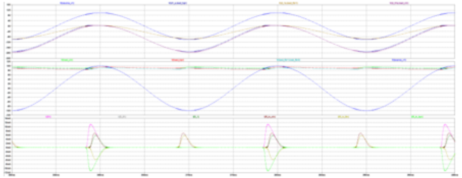
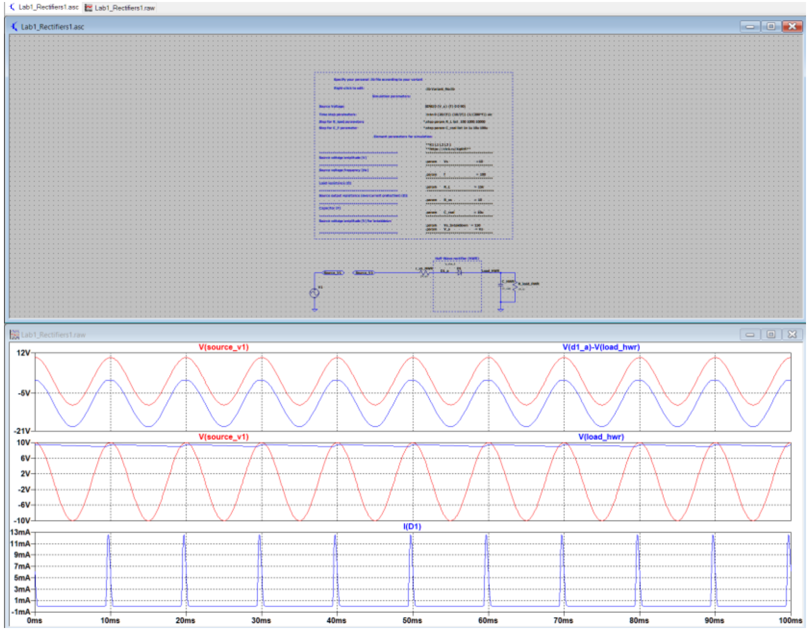
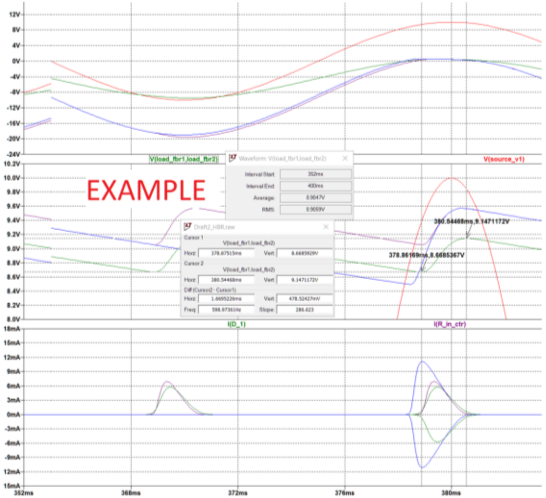


Fig 3.2 – Simulation results

Step Five: Results



$$K_p = \gamma = \sqrt[2]{\left(\frac{V_{S_{RMS}}}{V_{R_{L_{AVG}}}}\right)^2 - 1}$$



