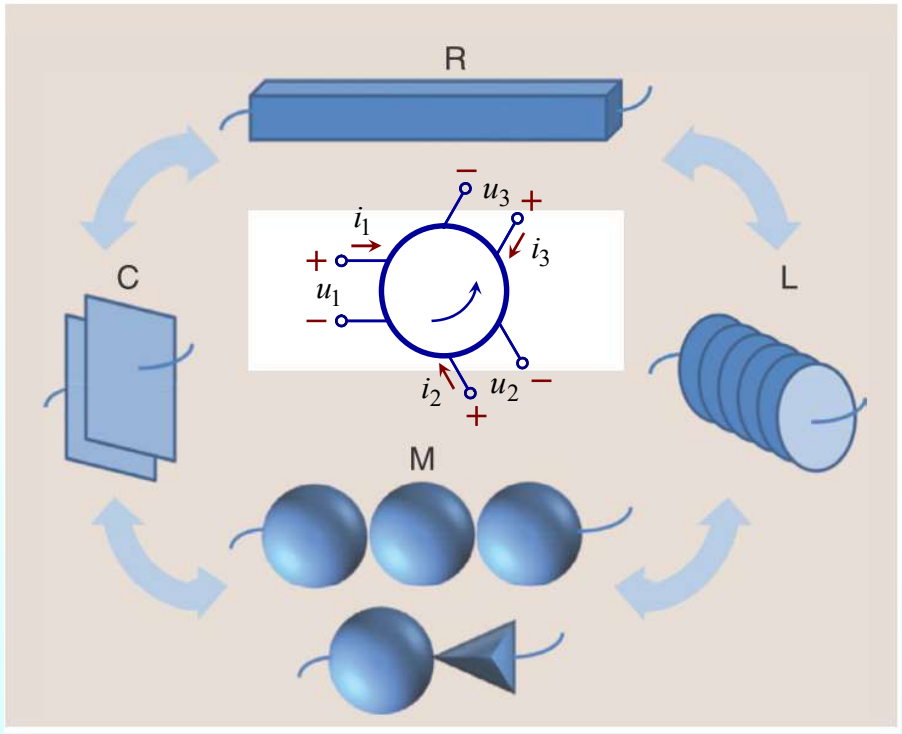
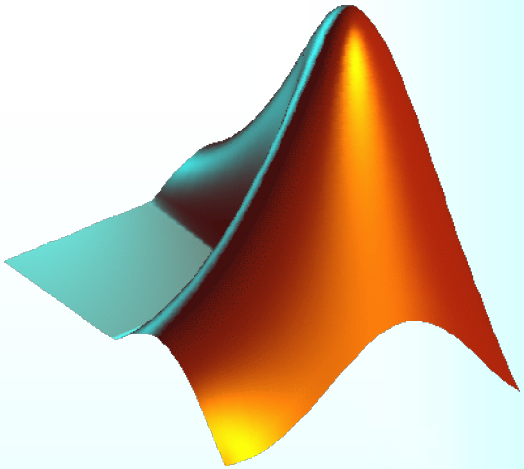
Практикум из рачунарске анализе кола

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**
- **Сарджај**: Рачунарске симулације електричних кола помоћу програма MATLAB/Simulink или Scilab/Xcos, LTspice и QucsStudio. Симболичко решавање кола програмима MATLAB/Symbolic Math или Symbolic Python и Maxima.

- **Наставници.** Др **Милка Потребић Иваниш**, редовни професор, соба 64 (milka_potrebic@etf.rs);
  Др **Никола Баста**, доцент, соба 80 (nbasta@etf.rs).
- **Сарадници:** мс. инж. **Ања Ковачевић**, асистент, дипл. инж. **Анђела Нинковић**, сарадник у настави*.

- 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.
- **Пратити** званично представљање предмета и објављивање општих службених порука на адреси **http://tek.etf. rs/**

Начин полагања

- **ПРЕДИСПИТНЕ ОБАВЕЗЕ (70%) + ИСПИТ (30%) = УКУПНО (100%)**
- **Предиспитне обавезе (MATLAB)** реализују се полагањем колоквијума у РЦ, израдом домаћег задатка са усменом одбраном, или поенима освојеним кроз активности на часу – израда једноставнијих задатака у вредности од 5 до 10 испитних поена.
- Добровољна израда **MATLAB Onramp** теста (самостални пролазак кроз основни MATLAB курс у слободно време) носи додатних 5 бонус поена.
- Поени са свих активности се сабирају и максимално се може освојити 70%.

- **Испит** подразумева израду пројекта и његову одбрану, укупно 30%.
- Одбрана пројекта може се реализовати у свим испитним роковима. Израда пројеката се може реализовати у наведеним алтернативним софтверским алатима.
- За заинтересоване студенте може се обезбедити предрок.
- Поред класичних тема за пројекте од ове године нове теме су: Симулатори кола на Интернету. Могућност примене вештачке интелигенције у решавању електричних кола.
- *Напомена: Домаћи задаци и пројекти се могу радити у тиму од два студента, али се бране индивидуално.*

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

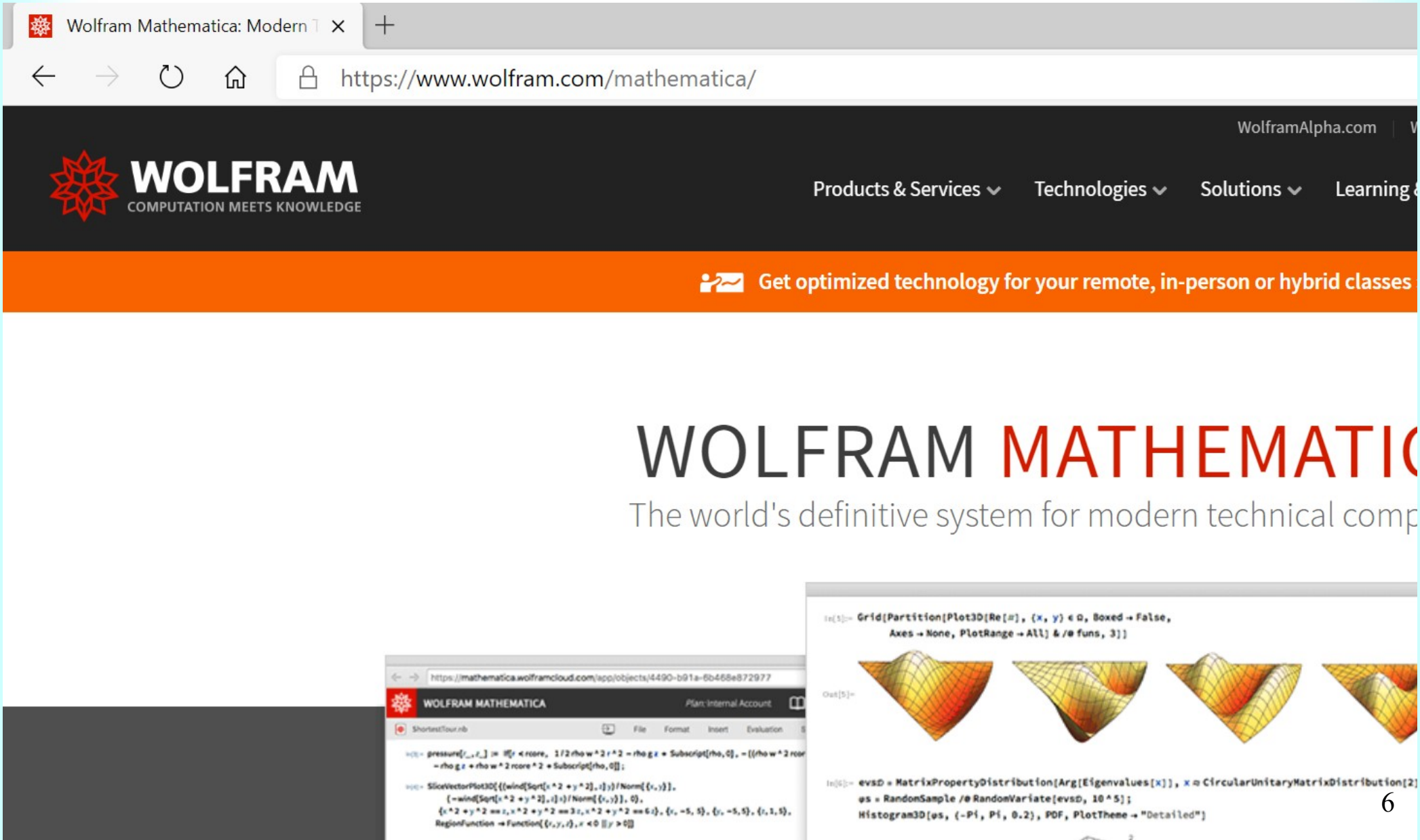
Free/Libre Open Source Software (FLOSS)

Моделовање електричних кола

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

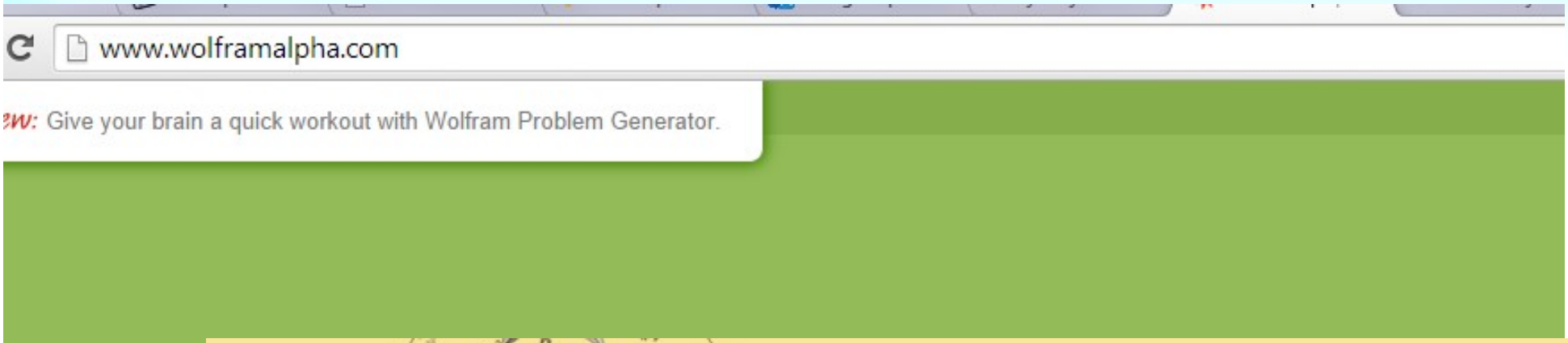
Mathematica

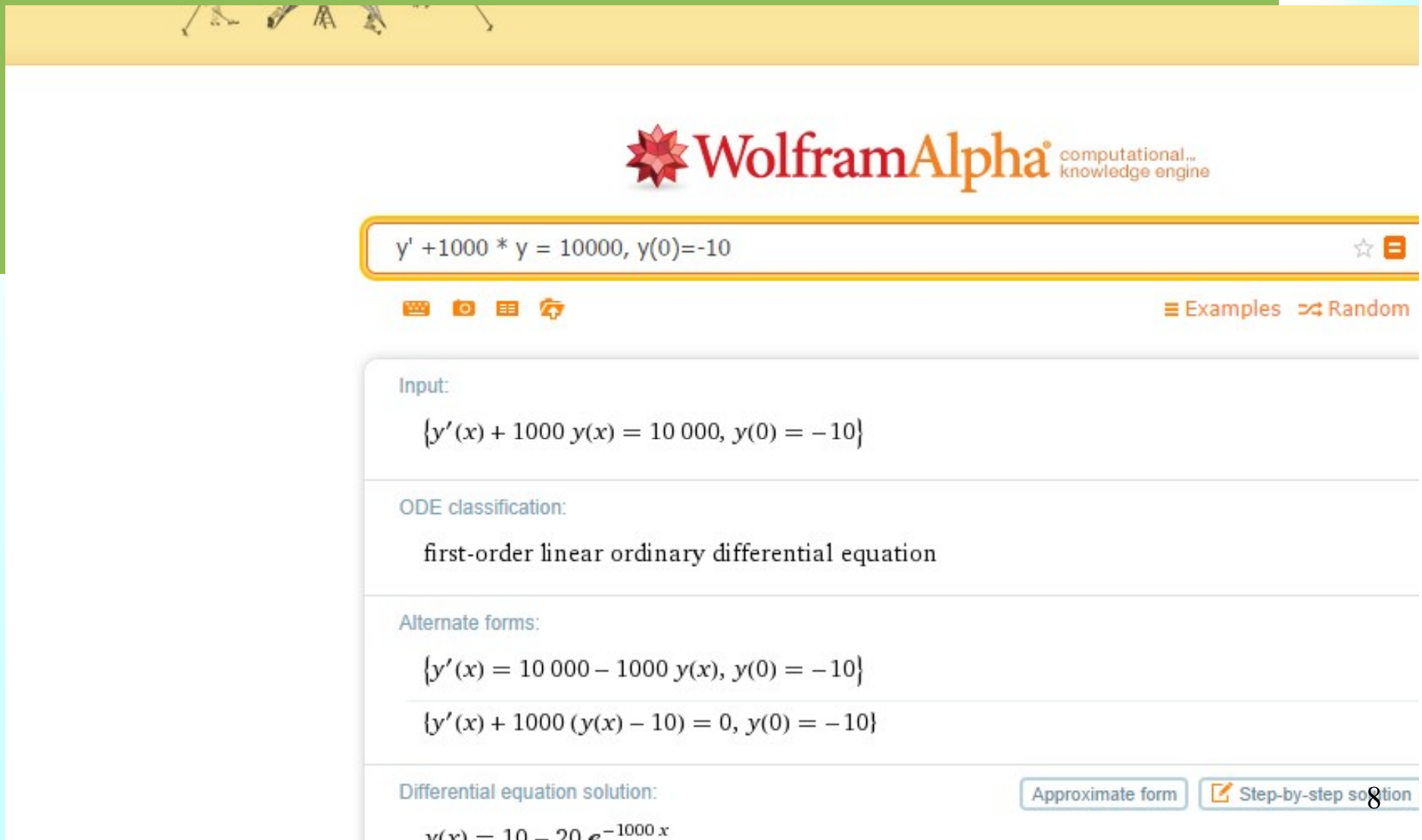
https://www.wolfram.com/mathematica/



Mathematica free on every Raspberry Pi!

