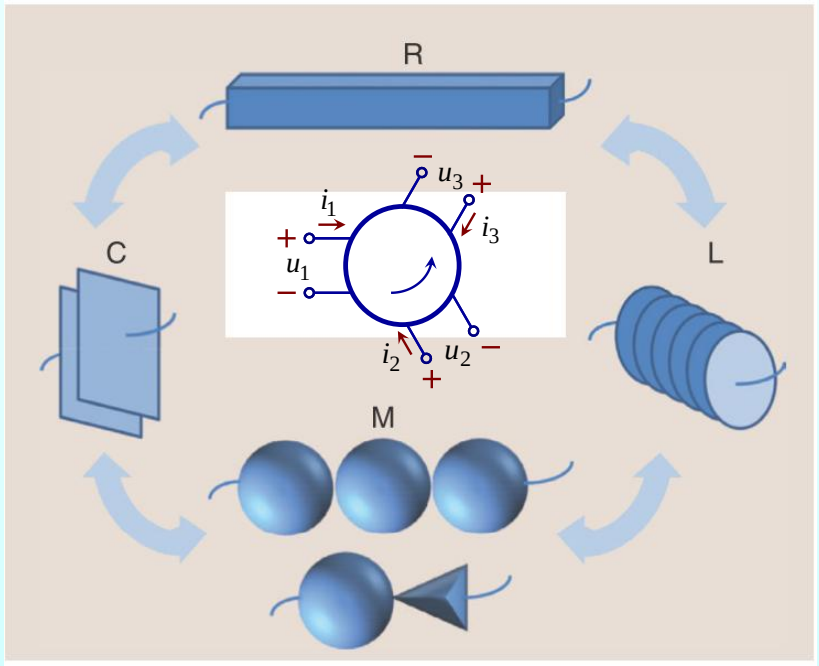
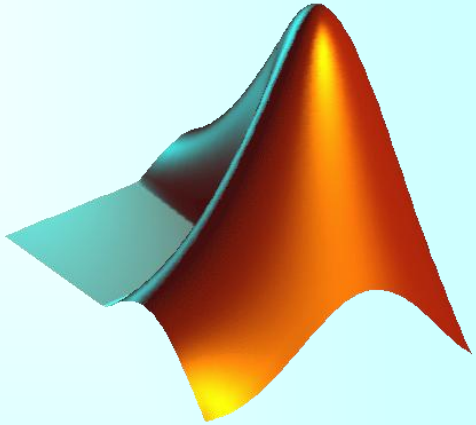
Практикум из рачунарске анализе кола

1. Увод





Милка Потребић Иваниш

Никола Баста

Практикум из рачунарске анализе кола 13Е072ПРК3, 19Е072ПРК

- **Настава се изводи према текућем студијском програму који је Електротехнички факултет акредитовао** http://www.etf.bg.ac.rs
- Студијски програм: **Електротехника и рачунарство**
- Изборно подручје (модул): **Физичка електроника, Сигнали и системи, Телекомуникације и информационе технологије**
- **Циљ.** Излагање основних концепата анализе помоћу рачунара који се користе у софтверским пакетима за симулацију електричних кола са гледишта инжењера и истраживача електротехнике. Увођење основа за анализу модела електротехничких система и направа за нумеричку и симболичку анализу у временском и фреквенцијском домену. Изградња основних знања аналогне обраде сигнала помоћу електричних кола.
- **Исход.** Разумевање основних концепата анализе електричних кола помоћу рачунара и одговарајућих математичких алгоритама. Решавање линеарних електричних кола у временском и фреквенцијском домену помоћу система компјутерске алгебре.
- **Садржај.** Основни концепти рачунарске симулације електричних кола помоћу савремених софтверских алата. Фазорска анализа. Одзив на почетне услове, побуду и потпун одзив. Резонанција. Фреквенцијски одзив. Бодеови дијаграми. Трофазна кола. Симболичко решавање електричних кола. Водови.
- **Наставници.** Др **Милка Потребић Иваниш**, редовни професор, соба 64 (milka_potrebic@etf.rs); Др **Никола Баста**, доцент, соба 63 (nbasta@etf.rs).
- **Сарадници у настави. Ања Ковачевић**, мс. инж., **Филип Нешковић**, мс. инж.
- Белешке са предавања и лаб. вежби, примери испитних задатака и питања, **http://tek.etf.rs**
- **Додатни материјали и консултације биће организовани преко канала на MS Teams платформи** (линкови за канале су на адреси **http://tek.etf.rs**)
- **Начин одржавања наставе.** Рачунски центар.
- **Начин полагања испита.** 1) Решавање задатака на рачунару у пару (или смостално) у РЦ, или алтернативно
  2) издрада два домаћа задатка у пару (или самостално) са пратећим извештајем у виду презентецајује која се усмено брани.
  Испит се може полагати у сваком испитном року.
  Усмена одбрана домаћих задатака се заказује са предметним наставницима.
  За израду домаћих задатака јавити се е-поштом Милки Потребић Иваниш.
- **Пратити** званично представљање предмета и објављивање општих службених порука на адреси **http://tek.etf. rs/**

Рачунарски (софтверски) алати

- *Mathematica*, WolframAlpha, MuPAD, **Maxima**, **SymPy**, **SymPy Live**, **SymPy Gamma**
- MATLAB, **Scilab**, **Octave**, **FreeMat**, **Julia**
- LTspice, **QucsStudio**, **ngspice**, **Xyce**, **XCircuit**
- **Python**, MathCAD, MAPLE, GeoGebra, Sage
- Symbolab, SpeQ Mathematics, meta-calculator, Desmos, …
- Android apk: NCalc+, CalcES, SymJa CAS, Scientific Calculator Pro, CYZSoft Scientific Calculator Plus

Free/Libre Open Source Software (FLOSS)

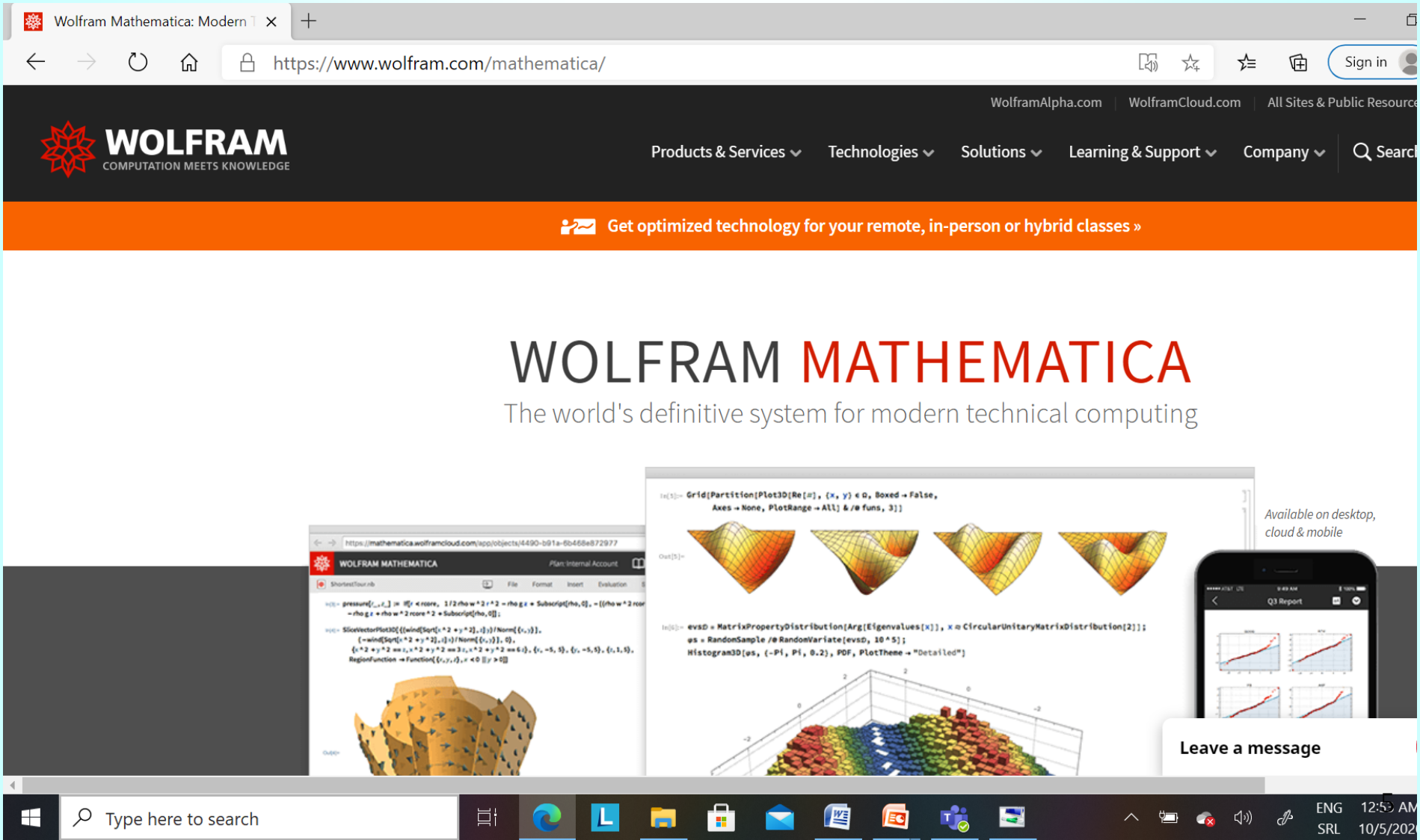
Моделовање електричних кола

- PSpice, ngSpice, Xcos, SciLab, TINA-TI, Micro-Cap, Plexim, 5Spice…
- **Online Circuit Simulator**: DoCircuits, Circuit Lab, PartSim, EasyEda, Multisim, PartQuest (SystemVision Cloud)...
- **Android circuit simulator:**
  Electric Circuit Studio,
  Circuit Safari SPICE Simulator...

др Милка Потребић Иваниш, ред. проф., др Никола Баста, доцент, 13E072PRK3, 19E072PRK, Универзитет у Београду – Електротехнички факултет, 2023.

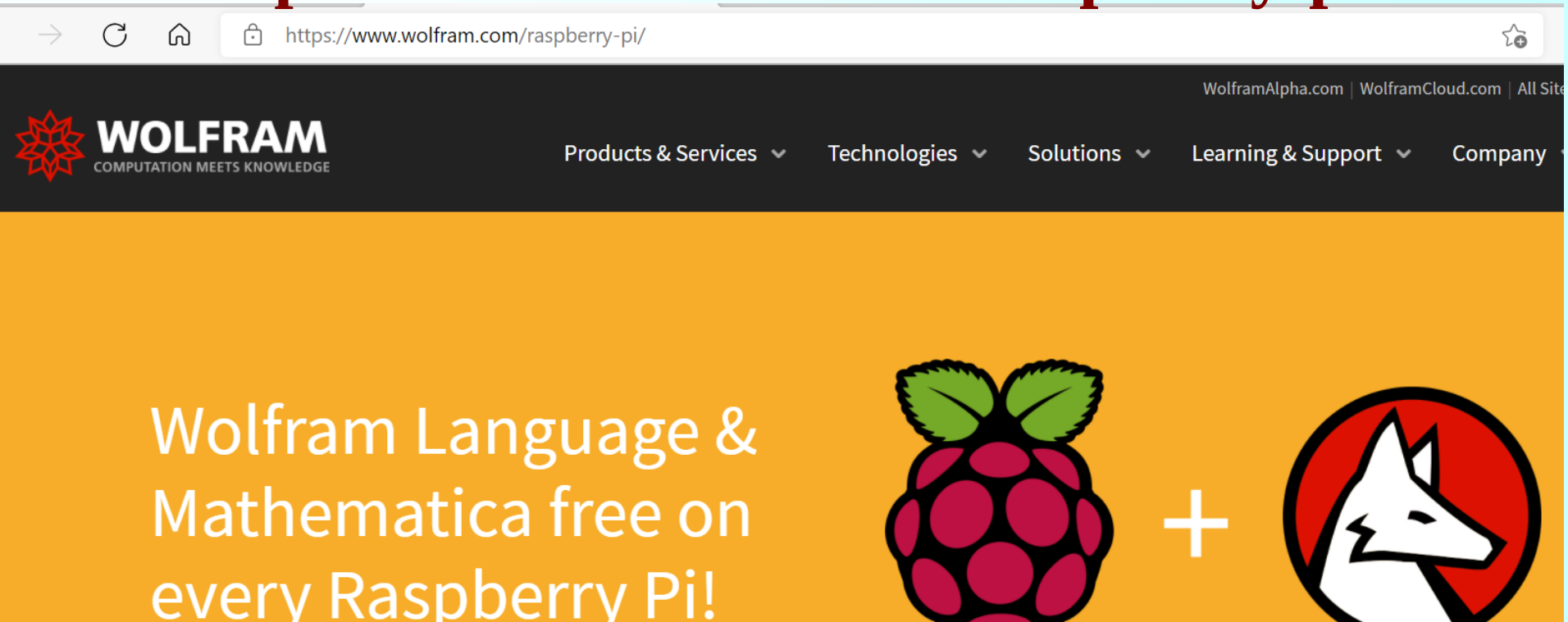
Mathematica

https://www.wolfram.com/mathematica/



Mathematica free on every Raspberry Pi!

https://www.wolfram.com/raspberry-pi/



www.wolframalpha.com

Give your brain a quick workout with Wolfram Problem Generator.

WolframAlpha computational knowledge engine

y' +1000 * y = 10000, y(0)=-10

Examples Random

Input:

$\{y'(x) + 1000\, y(x) = 10\,000,\ y(0) = -10\}$

ODE classification:

first-order linear ordinary differential equation

Alternate forms:

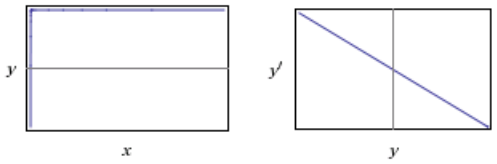
$\{y'(x) = 10\,000 - 1000\, y(x),\ y(0) = -10\}$

$\{y'(x) + 1000\,(y(x) - 10) = 0,\ y(0) = -10\}$

Differential equation solution: Approximate form | Step-by-step solution

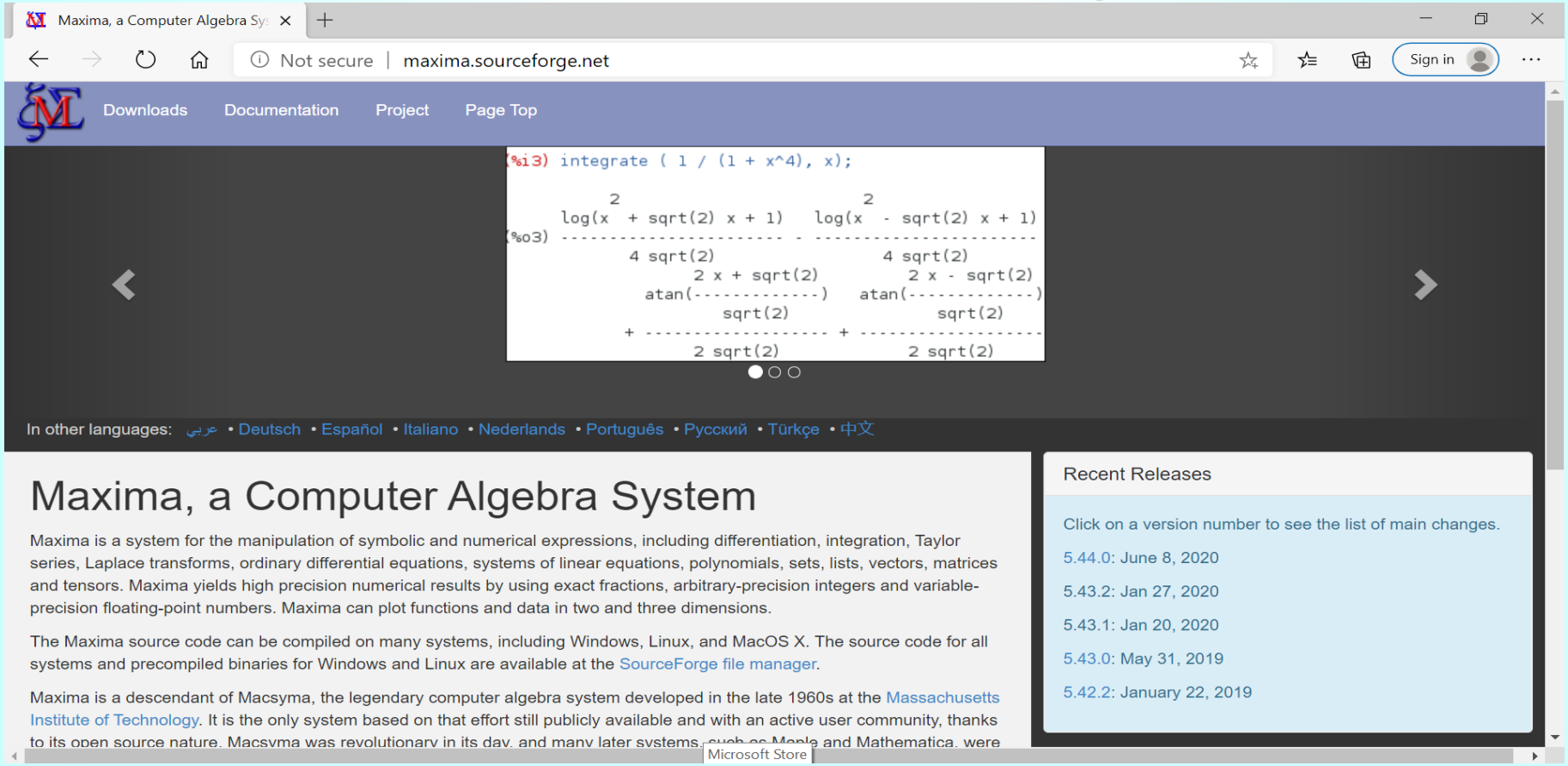
$y(x) = 10 - 20\, e^{-1000\, x}$

Plots of the solution:



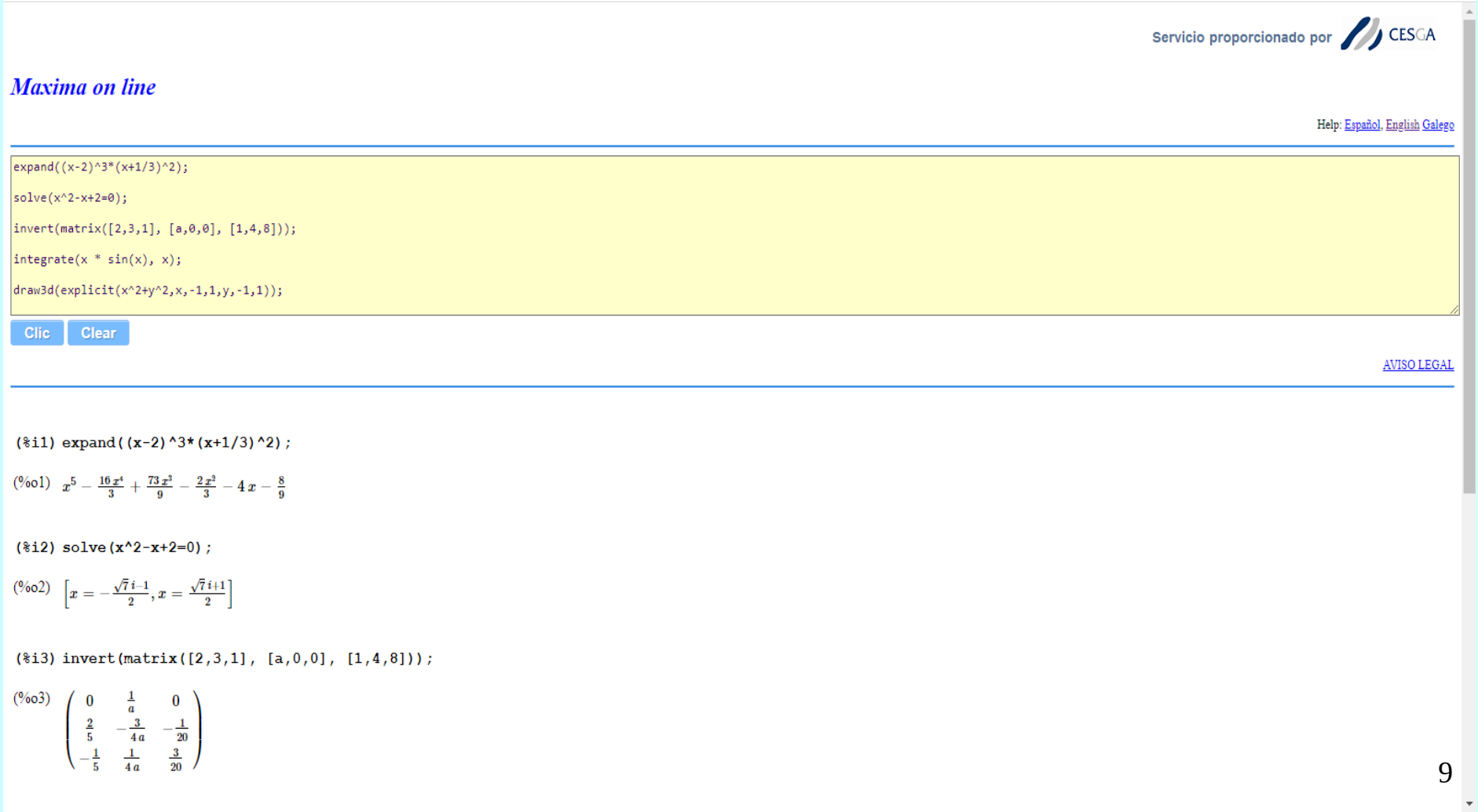
Maxima

http://maxima.sourceforge.net/



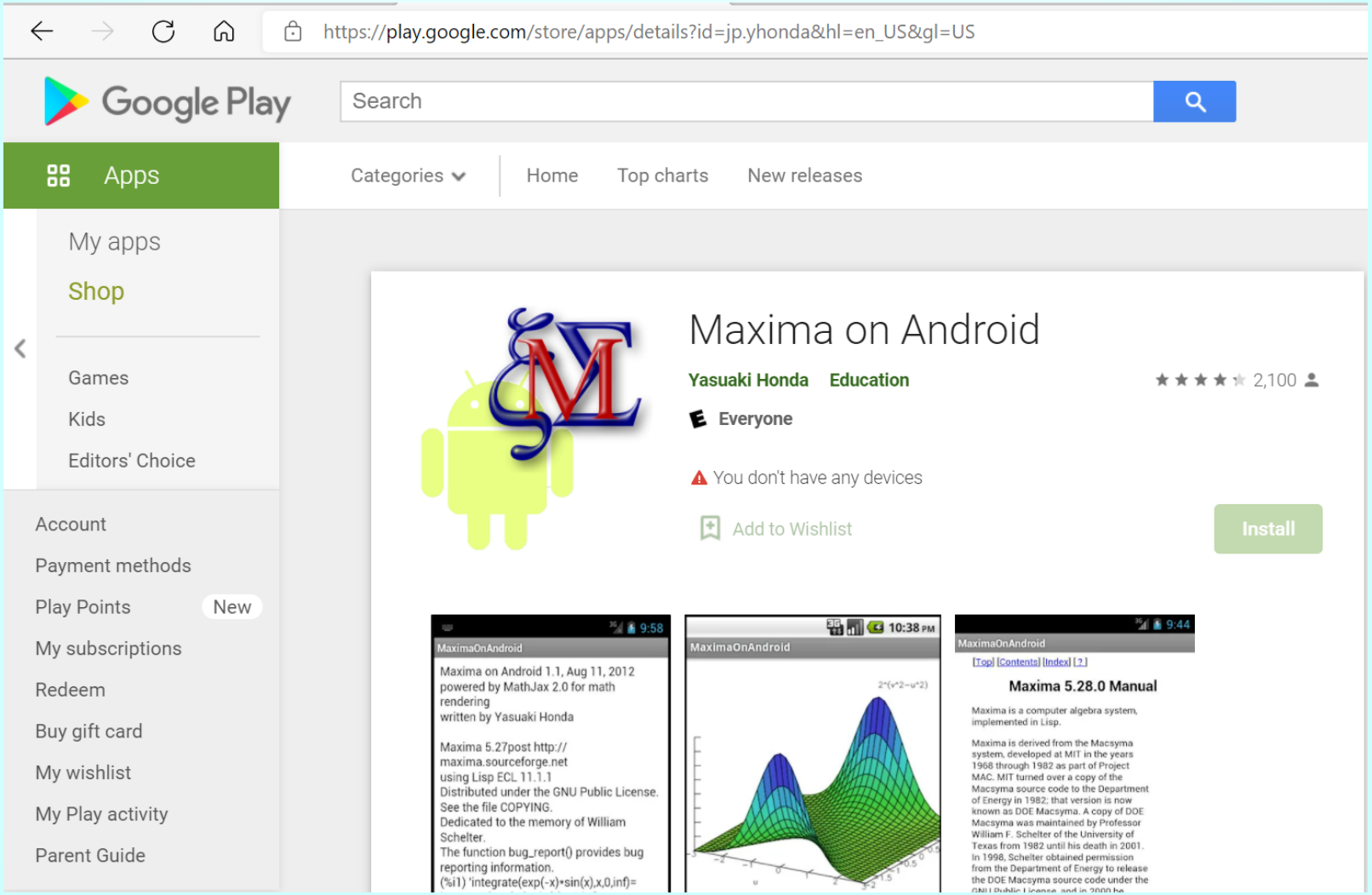
Maxima on line

http://maxima.cesga.es/



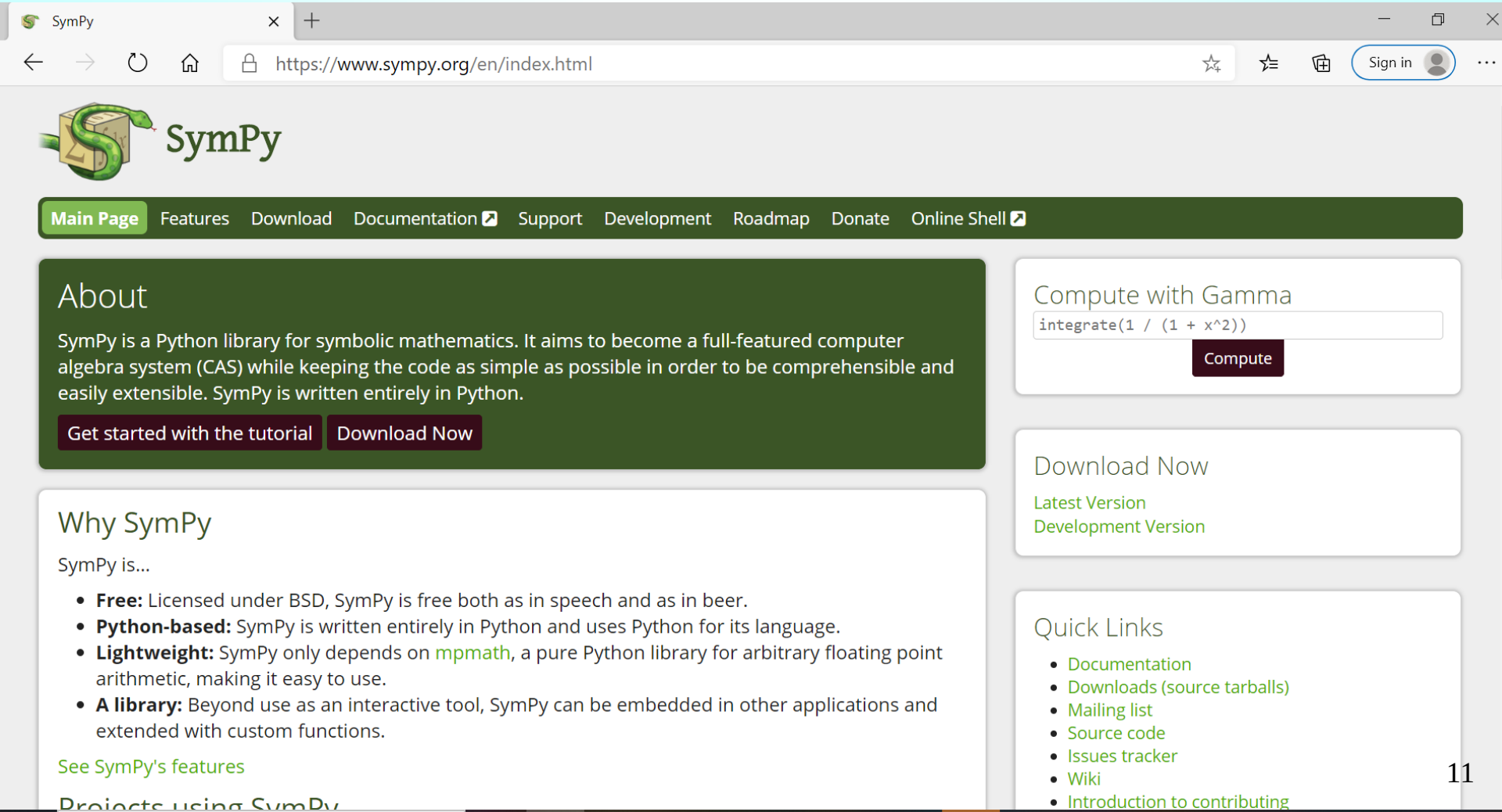
Maxima on Android

https://play.google.com/store/apps/details?id=jp.yhonda&hl=en_US&gl=US



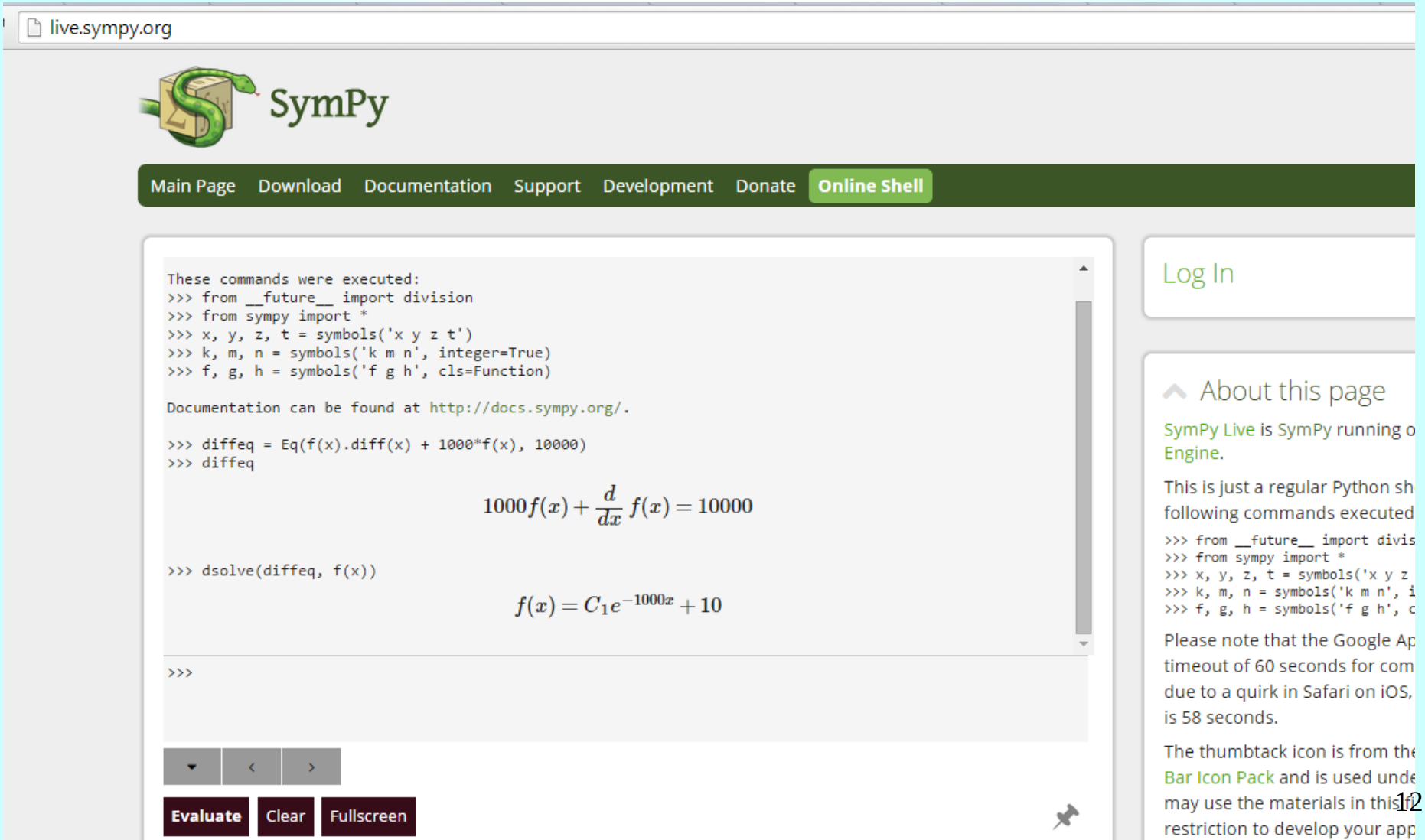
SymPy

www.sympy.org/



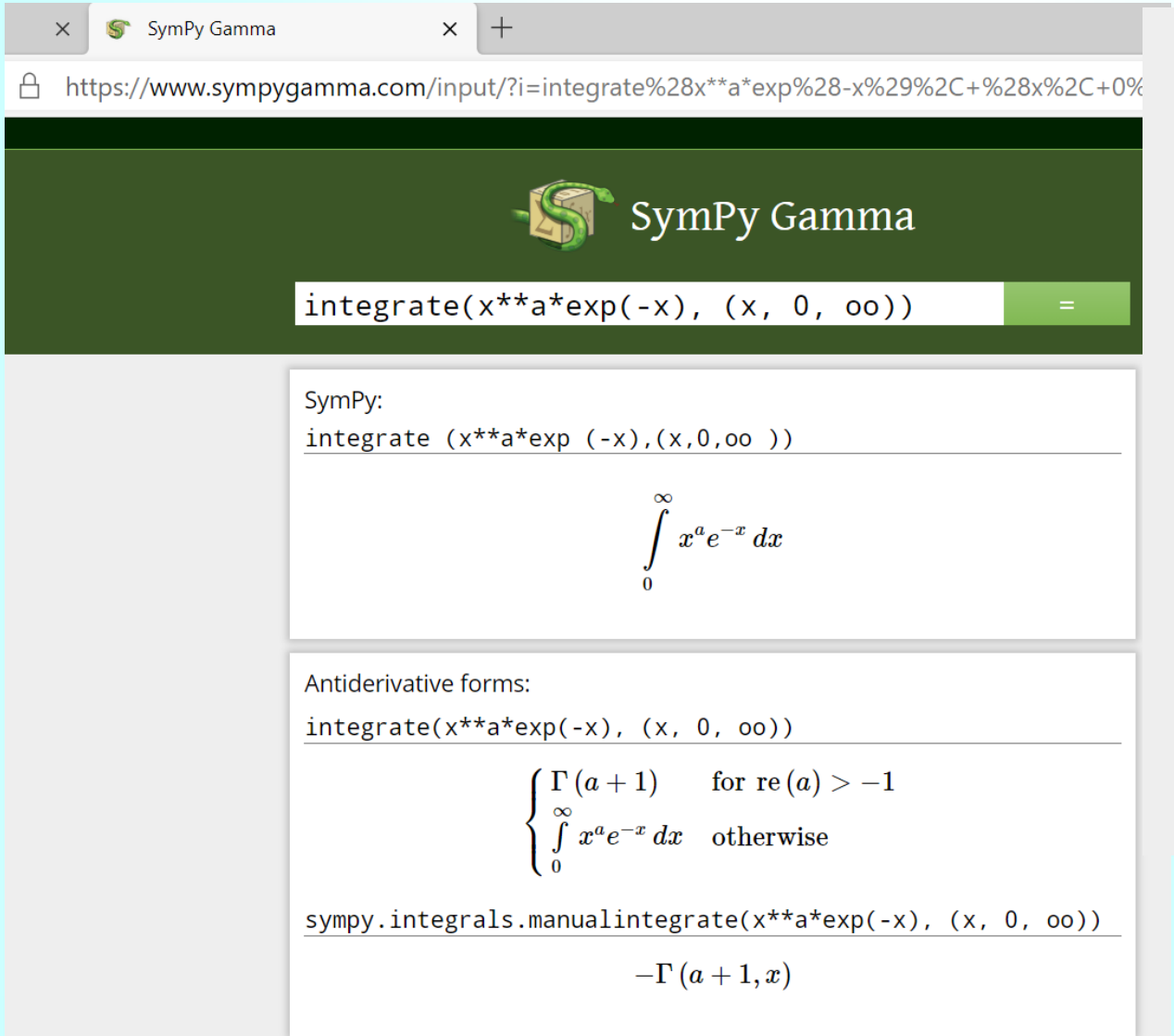
SymPy live

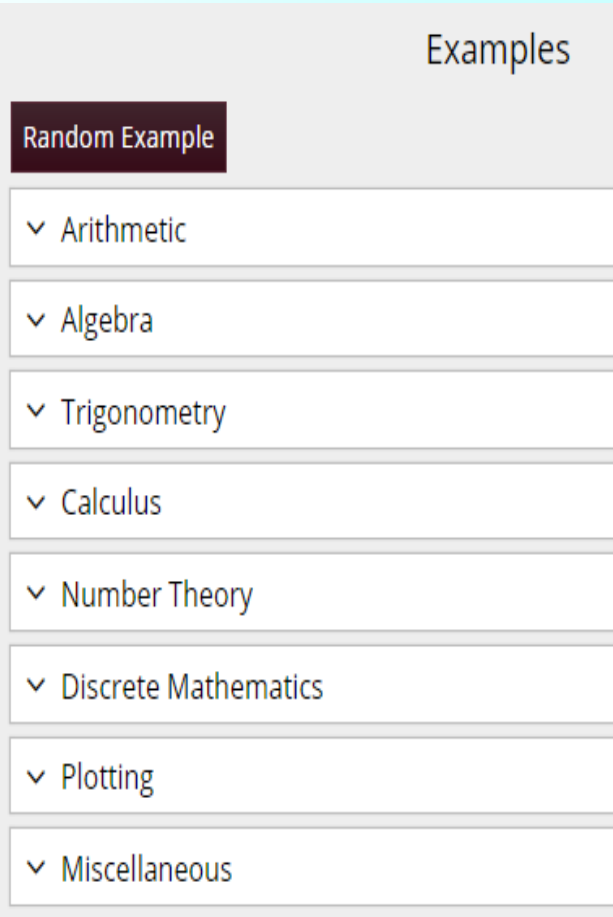
live.sympy.org

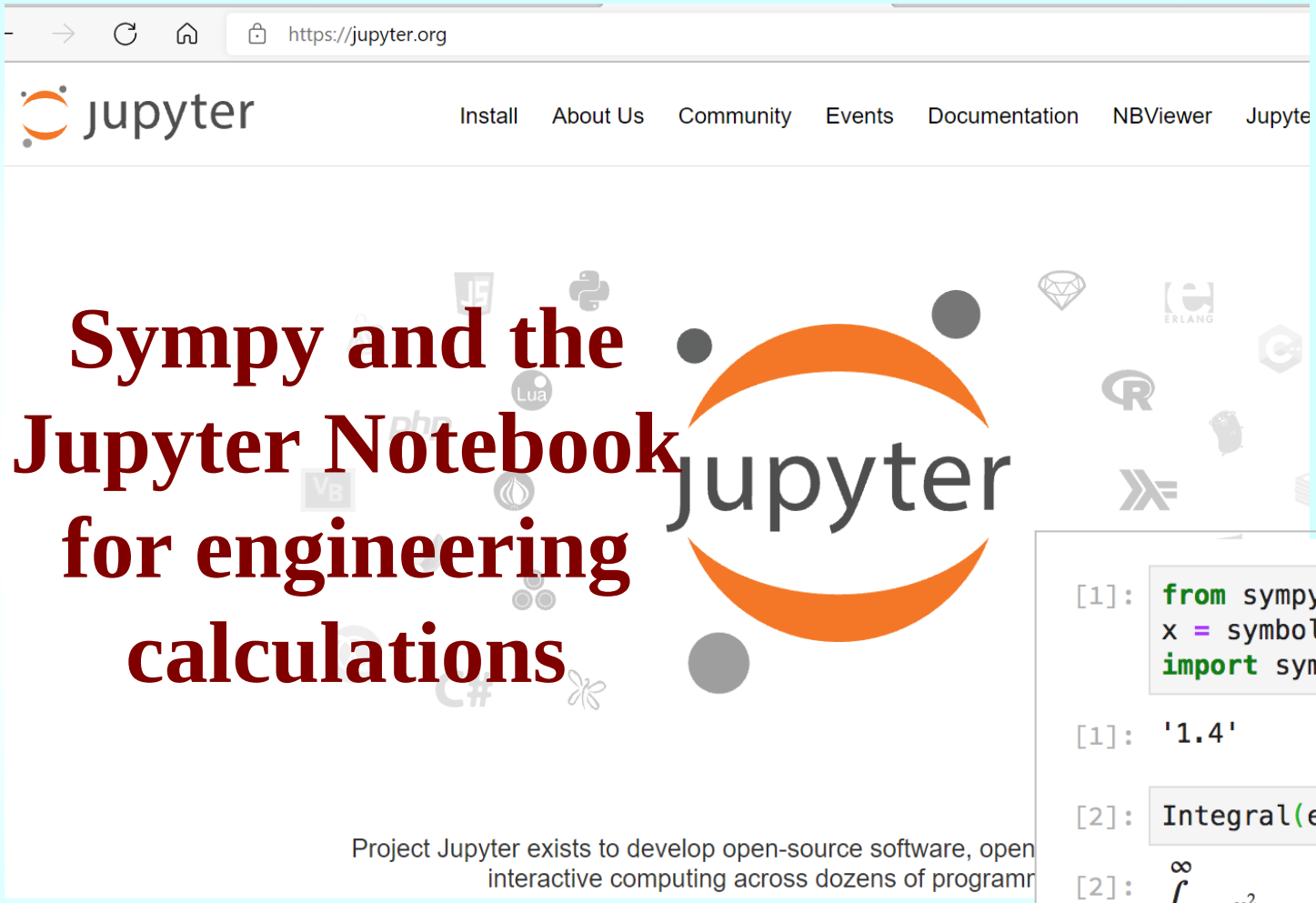


SymPy Gamma

https://www.sympygamma.com/



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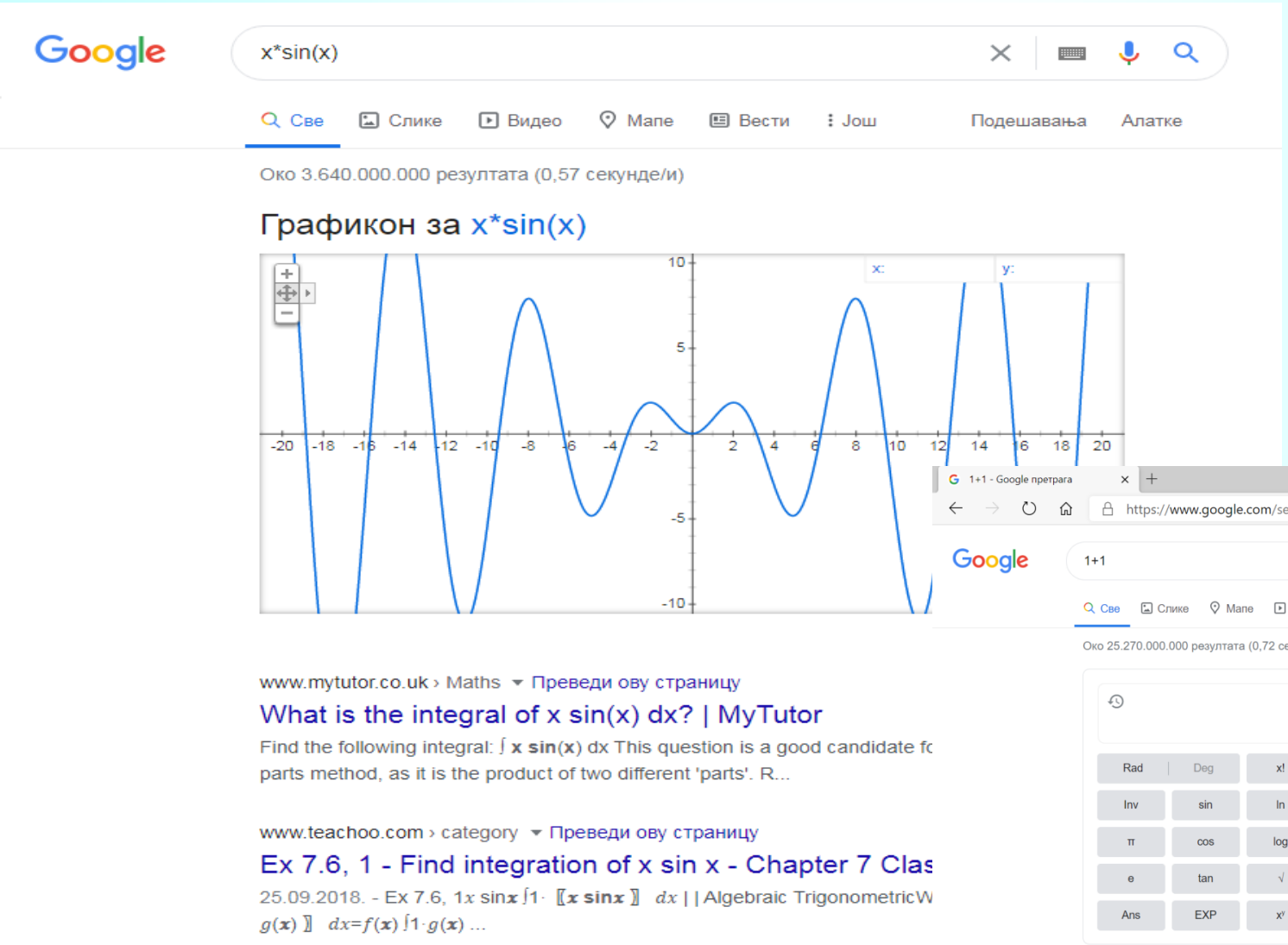
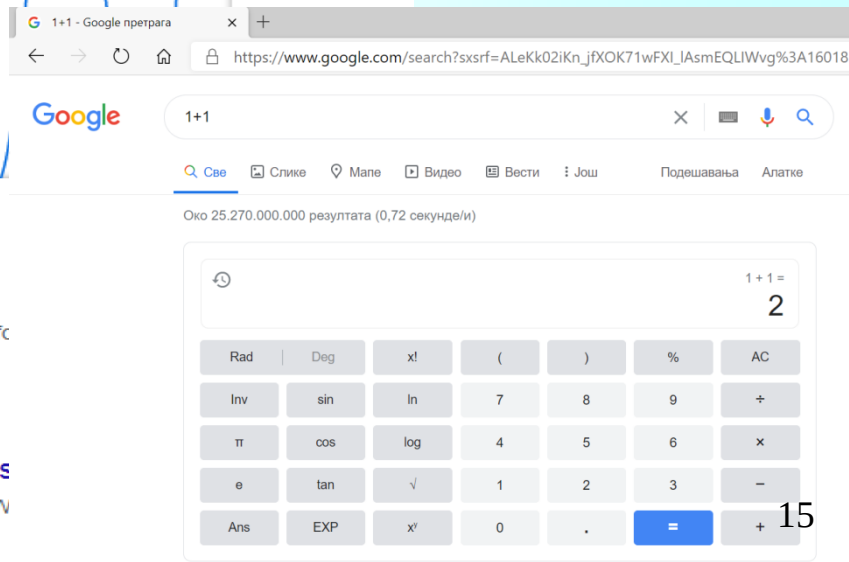
Jupyte
Sympy and the Jupyter Notebook for engineering calculations
jupyter
Project Jupyter exists to develop open-source software, open
interactive computing across dozens of programr
[1]: from sympy import *
x = symbols('x')
import sympy;sympy.__version__
[1]: '1.4'
[2]: Integral(exp(-x**2), (x, -oo, oo))
[2]: $\int_{-\infty}^{\infty} e^{-x^2}\,dx$
[3]: _.doit()
[3]: $\sqrt{\pi}$

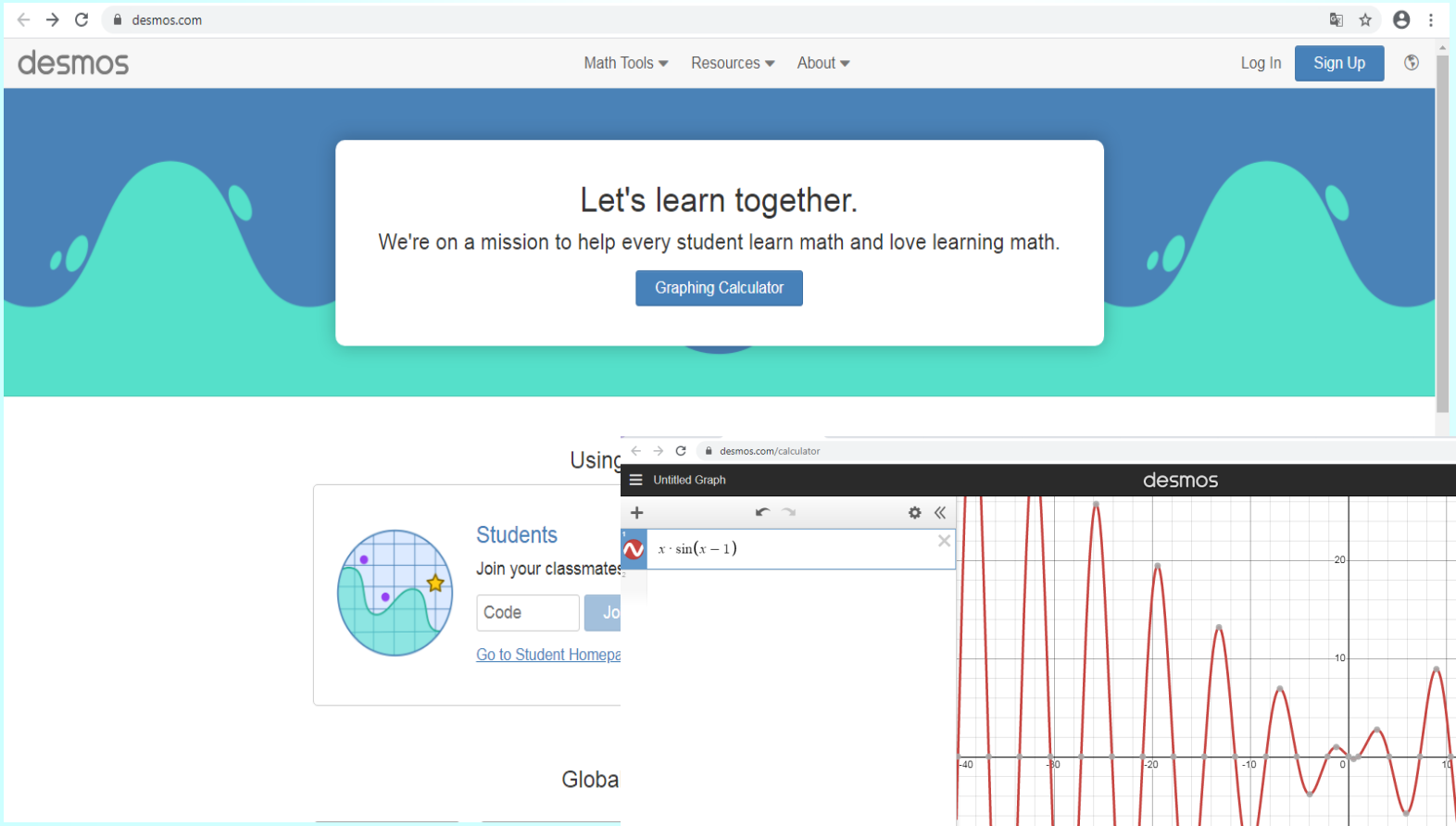
Google калкулатор

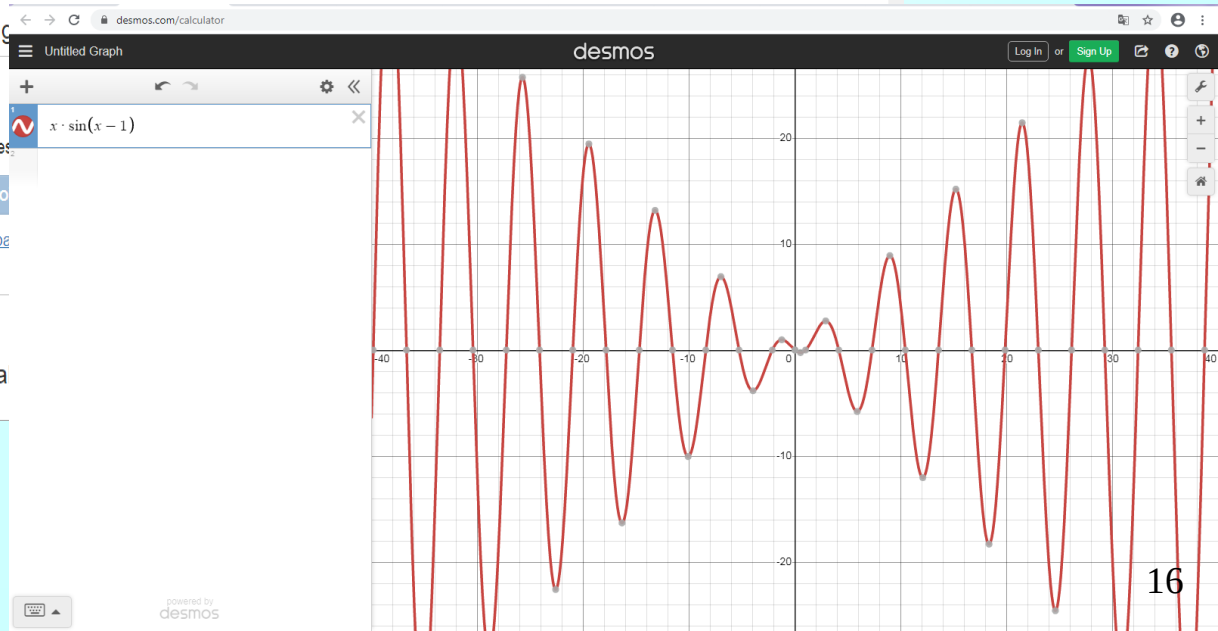




Graphing Calculator – Desmos

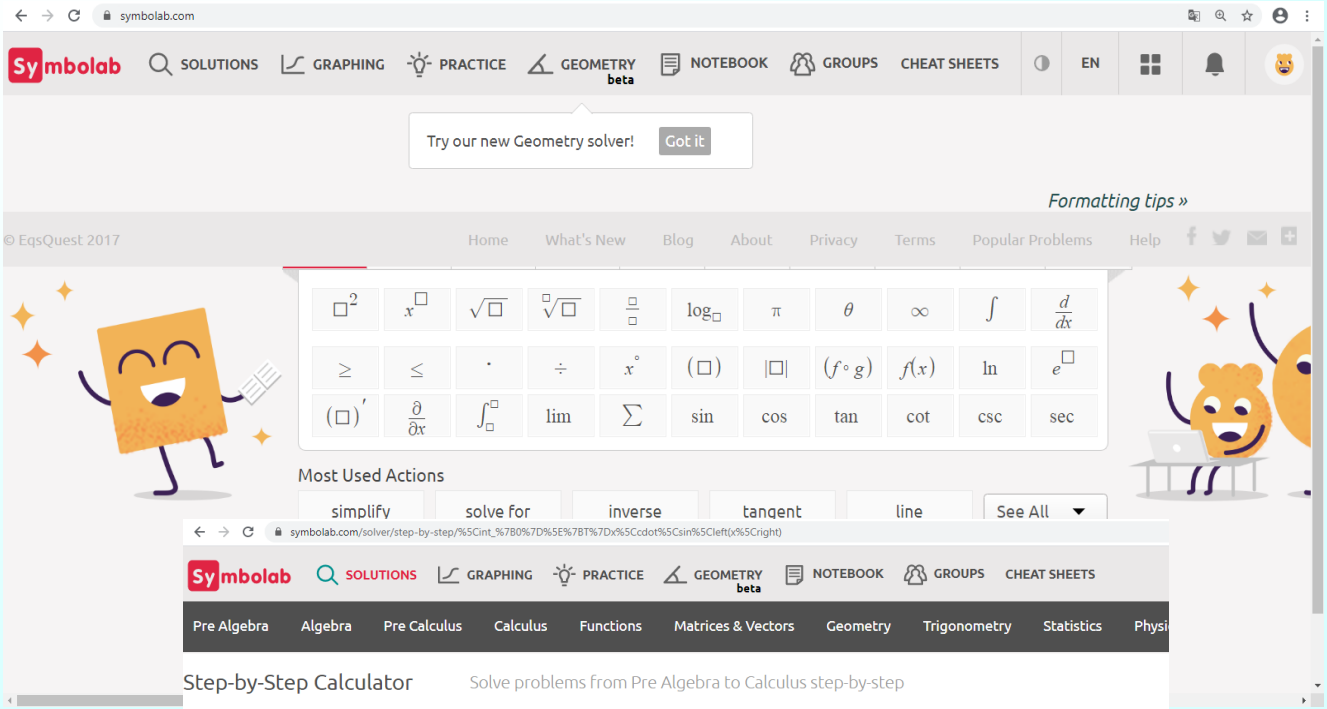
https://www.desmos.com/calculator

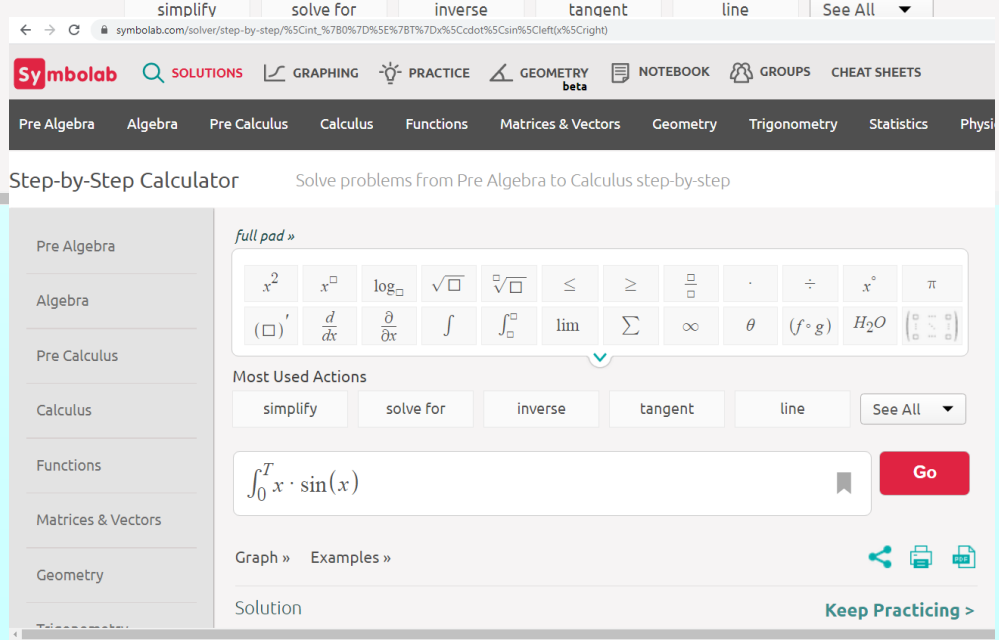


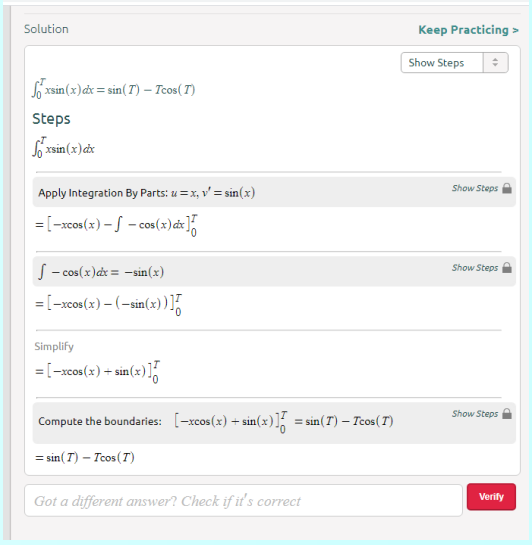


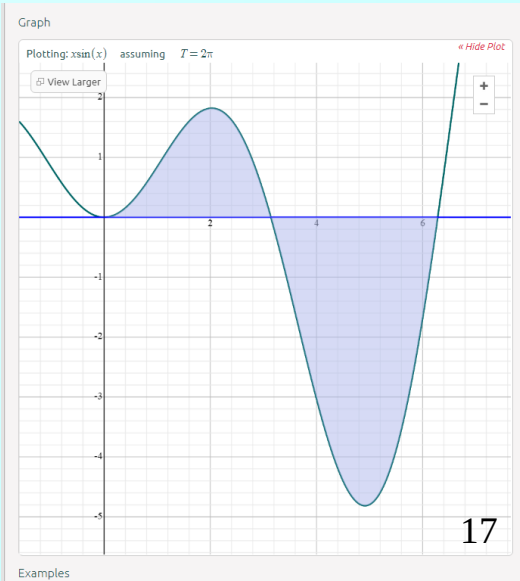
Symbolab Math Solver - Step by Step calculator

