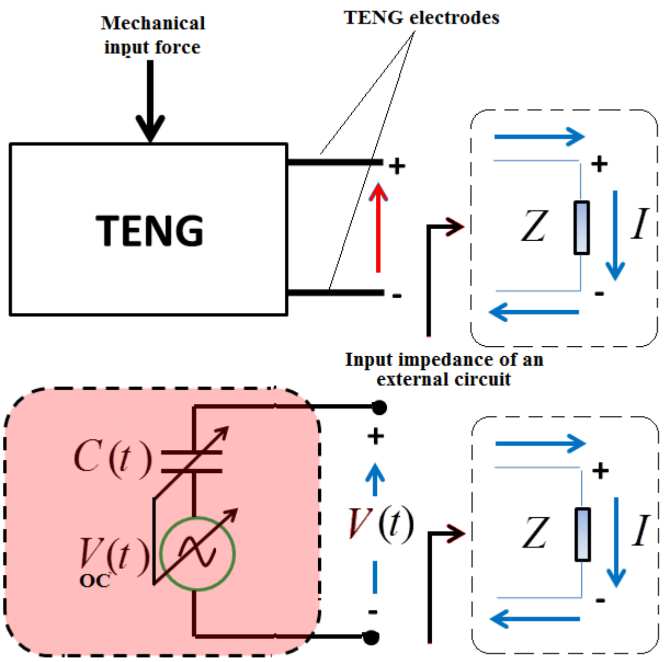
Verilog-A Triboelectric Nanogenerators

User's Manual



Zaky, A., M. Shehata, Y. Ismail, and H. Mostafa, "Characterization and Model Validation of Triboelectric Nanogenerators using Verilog-A", IEEE International Midwest Symposium on Circuits and Systems (MWSCAS 2017), Boston, MA, USA, pp. 1536-1539, 2017.

EN

Table of contents

1.0 GENERAL INFORMATION

Model developer: Ahmed Salah Zaky S-ahmed.zaky@Zewailcity.edu.eg
Intern mentor: Mohamed Shehata m.shehata_ieee@yahoo.com
Supervisor: Dr. Hassan Mostafa hmostafa@uwaterloo.ca

2.0 MODEL SUMMARY

2.1 System Configuration

This model code can be used immediately without any further configuration on cadence just follow "how to use this model "section.

2.2 User Access Levels

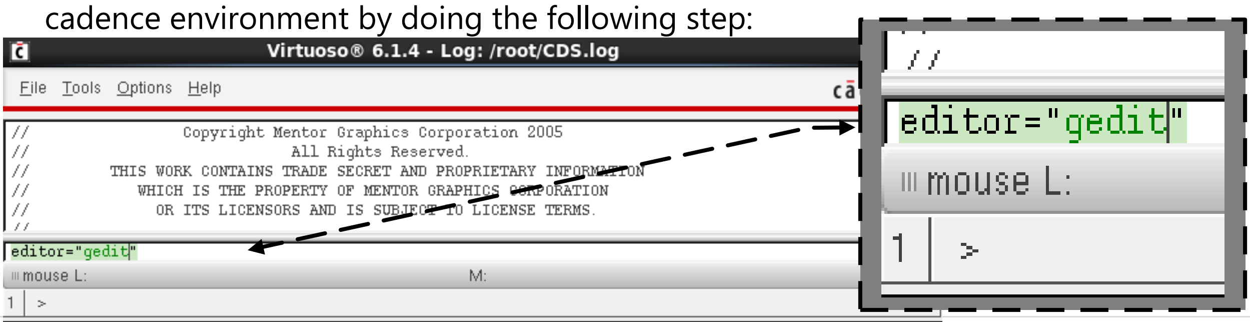
The user of this model can use it without any license but the model is in reference with the following publication, So kindly cite the paper when using this model:

- **Zaky, A., M. Shehata, Y. Ismail, and H. Mostafa, "Characterization and Model Validation of Triboelectric Nanogenerators using Verilog-A", IEEE International Midwest Symposium on Circuits and Systems (MWSCAS 2017), Boston, MA, USA, pp. 1536-1539, 2017.**

