Indian Journal of Science and Technology, *Vol 11(40), DOI: 10.17485/ijst/2018/v11i40/132289, October 2018*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Analytical Estimation of Power Reduction in Memristor Based Analog Circuits

Savarimuthu Prakash[1]* and Sam Thomas[2]

[1]Department of Electronics and Communication Engineering, Saveetha Institute of Medical and Technical Sciences, Velappanchavadi, Chennai - 600077, Tamil Nadu, India; drs.prakash@rediffmail.com
[2]Information and Communication Engineering, Anna University, Guindy, Chennai - 600025, Tamil Nadu, India; sam_thomas_st@yahoo.com

Abstract

Objectives: In this study, a TiO_2 memristor with a non-linear ion drift model is analytically estimated for the power reduction in a basic analog circuit. **Methods/Analysis:** For the estimation of power reduction, the non-inverting and inverting amplifier configurations for conventional resistance and memristors are considered. The circuit is chosen since the output is directly proportional to the input and the component values. The recent progress in the experimental realization of memristive devices has renewed interest in artificial neural networks. **Findings:** To emulate human brain like functionalities at circuit level require two components, neurons and the connecting synapses are required in artificial neural networks. The synapse is a crucial element in biological neural networks. The memristor has been predicated as electronic equivalent of biological synapse. Basically memristor, a resistor with memory; non-volatile and its response depends on continuous set of resistance values, making it ideal for tuning synaptic weights of neuromorphic cells. The first observation on analytical estimate power reduction from conventional op-amp based non-inverting and inverting amplifier circuits to that of memristance based op-amp non-inverting and inverting amplifier circuits indicate 99% reduction in power consumption. Secondly, by varying the amplitude of the input voltage resulted in varying power dissipation in conventional amplifier but resistance values remains constant as expected. However, by varying the amplitude of the input voltage applied to the memristor the power dissipation in the circuit provide an empirical estimating result a clear variation in memristance. **Novelty/Improvement:** Hence, this phenomenon indicates that weighted resistance function in a synapse can be implemented using memristors. The feasible scaling-up to approach real device densities requires reduced power consumption.

Keywords: Device Density, Inverting Amplifier, Memristance, Neuromorphic Cell, Non-inverting Amplifier, Non-linear Ion Drift Model

1. Introduction

An Artificial Neural Network (ANN) is a data processing model inspired on the biological nervous system, implemented as a parallel and distributed network of simple nonlinear processing units[1]. The memristor[2,3] has been predicated as electronic equivalent of biological synapse. Because, basically a resistor with memory; non-volatile and its response depends on continuous set of resistance values, making it ideal for tuning synaptic weights of neuromorphic cells[4,5]. Implementation of ANNs by Hardware (HW) constitutes an important step towards obtaining human brain-like functionalities at circuit-level. The basic components of ANNs are neurons ($\sim10^{11}$) and their connections, i.e. synapses ($\sim10^{15}$), whose circuit realization should be principally compact to make feasible scaling-up to approach the real device densities and power consumption[6]. In this work, for the first time in literature, a TiO_2 memristor with an non-linear ion drift doped model[7] applied and simulated to comprehensively evaluate the power reduction in memristor based circuits compared to the conventional basic analog circuits such as inverting and non-inverting amplifier.

*Author for correspondence

2. Spice Based Simulation Results

2.1 Inverting Configuration

The experiment was simulated using SPICE based OrCAD Cadence tool for both the conventional inverting configuration with resistive element and memristive element for different amplitude voltages keeping the frequency constant as shown in Figures 1-2. Further, the total power dissipated in the resistance and memristance for conventional and proposed inverting amplifier are evaluated and compared. The resistive element chosen was 1 kΩ because the ON resistance used in the non-linear ion-drift model was also 1 kΩ.

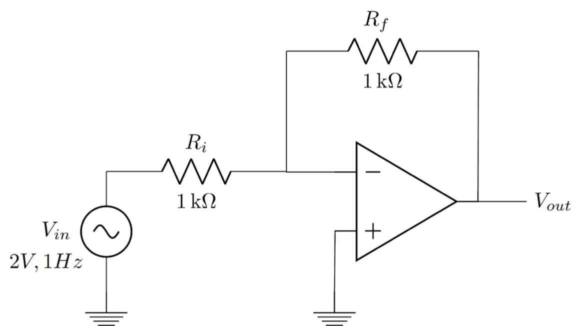

Figure 1. Inverting configuration with an ideal op-amp using resistive elements.

