Final Project - Memristor Emulator

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***Abstract*—The goal of this project to construct an emulator that would be able to model the characteristics of a memristor. This included thresholding and most importantly, a pinched hysteresis VI curve. Many possible emulator circuit were discussed but the one chosen for this experiment was based on —– due to it's documentation and relatively low number of parts.**

I. Introduction

As mentioned, the overall goal of this project was to explore methods for creating a memristor emulator. Both a simulated model and physical circuit were constructed and tested during this experiment. Despite the fact that a discrete memristor has been successfully fabricated, they are not readily available which has given rise to the importance of emulators. Building a successful memristor model is important for educational and commercial research, related to the memristor field, when a discrete memristor component is not attainable.

II. Background and Relevant Theory

Memristors, or memory-resistors, were a recently actualized circuit element that links charge and flux. They are two-terminal passives devices that change (program) their resistance accordingly with the history of input, otherwise known as non-volatile memory. In other words, they are devices that retain memory of their prior states. A memristor device should exhibit at least two resistance states. [1]

A. Equations

Memristor is the missing links between charge and flux.

$$M(q) = \frac{d}{dt}f(q) = \frac{d\phi}{dq} \tag{1}$$

Its resistance is a function of q (current integration). Memristor resistively connects voltage and current:

$$v = M(q) * i \tag{2}$$

HP Memristor's reported voltage-current dynamics:

$$v_m = R_{ON} + R_{OFF}(1 - w) \cdot i_m \tag{3}$$

$$w = \frac{dw}{dt} = (\mu_v R_{ON} \times i_m) \cdot H_w(w) \tag{4}$$

Flux-charge relation:

$$\phi = \int R(q) \cdot dq = \frac{\gamma}{2}q^2 \tag{5}$$

III. Procedure

As mentioned, the goal was to realize a simulated and physical circuit memristor using the core concepts discussed in previous sections and on Xiao-Yuan et. al. research paper [2]. Figure 1 shows the block diagram of the memristor based on the LDR characteristics. The circuit is not overly complex, with only four main blocks - each with an important role in making sure the memristor functions properly.

Three op-amps are connected in series, each in a different configuration, with the output connected to an optocoupler. The second op-amp is configured to be an integrator. This was to realize the input voltage as flux. This choice was based on the equation for memconductance as a function of flux and the integrator's effectivness in this role.

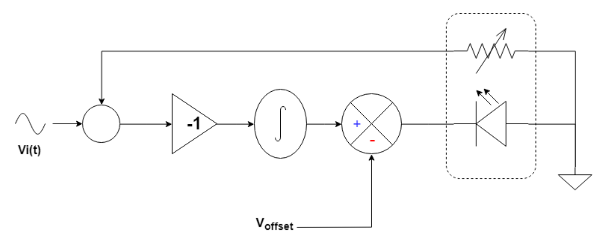

Fig. 1: Block Diagram for Memristor Simulation

Voltage input equation:

$$V_1(t) = V * sin(wt) \tag{6}$$

Voltage output at third op-amp stage (integrator):

$$V_4(t) = \frac{RgR2V}{wR5R3R1C1} * cos(wt) - \frac{R9}{R8} * V_{offset} \tag{7}$$

Figure 2 shows a photo of the optocoupler that was used in the physical circuit realization. The chosen analogue optocoupler was a Silonex NSL-32, consisting of an LED coupled to an LDR. The LDR resistance is high when the LED is off, and it is low when the LED is on [1]. The optocoupler was a simple and effective way to control a variable resistor through light. Another reason this particular device was chosen because the photocell has an inherit hysteresis curve which mimics the functionality of a memristor. The measured resistance across the photocell will eventually showcase the desired memristor characteristics.

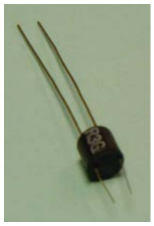

Fig. 2: Optocoupler: Sinolex NSL-32

In order to achieve the desired memristor characteristics, the optocoupler must be operating in the linear region. Figure 3 shows the range of voltage that will achieve the desired output. Between four and nine volts, the conductance equation of the optocoupler is effectively linear and can be seen below.

$$W(v) = 0.3v + 0.11 \tag{8}$$

Where W(v) is the optocoupler conductance equation.