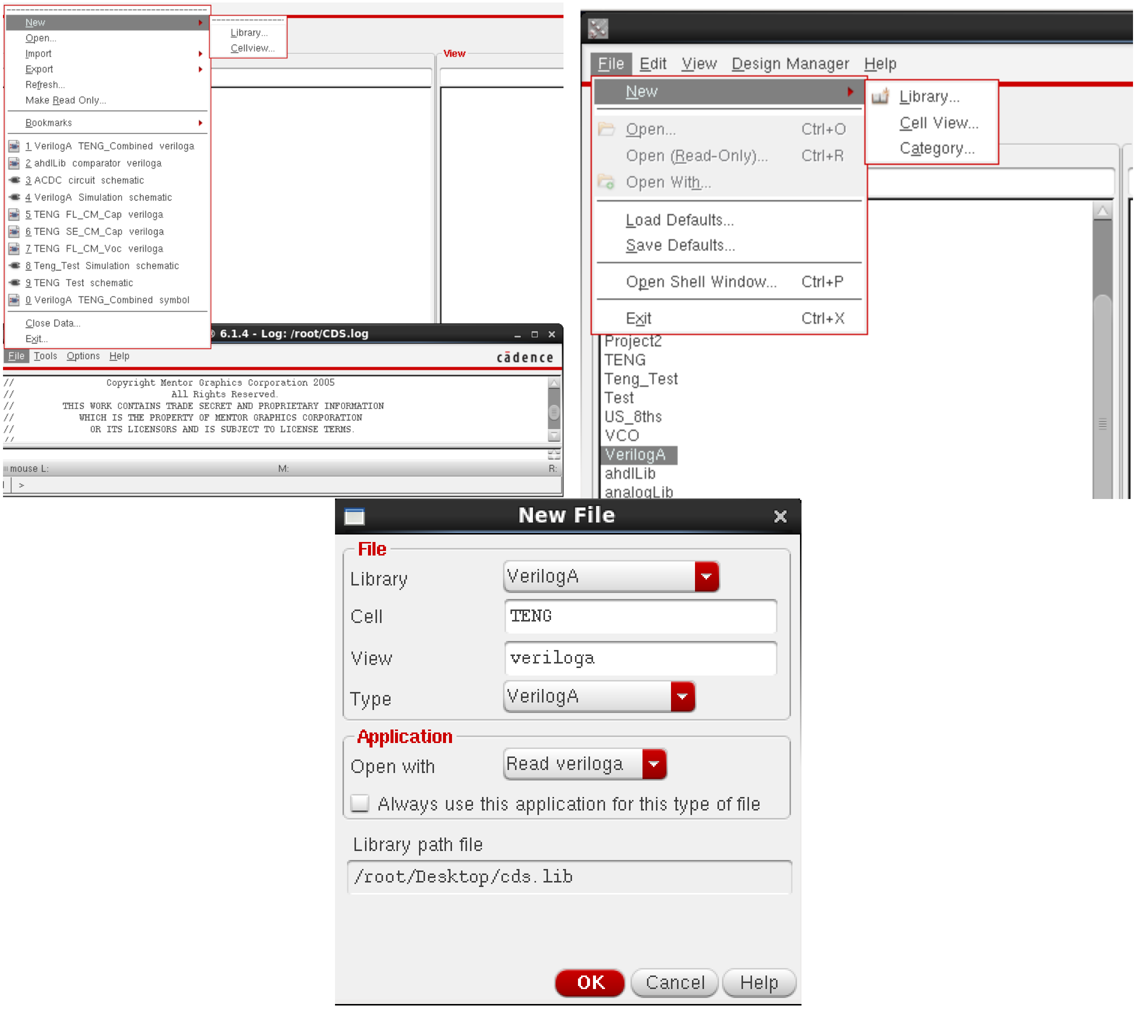
3.0 USING THE MODEL

3.1 HOW TO USE THIS MODEL

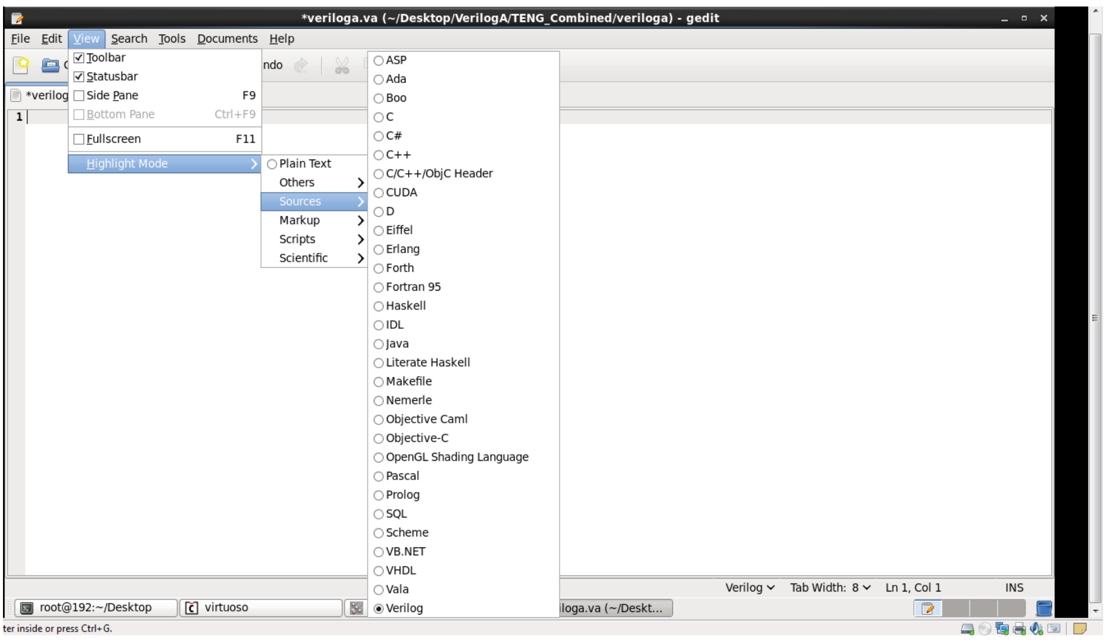
1. Open **Cadence virtuoso** software.
2. In order to write any Verilog-A model in cadence you need to define the editor first in cadence environment by doing the following step:



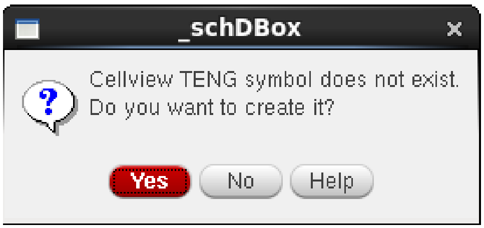
3. To create a Verilog-A model: Create new library “e.g. Verilog A” → Create a new cell “TENG”, in the type select Verilog A