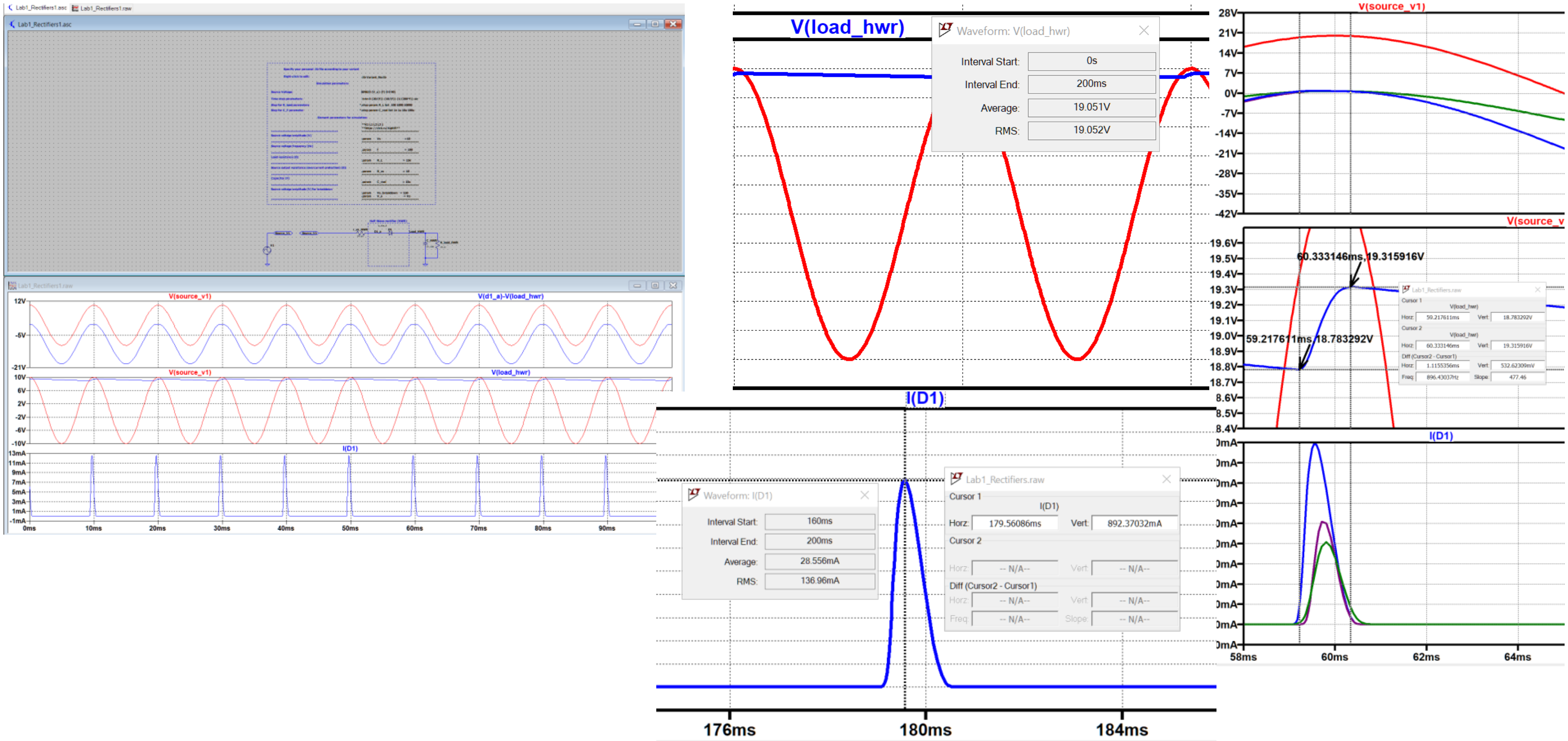
b) Full-bridge rectifier

Fig 3.3 –Voltage ripple analysis

To define Average and RMS values use CTRL+left click mouse button on the signal name. **Use 2-3 Voltage periods in the end of simulation interval**

Right-click with mouse on the signal name gives access to the signal cursor

Step Five: Results



Theta issues

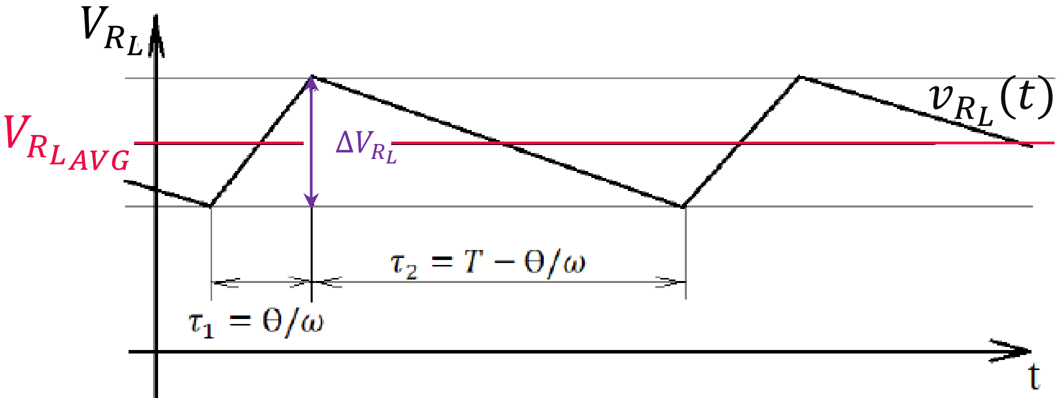
From equation of capacitor charge on the interval of $\tau_1 < t < \tau_2 = T - \frac{\theta}{\omega}$

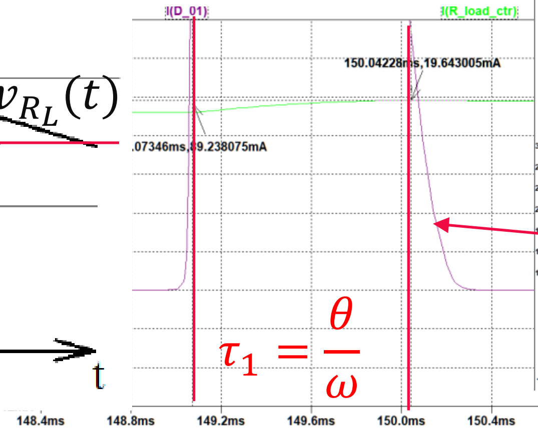
Capacitance evaluation:

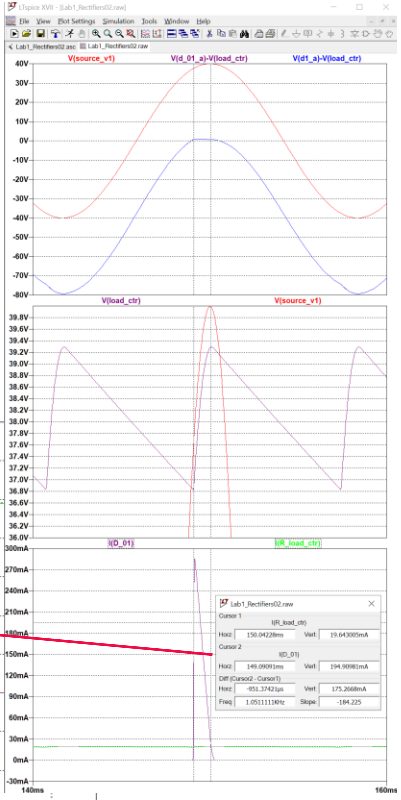
$$C = \begin{cases} \dfrac{I_{L_{AVG}}}{2\pi f \cdot \Delta V_{R_L}}(2\pi - \theta), & \text{for HWR schemes} \\ \dfrac{I_{L_{AVG}}}{2\pi f \cdot \Delta V_{R_L}}(\pi - \theta), & \text{for FBR or CTR schemes} \end{cases} \quad \text{(F)}$$