From Equations 7 and 8, we obtain the following emcond-ucatance equation, which will help us populate the resistance values:

$$\begin{aligned} W(t) = 0.3 * (0 - \frac{RgR2V}{wR5R3R1C1} * cos(wt) \\ - \frac{R9}{R8} * V_{offset}) + 0.11 \end{aligned} \tag{9}$$

In order to ensure the optocoupler was operating within the desired range, the third op-amp was arranged in summing configuration. This allowed for percise voltage control through the voltage offset. Properly setting VCC and VEE made sure the op-amp was outputting between four and nine volts. The first op-amp was in inverting buffer configuration which flipped the input signal. This was done to minimize current dram.

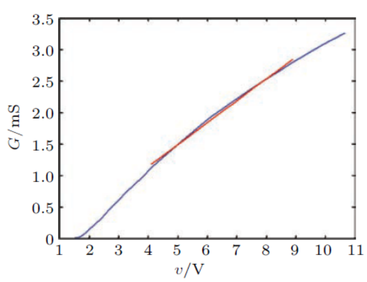

Fig. 3: Voltage/Conductance relationship of the optocoupler

Figure 2 shows the constructed simulation of the memristor emulator in spice. The circuit was tested in Multisim. Voltage readings were taken at the output of each op-amp stage in order to verify if they were operating as intended. In order to confirm the overall circuit was successfully emulating a memristor, the current and voltage readings were taken across the variable resistor.

As mentioned, the simulation utilized a voltage controlled resistor instead of the LDR due to limitations in the spice

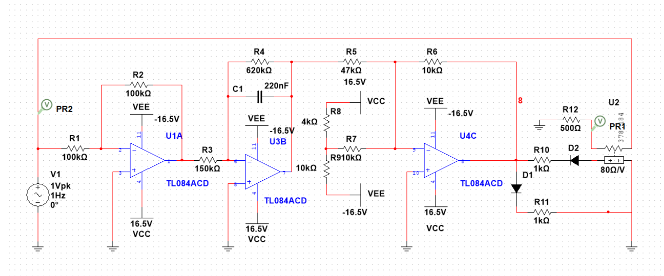

Fig. 4: Constructed memristor emulator

program. This can be seen in Figure 4. After the simulations of the emulator were completed and verified, the circuit was then constructed using components on a breadboard.

IV. Results and Discussion

After the completion of the model simulation, the physical circuit was constructed. Figure 5 shows an image of the physical relization using the TL084 op-amp and the Silonex NSL-32 optocoupler. The input voltage of the circuit was 1V while the frequency was set to 2π radian/second.

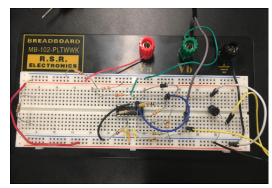

Fig. 5: Simulation voltage-current curve for input of 1 V @ 1 Hz

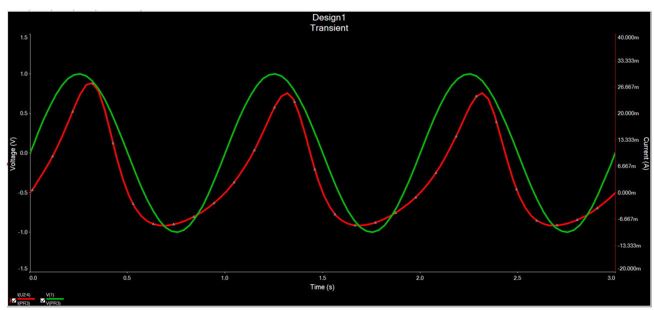

Fig. 6: Simulation voltage-current waveform for input of 1 V @ 1 Hz

In the Figure 8, the green line represents voltage across the LDR in the simulation and the red waveform represents the current through the LDR. The waveforms show that the current output change is dependant on the past current input. The slightly offset waveforms show that the resistance depends on the amount of charge passing through the LDR.

Figure 8 shows the plotted V-I curve of the simulated memristor emulator. It shows the expected hysteresis, figure 8 curve of a memristor. The waveforms have the same zero crossing, no phase shift between them.