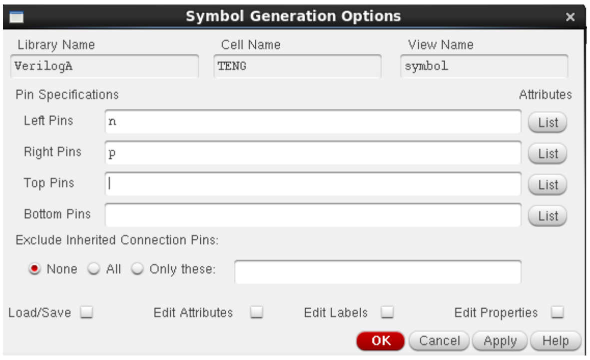
4. Double click on ‘Verilog A’ in the view section it will open the editor for you and do as the figure.

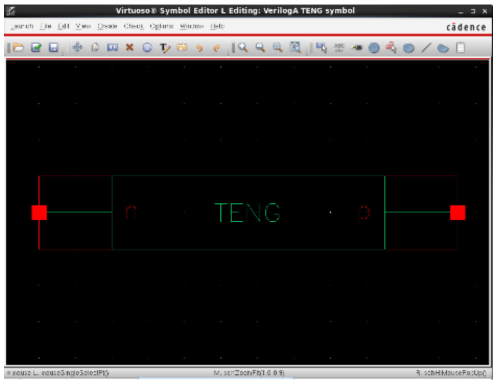


5. Open the downloaded model file “TENG. va”, copy and paste in the project you have just created.
6. Save and exit → in case of no errors it will show up this message

