Helwan University - Faculty of Engineering (Helwan)
Electronics and Communications Engineering Department

# *Lec-2 Diodes: Structure & Operation*
# ***(Examples)***

**Presented By:**

Azza Mohamed Anis

# Example-1

Consider a diode is doped with $N_A$ corresponding to 1 acceptor atom per $10^8$ germanium atoms. Calculate the barrier potential ($V_B$) at room temperature. Assume $N_D = 10^3 N_A$ .
Repeat for silicon diode.

*Solution:*

***Barrier Potential is given by:*** $$V_B = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

***At room temperature,***

$n_i$ (Si) = $1.5 \times 10^{10}$ atoms/cm$^3$

$n_i$ (Ge) = $2.5 \times 10^{13}$ atoms/cm$^3$

$V_T = 0.025\ V$

$N_A = 1 : 10^8$ Germanium atoms

But total number of germanium atoms equals $4.4\text{x}10^{22}$ atoms/$\text{cm}^3$

$N_A = ?? : 4.4 \text{ x } 10^{22}$ Germanium atoms

$$N_A = \frac{1 \text{ x } 4.4 \text{ x } 10^{22}}{10^8} = 4.4\text{x}10^{14}\text{atoms/cm}^3$$

$$N_D = 10^3 \; N_A = 10^3 \text{ x } 4.4\text{x}10^{14} = 4.4\text{x}10^{17}\text{atoms/cm}^3$$

$$V_B = 0.025 \; x \ln\left(\frac{4.4\text{x}10^{14} x 4.4\text{x}10^{17}}{\left(2.5\text{x}10^{13}\right)^2}\right) \qquad \textbf{Volts}$$

# Example-2

The resistivity of two sides of germanium diode is 2 Ω.cm (p side) and 1 Ω.cm (n side). Calculate the barrier potential ($V_B$) at room temperature. Repeat for silicon diode.

*Solution:*

***Barrier Potential is given by :*** $$V_B = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

***At room temperature,***

$n_i$ (Si) = $1.5 \times 10^{10}$ atoms/cm$^3$

$n_i$ (Ge) = $2.5 \times 10^{13}$ atoms/cm$^3$

$V_T = 0.025\ V$

$$\rho_p = \frac{1}{\sigma_p} = \frac{1}{q\ p\ \mu_p} = \frac{1}{q\ N_A\ \mu_p} = 2 \quad \Rightarrow \quad N_A = \frac{1}{2\ q\ \mu_p}$$

$$\rho_n = \frac{1}{\sigma_n} = \frac{1}{q\ n\ \mu_n} = \frac{1}{q\ N_D\ \mu_n} = 1 \quad \Rightarrow \quad N_D = \frac{1}{q\ \mu_n}$$

**At room temperature,**

$\mu_n$ (Si) = 1300 $cm^2$ /V.s

$\mu_p$ (Si) = 500 $cm^2$ /V.s

$\mu_n$ (Ge) = 3800 $cm^2$ /V.s

$\mu_p$ (Ge) = 1800 $cm^2$ /V.s

After that find barrier potential using:

$$V_B = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

# Example-3

If the reverse saturation current in a silicon diode is 1nA, what is the applied voltage for a diode current 2.5 μA at room temp.

Solution:

$$I_D = I_s \left[ exp\left(\frac{V_D}{\eta V_T}\right) - 1 \right]$$

$$2.5x10^{-6} = 1x10^{-9} \left[ exp\left(\frac{V_D}{2\ x\ 0.025}\right) - 1 \right]$$

$$2.5x10^{-6} = 1x10^{-9}\left[exp\left(\frac{V_D}{2\ x\ 0.025}\right) - 1\right]$$

$$\frac{2.5x10^{-6}}{1x10^{-9}} = \left[exp\left(\frac{V_D}{2\ x\ 0.025}\right) - 1\right]$$

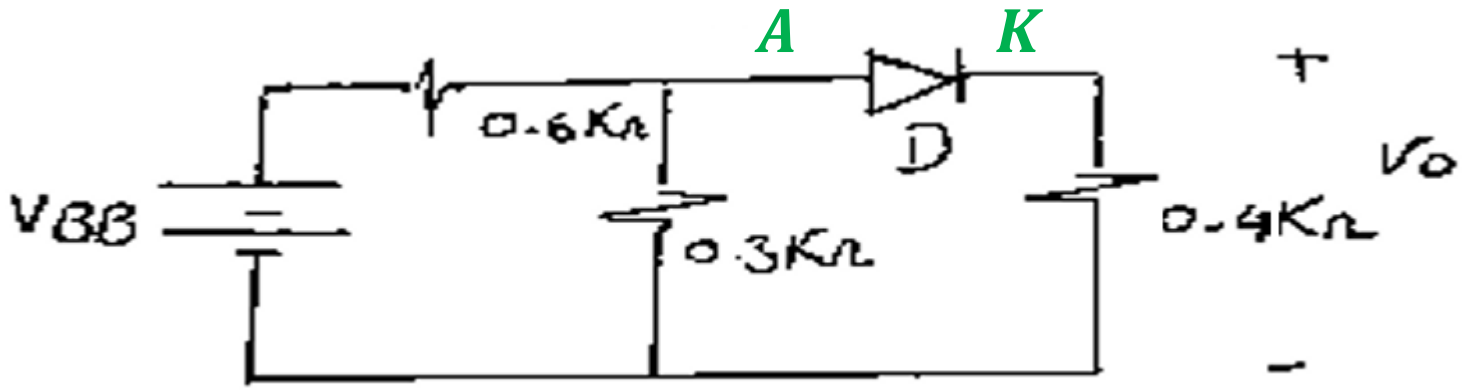
$$\left(\frac{2.5x10^{-6}}{1x10^{-9}}\right) + 1 = exp\left(\frac{V_D}{2\ x\ 0.025}\right)$$ *take* **ln** *function for both sides*

$$\ln\left[\left(\frac{2.5x10^{-6}}{1x10^{-9}}\right) + 1\right] = \frac{V_D}{2\ x\ 0.025}$$

$$V_D = 2\ x\ 0.025\ x \ln\left[\left(\frac{2.5x10^{-6}}{1x10^{-9}}\right) + 1\right]$$ *Volts*

# Example-4

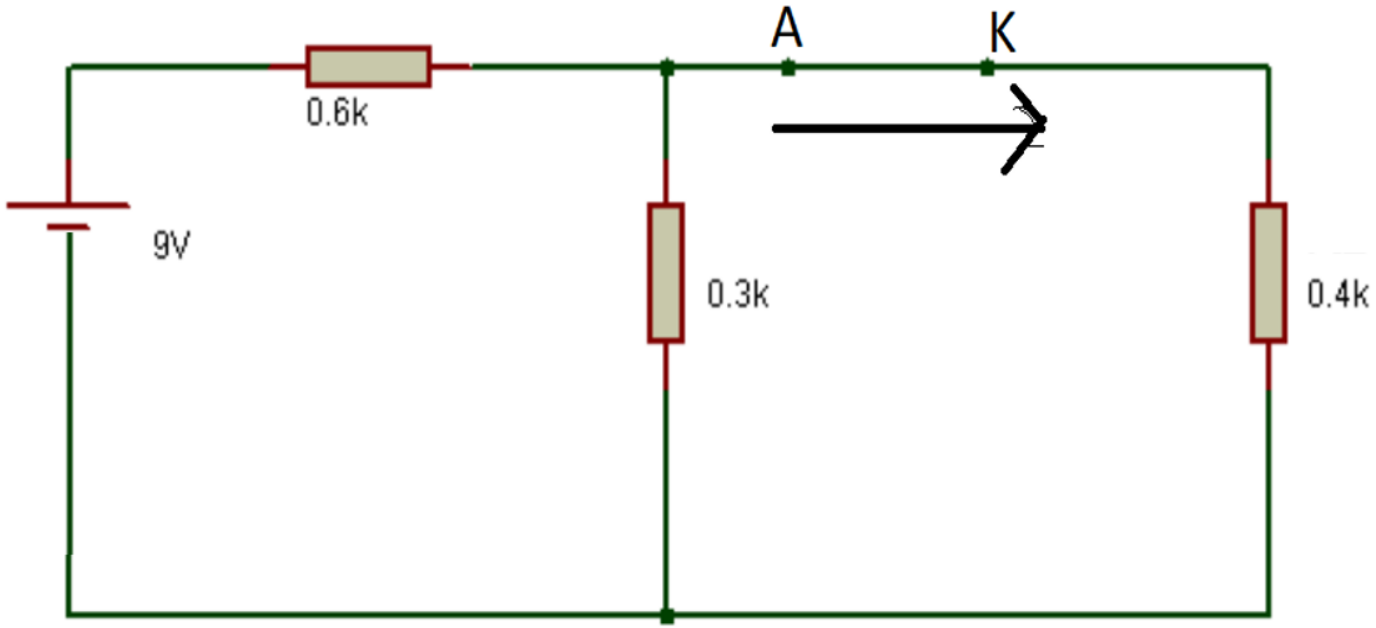
**The circuit shown uses an ideal diode. Find $V_o$ when $V_{BB}$=9V**




## Solution:

$(V_A = 7) > (V_K = 0)$

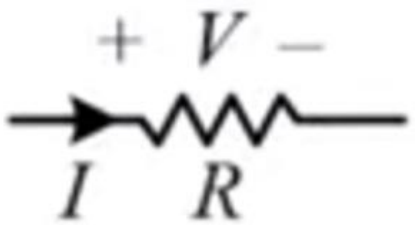
∴ Assume diode is forward

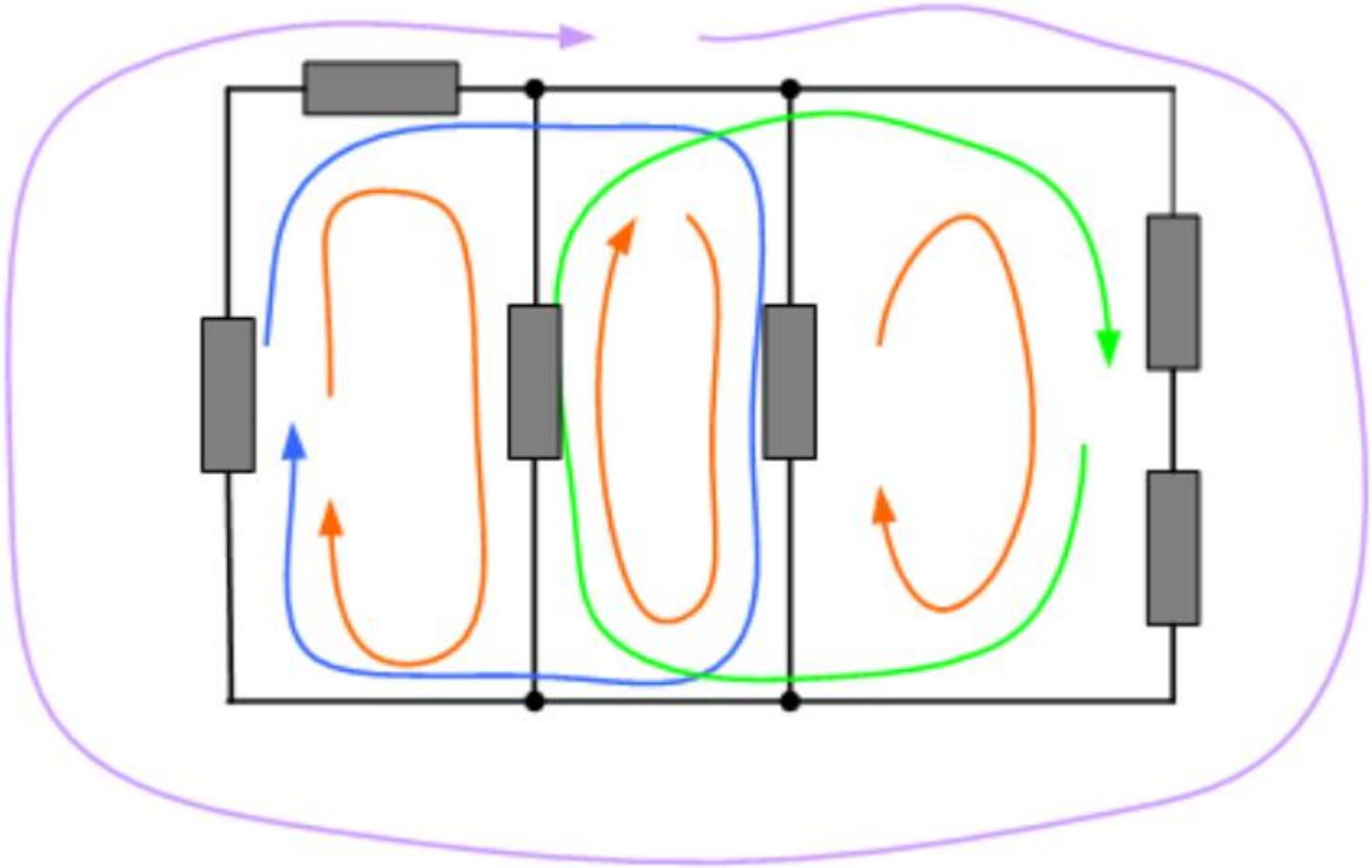


# Kirchhoff Voltage Law *(KVL)*

states the sum of all voltage differences around any closed loop is zero.

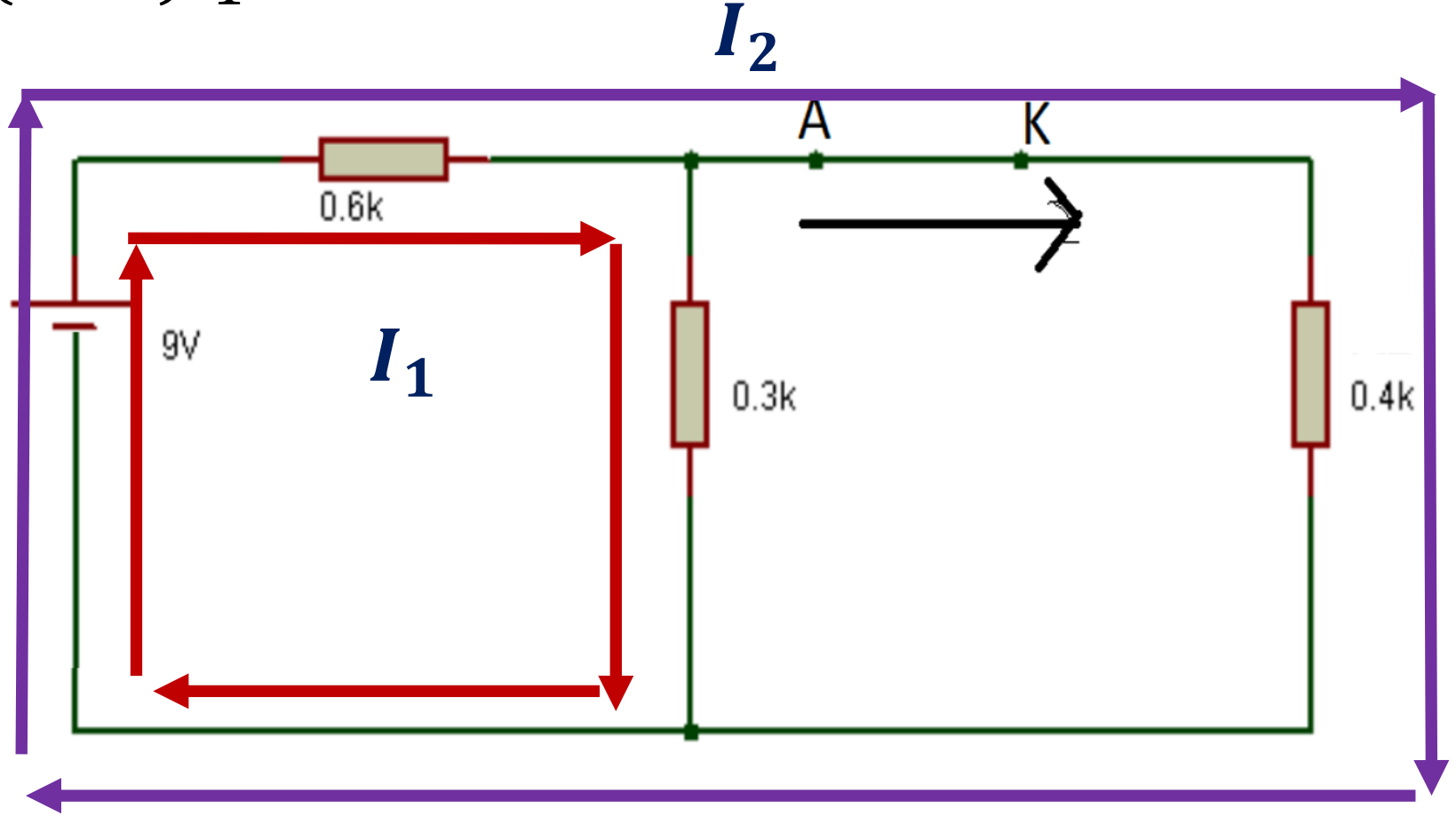
$$\sum V = 0$$



$$\sum V \text{ in first loop} = 0$$

$$9 - (0.6k)(I_1 + I_2) - (0.3k)I_1 = 0$$




$$\sum V \text{ in second loop} = 0$$

$$9 - (0.6\,k)(I_1 + I_2) - (0.4k)I_2 = 0$$

*Analysis of the first equation:*

$$9 - (0.6k)(I_1 + I_2) - (0.3k)I_1 = 0$$

$$9 - (0.6k)I_1 - (0.6k)I_2 - (0.3k)I_1 = 0$$

$$9 - (0.6k + 0.3k)I_1 - (0.6k)I_2 = 0$$

$$9 - (0.9k)I_1 - (0.6k)I_2 = 0$$

$$9 = (0.9k)I_1 + (0.6k)I_2$$

*Analysis of the second equation:*

$$9 - (0.6k)(I_1 + I_2) - (0.4k)I_2 = 0$$

$$9 - (0.6k)I_1 - (0.6k)I_2 - (0.4k)I_2 = 0$$

$$9 - (0.6k)I_1 - (0.6k + 0.4k)I_2 = 0$$

$$9 - (0.6k)I_1 - (1k)I_2 = 0$$

$$9 = (0.6k)I_1 + (1k)I_2$$

$$9 = (0.9k)I_1 + (0.6k)I_2$$
$$9 = (0.6k)I_1 + (1k)I_2$$ $x\ -0.6$ *in second equation*

