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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.



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1.0 GENERAL INFORMATION

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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 ei	nvironment by doing the following ste	ep:	
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Page		USER MANUA	L

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

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ACDC circuit schematic				🛛 🕞 Open Wit <u>h</u>			
4 VerilogA Simulation schematic							
5 TENG FL_CM_Cap veriloga				Load Defaults			
6 TENG SE_CM_Cap veriloga				Source Defaulte			
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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 \rightarrow in case of no errors it will show up this message



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

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Library Name		Cell Name		View N	lame	
VerilogA		TENG		symbol	-	
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Right Pins	P				List	
Top Pins	1				List	
Bottom Pins					List	
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Load/Save 🗌	Edit Attrib	utes 📃	Edit Labels		Edit Properties 📃	
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- **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 \rightarrow insert the TENG cellview \rightarrow click on the instance and press Q this box will show up:

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11. The last option called :

CDF parameter view \rightarrow 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!

CDF Parameter of view	veriloga 🧧	Display
model	0	off 🔽
motion_senario	0	name 🔽
EO	8.85e-12	off 🔽
1	0.1	off 🔽
W	0.1	off 🔽
d_1	7.5e-05	off 🔽
d_2	0	off 🔽
E_r1	2.1	off 🔽
E_r2	2.1	off 🔽
×ma×	0.02	off 🔽
surface_charge	7e-06	off 🔽
V	1	off 🔽
g	0.01	off 🧧
Q0	1e-08	off 🧧
int_1	0	off 🔽
int_2	0	off 🔽
int_3	0	off 🔽
int_4	0	off 🔽
×0	0.005	off 🔽
A0	0.005	off 🔽

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

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

 Table 1
 Parameter utilized in the output characteristic

calculation of CFTENGs.

1- Create a schematic cell view \rightarrow 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.

CDF Parameter of view	veriloga 🧧	Display
model	3	off 🔽
motion_senario	1	off 🔽
E0	8.85e-12	off 🔽
1	0.1	off 🔽
W	0.1	off 🔽
d_1	5e-05	off 🧧
d_2	0	off 🔽
E_r1	2.1	off 🔽
E_r2	2.1	off 🔽
×max	0.02	off 🔽
surface_charge	10e-06	off 🔽
v	1	off 🔽
g	0.01	off 🧧
QU	1e-08	off 🔽
int_1	0	off 🔽
int_2	0	off 🔽
int_3	0	off 🔽
int_4	0	off 🔽
×0	0.005	off 🔽
A0	0.005	off 🔽
ОК	Cancel Apply Defaults	Previous Next Help

3- Start simulating the circuit by making parametric analysis for different R values \rightarrow 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.





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



MODEL CODE

```
// VerilogA model for Triboelectric Nanogenerators (TENGs)
11
// s-ahmed.zaky@zewailcity.edu.eg
// m.shehata ieee@yahoo.com
// hmostafa@uwaterloo.ca
11
// The University of Science and Tecnology at Zewailcity
// Cairo University
// EE Dept. Sept 2017
11
`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
                                                 // Width of the device
parameter real w= 100m from (0:inf);
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 g = 10m from (0:inf); // The motion velocity two plates in certain real // 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. // S is the effective surface area of real s; the device. real c; // Is the inheritance capacitance of TENG. This relation is unique for every mode and can be got by electrodynamics. // The output voltage of TENG, again the real output volt; 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 // Single Electrode Initial charge on real int charge ; Cap analog begin // calculating fixed variables d0 = (d 1/E r1) + (d 2/E r2);s = w*l;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*$abstime/xmax));
    // End Simple Harmonic Motion
end
c= (E0*s)/(d0+x);
output volt= (surface charge*x)/(E0);
if (analysis("ic"))
V(p,n) <+ Q0*c;
else
V(p,n) <+ idt(I(p,n), int 1)/c;
                                    // Voltage due to the inhertenc
capacitence.
V(p,n) <+ output volt ;</pre>
                               // Voltage due to the potential difference
between the two electrodes.
// The output voltage of the TENG is considered to be a superposition of the two
voltages.
end // AE-CM
if (model==1) begin // Begin AE-SM
if (motion senario==0) begin // Begin Linear Motion
x = v*$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*(1-x))/(d0);
output volt= (surface charge*x*d0)/(E0*(l-x));
V(p,n) <+ idt(I(p,n),int 2)/c;</pre>
V(p,n) <+ output_volt ;</pre>
end // End AE-SM
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*(1-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;</pre>
V(p,n) <+ output volt ;</pre>
end // End SE-CM
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 ;</pre>
V(p,n) <+ idt(I(p,n))/c;</pre>
end // End FL-CM
end // end Analog
endmodule
```