https://www.symbolab.com/



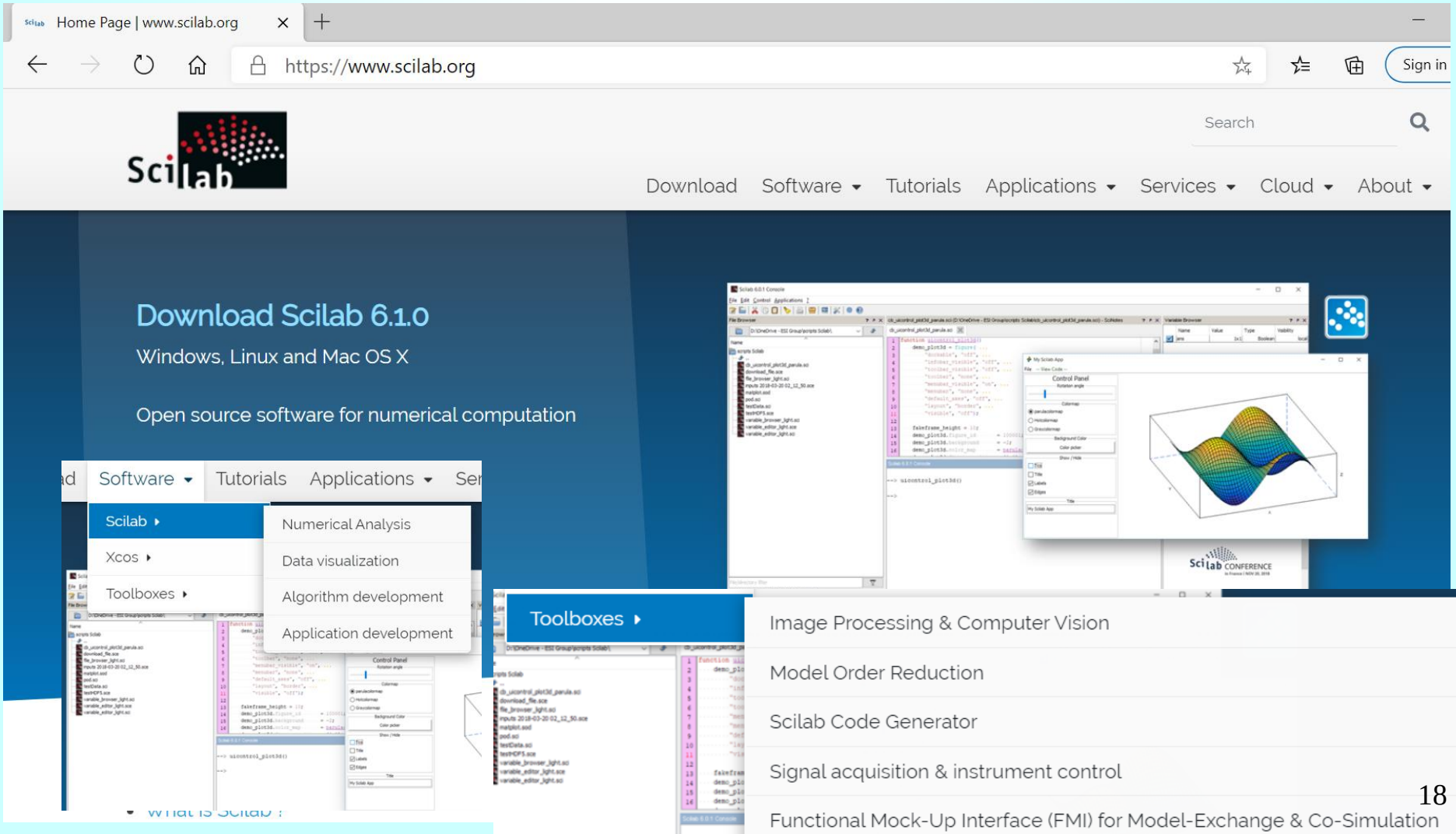






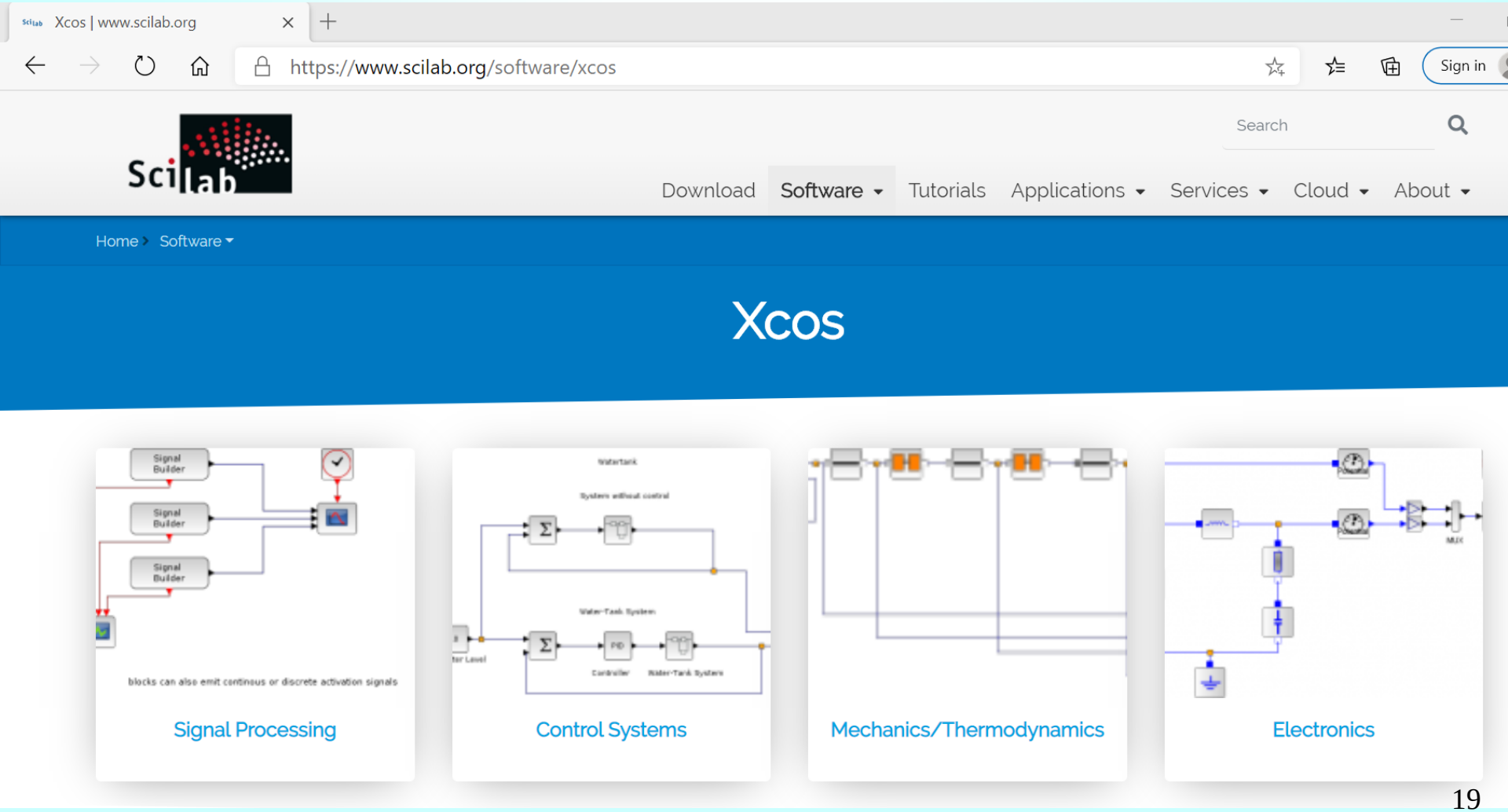
SciLab

https://www.scilab.org/



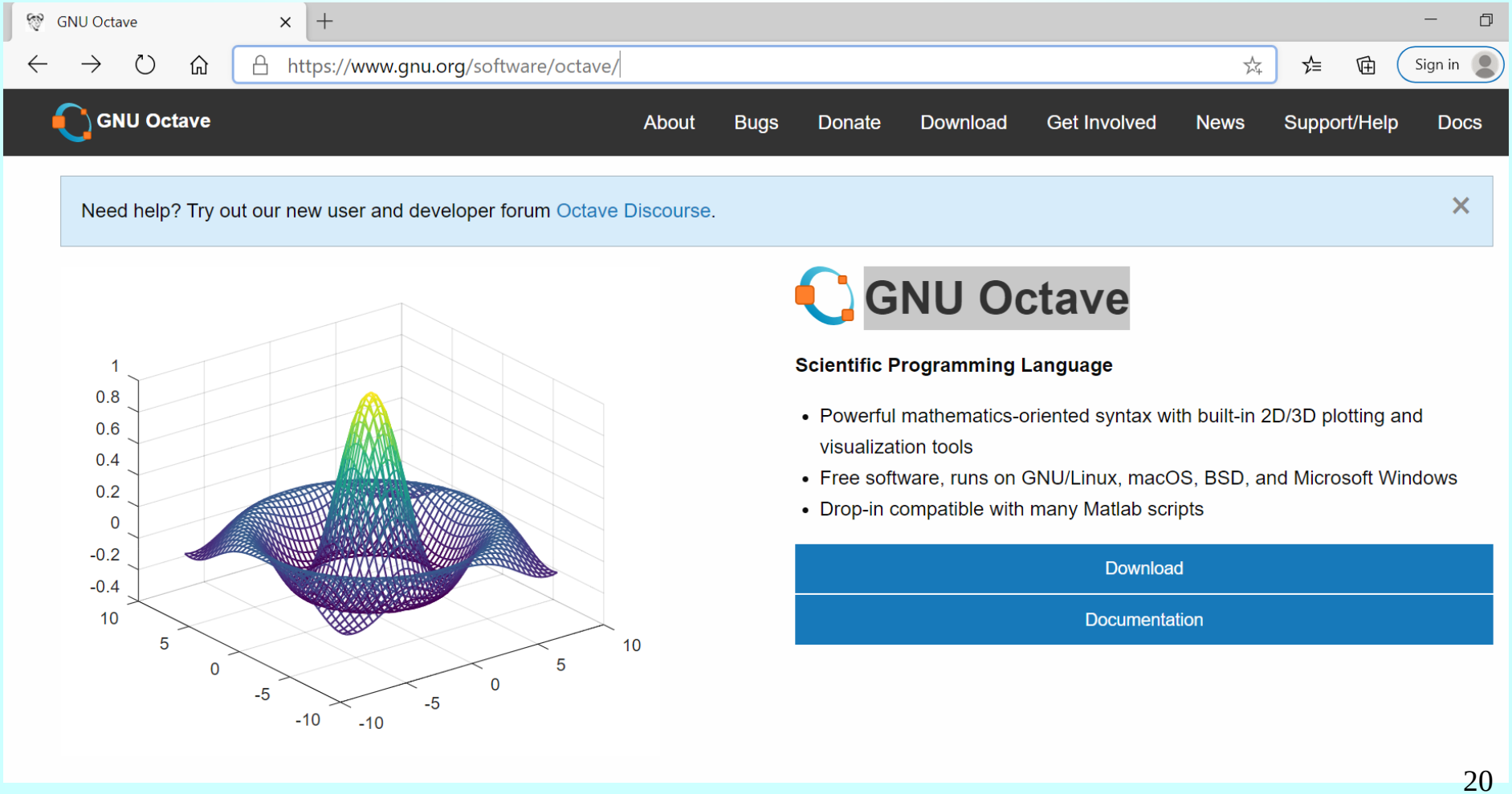
Xcos

https://www.scilab.org/software/xcos



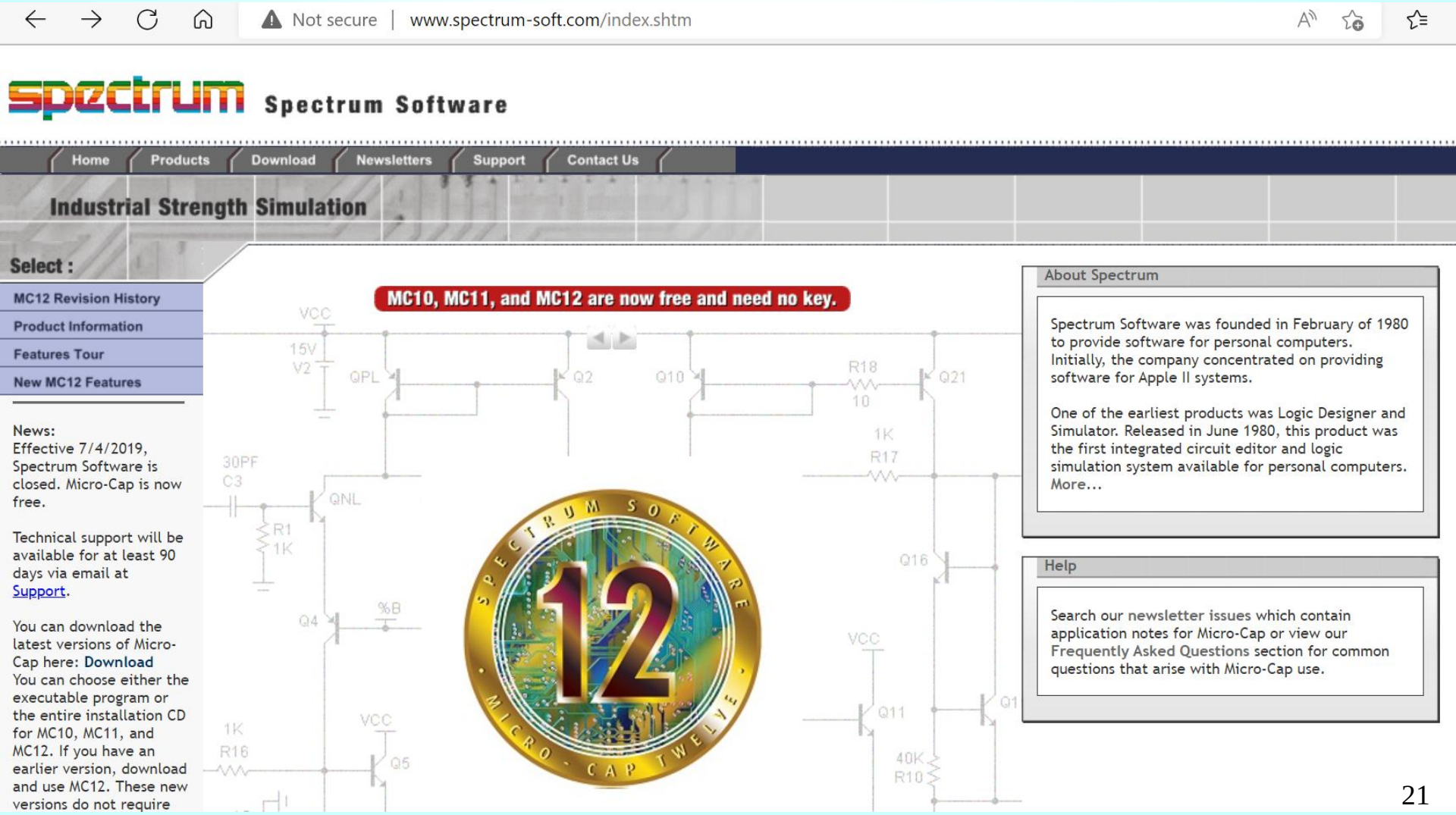
GNU Octave

https://www.gnu.org/software/octave/



Micro-Cap

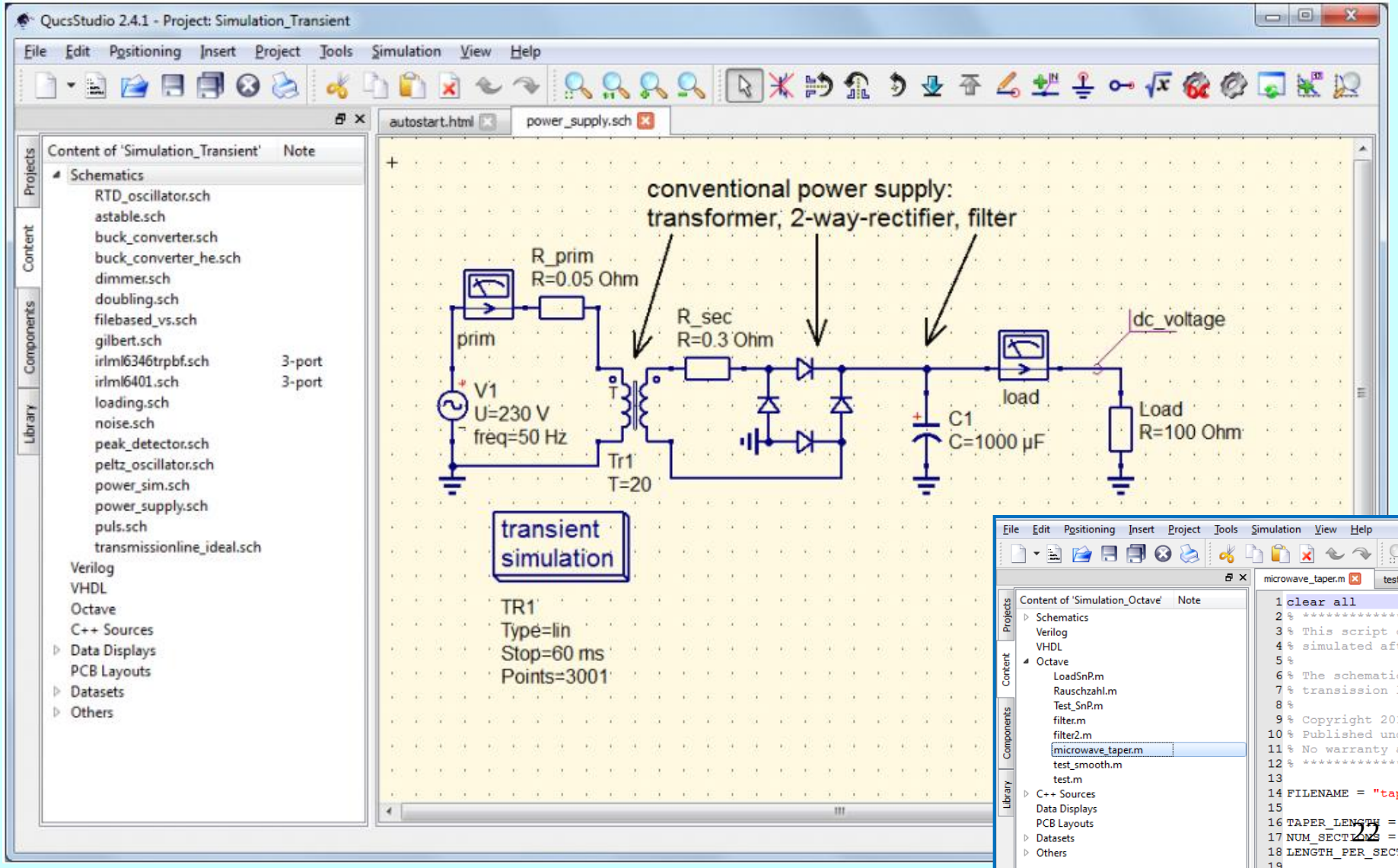
http://www.spectrum-soft.com/index.shtm



QucsStudio

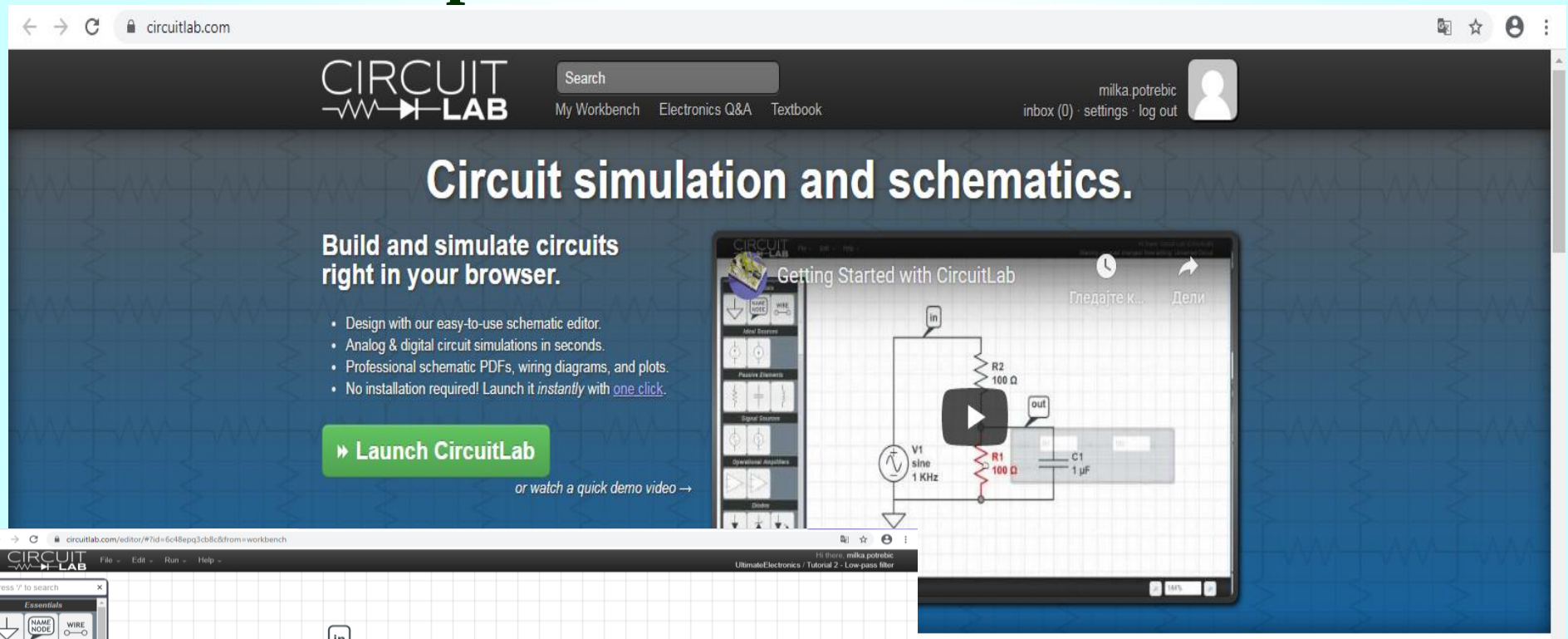
http://qucsstudio.de

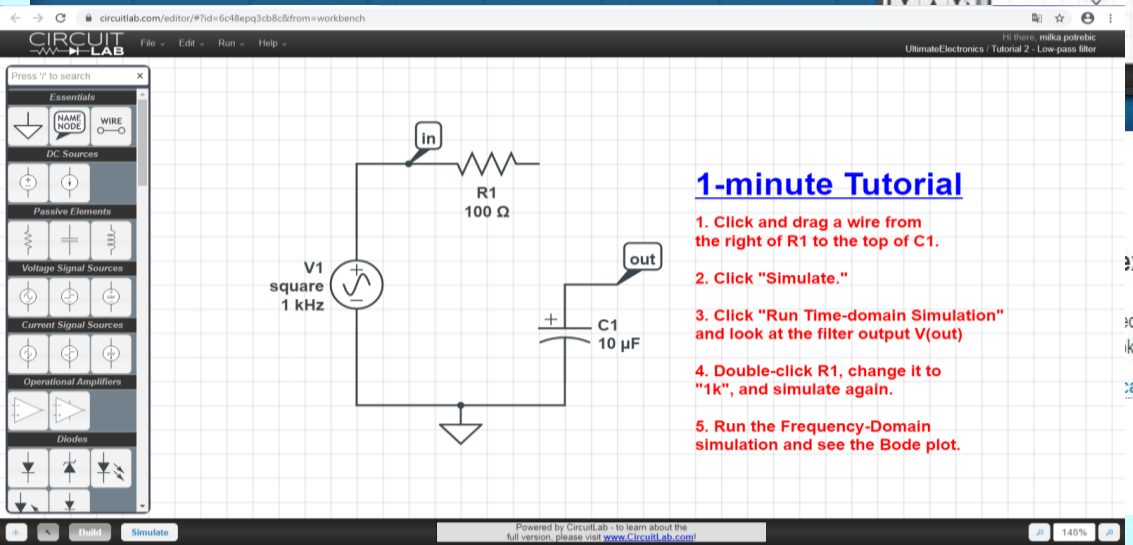
Octave engine inside!



CircuitLab

https://www.circuitlab.com/





DoCircuits Circuit Simulator

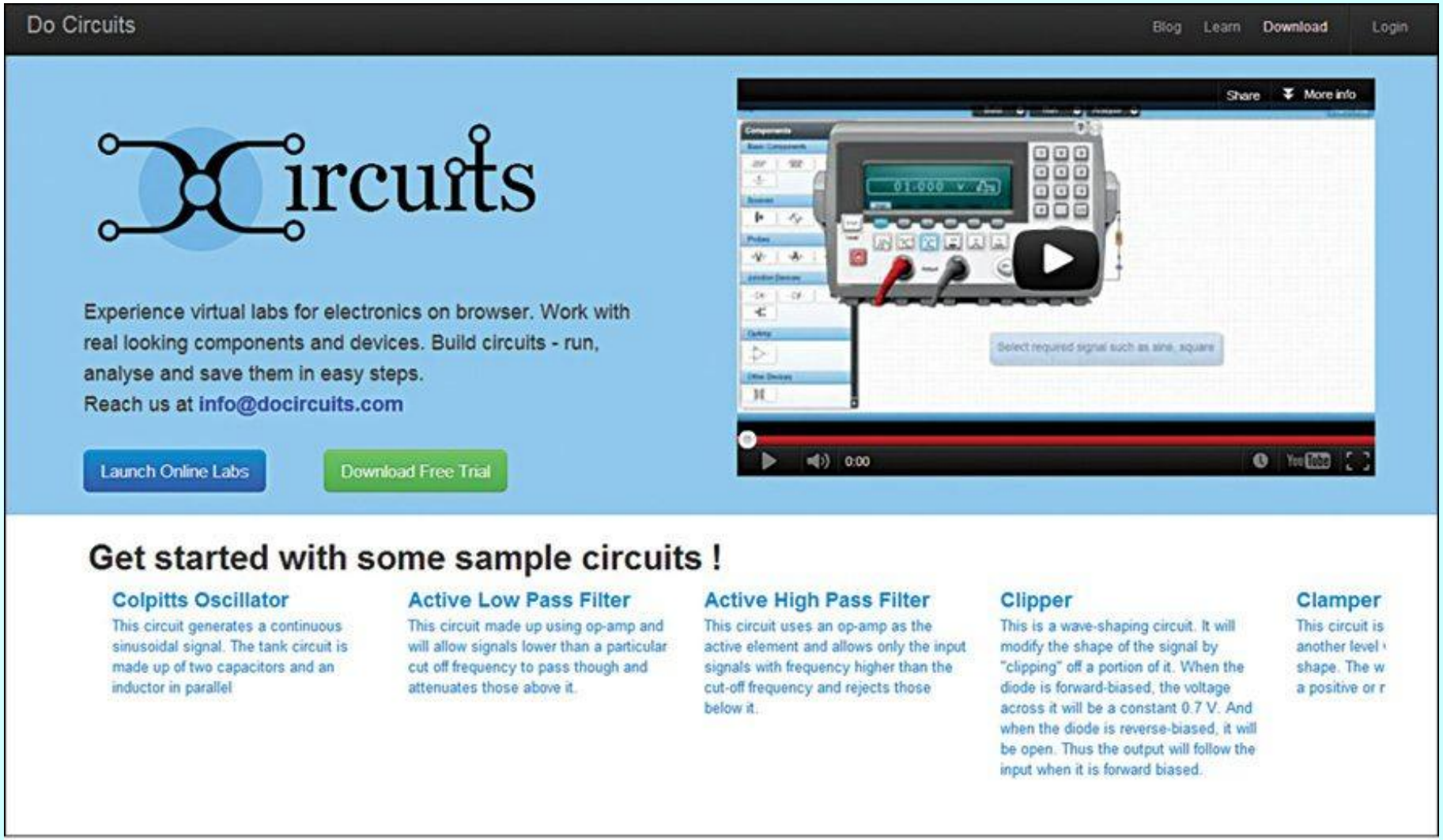


Fig. 1: DoCircuits - Home

ngSpice

http://ngspice.sourceforge.net/

Not secure | ngspice.sourceforge.net

NGSPICE

MIXED MODE - MIXED LEVEL CIRCUIT SIMULATOR

BASED ON BERKELEY'S SPICE3F5

NGSPICE SUMMARY

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- Home
- What is ngspice ?
- Features, Extras & Options
- F.A.Q.
- Tutorials

Sourceforge Developer Pages

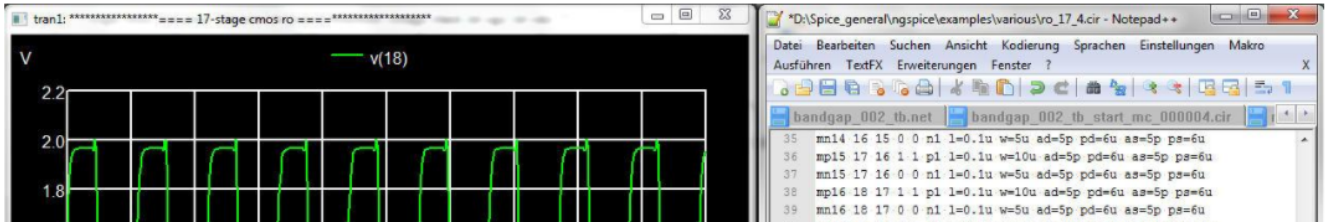
ngspice - open source spice simulator

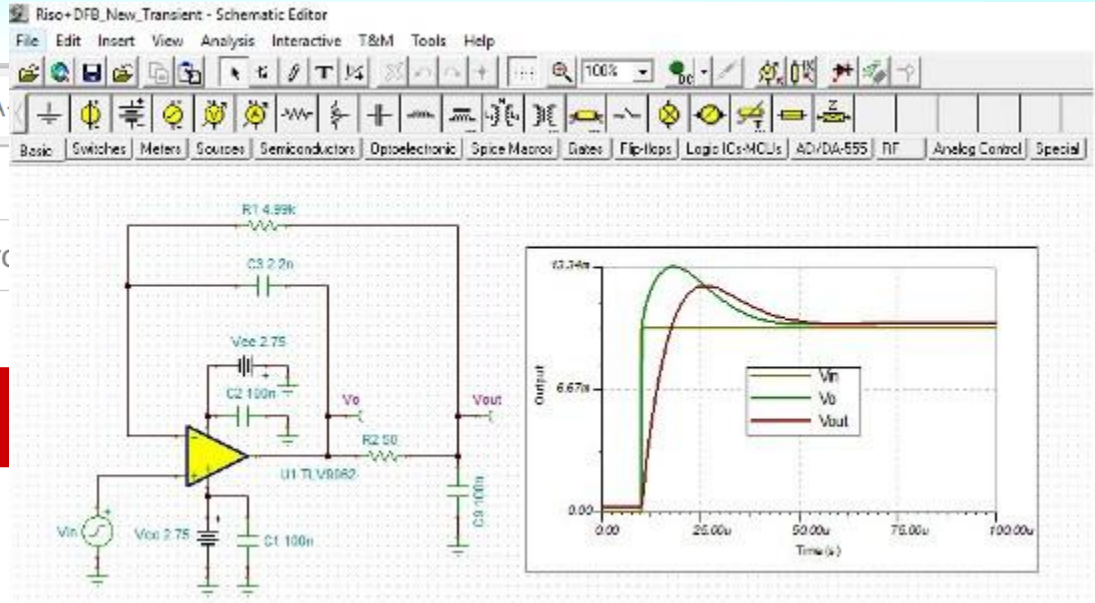
ngspice is the open source spice simulator for electric and electronic circuits.