$$9 = (0.9k)I_1 + (0.6k)I_2$$
$$-5.4 = -(0.36\,k)I_1 - (0.6k)I_2$$ *add two equations*

$$3.6 = (0.54k)I_1$$

$$\frac{3.6\ V}{(0.54\ k\Omega\ )} = \ I_1 = \ \frac{3.6\ V}{(0.54\ x\ \ 10^3\ \Omega\ )}$$

$$I_1 = 6.67\ x\ \ 10^{-3} A = 6.67\ mA$$

$$9 = (0.6k)I_1 + (1k)I_2$$

$$9 = (0.6\,k)\,(6.67mA) + (1k)I_2$$

$$9 = (0.6\ x\ 10^3)\,(6.67\,x\ 10^{-3}) + (1x\ 10^3)I_2$$

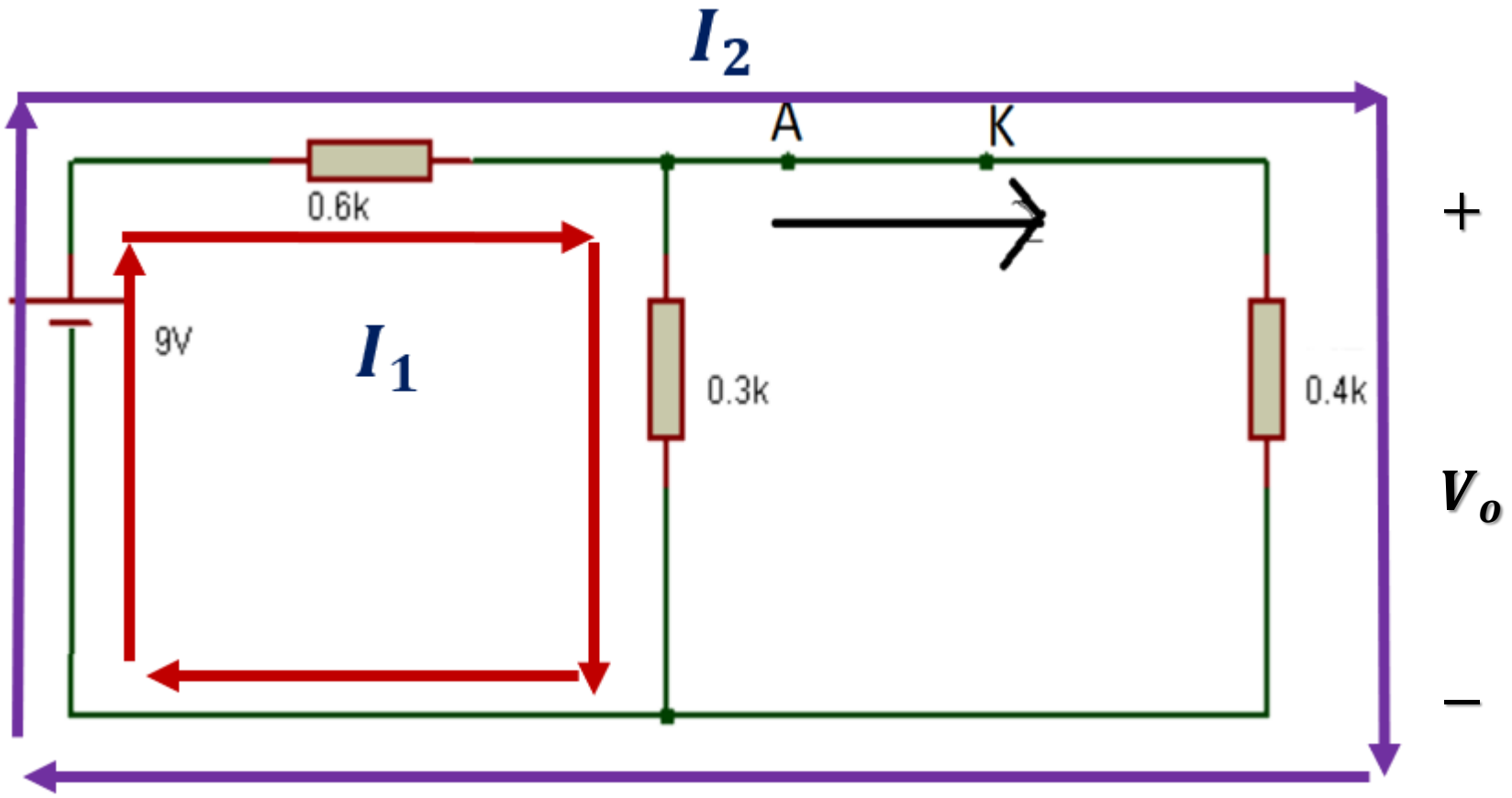
$$9 = (4) + (1x\ 10^3)I_2$$

$$9 - 4 = (1x\ 10^3)I_2$$

$$5 = (1\,x\ 10^3)I_2$$

$$\frac{5}{(1x\ 10^3)} = I_2$$

$$I_2 = 5\,x\ 10^{-3} = 5\,mA$$




$\because I_2 = 5\ mA = I_D$

$\because I_D = positive\ value$

$\therefore I_D\ in\ correct\ direction$

$\therefore$ *our assumption is true*

*Diode is forward*

$$Vo = 0.4k\ x\ I_D = 2V$$

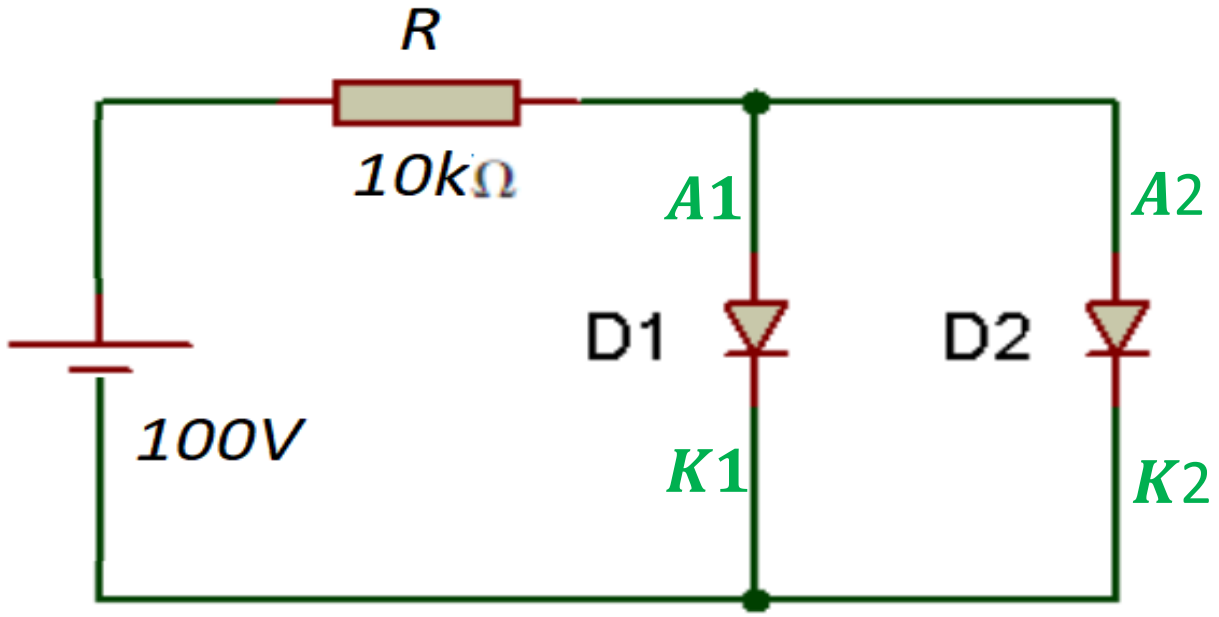
# Example-5

The diode $D_1$ is germanium with a potential barrier ($V_B$) 0.2V and an incremental resistance ($R_f$) 20Ω whereas the diode $D_2$ is silicon with a potential barrier ($V_B$) 0.6V and an incremental resistance ($R_f$) 15Ω. Calculate the diodes currents.

**Solution:**

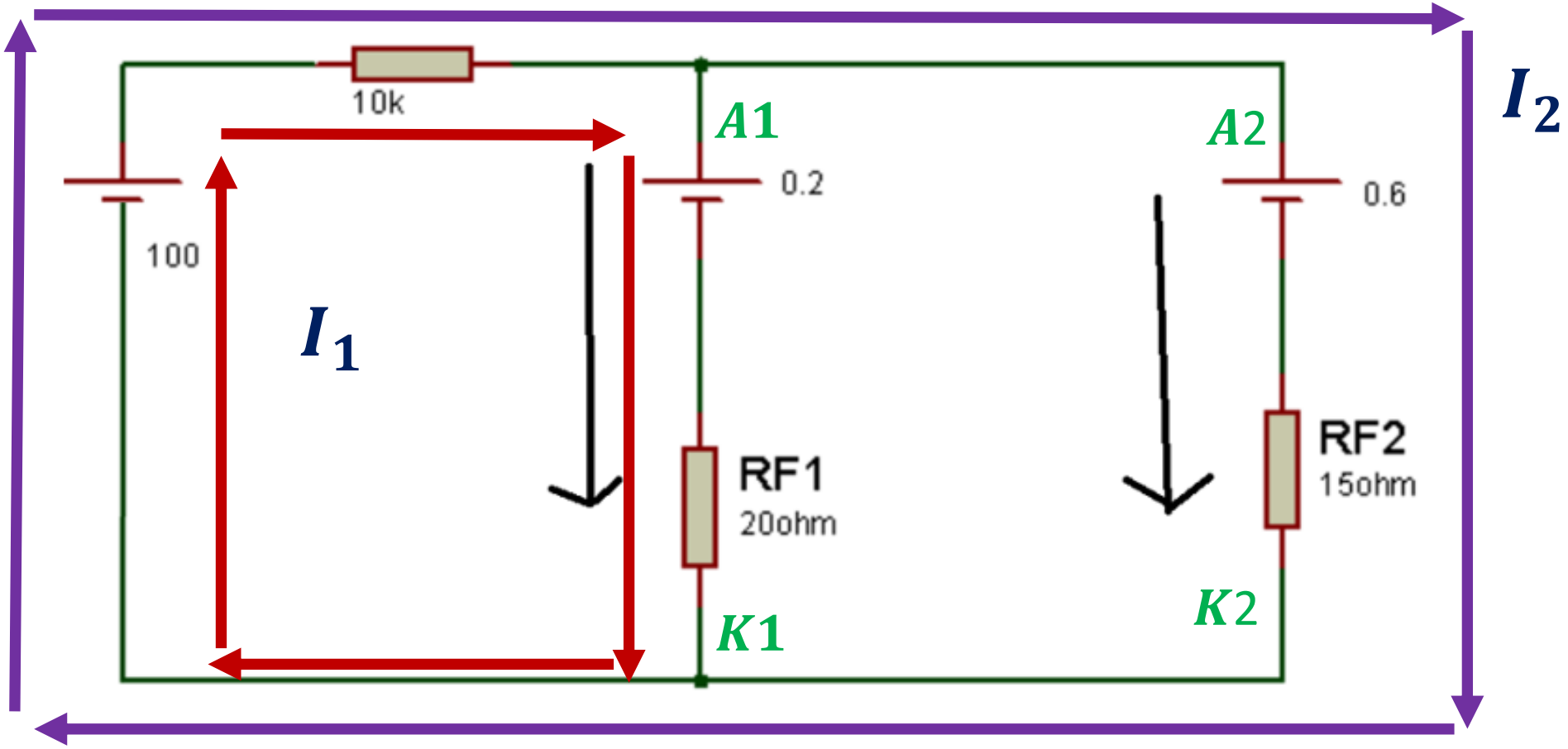
$$(V_{A1} = 90) > (V_{K1} = 0) + (V_{B1} = 0.2)$$

$$(V_{A2} = 90) > (V_{K2} = 0) + (V_{B2} = 0.6)$$




**∴ Assume D1 and D2 are forward**

$\sum V \text{ in first loop} = 0$ ⇒ $100 - 0.2 - (10\,k)(I_1 + I_2) - (20)I_1 = 0$




$\sum V \text{ in second loop} = 0$ ⇒ $100 - 0.6 - (10\,k))(I_1 + I_2) - (15)I_2 = 0$

*Analysis of the first equation:*

$$100 - 0.2 - (10\,k)\,(I_1 + I_2)\; - (20)I_1 = 0$$

$$99.8\; - (10\,k)I_1 - (10\,k)I_2\; - (20)I_1 = 0$$

$$99.8\; - (10\,k + 20)I_1 - (10\,k)I_2\; = 0$$

$$99.8\; - (10\,x1000 + 20)I_1 - (10x1000)I_2\; = 0$$

$$99.8\; - (10x1000 + 20)I_1 - (10x1000)I_2\; = 0$$

$$99.8\; - (10020)I_1 - (10000)I_2\; = 0$$

$$99.8 = (10020)I_1 + (10000)I_2$$

*Analysis of the second equation:*

$$100 - 0.6 - (10\ k)\ (I_1 + I_2) - (15)I_2 = 0$$

$$99.4 - (10\ k)I_1 - (10\ k)I_2 - (15)I_2 = 0$$

$$99.4 - (10\ k)I_1 - (10\ k + 15)I_2 = 0$$

$$99.4 - (10x1000)I_1 - (10x1000 + 15)I_2 = 0$$

$$99.4 - (10000)I_1 - (10015)I_2 = 0$$

$$99.4 = (10000)I_1 + (10015)I_2$$

$$99.8 = (10020)I_1 + (10000)I_2$$ *x* $-(10000)$ *in the first equation*

$$99.4 = (10000)I_1 + (10015)I_2$$ *x* $(10020)$ *in the second equation*

$$-(10000)x\ 99.8 = -(10000)(10020)I_1 - (10000)(10000)I_2$$

*add two equations*

$$(10020)x\ 99.4 = (10000)(10020)I_1 + (10020)(10015)I_2$$

$$-(10000)x\ 99.8 + (10020)x\ 99.4 = -(10000)(10000)I_2 + (10020)(10015)I_2$$

$$-2012 = -100000000\ I_2 + 100350300\ I_2$$

$$-2012 = 350300\ I_2 \quad \Rightarrow \quad \frac{-2012}{350300} = I_2 = -0.0057A = -5.7mA$$

$$I_2 = -0.0057\ A$$

$$99.8 = (10020)I_1 + (10000)I_2$$

$$99.8 = (10020)I_1 + (10000)\ (-0.0057)$$

$$99.8 = (10020)I_1 - \ 57$$

$$99.8 + \ 57 = (10020)I_1$$

$$156.8 = (10020)I_1$$

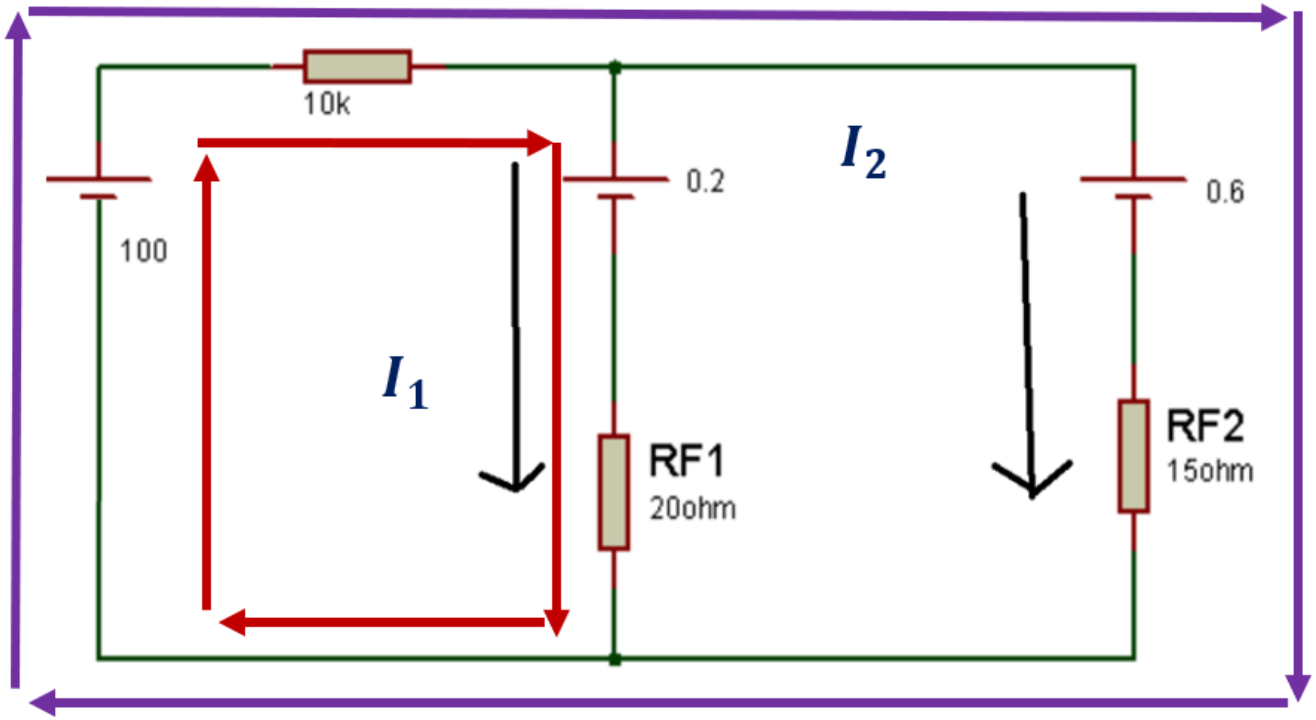
$$\frac{156.8}{10020} \ = I_1 \ = 0.01565A = 15.65mA$$