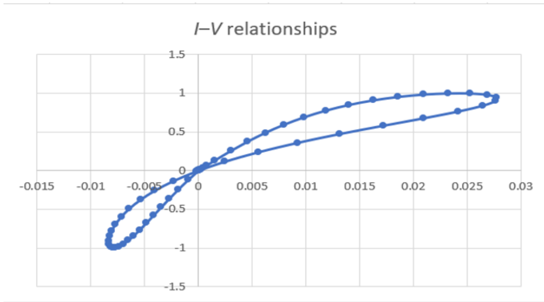

Fig. 7: Simulation voltage-current curve for input of 1 V @ 1 Hz

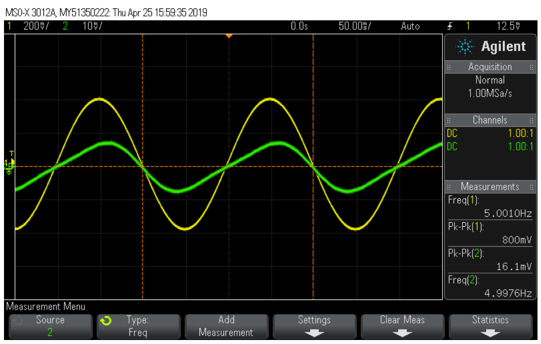

Fig. 8: Actual voltage-current waveform for sine input of 0.8V @ 5 Hz

Figure 9 shows the actual oscilloscope reading from the memristor emulator circuit. It proves that the physical realization is operating successfully since it shows similar results to Figure 7. Yellow shows the voltage across the photocell while green is current through the photocell.

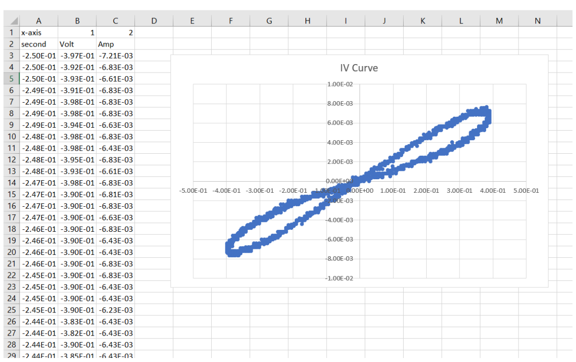

Fig. 9: Actual voltage-current curve for sine wave input of 0.8V @ 5 Hz

Figure 10 is the V-I curve of the physical circuit and is similair to the results from the simulated emulator. It shows a pinched figure 8 curve that shows that the constructed circuit has the same characteristics as a memristor.

Figures 10 and 11 show experimentation that was done with the successfully constructed memristor emulator but with a

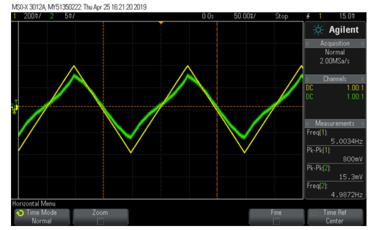

Fig. 10: Actual voltage-current waveform for ramp input of 0.8V @ 5 Hz

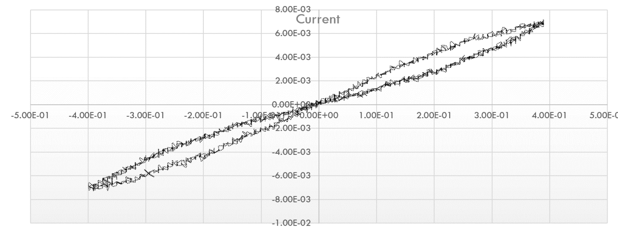

Fig. 11: Actual voltage-current curve for ramp input of 0.8V @ 5 Hz

ramp function input. The resulting V-I curve still has a figure 8 curve but with a more pointed minimum and maximum. This was due to the effects of the integrator on the ramp function input. The again verifies the effectiveness of the memristor emulator because it shows that the circuit has frequency dependant dynamics and linear resistance at high frequencies.

V. Conclusions

The design process of completing an memristor emulator was fully explained in this report. The accuracy of the design can be determined by comparing the simulated circuit and physical realization to the expected memristor characteristics.

The successful completion of this experiment relied on the use of a light dependant resistor (LDR) by using an opto-coupler. With the addition of the three op-amp configurations (inverting buffer, integrator, and summer), the results confirm that the 'memristor' operates as expected.

In conclusion, a memristor emulator model was successfully simulated and then physically constructed. The results show a clear hysteresis IV curve when measuring the resistance across the photocell of the optocoupler. This emulator can be used for education and research purposes related to the field of memristors and nano-technology. It is an important step in gaining a deeper understanding of the 4th circuit element.

References

[1] Memristor. Mepits, $www.mepits.com/tutorial/279/basic-electronics/memristor$.

[2] Xiao-Yuan, Wang, et al. "Implementation of an analogue model of a memristor based on a light-dependent resistor."Chinese Physics B21.10 (2012): 108501