Voltage ripple:

$$\Delta V_{R_L} = \begin{cases} \dfrac{I_{L_{AVG}}}{2\pi f \cdot C}(2\pi - \theta), & \text{for HWR schemes} \\ \dfrac{I_{L_{AVG}}}{2\pi f \cdot C}(\pi - \theta), & \text{for FBR or CTR schemes} \end{cases} \quad \text{(V)}$$







Theta issues

From equation of capacitor charge on the interval of $\tau_1 < t < \tau_2 = T - \frac{\theta}{\omega}$

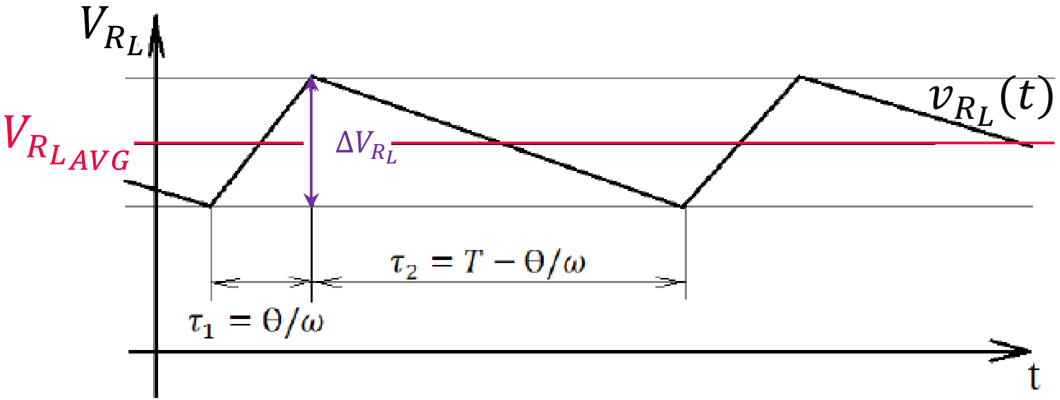
Capacitance evaluation:

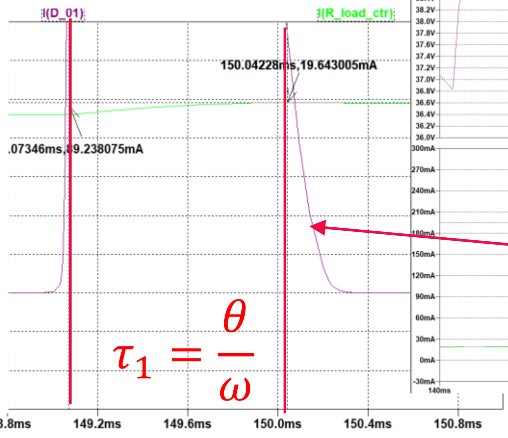
$$C = \begin{cases} \frac{I_{L_{AVG}}}{2\pi f \cdot \Delta V_{R_L}}(2\pi - \theta), & \text{for } \textbf{HWR} \text{ schemes} \\ \frac{I_{L_{AVG}}}{2\pi f \cdot \Delta V_{R_L}}(\pi - \theta), & \text{for } \textbf{FBR} \text{ or } \textbf{CTR} \text{ schemes} \end{cases} \qquad \text{(F)}$$

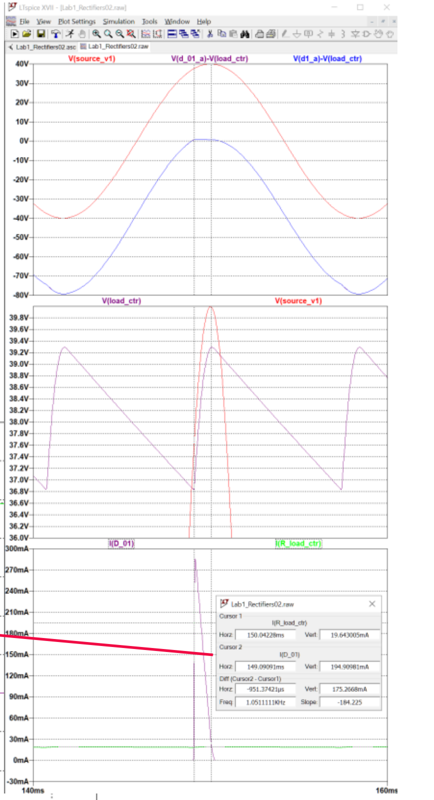
Voltage ripple:

$$\Delta V_{R_L} = \begin{cases} \frac{I_{L_{AVG}}}{2\pi f \cdot C}(2\pi - \theta), & \text{for } \textbf{HWR} \text{ schemes} \\ \frac{I_{L_{AVG}}}{2\pi f \cdot C}(\pi - \theta), & \text{for } \textbf{FBR} \text{ or } \textbf{CTR} \text{ schemes} \end{cases} \qquad \text{(V)}$$

If currents are less 1A it is better to use open –state current value al least 100mA to determine theta from simulation







Step Five: Results

3.2.2. Voltage ripple from simulation results

$$V_{R_{L AVG} exp} = \qquad (V)$$

$$V_{R_{L RMS} exp} = \qquad (V)$$

$$V_{R_{L max}} = \qquad (V)$$

$$V_{R_{L min}} = \qquad (V)$$

$$\Delta V_{R_{L} exp} = V_{R_{L max}} - V_{R_{L min}} = \qquad (V)$$

3.2.3. Ripple factor

$$K_p = \gamma = \sqrt[2]{\left(\frac{V_{S_{RMS}}}{V_{R_{L AVG}}}\right)^2 - 1}$$