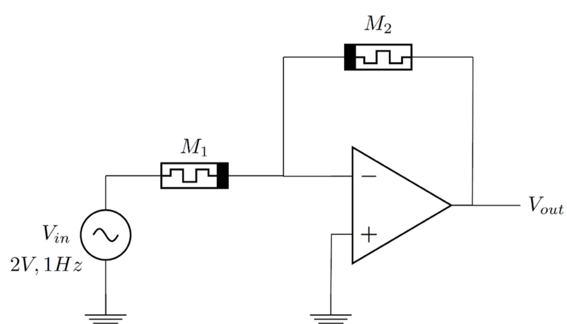

Figure 2. Inverting configuration with an ideal op-amp using memristive elements.

The Figure 3 satisfies the basic equation of an inverting amplifier.

$$V_O = -\frac{R_f}{R_i} V_{in}$$

Where the output voltage of -2 V derived for the applied input voltage of V_{in} = 2 V as observed in the Figure 3.

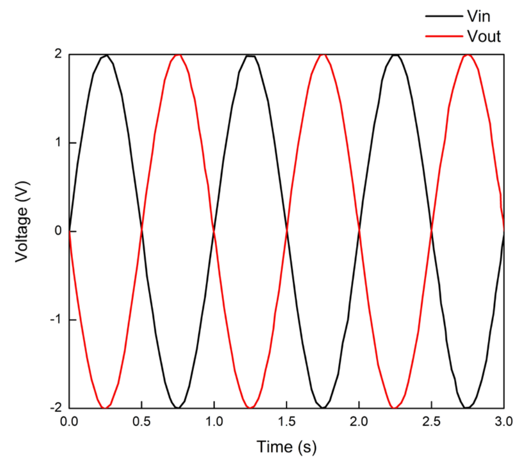

Figure 3. Inverting amplifier output and input using memristive element with ideal op-amp.

It can inferred from (Figure 4). The peak output current through the conventional resistor was 2 mA. Whereas the memristor based was 0.0258 mA only.

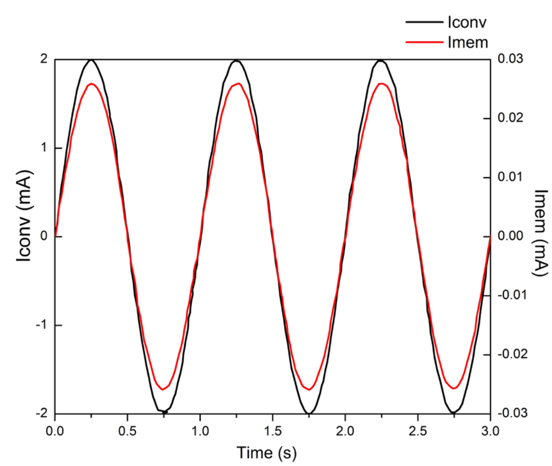

Figure 4. Comparison of the output current in inverting amplifier for an input voltage of 2 V.

This indicates from (Figure 5) a total peak power dissipated in conventional resistor and memristor based inverting amplifier was 7.9854 mW and 0.106781 mW respectively as shown in Figure 6.

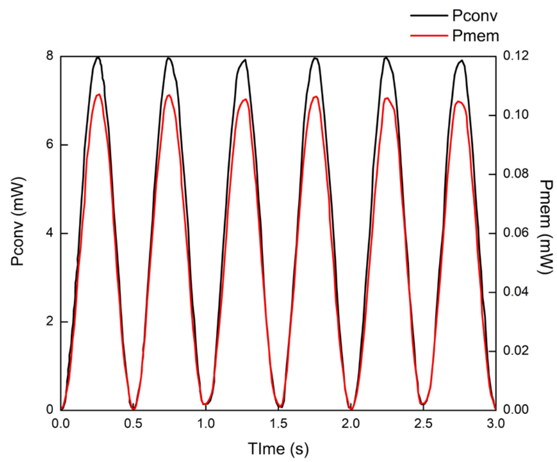

Figure 5. Comparison of total peak power dissipated inverting amplifier for an input voltage of 2 V.