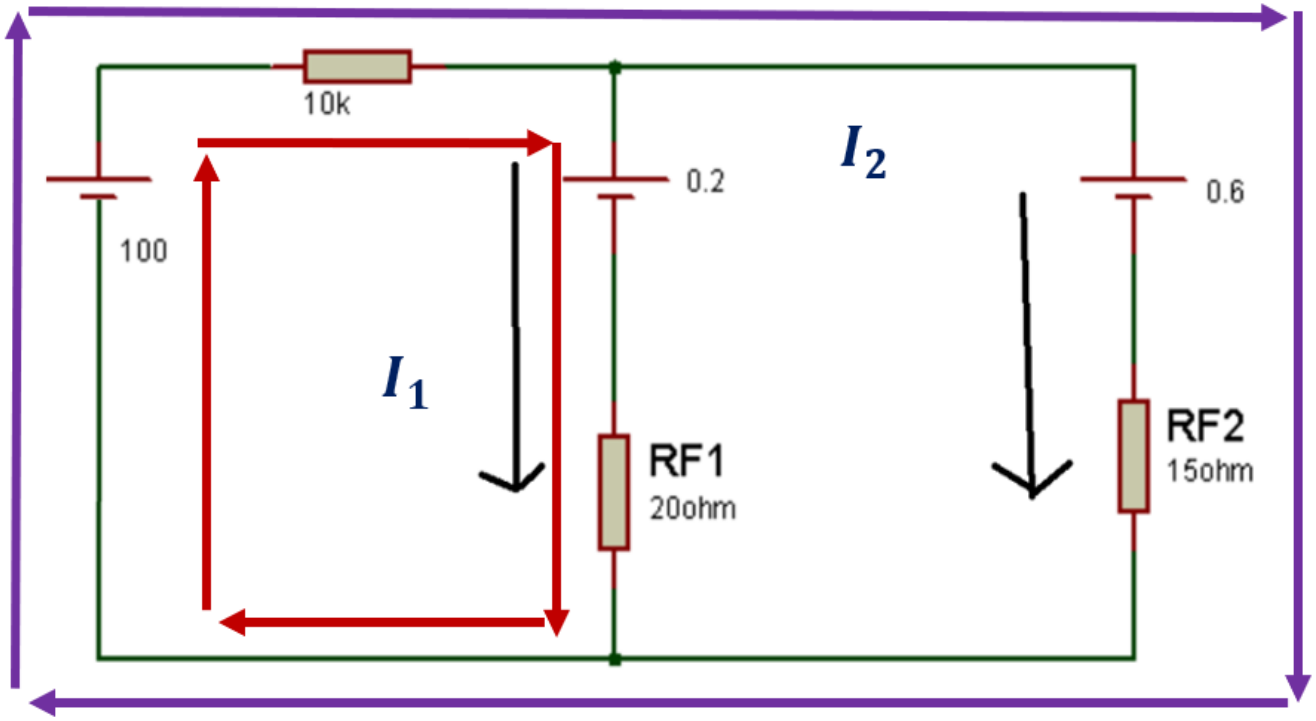
$\because\ I_{D2} = I_2 = -0.0057\ A$ ⇒ $\because\ I_{D2}$ = **negative value**

$\therefore\ I_{D2}$ ***must flow in a reverse direction***

**Our assumption is false**

**Assume again diode $D_2$ is reverse**






$\because I_1 = I_{D1} = positive\ value$

$\therefore I_{D1}\ in\ correct\ direction$

$\therefore$ *our assumption is true*

*Diode* $D_1$ *is forward*

## *New assumption: diode $D_1$ is forward and diode $D_2$ is reverse*

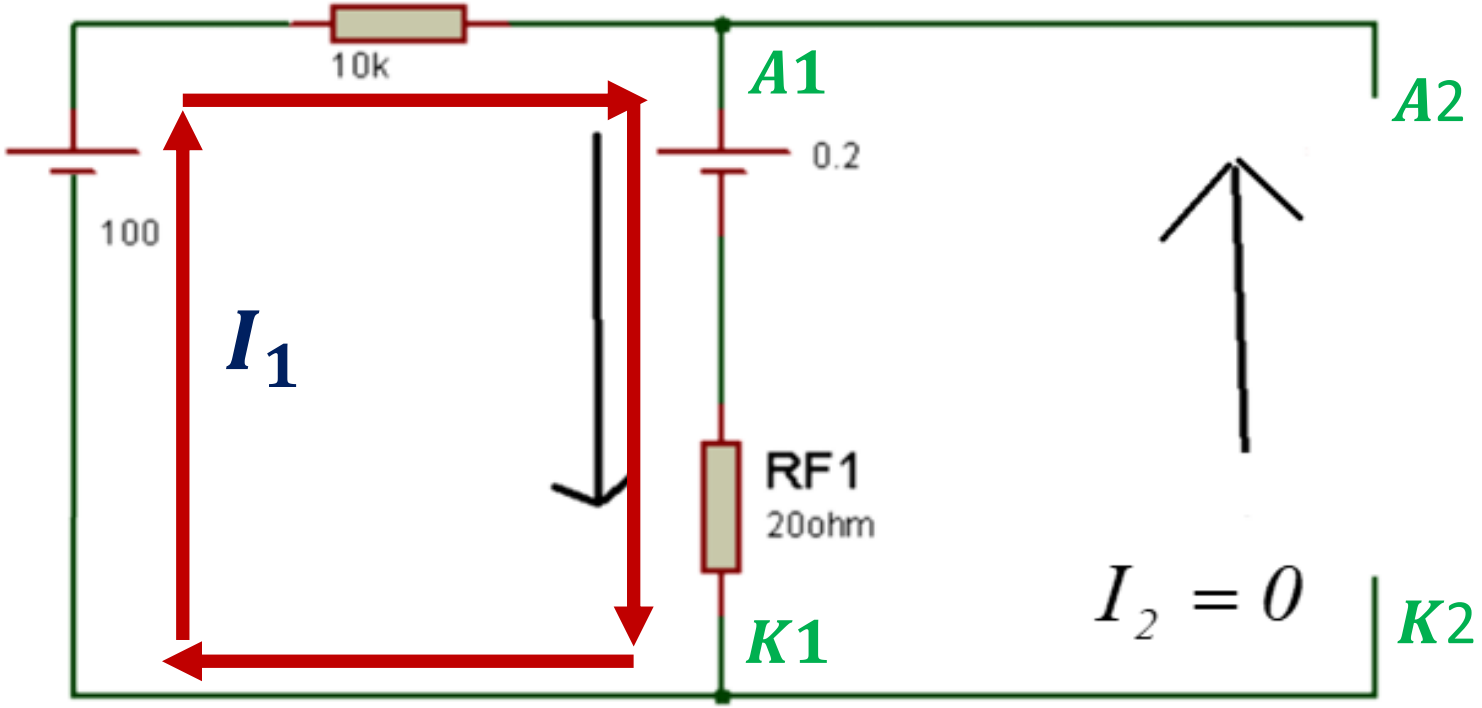
$$100 - 0.2 - (10x1000 + 20)I_1 = 0$$

$$99.8 - 10020\ I_1 = 0$$

$$99.8 = 10020\ I_1$$

$$I_1 = \frac{99.8}{10020}$$

*If $R_r$ not given*
*assume $R_r = \infty$ (open circuit)*




$I_1 = 0.01A=10mA$

$I_2 = 0\ A$

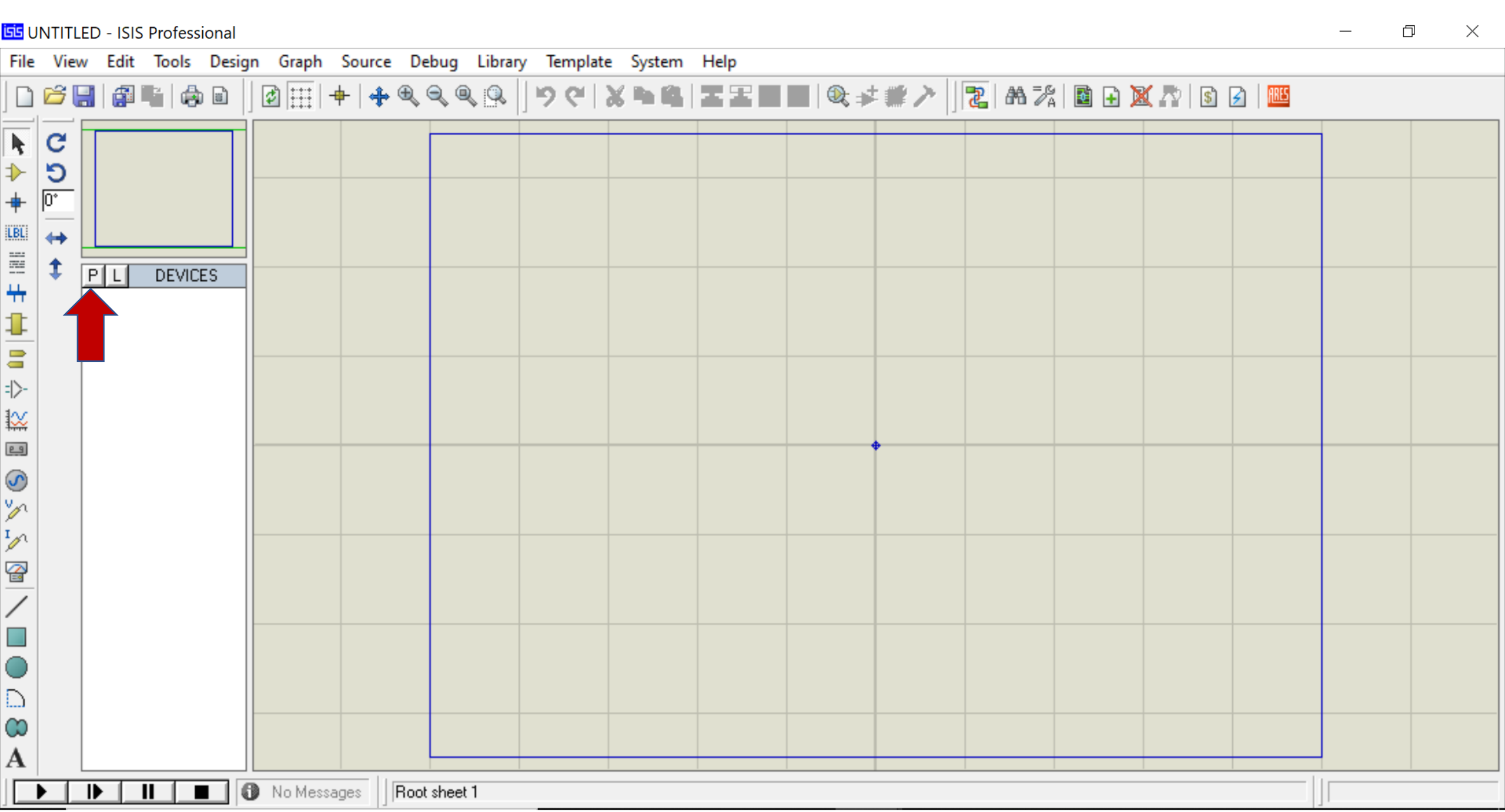
*Values of diodes currents are positive*

*∴ New assumption is true*

$I_1 = I_{D1} = 0.01\ A$

$I_2 = I_{D2} = 0\ A$

# Simulation Using Proteus (ISIS)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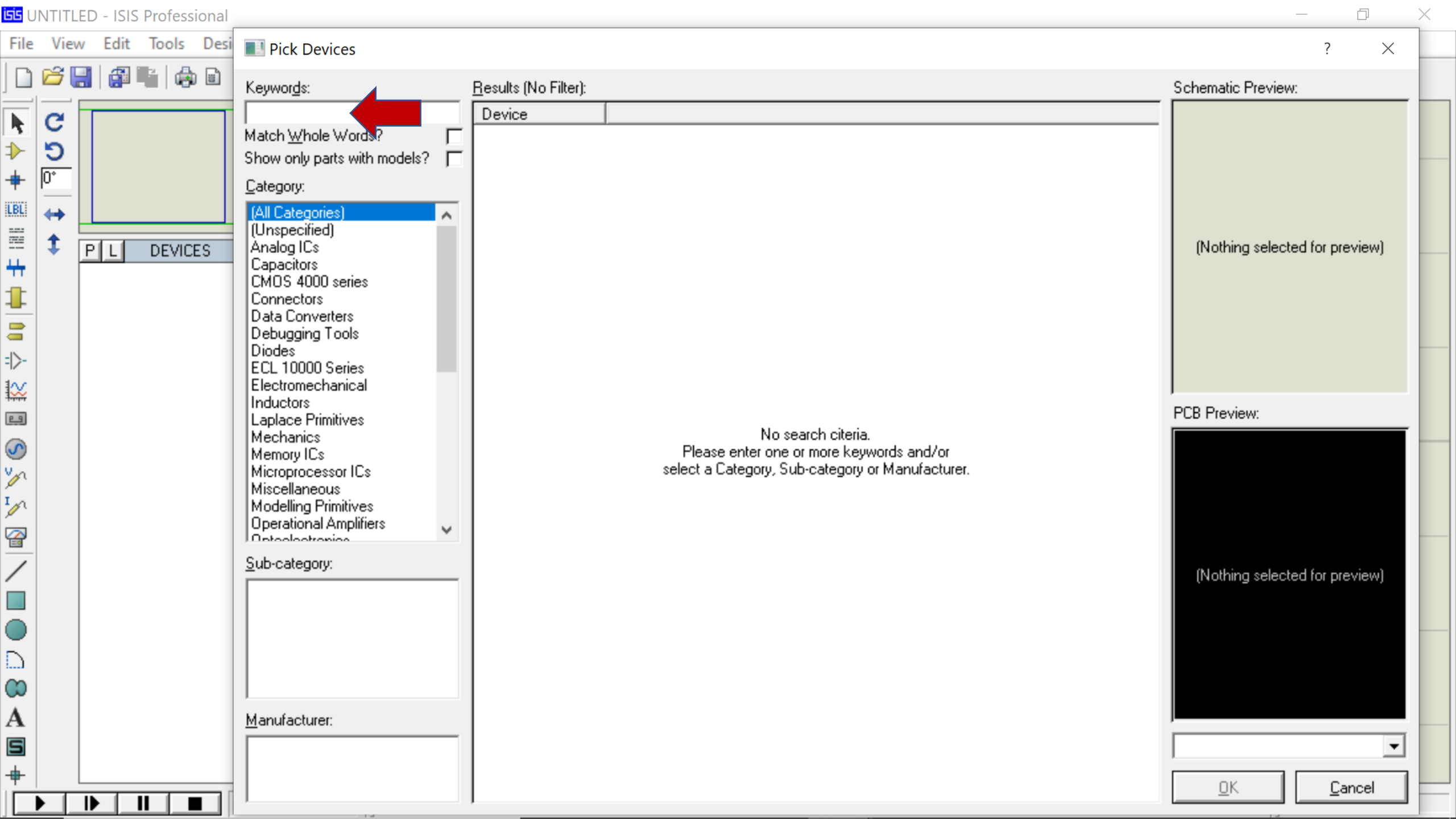
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Analog ICs
Capacitors
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Connectors
Data Converters
Debugging Tools
Diodes
ECL 10000 Series
Electromechanical
Inductors
Laplace Primitives
Mechanics
Memory ICs
Microprocessor ICs
Miscellaneous
Modelling Primitives
Operational Amplifiers
Sub-category:
Manufacturer:
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## Pick Devices

Keywords:

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Category:

- (All Categories)
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- Analog ICs
- Capacitors
- CMOS 4000 series
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- Diodes
- ECL 10000 Series
- Laplace Primitives
- Memory ICs
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- Miscellaneous
- Modelling Primitives
- Resistors
- Transducers
- Transistors
- TTL 74 series
- TTL 74ALS series

Sub-category:

Manufacturer:

Results (2):

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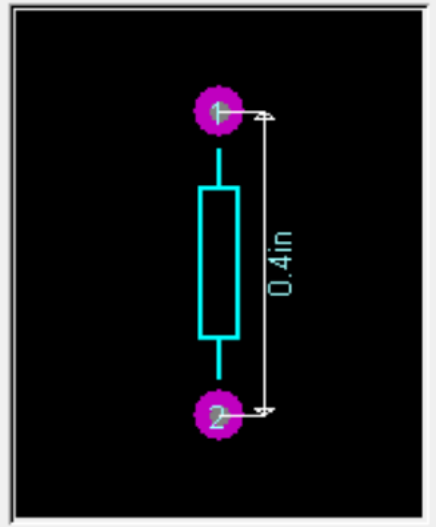
| RES | USERDVC | Generic resistor symbol |

RES Preview:

Analogue Primitive [RESISTOR]

PCB Preview:

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Category:

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Analog ICs
Capacitors
CMOS 4000 series
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Miscellaneous
Modelling Primitives
Resistors
Transducers
Transistors
TTL 74 series
TTL 74ALS series

Sub-category:

Manufacturer:

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| RES | DEVICE | Generic resistor symbol |
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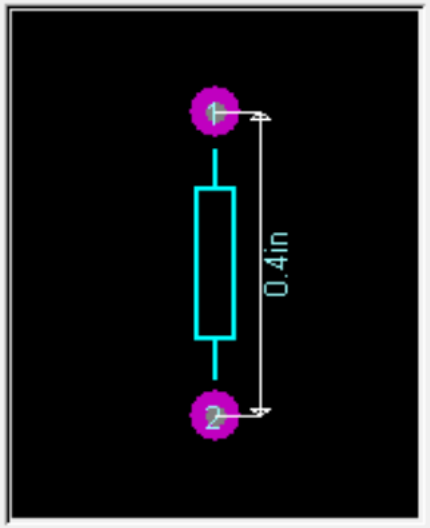
RES Preview:

Analogue Primitive [RESISTOR]

PCB Preview:

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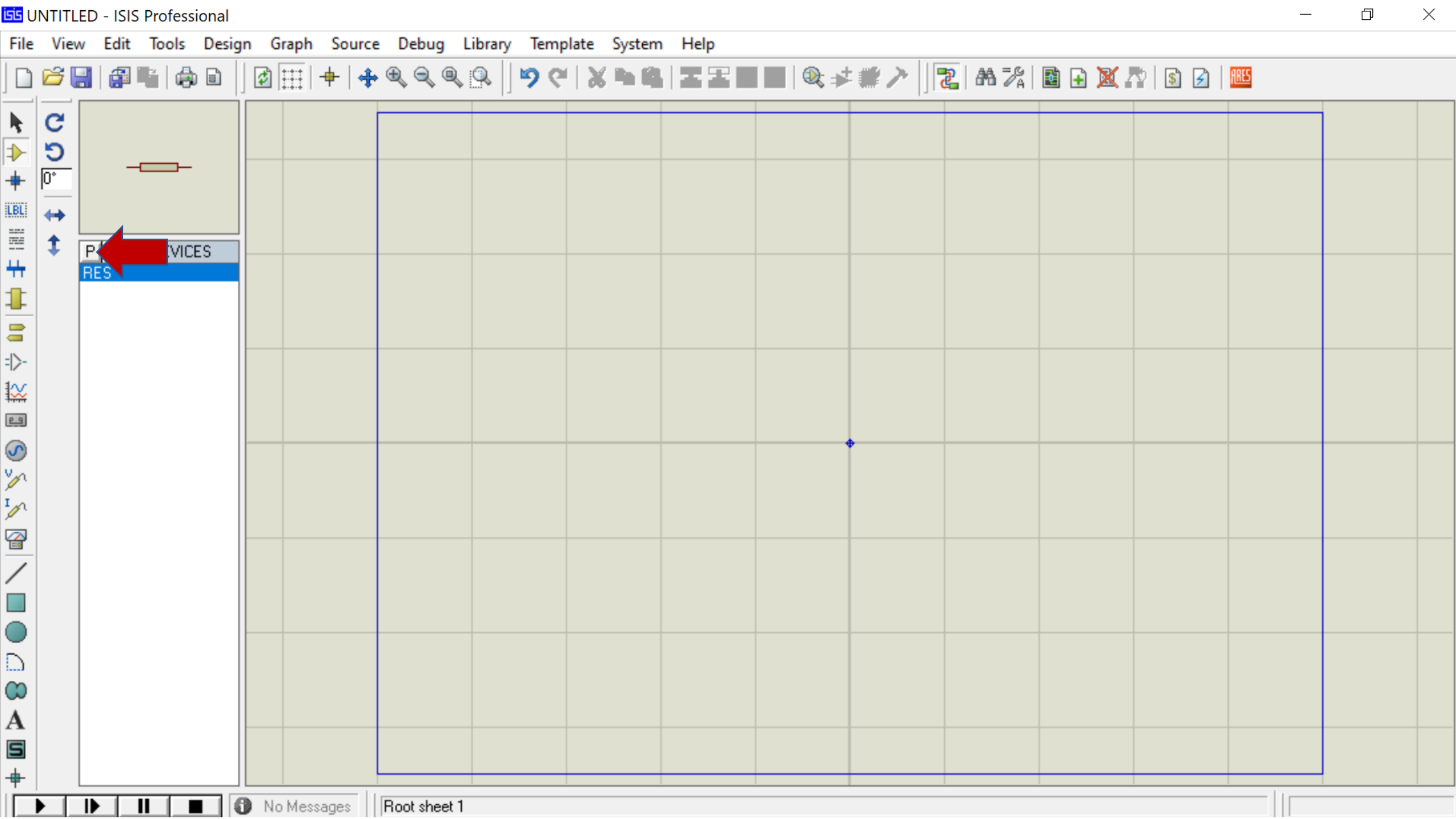
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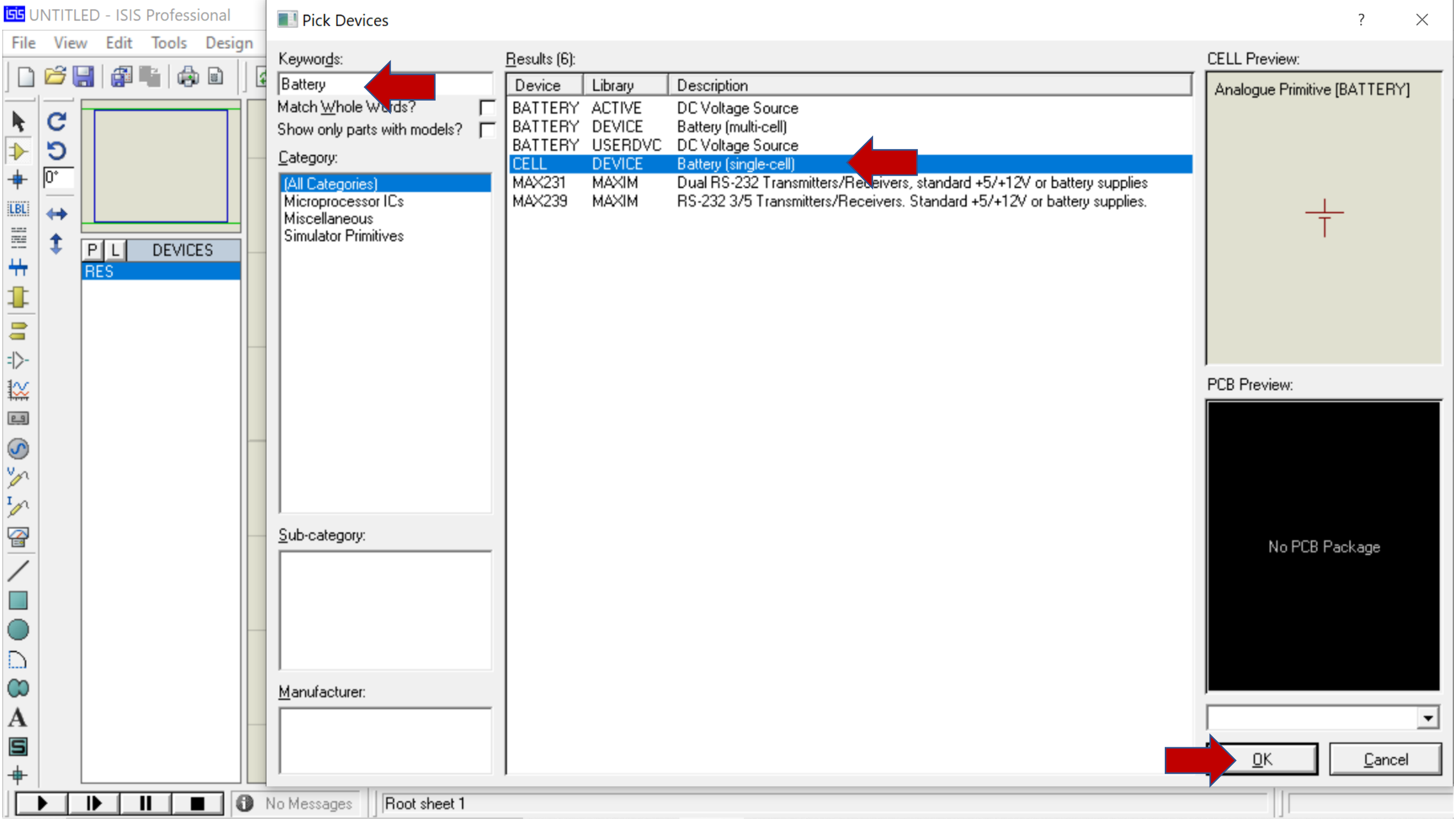
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Microprocessor ICs
Miscellaneous
Simulator Primitives
Sub-category:
Manufacturer:
Results (6):
Device Library Description
BATTERY ACTIVE DC Voltage Source
BATTERY DEVICE Battery (multi-cell)
BATTERY USERDVC DC Voltage Source
CELL DEVICE Battery (single-cell)
MAX231 MAXIM Dual RS-232 Transmitters/Receivers, standard +5/+12V or battery supplies
MAX239 MAXIM RS-232 3/5 Transmitters/Receivers. Standard +5/+12V or battery supplies.
CELL Preview:
Analogue Primitive [BATTERY]
PCB Preview:
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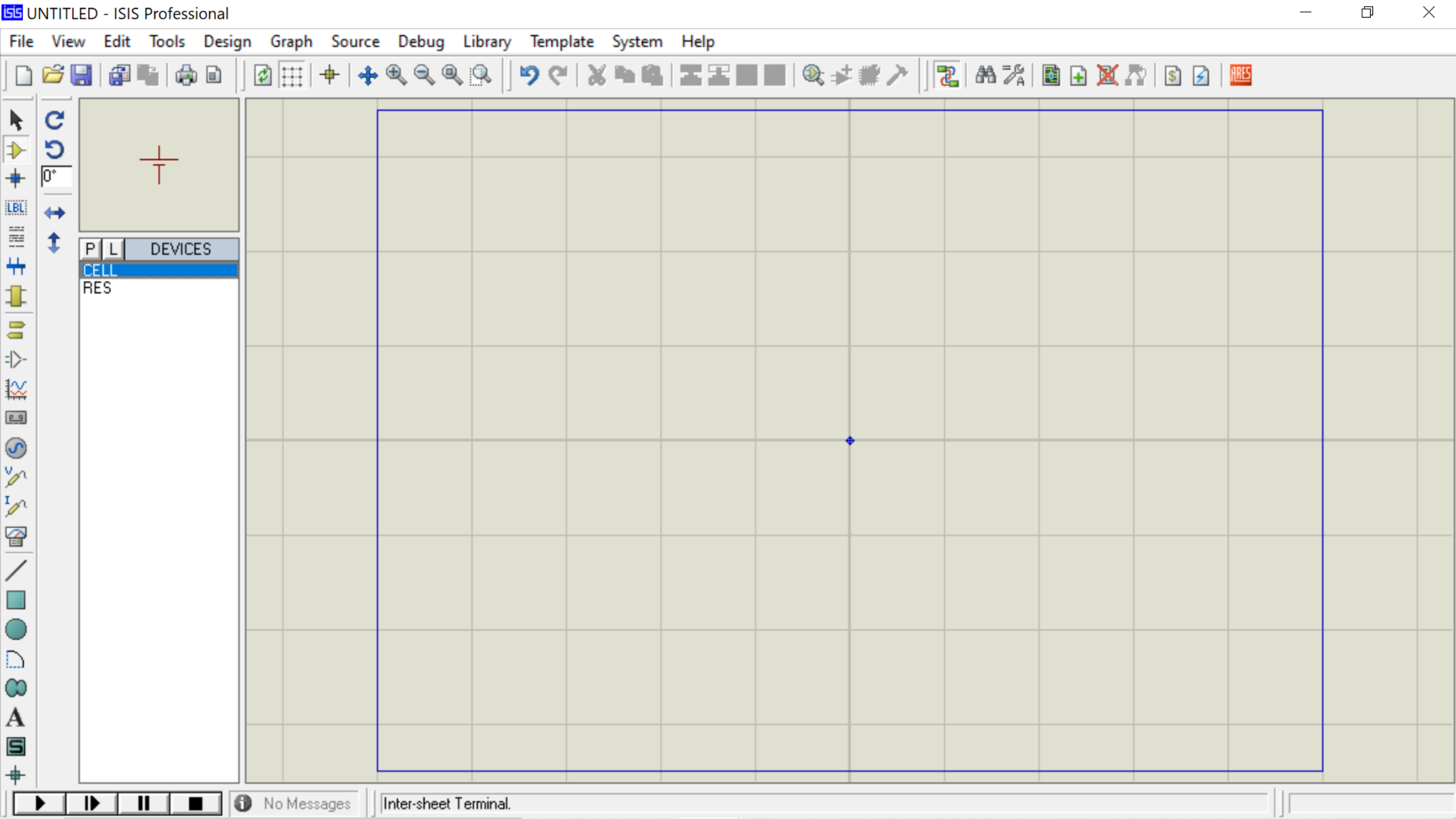
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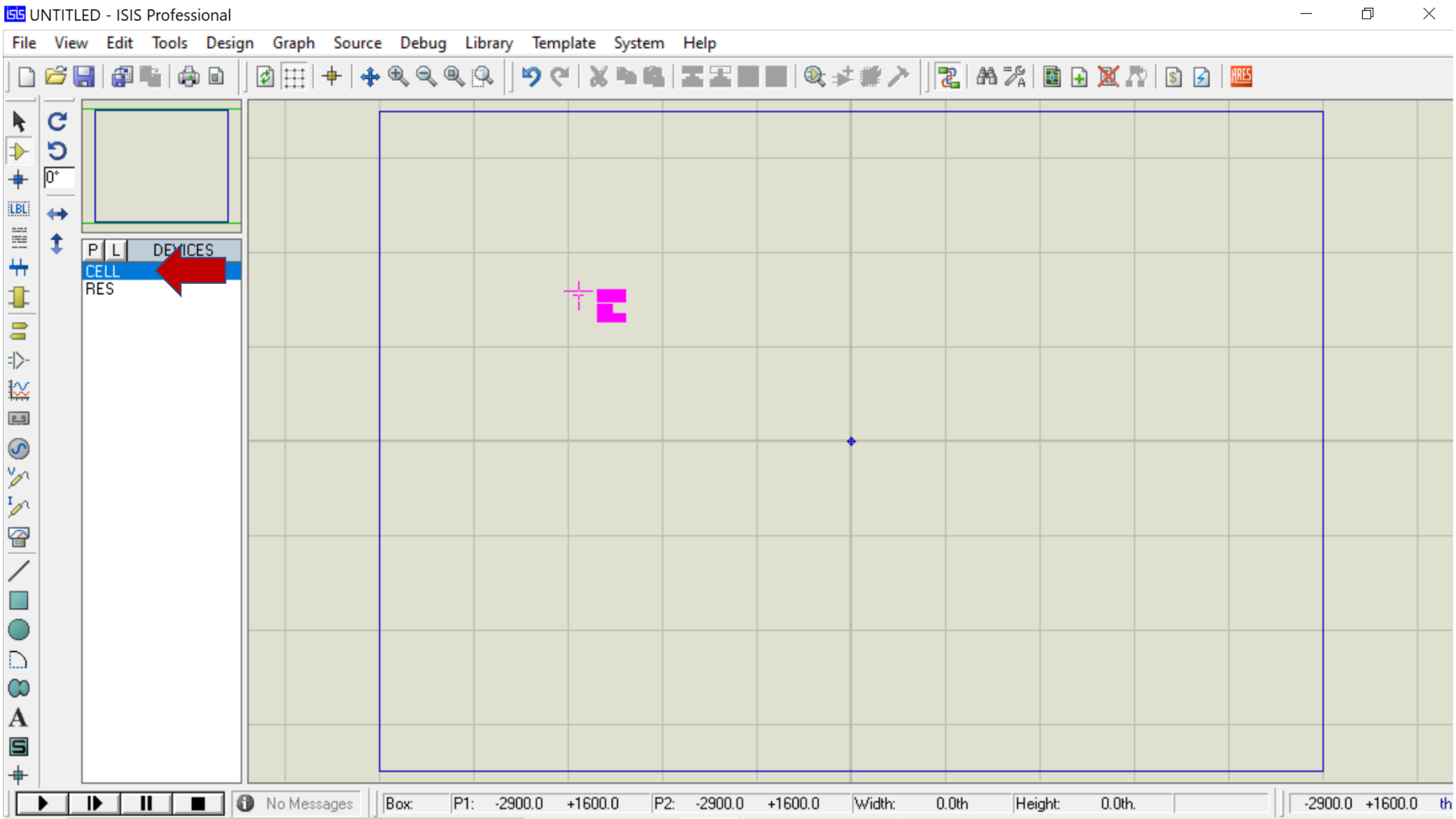
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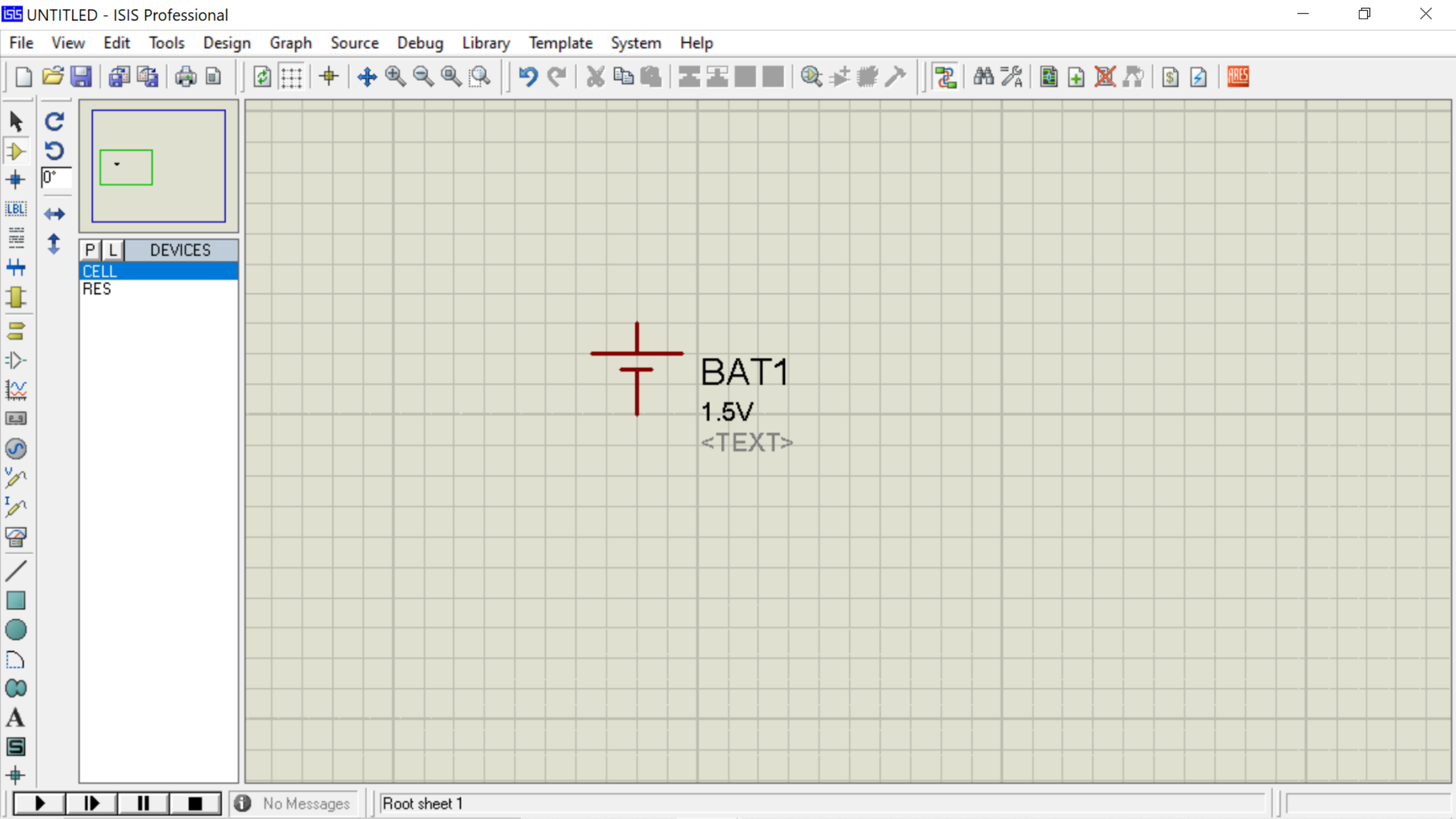
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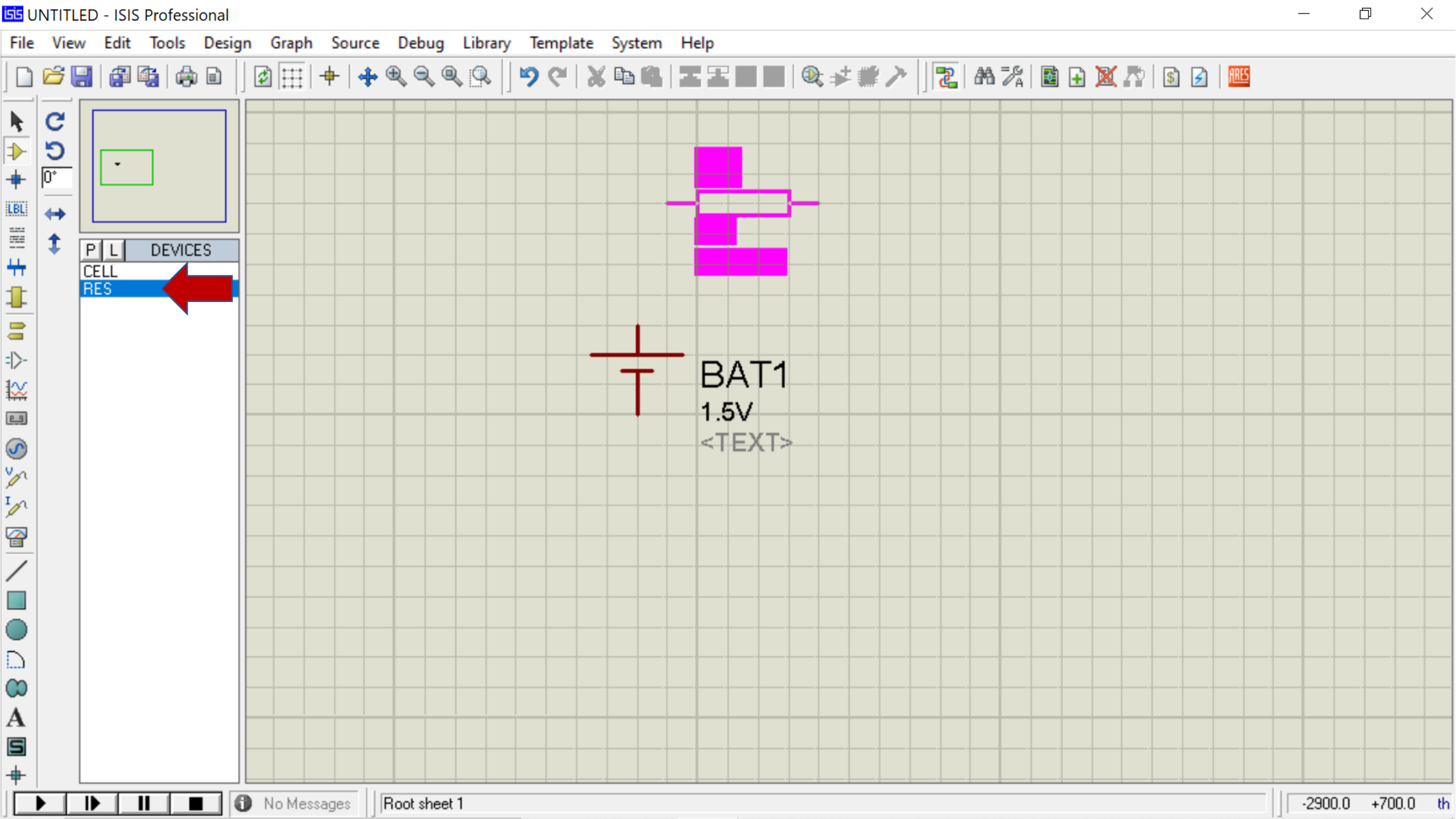
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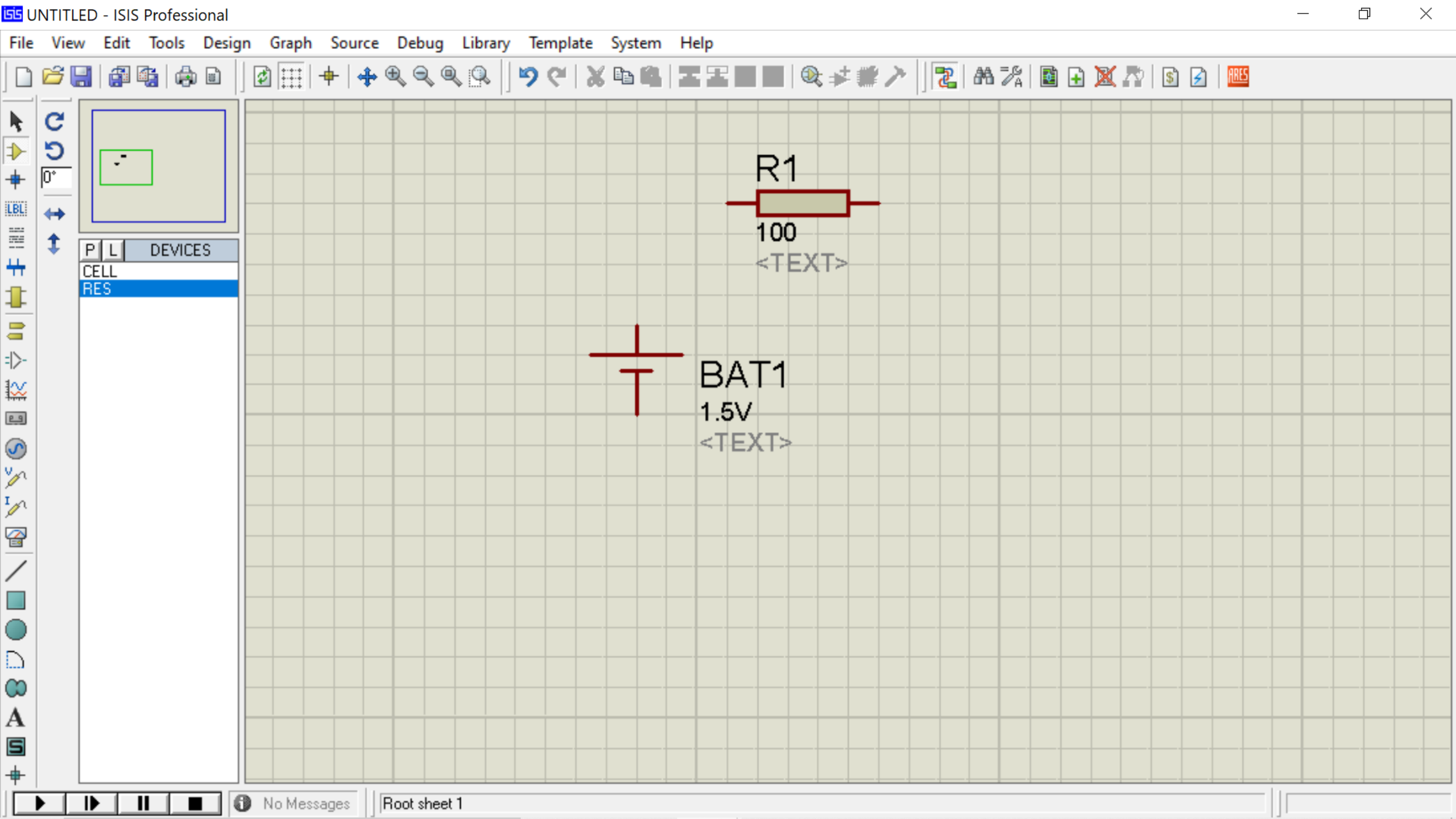
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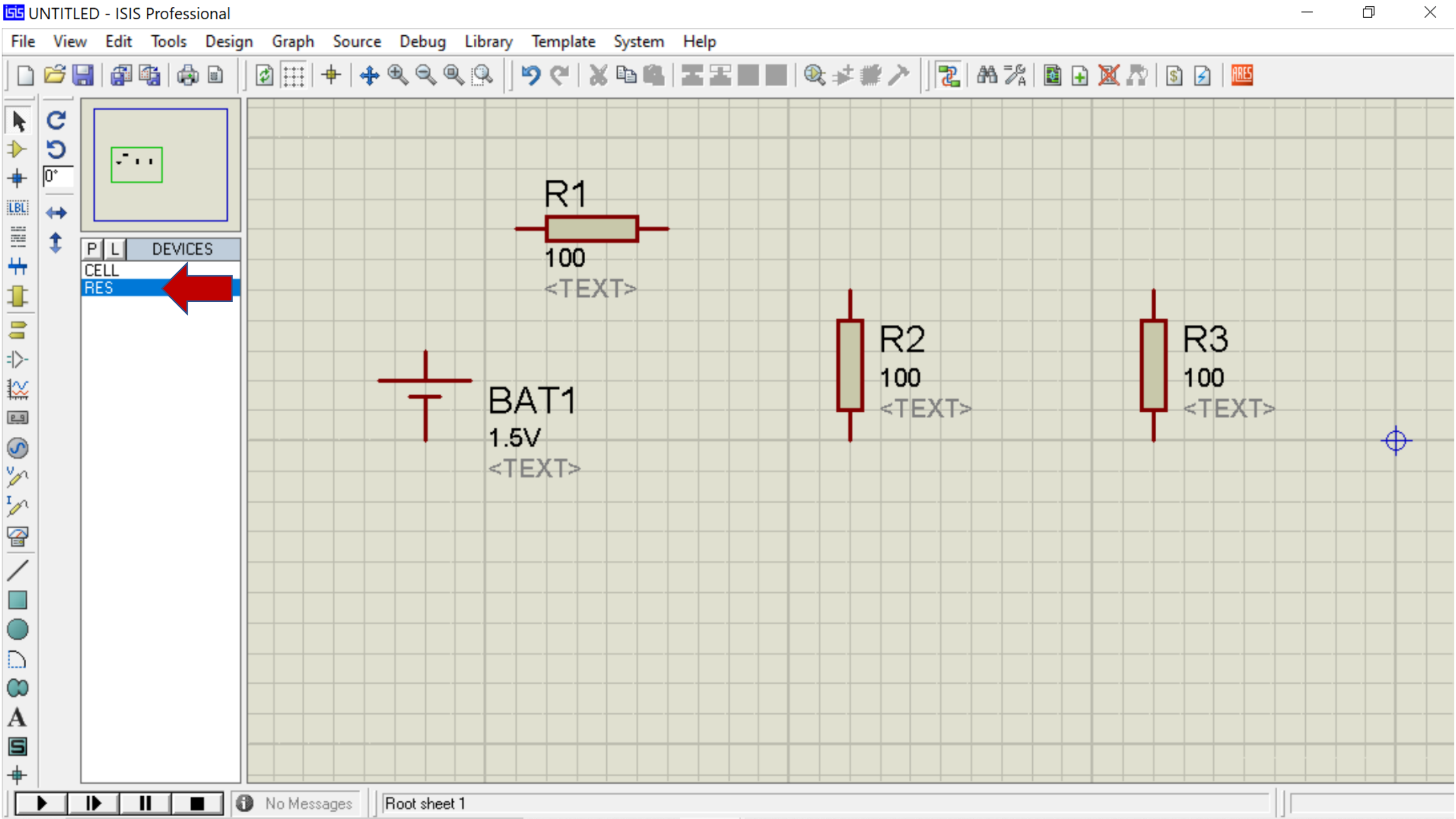
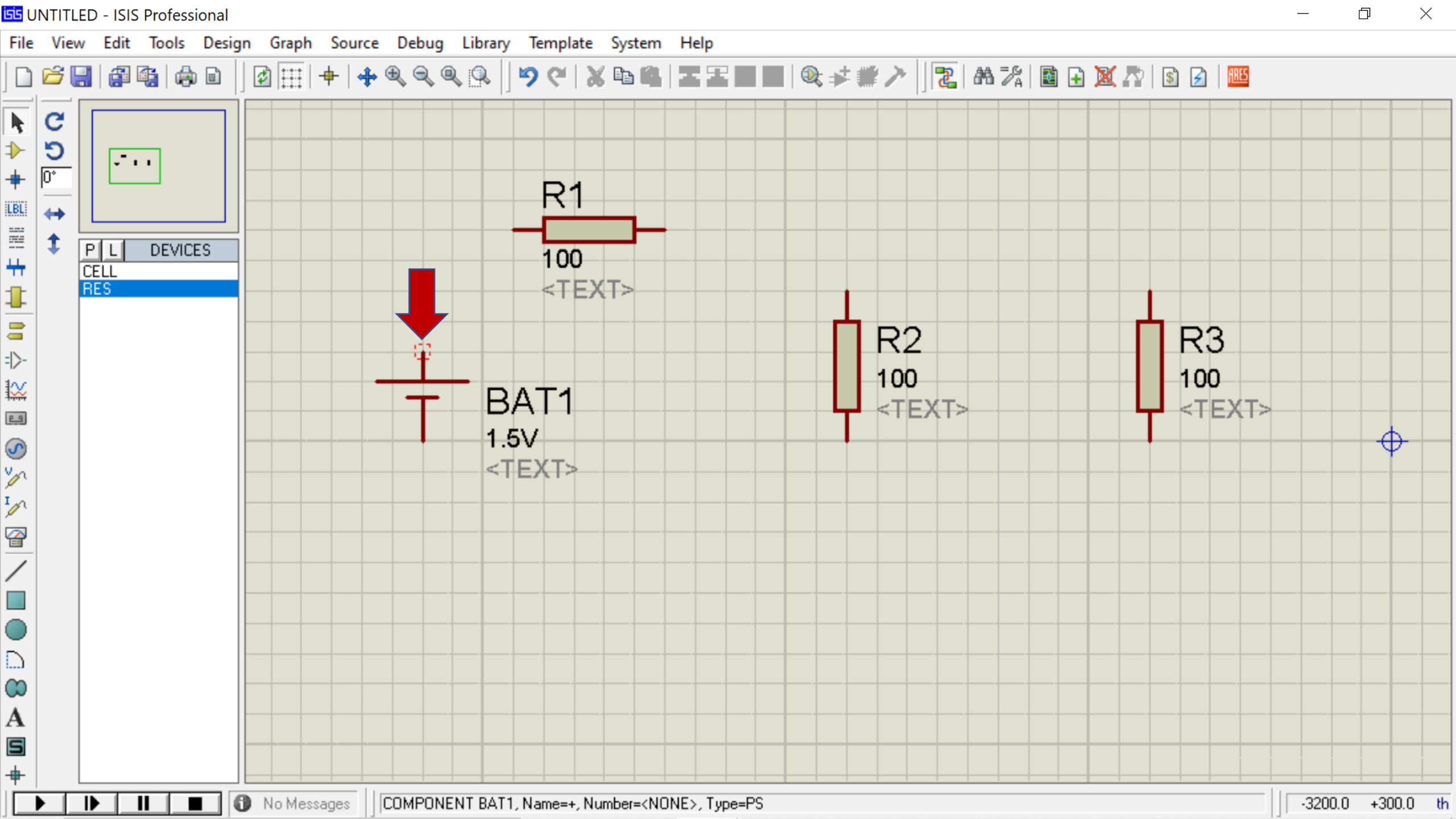
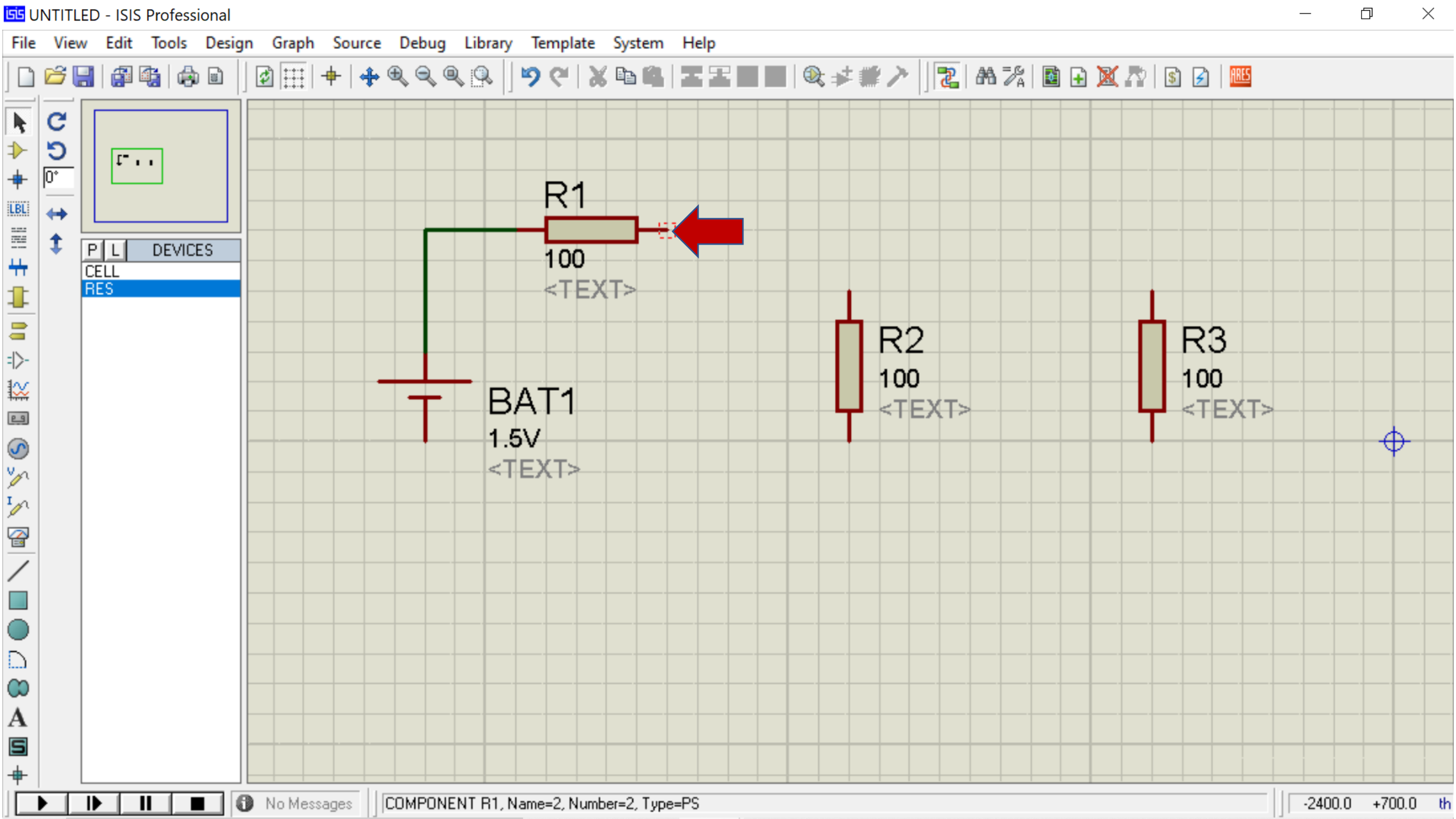
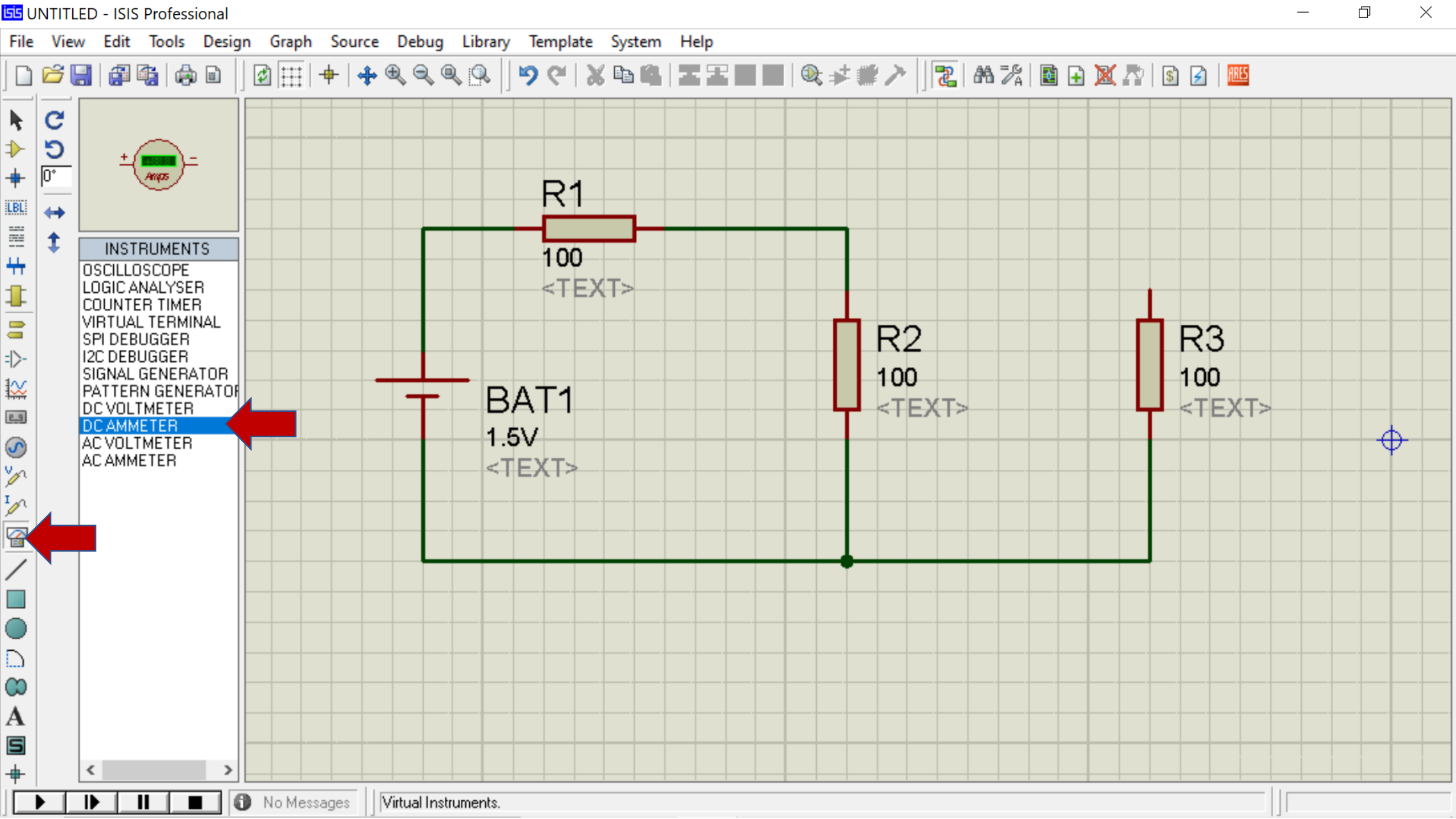
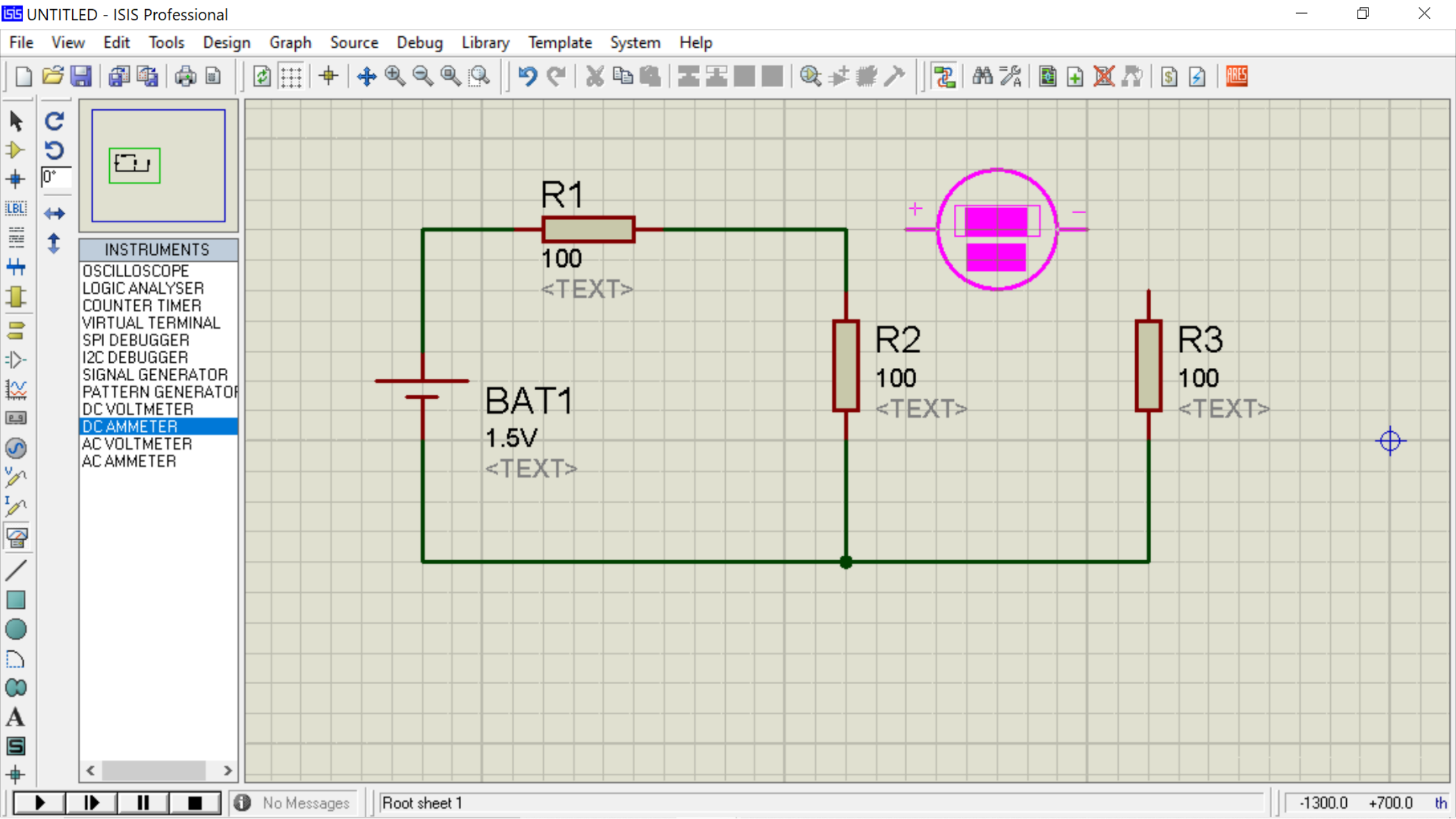
No Messages
Root sheet 1