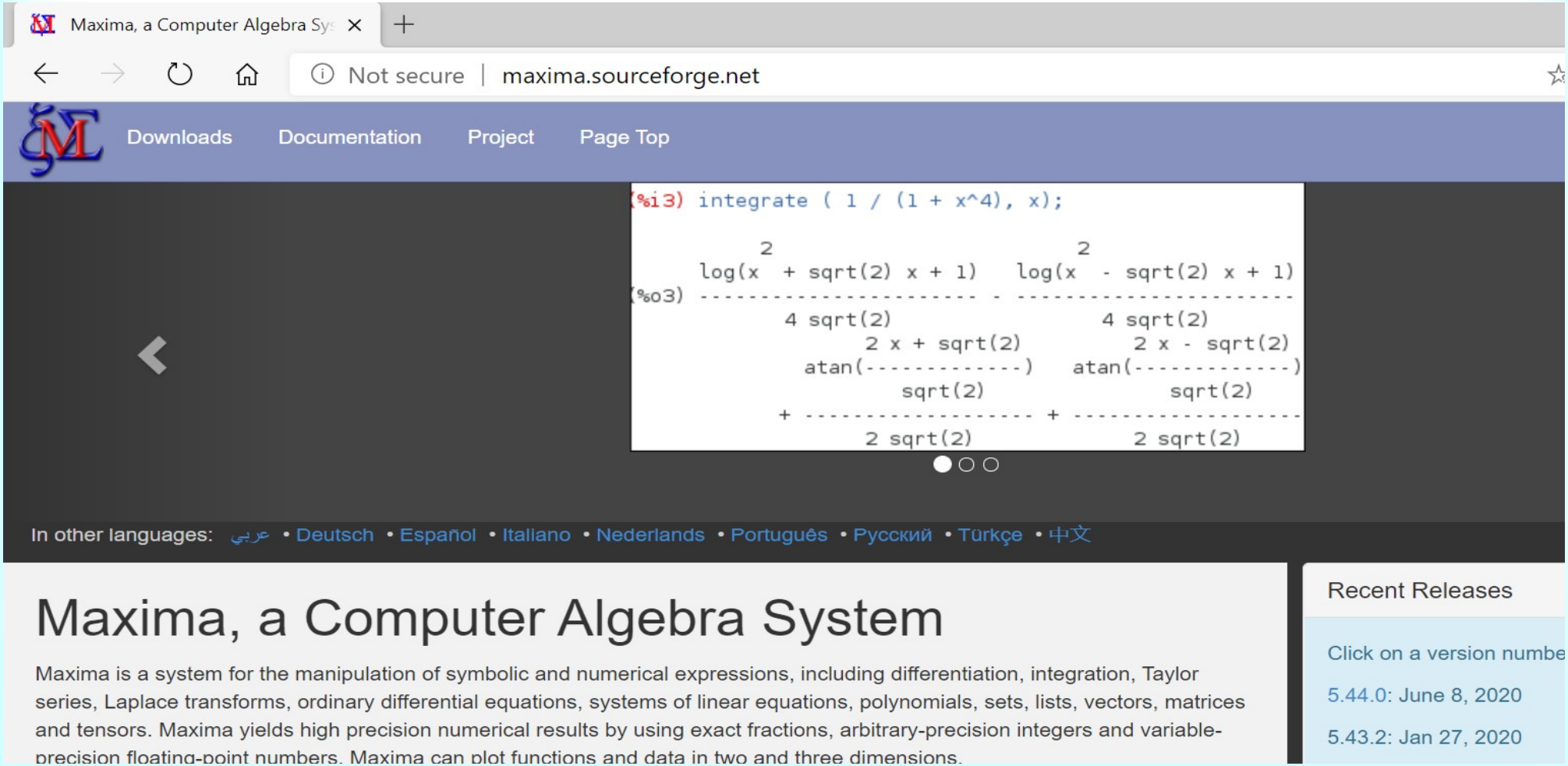
https://www.wolfram.com/raspberry-pi/


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

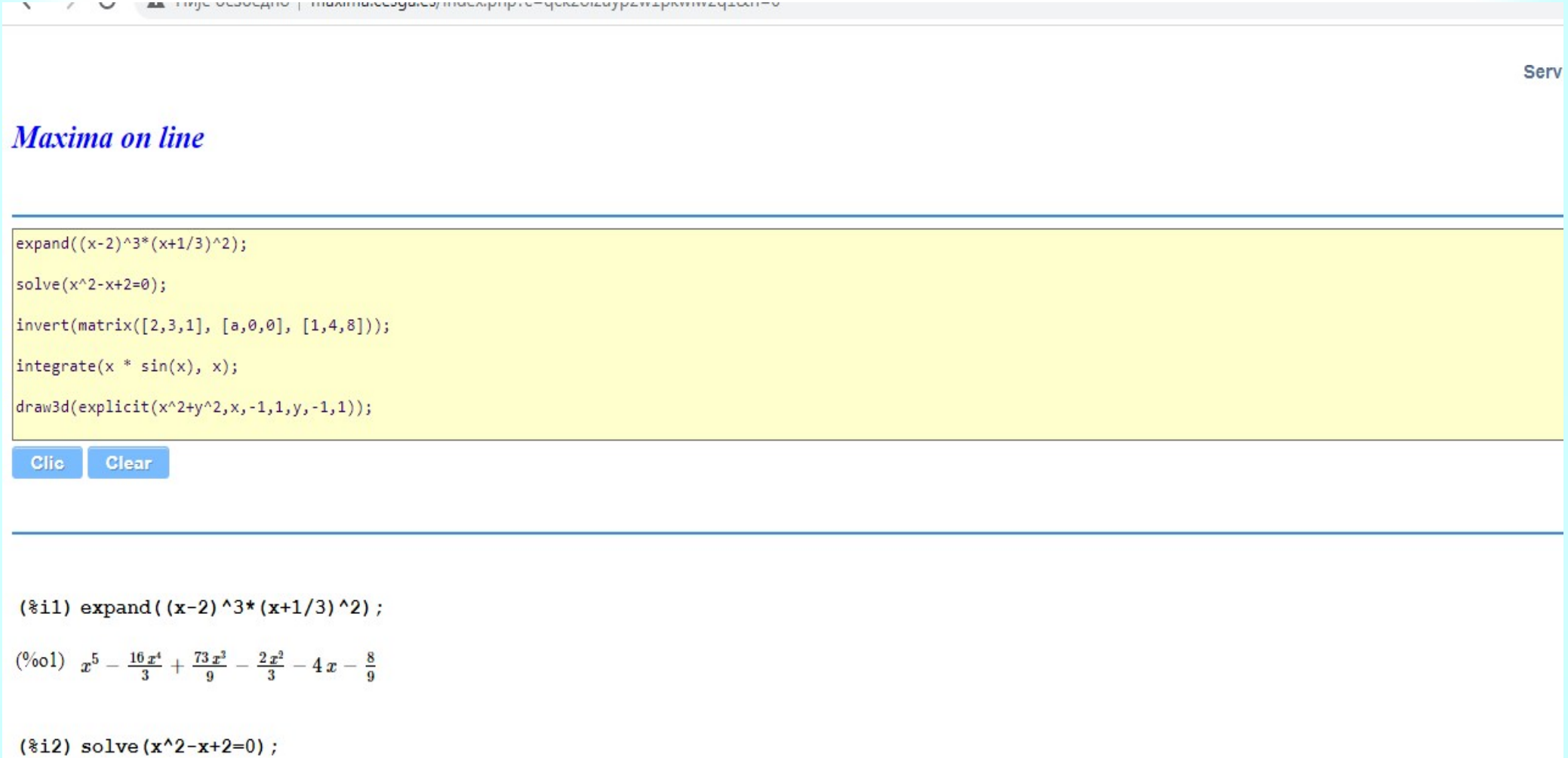
Maxima

http://maxima.sourceforge.net/



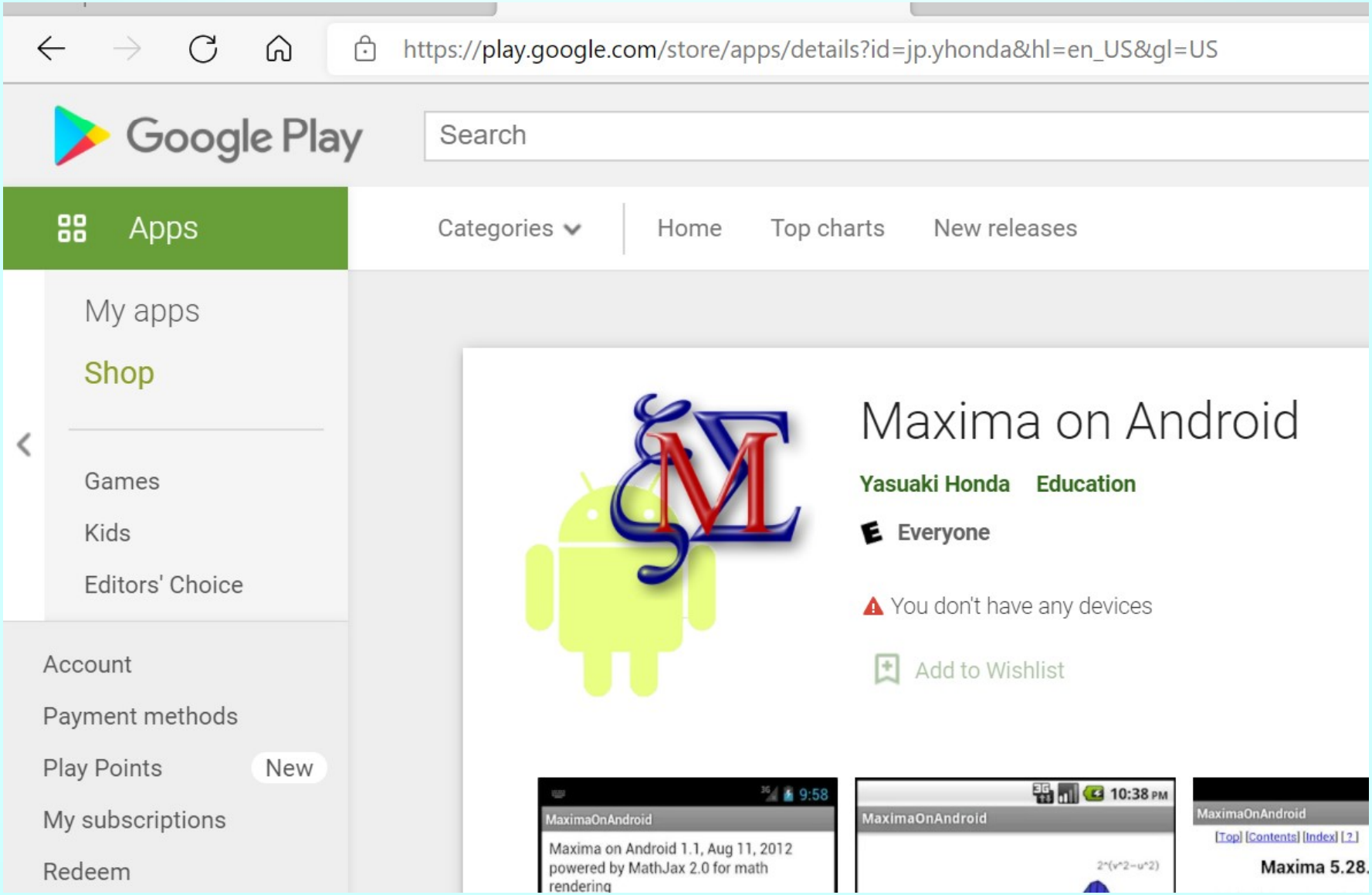
Maxima on line

http://maxima.cesga.es/



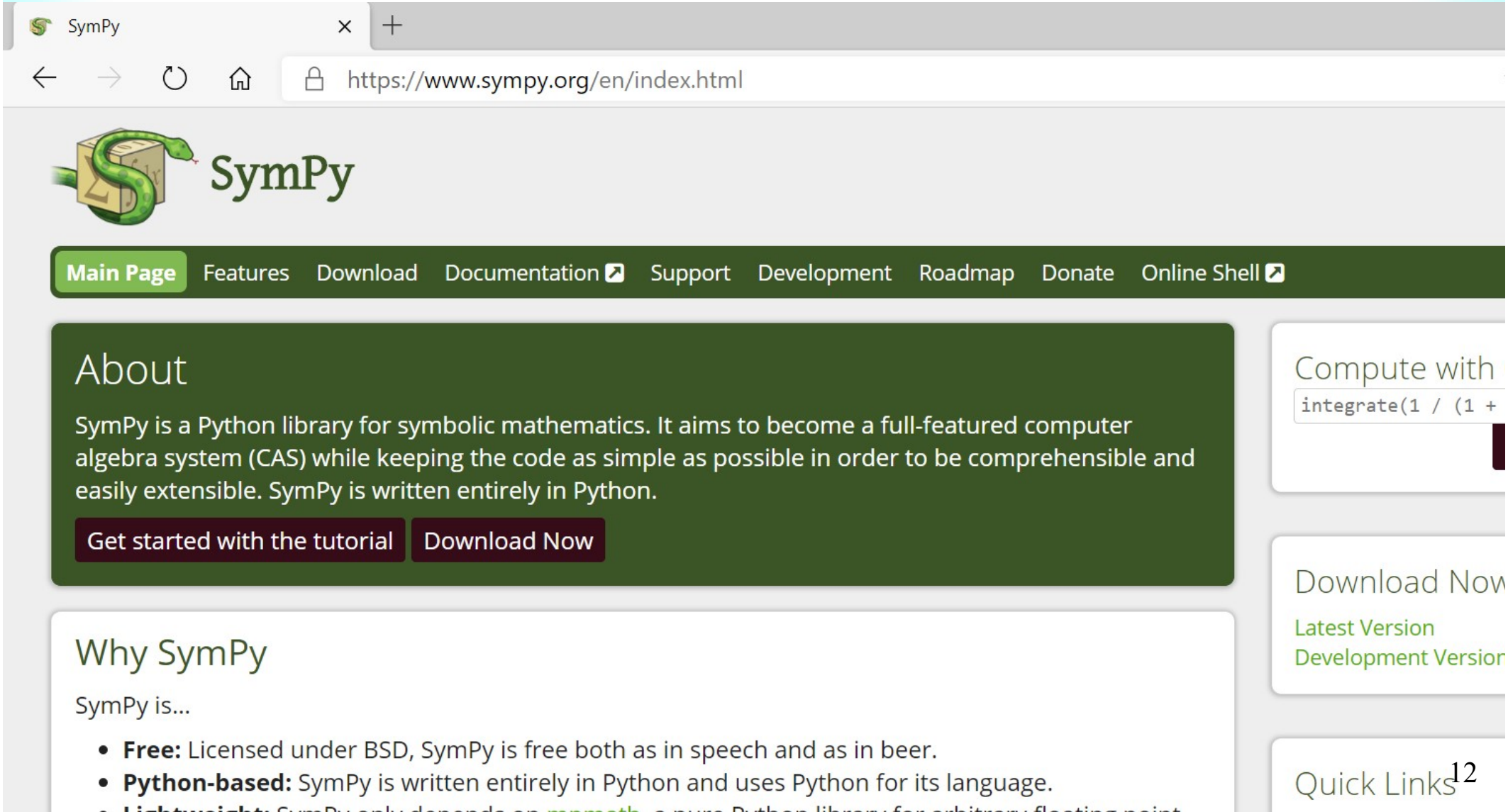
Maxima on Android

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



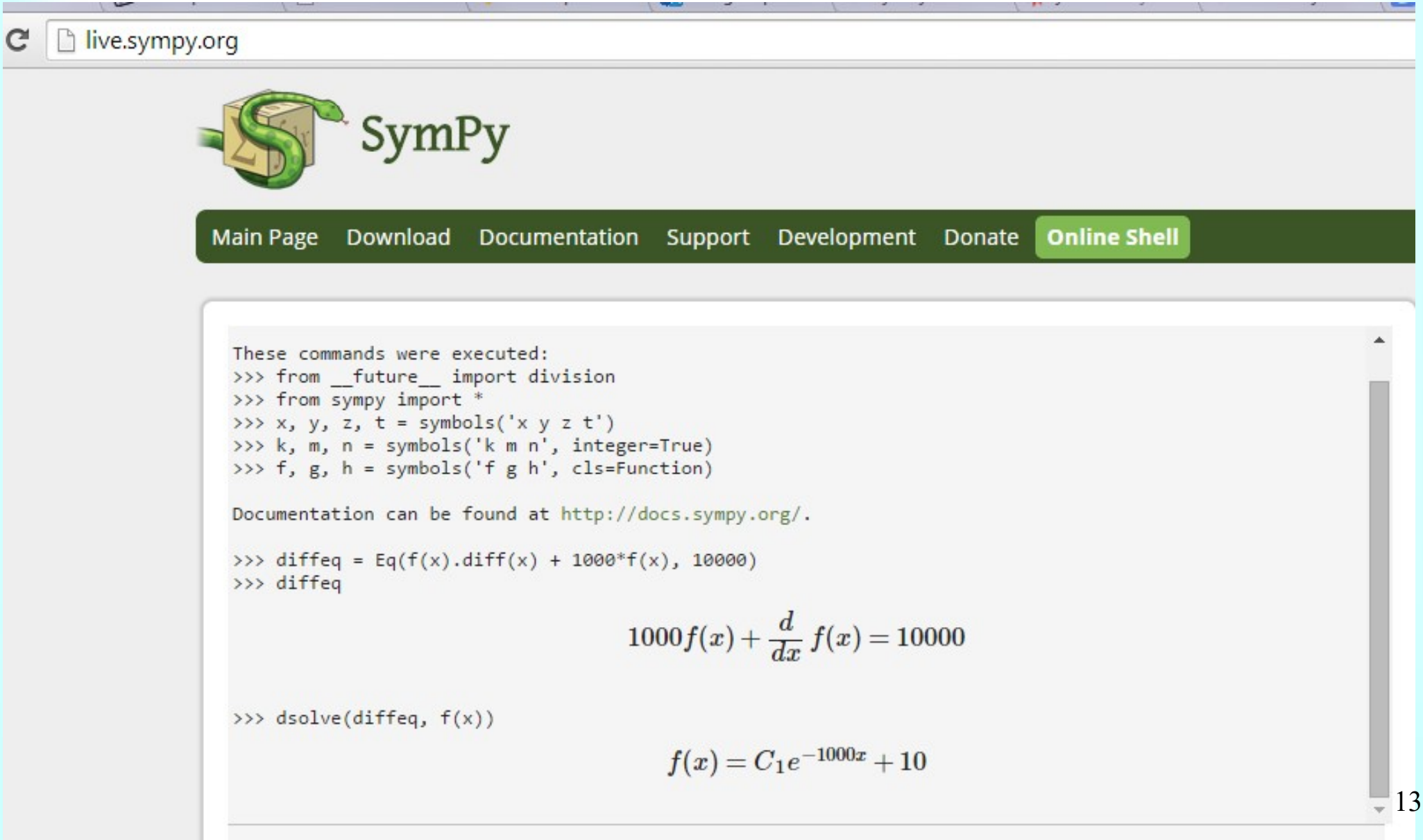
SymPy

www.sympy.org/



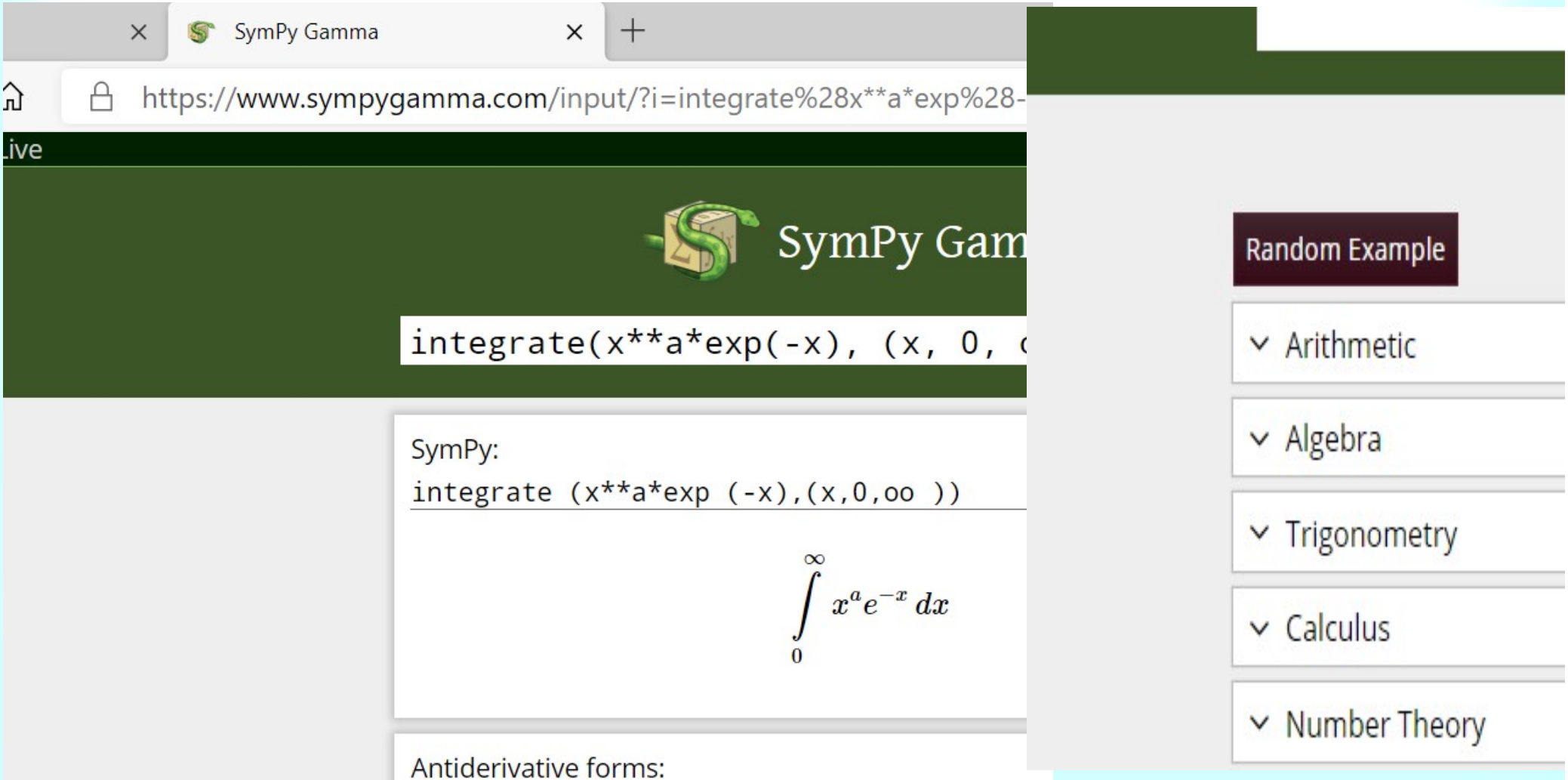
SymPy live

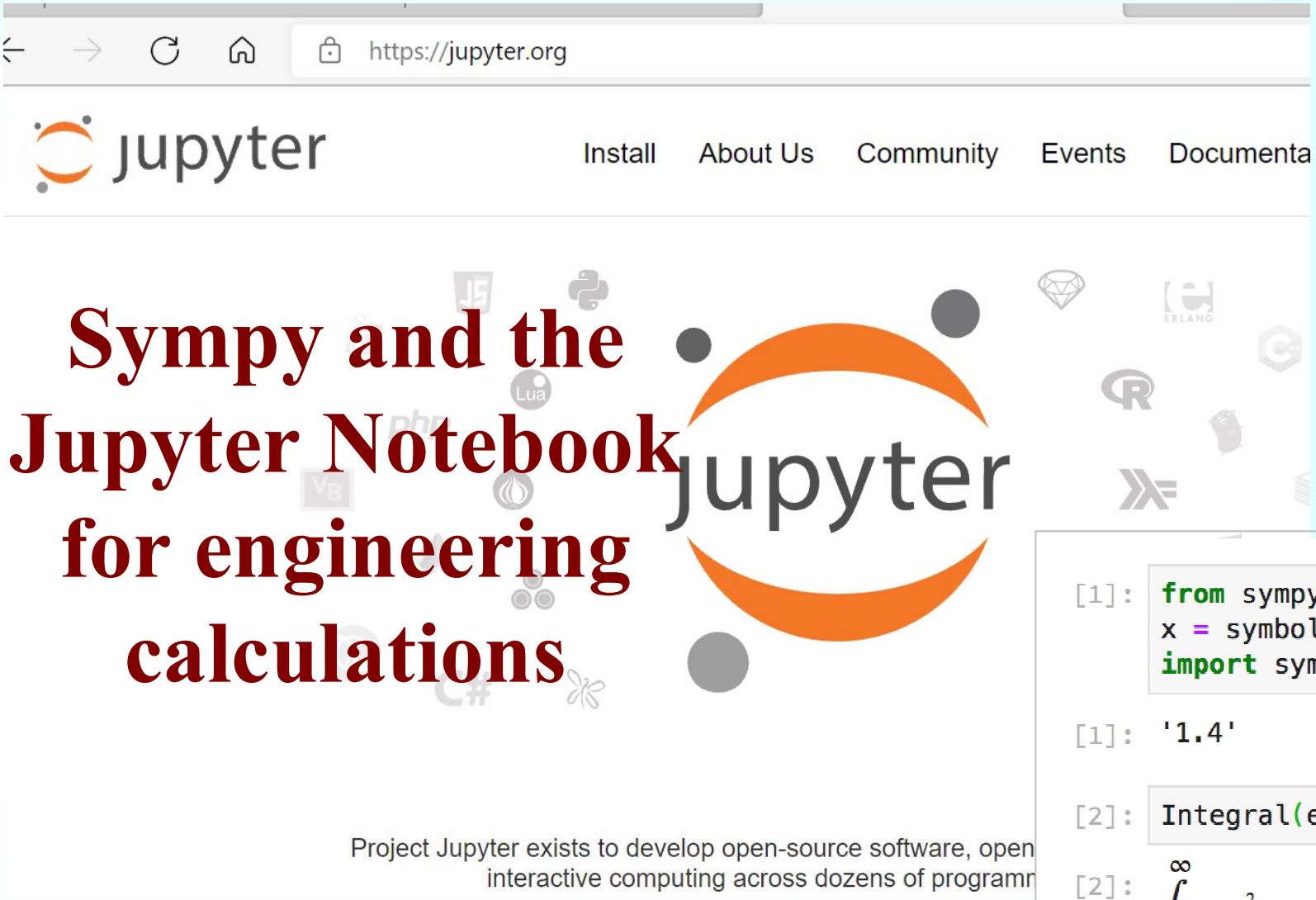
live.sympy.org



SymPy Gamma

https://www.sympygamma.com/

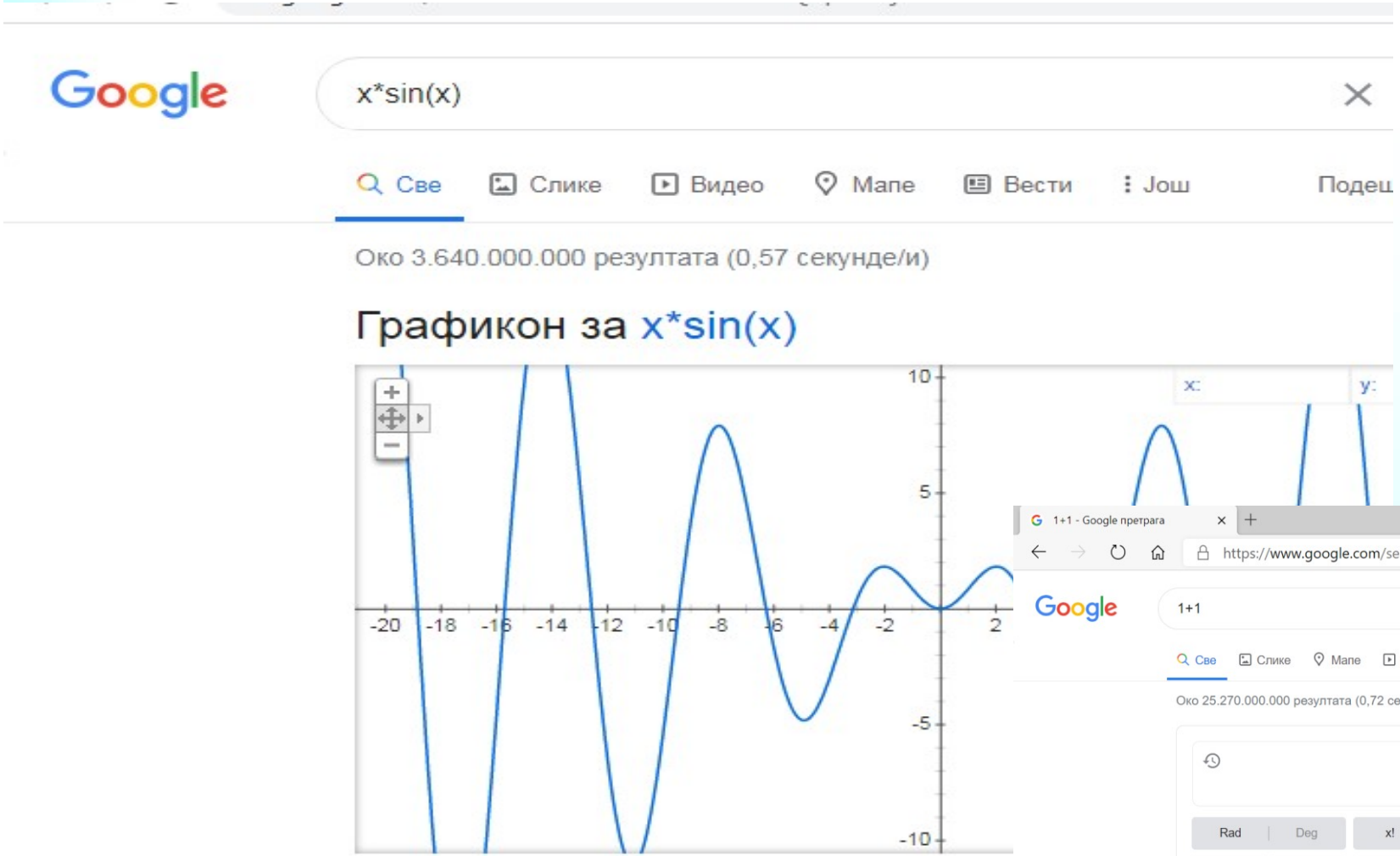


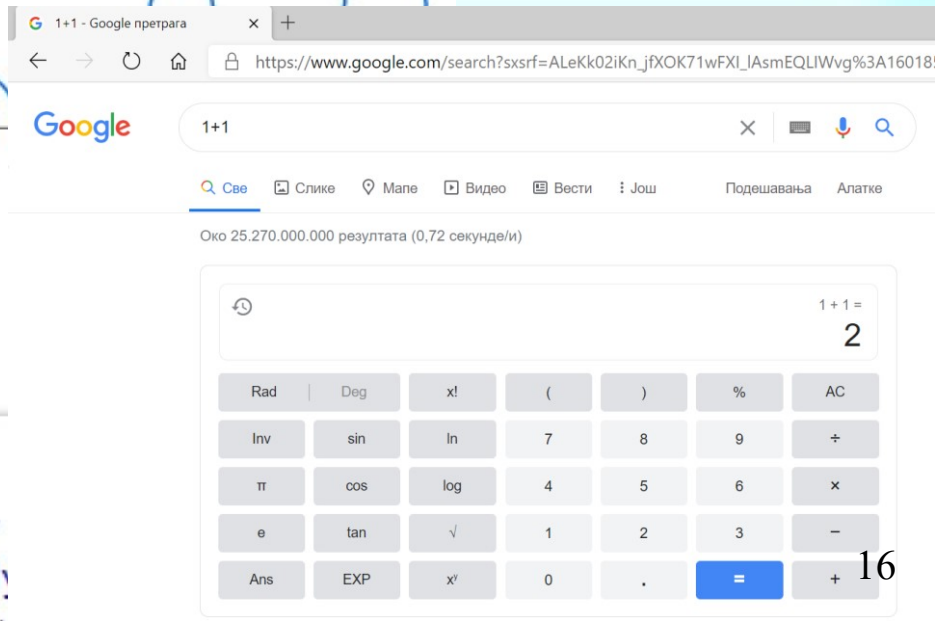


Sympy and the Jupyter Notebook for engineering calculations


```
[1]: from sympy import *
     x = symbols('x')
     import sympy;sympy.__version__

[1]: '1.4'

[2]: Integral(exp(-x**2), (x, -oo, oo))

[2]: ∫_{-∞}^{∞} e^{-x^2} dx

[3]: _.doit()

[3]: √π
```

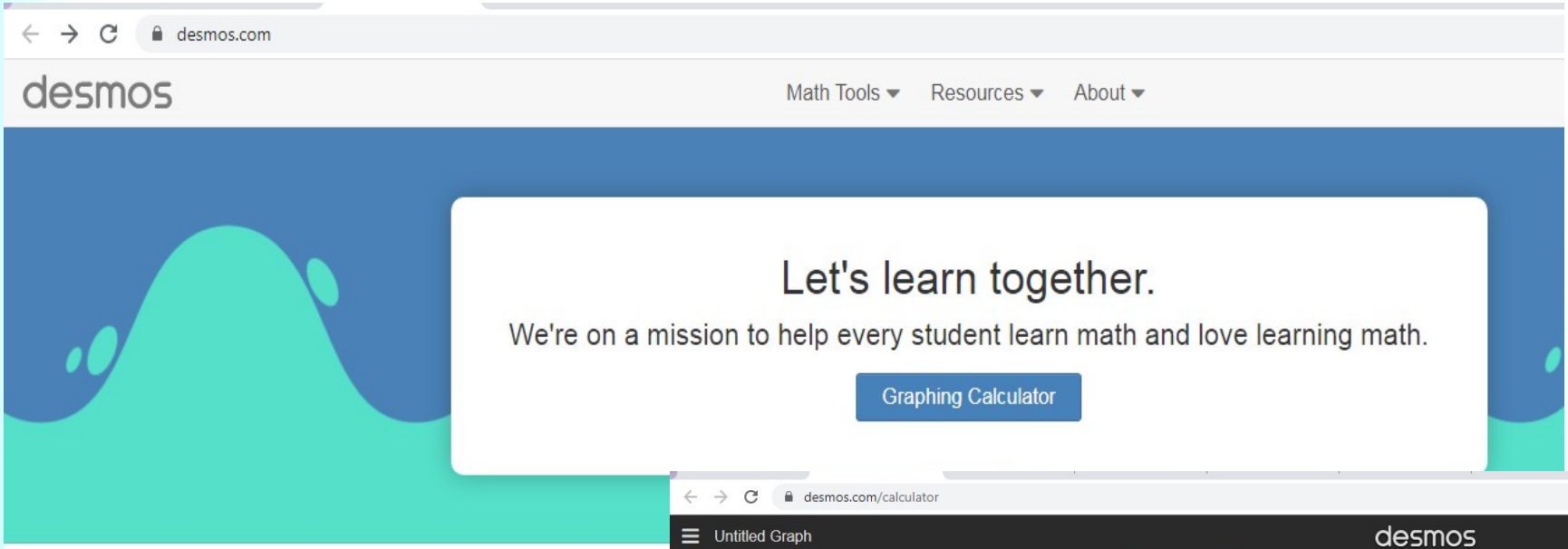
Google калкулатор





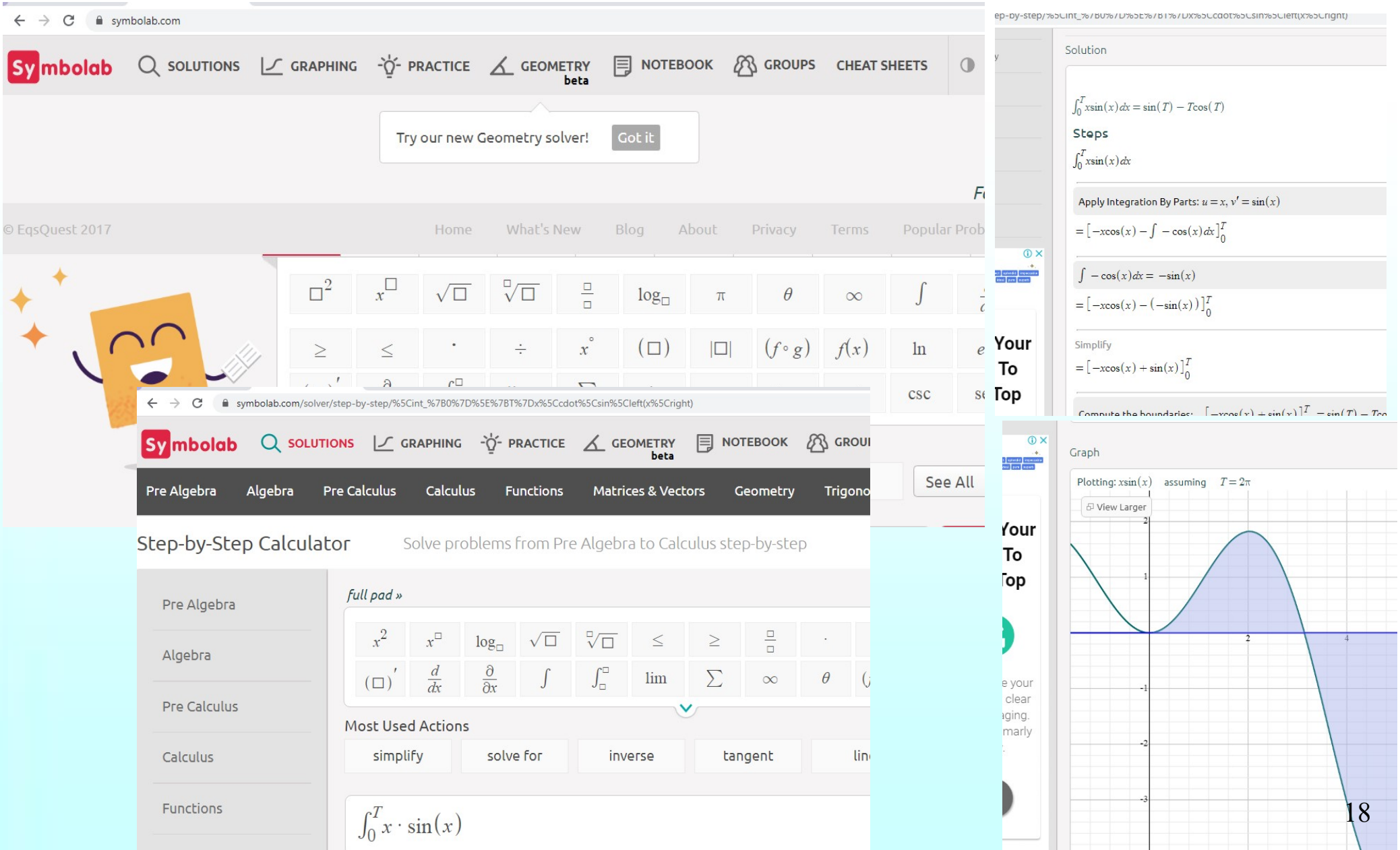
Graphing Calculator – Desmos

https://www.desmos.com/calculator



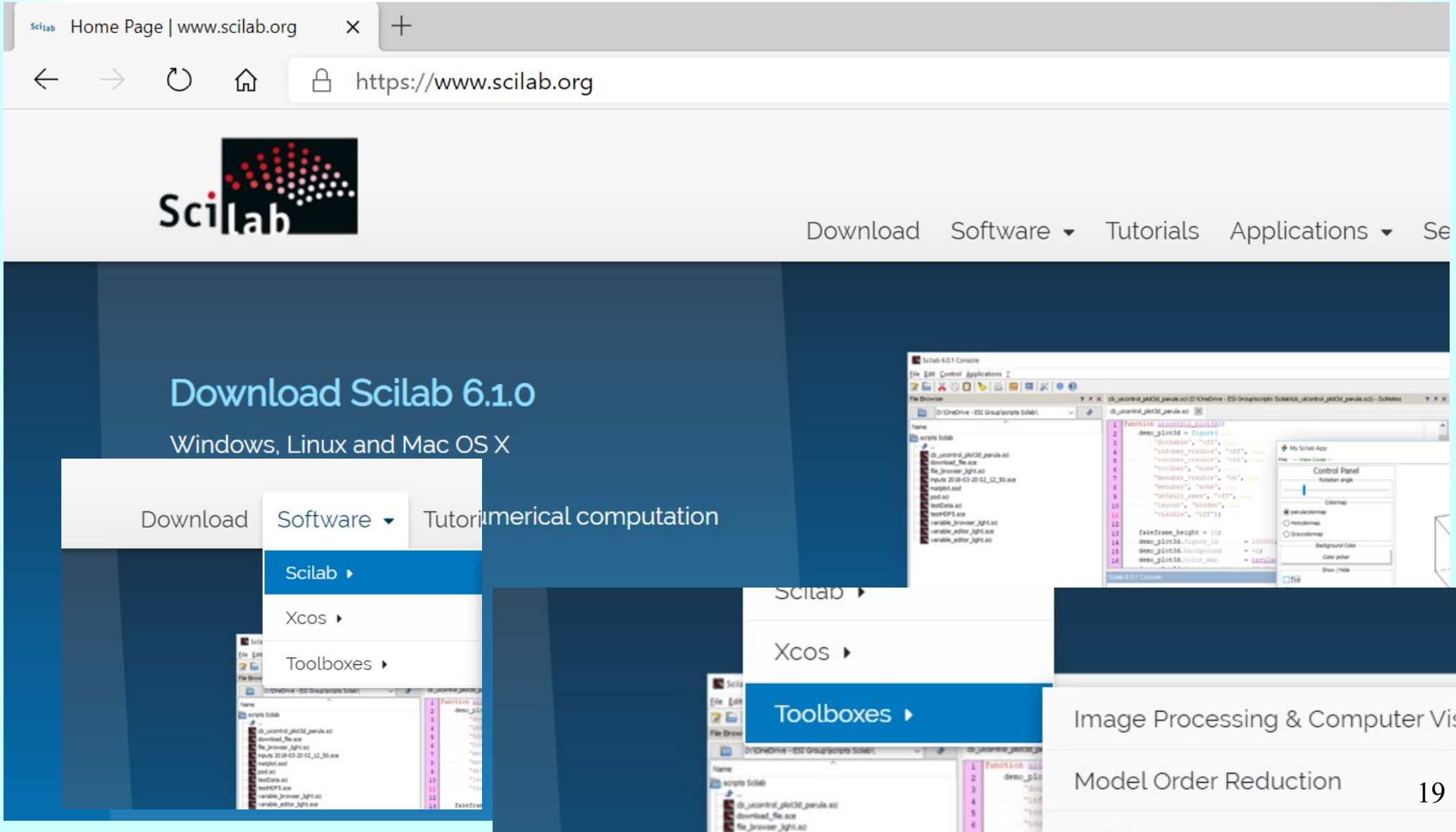
Symbolab Math Solver - Step by Step calculator