3.2.4. Diode opening state angle:

$$\tau_1 = \qquad (s)$$

$$\theta_{exp} = \tau_1 \cdot f \cdot 2\pi = \frac{\tau_1}{T} \cdot 2\pi = \qquad (rad)$$

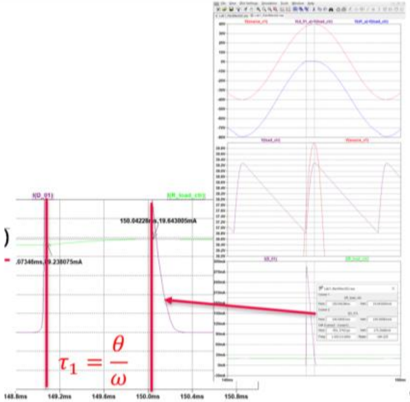


Fig 3.4 – θ_{exp} angle definition from simulation results
(It is recommended to consider diode open state at current level 0.05-0.1 A or determine theta on the capacitor charging interval)

3.2.6. Starting (Non-repetitive) maximum peak surge diode current in rectifier scheme

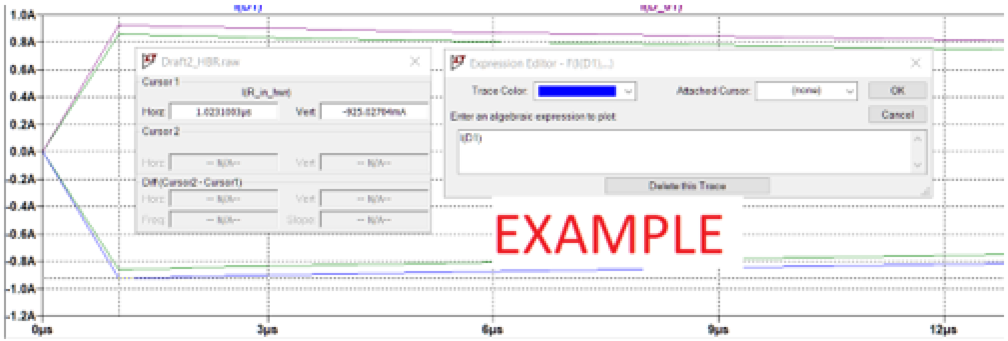


Fig 3.5 – Starting current

$$I_{VD_{ON} exp} = 2.493 \qquad (A)$$

Step Five: Results

Conclusions should contain:

1) Diode check results:
- Is breakdown voltage check passed? /Is voltage source changed because of overvoltage?
- Is starting current check passed? /Is additional resistance r_vs added to prevent overcurrent in diode/capacitor?

2) Capacitor information: nominal value, tolerance, allowed current

3) Provided ripple factor value

Step Five: Results

Conclusion should contain:

1) Diode check results:

- Is breakdown voltage check passed? Is voltage source changed because of overvoltage?
- Is starting current check passed? /Is additional resistance r_vs added to prevent overcurrent in diode/capacitor?

2) Capacitor information: nominal value, tolerance, allowed current

3) Ripple factor value

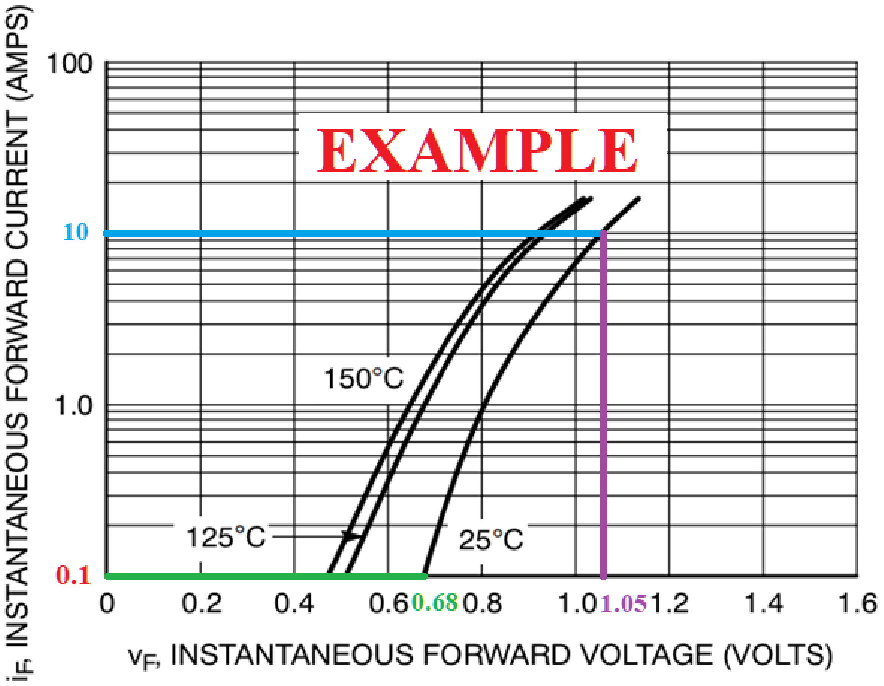
If there are no conclusion or some parts o conclusion is missing – the score will be reduced by 1 point of 3

Practice task 1

Simple semiconductor device circuits design

Nikolai Poliakov (polyakov_n_a@itmo.ru)
Arina Arbuzina (arbyzina99@gmail.com)