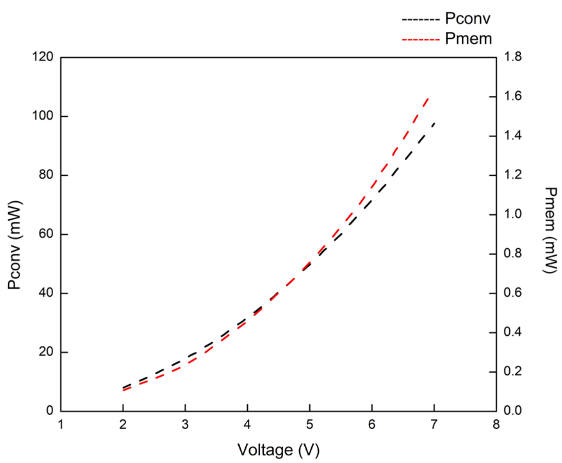

Figure 6. Inverting amplifier power curve fitting parameter equation for P_{mem}=0.0224$v^{2.1924}$ and P_{conv} = 1.993$v^{2.0}$.

The fitting curve of power dissipated in memristor and resistor indicates the constants differ by factor ~100. This also proved by simulation experiments the power reduction of 98%.

2.2 Non-inverting Configuration

The Figures 7-9 satisfies the basic equation of a non-inverting amplifier:

$$V_O = (1 + \frac{R_f}{R_i})V_{in}$$

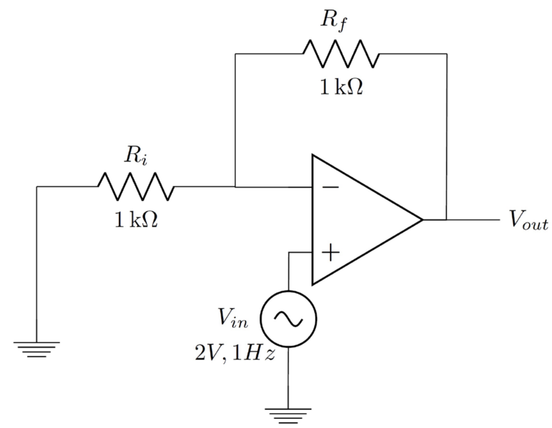

Figure 7. Non- Inverting configuration with an ideal op-amp using resistive elements.

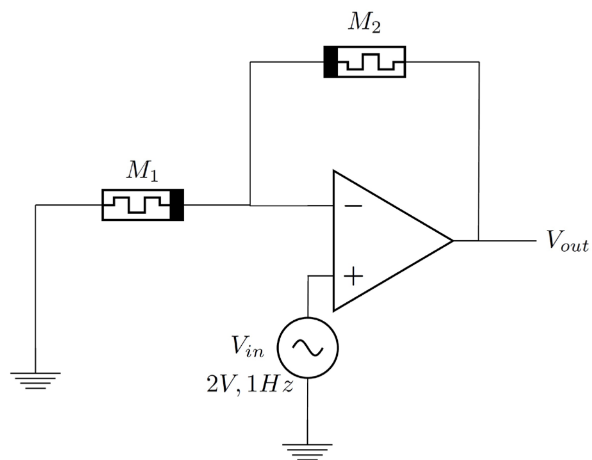

Figure 8. Non- Inverting configuration with ideal op-amp using memristive elements.

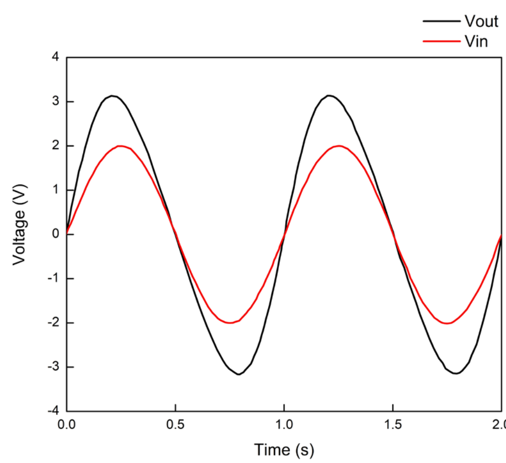

Figure 9. Illustration of non- inverting amplifier using memristive element for V_{in} =2 V with ideal op-amp.

Where the output voltage of 4 V for the applied input voltage of V_{in} = 2 V as observed in the Figure 3.

It can infer from (Figure 10). The peak output current through the non-inverting configuration in conventional resistor and in the memristor based was 2 mA and 0.02119 mA respectively.