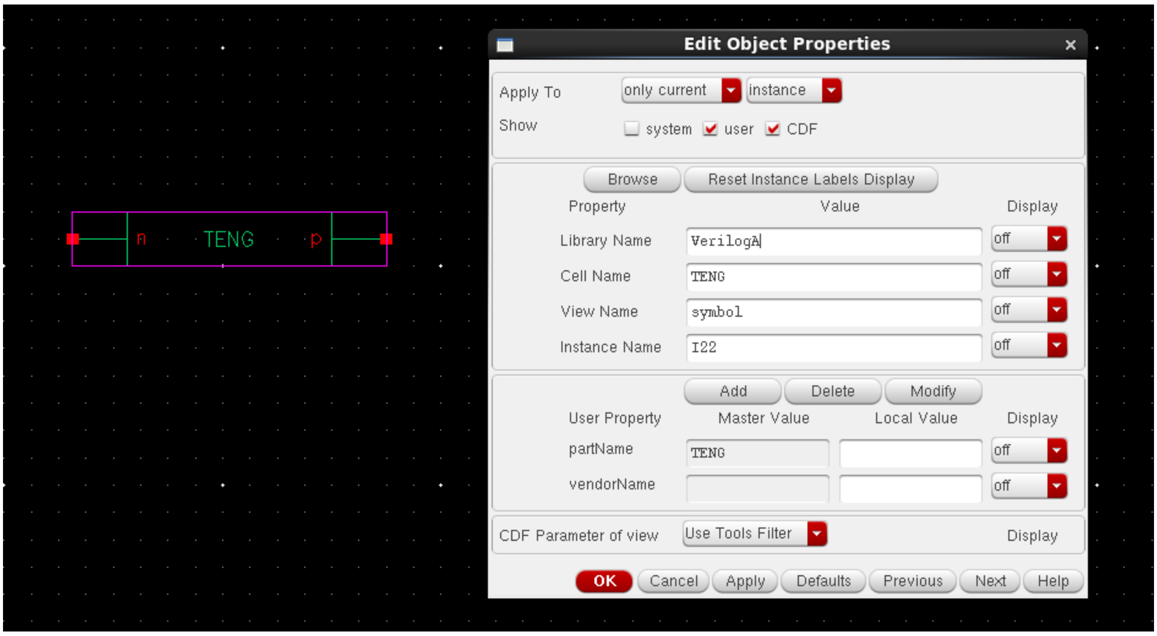


7. Choose **yes** to create your cell view → Click **ok** to continue → edit words if needed save and you are ready to go!





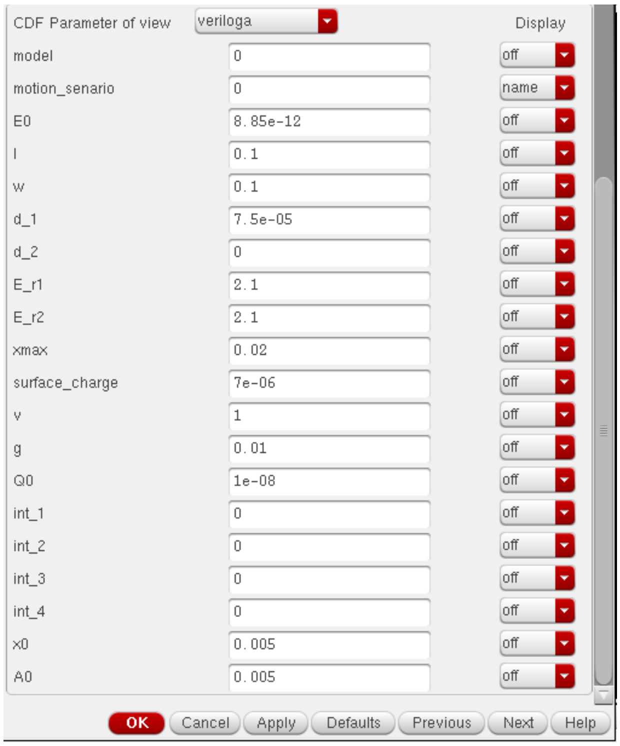
8. The following steps is done assuming that you know how to use Cadence virtuoso, however if you faced any problems or you need any assist contact **Ahmed Zaky** directly.
9. You can now insert the TENG in any schematic as a regular element from any other library such as res from analogLib.
10. Let’s explore different parameters in the model, create new schematic → insert the TENG cell-view → click on the instance and press Q this box will show up:



11. The last option called :

CDF parameter view → choose VerilogA it will gives you the following options:

We have the most important two parameters:



Model which defines the TENG model

0. Attached Electrode Contact Mode (AE-CM)
1. Attached Electrode Sliding Mode (AE-SM)
2. Single Electrode Contact Mode (SE-CM)
3. Freestanding layer Contact Mode (FL-CM)
4. Any other geometrical structure,

> If you created your own mode you can easily add it to the model!

Motion scenario Which defines the type of motion/ mechanical force applied to the TENG.

0. Linear Motion.
1. Simple harmonic Motion.
2. Any other type of motion.

> You can test applying step input, pulses… etc. by changing only one line of code!

3.2 Example

Freestanding layer in contact mode, in reference with:

"S. Niu, Y. Liu, X. Chen, S. Wang, Y. Zhou, L. Lin, Y. Xie and Z. Wang, "Theory of freestanding triboelectric-layer-based nanogenerators", Nano Energy, vol. 12, pp. 760-774, 2015."

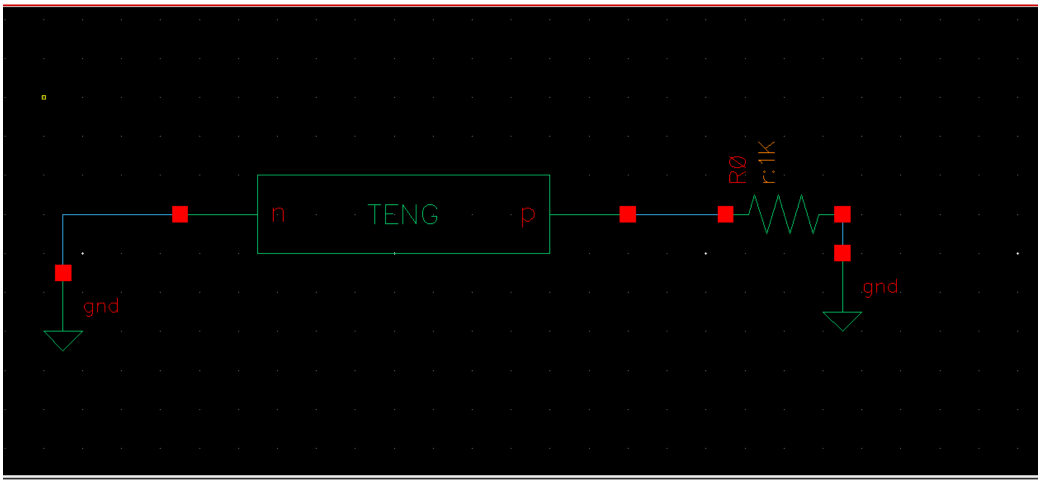
Here are the steps:

> In pg.5 you find the table of parameters to use

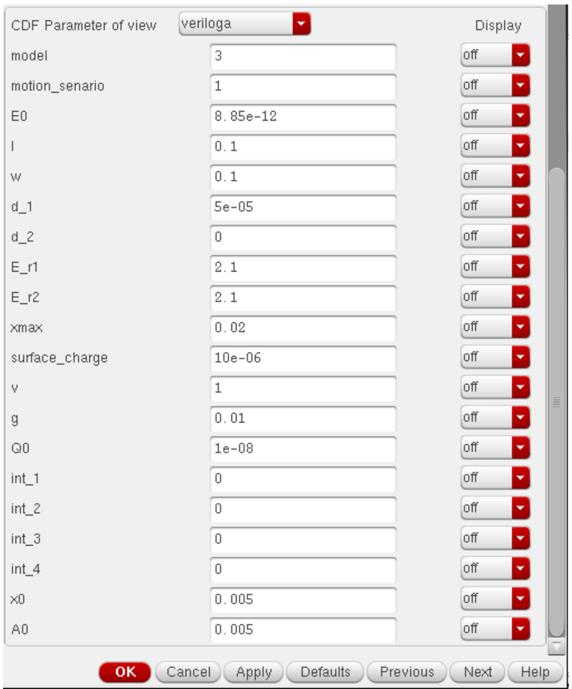
Table 1 Parameter utilized in the output characteristic calculation of CFTENGs.