Diode active resistance



Maximum repetitive peak surge forward current

$I_{fwd\_imp} =$ (A)

Diode forward bias voltage

$V_{fwd\_max}(I_{fwd\_imp}) =$ (V)

Diode threshold voltage:

$v_{ON} =$ (V)

Diode current at starting conduct state:

$I_{fwd}(v_{ON}) =$ (A)

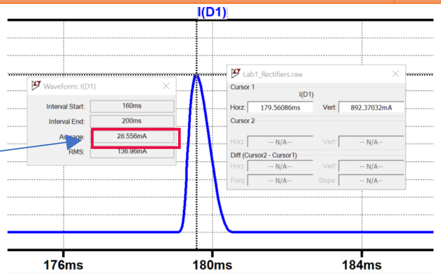
Diode active resistance:

$$r_{VD} = \frac{V_{fwd\_max} - v_{ON}}{I_{fwd_{imp}} - I_{fwd}(v_{ON})} = \quad (\Omega)$$

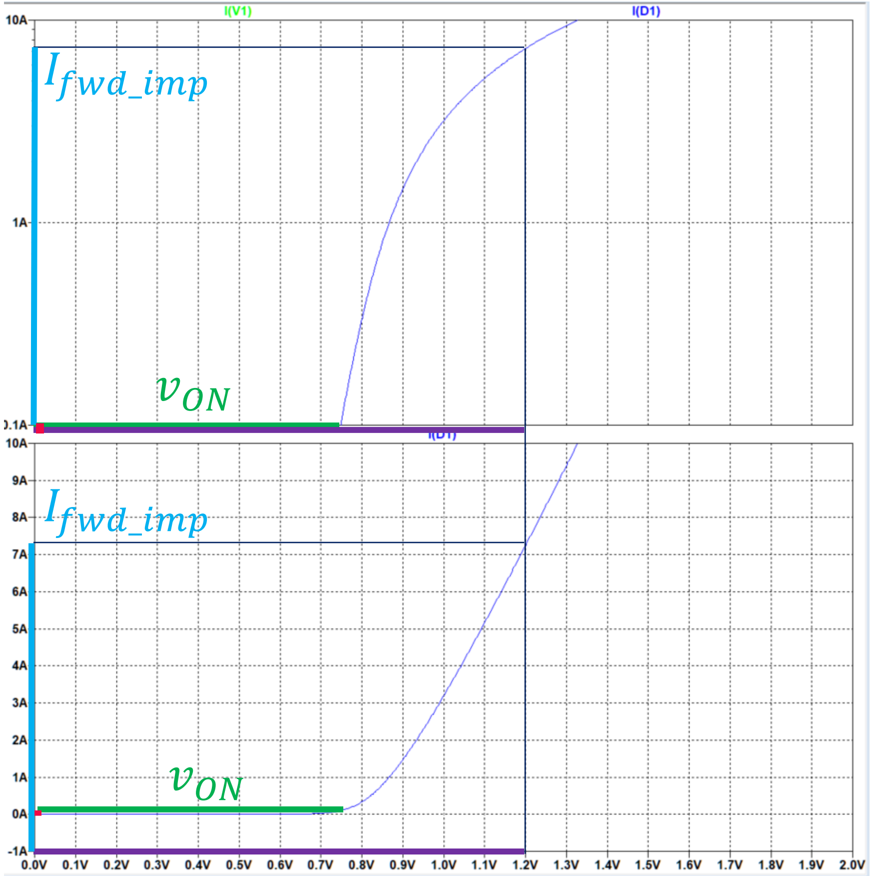
Evaluations

	$I_{VD_{AVG}}$	$I_{VD_{max}} = I_{fwd\_imp}$	$V_{VD_{max}}$	r_{IN}
Half - Wave rectifier (HWR)	$= I_{L_{AVG}}$	$\approx 7I_{L_{AVG}}$	$= V_S \cdot 2 \approx 3V_{R_{L_{AVG}}}$	$= r_{VD} + r_{V_S}$
Central Tap Rectifier (CTR)	$= \frac{I_{L_{AVG}}}{2}$	$\approx 3.5I_{L_{AVG}}$	$= V_S \cdot 2 \approx 3V_{R_{L_{AVG}}}$	$= r_{VD} + r_{V_S}$
Full bridge (Graetz) rectifier (FBR)	$= \frac{I_{L_{AVG}}}{2}$	$\approx 3.5I_{L_{AVG}}$	$= V_S \approx 1.5V_{R_{L_{AVG}}}$	$=2r_{VD} + r_{V_S}$