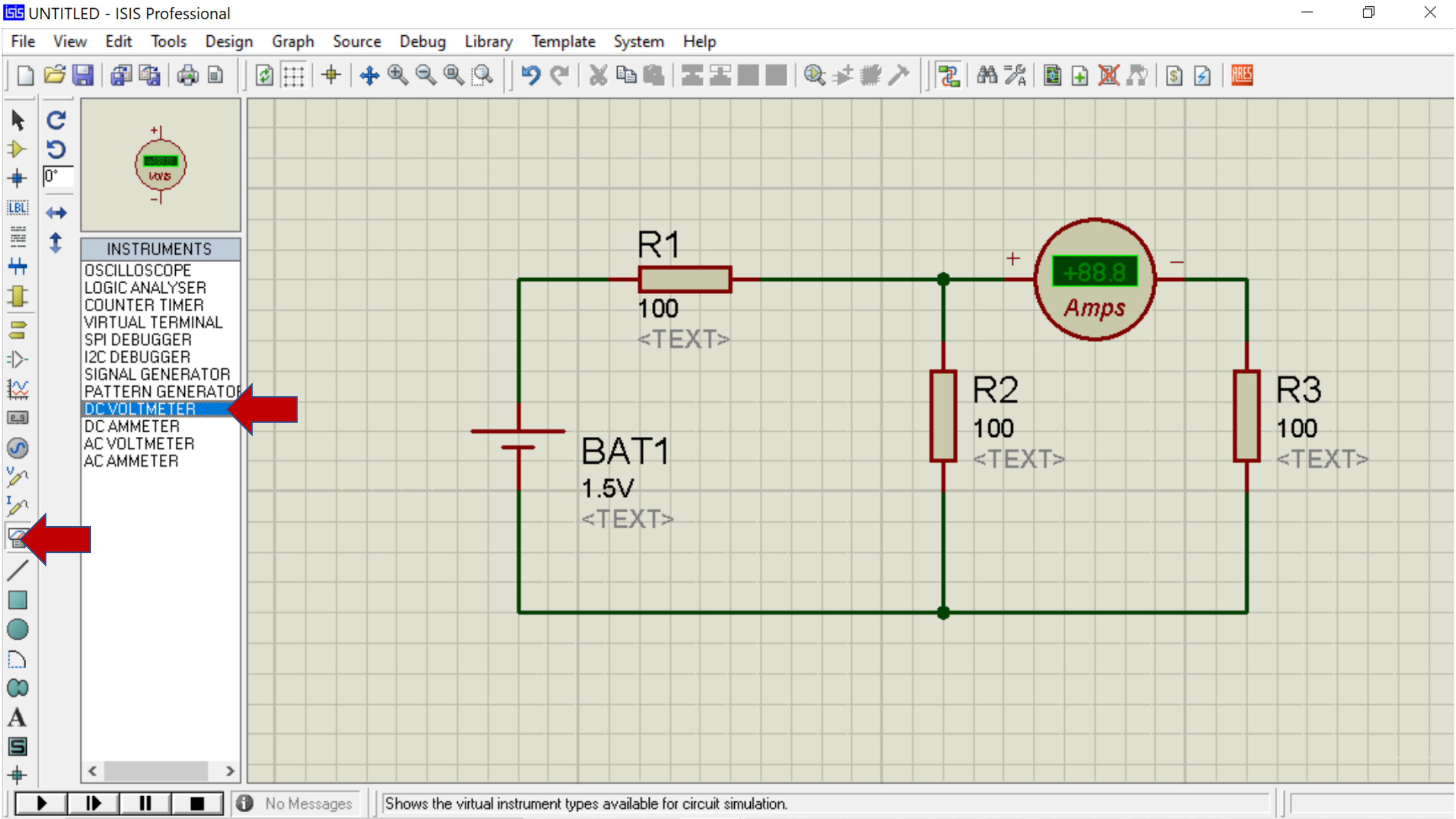

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
0°
P L DEVICES
CELL
RES
R1
100
<TEXT>
BAT1
1.5V
<TEXT>
R2
100
<TEXT>
R3
100
<TEXT>
No Messages
Root sheet 1

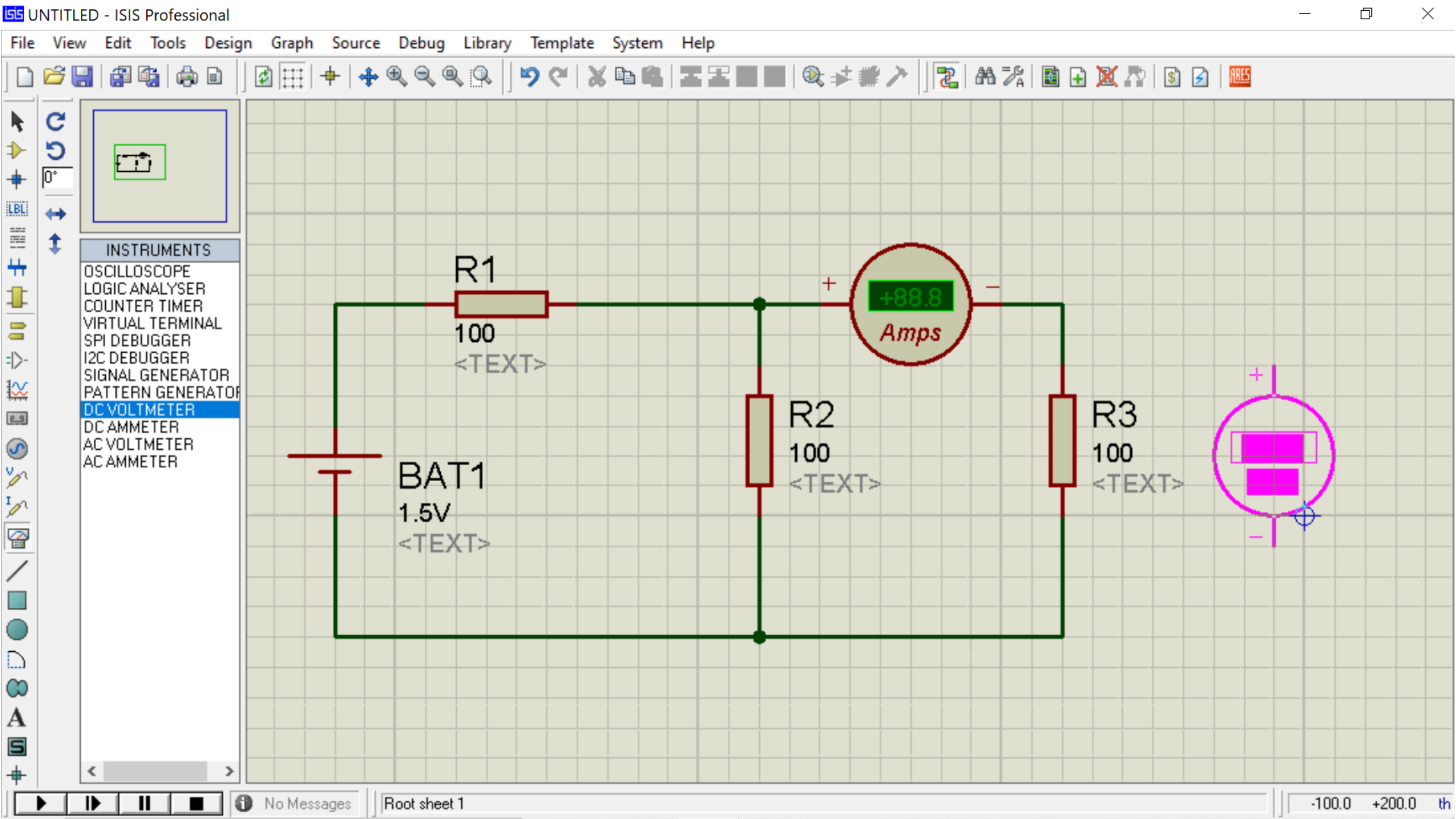

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
0°
P L DEVICES
CELL
RES
R1
100
<TEXT>
BAT1
1.5V
<TEXT>
R2
100
<TEXT>
R3
100
<TEXT>
No Messages
COMPONENT BAT1, Name=+, Number=<NONE>, Type=PS
-3200.0 +300.0