Such a circuit may comprise of JFETs, bipolar and MOS transistors, passive elements like R, L, or C, diodes, transmission lines and other devices, all interconnected in a netlist. Digital circuits are simulated as well, event driven and fast, from single gates to complex circuits. And you may enter the combination of both analog and digital as a mixed-signal circuit.

ngspice offers a wealth of device models for active, passive, analog, and digital elements. Model parameters are provided by our collections, by the semiconductor device manufacturers, or from semiconductor foundries. The user adds her circuits as a netlist, and the output is one or more graphs of currents, voltages and other electrical quantities or is saved in a data file.

ngspice does not provide schematic entry. Its input is command line or file based. There are however third party interfaces available.





https://www.ti.com/tool/TINA-

TEXAS INSTRUMENTS

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TINA-TI

SPICE-based analog simulation program

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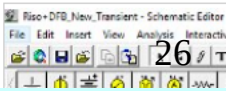
TINA-TI

https://www.ti.com/tool/TINA-TI

Overview

TINA-TI provides all the conventional DC, transient and frequency domain analysis of SPICE and much more. TINA has extensive post-processing capability that allows you to format results the way you want them. Virtual instruments allow you to



Electric Circuit Studio

https://play.google.com/store/apps/details?id=com.ecstudiosystems.electriccircuitstudio&hl=en_US&gl=US

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Electric Circuit Studio

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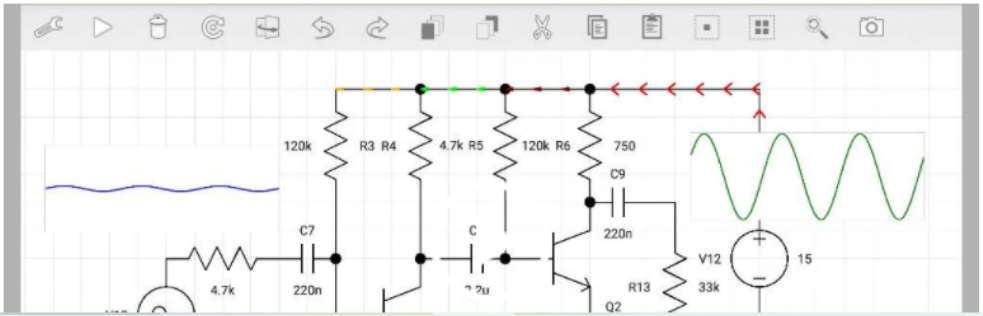

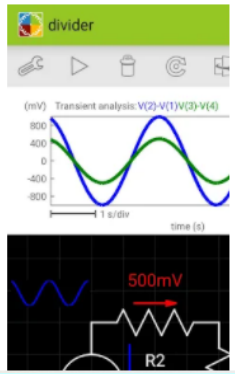

CircuitSafari SPICE Simulator

https://play.google.com/store/apps/details?id=com.logipipe.circuitsafari&hl=en_US&gl=US

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Parent Guide

CircuitSafari SPICE Simulator (Early Access)

Logipipe, LLC Productivity

Everyone

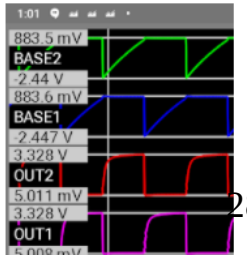
Offers in-app purchases

This app is in development. It may be unstable.

You don't have any devices

Add to Wishlist

Install



MATLAB

MathWorks - Makers of MATLAB

https://www.mathworks.com

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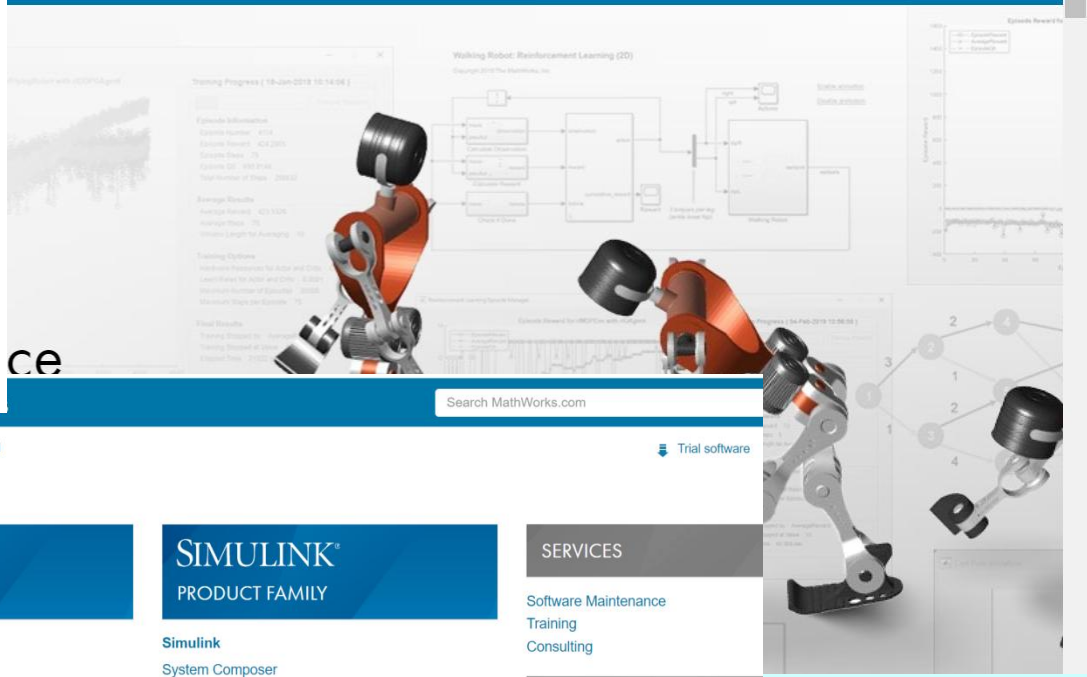
Millions of Engineers and Scientists Trust MATLAB

MATLAB® combines a desktop environment tuned for iterative analysis and design processes with a programming language that expresses matrix and array mathematics directly. It includes the Live Editor for creating scripts that combine code, output, and formatted text in an executable notebook.



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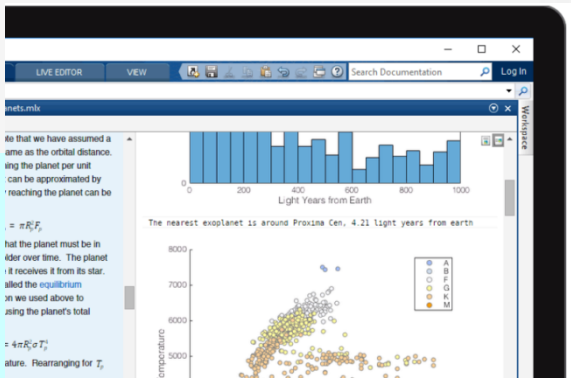

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MATLAB

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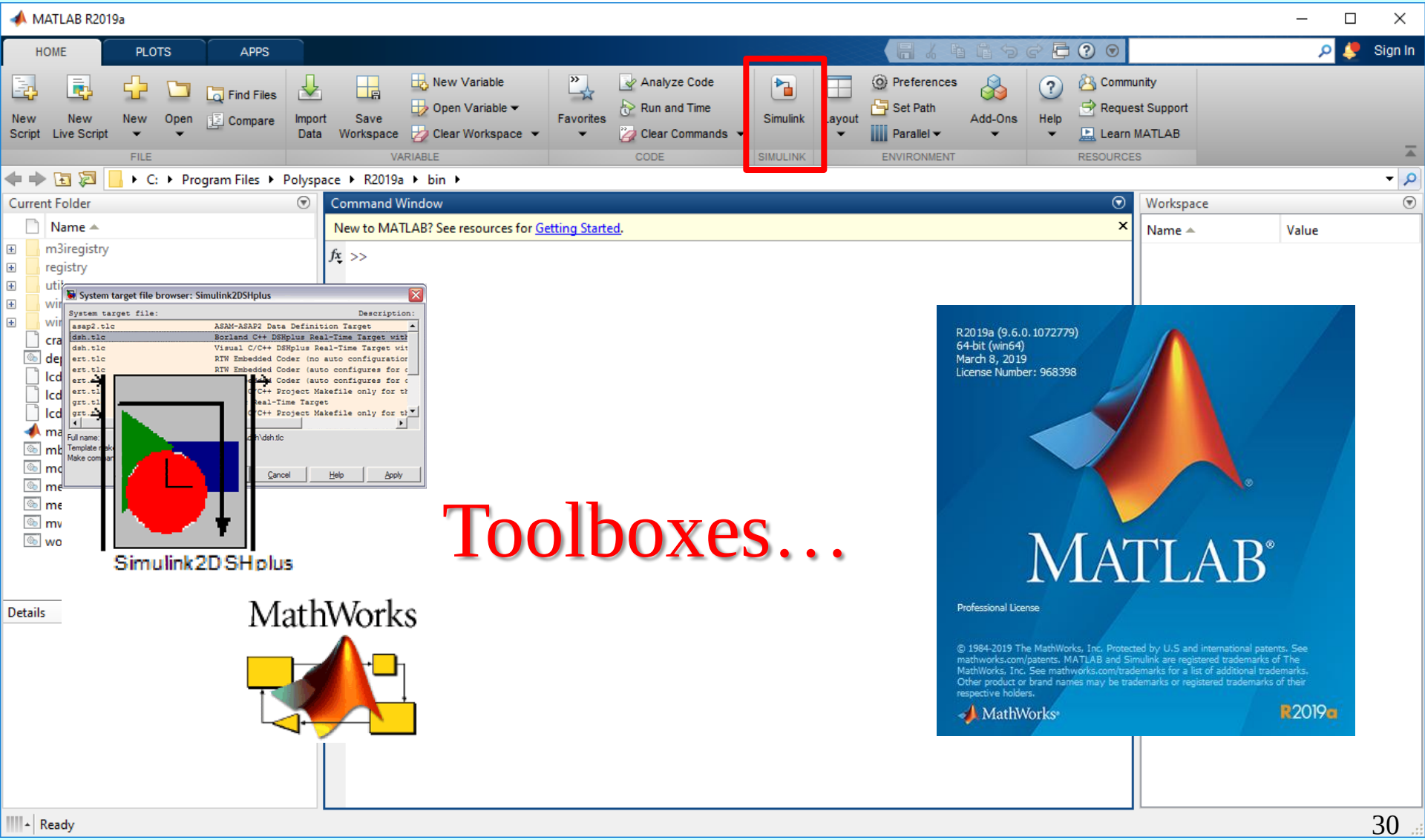
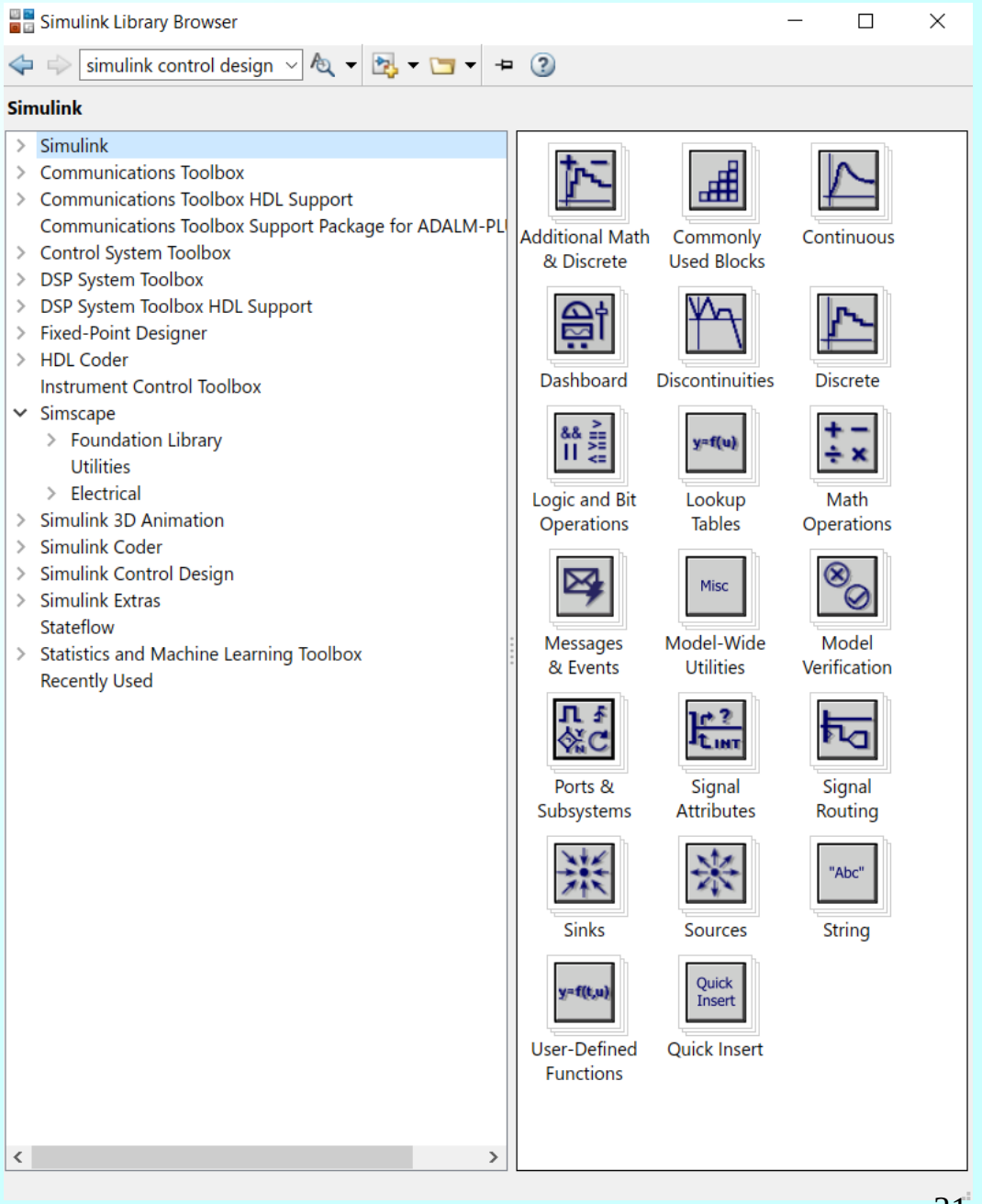


Toolboxes…

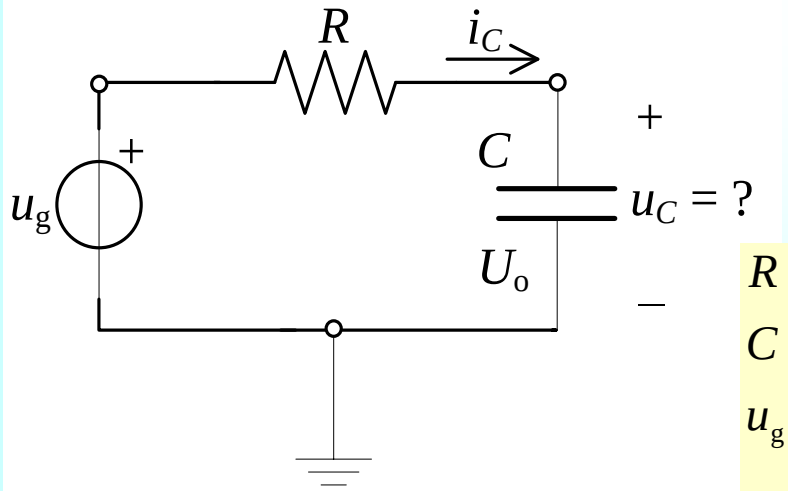
MATLAB Simulink

- Алатка за нумеричку анализу математичких модела
- Систем се дефинише графички, уметањем блокова и њиховим повезивањем у мрежу

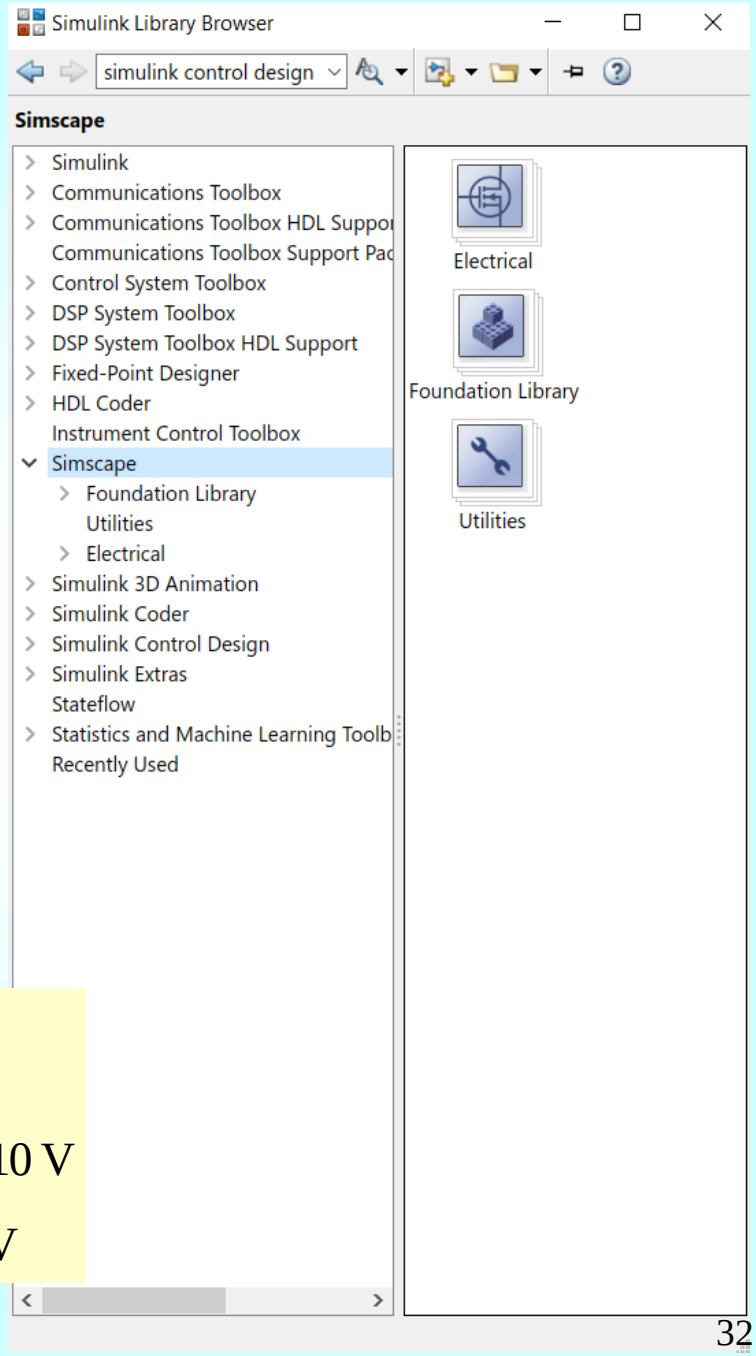


Simulink > Simscape

- Библиотека за симулацију и нумеричку анализу мултидоменских проблема (механика, електродинамика, оптика)
- Пример једноставног електричног кола:

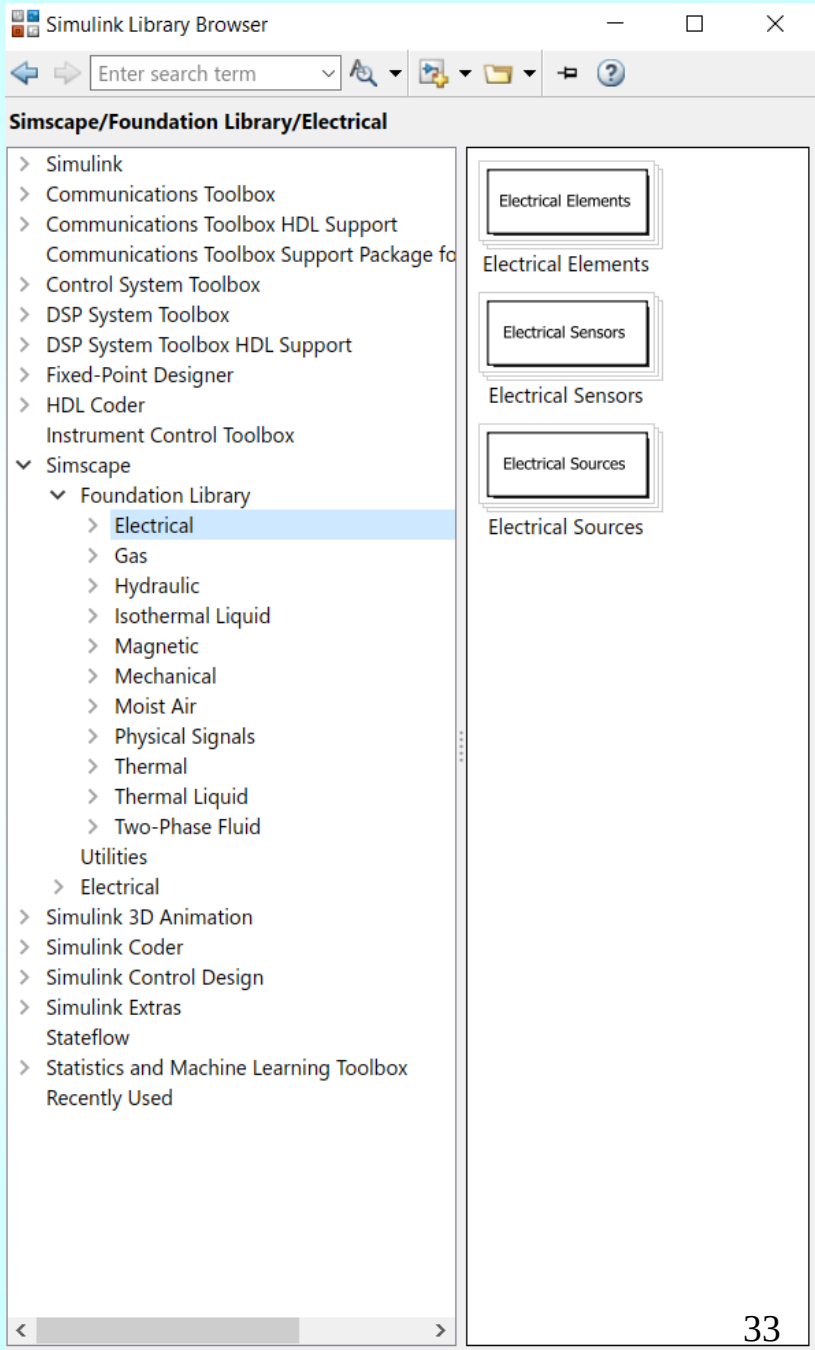


$$R = 1\,\mathrm{k\Omega}$$
$$C = 1\,\mu\mathrm{F}$$
$$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$$
$$u_C(t_0^-) = U_0 = -10\,\mathrm{V}$$



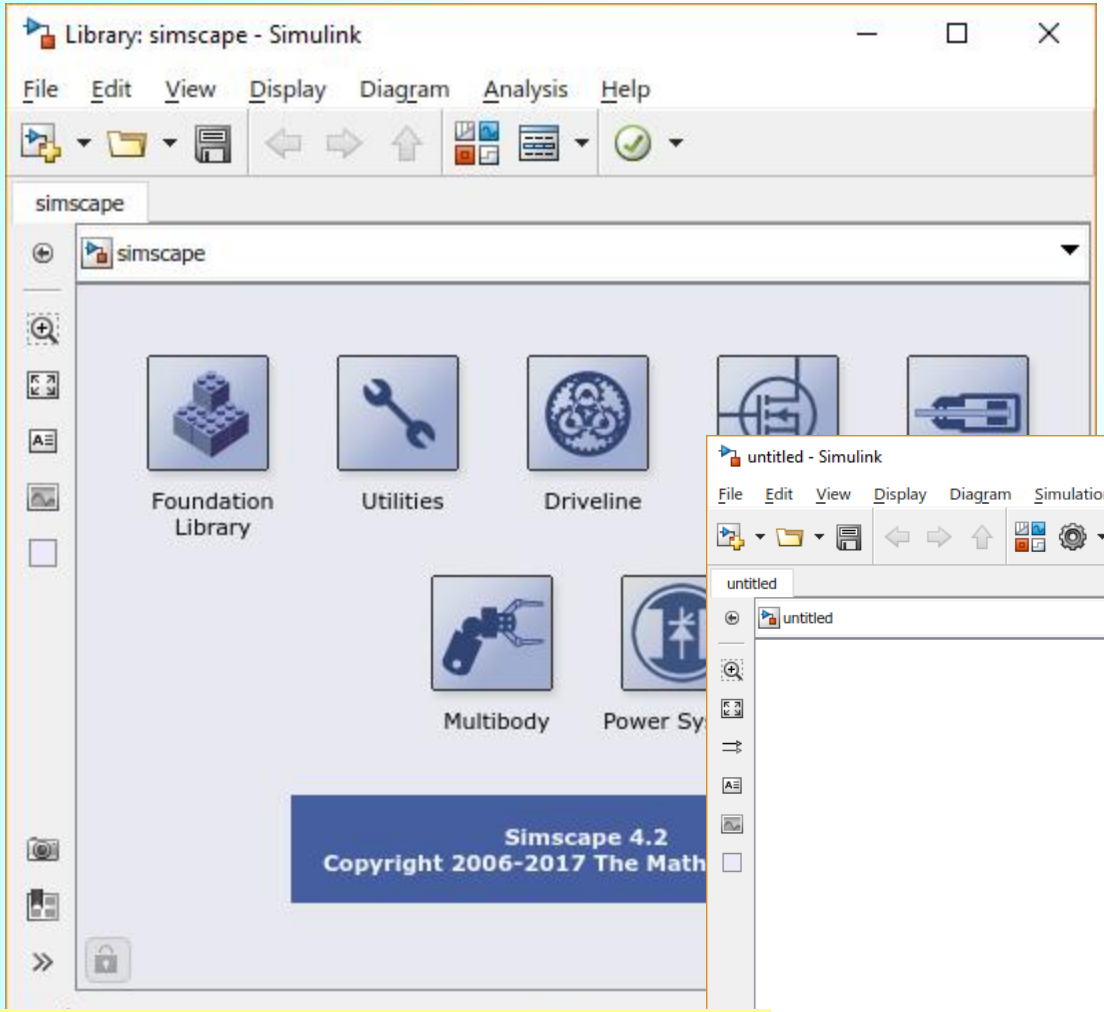
Simulink > Simscape > Foundation Library > Electrical

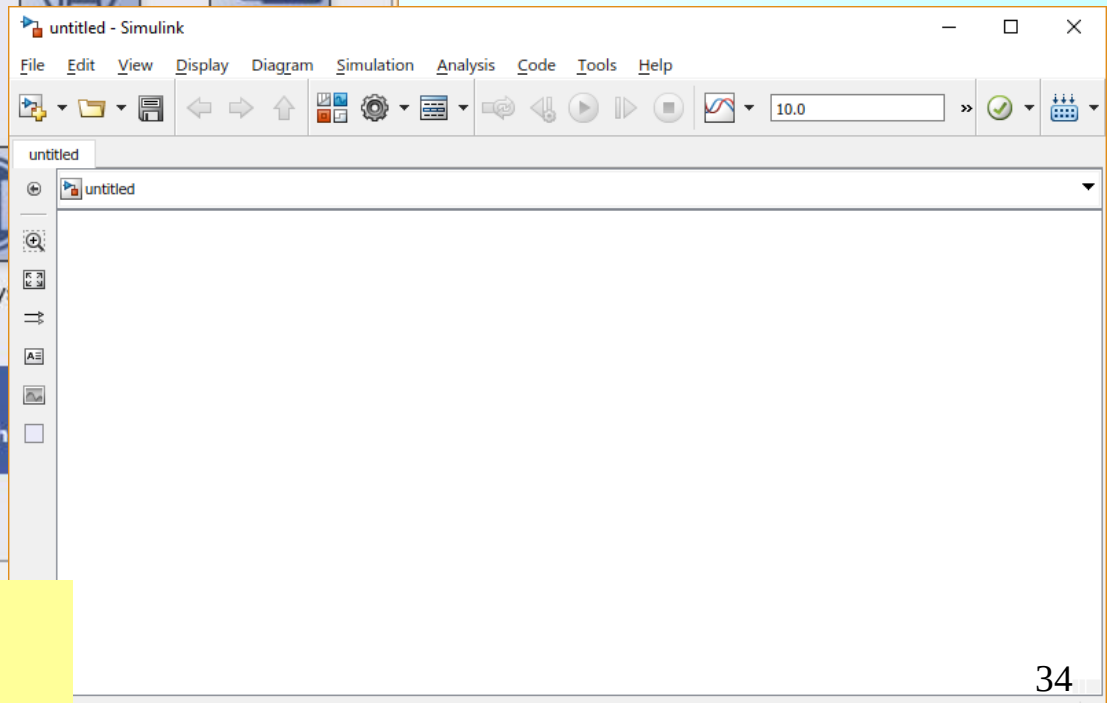
- Симулација линеарних и нелинеатних електричних кола



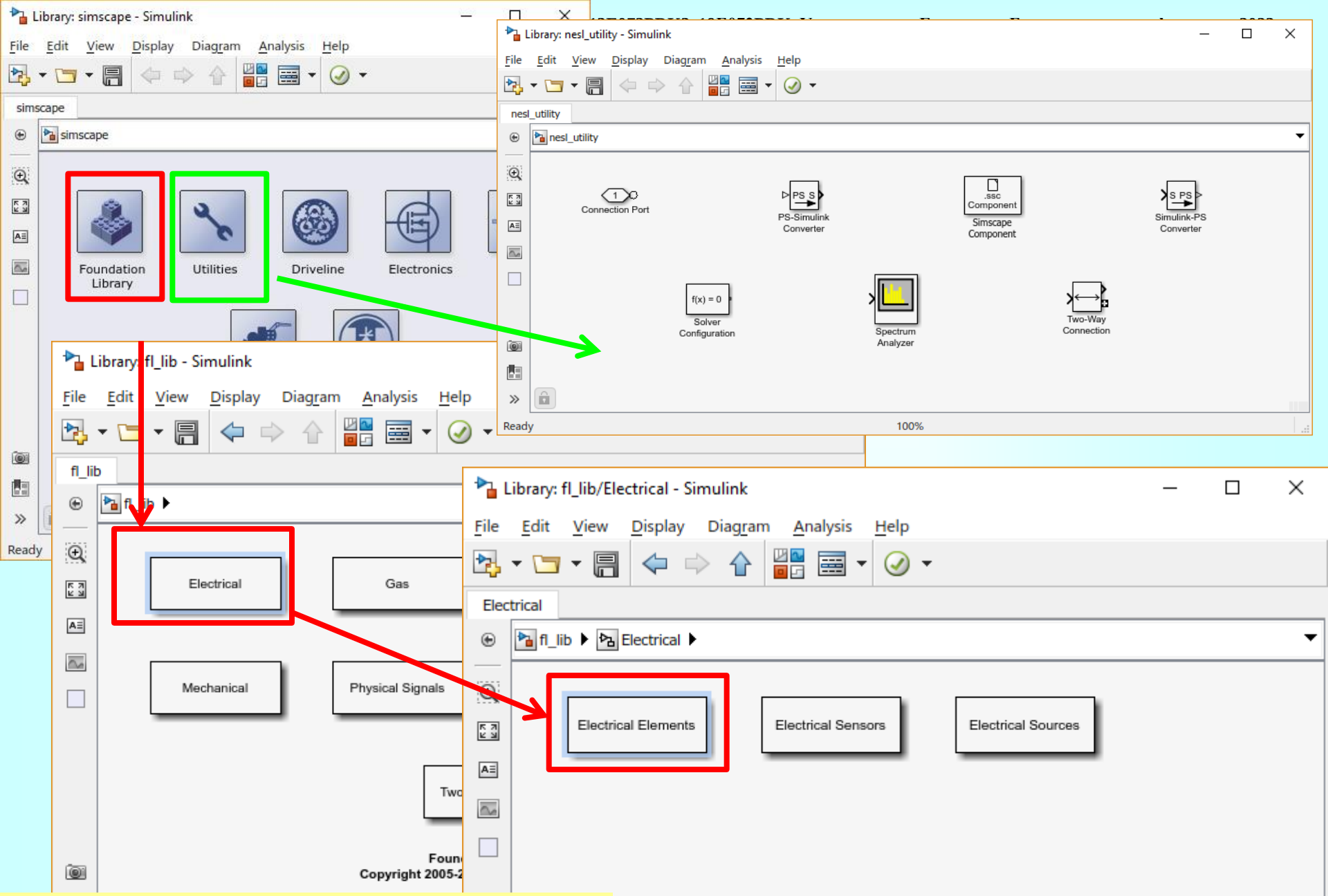
MATLAB > Simscape > Foundation Library, Utilities

Симулација електричног кола коришћењем **Simscape > Foundation Library** библиотеке