Structure component	Parameter utilized
Dielectric 1	$d_1 = 50\ \mu m$, $\varepsilon_{r1} = 2.1$
Area size of the dielectrics S	100 cm^2
Air gap distance g	1 cm
Tribo-charge surface density σ	10 $\mu C\ m^{-2}$
Vibration angular frequency ω	$4\pi\ s^{-1}$
Vibration amplitude A_0	5 mm
Vibration central position x_0	5 mm

1- Create a schematic cell view → insert your TENG model + simple resistor

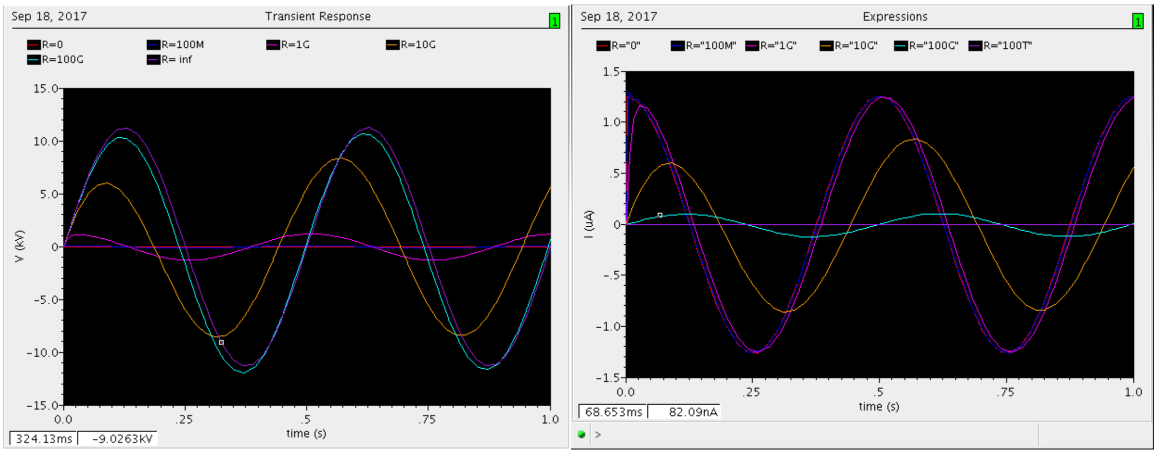


2- Select the TENG model and press Q to edit parameters of the model: insert the parameters as shown in the table from the reference. - Model = 3 for FL-CM, Motion_senario= 1 for simple harmonic motion.

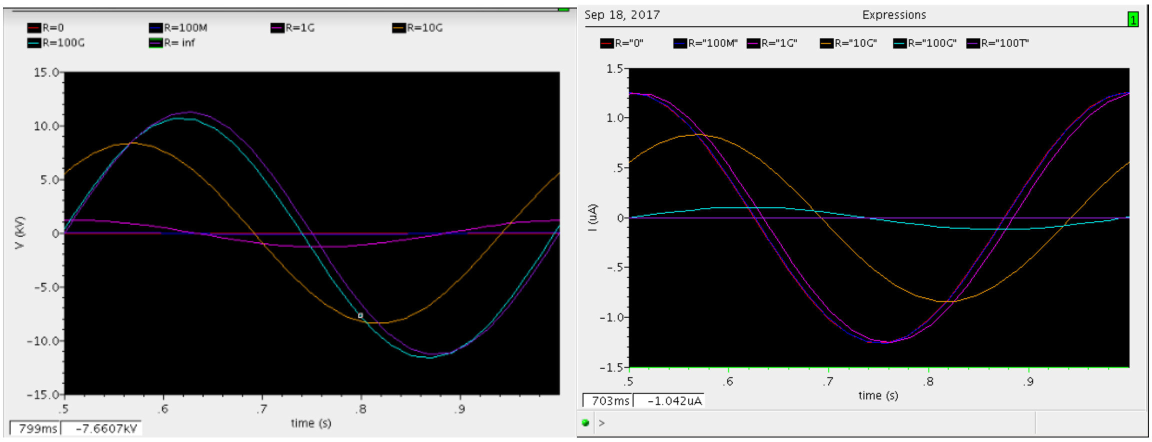


3- Start simulating the circuit by making parametric analysis for different R values → the 1st graph shows the results of two successive cycles, the 2nd one with the 1st cycle truncated to eliminate the transient effects and the results gives exactly the same as reference.

