Simscape Design Flow for Memristor Based Programmable Oscillators

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ABSTRACT

In this paper a design optimization flow is proposed for memristor-based oscillators using the Gravitational Search Algorithm. This paper presents for the first time a memristor behavioral model in the Simscape physical modeling language. Using this model, a memristor based Wien oscillator is characterized within the Simscape framework. The oscillation frequency and power consumption of the oscillator for different configurations are explored.

Categories and Subject Descriptors

B.7.1 [**Integrated Circuits**]: Types and Design Styles—VLSI (very large scale integration)

Keywords

Simscape Modeling; Memristor; Programmable Oscillator

1. INTRODUCTION & CONTRIBUTIONS

Simscape is an integral part of the MATLAB framework. It can model multiple-discipline systems including mechanical and electrical. Simulink uses the signal-flow approach which is suitable for high-level system modeling.

A graphical block-based Simulink/Simscape memristor model was presented in [4]. In the current paper a memristor model is presented that is native to Simscape.

As a case study, the design and optimization of a Wien oscillator is presented with the memristor assisted programmability using the proposed Simscape memristor model.

The **novel contributions** of this paper to the state-of-art include the following: (1) The first ever flow for design optimization of memristor-based oscillators. (2) A Gravitational Search Algorithm (GSA) based optimization algorithm for memristor-based Wien oscillators. (3) A programmable oscillator using a memristor is presented. As case study circuit design exploration of the oscillator under five memristor configurations is presented in terms of power consumption and frequency. (4) The first ever Simscape based models for titanium oxide memristors. The Simscape model construction and simulation setup are presented.

GLSVLSI'14, May 21–23, 2014, Houston, Texas, USA.
ACM 978-1-4503-2816-6/14/05.
http://dx.doi.org/10.1145/2591513.2591545.

2. OPTIMIZATION ALGORITHM

The Gravitational Search Algorithm (GSA) is based on the law of gravity and the law of motion of masses [2, 3]. Search agents are characterized as masses, and the interaction between them is governed by Newtonian gravitational force as follows.

$$F = G\frac{M_1 M_2}{R^2}, \tag{1}$$

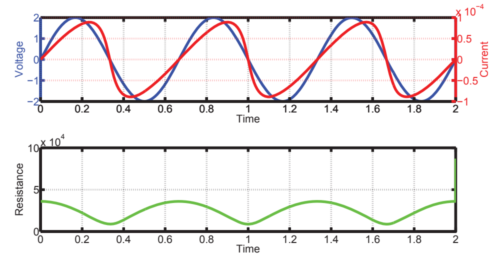
where M_1 and M_2 are two masses, G is a constant and R is the Euclidian distance between the masses. The performance of the agents is measured in terms of their masses. All the masses attract each other by force of gravity and objects with heavier mass tend to attract other objects toward them. The heavier mass is considered the optimal solution. With lapse of time, more masses are attracted toward the heaviest mass.

3. SIMSCAPE MEMRISTOR MODEL

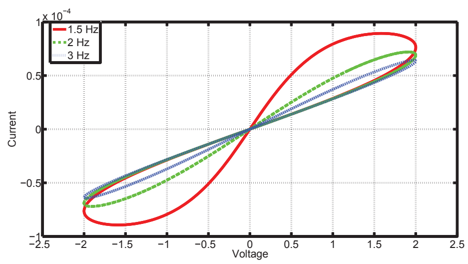
The proposed Simscape memristor model is presented in Algorithm 1.

Algorithm 1 Proposed Simscape Memristor Model.

```
component memristor<foundation.electrical.branch

  parameters
      u = { 1e-14,'m^2/s/V' };   % Mobility
      x0 = { .5,'1' }; % Initial (W/D)
      d = { 20e-9, 'm' };  % Memristor Width
      ron = {100,'Ohm'}; % Minimum Resistance
      roff = {36e3, 'Ohm'}; % Maximum Resistance
  end

  variables
    x={.5,'1'};
    Rmem ={1e3,'Ohm'};
  end

  function setup
     x=x0;
  end

  equations
   let
        az = u * ron / d^2;
     in
        if(x <= 0 && v <= 0)||(x >= 1 && v >= 0)
           x.der == 0;
        else
           x.der == az * i;
        end % if
     end
     Rmem == ron * x + roff * (1 - x);
     v == i * Rmem;
   end % equations
end % component
```



(a) Time-domain simulation result for a 2-V, 1.5 Hz applied sinusoidal voltage.