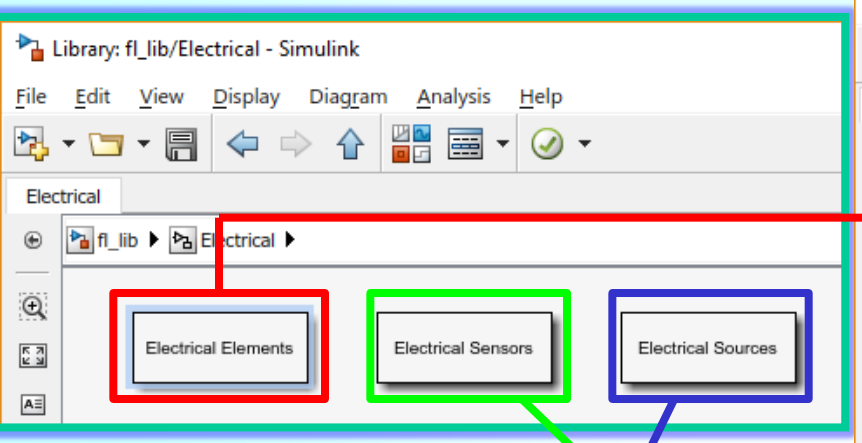


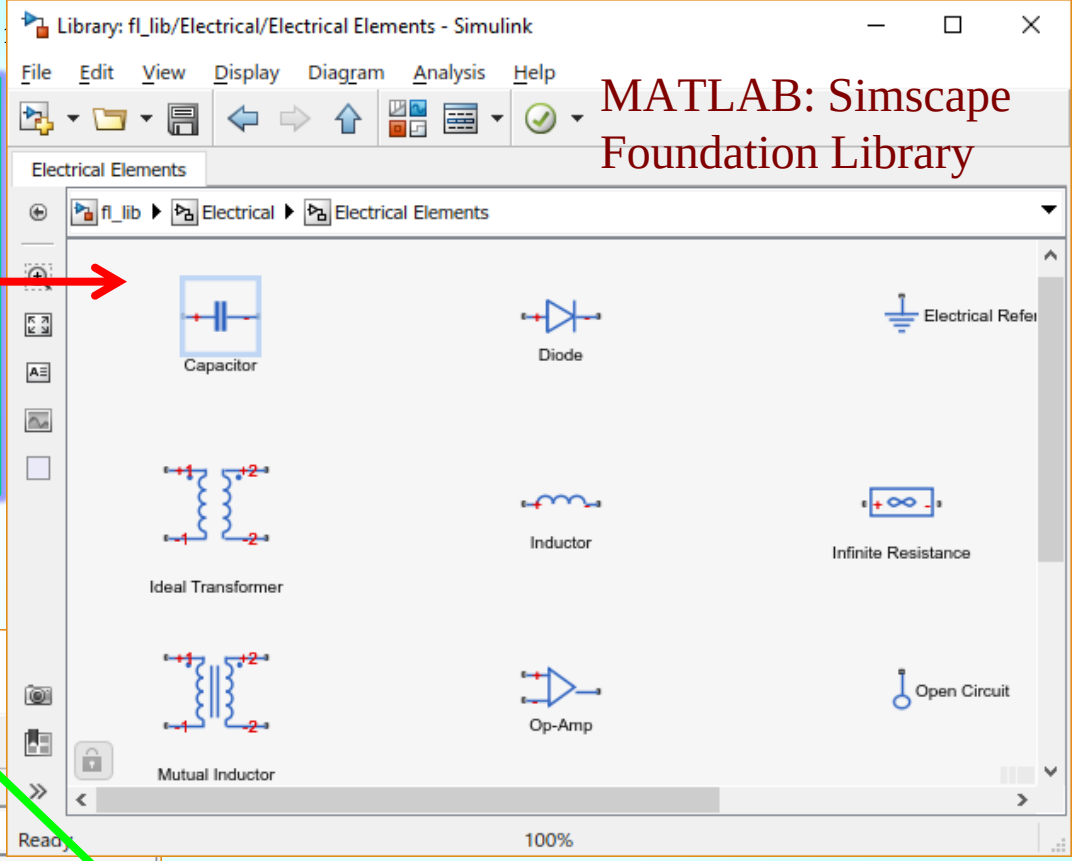
MATLAB > Simscape > Foundation Library, Utilities

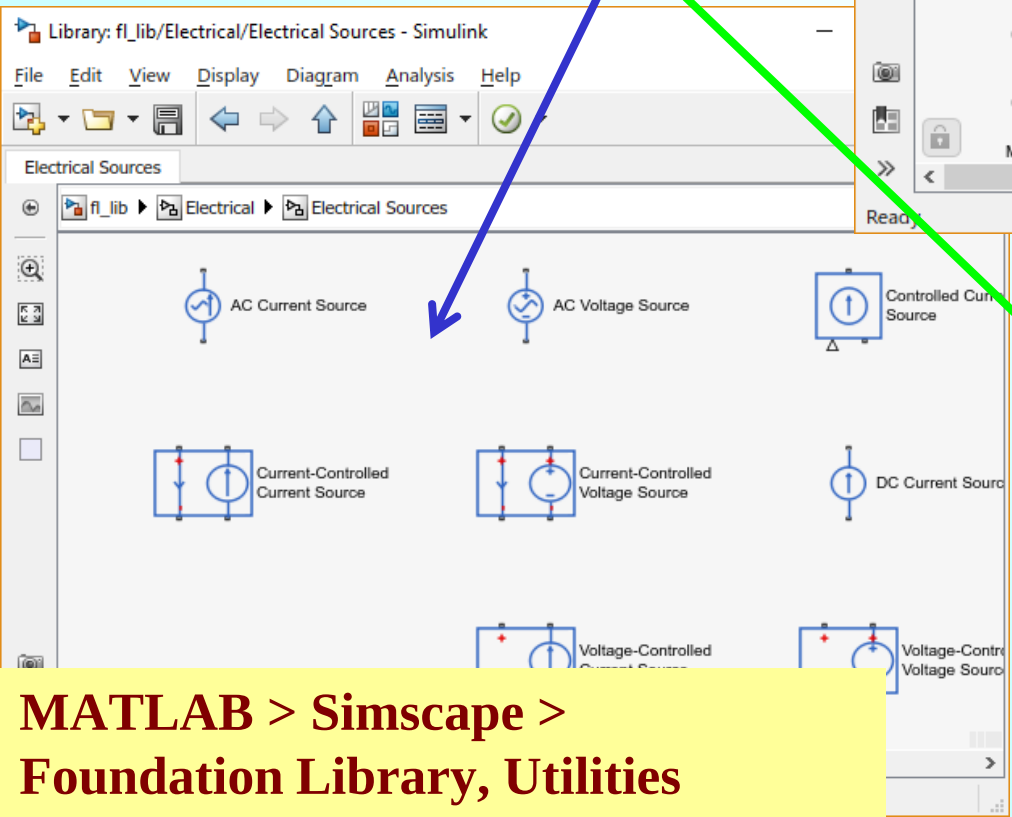


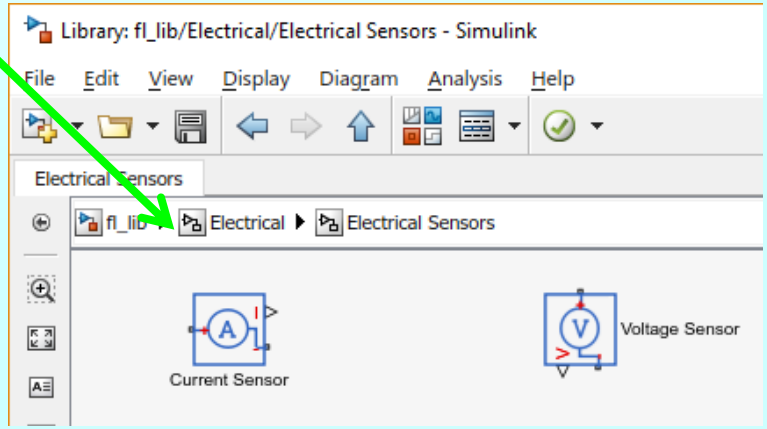
MATLAB > Simscape > Foundation Library, Utilities

MATLAB: Simscape Foundation Library



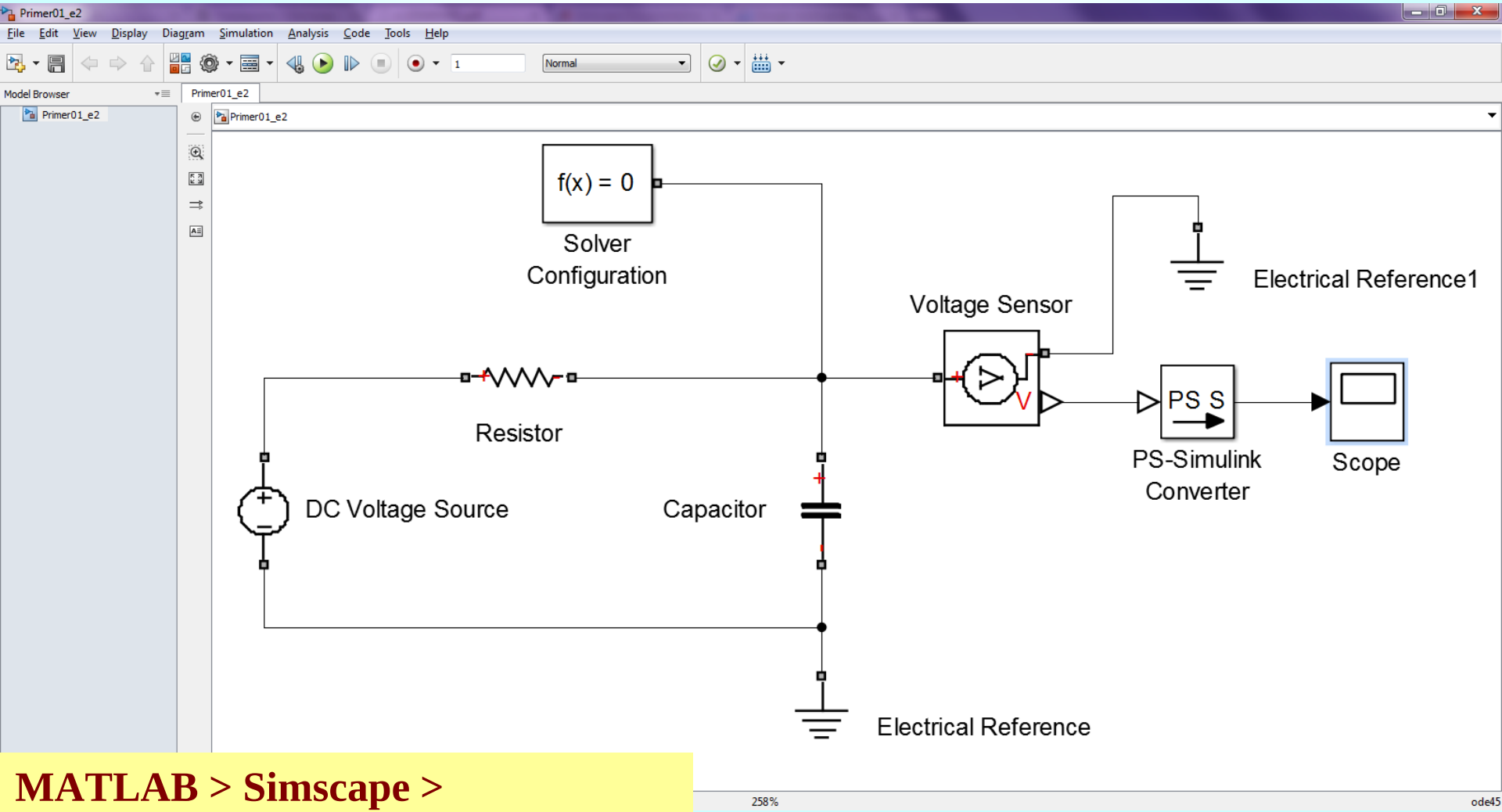




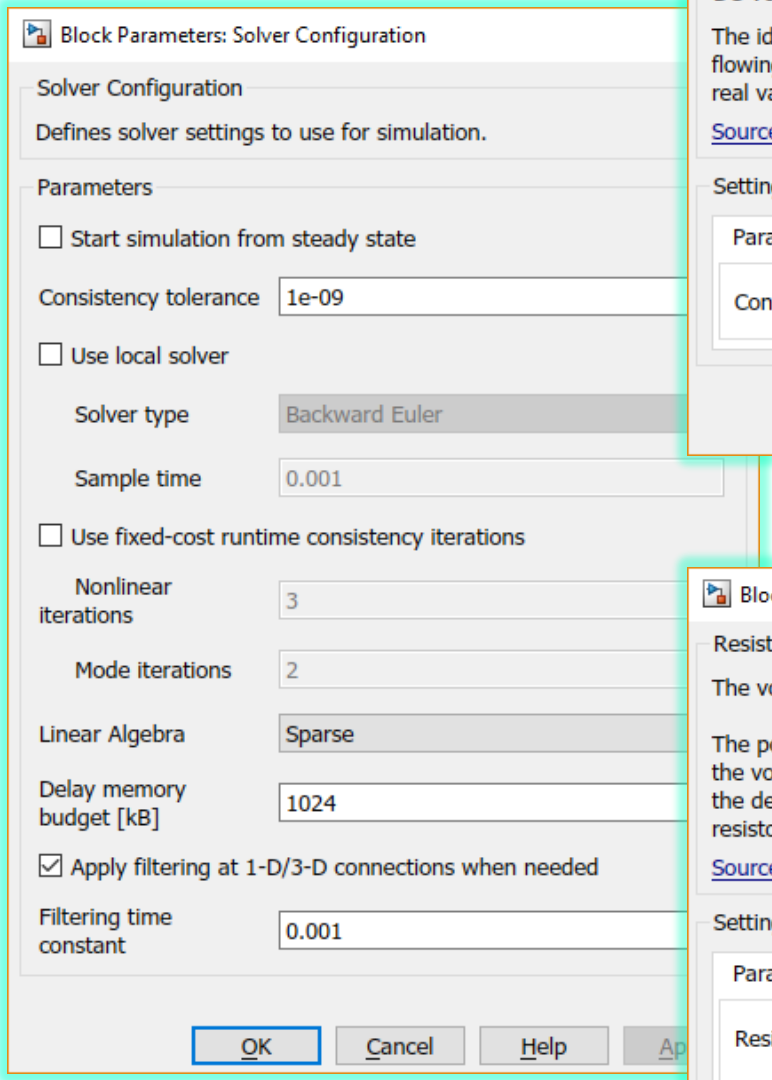


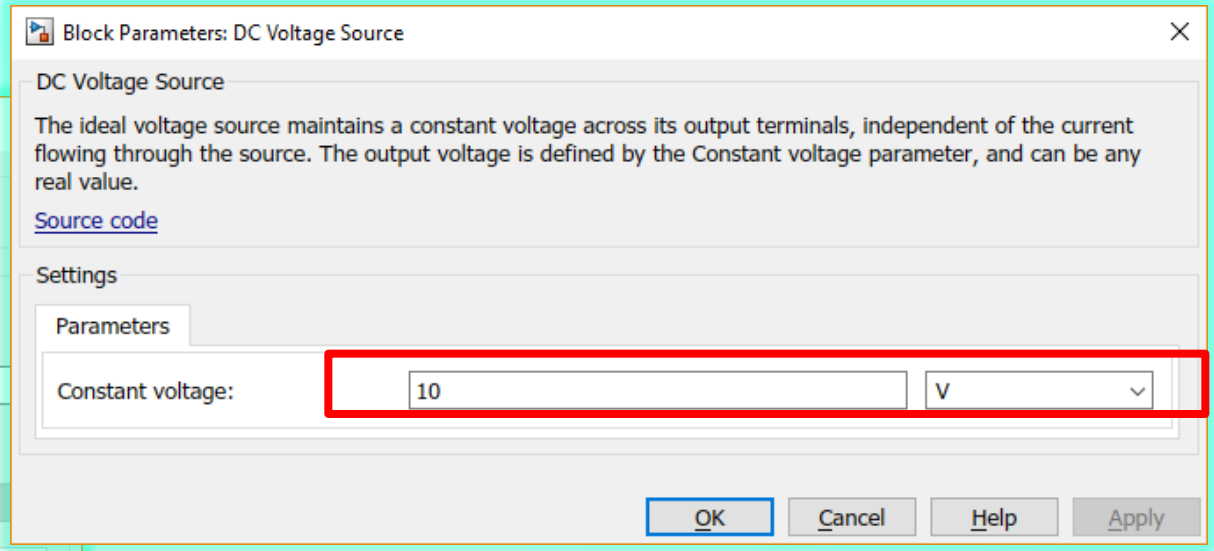
MATLAB > Simscape > Foundation Library, Utilities

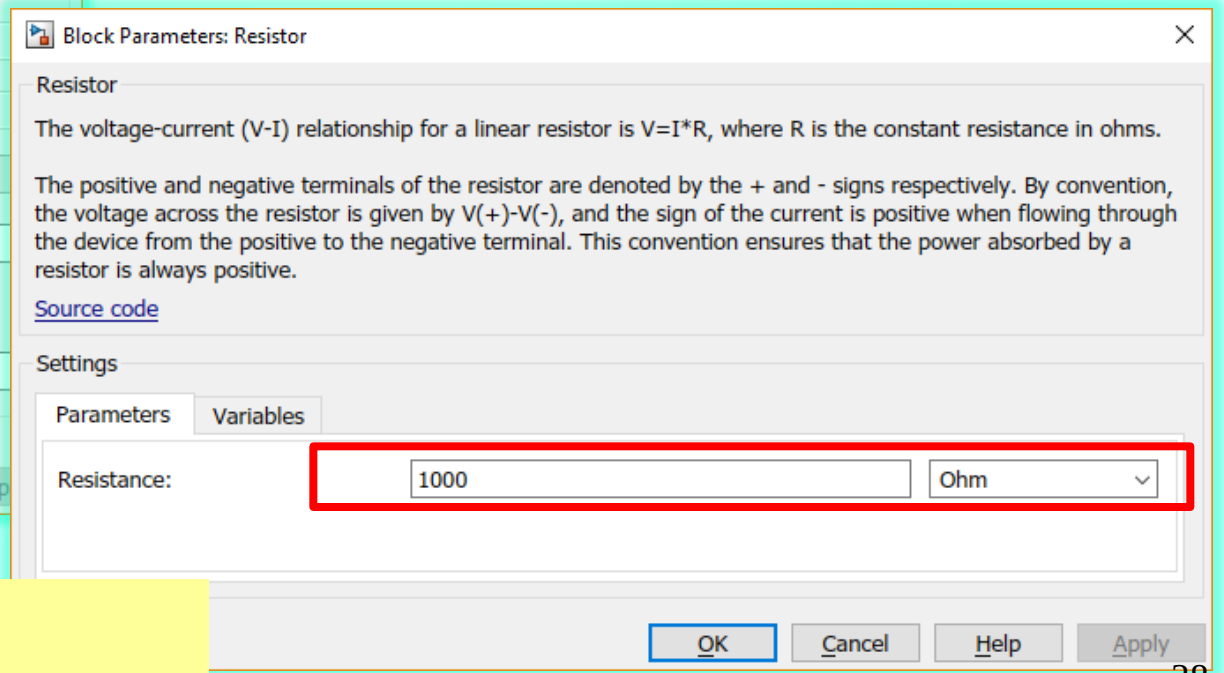
Симулација електричног кола коришћењем **Simscape > Foundation Library** библиотеке



MATLAB > Simscape > Foundation Library, Utilities







MATLAB > Simscape > Foundation Library, Utilities

Почетни услов...

Block Parameters: Capacitor

Capacitor

Models a linear capacitor. The relationship between voltage V and and current I is I=C*dV/dt where C is the capacitance in farads.

The Series resistance and Parallel conductance represent small parasitic effects. The parallel conductance can be used to model dielectric losses and the series resistance used to represent the effective series resistance (ESR) of the capacitor. Simulation of some circuits may require the presence of the small series resistance. Consult the documentation for further details.

Source code

Settings

Parameters | Variables

Capacitance:	1e-6	F
Series resistance:	0	Ohm
Parallel conductance:	0	1/Ohm

OK | Cancel | Help | Apply

*dV/dt where C is the capacitance in farads.

arallel conductance can be used to model
nce (ESR) of the capacitor. Simulation of
mentation for further details.

Settings

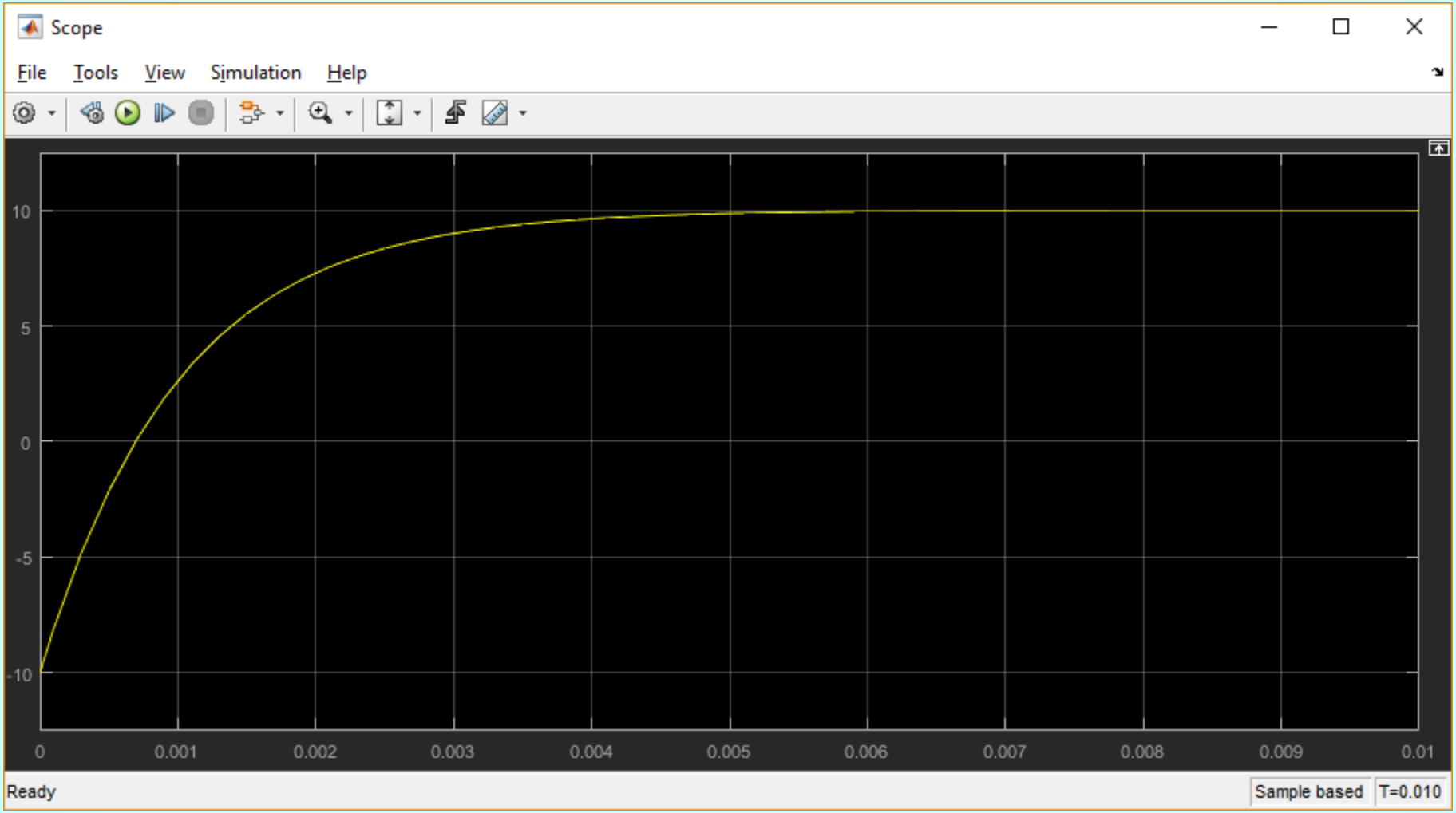
Parameters | Variables

Override	Variable	Priority	Beginning Value	Unit
☐	Current	None	0	A
☐	Voltage	None	0	V
☑	Capacitor voltage	High	-10	V

OK | Cancel | Help | Apply

MATLAB > Simscape > Foundation Library, Utilities

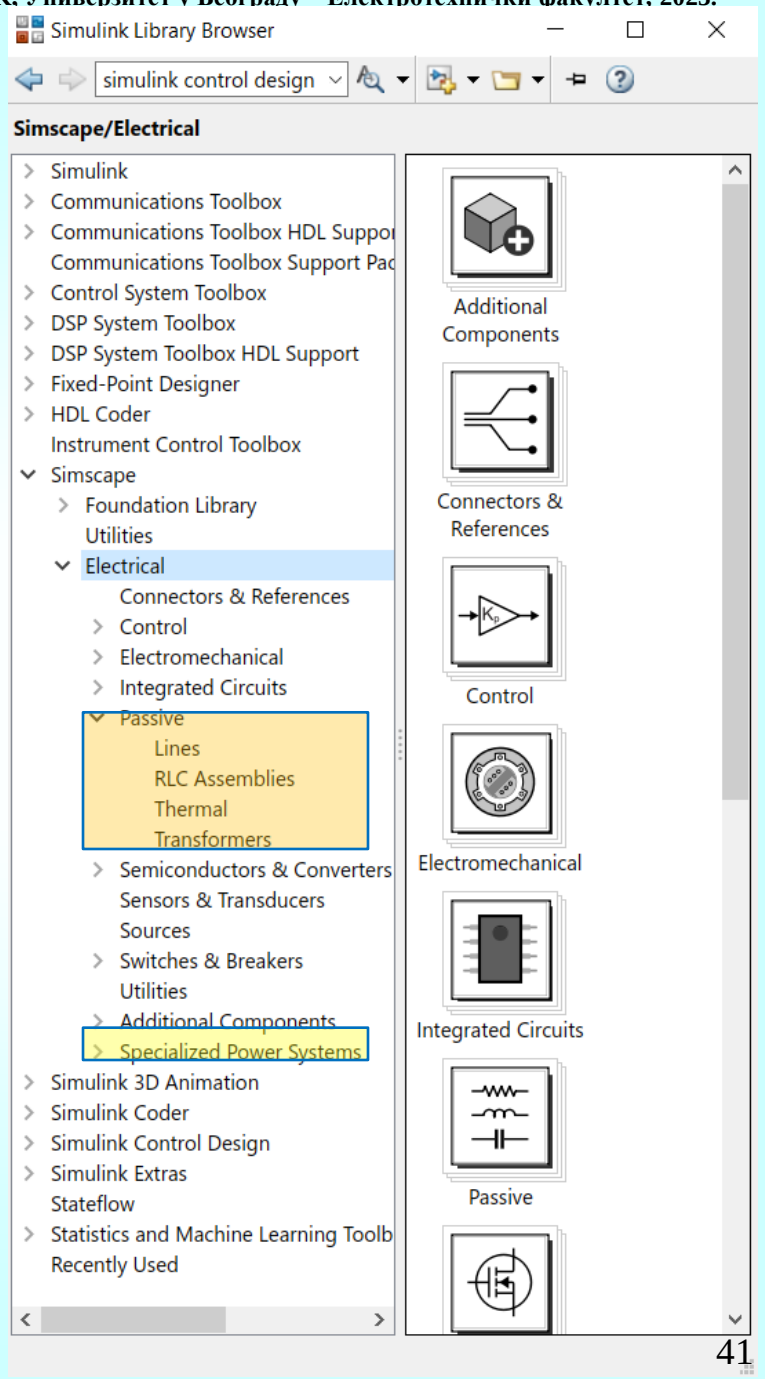
Налажење одзива...