1



2



When using any model you need to delete its int_x and let the others as it is.

```
////////////////////// Freestanding Layer Contact Mode ///////////////
if (model==3) begin  // Begin FL-CM
if (motion_senario==0) begin // Begin Linear Motion
x = v*$abstime;
end // End Linear motion
if (motion_senario==1) begin // Begin Simple harmonic Motion
ang_vel = 4*`M_PI;
x=x0+A0*sin(ang_vel*$abstime);
$bound_step(ang_vel/10);
end // End Simple Harmonic Motion
c= (E0*s)/(d0+g);
output_volt= (2*surface_charge*x)/(E0);
V(p,n) <+ output_volt ;
V(p,n) <+ idt(I(p,n),int_4)/c;
```

DELETE “, int_4”

```
idt(I(p,n),int_4)/c;
```

MODEL CODE

```
//////////////////////////////////////////////////
// VerilogA model for Triboelectric Nanogenerators (TENGs)
//
// s-ahmed.zaky@zewailcity.edu.eg
// m.shehata_ieee@yahoo.com
// hmostafa@uwaterloo.ca
//
// The University of Science and Tecnology at Zewailcity
// Cairo University
// EE Dept. Sept 2017
//
//////////////////////////////////////////////////

`include "constants.vams"
`include "disciplines.vams"

// define meter units for geometrical dimensions

nature distance
  access = Metr;
  units = "m";
  abstol = 10p;
endnature


module TENG(p,n);
inout p,n;
electrical p,n;

parameter real model = 0;
// define the model:
// 0 - Attached Electrode Contact Mode (AE-CM)
// 1 - Attached Electrode Sliding Mode (AE-SM)
// 2 - Single Electrode Contact Mode (SE-CM)
// 3 - Single Electrode Sliding Mode (SE-SM)
// 4 - Freestanding layer Contact Mode (FL-CM)
// 5 - Freestanding layer Contact Mode (FL-CM)
// 6 - Any other geometrical strucuture.

   parameter real motion_senario=0;
// define the type of motion (Mechanical force):
// 0 - Linear Motion;
// 1 - Simple harmonic Motion;
// 2 - Step Input;
// 3 - Pulse Input;
// 4 - any other type of motion.


 //Global parameters definitions and default values

parameter real E0 = 8.85p from (0:inf) ;            // Air permitivity
parameter real l= 100m from (0:inf);                // length of the device
parameter real w= 100m from (0:inf);                // Width of the device
parameter real d_1= 75u from (0:inf);               // Thickness of the First
Dielectric
parameter real d_2 = 0  from (-inf:inf);            // Thickness of the Second
Dielectric
parameter real E_r1 = 2.1 from (0:inf);             // Relative Permitivity of the
first dielectric
parameter real E_r2 = 2.1 from (0:inf);             // Relative Permitivity of the
second dielectric
```

```
parameter real xmax= 20m from (0:inf);             // Maximum separation distance
between the two plates
parameter real surface_charge = 7u from (0:inf);   // Definign the tribocharge
density
parameter real v= 1 from (0:inf);            // The motion velocity
parameter real g = 10m from (0:inf);               // The Gap distance between the
two plates in certain modes.
parameter real Q0 = 10n from (-inf:inf);           // Intiail Charge on the
capacitor
parameter real int_1 = 0 from (-inf:inf);                // Initial Condition in
AE-CM
parameter real int_2 = 0 from (-inf:inf);                // Initial Condition in
AE-SM
parameter real int_3 = 0 from (-inf:inf);                // Initial Condition in
SE-CM
parameter real int_4 = 0 from (-inf:inf);                // Initial Condition in
FL-CM


// Parameters used for Simple harmonic Motion

parameter real x0 = 5m from (0:inf) ;              // Vibrational centeral
position
parameter real A0 = 5m from (0:inf) ;              // Vibration Amplitude


// Global Variables