https://www.symbolab.com/



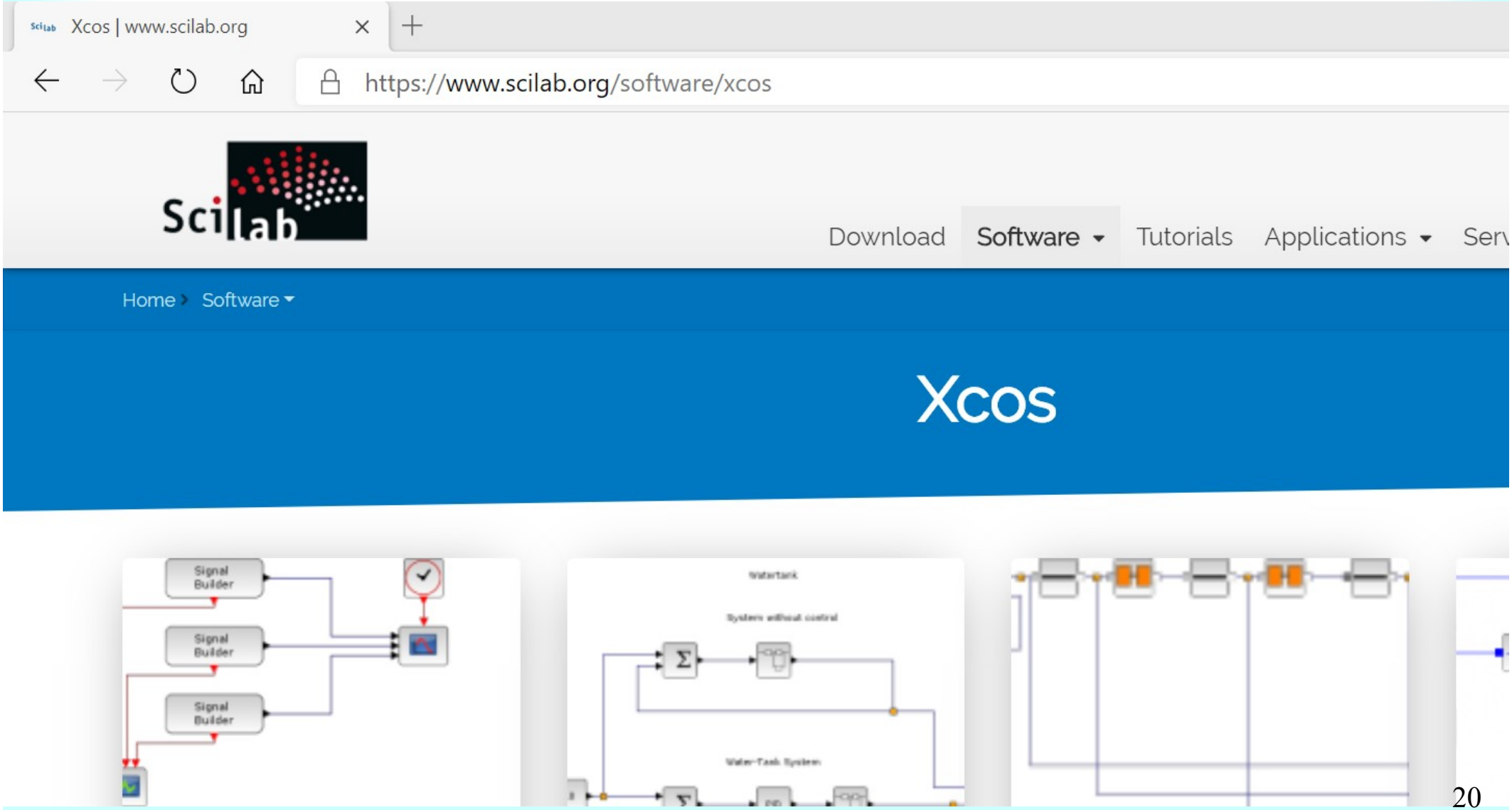
SciLab

https://www.scilab.org/



Xcos

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

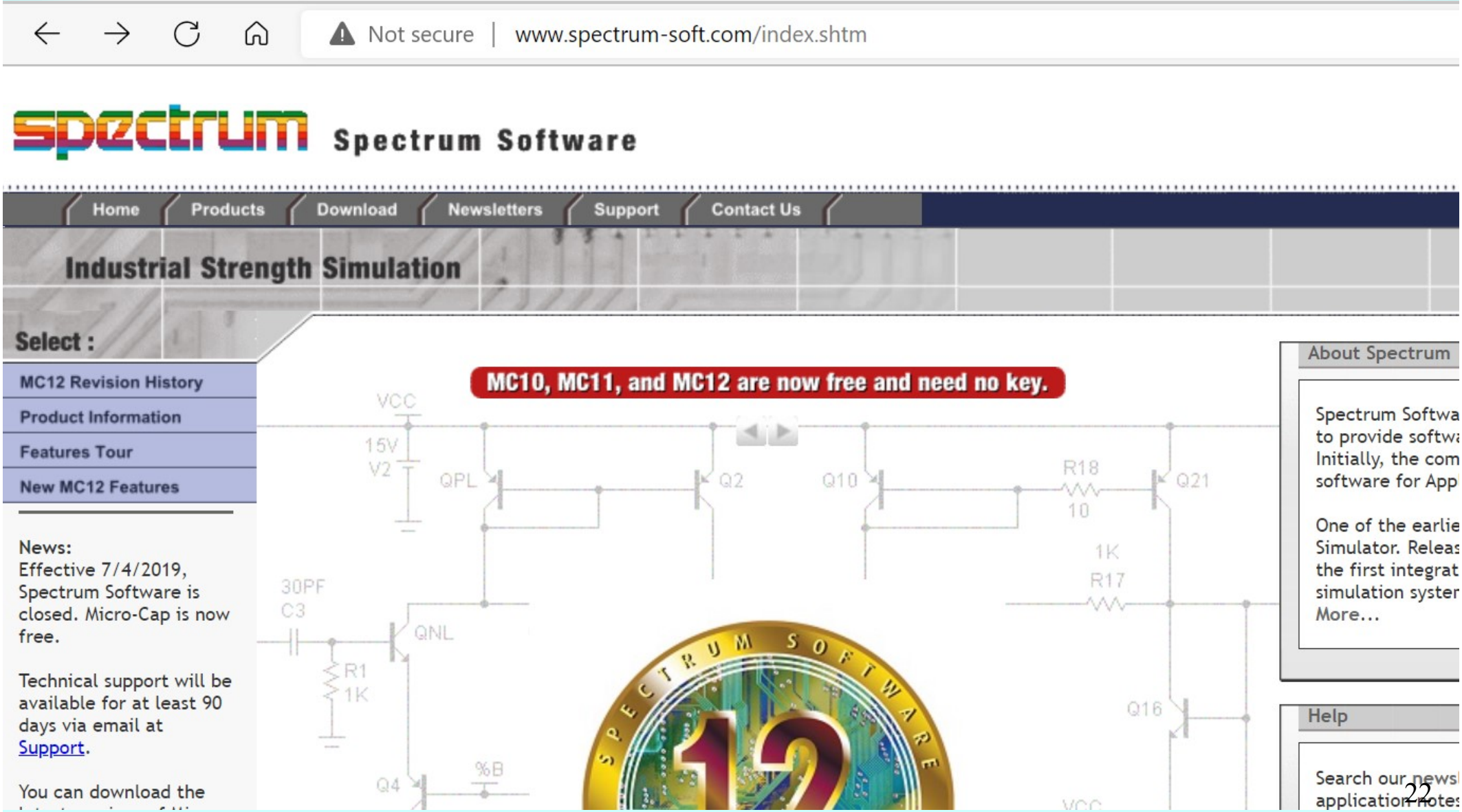


GNU Octave

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

Micro-Cap

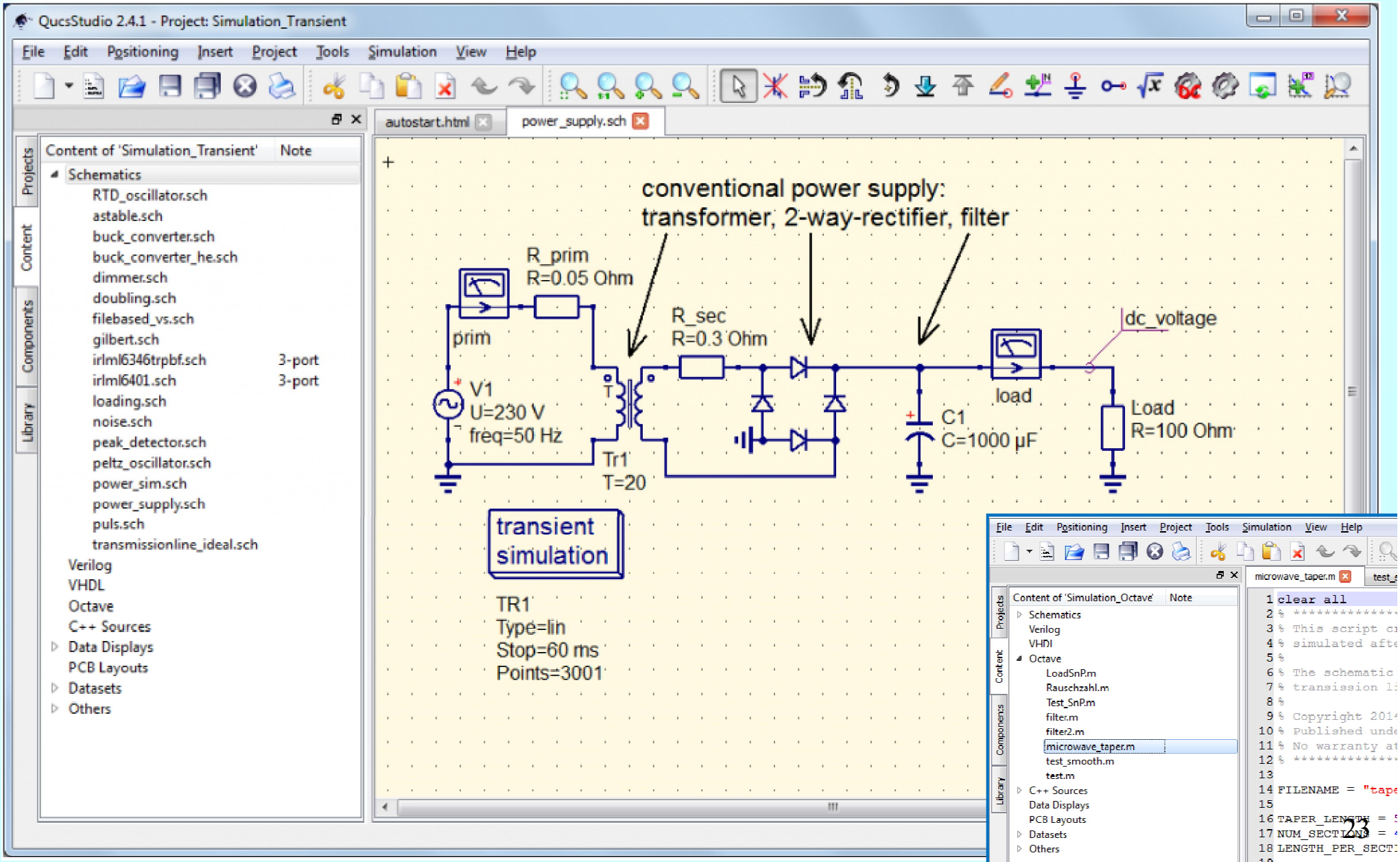
http://www.spectrum-soft.com/index.shtm



QucsStudio

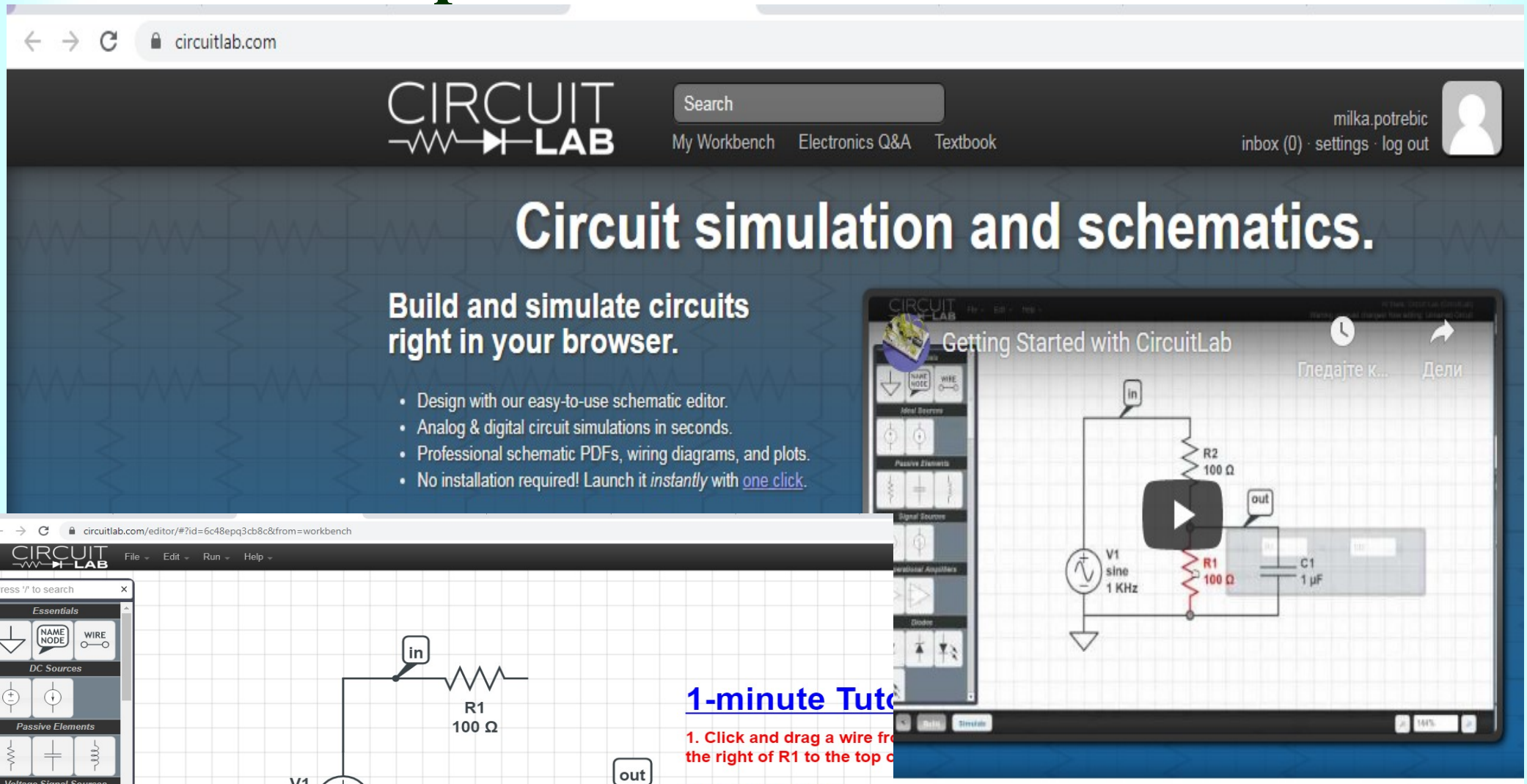
http://qucsstudio.de

Octave engine inside!



CircuitLab

https://www.circuitlab.com/



eractive Electronics Textbook NEW!

DoCircuits Circuit Simulator

ngSpice

http://ngspice.sourceforge.net/

NGSPICE

MIXED MODE - MIXED LEVEL CIRCUIT SIMULATOR

BASED ON BERKELEY'S SPICE3F5

NGSPICE

Home | News | Screenshots | Download | Documentation | Tutorials | Extras/Options | Applications | Development | Simulation

Ngspice Home

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

Sourceforge Developer Pages

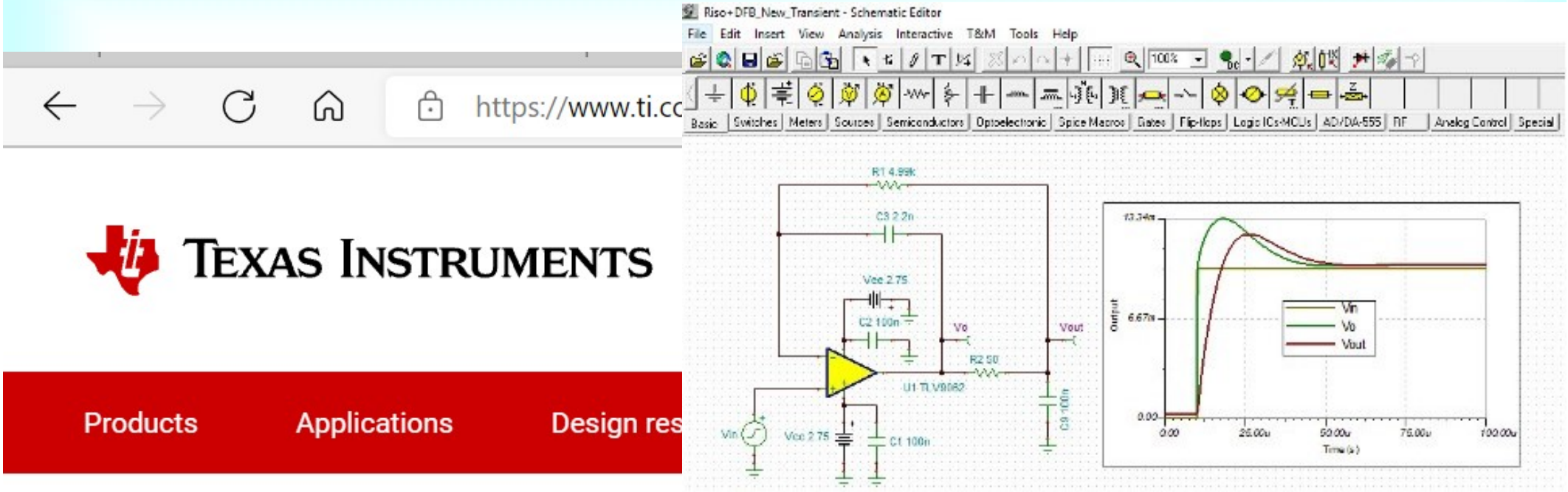
ngspice - open source spice simulator

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

Such a circuit may comprise of JFETs, bipolar and MOS transistors, passive eleme transmission lines and other devices, all interconnected in a netlist. Digital circuits ar driven and fast, from single gates to complex circuits. And you may enter the comb digital as a mixed-signal circuit.

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

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



Home / Design resources

TINA-TI

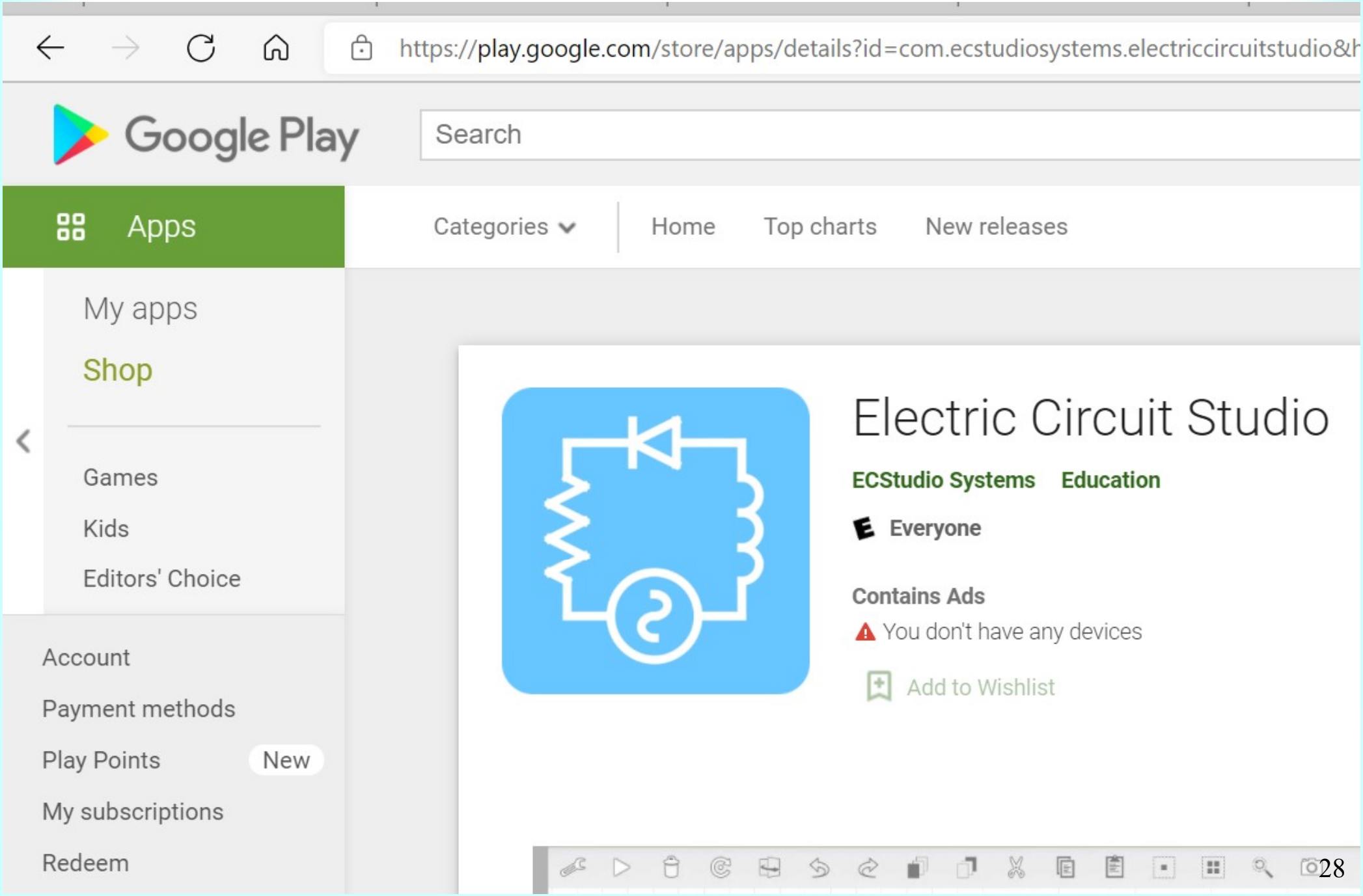
SPICE-based analog simulation program

TINA-TI

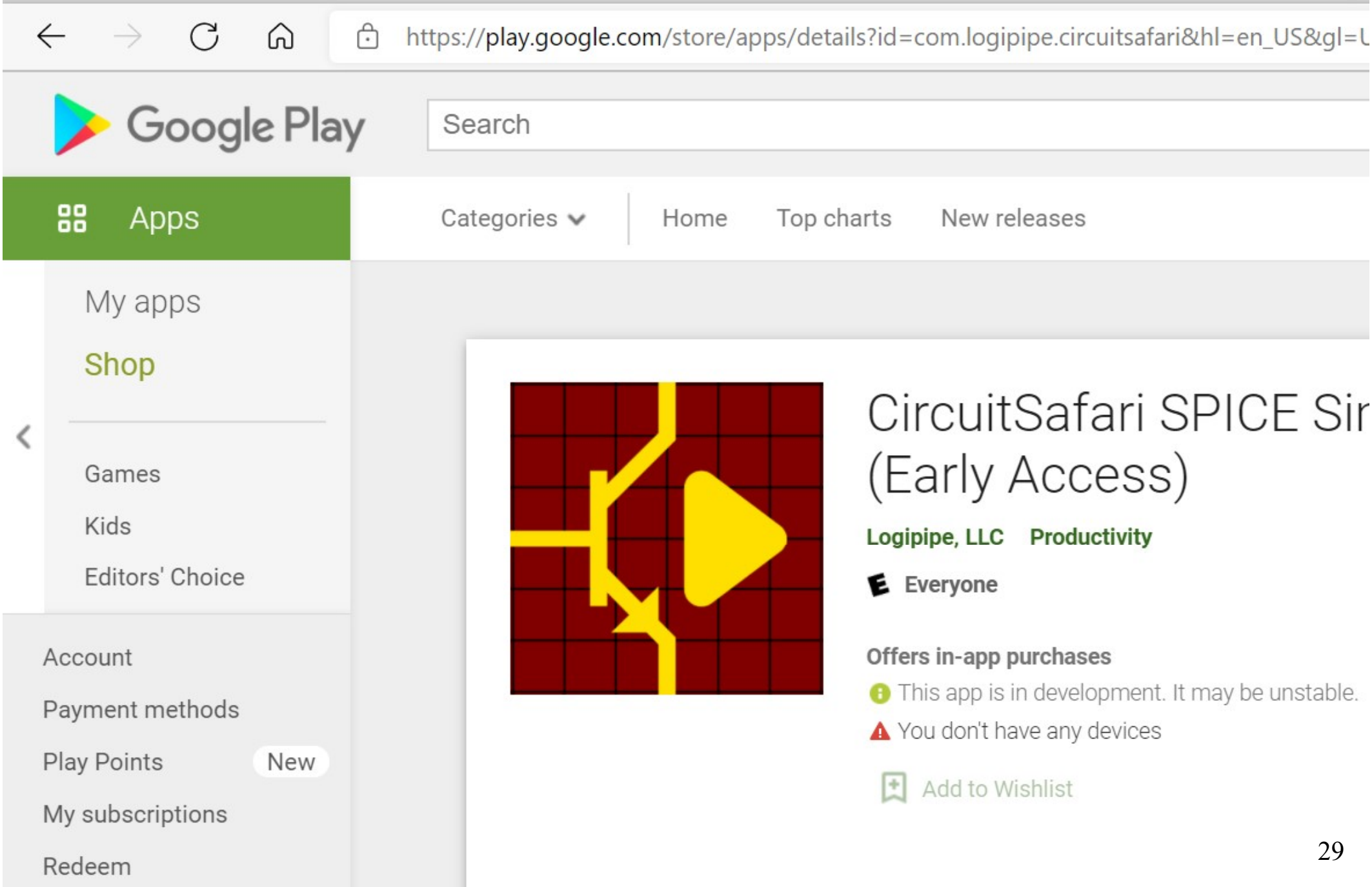
https://www.ti.com/tool/TINA-TI

Overview | Downloads | Technical documentation | Support & training

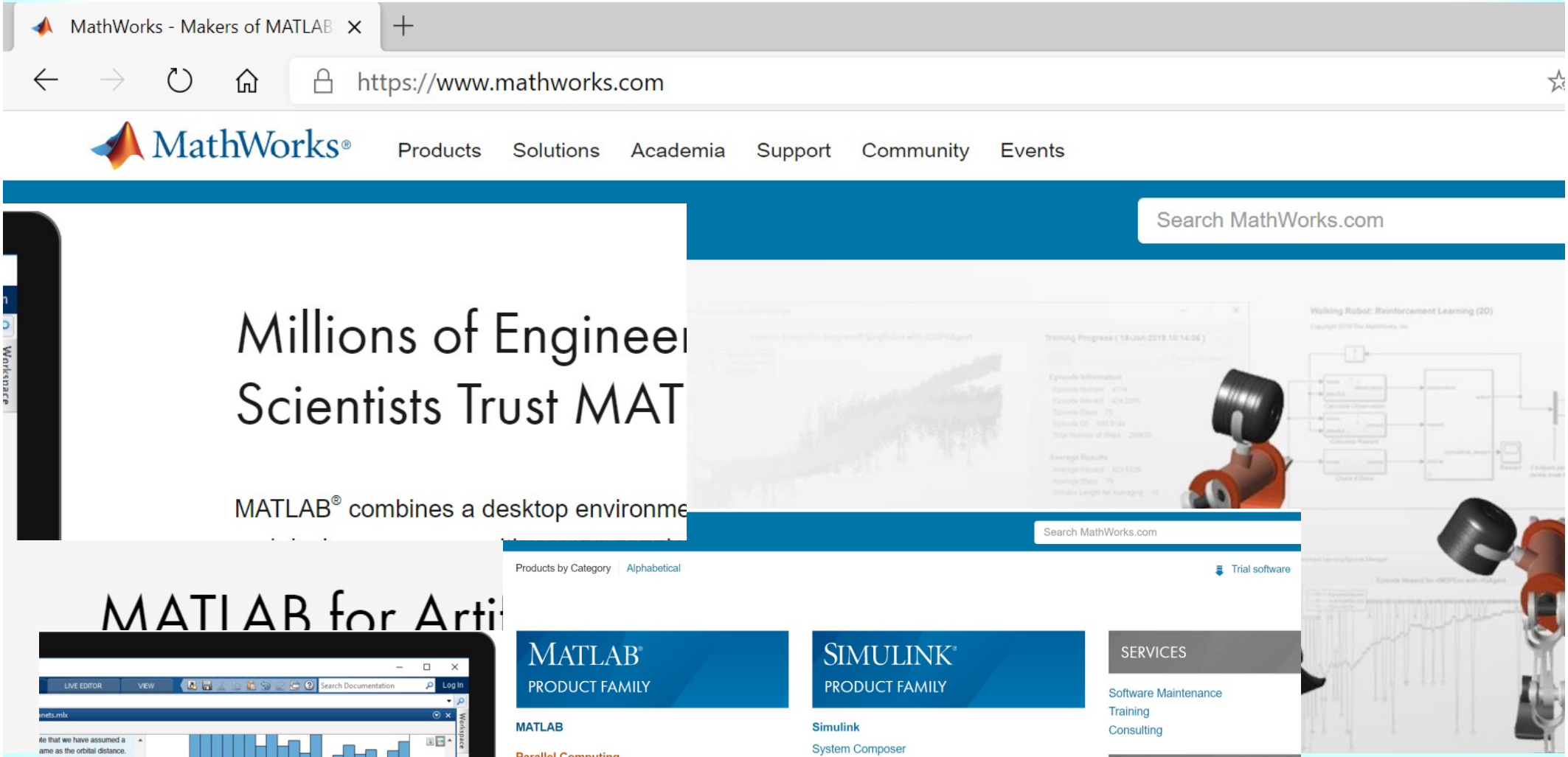
Electric Circuit Studio



CircuitSafari SPICE Simulator



MATLAB


MathWorks - Makers of MATLAB
https://www.mathworks.com
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Community
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Trial software
MATLAB®
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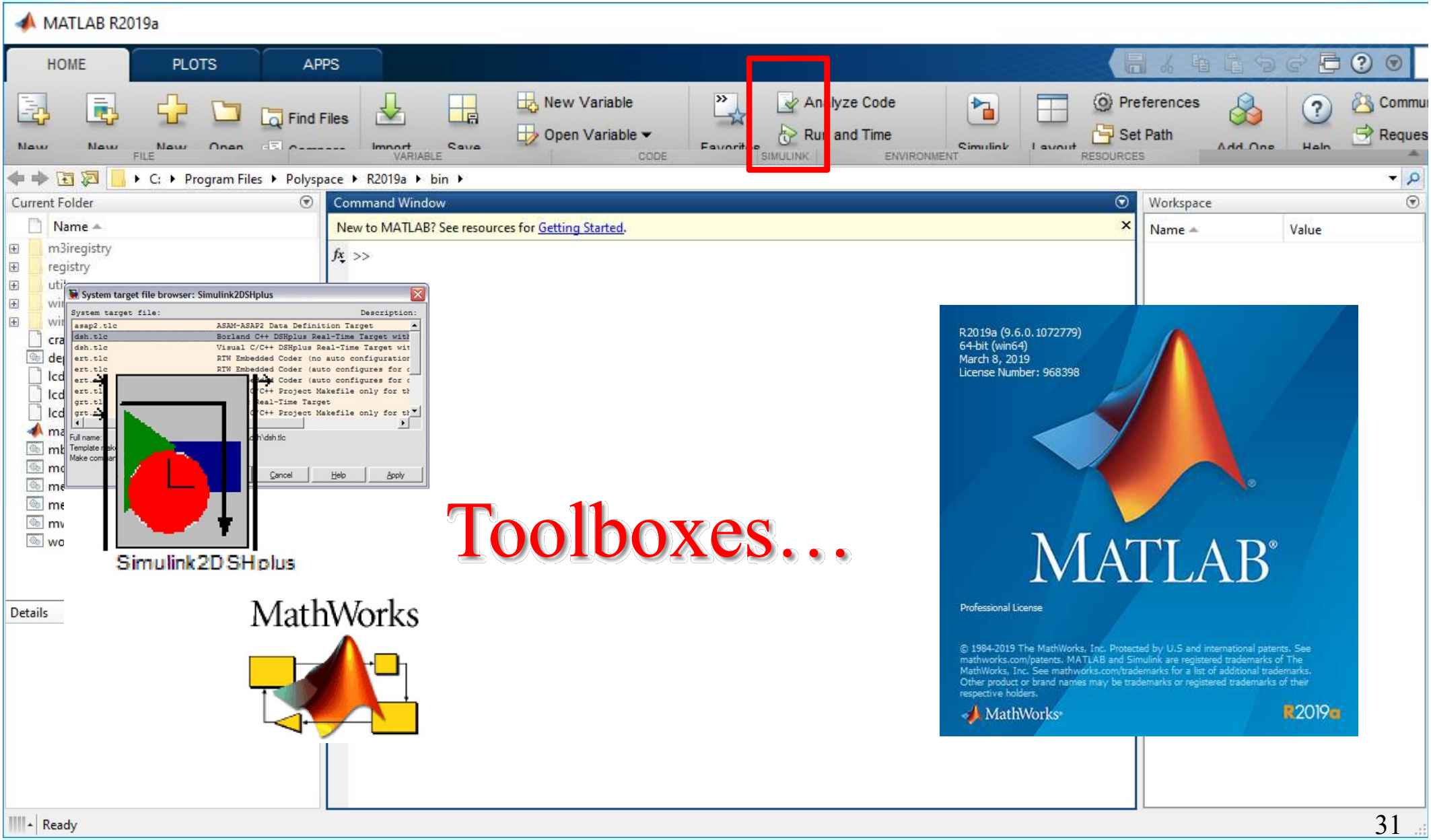
MATLAB
Parallel Computing
Parallel Computing Toolbox
MATLAB Parallel Server
Math and Optimization
Curve Fitting Toolbox
Optimization Toolbox
Global Optimization Toolbox
Symbolic Math Toolbox
Mapping Toolbox
SIMULINK®
PRODUCT FAMILY
Simulink
System Composer
Event-Based Modeling
Stateflow
SimEvents
Physical Modeling
Simscape
Simscape Driveline
Simscape Electrical
Simscape Fluids
SERVICES
Software Maintenance
Training
Consulting
LICENSE TYPES
Industry Use
Student Use
University Use
Startup Use
Primary and Secondary School Use
Home Use