MATLAB > Simscape > Foundation Library, Utilities

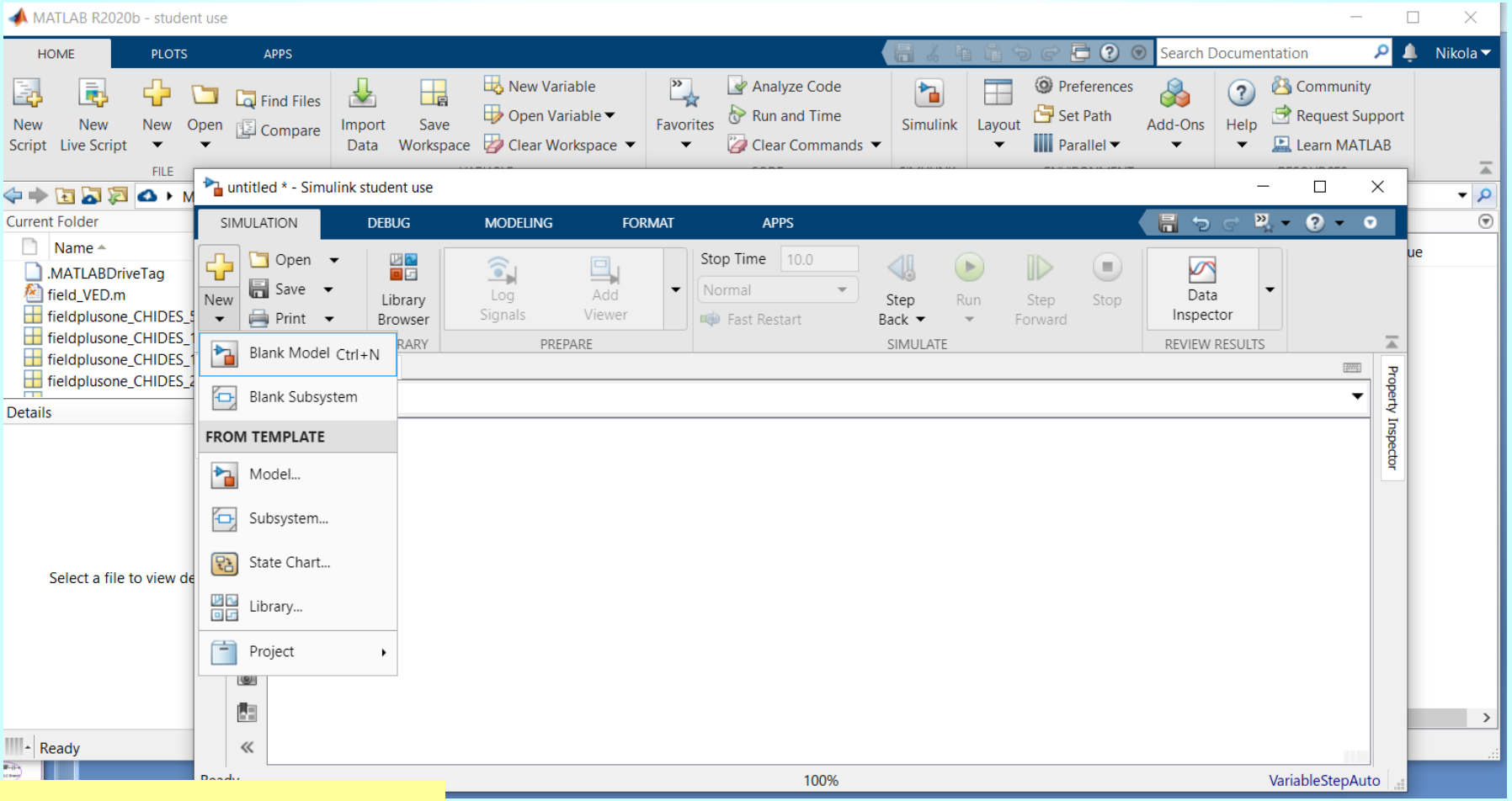
Simulink > Simscape > Electrical

- Библиотека за симулацију и нумеричку анализу електроенергетских система
- Трофазни извори, водови, трансформатори, потрошачи
- Термална анализа



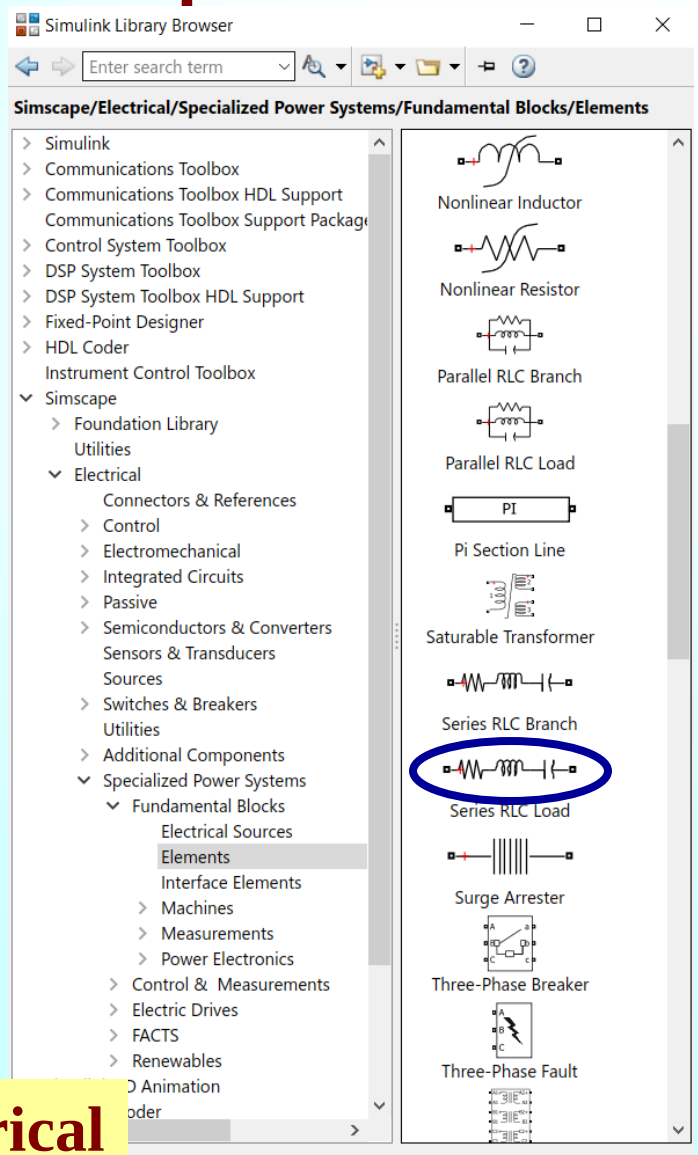
Simscape > Electrical

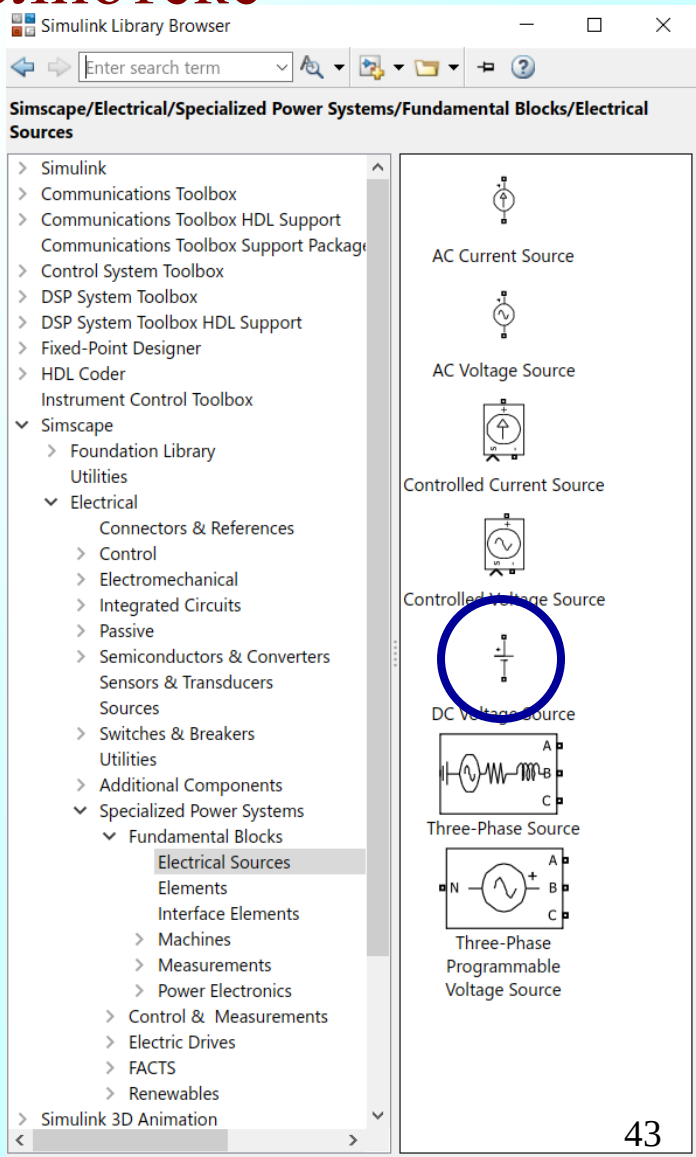
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке



Simscape > Electrical

Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

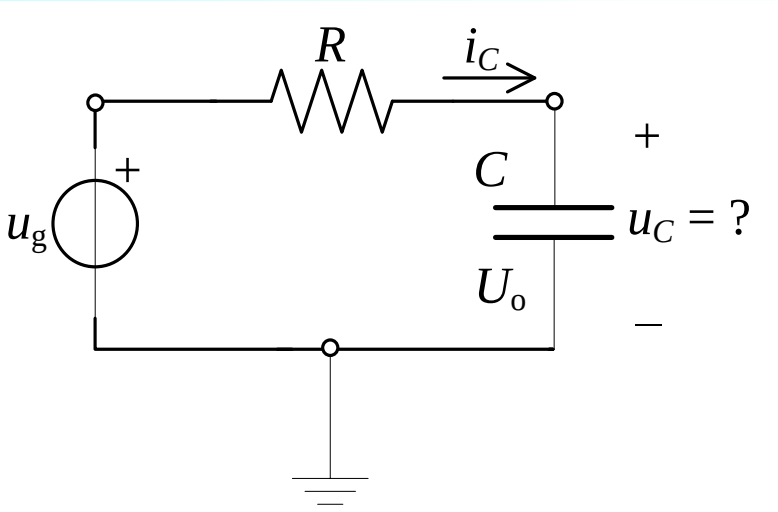


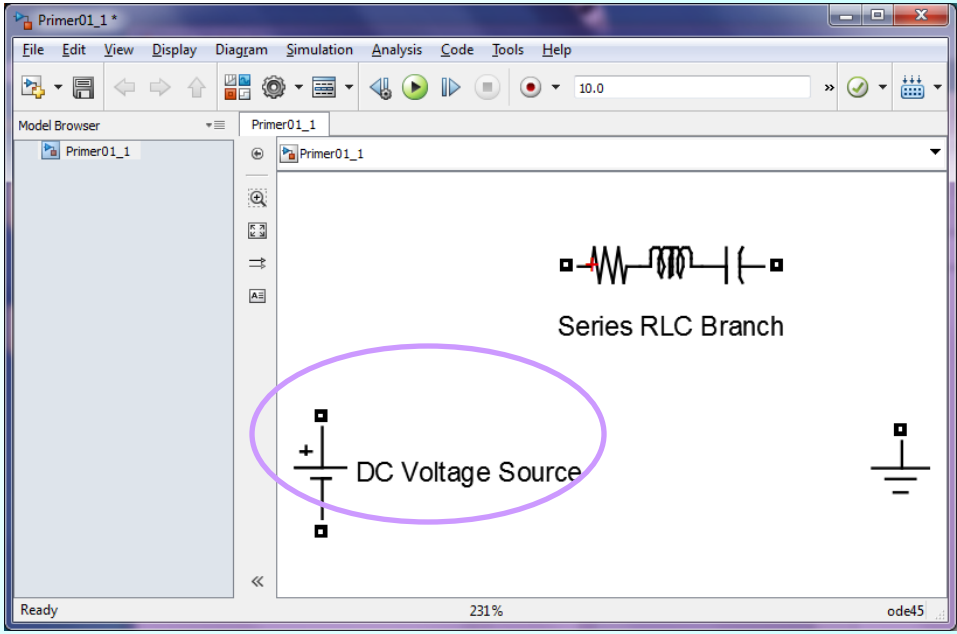


Simscape > Electrical

Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

коло је образовано у тренутку $t_0 = 0$



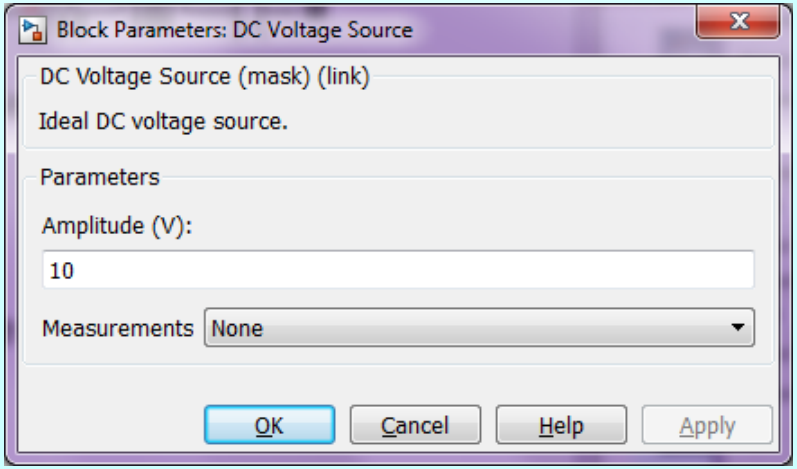


$R = 1\,\mathrm{k\Omega}$

$C = 1\,\mu\mathrm{F}$

$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$

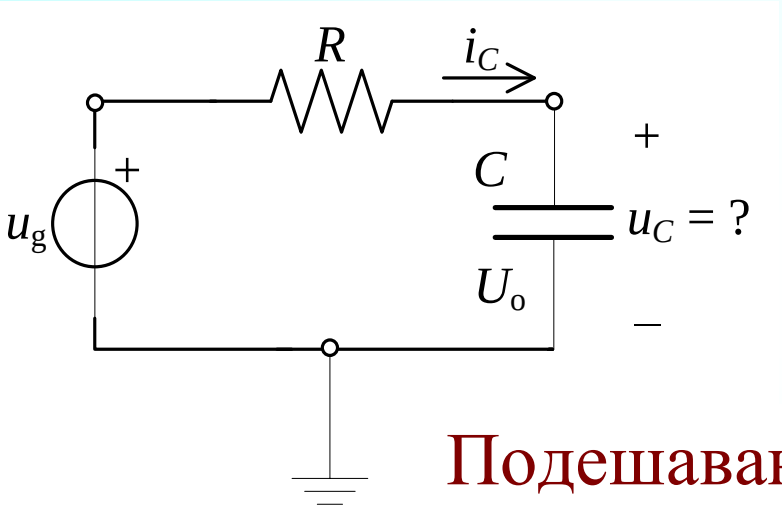
$u(t_0^-) = U_0 = -10\,\mathrm{V}$



Simscape > Electrical

Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

коло је образовано у тренутку $t_0 = 0$



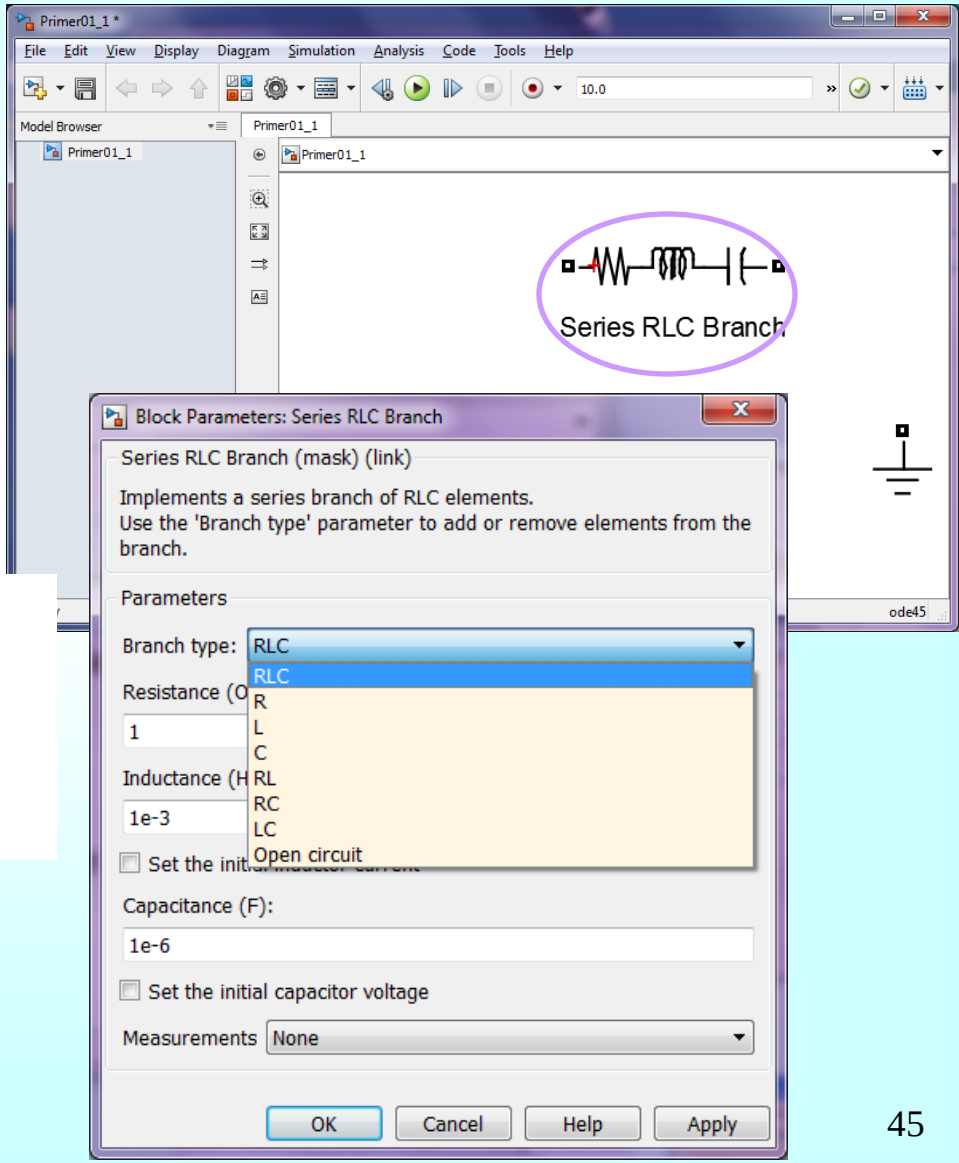
$R = 1\,\mathrm{k\Omega}$

$C = 1\,\mu\mathrm{F}$

$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$

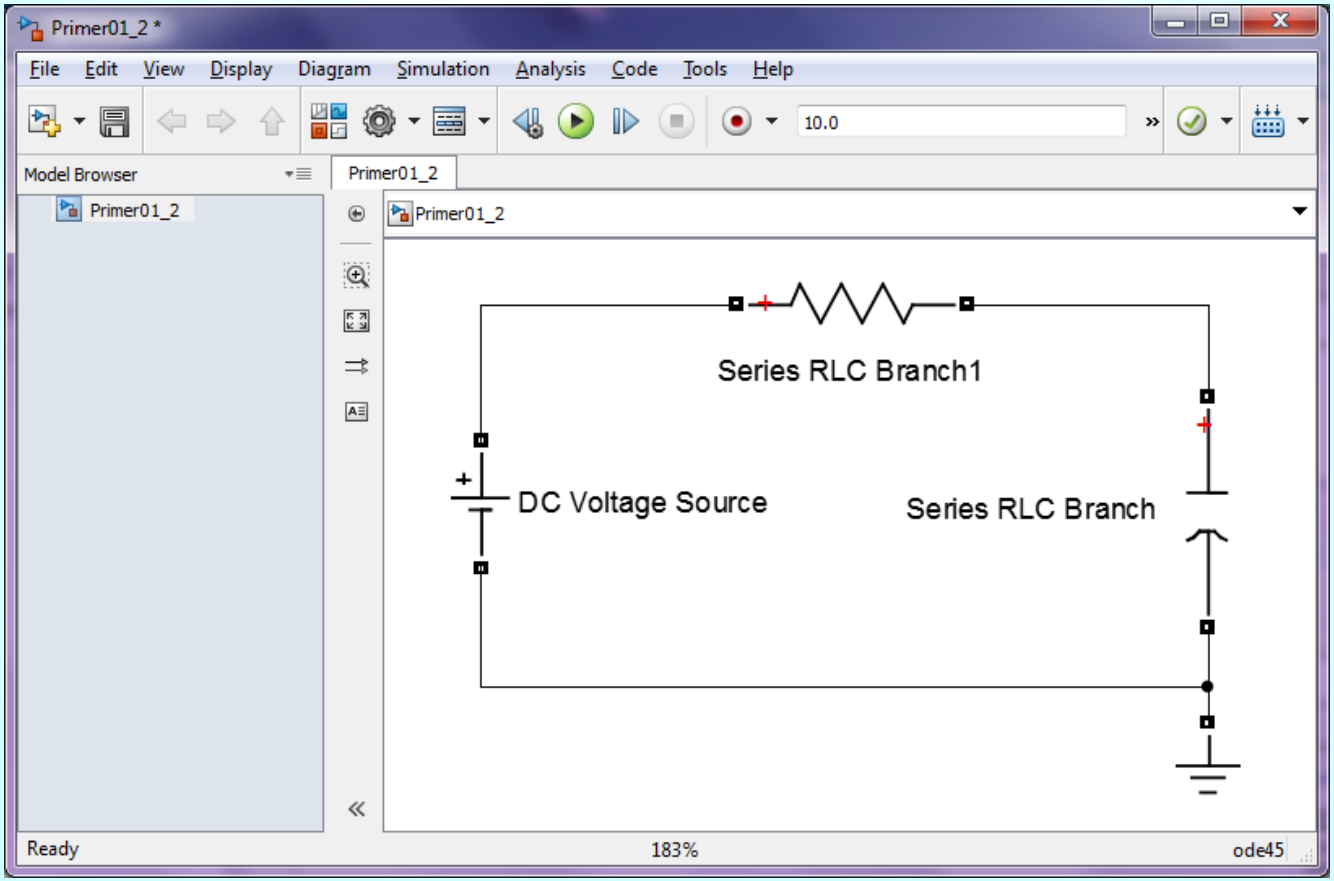
$u(t_0^-) = U_0 = -10\,\mathrm{V}$

Подешавање параметара симулације



Simscape > Electrical

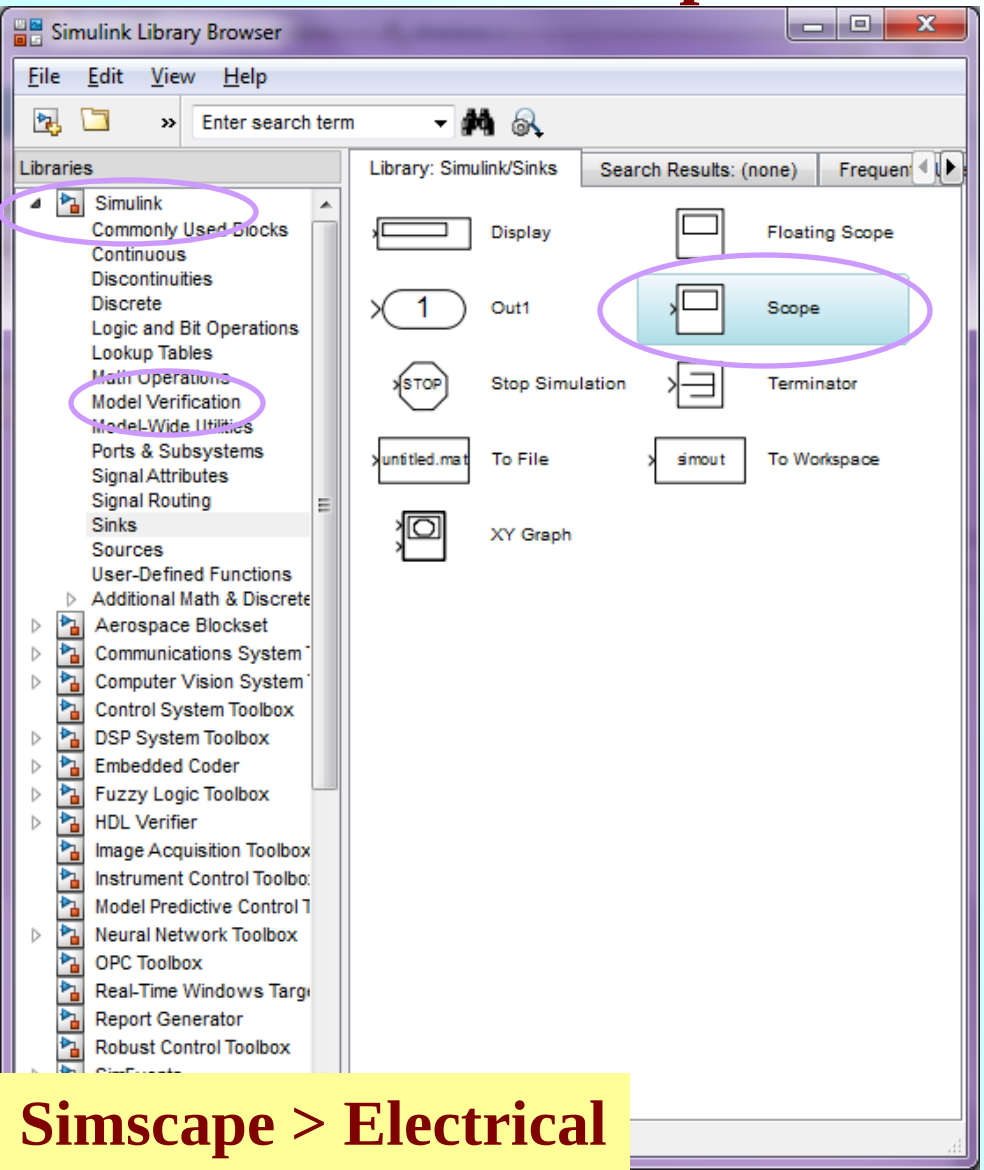
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

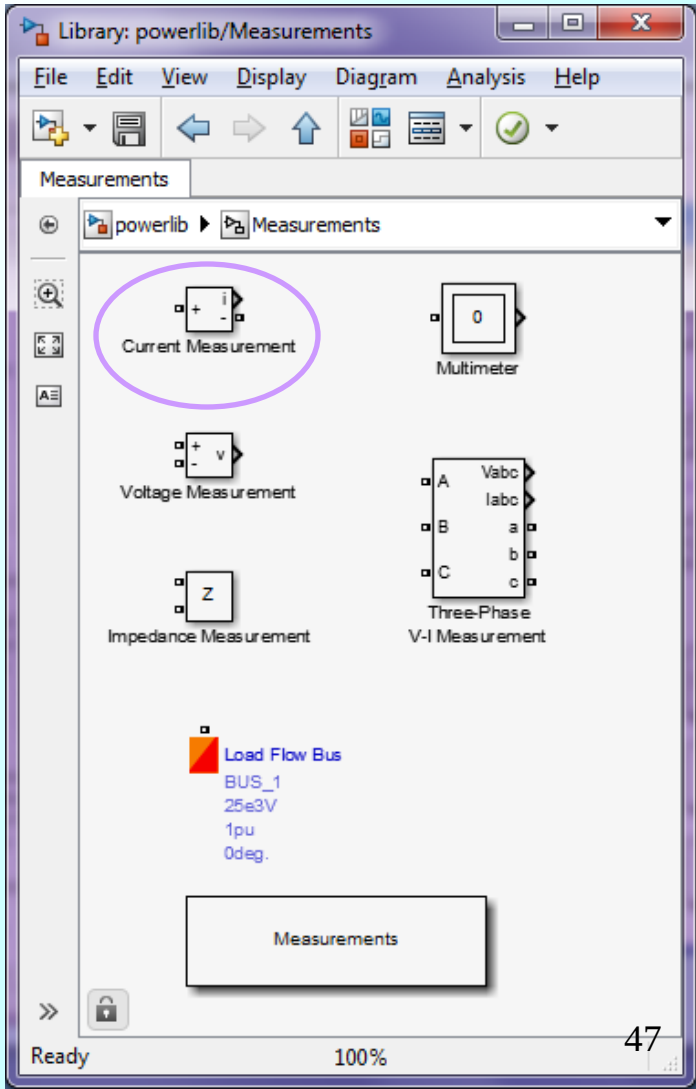


Како се мери напон?

Simscape > Electrical

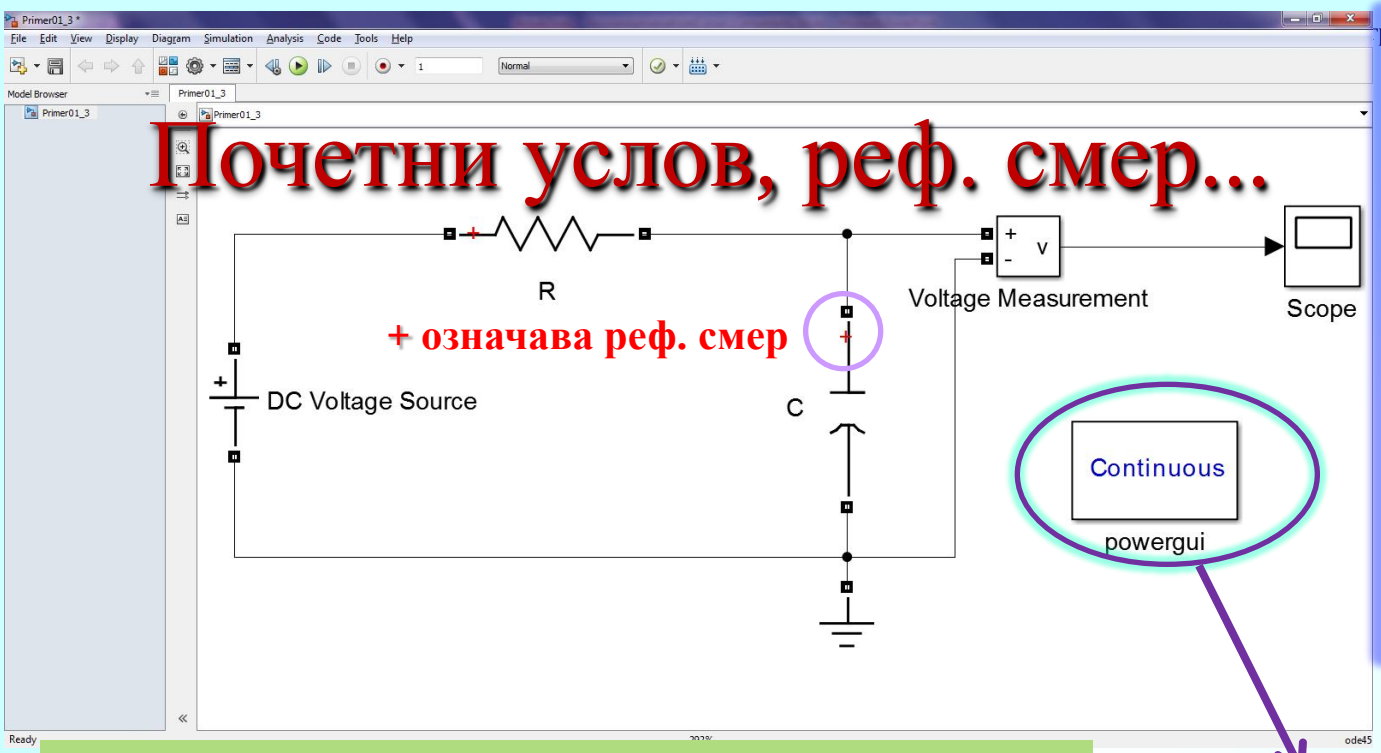
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке



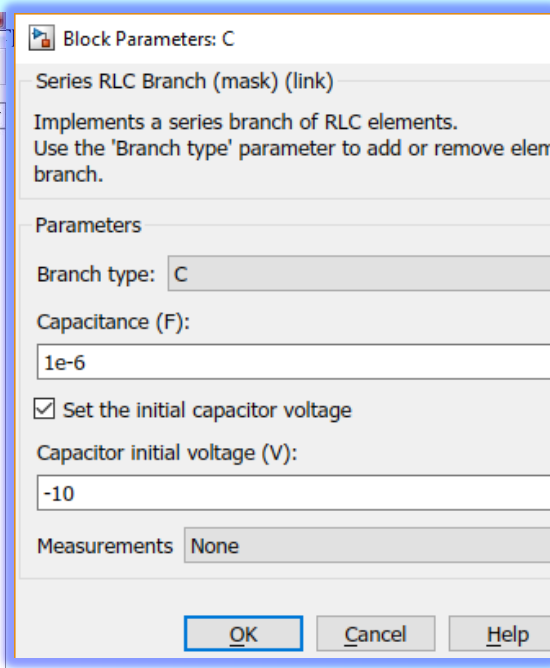


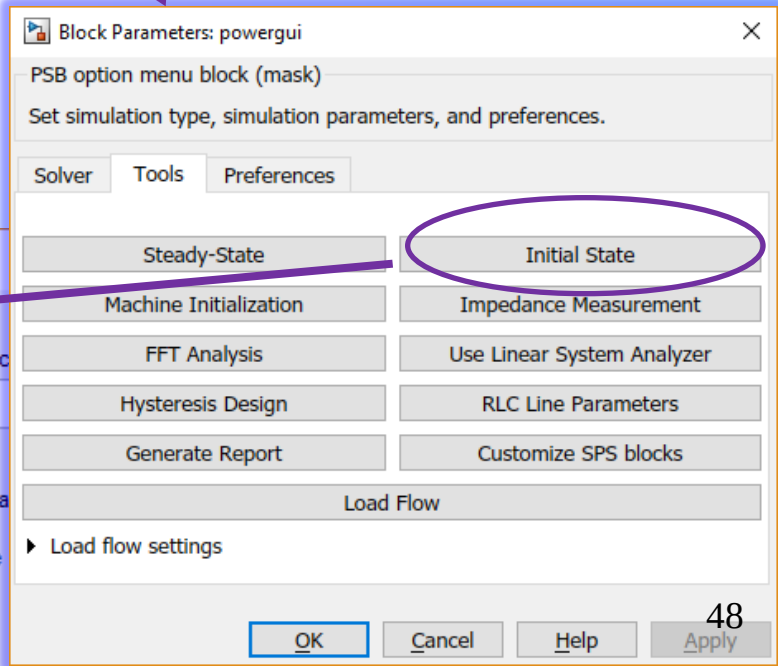
Simscape > Electrical

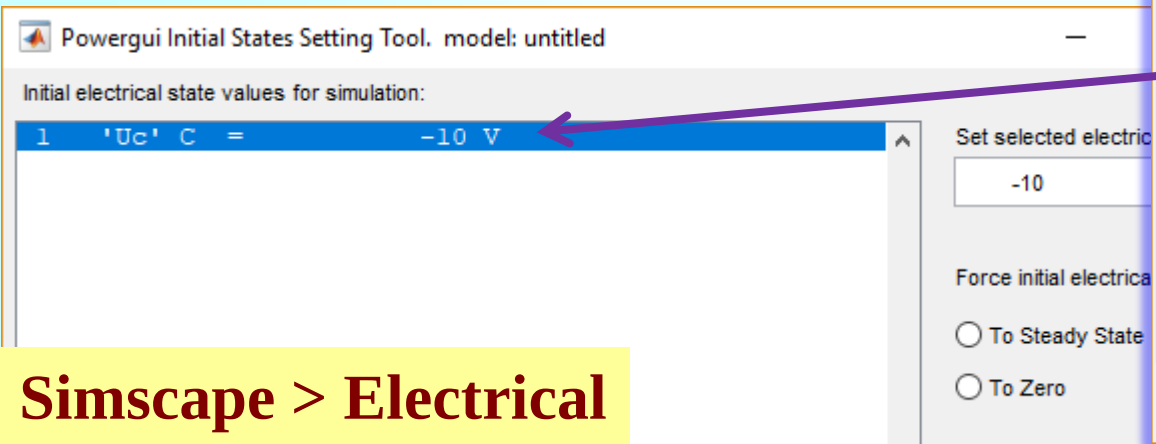
Почетни услов, реф. смер...