real x;                                      // X--> is the equation of motion,
$abstime is the simulation time in transient analysis.
real d0;                                // d0 is the eefecticve dielectric
constant.
real s;                                      // S is the effective surface area of
the device.
real c;                                      // Is the inheritance capacitance of
TENG. This relation is unique for every mode and can be got by electrodynamics.
real output_volt;                       // The output voltage of TENG, again the
relation is unique and can be found only by solving the electrodynamics of the
problem.
real ang_vel;                                // is the Angular frequency of the
simple harmonic motion.
real const;                             // Single Electrode longe dominator
real int_charge  ;                           // Single Electrode Initial charge on
Cap

/////////////////// MAIN ///////////////////////

analog begin

// calculating fixed variables

d0= (d_1/E_r1)+(d_2/E_r2);

s = w*l;

////////////////////// Attached Electrode Contact Mode ///////////////


if (model==0) begin  // Begin AE-CM

if (motion_senario==0) begin // Begin Linear Motion

x = v*$abstime;
```

```
end // End Linear Motion

if (motion_senario==1) begin  // Begin Simple harmonic motion

ang_vel = 4*`M_PI;

x=(xmax/2)*(1-cos(`M_PI*v*$abstime/xmax));

end   // End Simple Harmonic Motion

c= (E0*s)/(d0+x);

output_volt= (surface_charge*x)/(E0);

if (analysis("ic"))
V(p,n) <+ Q0*c;
else

V(p,n) <+ idt(I(p,n),int_1)/c;          // Voltage due to the inhertenc
capacitence.

V(p,n) <+ output_volt ;            // Voltage due to the potential difference
between the two electrodes.

// The output voltage of the TENG is considered to be a superposition of the two
voltages.

end // AE-CM

/////////////////// Attached Electrode Sliding Mode ///////////////

if (model==1) begin // Begin AE-SM

if (motion_senario==0) begin // Begin Linear Motion

x = v*$abstime;

end // End Linear Motion


if (motion_senario==1) begin // Begin Simple harmonic Motion

ang_vel = 4*`M_PI;

x=x0+A0*sin(ang_vel*$abstime);

end // End simple harmonic motion

c= (E0*w*(l-x))/(d0);

output_volt= (surface_charge*x*d0)/(E0*(l-x));

V(p,n) <+ idt(I(p,n),int_2)/c;

V(p,n) <+ output_volt ;

end // End AE-SM

//////////////////// Single Electrode Contact Mode ///////////////

if (model==2) begin // Begin SE-CM

if (motion_senario==0) begin // Begin Linear Motion
```

```
x = v*$abstime;

end // End Linear Motion



if (motion_senario==1) begin // Begin Simple harmonic Motion

ang_vel = 4*`M_PI;

x=x0+A0*sin(ang_vel*$abstime);

end // End simple harmonic motion

const = ((x+g)*(E0*s*E_r1)*(1/(x*(x+g))+1/(g*(x+g))+1/(g*x)));

c= (E0*w*(l-x))/(d0);

output_volt= 2*surface_charge*s/const;

int_charge=surface_charge*s;
c = ((E0*s)/g);
if (analysis("ic"))
V(p,n) <+ Q0*c;
else
V(p,n) <+ idt(I(p,n),int_3)/c;

V(p,n) <+ output_volt ;

end // End SE-CM

////////////////////// Freestanding Layer Contact Mode ///////////////


if (model==3) begin  // Begin FL-CM

if (motion_senario==0) begin // Begin Linear Motion

x = v*$abstime;

end // End Linear motion

if (motion_senario==1) begin // Begin Simple harmonic Motion

ang_vel = 4*`M_PI;

x=x0+A0*sin(ang_vel*$abstime);

$bound_step(ang_vel/10);
end // End Simple Harmonic Motion

c= (E0*s)/(d0+g);

output_volt= (2*surface_charge*x)/(E0);

V(p,n) <+ output_volt ;

V(p,n) <+ idt(I(p,n))/c;

end // End FL-CM
end // end Analog
endmodule
```