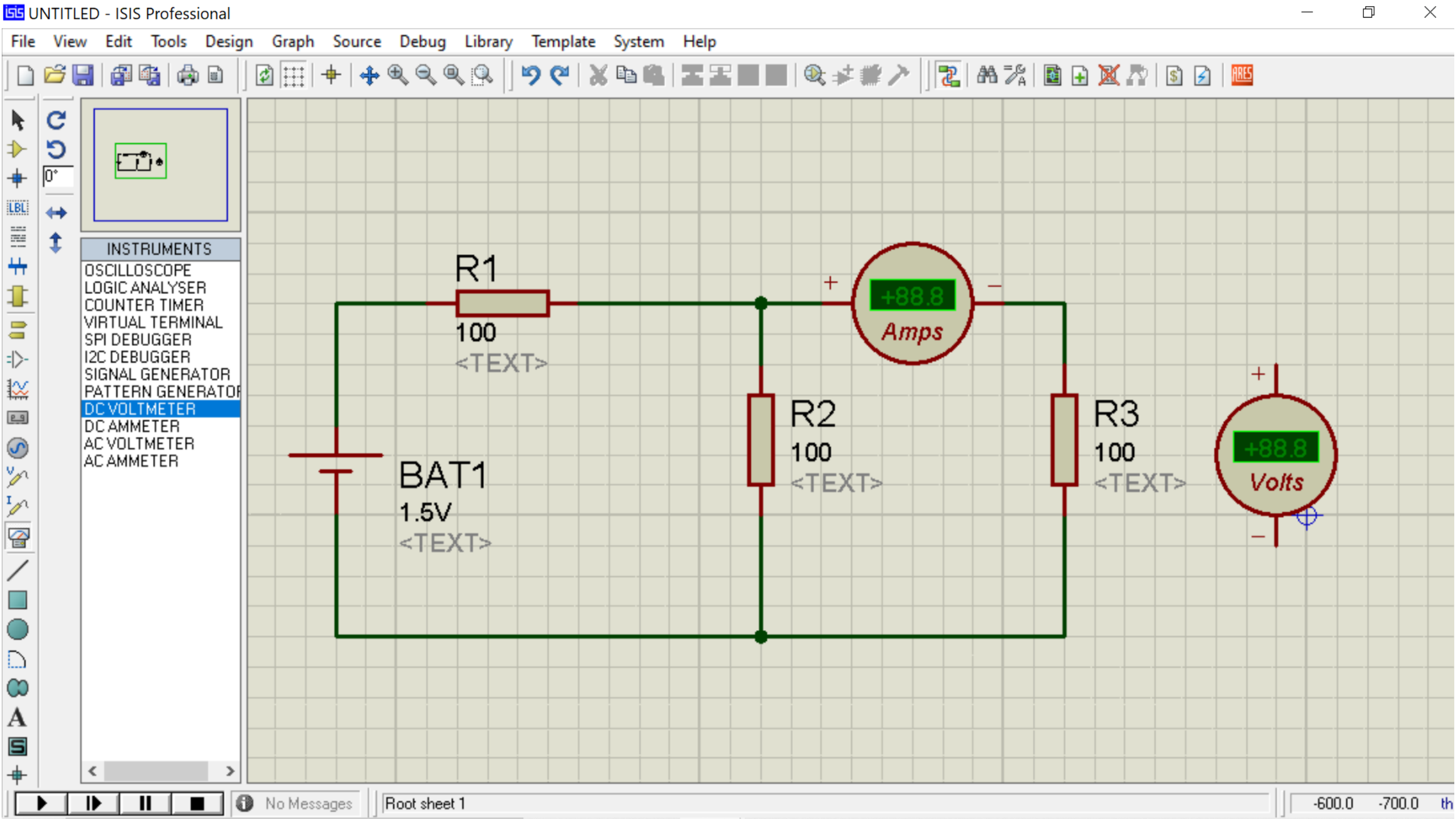

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
P L DEVICES
CELL
RES
R1
100
<TEXT>
BAT1
1.5V
<TEXT>
R2
100
<TEXT>
R3
100
<TEXT>
No Messages
COMPONENT R1, Name=2, Number=2, Type=PS
-2400.0 +700.0

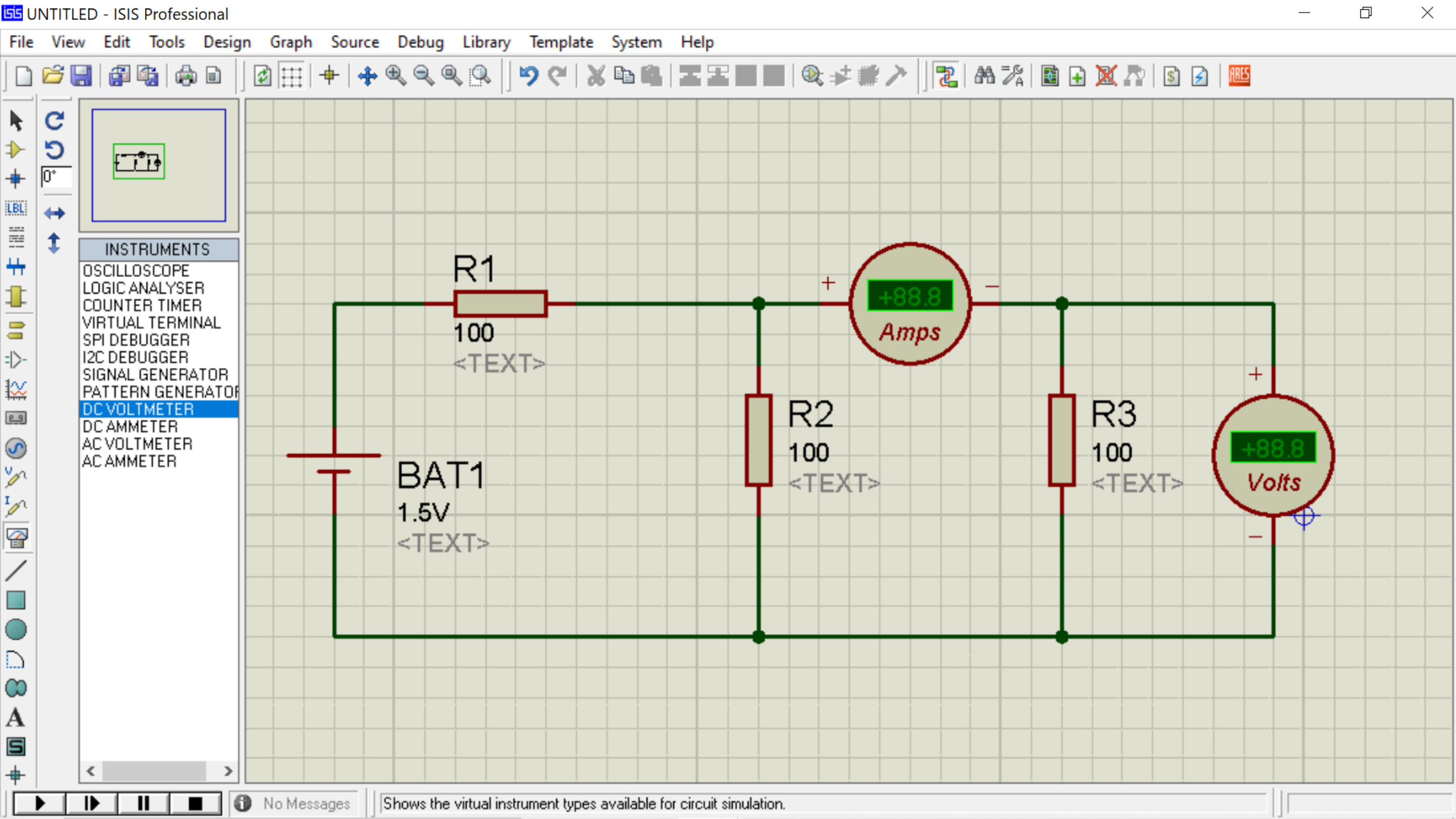

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
100
<TEXT>
R2
100
<TEXT>
R3
100
<TEXT>
BAT1
1.5V
<TEXT>
No Messages
Virtual Instruments.

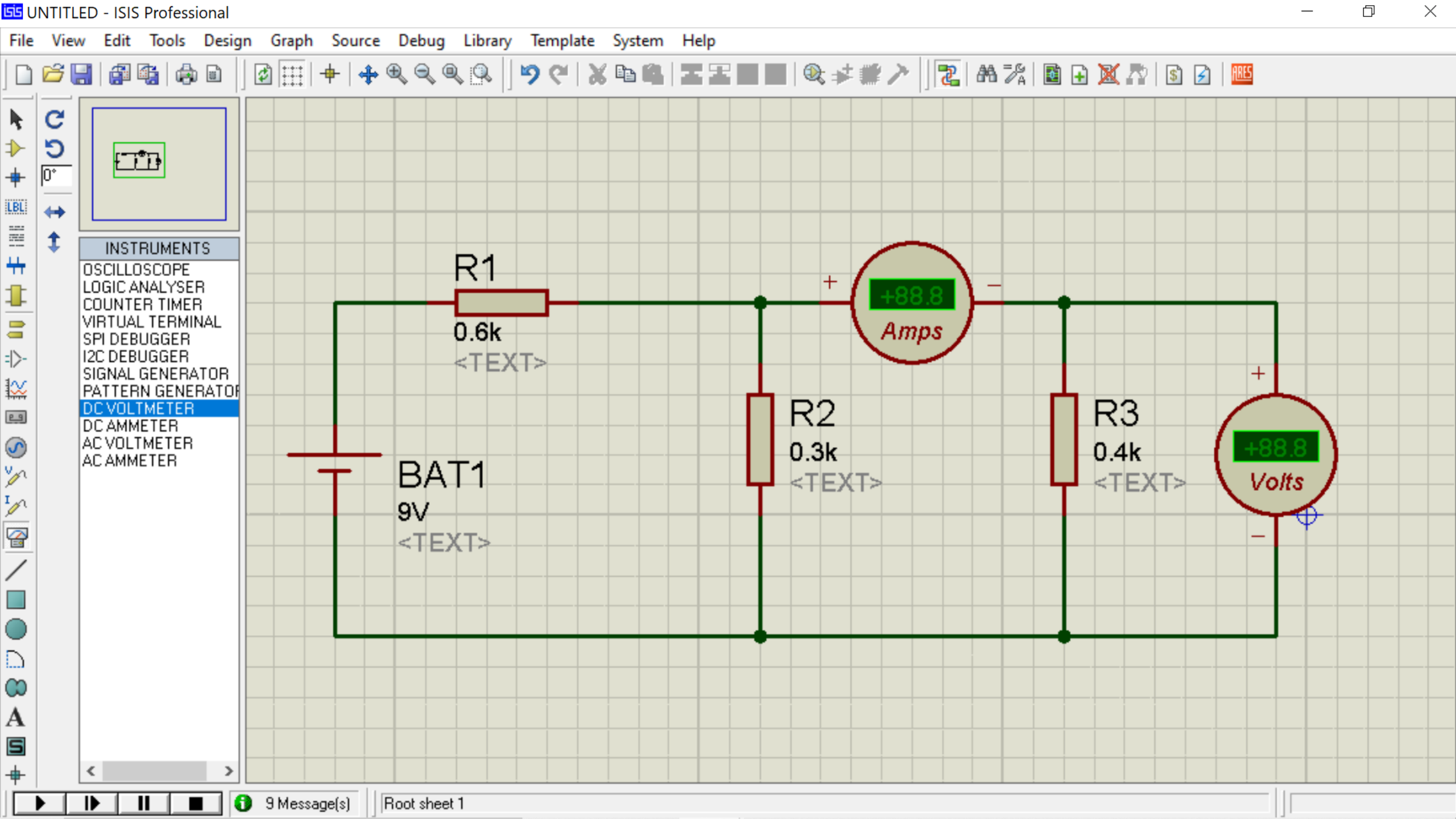

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
100
<TEXT>
R2
100
<TEXT>
R3
100
<TEXT>
BAT1
1.5V
<TEXT>
No Messages
Root sheet 1
-1300.0
+700.0


UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
100
<TEXT>
+88.8
Amps
R2
100
<TEXT>
R3
100
<TEXT>
BAT1
1.5V
<TEXT>
No Messages
Shows the virtual instrument types available for circuit simulation.

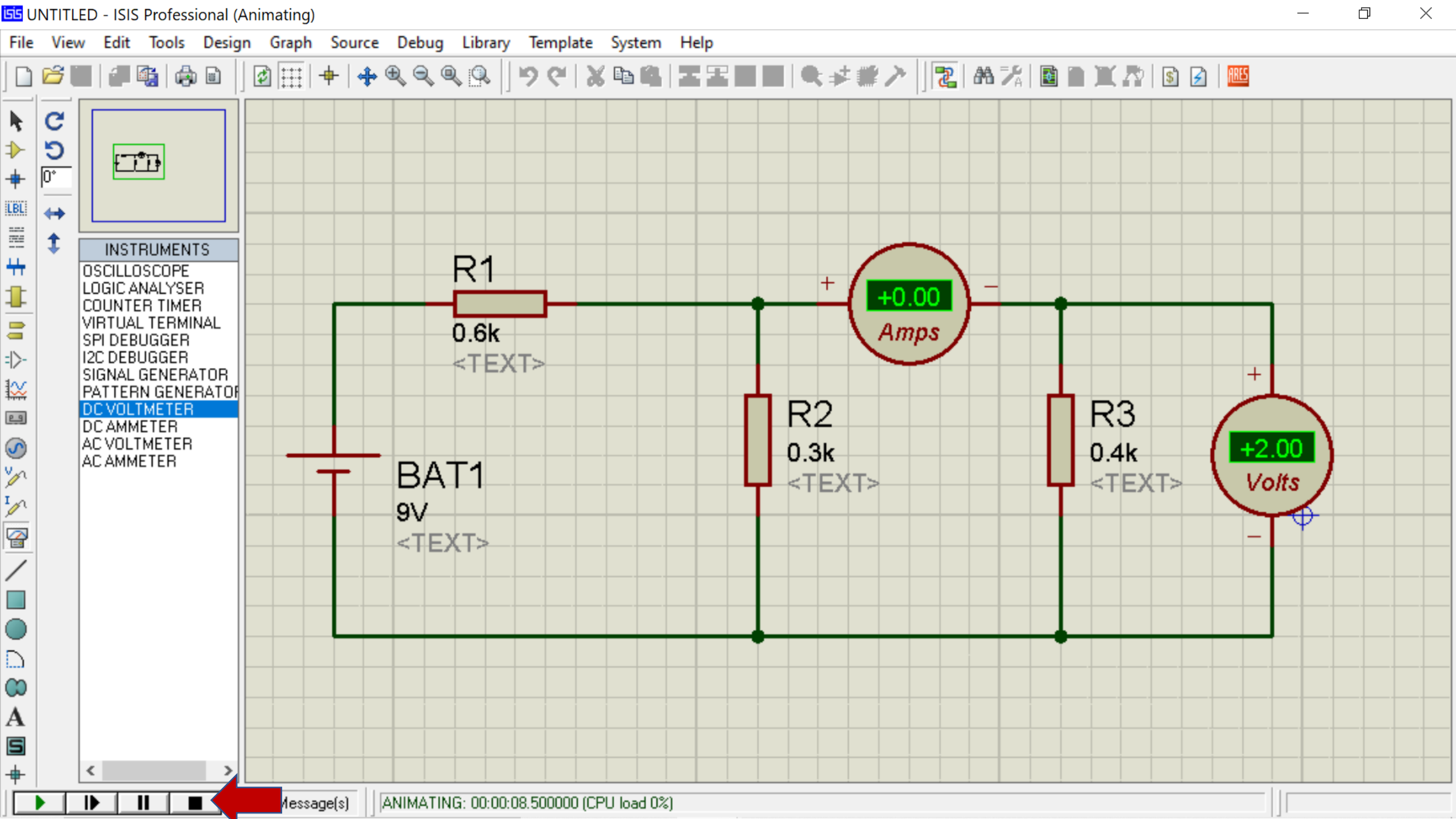

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
100
<TEXT>
+88.8
Amps
R2
100
<TEXT>
R3
100
<TEXT>
BAT1
1.5V
<TEXT>
No Messages
Root sheet 1
-100.0
+200.0

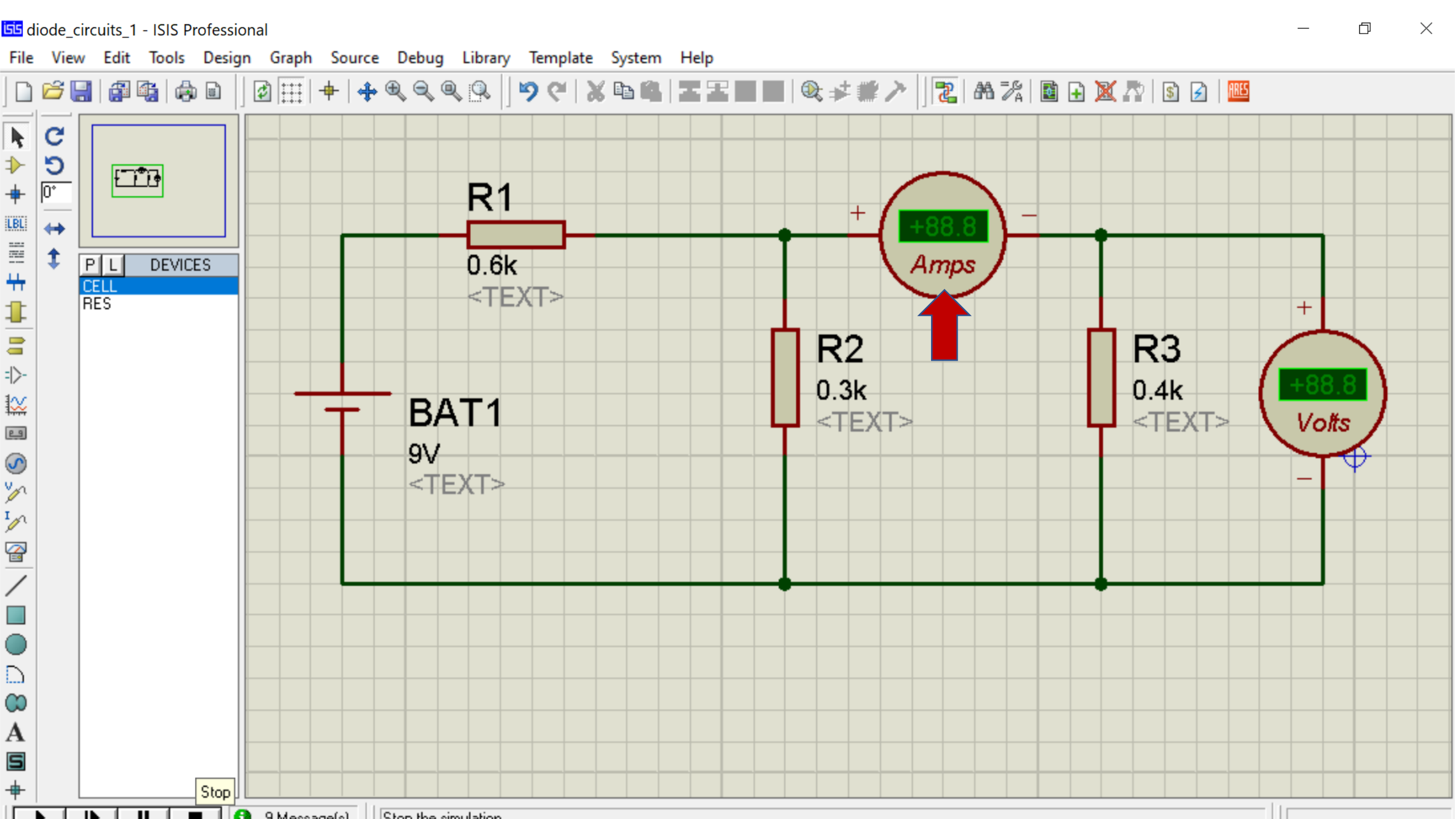

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
100
<TEXT>
+88.8
Amps
R2
100
<TEXT>
R3
100
<TEXT>
BAT1
1.5V
<TEXT>
+88.8
Volts
No Messages
Root sheet 1
-600.0
-700.0