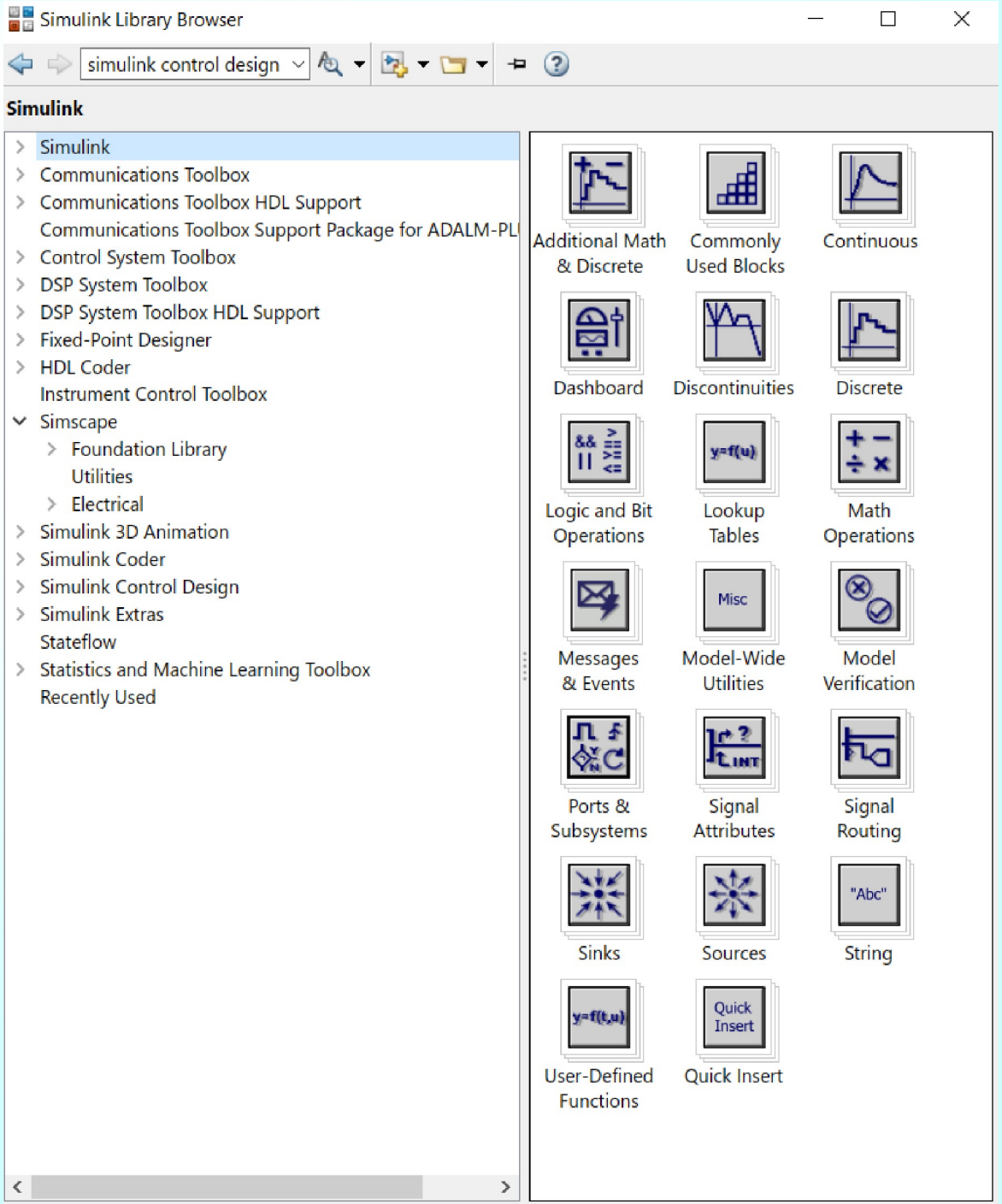
MATLAB

http://www.mathworks.com/



MATLAB Simulink

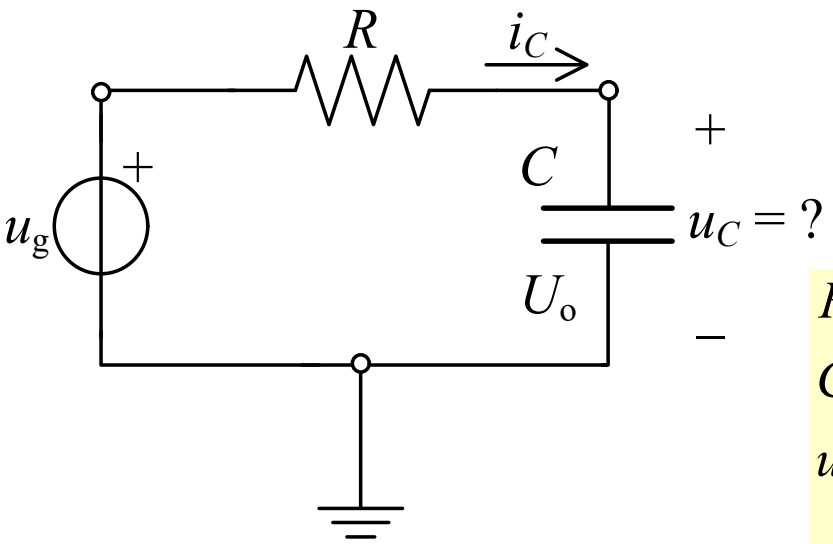
- Алатка за нумеричку анализу математичких модела
- Систем се дефинише графички, уметањем блокова и њиховим повезивањем у мрежу



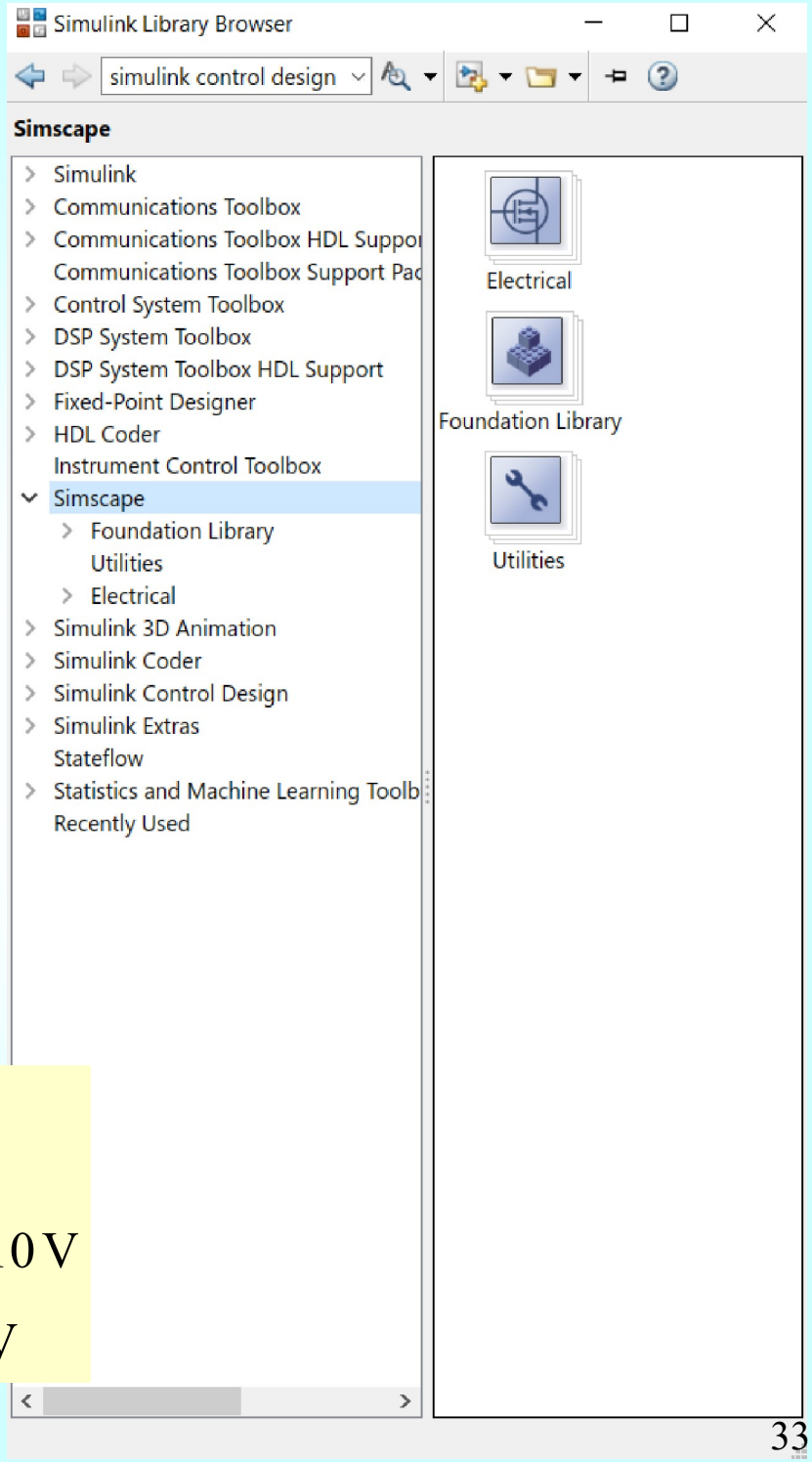
Simulink > Simscape

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

коло је образовано у тренутку $t_0 = 0$

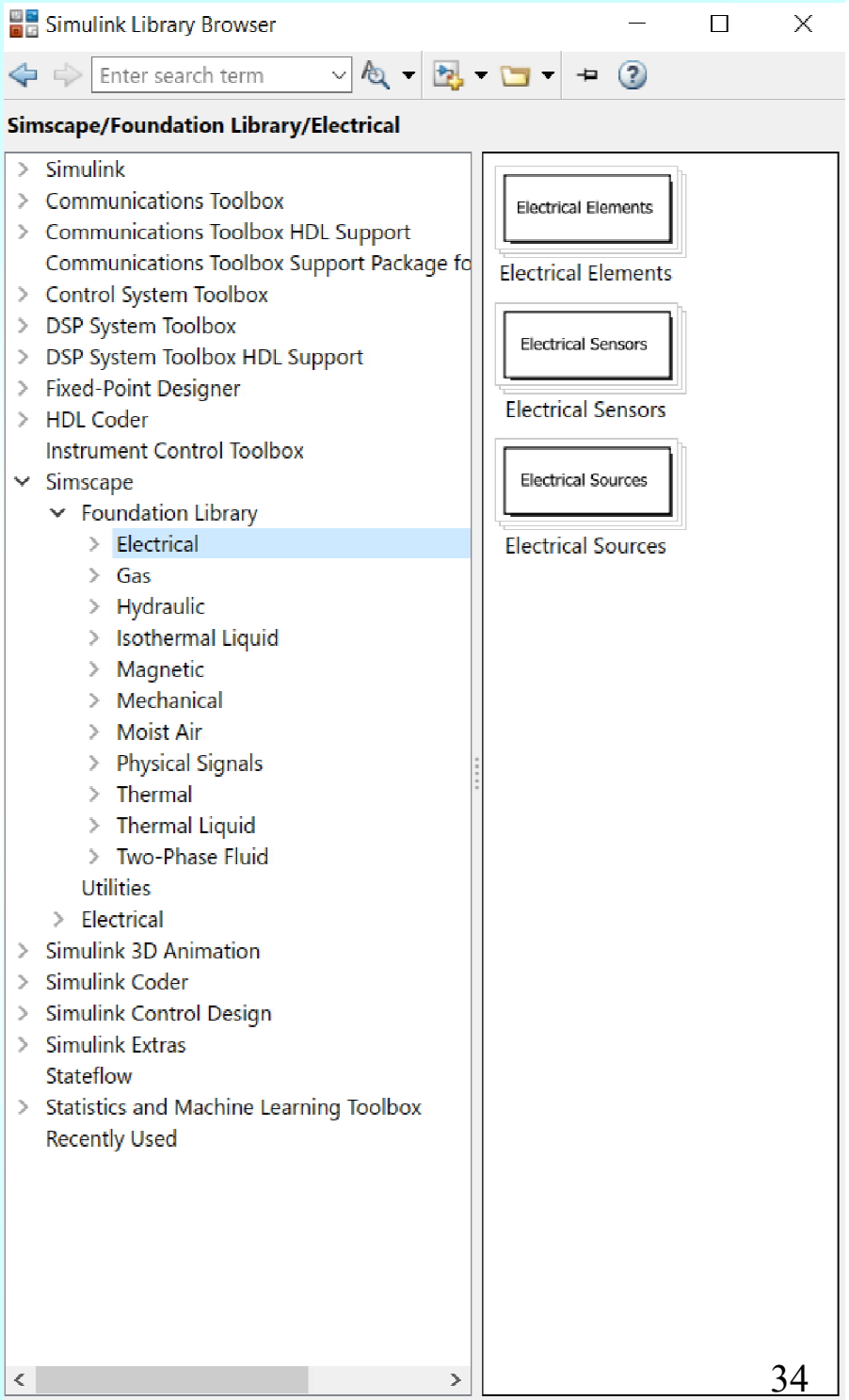


$$R = 1\,\mathrm{k\Omega}$$
$$C = 1\,\mu\mathrm{F}$$
$$u_g(t) = U\,h(t), U = 10\,\mathrm{V}$$
$$u_C(t_0^-) = U_0 = -10\,\mathrm{V}$$



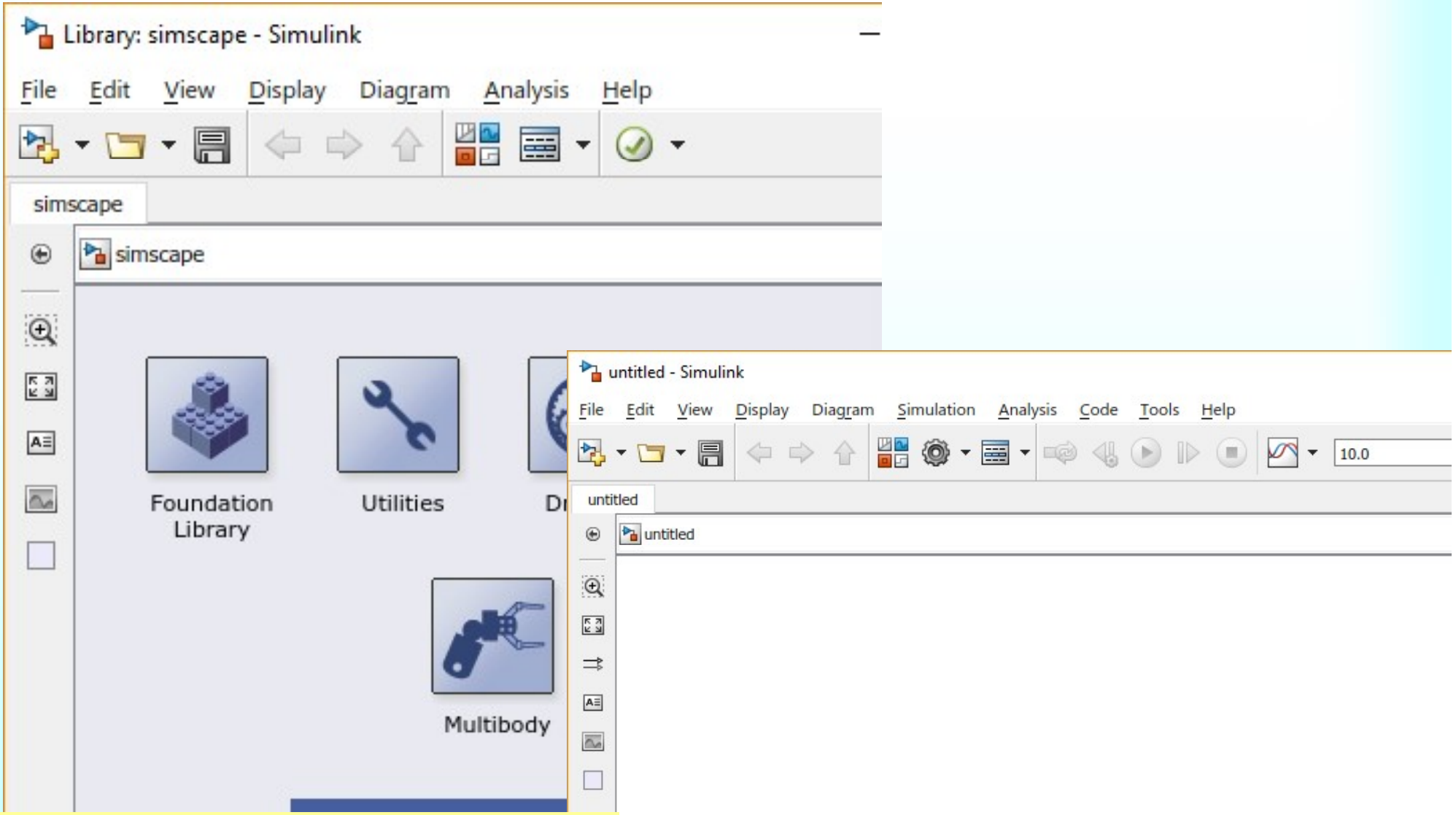
Simulink > Simscape > Foundation Library > Electrical

- Симулација линеарних и нелинеатних електричних кола

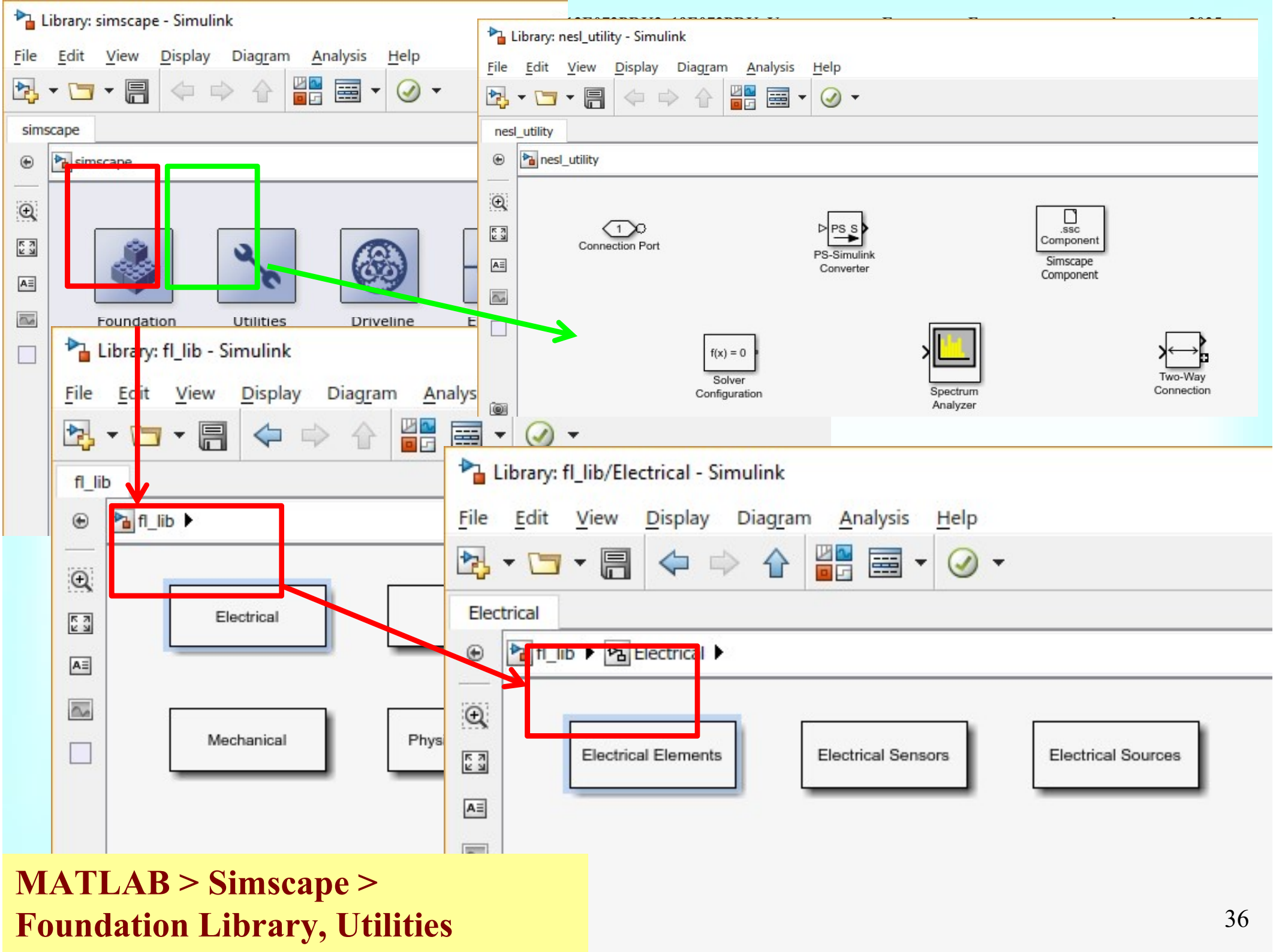


MATLAB > Simscape > Foundation Library, Utilities

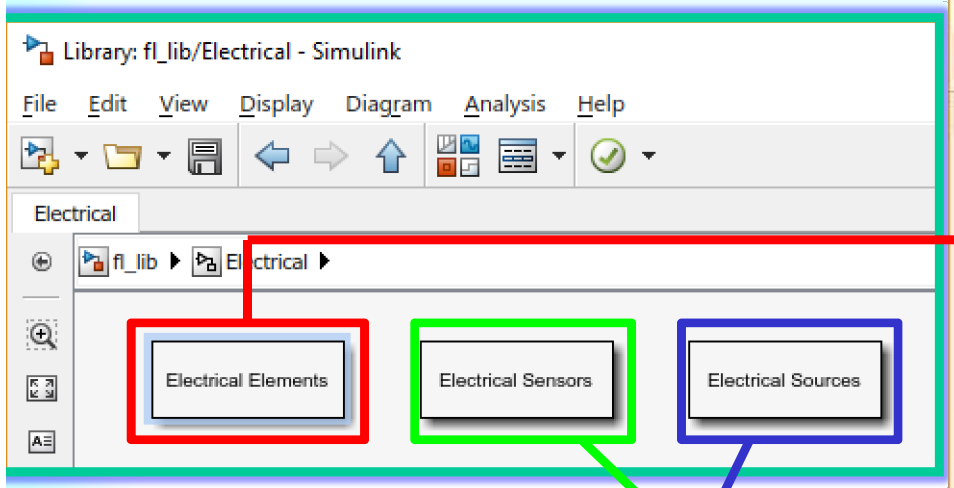
Симулација електричног кола коришћењем **Simscape > Foundation Library** библиотеке

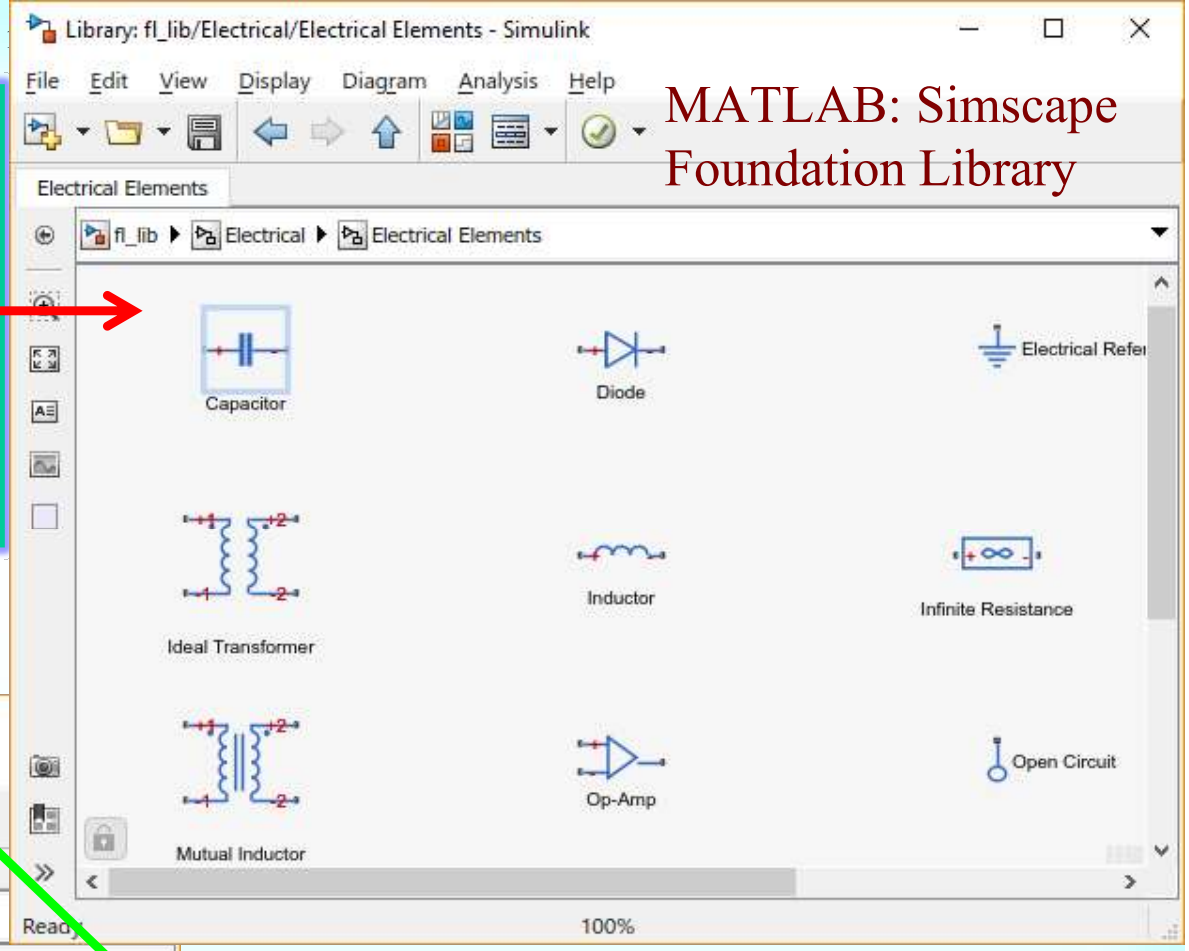


MATLAB > Simscape > Foundation Library, Utilities

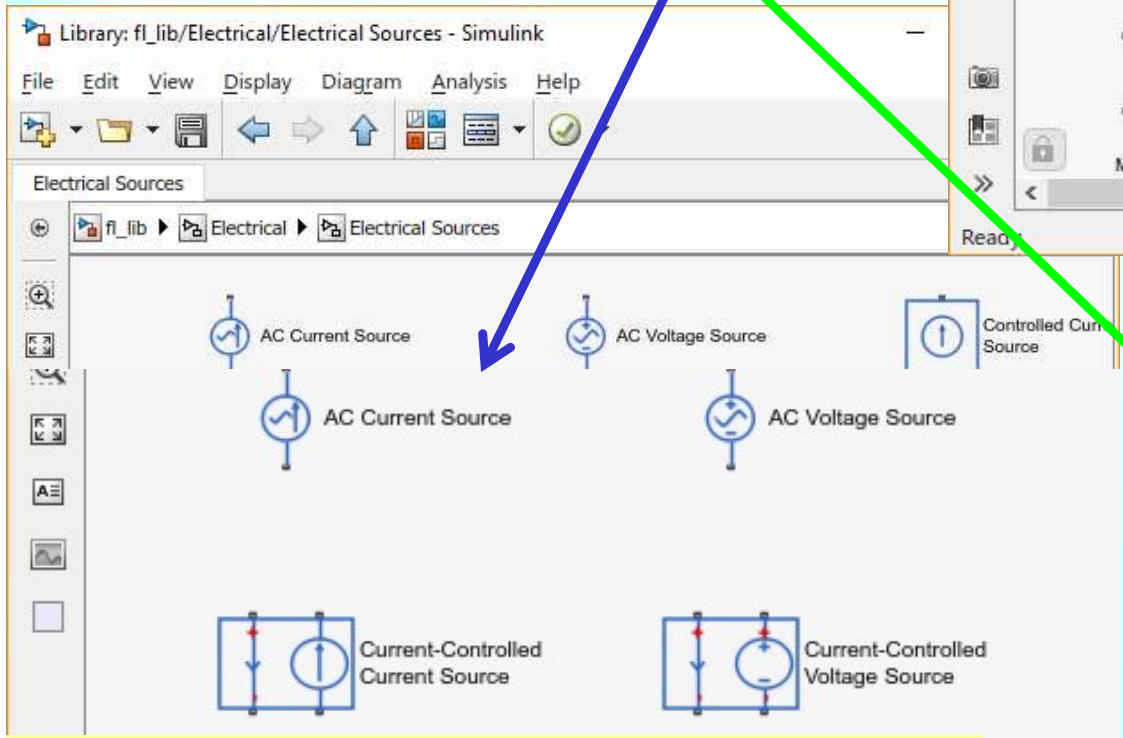


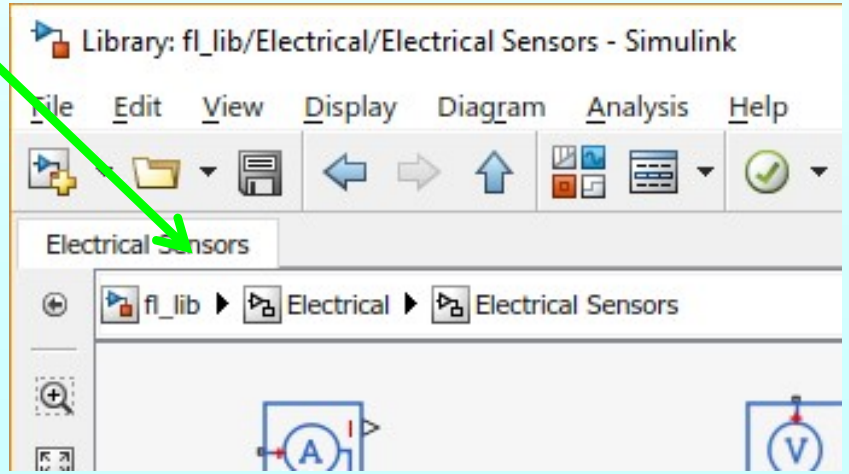
MATLAB > Simscape > Foundation Library, Utilities