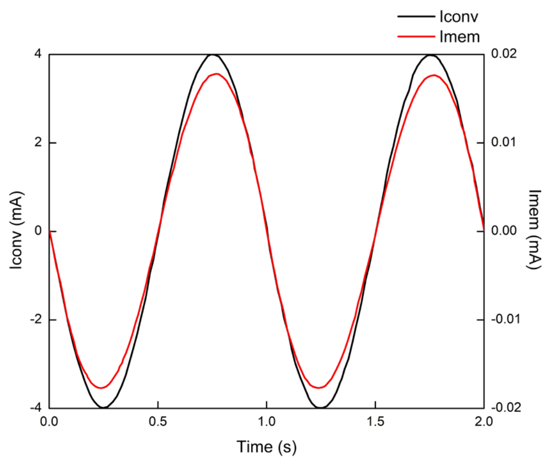

Figure 10. Comparison of I_{OUT} non- inverting amplifier for an input voltage of 2 V.

This indicate a peak power dissipated in conventional resistor and memristor based non-inverting amplifier was 7.9995 mw and 0.066049 mw respectively as shown in Figure 11.

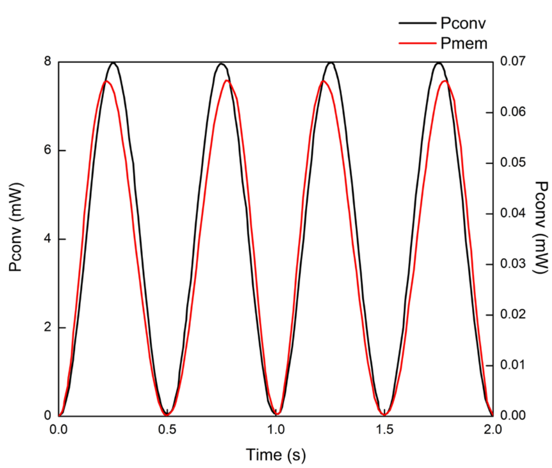

Figure 11. Comparison of total peak power dissipated for a non-inverting amplifier for V_{in} = 2 V.

Figure 12 shows fitting curve of power dissipated in memristor and resistor indicates the constants differ by factor ~100. Which also proved by experimental simulation a power reduction of 99%.

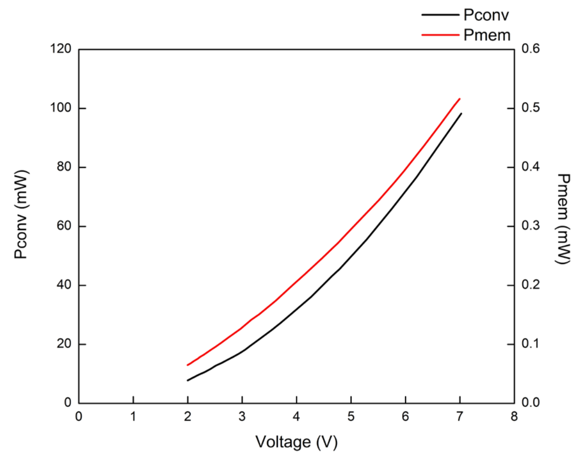

Figure 12. Non-inverting power curve fitting parameter equation for $P_{mem} = 0.0214v^{1.6382}$ and $P_{conv} = 1.9999v^2$.

3. Discussion

It is interesting to note from both the inverting and non-inverting amplifiers of memristor with different applied input voltage, not only the power dissipation values varies. But the memristance values also vary. On the other hand by varying the amplitude of the input voltage resulted in varying power dissipation in conventional amplifier but the resistance values remains constant as expected. We computed from Table 1&2 that by applying the power dissipation calculation formula ($P=V^2/R$) to the obtained power dissipation values. Table 3&4 show the comparison of conventional circuit the average resistance value was found to have and remain constant value of 0.5 kΩ. On the other hand, the power variation obtained computed by applying the same formula to the memristance based circuit indicate varying memristance value. Hence, this type of memristance variation indicates the weighted resistance function in a synapse can be implemented using memristor just by varying the amplitude of the input voltage applied to the memristor.