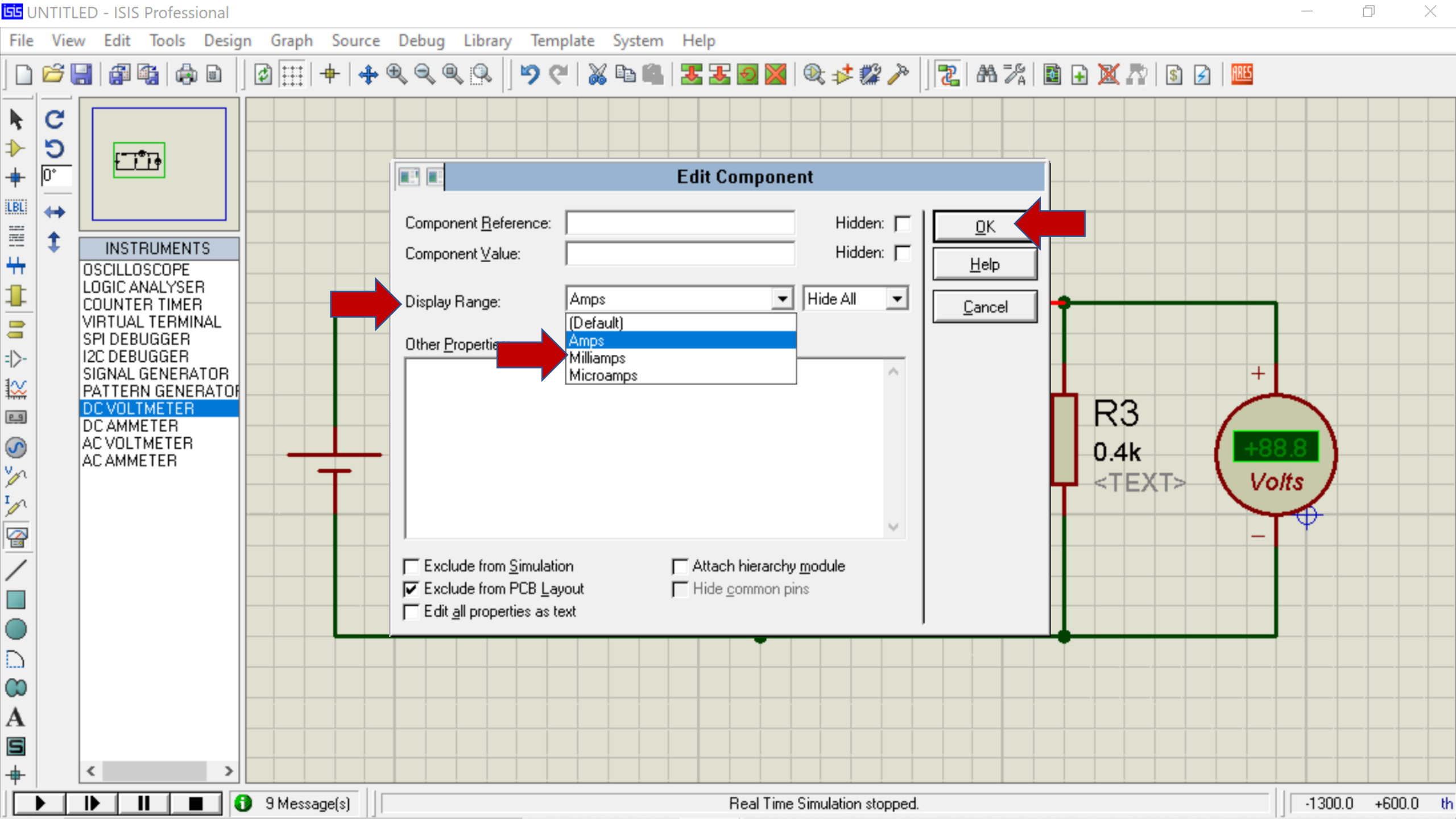

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
100
<TEXT>
+88.8
Amps
R2
100
<TEXT>
R3
100
<TEXT>
+88.8
Volts
BAT1
1.5V
<TEXT>
No Messages
Shows the virtual instrument types available for circuit simulation.

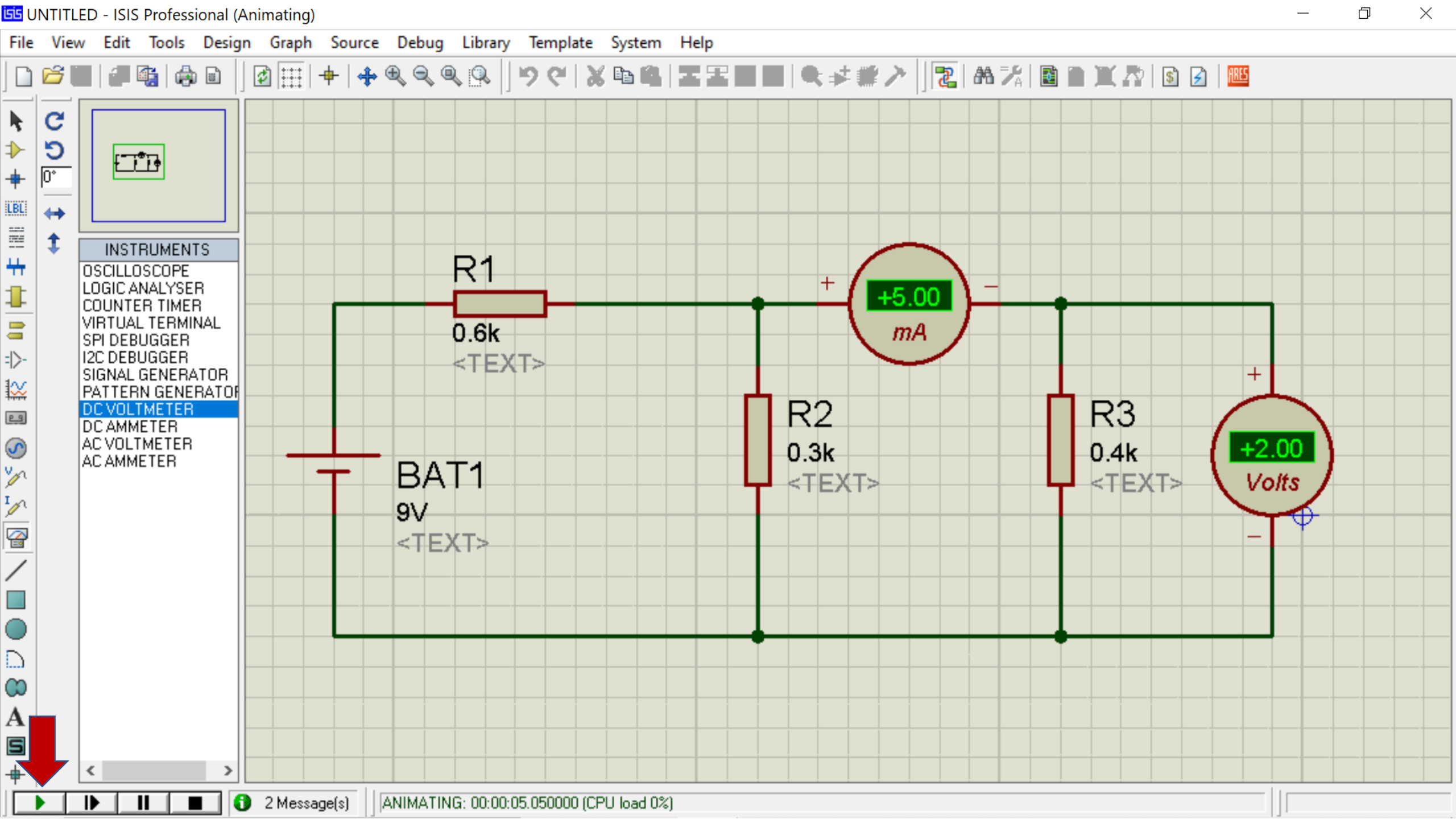

UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
0.6k
<TEXT>
+88.8
Amps
R2
0.3k
<TEXT>
R3
0.4k
<TEXT>
+88.8
Volts
BAT1
9V
<TEXT>
9 Message(s)
Root sheet 1

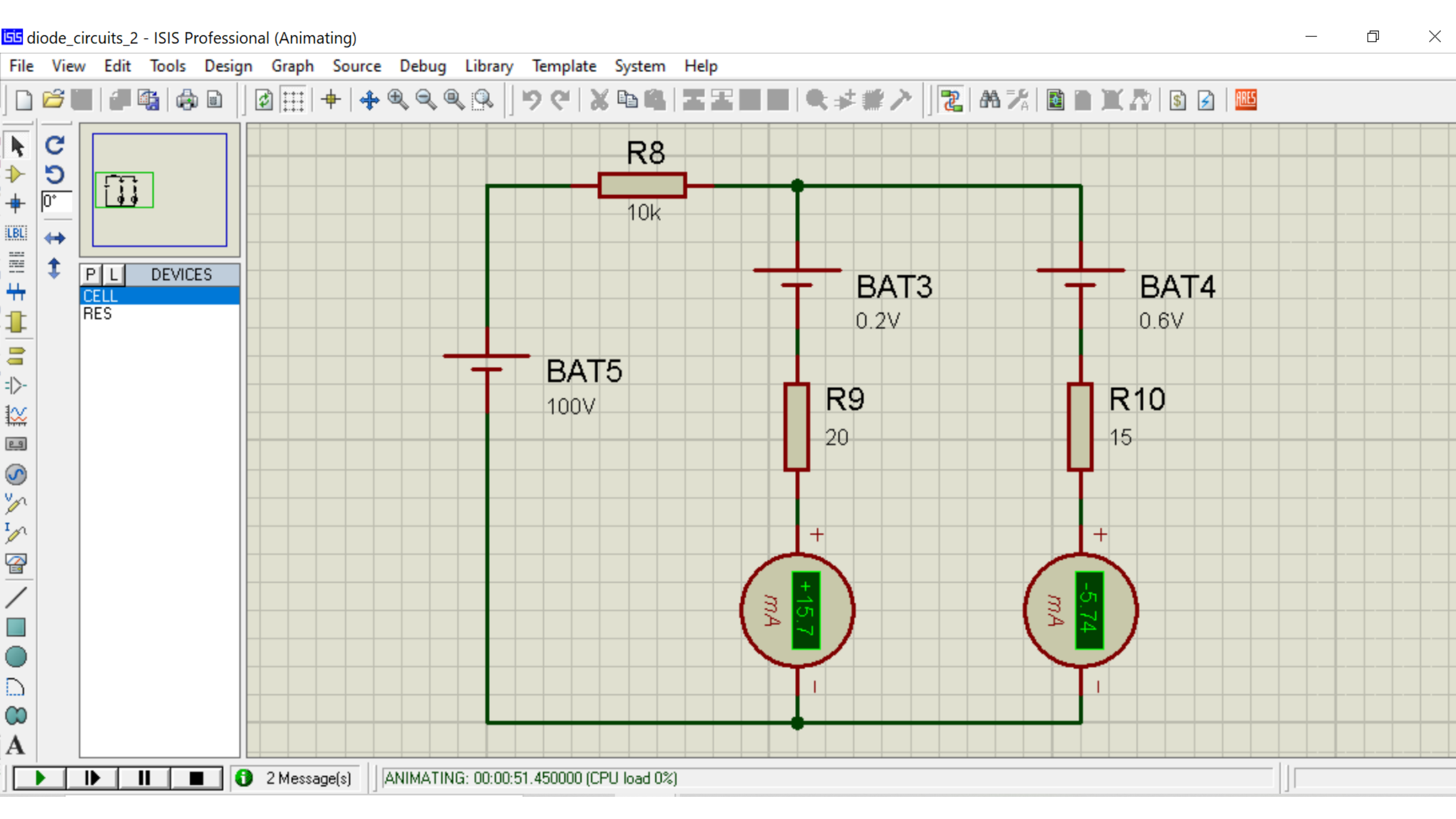
# Run Simulation

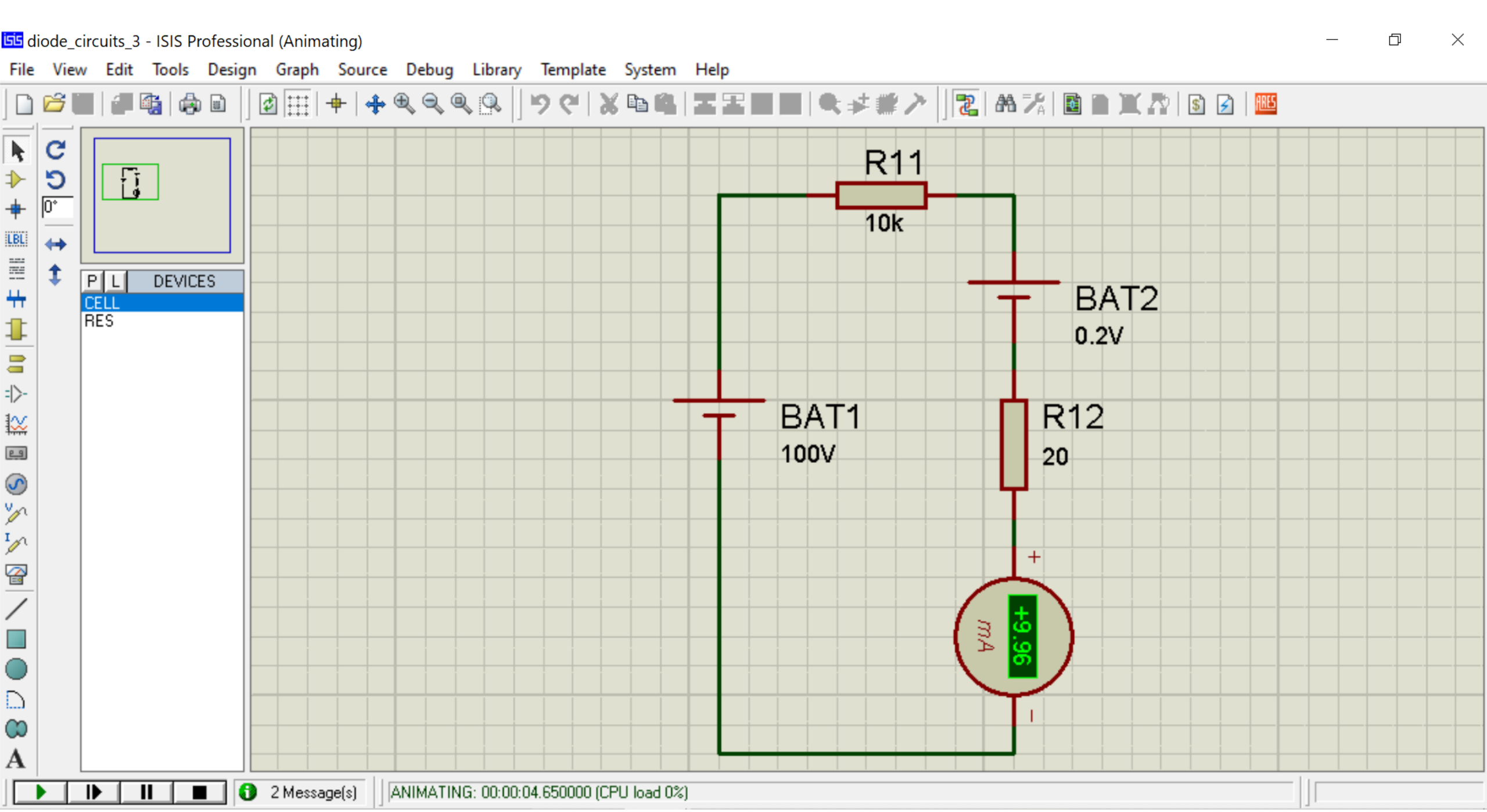

UNTITLED - ISIS Professional (Animating)
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
0.6k
<TEXT>
+0.00
Amps
R2
0.3k
<TEXT>
R3
0.4k
<TEXT>
+2.00
Volts
BAT1
9V
<TEXT>
Message(s)
ANIMATING: 00:00:08.500000 (CPU load 0%)


diode_circuits_1 - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
P L DEVICES
CELL
RES
0°
R1
0.6k
<TEXT>
+88.8
Amps
R2
0.3k
<TEXT>
R3
0.4k
<TEXT>
BAT1
9V
<TEXT>
+88.8
Volts
Stop


UNTITLED - ISIS Professional
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
Edit Component
Component Reference:
Hidden:
Component Value:
Hidden:
Display Range:
Amps
Hide All
(Default)
Amps
Milliamps
Microamps
Other Properties:
Exclude from Simulation
Attach hierarchy module
Exclude from PCB Layout
Hide common pins
Edit all properties as text
OK
Help
Cancel
R3
0.4k
<TEXT>
+88.8
Volts
9 Message(s)
Real Time Simulation stopped.
-1300.0
+600.0


UNTITLED - ISIS Professional (Animating)
File View Edit Tools Design Graph Source Debug Library Template System Help
INSTRUMENTS
OSCILLOSCOPE
LOGIC ANALYSER
COUNTER TIMER
VIRTUAL TERMINAL
SPI DEBUGGER
I2C DEBUGGER
SIGNAL GENERATOR
PATTERN GENERATOR
DC VOLTMETER
DC AMMETER
AC VOLTMETER
AC AMMETER
R1
0.6k
<TEXT>
+5.00
mA
R2
0.3k
<TEXT>
R3
0.4k
<TEXT>
+2.00
Volts
BAT1
9V
<TEXT>
2 Message(s)
ANIMATING: 00:00:05.050000 (CPU load 0%)


diode_circuits_2 - ISIS Professional (Animating)
File View Edit Tools Design Graph Source Debug Library Template System Help
P L DEVICES
CELL
RES
R8
10k
BAT3
0.2V
BAT4
0.6V
BAT5
100V
R9
20
R10
15
+15.7
mA
-5.74
mA
2 Message(s)
ANIMATING: 00:00:51.450000 (CPU load 0%)


diode_circuits_3 - ISIS Professional (Animating)
File View Edit Tools Design Graph Source Debug Library Template System Help
P L DEVICES
CELL
RES
R11
10k
BAT2
0.2V
BAT1
100V
R12
20
+
9.96
mA
-
2 Message(s)
ANIMATING: 00:00:04.650000 (CPU load 0%)