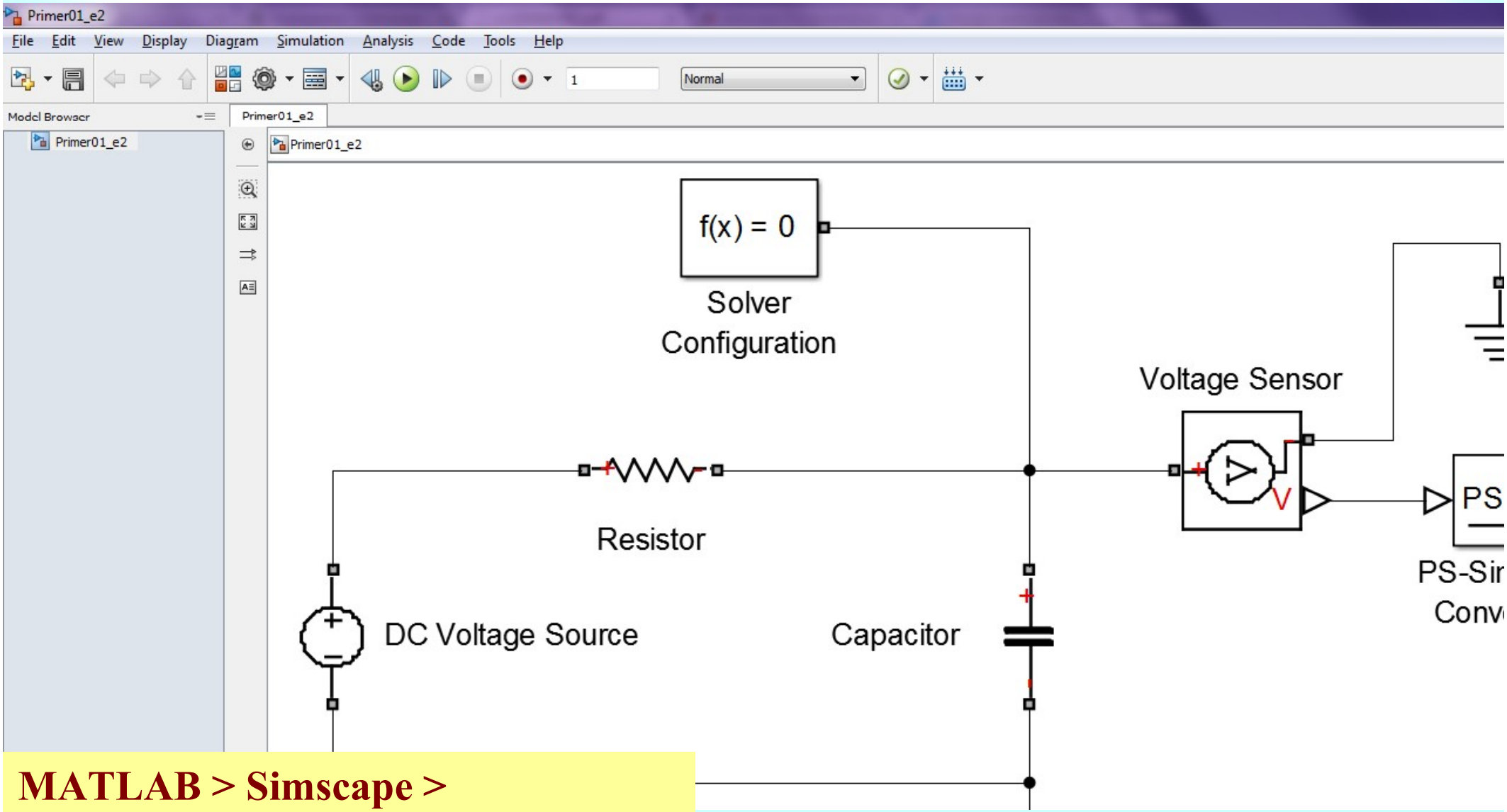
MATLAB: Simscape Foundation Library



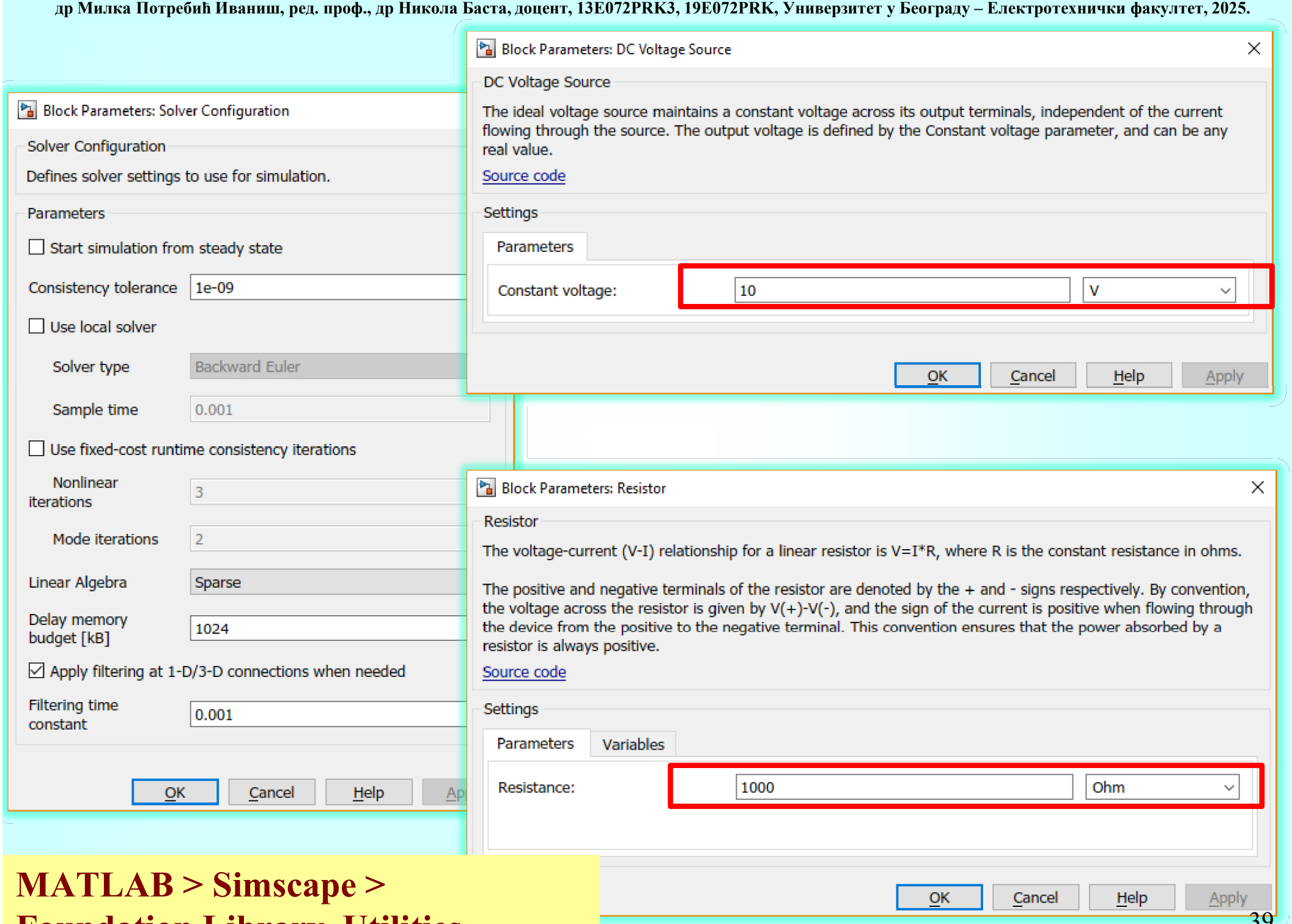


MATLAB > Simscape > Foundation Library, Utilities

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

Source code

Settings

Parameters | Variables

Capacitance: 1e-6 F

Series resistance: 0 Ohm

d current I is I=C*dV/dt where C is the

itic effects. The parallel conductance ca

tive series resistance (ESR) of the capa

some circuits may require the presence of the small series resistance. Consult the documentation for further

Source code

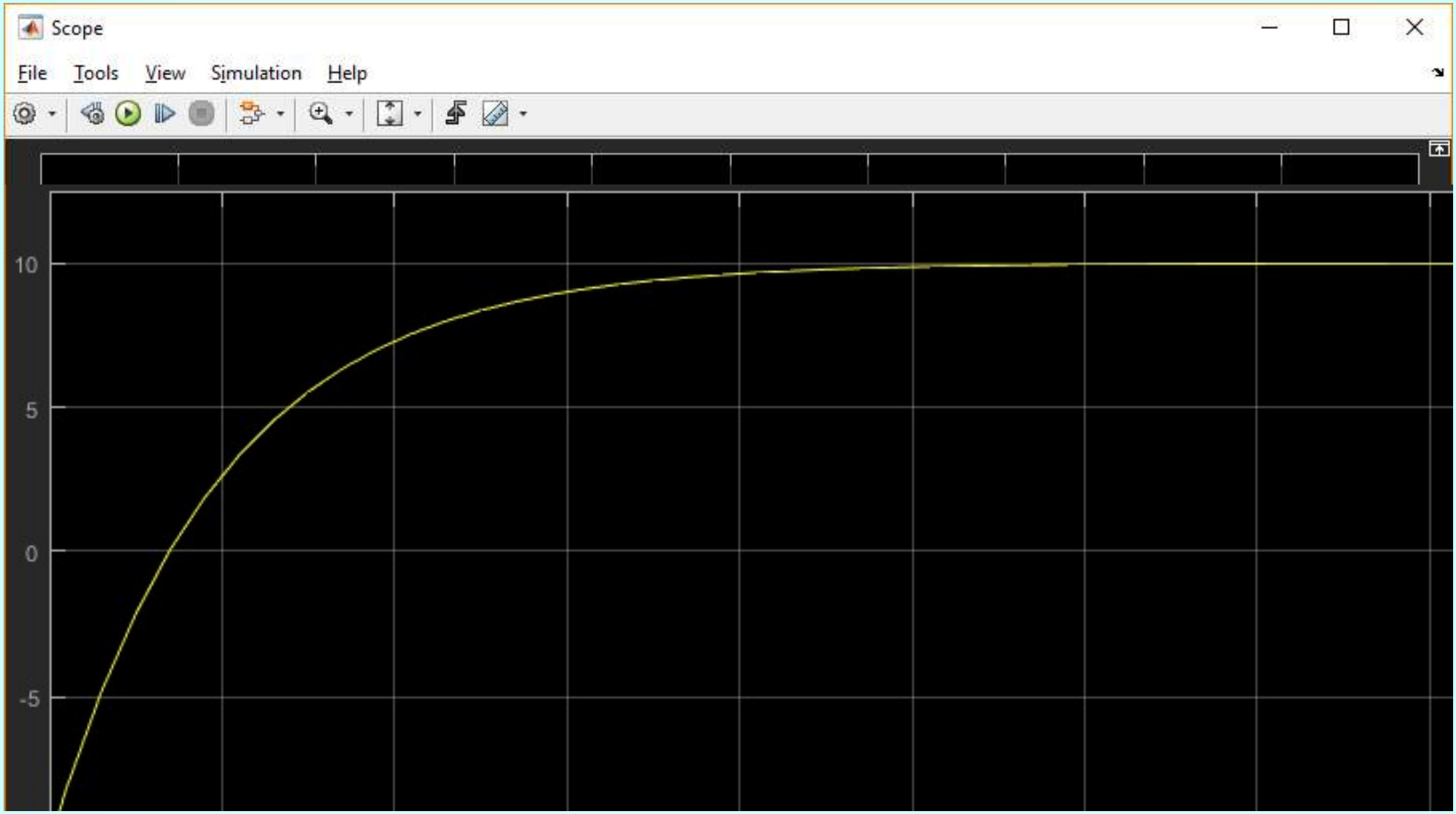
Settings

Parameters | Variables

Override	Variable	Priority	Beginning Value	
☐	Current	None	0	A
		None	0	V
		High	-10	V

MATLAB > Simscape > Foundation Library, Utilities

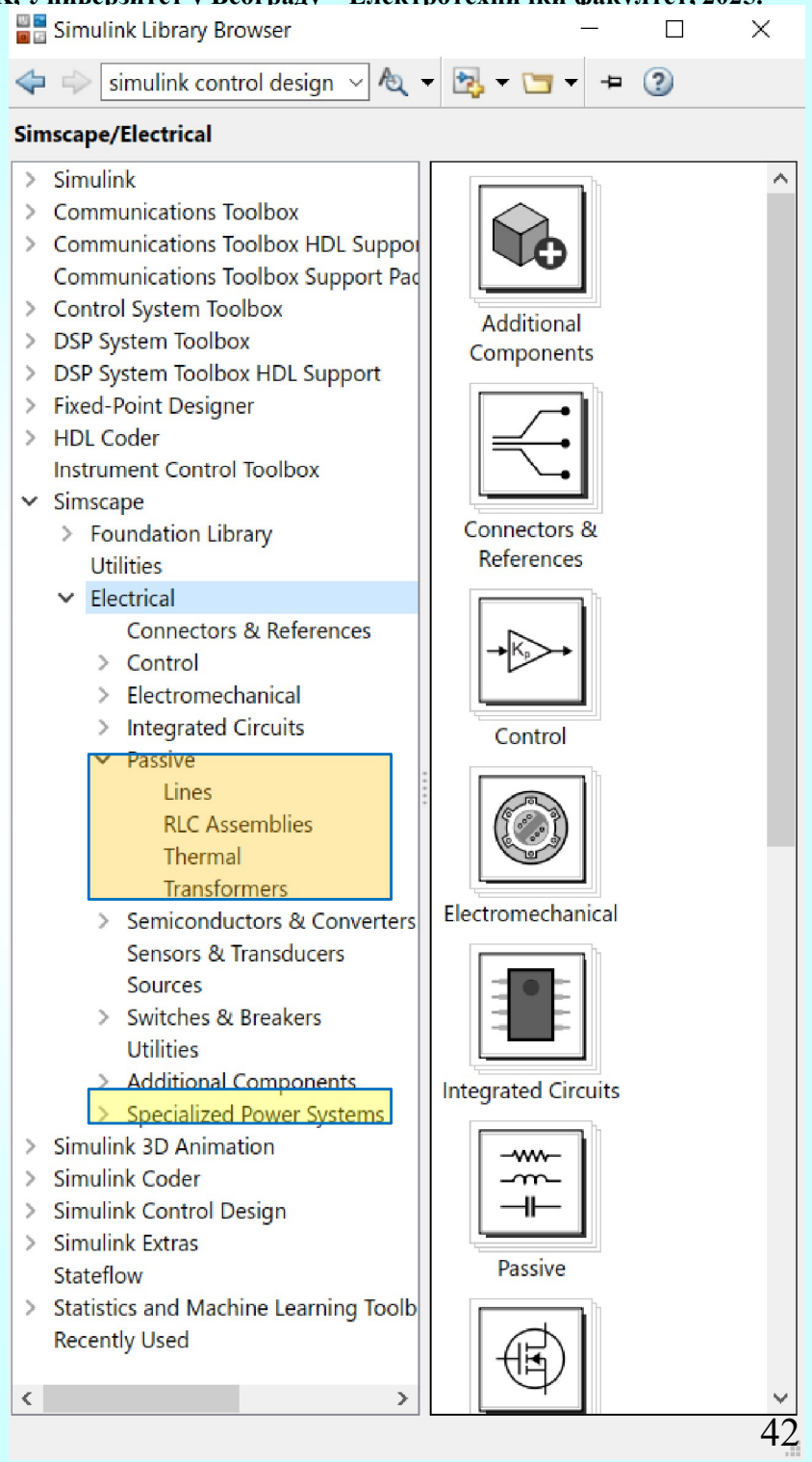
Налажење одзива...



MATLAB > Simscape > Foundation Library, Utilities

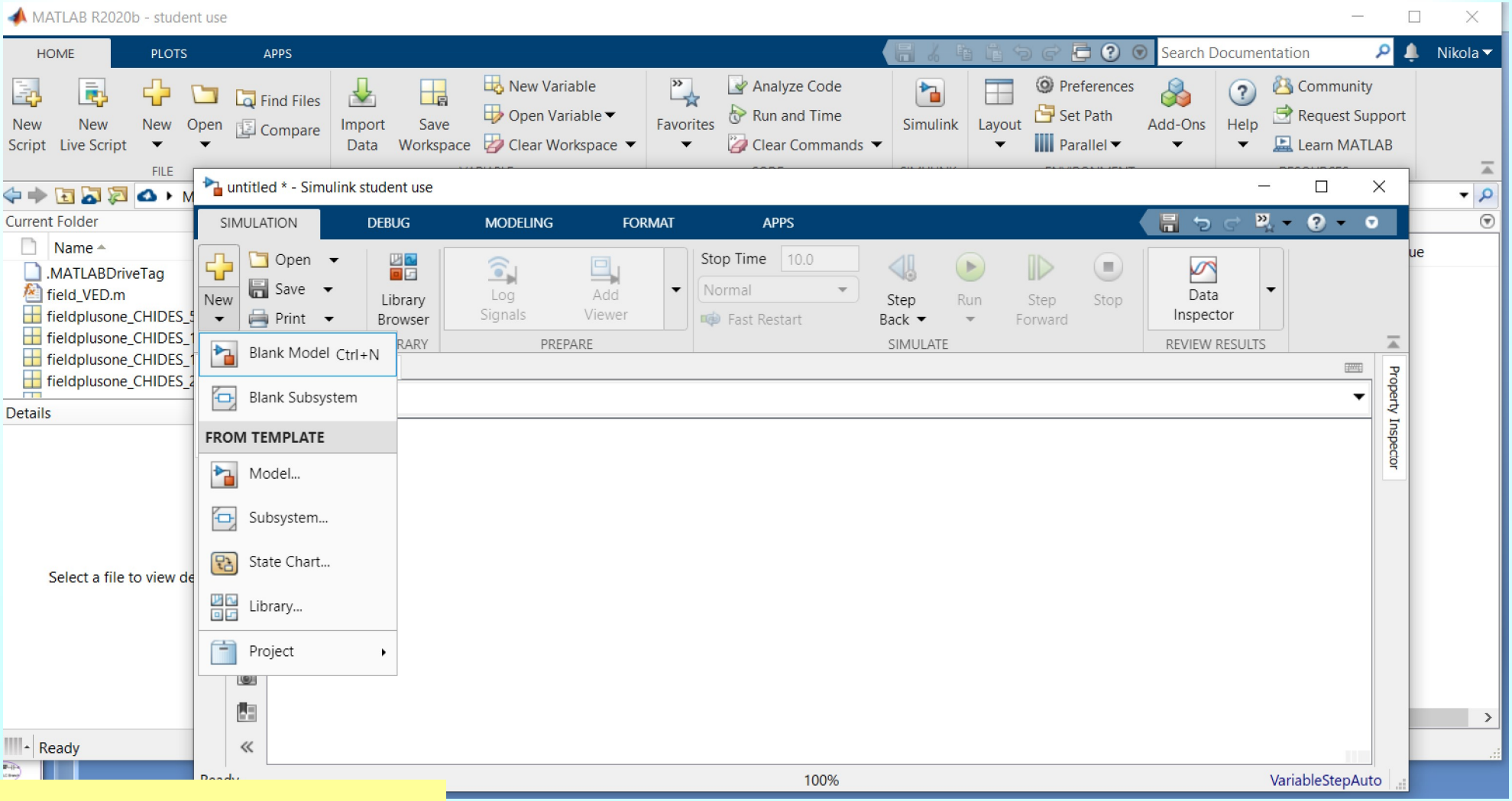
Simulink > Simscape > Electrical

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



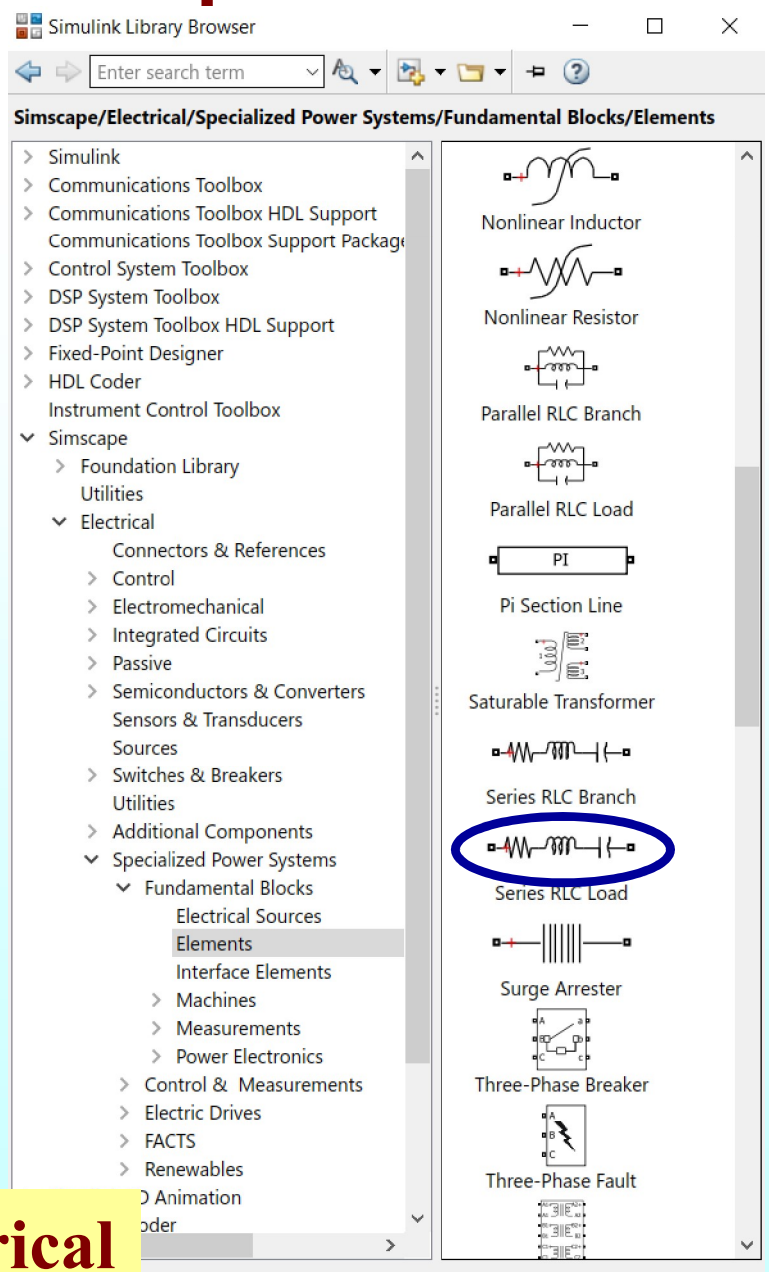
Simscape > Electrical

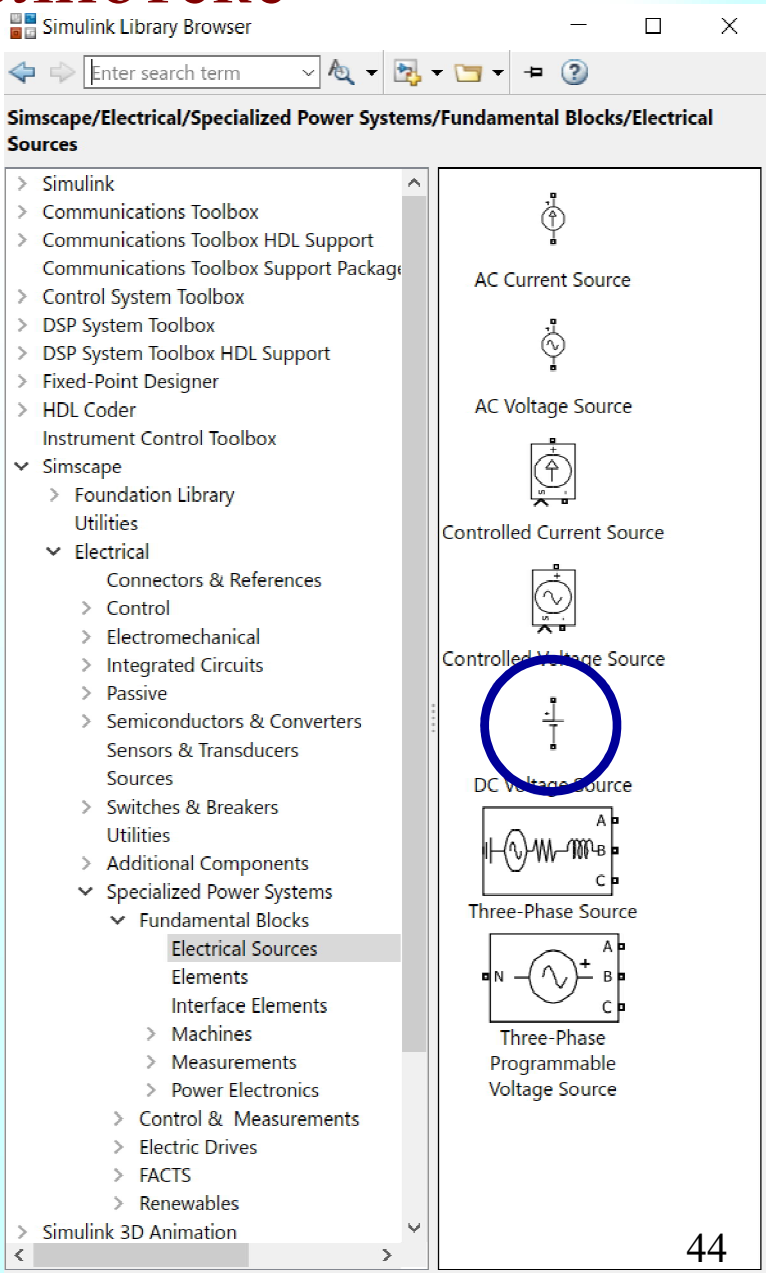
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке