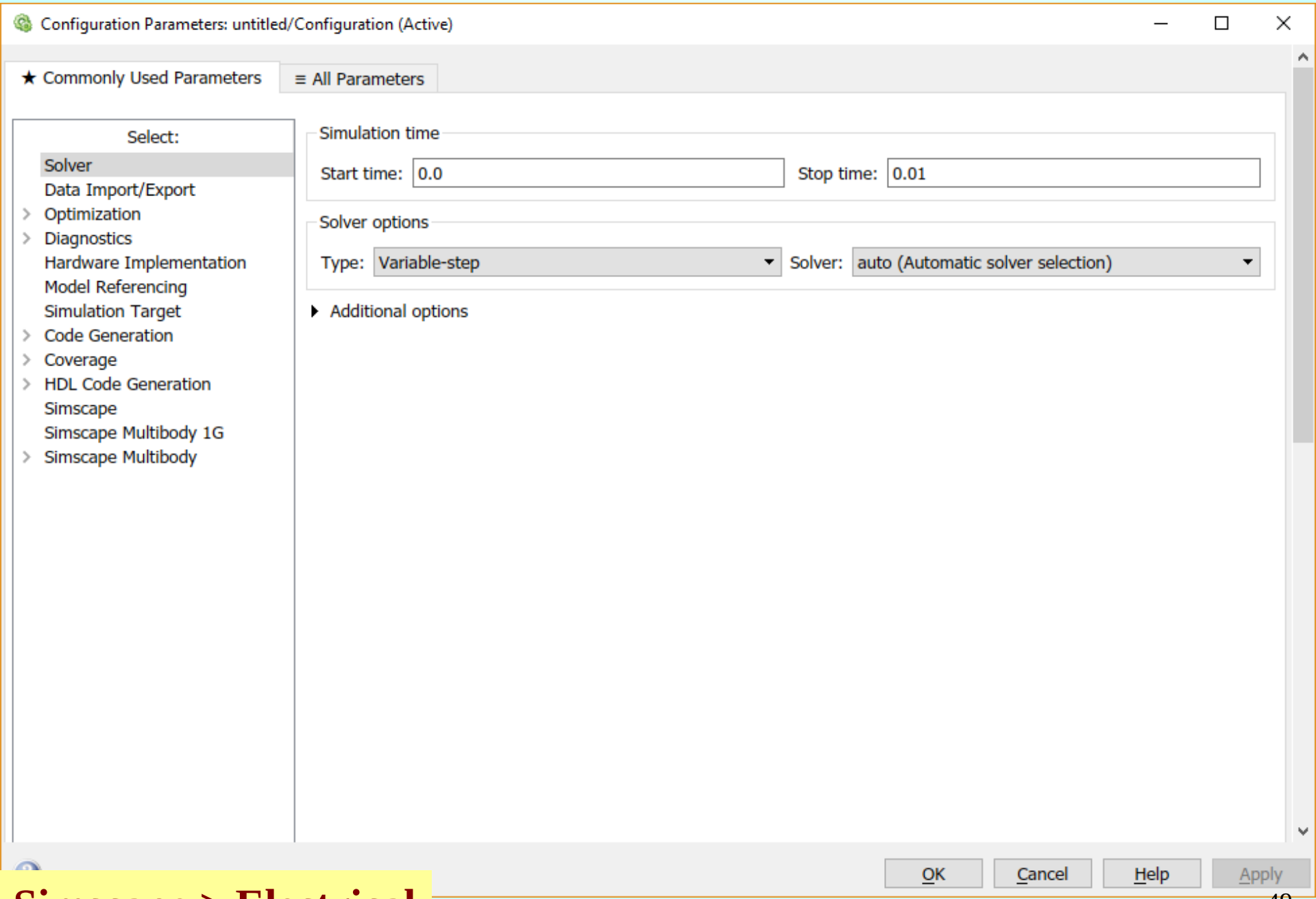
Плоче кондезатора се разликују!!!



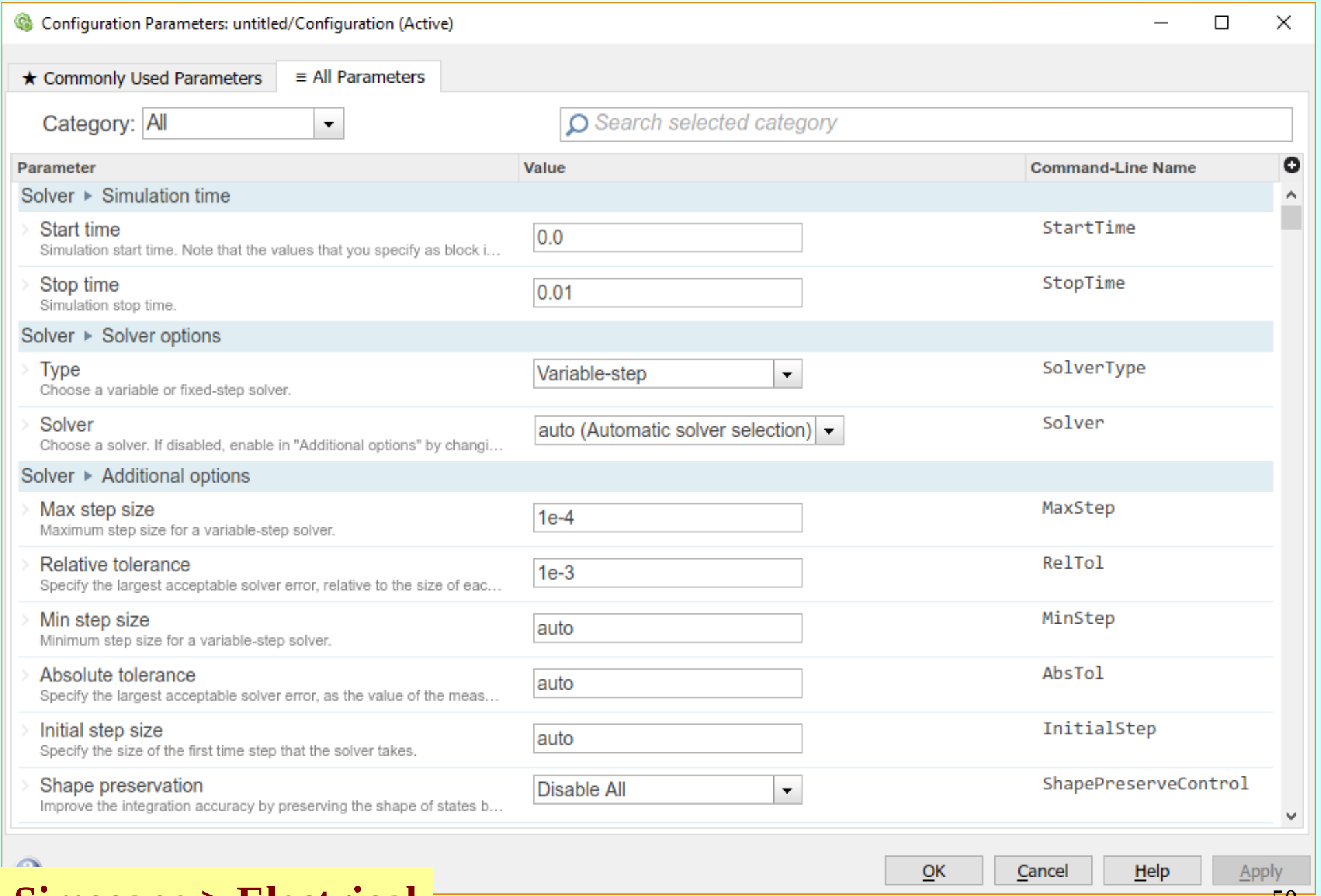




Simscape > Electrical

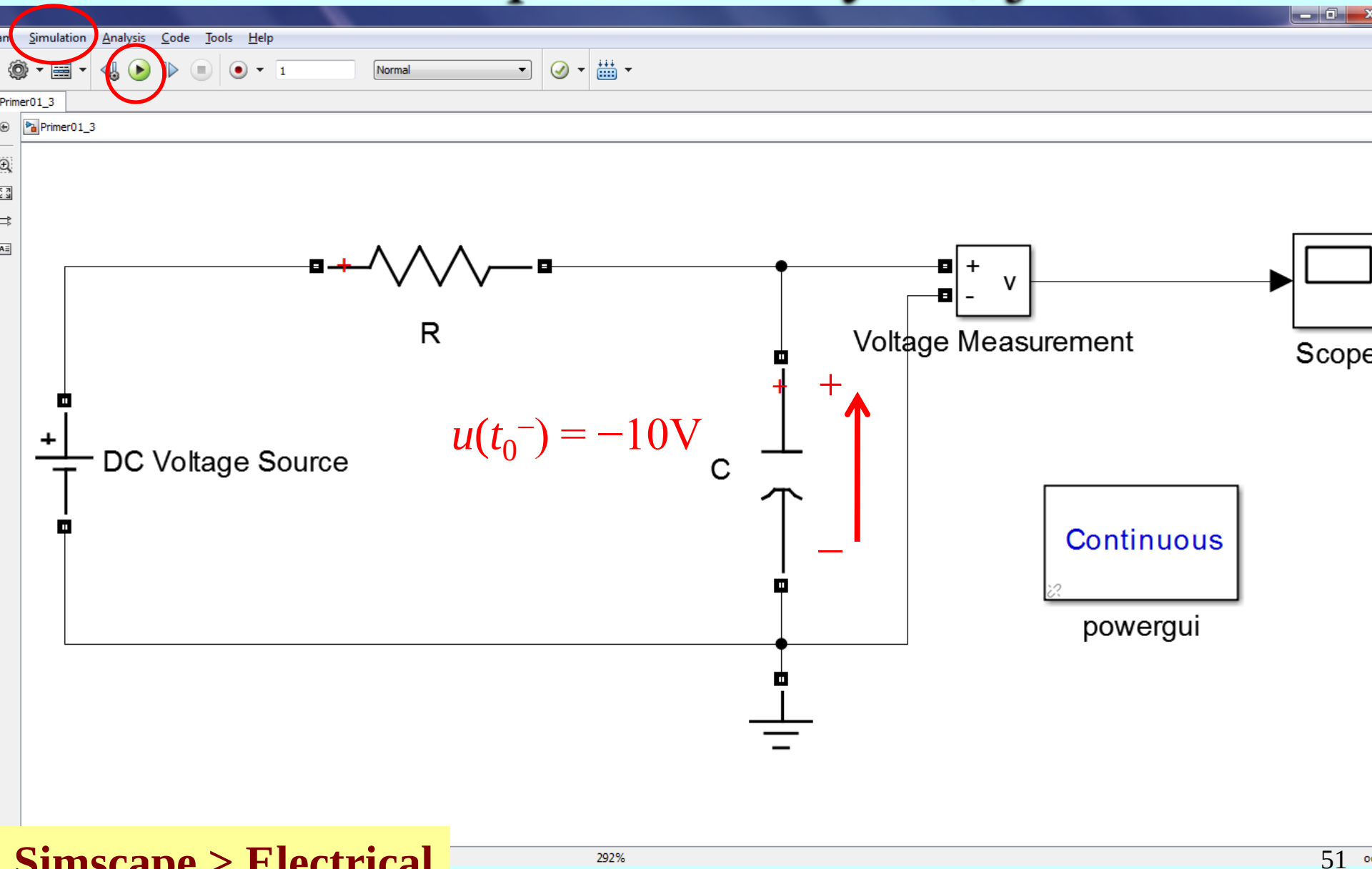


Simscape > Electrical



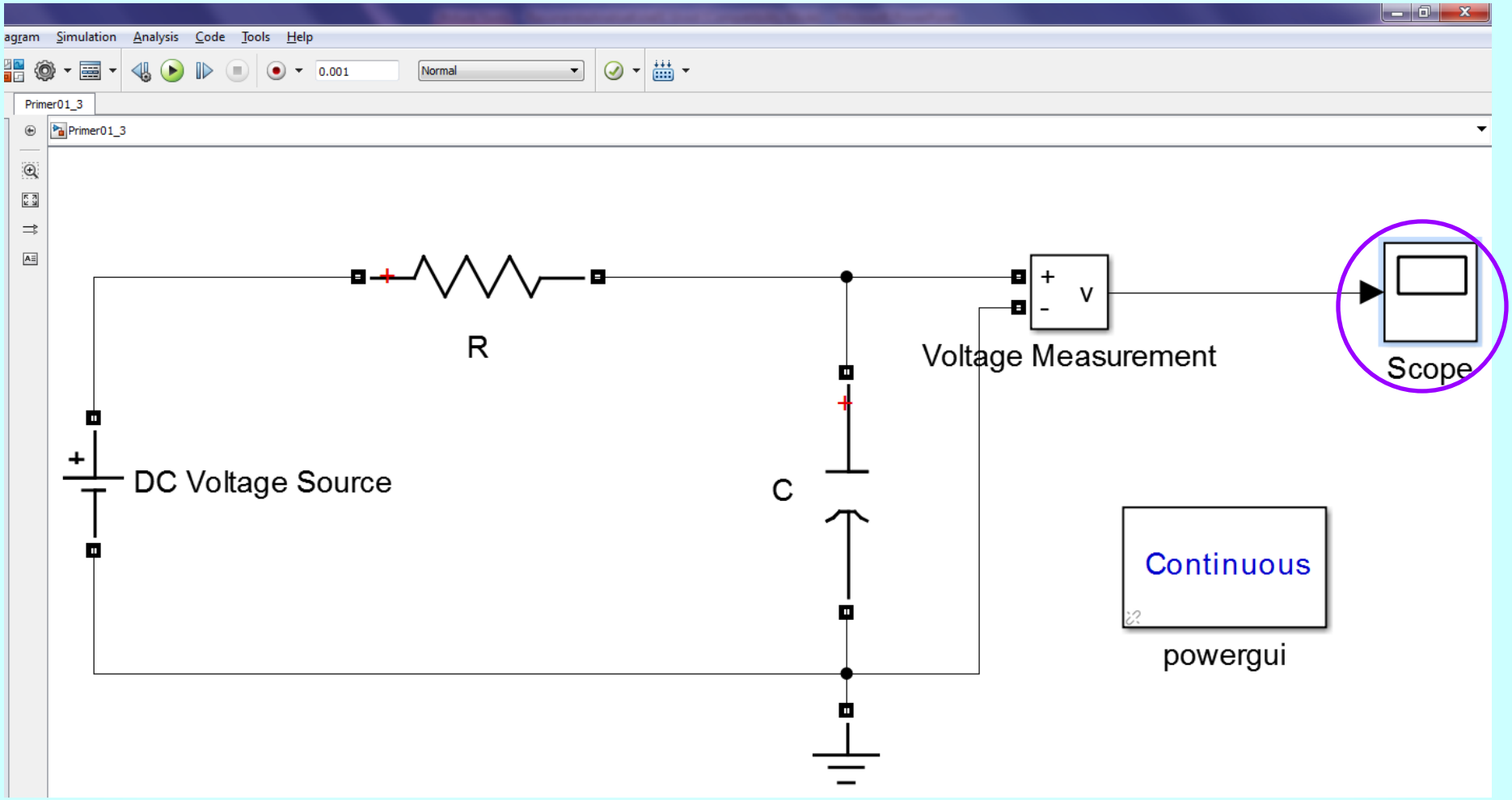
Simscape > Electrical

Покретање симулације...

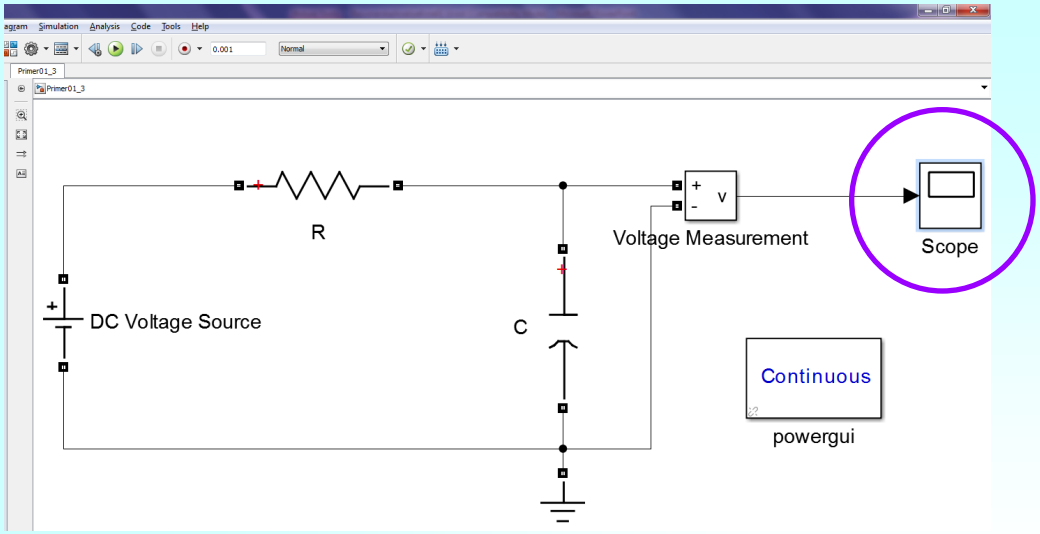


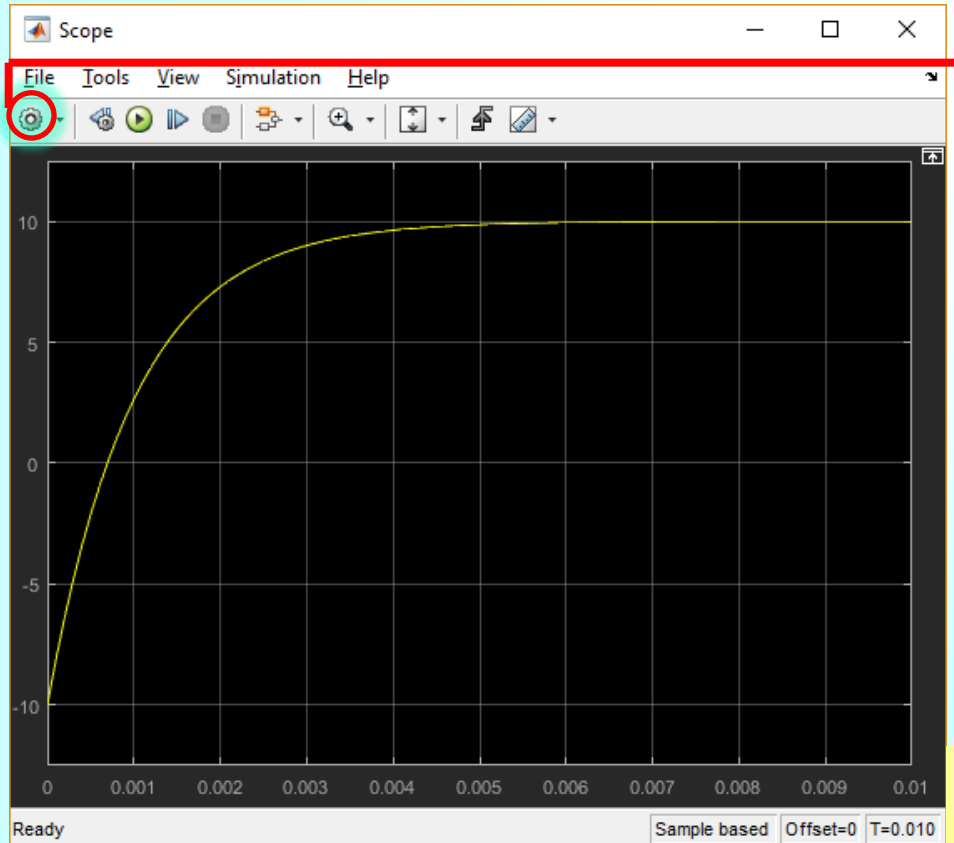
Simscape > Electrical

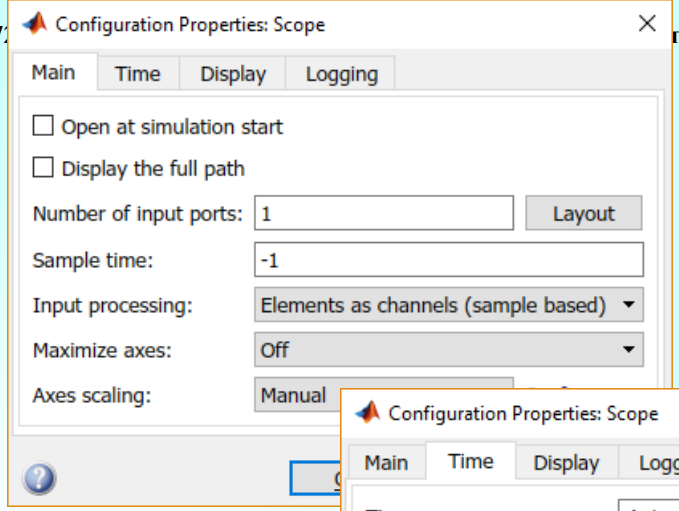
Налажење одзива... Осцилоскоп

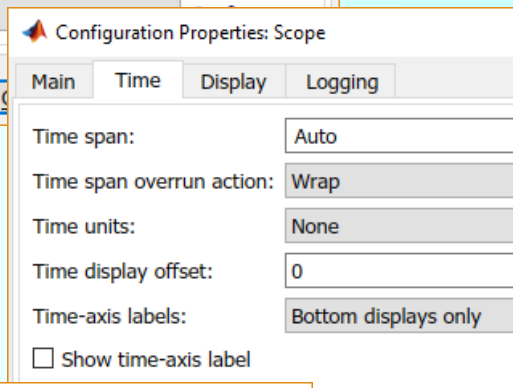


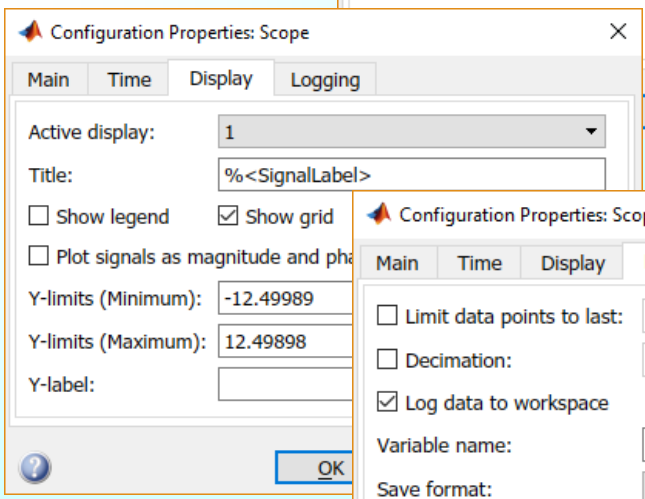
Simscape > Electrical

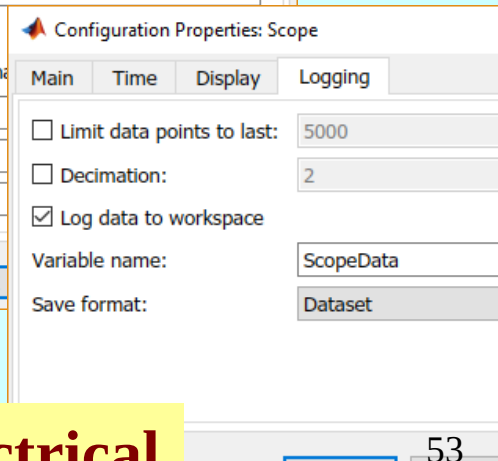




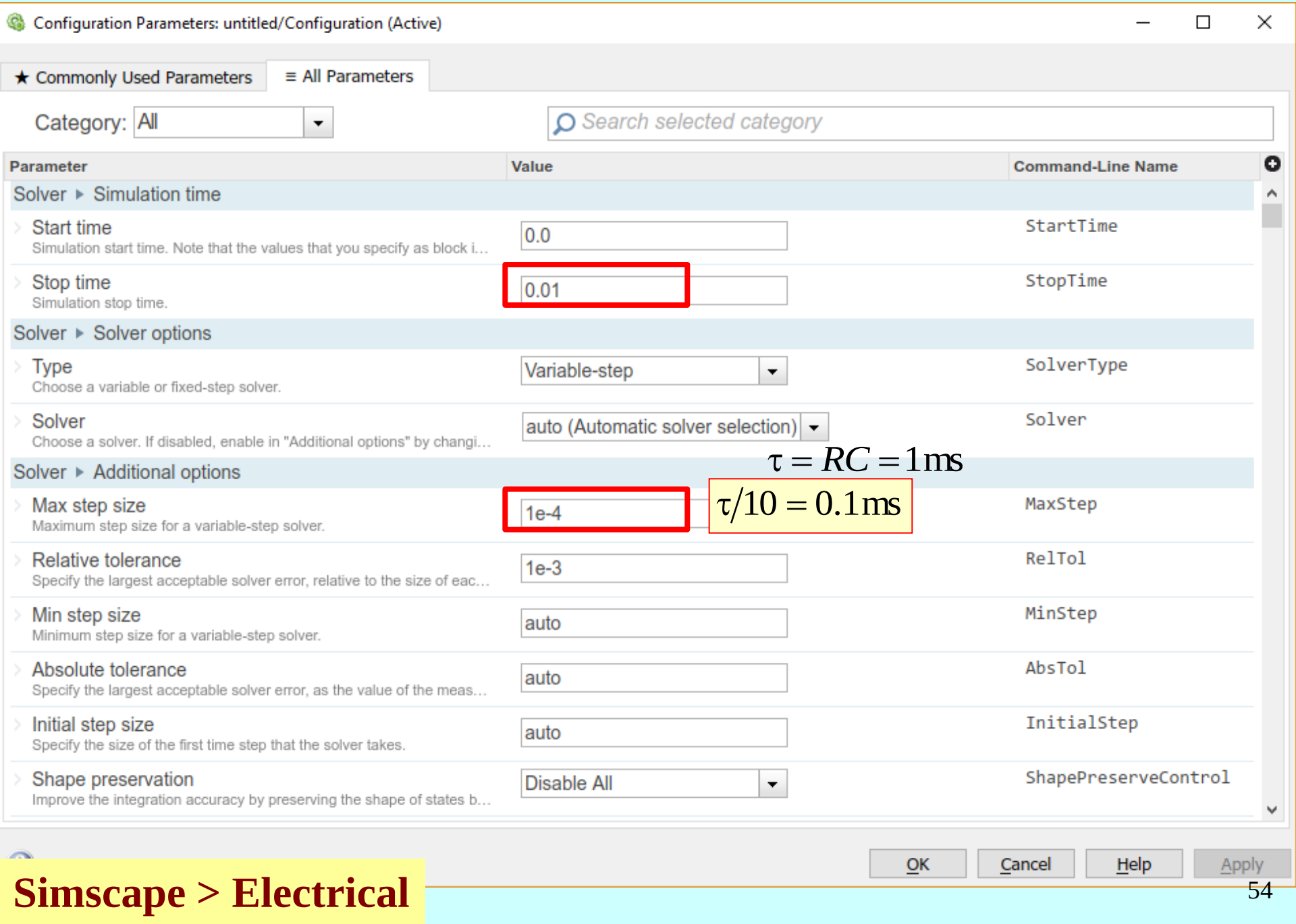








Simscape > Electrical



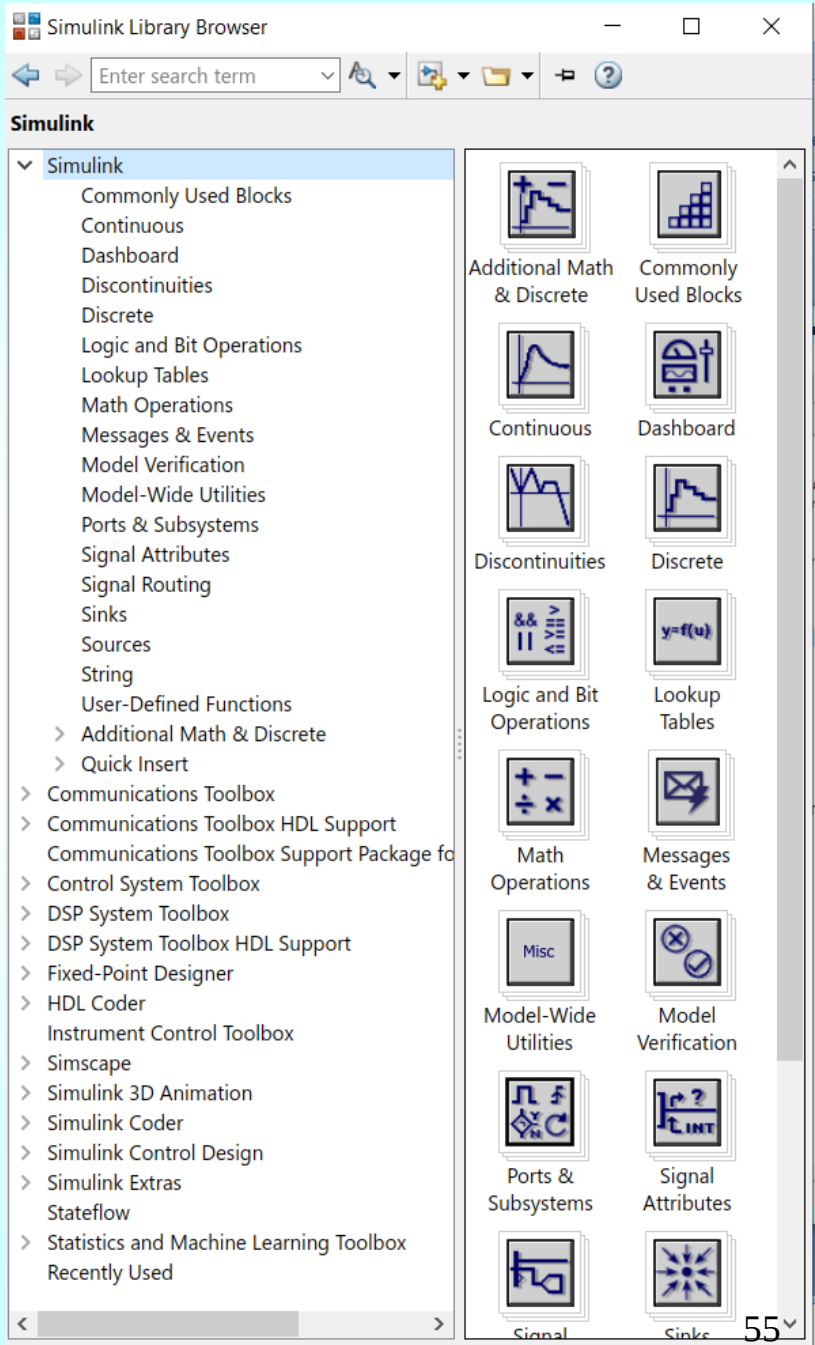
$\tau = RC = 1\text{ms}$

$\tau/10 = 0.1\text{ms}$

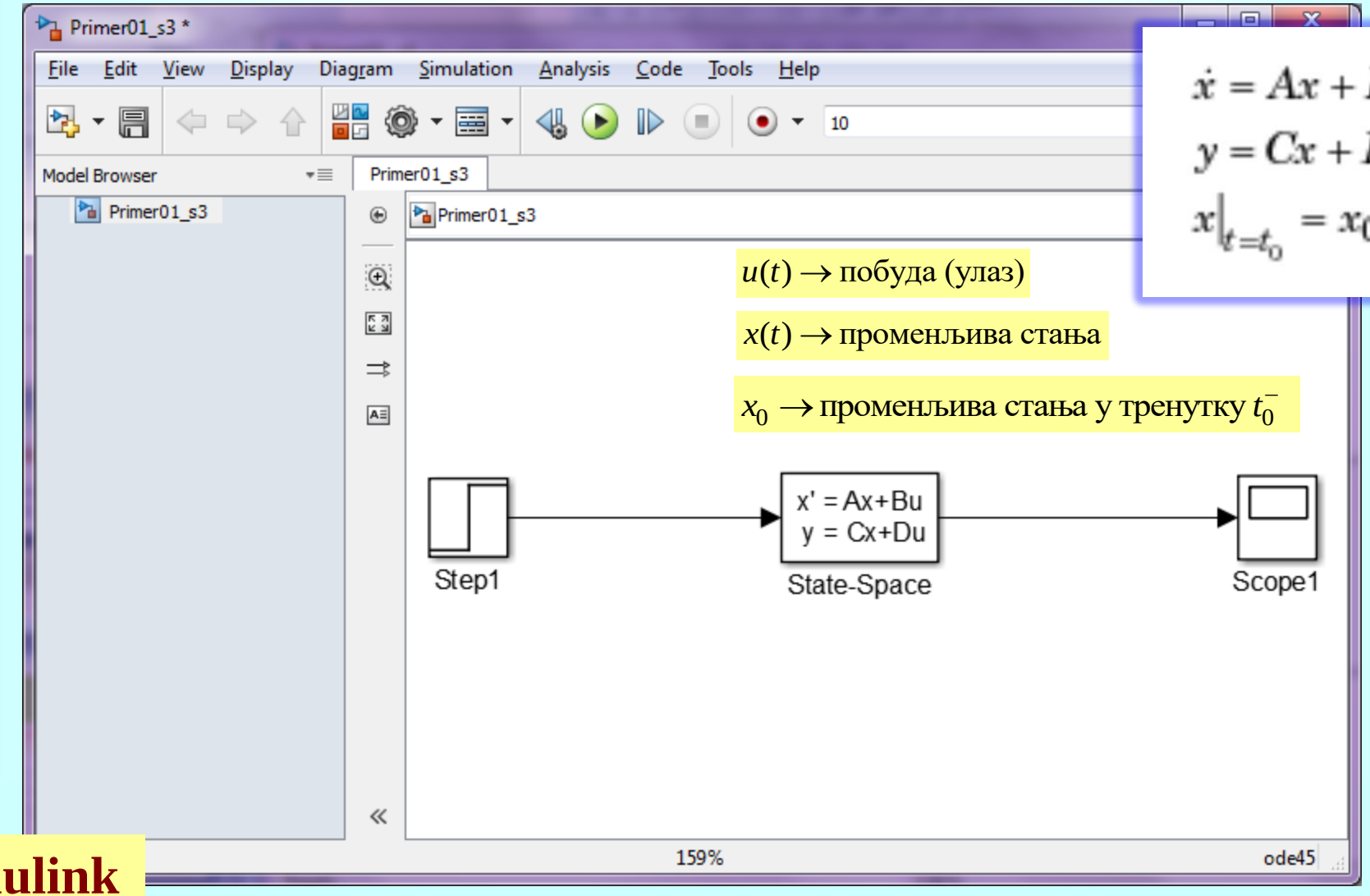
Simscape > Electrical

Simulink

- Решавање кола може се извршити његовим свођењем на систем линеарних диференцијалних једначина
- Дати систем може се представити једноставним блоком са више улаза и излаза