$I_{VD_{AVG}(experimental)}$



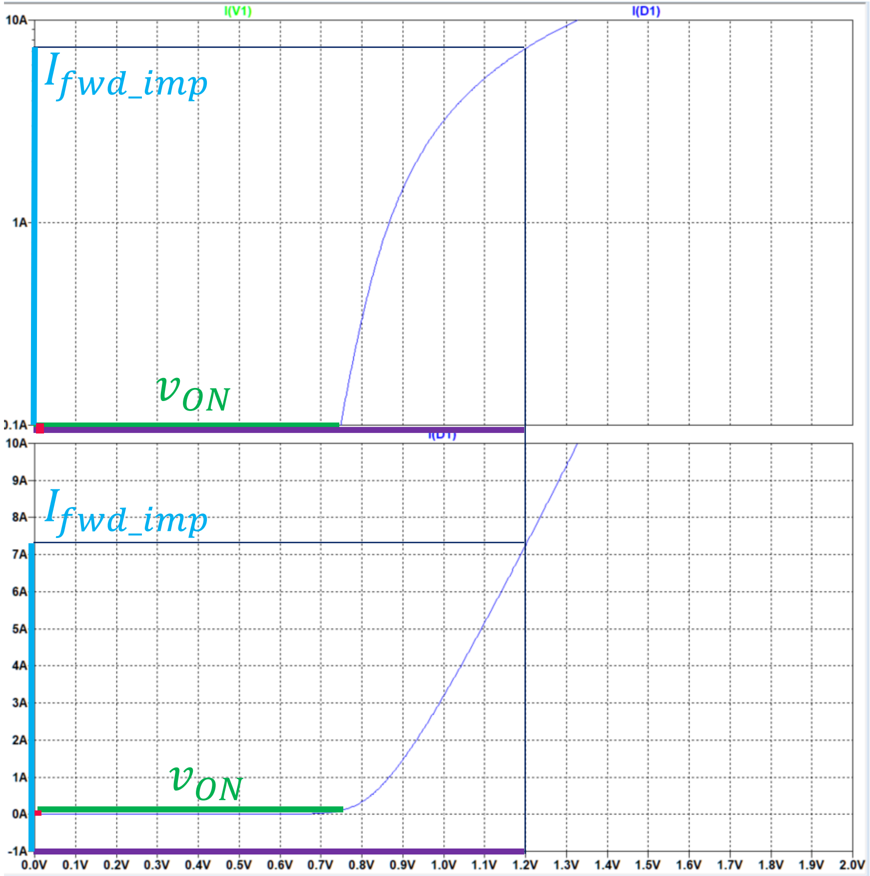
Diode active resistance

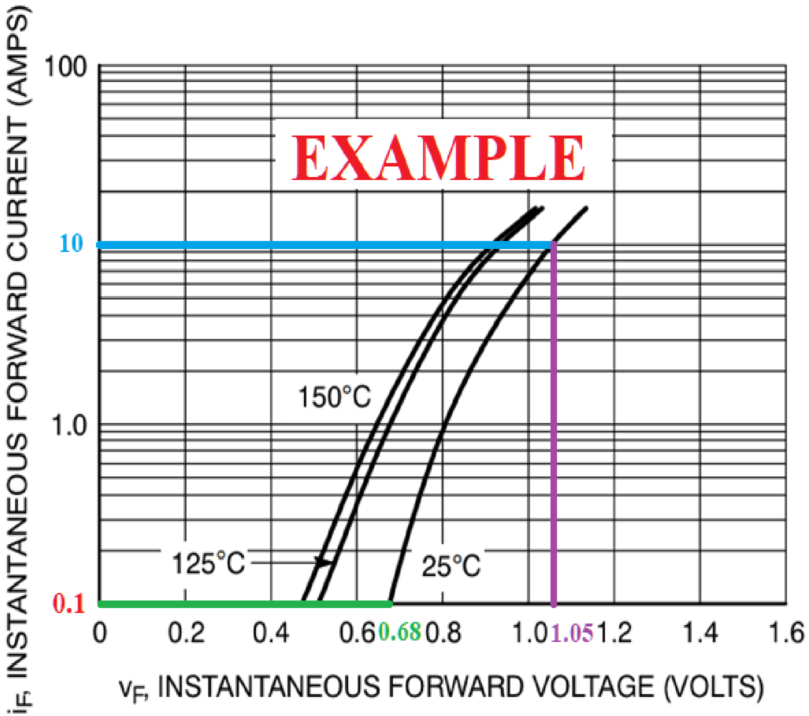


Diode active resistance:

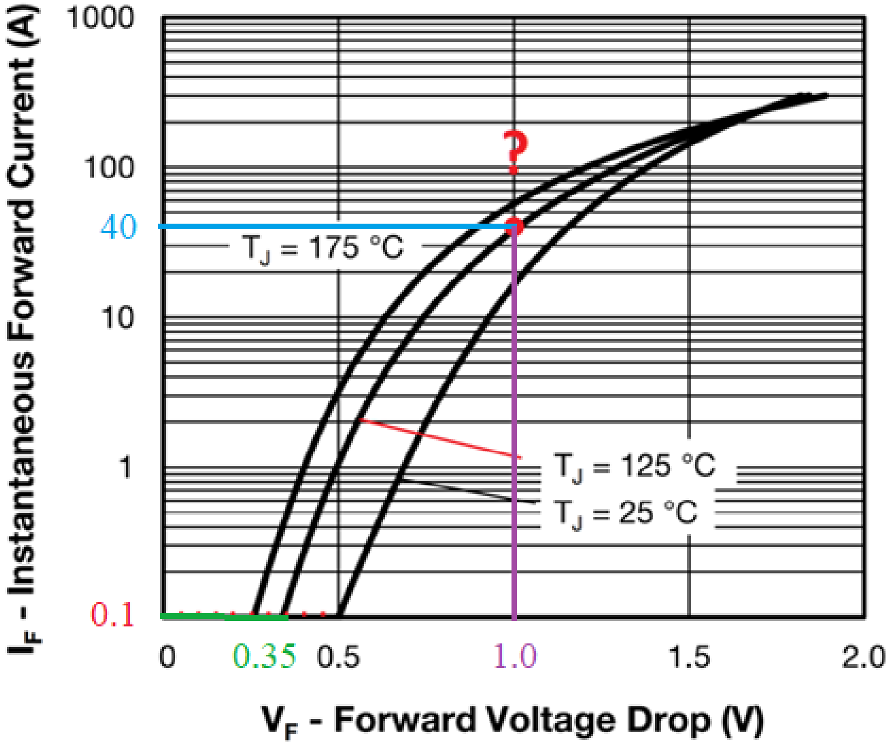
$$r_{VD} = \frac{V_{fwd\_max} - v_{ON}}{I_{fwd_{imp}} - I_{fwd}(v_{ON})} \quad (\Omega)$$