Simscape > Electrical

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

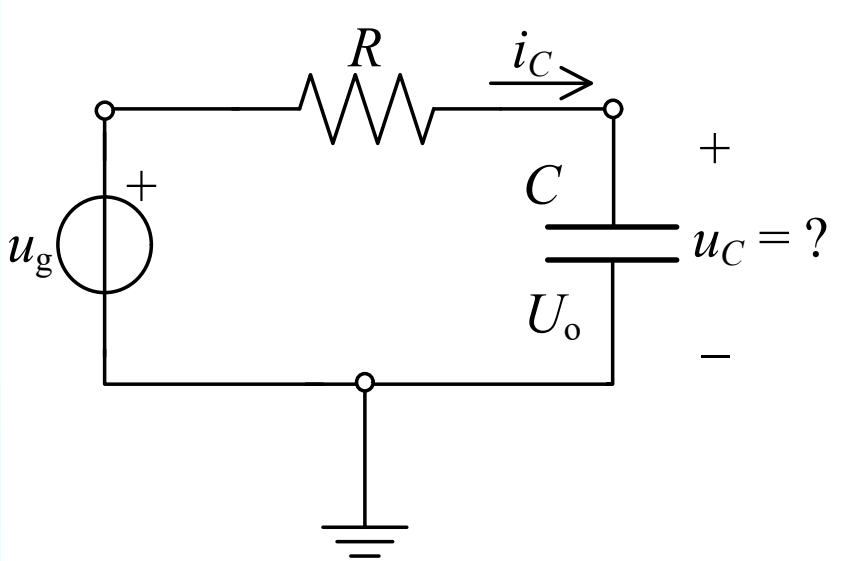


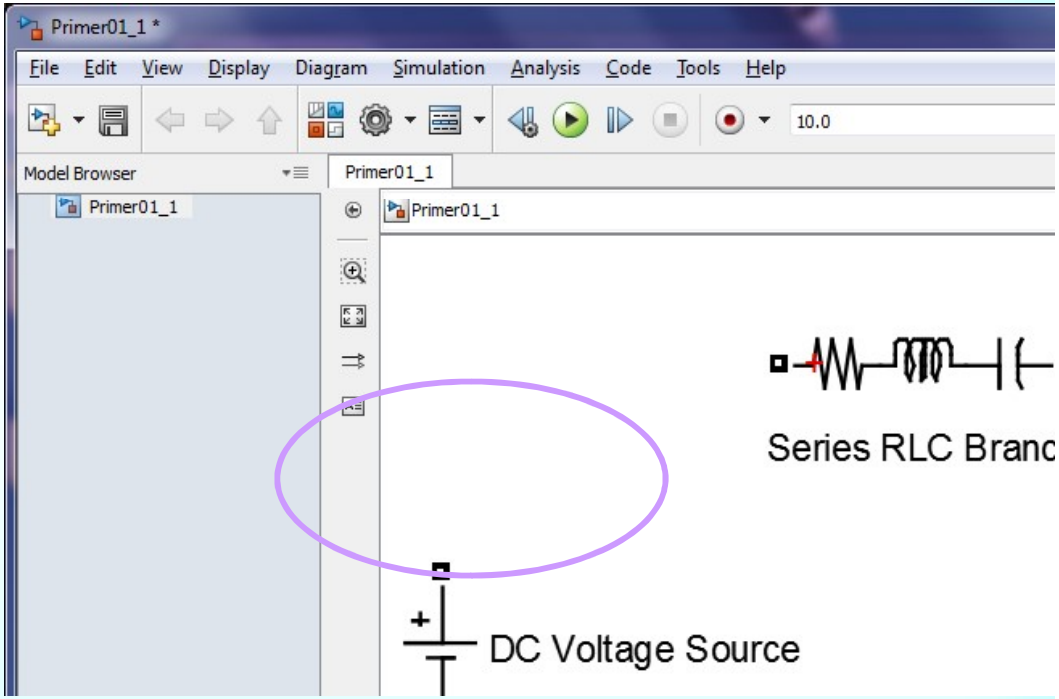


Simscape > Electrical

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

коло је образовано у тренутку $t_0 = 0$



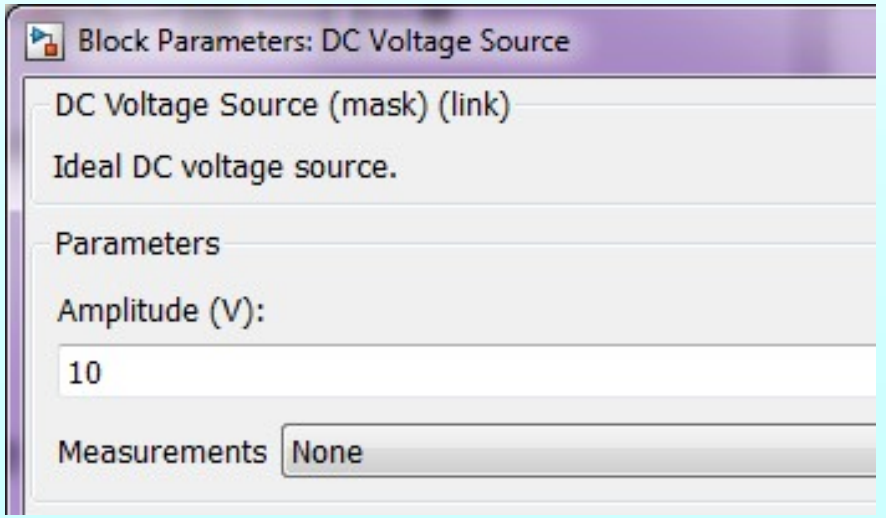


$R = 1\,\mathrm{k\Omega}$

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

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

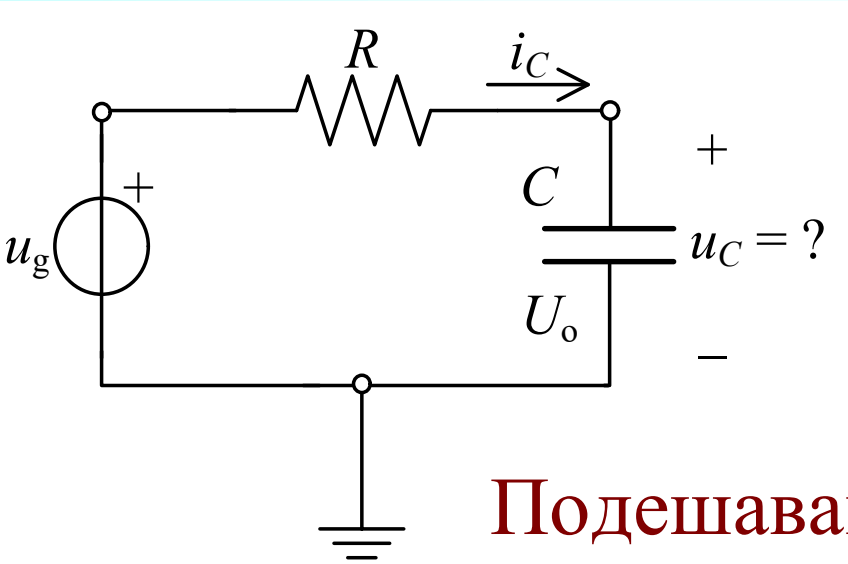
$u(t_0^-) = U_0 = -10\,\mathrm{V}$



Simscape > Electrical

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

коло је образовано у тренутку $t_0 = 0$



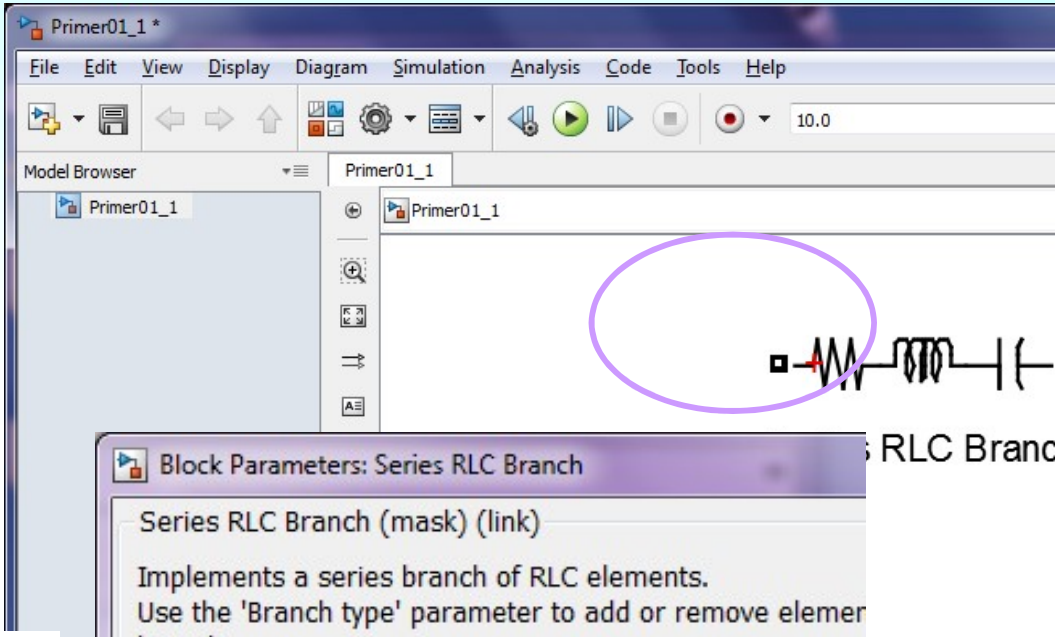
$R = 1\,\mathrm{k\Omega}$

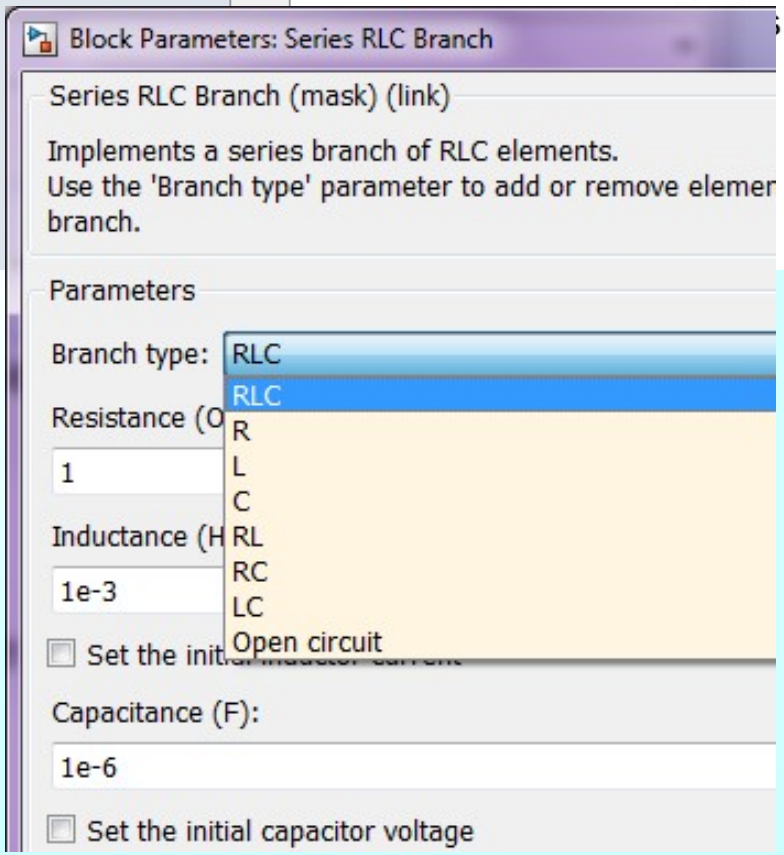
$C = 1\,\mu\mathrm{F}$

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

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

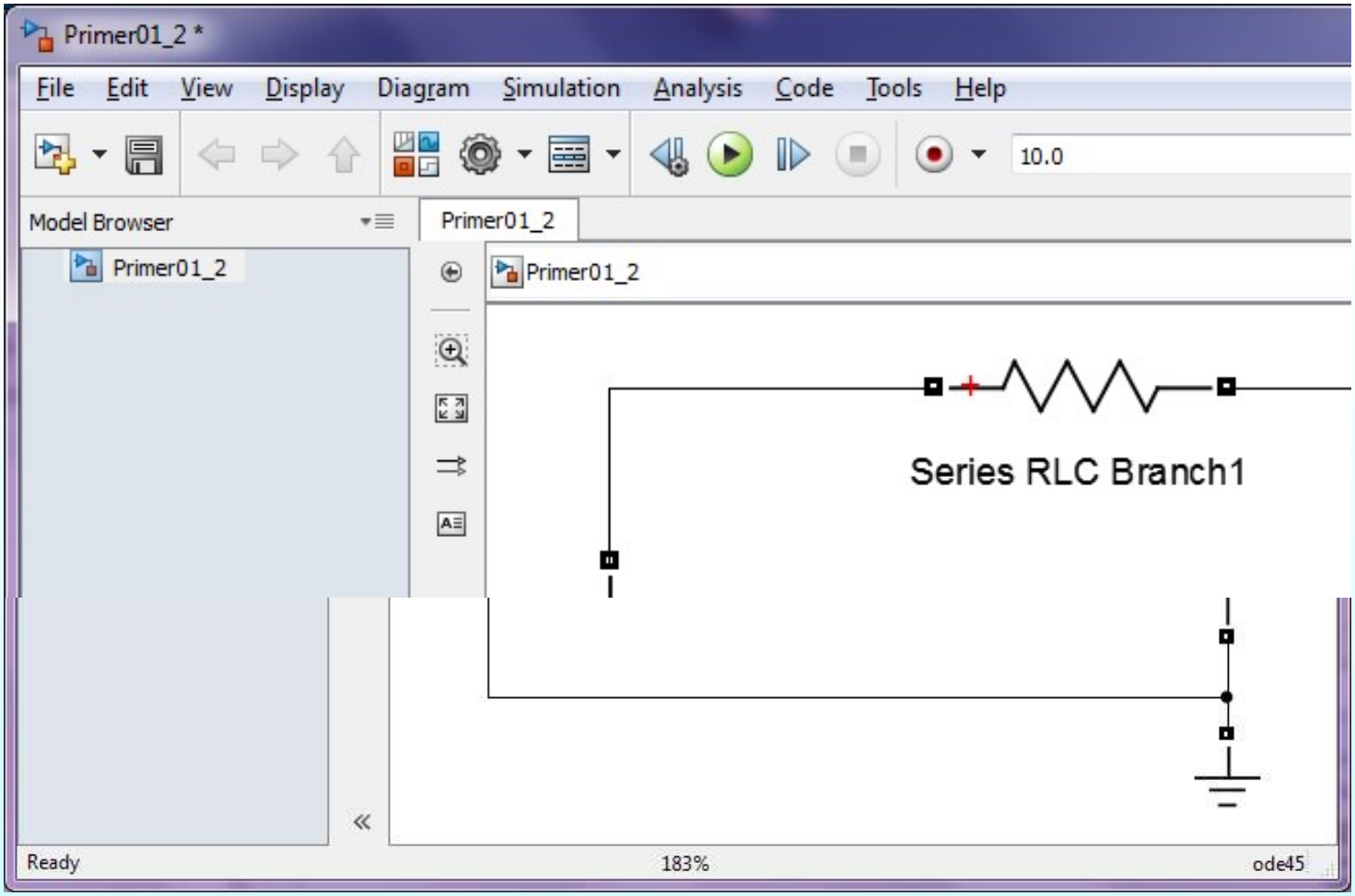
Подешавање параметара симулације





Simscape > Electrical

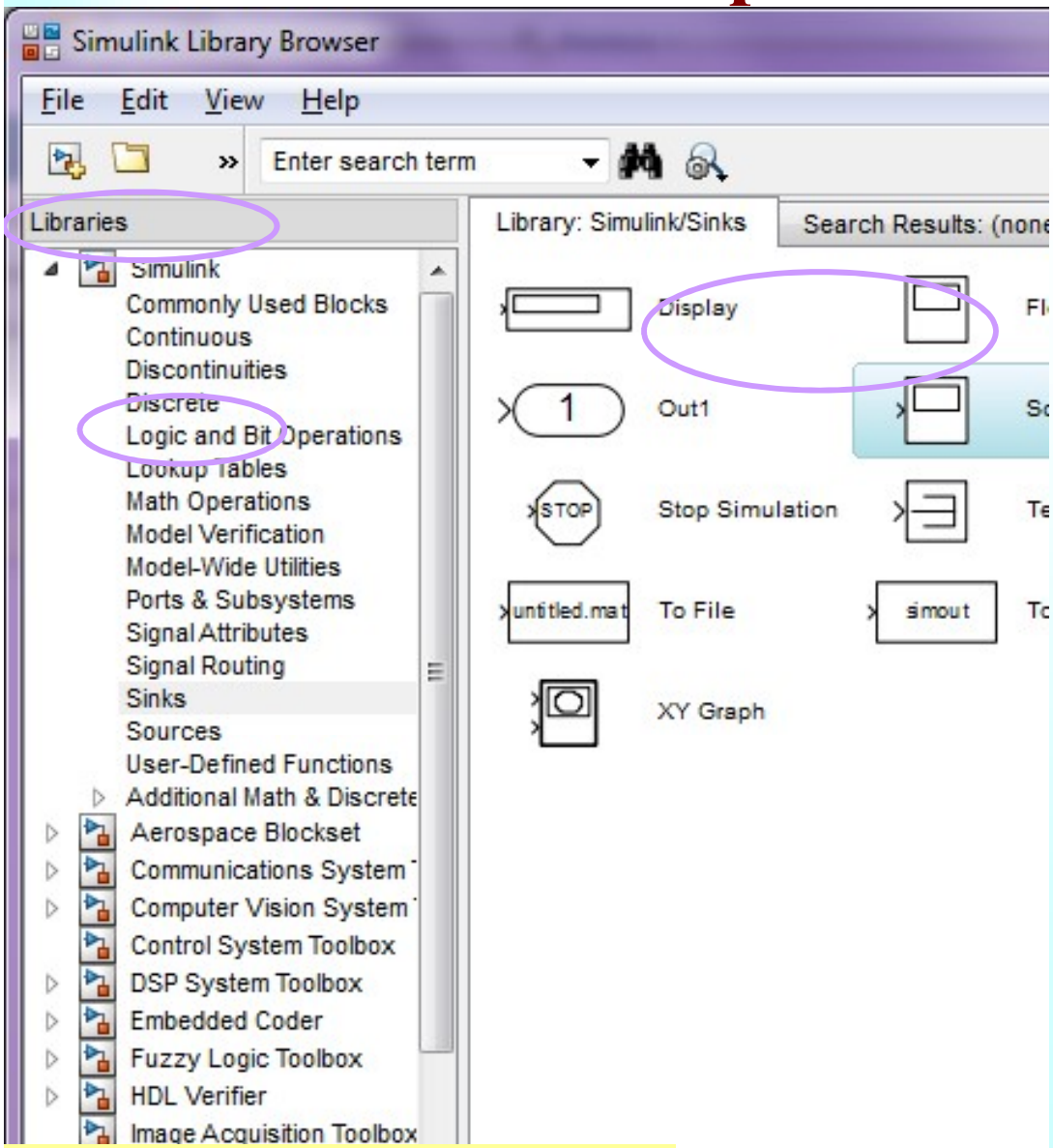
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

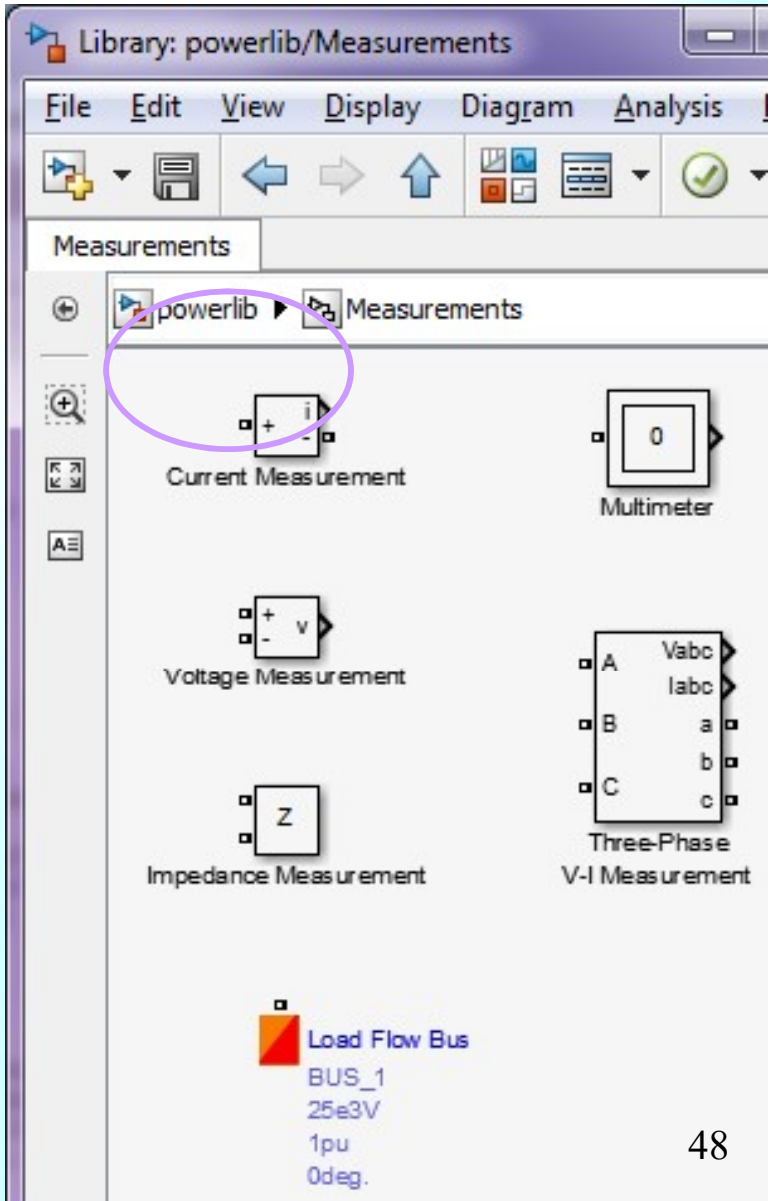


Како се мери напон?

Simscape > Electrical

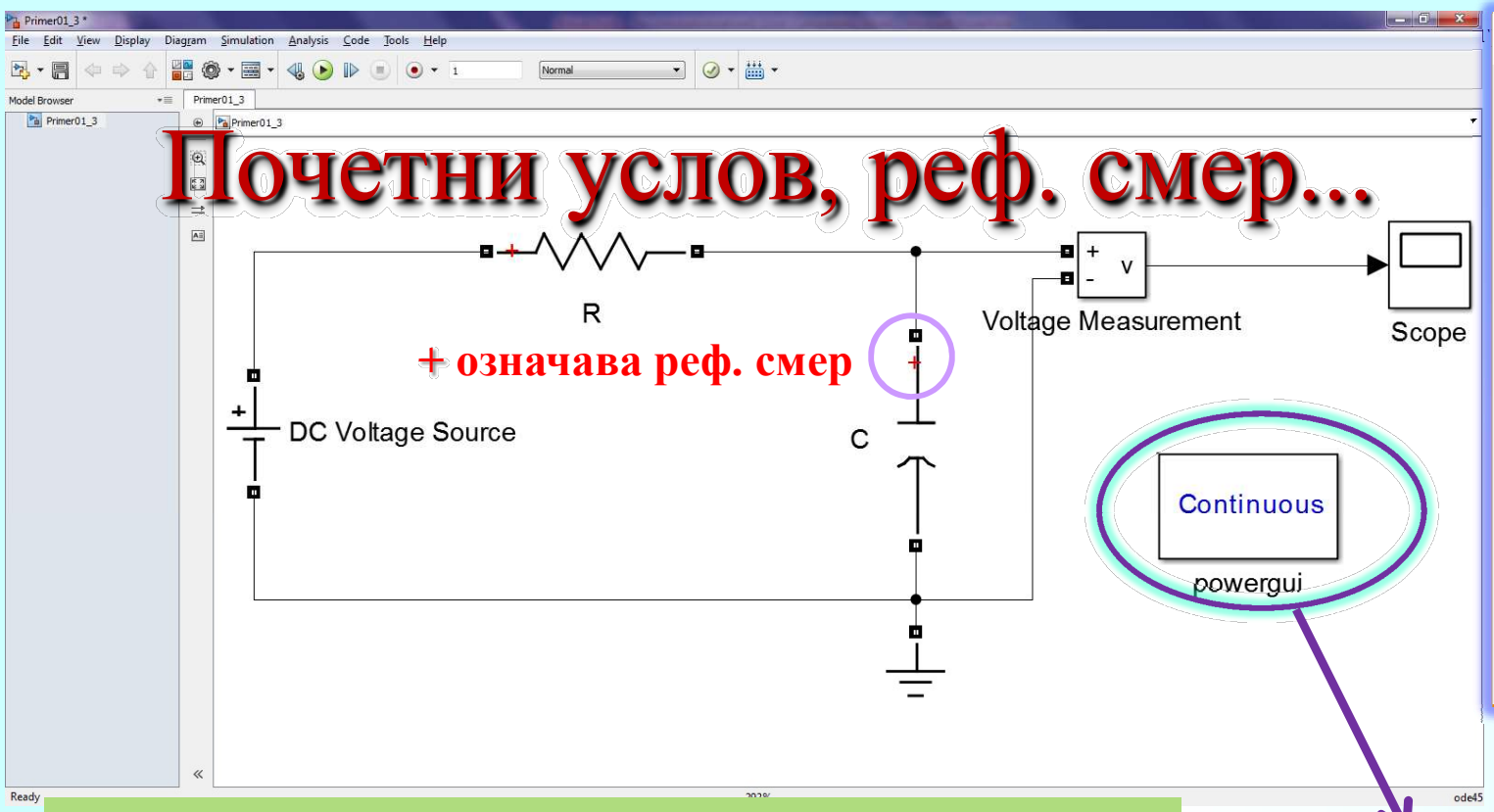
Симулација електричног кола коришћењем **Simscape>Electrical** библиотеке

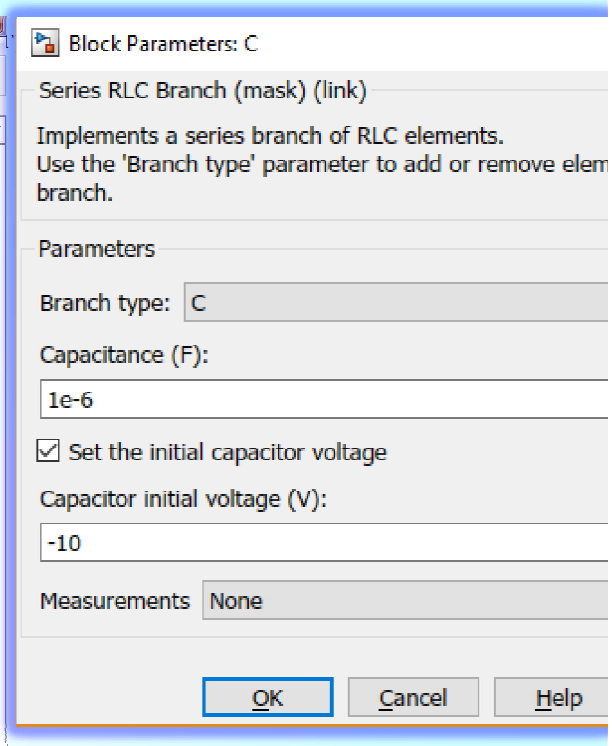




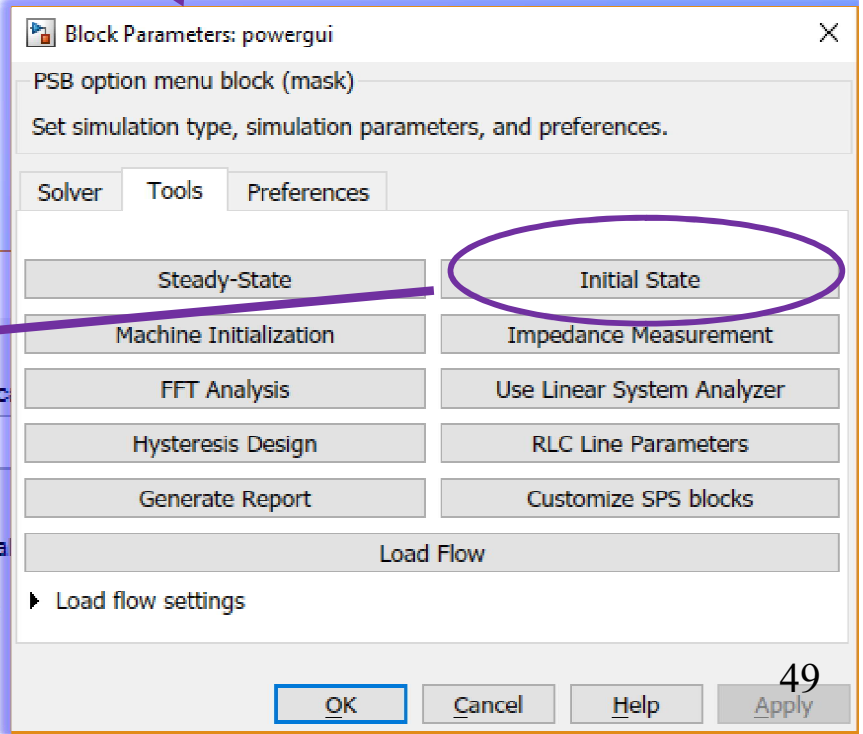
Simscape > Electrical

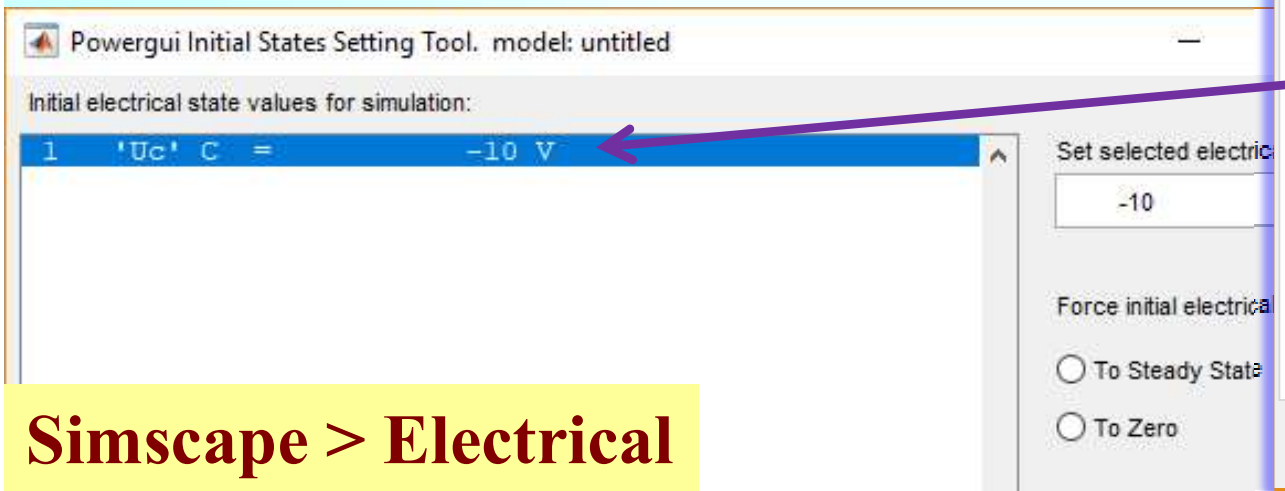
Почетни услов, реф. смер...



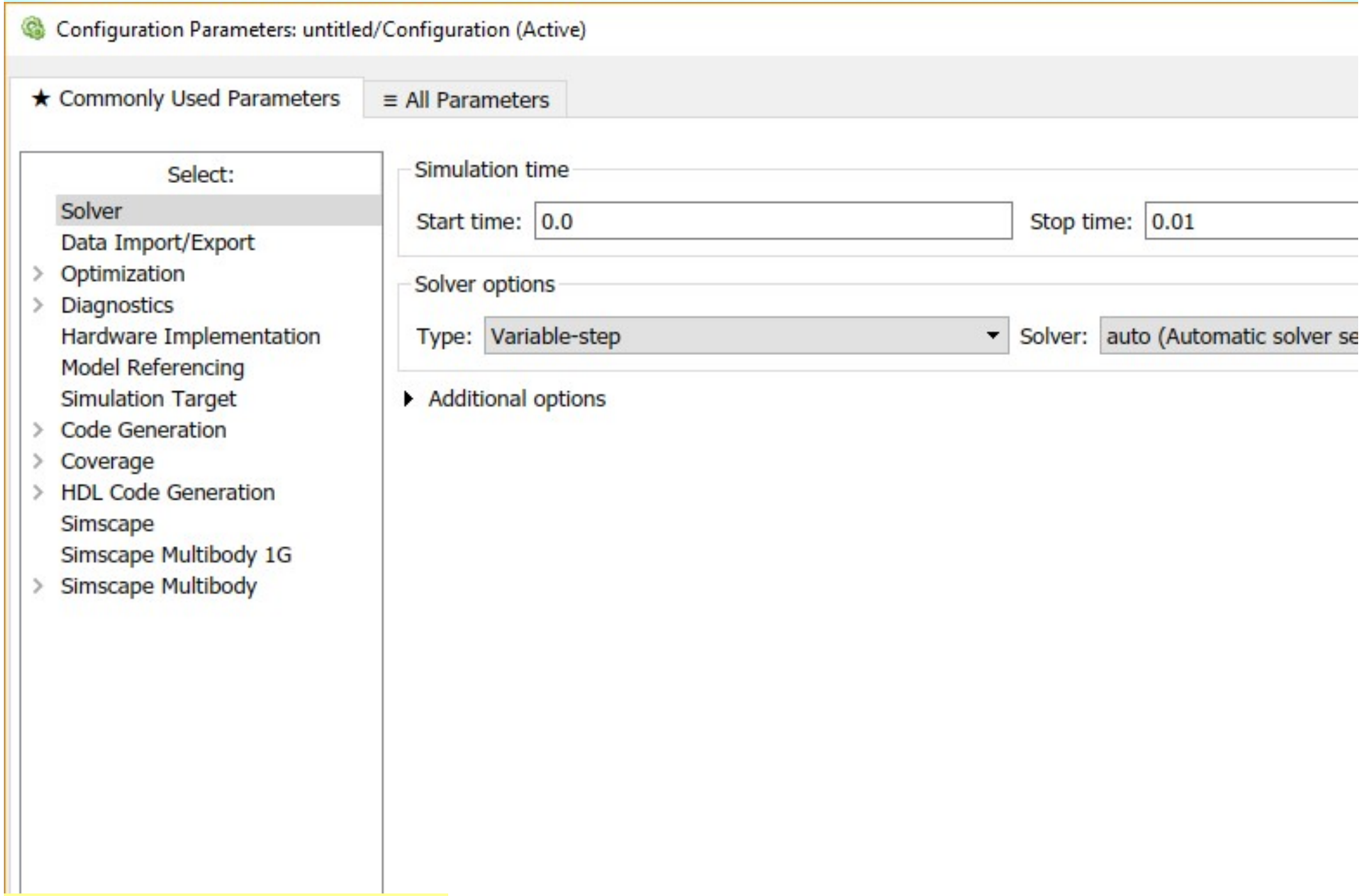


Плоче кондезатора се разликују!!!