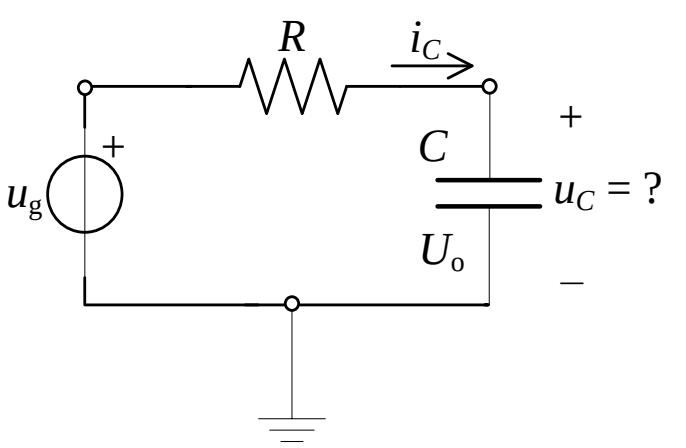


Симулација електричног кола као уопштеног система коришћењем **Simulink**-а



Simulink

Симулација електричног кола као уопштеног система коришћењем **Simulink**-а



$u = u_g(t) \rightarrow$ побуда (улаз)

$x = u_C(t) \rightarrow$ напон кондензатора (промењљива стања и одзив - излаз)

$x(t_0^-) = U_0 \rightarrow$ напон кондензатора у тренутку t_0^-

коло је образовано у тренутку $t_0 = 0$

$$u_g(t) = Ri_C + u_C(t)$$

$$i_C = C\frac{du_C}{dt}$$

$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

$$\dot{x} = Ax + Bu$$
$$y = Cx + Du$$
$$x\big|_{t=t_0} = x_0\,,$$

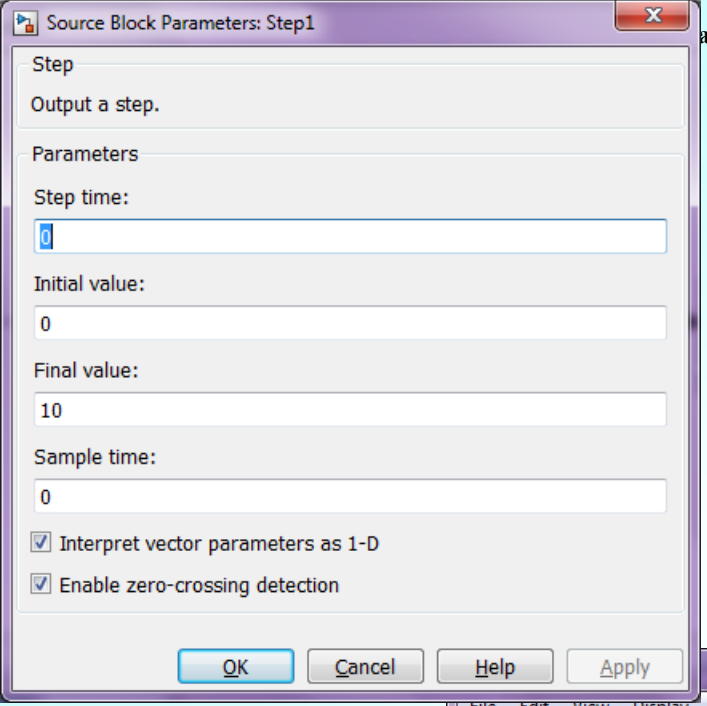
$$R = 1\,\text{k}\Omega$$
$$C = 1\,\mu\text{F}$$
$$u_g(t) = U\,h(t), U = 10\,\text{V}$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

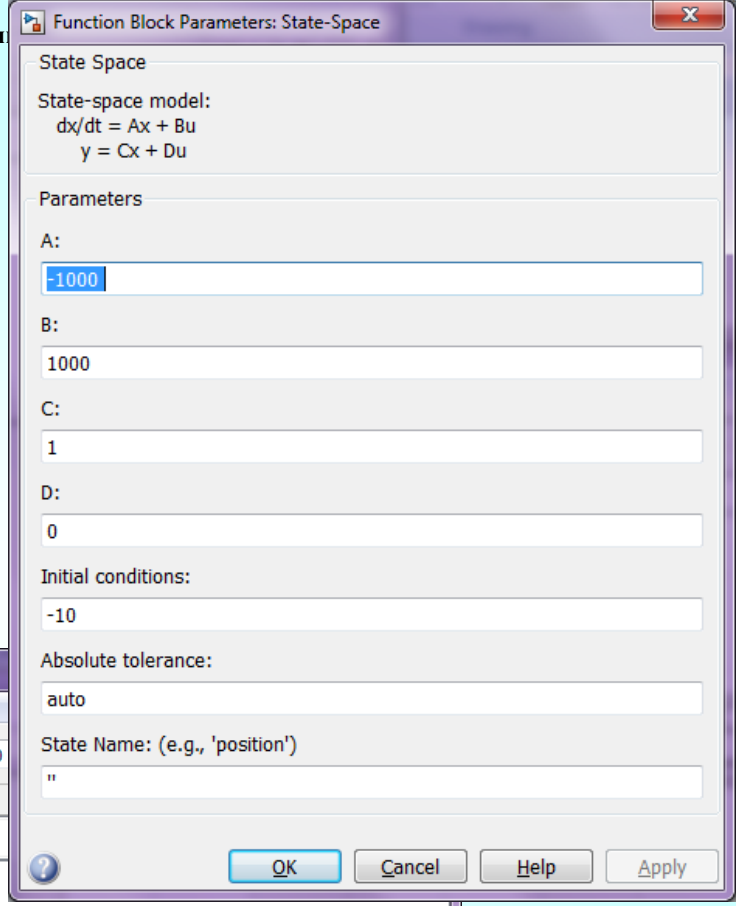
$$\frac{du_C(t)}{dt} = \frac{i_C}{C} = \frac{u_g(t) - u_C(t)}{RC} = -\frac{u_C(t)}{RC} + \frac{u_g(t)}{RC}$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

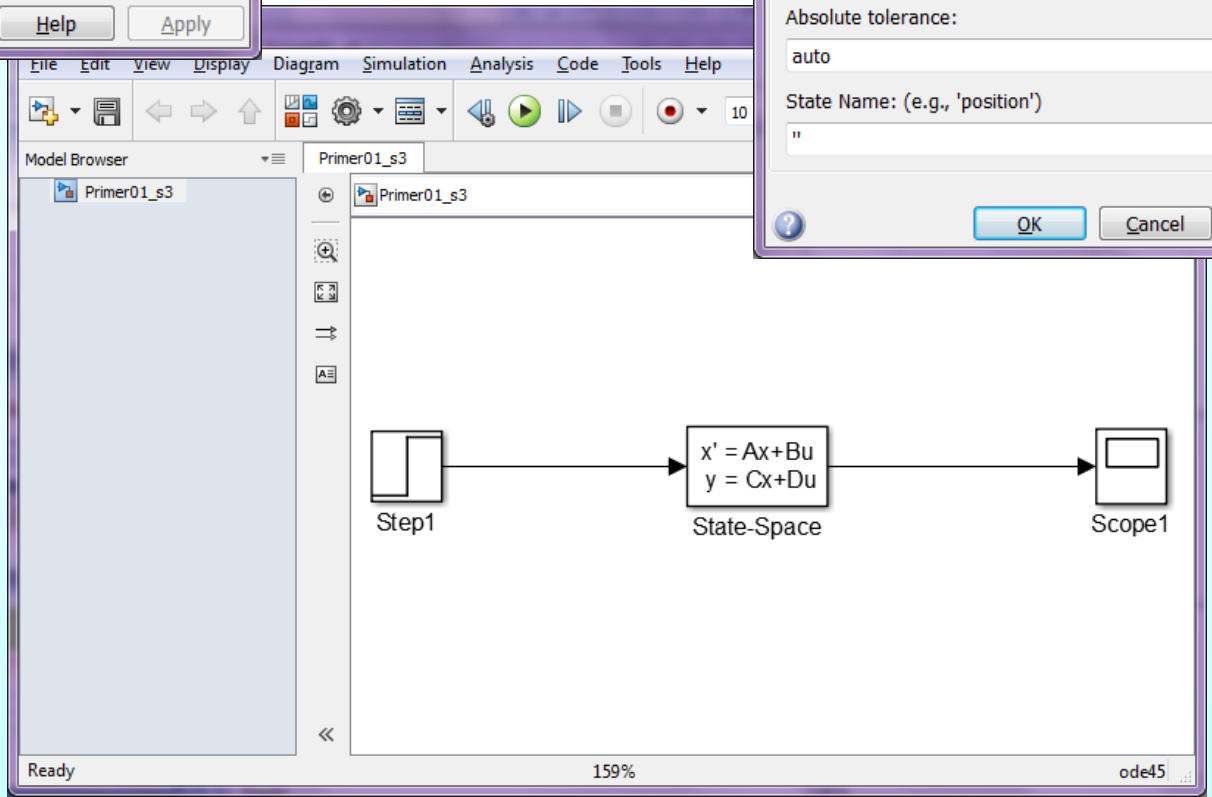
$$\frac{du_C(t)}{dt} = Au_C(t) + Bu_g(t) \Rightarrow A = -\frac{1}{RC} = -1000\,,\ B = 1000$$
$$u_C(t) = Cu_C(t) \Rightarrow C = 1, D = 0$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

Simulink

Симулација електричног кола као уопштеног система коришћењем **Simulink**-а

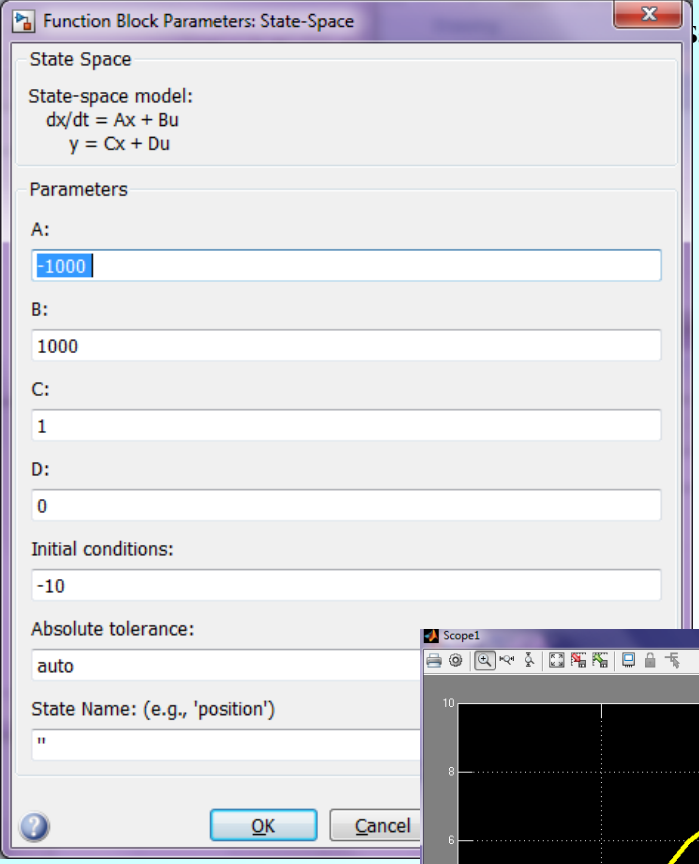


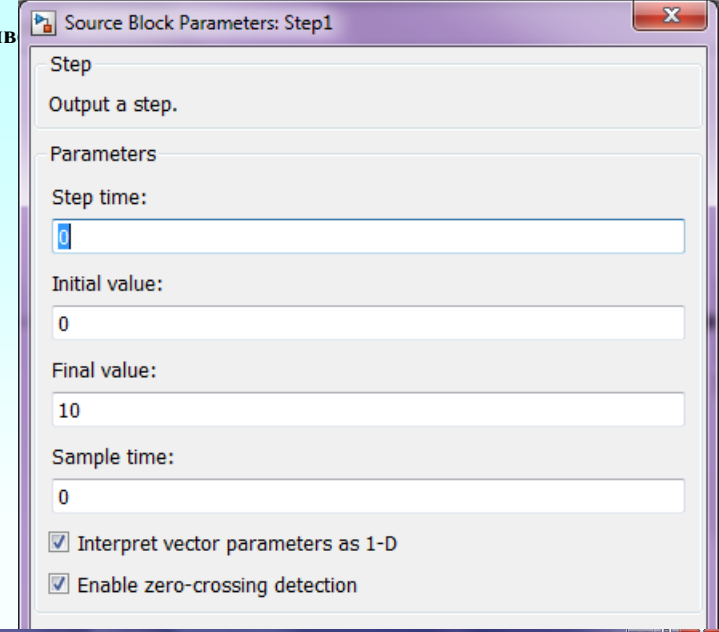


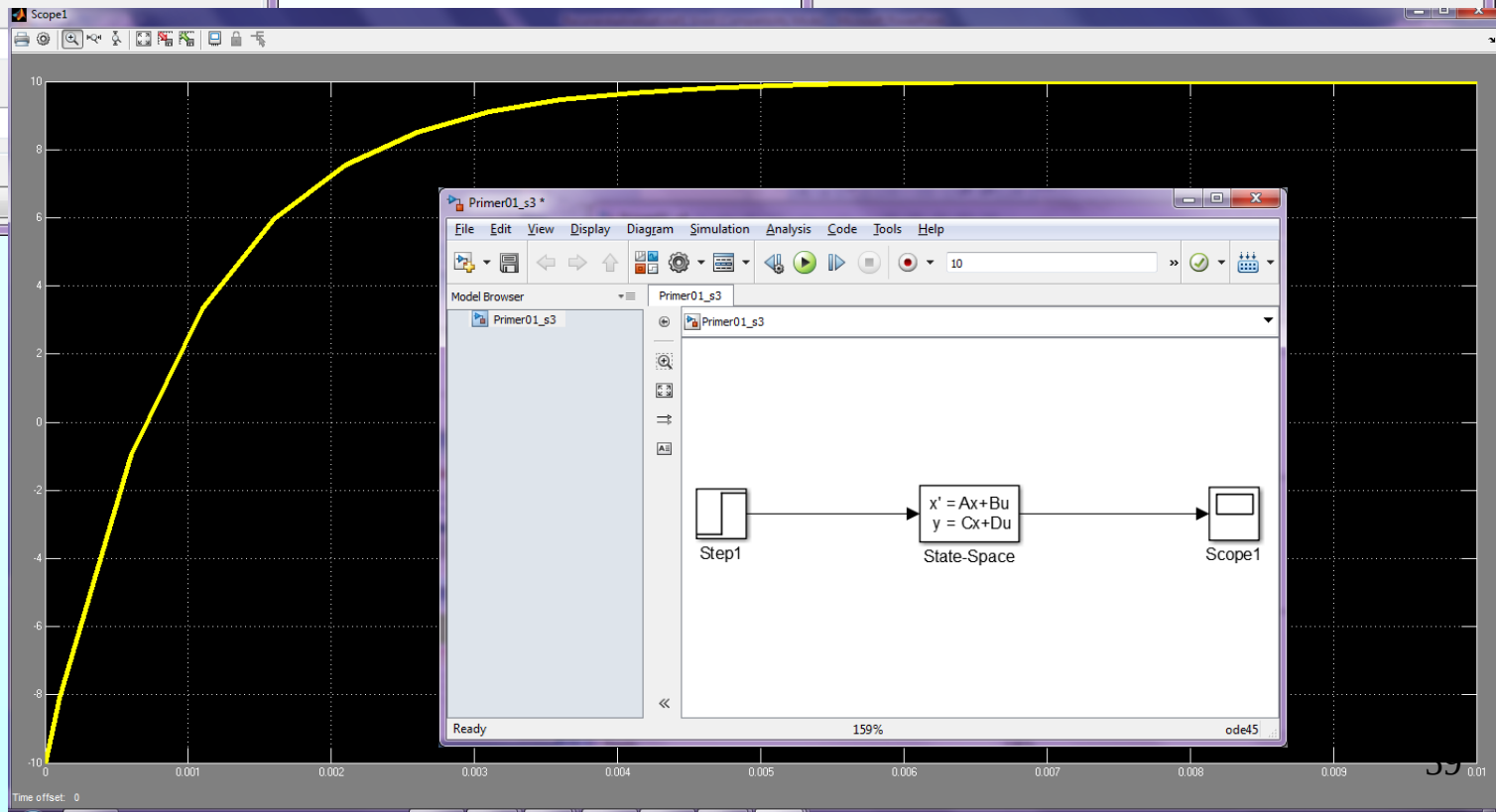


Simulink

Симулација електричног кола као уопштеног система коришћењем **Simulink**-а

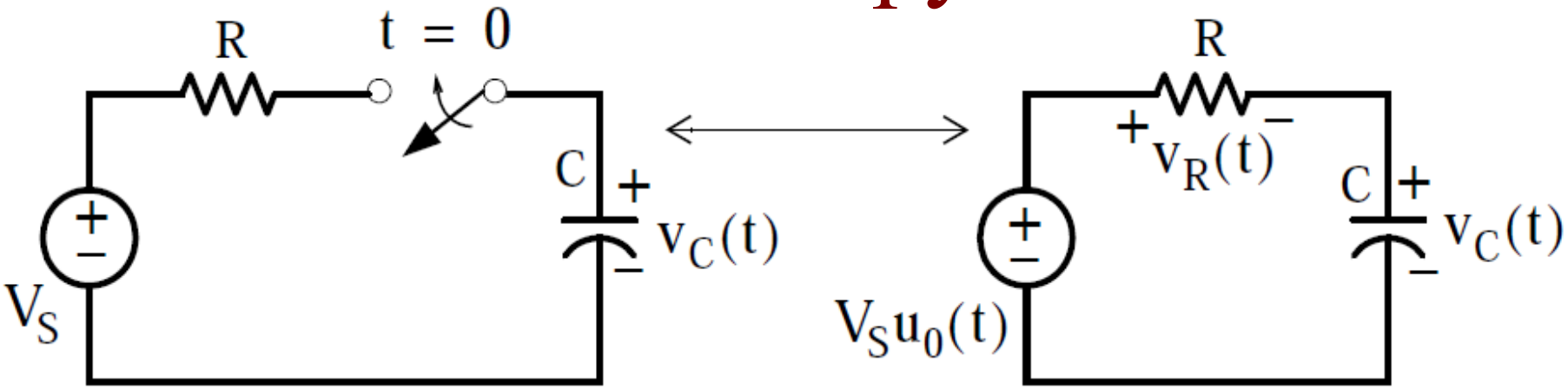






Simulink

Решимо “ручно”



$$v_R + v_C = V_S u_0(t)$$

$$i = i_C = C\frac{dv_C}{dt}$$

$$v_R = Ri = RC\frac{dv_C}{dt}$$

$$RC\frac{dv_C}{dt} + v_C = V_S u_0(t)$$

$t > 0$

$$RC\frac{dv_C}{dt} + v_C = V_S$$

$$v_C(t) = (V_S - V_S\, e^{-(1/RC)t})u_0(t)$$

MATLAB
Symbolic Math Toolbox (Live Script)

- Библиотека за симболички рачун (алгебарске и диференцијалне једначине)
- Омогућава нумеричку анализу резултата прорачуна

Live Editor - D:\Engineering_Work\ETF\Teaching\PRK\RCKolo_v0.mlx

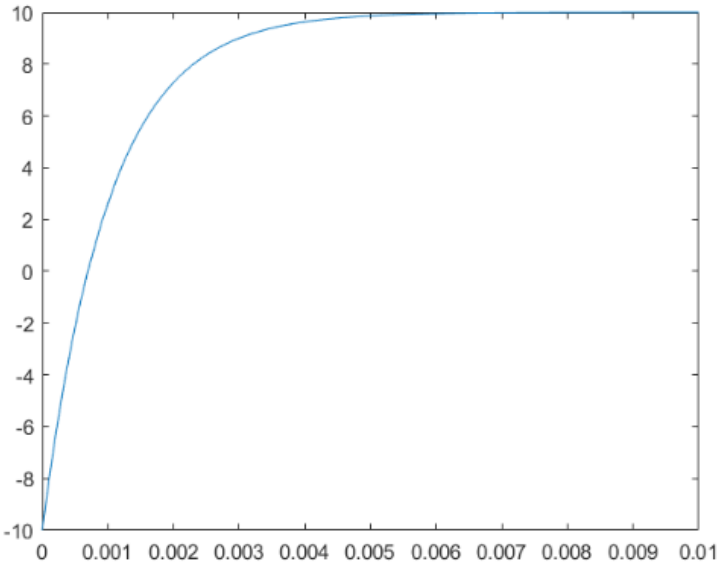
pluto1.m | template1.m | RCKolo_v0.mlx

```
1  syms v_c(t)
2  ode = diff(v_c,t) ==-1000*v_c+10000
3  cond = v_c(0)==-10
4  v_csol = dsolve(ode,cond)
5
6  fplot(v_csol, [0 0.01])
```

$$\frac{\partial}{\partial t} v_c(t) = 10000 - 1000\, v_c(t)$$

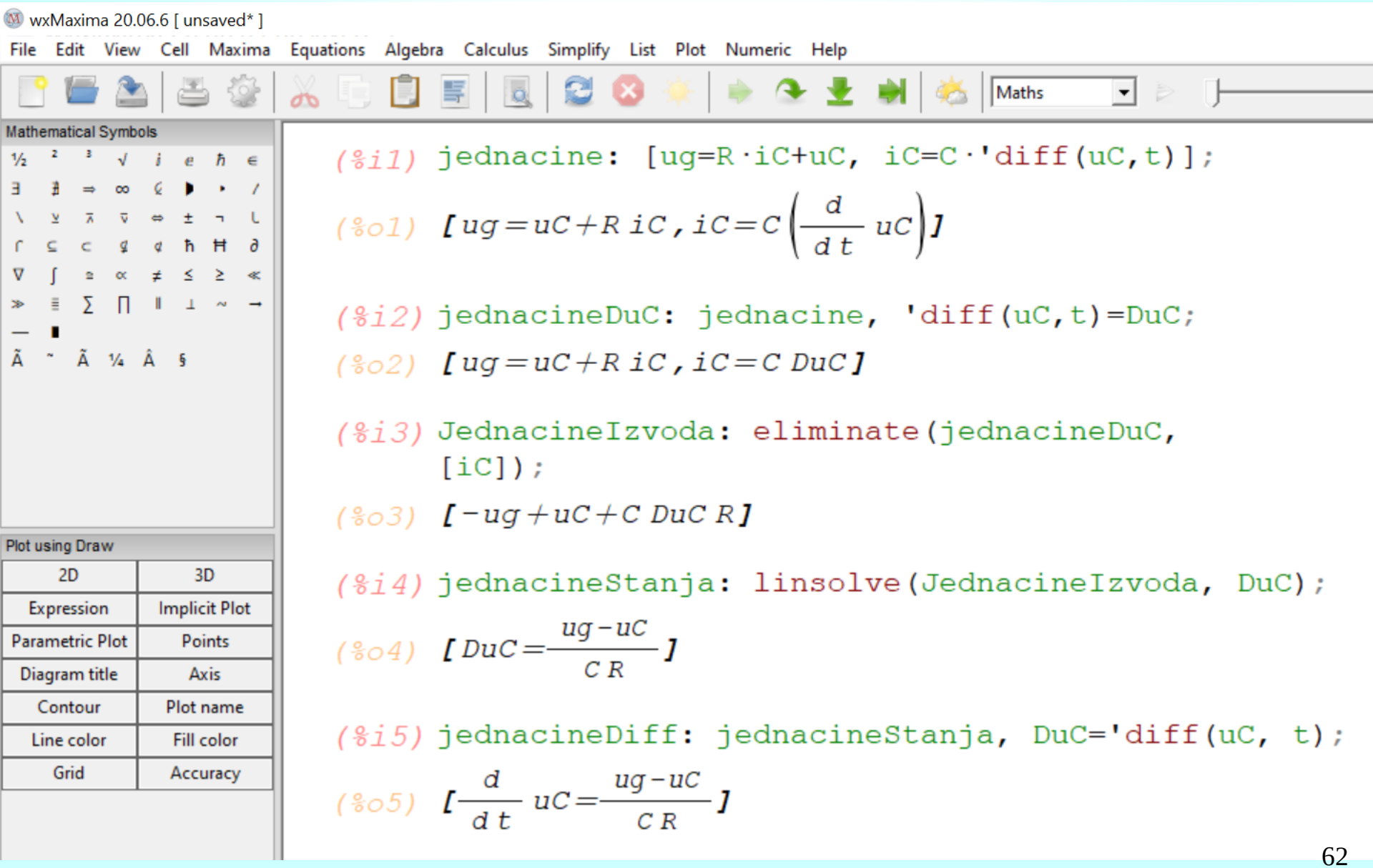
cond = $v_c(0) = -10$

v_csol = $10 - 20\, e^{-1000\, t}$



Simbolic Math Toolbox

wxMaxima


wxMaxima 20.06.6 [unsaved*]
File Edit View Cell Maxima Equations Algebra Calculus Simplify List Plot Numeric Help
Maths
Mathematical Symbols
Plot using Draw
2D
3D
Expression
Implicit Plot
Parametric Plot
Points
Diagram title
Axis
Contour
Plot name
Line color
Fill color
Grid
Accuracy
(%i1) jednacine: [ug=R·iC+uC, iC=C·'diff(uC,t)];
(%o1) [ug=uC+R iC, iC=C (d/d t uC)]
(%i2) jednacineDuC: jednacine, 'diff(uC,t)=DuC;
(%o2) [ug=uC+R iC, iC=C DuC]
(%i3) JednacineIzvoda: eliminate(jednacineDuC, [iC]);
(%o3) [-ug+uC+C DuC R]
(%i4) jednacineStanja: linsolve(JednacineIzvoda, DuC);
(%o4) [DuC=(ug-uC)/(C R)]
(%i5) jednacineDiff: jednacineStanja, DuC='diff(uC, t);
(%o5) [d/d t uC=(ug-uC)/(C R)]

```
(%i6) zamene: [ug=U];
```

(%o6) $[ug=U]$

```
(%i7) vrednosti: [R=1000, C=10^(-6), U=10, U0=-10];
```

(%o7) $[R=1000, C=\frac{1}{1000000}, U=10, U0=-10]$

```
(%i8) JednacineDiffZamena: jednacineDiff, zamene;
```

(%o8) $[\frac{d}{dt} uC = \frac{U-uC}{CR}]$

```
(%i9) ode2(JednacineDiffZamena, uC, t);
```

(%o9) $uC = \%e^{-\frac{t}{CR}} \left(U\ \%e^{\frac{t}{CR}} + \%c \right)$

```
(%i10) ic1(%, t=0, uC=U0);
```

(%o10) $uC = \%e^{-\frac{t}{CR}} \left(U\ \%e^{\frac{t}{CR}} + U0 - U \right)$

```
(%i11) uCt: ev(%, vrednosti);
```

(%o11) $uC = \%e^{-1000\,t} \left(10\ \%e^{1000\,t} - 20 \right)$

```
(%i17) wxplot2d(rhs(uCt), [t,0,0.01],
       [xlabel," t [s] "],
       [ylabel," uC [V] "],
       [xtics, 0, 0.002, 0.01],
       [legend, "Napon kondenzatora"], grid2d)$
```