Diode active resistance





Diode active resistance



Maximum repetitive peak surge forward current

$$I_{fwd\_imp} = 40 \qquad \text{(A)}$$

Diode forward bias voltage

$$V_{fwd\_max}\left(I_{fwd\_imp}\right) = 1.0 \qquad \text{(V)}$$

Diode threshold voltage:

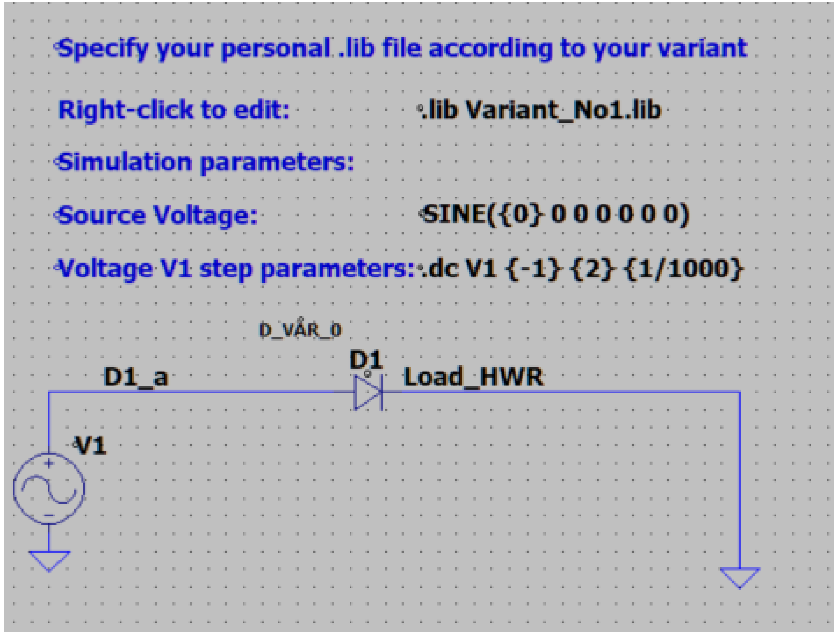
$$v_{ON} = 0.35 \qquad \text{(V)}$$

Diode active resistance:

$$r_{VD} = \frac{V_{fwd\_max} - v_{ON}}{I_{fwd_{imp}} - I_{fwd}(v_{ON})} \qquad (\Omega)$$

$$r_{VD} = \frac{1 - 0.35}{40 - 0.1} = 0.0163\ \Omega$$

Diode VI in LT Spice



Maximum repetitive peak surge forward current

$I_{fwd\_imp} =$ (A)

Diode forward bias voltage

$V_{fwd\_max}(I_{fwd\_imp}) =$ (V)

Diode threshold voltage:

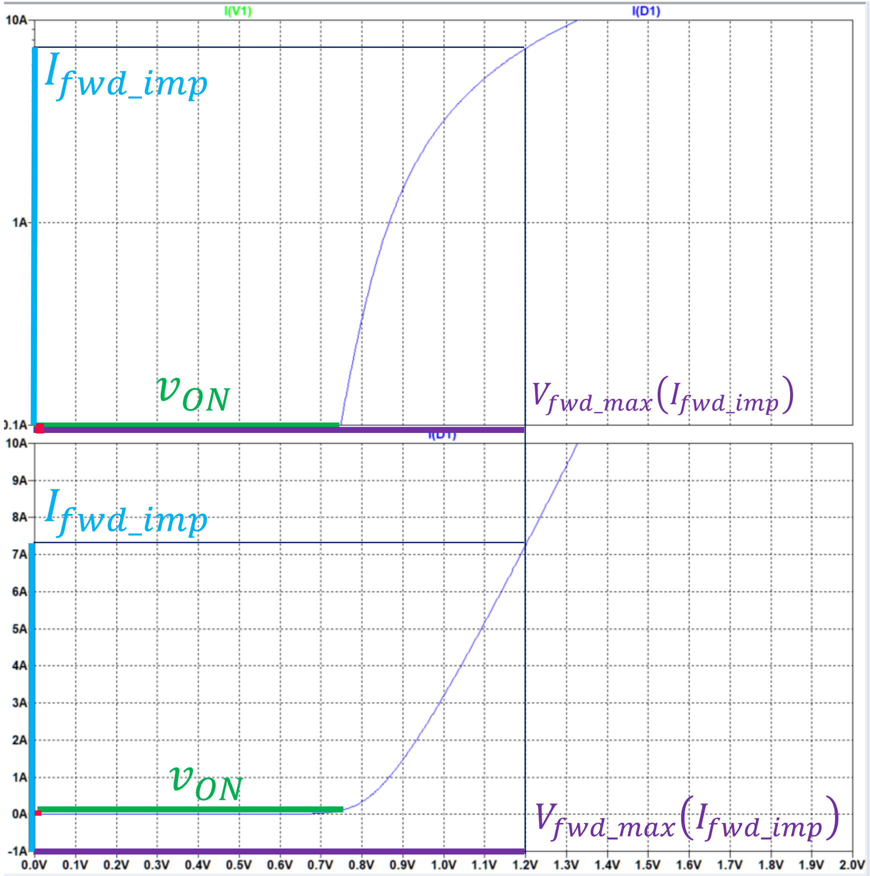
$v_{ON} =$ (V)