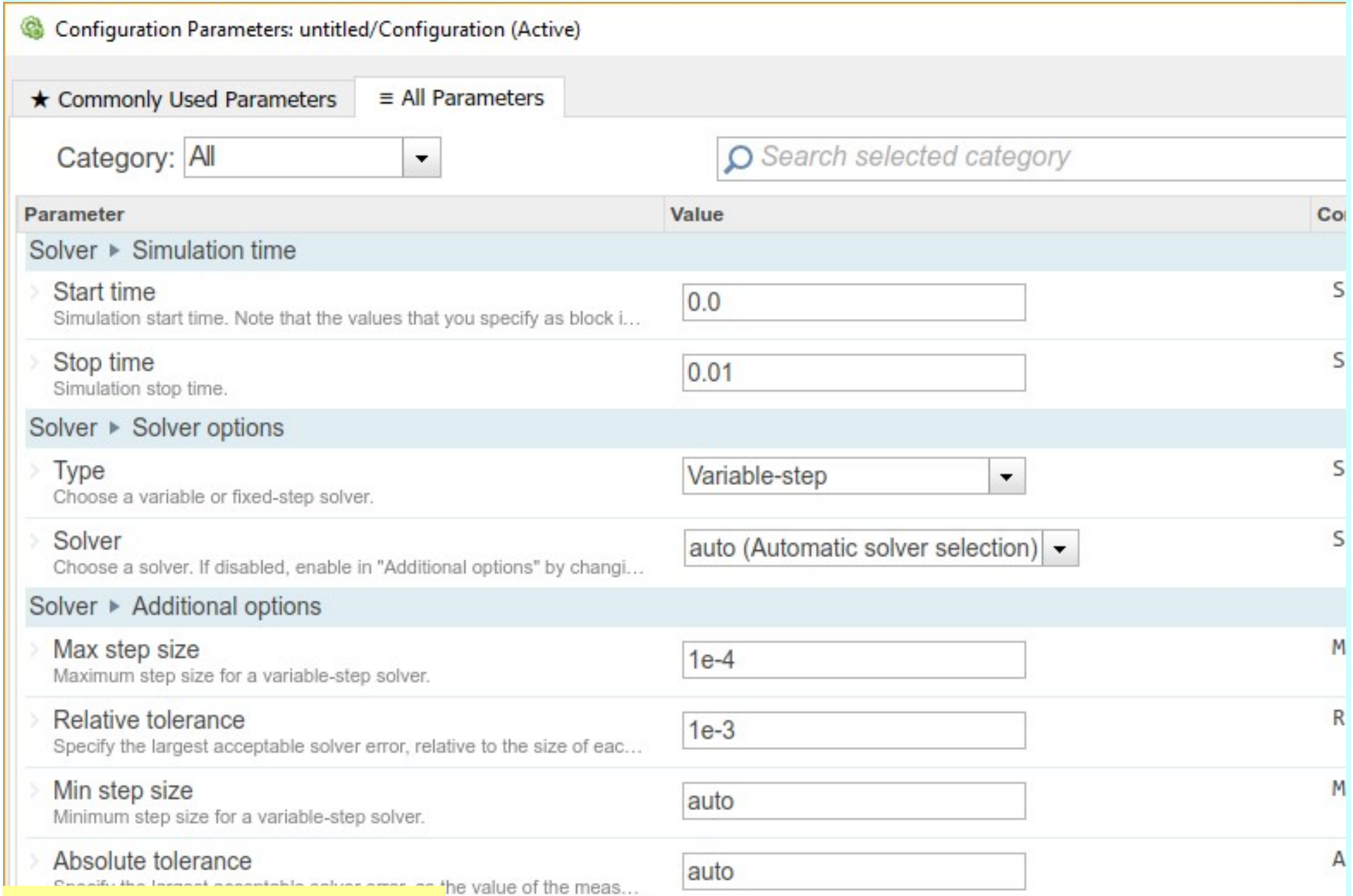




Simscape > Electrical

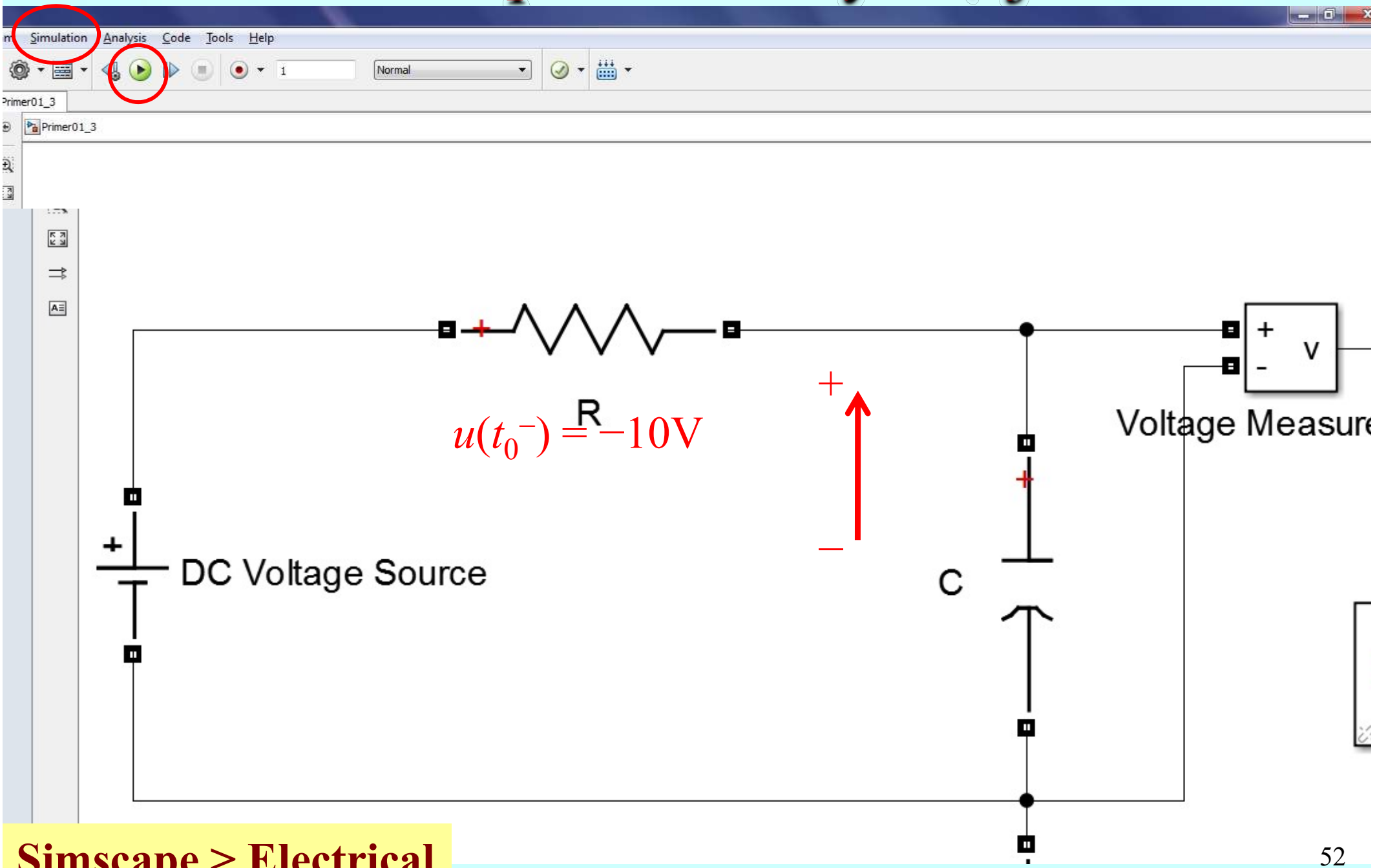


Simscape > Electrical



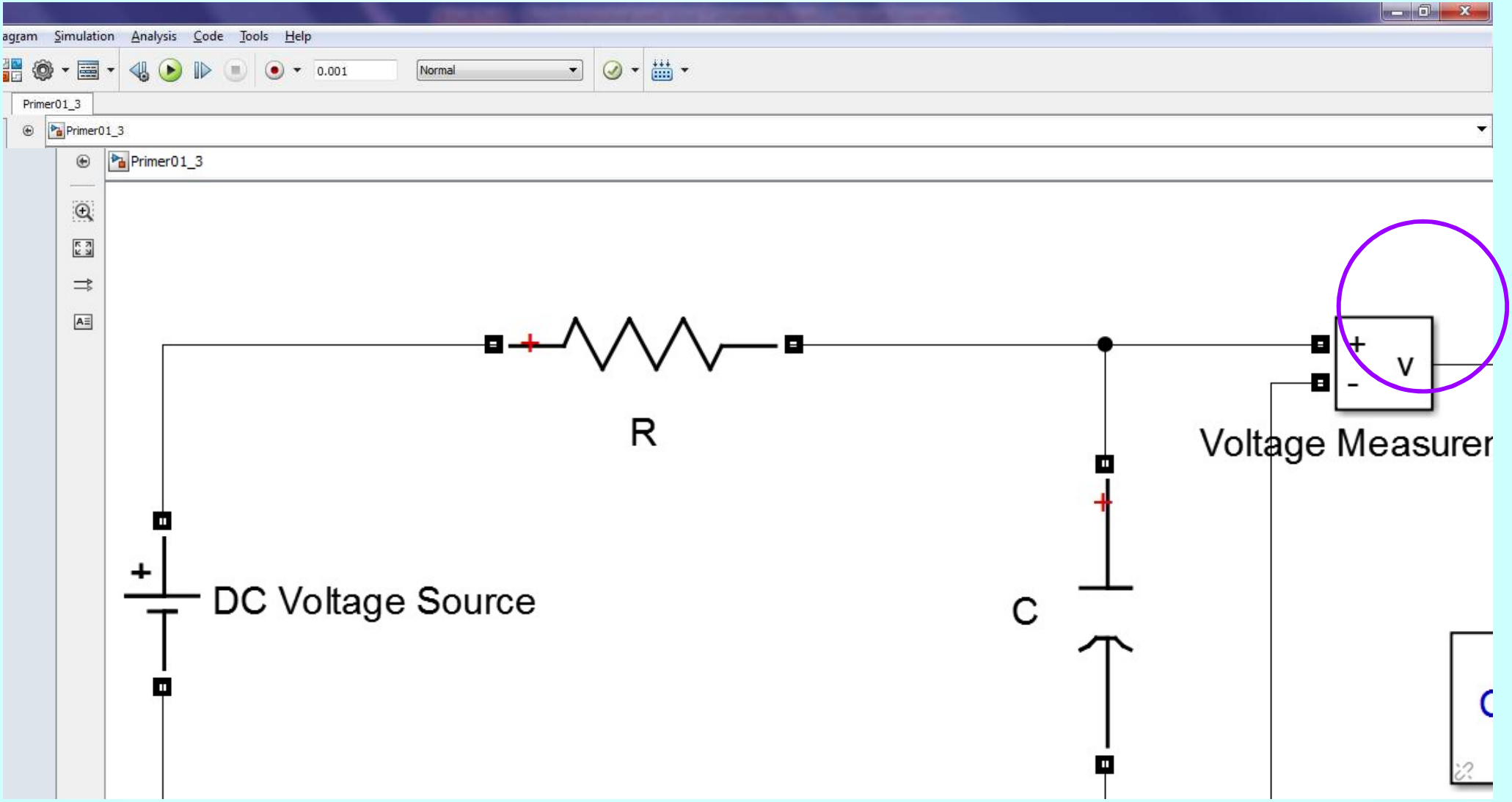
Simscape > Electrical

Покретање симулације...