(b) $I-V$ characteristics for various input frequencies.

Figure 1: Simscape memristor simulation.

The memristor model was tested in Simulink/Simscape. The output is shown in Fig. 1. Fig. 1(a) shows the current, voltage, and memristance against time. Fig. 1(b) shows the $I-V$ characteristics of the memristor with three different input frequencies [1].

4. MEMRISTOR-CONTROLLED PROGRAMMABLE OSCILLATOR

A traditional Wien oscillatorcomprises of four resistors and two capacitors. The condition for sustained oscillation is given by:

$$\frac{C_2}{C_1} + \frac{R_1}{R_2} = \frac{R_3}{R_4}. \tag{2}$$

The frequency of oscillation is given by the following:

$$f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}. \tag{3}$$

When the resistors are replaced with memristors, the oscillation frequency can be varied by controlling the memristance according to Eq. (3). Assuming the memristance is not intentionally changed during normal oscillation, the initial condition of memristor determine the frequency of the oscillator. Five different configurations of a memristor integrated Wien oscillator have been studied. In Configuration 1 we replaced R_1 with memristor M_1 whose resistance is labeled as $R_{1,mem}$. In Configuration 2, we replaced R_2 with memristor M_2 whose resistance is labeled as $R_{2,mem}$. In Configuration 3, R_3 and R_4 were replaced with M_3 and M_4, respectively, whose resistance is labeled as $R_{3,mem}$ and $R_{4,mem}$. Similarly in Configuration 4, we replaced R_2 and R_4 with M_2 and M_4 whose resistance is labeled as $R_{2,mem}$ and $R_{4,mem}$ respectively. In Configuration 5 we replaced all resistors with memristors.

Table 1: Oscillating Frequency of Wien oscillators.

		Frequency		
Configuration		Simulated	Calculated	Error %
Traditional		1591.3	1591.54	0.02
Configuration 1	$X_0 = 0$	118.65	118.65	0.01
	$X_0 = 1$	2030.3	2077.3	2.26
Configuration 2	$X_0 = 0$	264.67	265.26	0.22
	$X_0 = 1$	4309	4317.27	0.19
Configuration 3	$X_0 = 0$	1591	1591.54	0.03
	$X_0 = 1$	1591	1591.54	0.03
Configuration 4	$X_0 = 0$	265	265.41	0.15
	$X_0 = 1$	4765.3	4768.44	0.07
Configuration 5	$X_0 = 0$	44	44.23	0.52
	$X_0 = 1$	12388	12791	3.15

Table 2: Optimization Results for Wien Oscillator (Configuration 5).

Metric	Power (W)	Frequency (Hz)
Baseline Design	2.43E-5	88.5
Optimal Design	1.66E-5	57.6
Reduction	32%	35%

Table 1 shows the simulation results obtained from Simscape and calculations obtained using Eq. 3.

5. EXPERIMENTAL RESULTS

The GSA algorithm is applied to the simscape model.

The algorithm took 302 iterations to achieved the optimal power consumption of 16.6 μW. As presented in Table 2, the power consumption is reduced by 32 % at cost of 35 % reduction in frequency.

6. CONCLUSIONS

This paper presented a pure Simscape memristor model for the first time. As a case study, a memristor integrated programmable Wien oscillator is presented. The simulated oscillation frequencies have been verified with the calculated values from mathematical formulas. The paper also presented the power analysis and observations on various configurations of the memristor-based Wien oscillator. Optimization of the memristor-based Wien oscillator circuit using the GSA algorithm is done. The results obtained show that reduction in power consumption can be achieved at the cost of frequency reduction.

7. REFERENCES

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