Diode active resistance:

$$r_{VD} = \frac{V_{fwd\_max} - v_{ON}}{I_{fwd_{imp}} - I_{fwd}(v_{ON})} \quad (\Omega)$$

$$r_{VD} = \frac{}{} = \quad \Omega$$

Diode active resistance



Maximum repetitive peak surge forward current

$$I_{fwd\_imp} = 7 \qquad \text{(A)}$$

Diode forward bias voltage

$$V_{fwd\_max}(I_{fwd\_imp}) = 1.2 \qquad \text{(V)}$$

Diode threshold voltage:

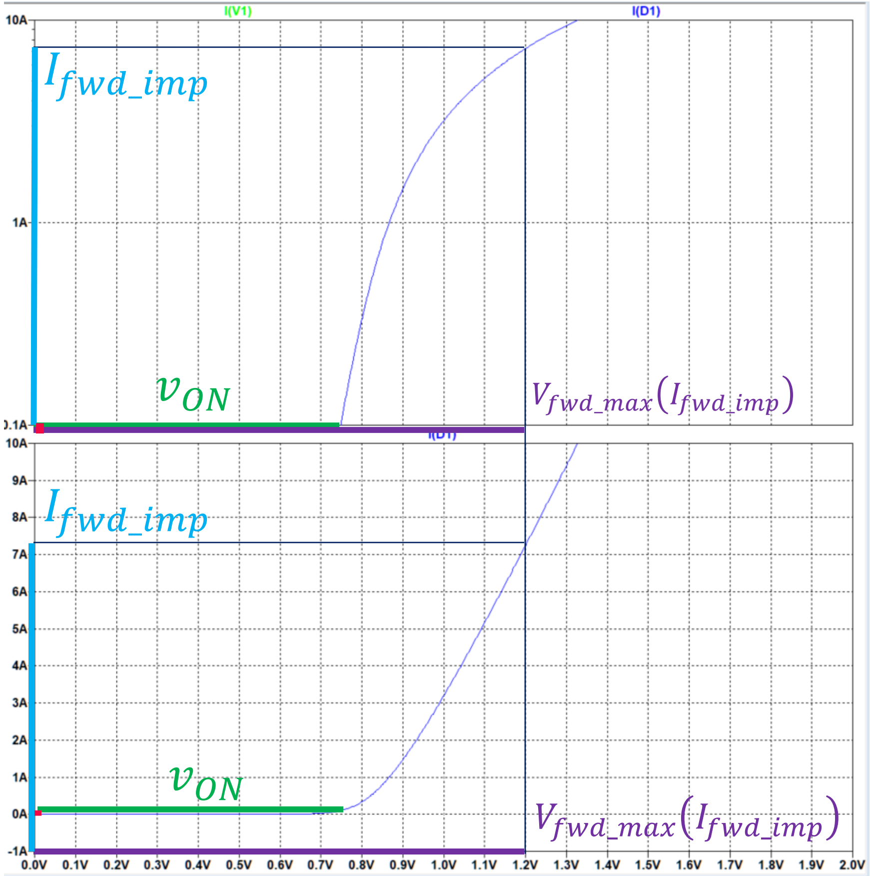
$$v_{ON} = 0.75 \qquad \text{(V)}$$

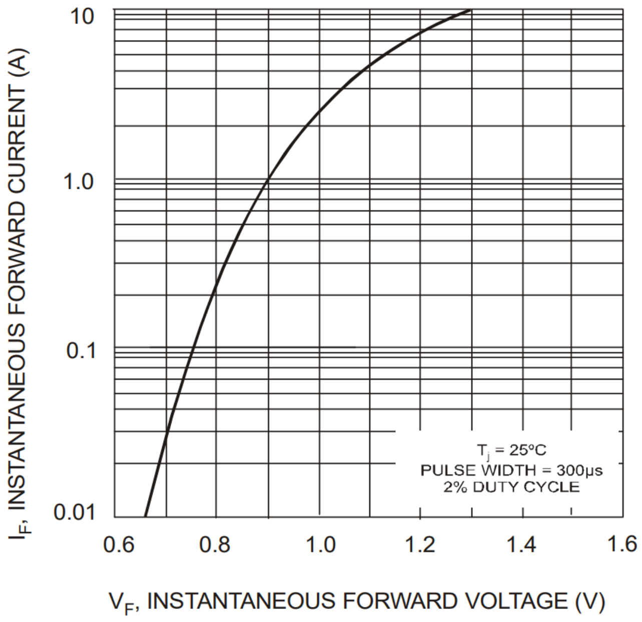
Diode active resistance:

$$r_{VD} = \frac{V_{fwd\_max} - v_{ON}}{I_{fwd_{imp}} - I_{fwd}(v_{ON})} \qquad (\Omega)$$

$$r_{VD} = \frac{1.2 - 0.75}{7 - 0.1} = 0{,}065\ \Omega$$

Diode active resistance





Step Five: Submit practice results form before 1.10.2023!!

Laboratory Work 1

https://forms.yandex.com/cloud/6500ee1702848f28e1856a23/

https://clck.ru/35gixy

Practice task 1

https://forms.yandex.com/cloud/650103e590fa7b299554a509/

https://clck.ru/35giyD

ITMO

Thank you for your attention!