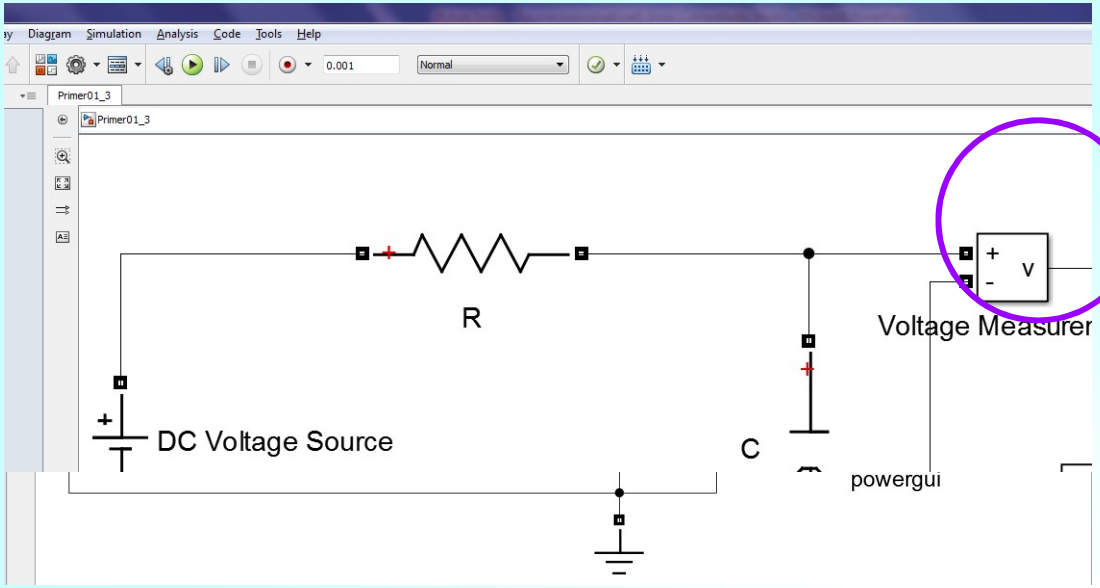


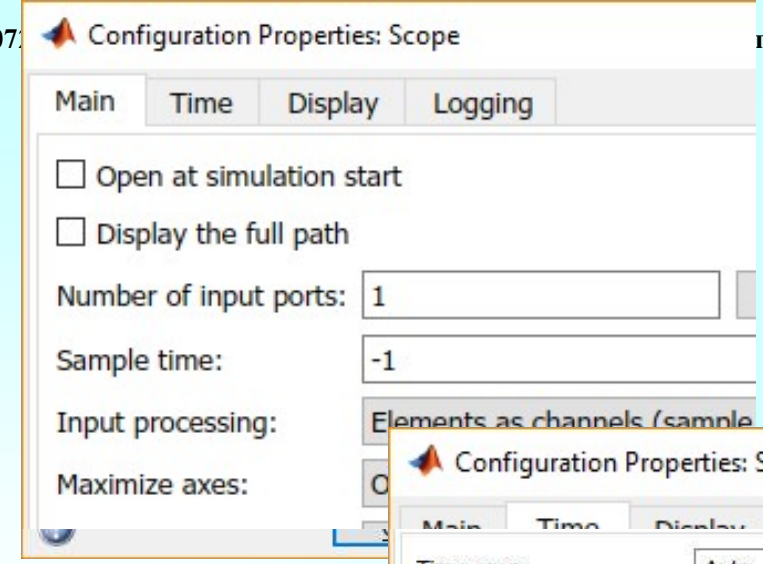
Simscape > Electrical

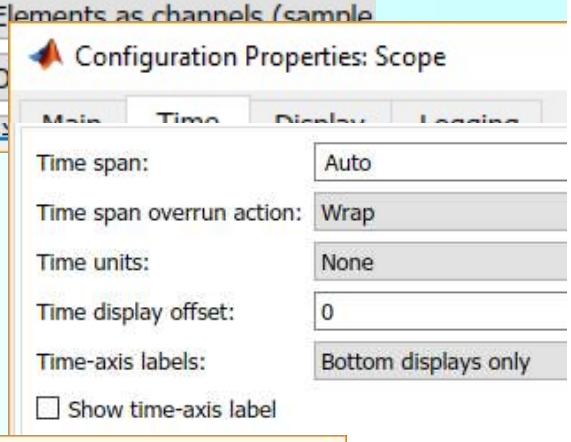
Налажење одзива... Осцилоскоп

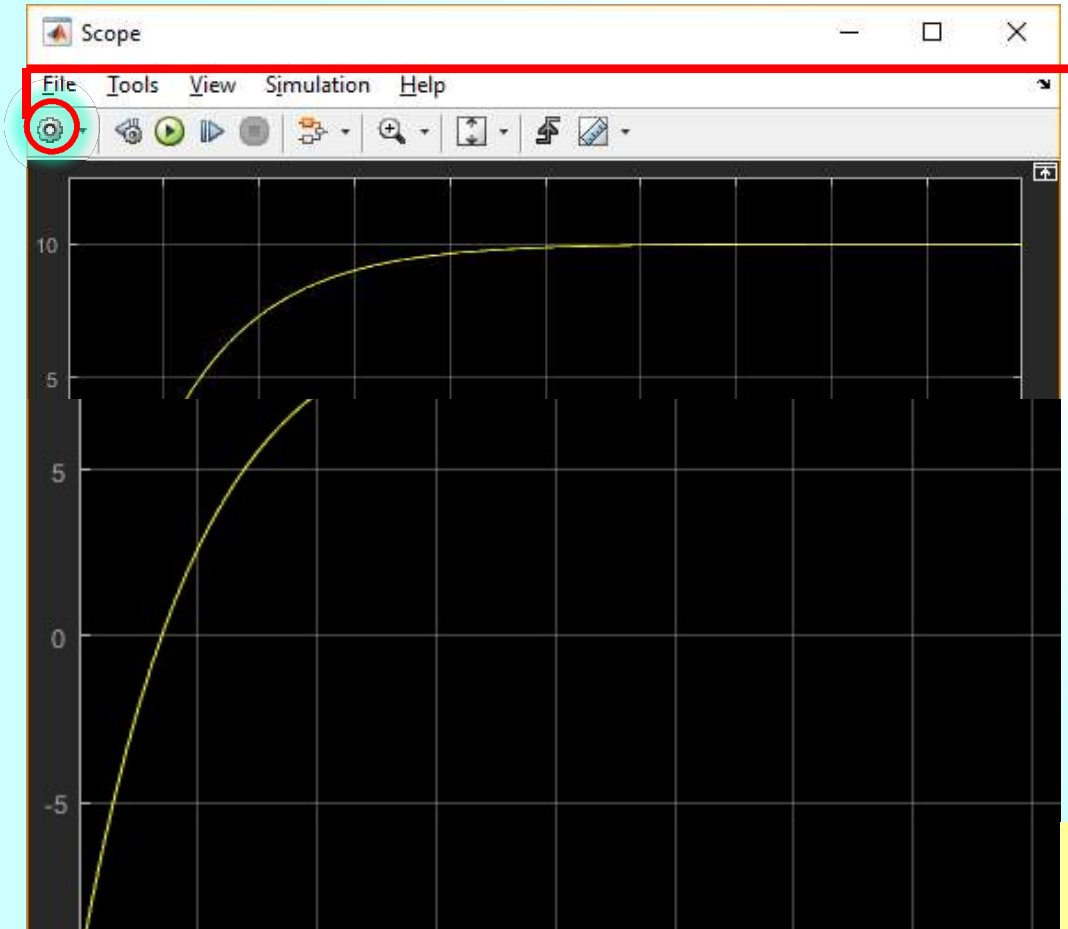


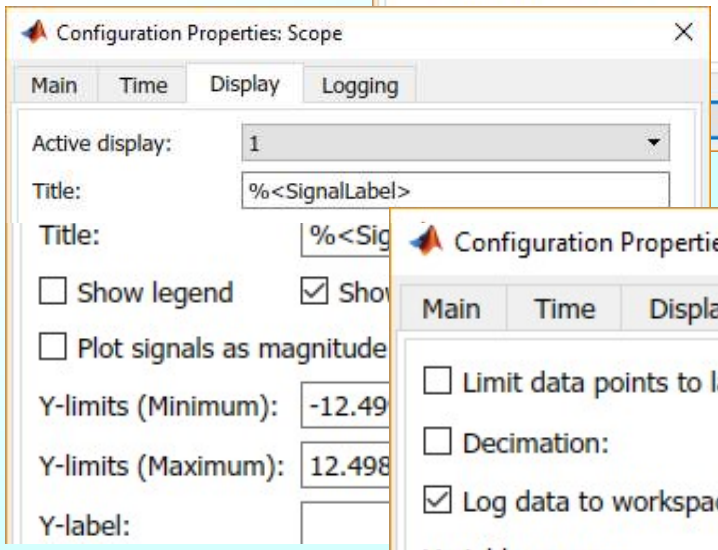
Simscape > Electrical

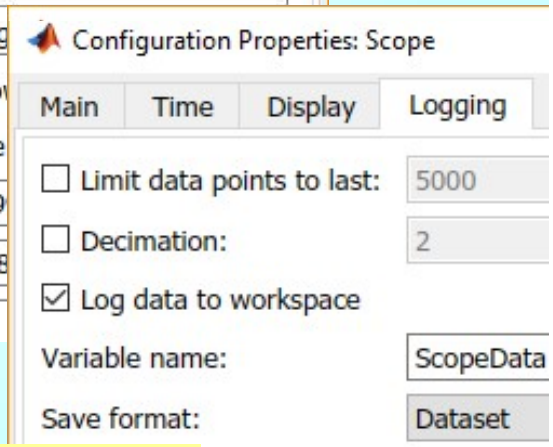




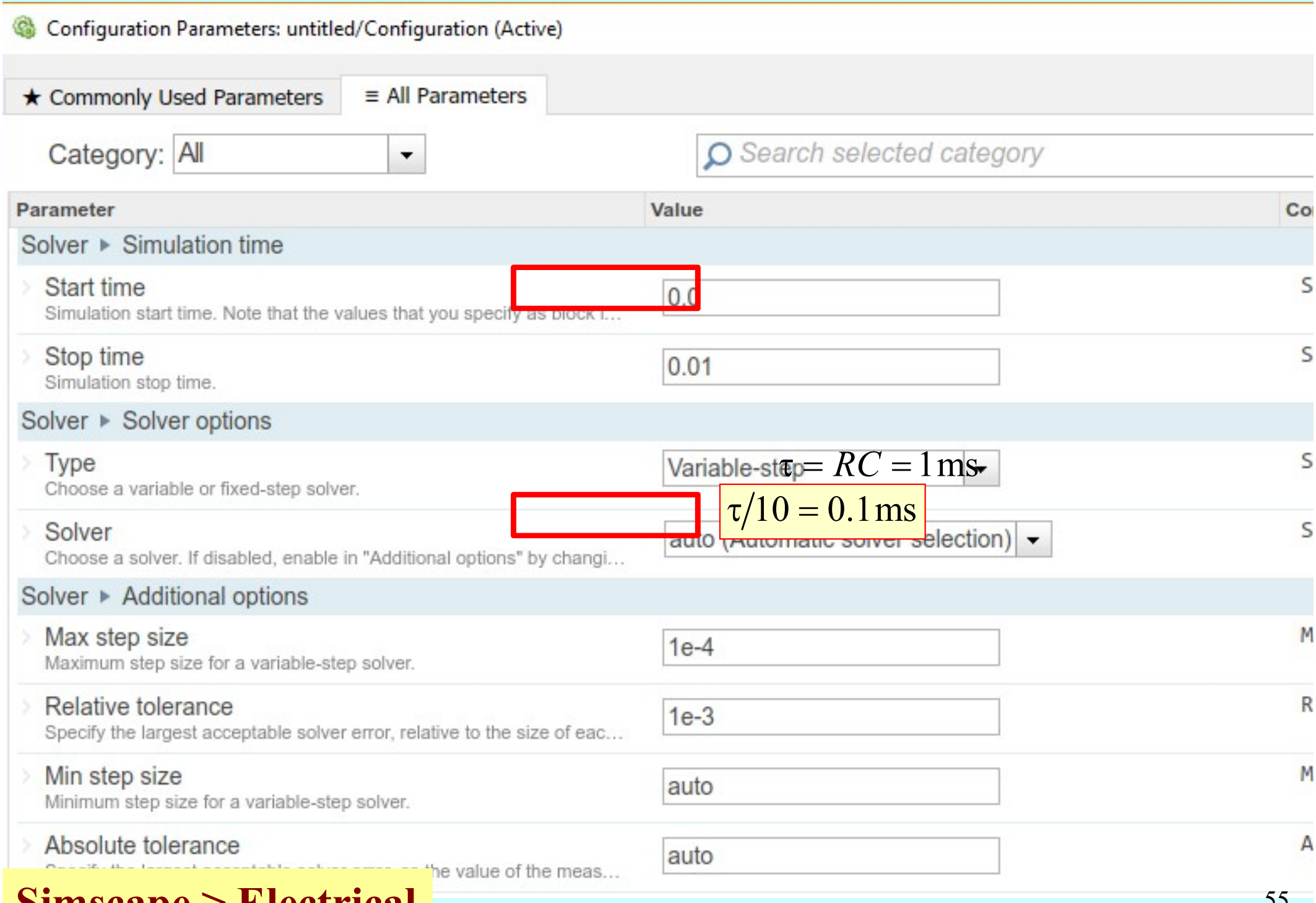








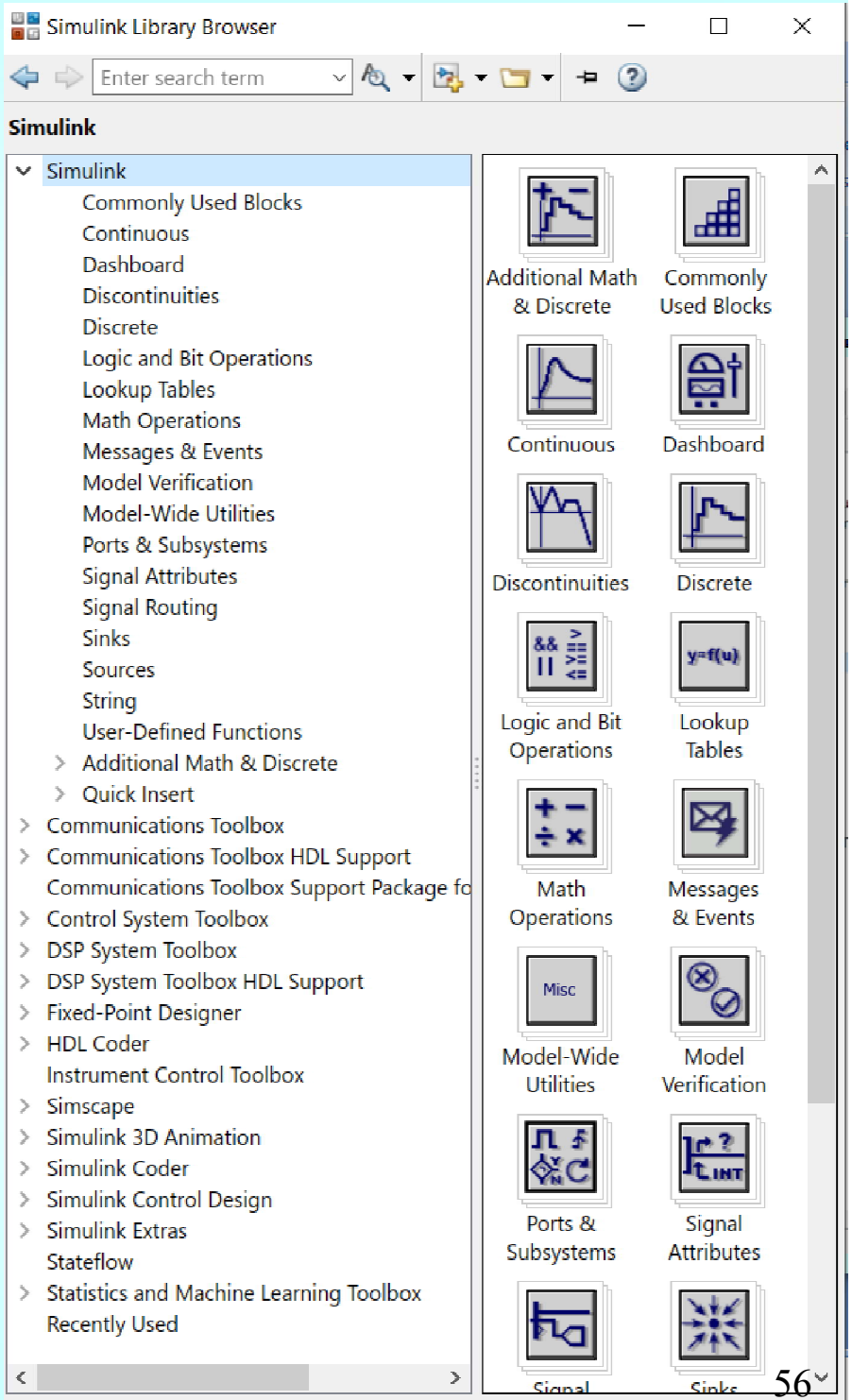
Simscape > Electrical



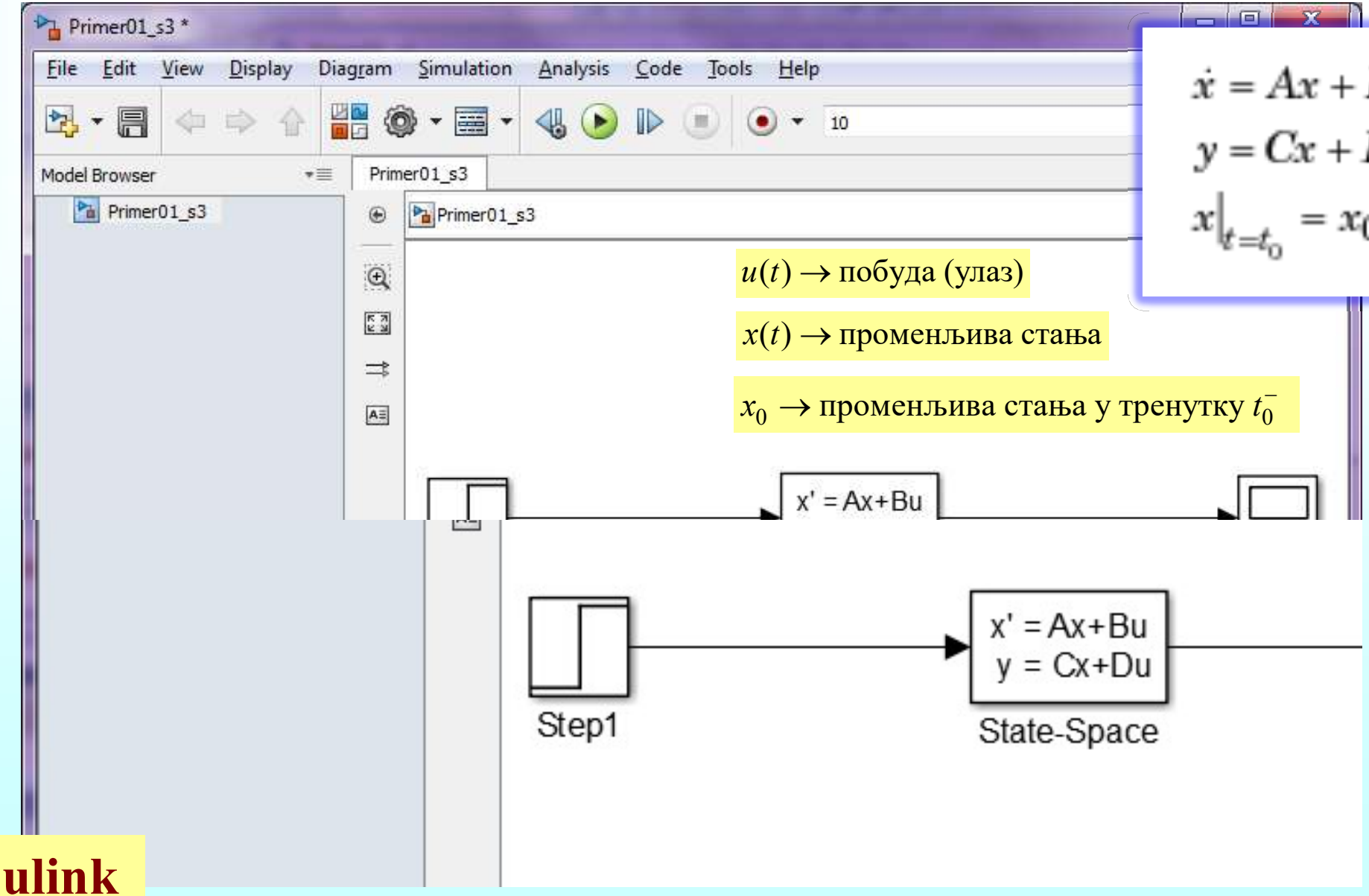
Simscape > Electrical

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



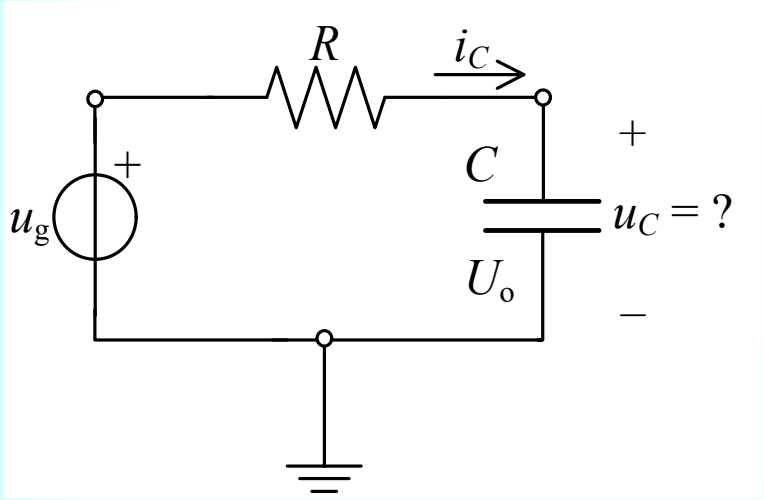
Симулација електричног кола као уопштеног система коришћењем **Simulink**-а



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

Simulink

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



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

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

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

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

коло је образовано у тренутку $t_0 = 0$

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

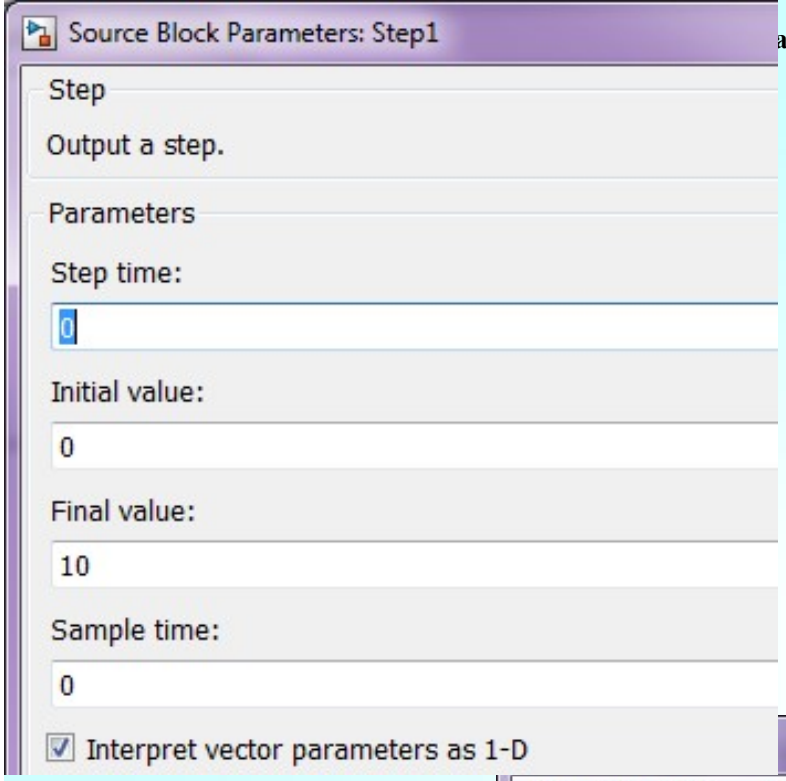
$$u_g(t) = Ri_C + u_C(t)$$
$$i_C = C\frac{du_C}{dt}$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

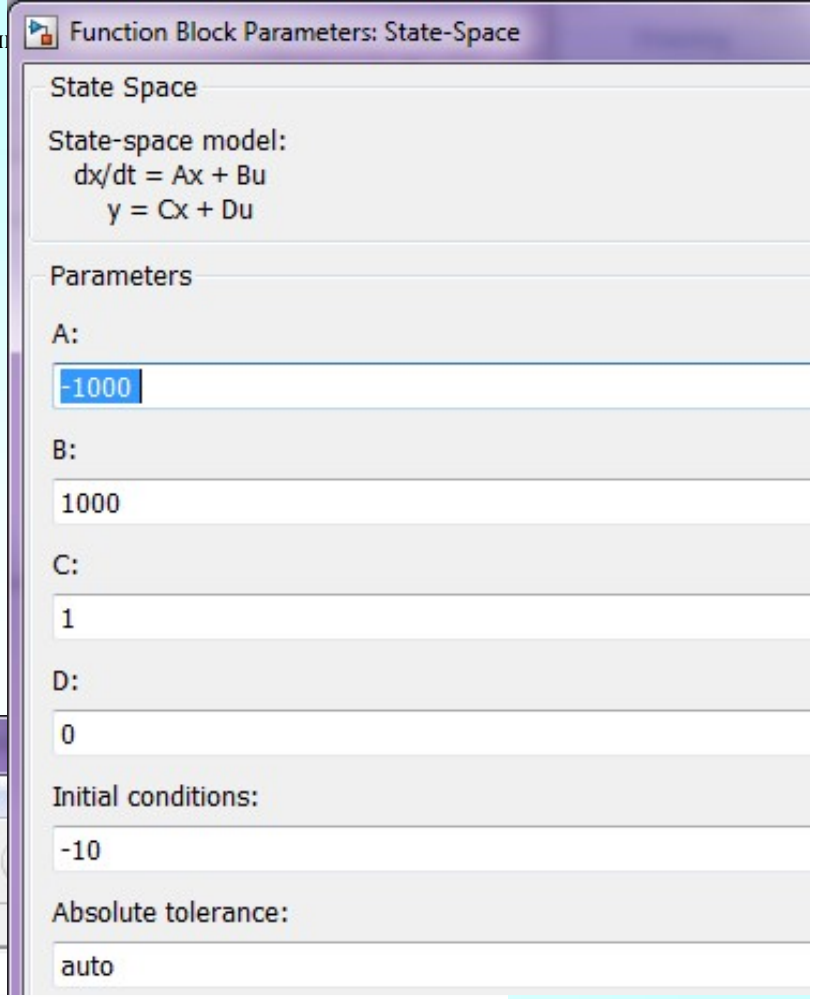
$$\frac{du_C(t)}{dt} = \frac{i_C}{C} = \frac{u_g(t) - u_C(t)}{RC} = -\frac{u_C(t)}{RC} + \frac{u_g(t)}{RC}$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

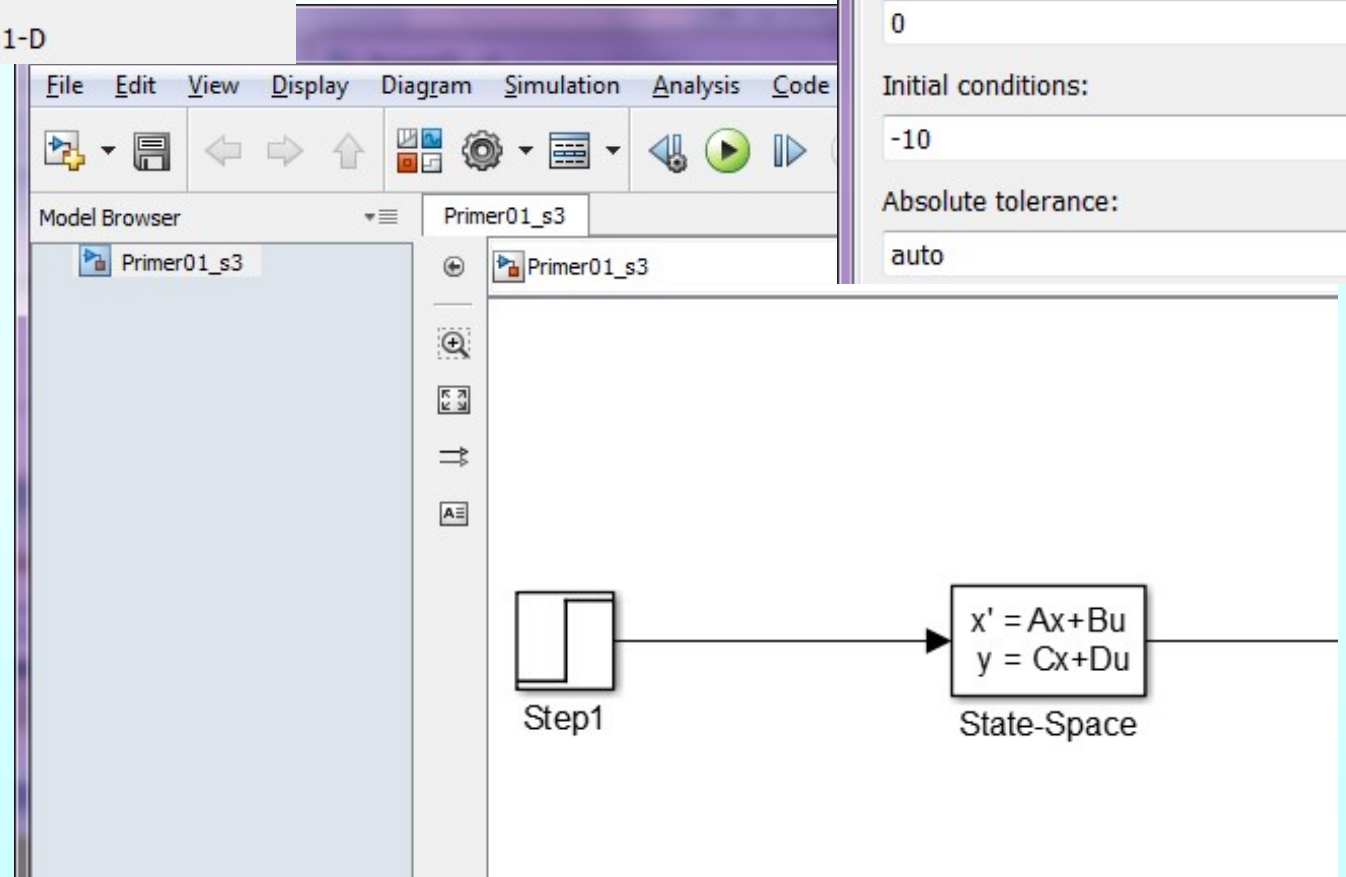
$$\frac{du_C(t)}{dt} = Au_C(t) + Bu_g(t) \Rightarrow A = -\frac{1}{RC} = -1000, B = 1000$$
$$u_C(t) = Cu_C(t) \Rightarrow C = 1, D = 0$$
$$u_C(t_0^-) = U_0 = -10\,\text{V}$$

Simulink

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



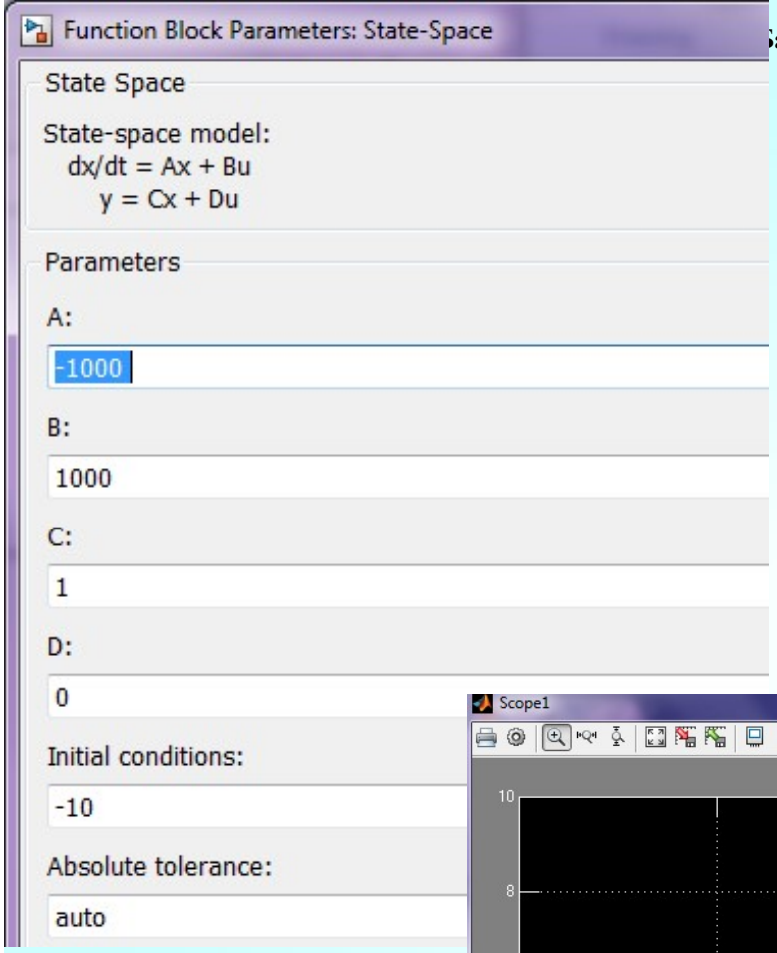


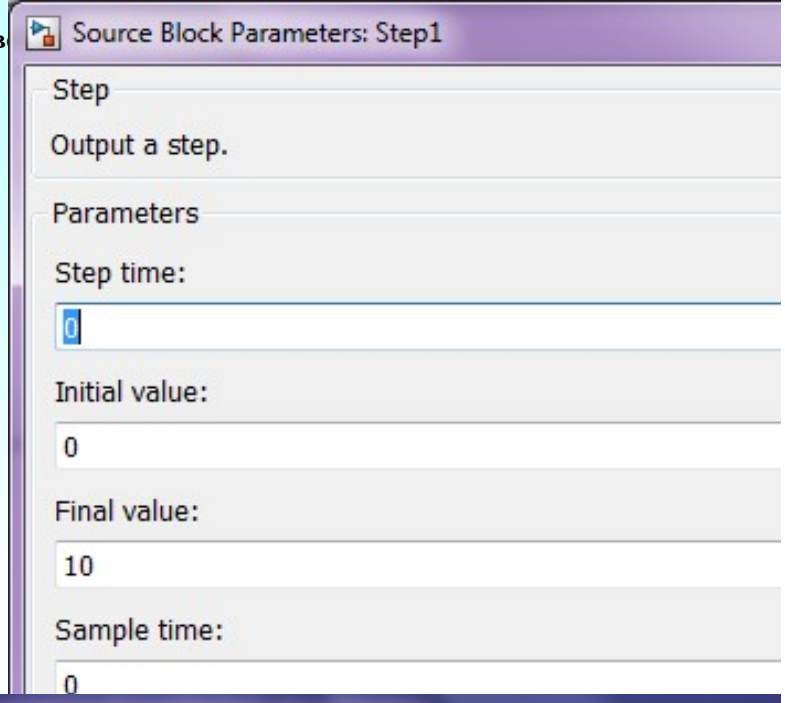


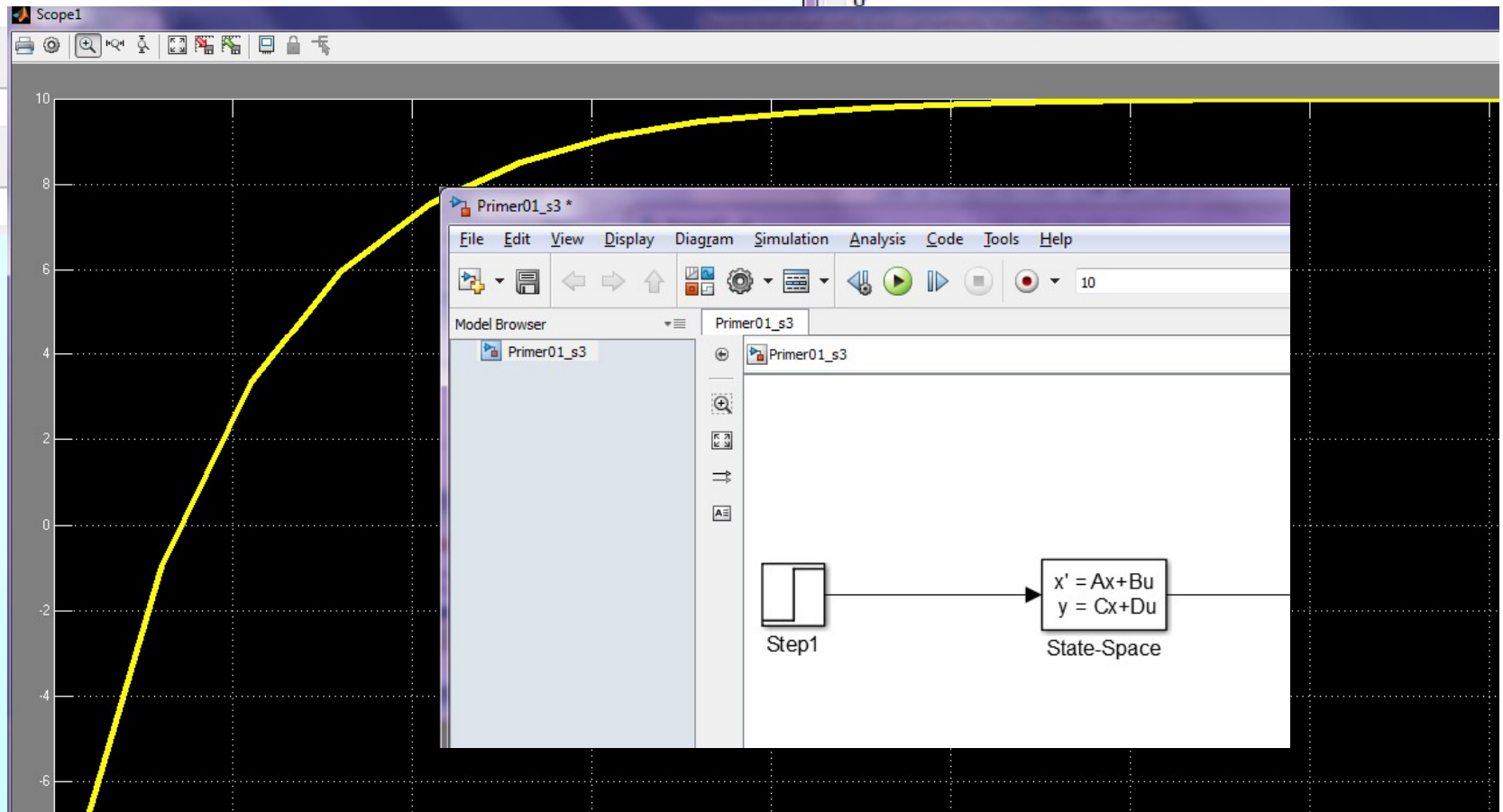
Simulink

аста, доцент, 13E072PRK3, 19E072PRK, Унив

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

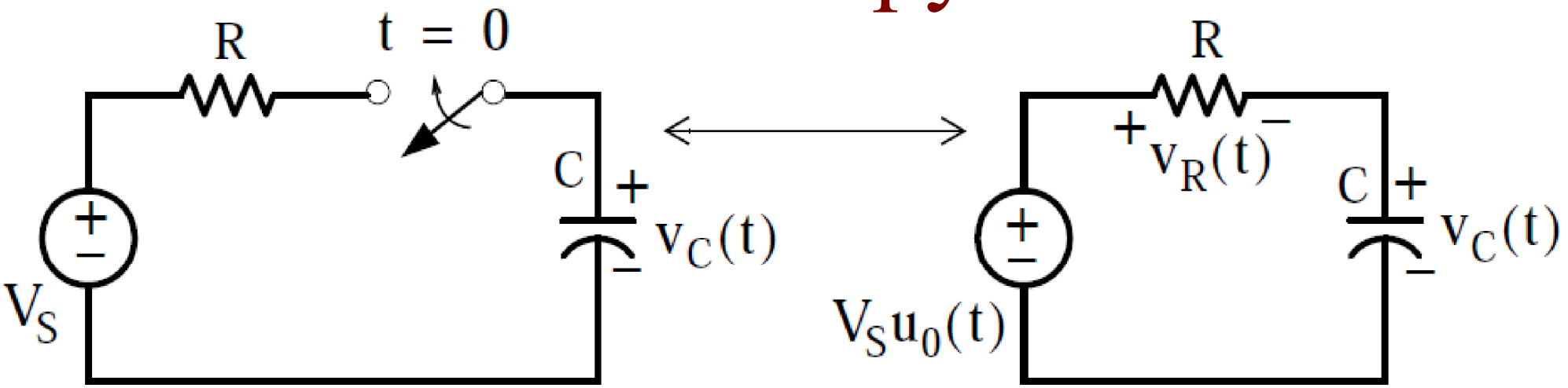






Simulink

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

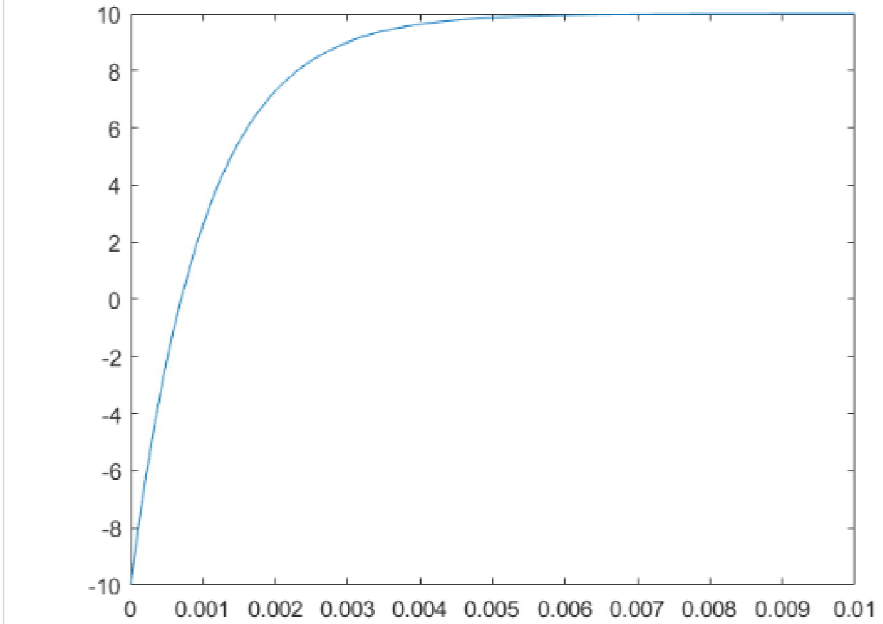
pluto1.m | template1.m | RCKolo_v0.mlx

```
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])
```

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

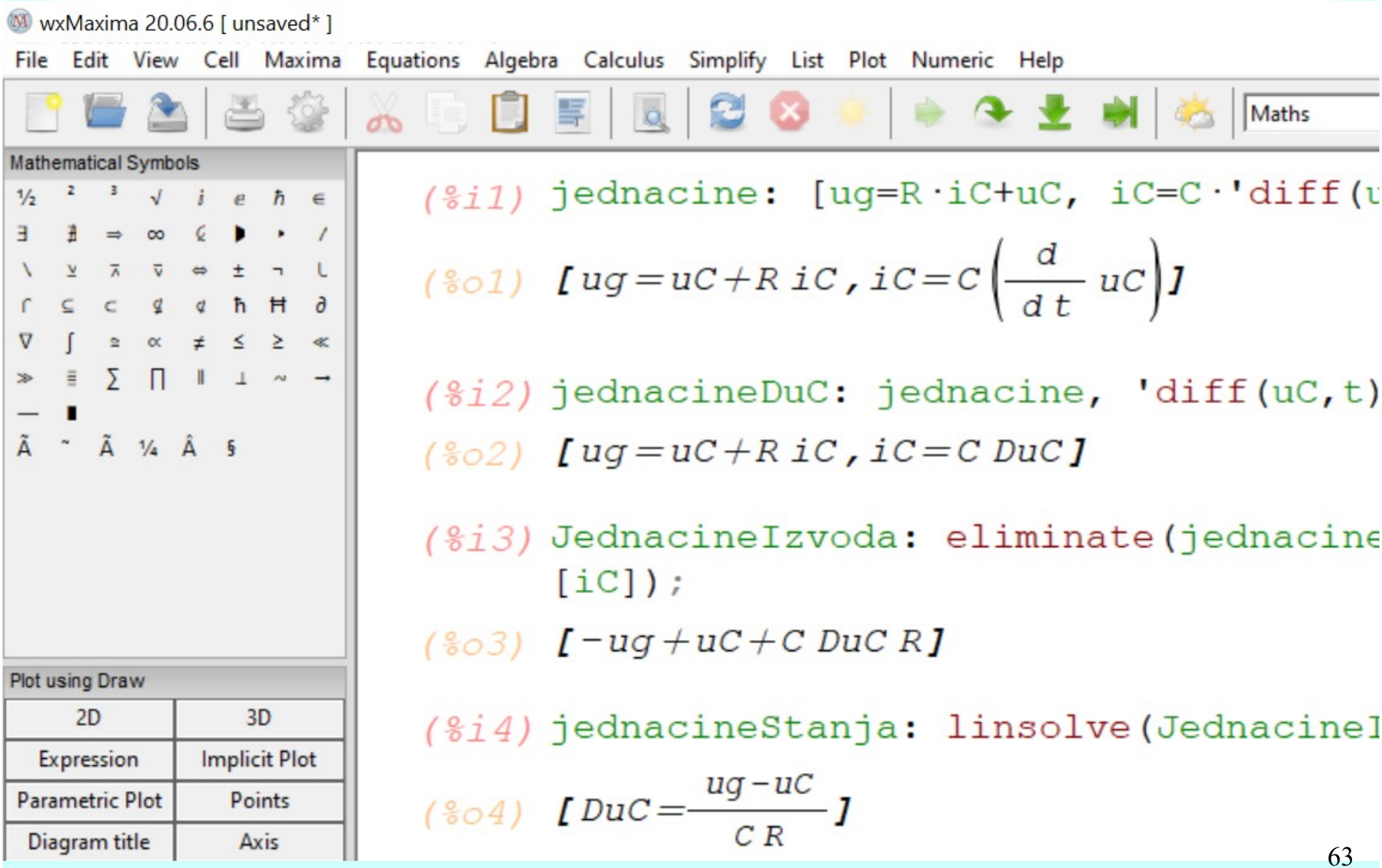
cond = $v_c(0) = -10$

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
(%i1) jednacine: [ug=R·iC+uC, iC=C·'diff(u
(%o1) [ug=uC+R iC, iC=C (d/dt uC)]
(%i2) jednacineDuC: jednacine, 'diff(uC,t)
(%o2) [ug=uC+R iC, iC=C DuC]
(%i3) JednacineIzvoda: eliminate(jednacine
[iC]);
(%o3) [-ug+uC+C DuC R]
(%i4) jednacineStanja: linsolve(JednacineI
(%o4) [DuC=(ug-uC)/(C R)]

```
(%i6) zamene: [ug=U];
(%o6) [ug=U]

(%i7) vrednosti: [R=1000, C=10^(-6), U
(%o7) [R=1000,C=1/1000000,U=10,U0=-1
```

$$\frac{dt}{CR}$$

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

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

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

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

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

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

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