Table 1. Comparison of Peak Power dissipated in the memristors and resistors in the memristor based in conventional inverting amplifier with different input amplitude voltage

Amplitude (volts)	Memristor (mW)	Resistor (mW)	Power Reduction (%)
2	0.106781	7.9854	98.6628
3	0.237518	17.967	98.678
4	0.463528	31.942	98.5488
5	0.75716	49.909	98.4829
6	1.1441	71.869	98.4081
7	1.641	97.821	98.3224

Table 2. Comparison of Power dissipated in the memristors and resistors in the memristor based in conventional non-inverting amplifier for different input amplitude voltage

Amplitude (volts)	Memristor (mW)	Resistor (mW)	Percentage Reduction (%)
2	0.066049	7.9995	99.17434
3	0.130631	17.999	99.27423
4	0.208215	31.998	99.34929
5	0.297522	49.997	99.40492
6	0.399569	71.996	99.44501
7	0.519417	97.994	99.46995

Table 3. Comparison of resistance change in memristors and resistors in the memristor based in conventional inverting amplifier with different input amplitude voltage

Amplitude (volts)	Memristor (mW)	Resistor (mW)	Memristance (kΩ)	Resistor (kΩ)
2	0.106781	7.9854	37.45985	0.5
3	0.237518	17.967	37.89187	0.5
4	0.463528	31.942	34.51787	0.5
5	0.75716	49.909	33.01812	0.5
6	1.1441	71.869	31.46578	0.5
7	1.641	97.821	29.85984	0.5

Table 4. Comparison of resistance change in memristors and resistors in the memristor based in conventional non-inverting amplifier with different input amplitude voltage

Amplitude (Volts)	Memristor (mW)	Resistor (mW)	Memristance (kΩ)	Resistor (kΩ)
2	0.066049	7.9995	60.561	0.5
3	0.130631	17.999	68.89636	0.5
4	0.208215	31.998	76.84365	0.5
5	0.297522	49.997	84.0274	0.5
6	0.399569	71.996	90.09708	0.5
7	0.519417	97.994	94.33653	0.5

4. Conclusion

In this work, for the first time in literature, a TiO_2 memristor with a non-linear ion drift doped model was applied and analytically estimated the power reduction in memristor based circuits. The experimented results indicate a power reduction of 98.6628 and 99.17434 percentage on memristor based inverting and non-inverting circuit amplifier compared to the conventional resistor respectively for the given input voltage of 2 V. Also, from the varying power dissipation obtained by varying the applied input voltage indicate memristance variation. Therefore, the resistance tuning in memristor can be implemented by varying the applied input voltage to the memristor which is suitable for weighted synaptic circuit.

5. References

1. Vourkas I, Abusleme A, Ntinas V, Sirakoulis GC, Rubio A. A Digital Memristor Emulator for FPGA-Based Artificial Neural Networks. 1st IEEE International Verification and Security Workshop (IVSW); 2016. p. 1-4. https://doi.org/10.1109/IVSW.2016.7566607.
2. Vourkas I, Sirakoulis GC. Memristor-Based Nanoelectronic Computing Circuits and Architectures. Springer International Publishing; 2016. 19, p. 1-241. https://doi.org/10.1007/978-3-319-22647-7.
3. Jo SH, Chang T, Ebong I, Bhadviya BB, Mazumder P, Lu W. Nanoscale memristor device as synapse in neuromorphic systems, Nano Letters. 2010; 10(4):1297-301. https://doi.org/10.1021/nl904092h. PMid: 20192230.
4. Li B, Chow M-Y, Tipsuwan Y, Hung JC. Neural-network-based motor rolling bearing fault diagnosis, IEEE Transactions on Industrial Electronics. 2000; 47(5):1060–69. https://doi.org/10.1109/41.873214.

5. Chen B, Wang X, Gao B, Fang Z, Kang J, Liu L. Highly Compact (4F2) and Well Behaved Nano-Pillar Transistor Controlled Resistive Switching Cell for Neuromorphic System Application. Scientific Reports; 2015. 4, p. 1-5. https://doi.org/10.1038/srep06863. PMid: 25359219, PMCid: PMC4215303.
6. Chua L. If it's pinched it's a memristor, Semiconductor Science and Technology. 2014; 29(10). https://doi.org/10.1088/0268-1242/29/10/104001.
7. Thomas S, Prakash S, Priya K. Characterization of memristor based on non-linear ion drift model. IEEE International Conference on Energy, Communication, Data Analytics and Soft Computing (ICECDS); 2017. p. 2189-92. https://doi.org/10.1109/ICECDS.2017.8389839.