DESIGN AND PERFORMANCEANALYSIS OF A MEMRISTOR-BASED WEIN OSCILLATOR

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Abstract— In this paper, we insinuated an approach to employ Memristors (resistors with memory) in programmable analog circuits in which low voltage is applied to Memristor throughout their operation. Being the fourth passive circuit element, a memristor is a nonlinear resistor that can "memorize" the amount of charge fleeting through it. Here, the Wein Oscillator (WO) is designed and analyzed using Memristors by replacing the resistor in the conventional Wein Oscillator. We analyzed the power parameters like Average power and Peak Power. After simulating the circuit we found reduction in Average power of Wein Oscillator with Memristor as compared to the conventional Wein Oscillator i.e.it reduces to 292.9 milli-Watt (mW) from 69.93 nano-Watt (nW) and, also reduction is noticeable in Peak Power of the circuit from 293.1 mW to 213.8 nW. The unique characteristic of "memorizing" the charge and non-volatility makes memristors great potential entrants in many fields.

Keywords— Memristor; Memristance; Wein Oscillator; Non-volatile; Low Power.

I. INTRODUCTION

In order to broaden the Moore's law, many novel devices have been created at the nano-scale recently. The scaling at nanoscale also guided to the discovery of the fourth circuit element [1-3], called Memristor by Leon Chua in 1971. The memristor is defined as a two-terminal circuit element in which the flux between the terminals is a function of electric charge q that has passed through the device. Memristors are two-terminal devices with varying resistance, where the behaviour is dependent on the history of the device. A memristive device is basically any resistor with a variable resistance, that only changes when voltage is applied across the device or, alternatively, the current flowing through the device. Since the resistance does not change when there is no voltage applied across the device. The Memristance (Memory+ Resistance) is a property of an [1]electrical component that describes the variation in resistance of a component with the flow of charge. Any two terminal electrical components that exhibit Memristance is known as a Memristor and is shown in Fig. 1 above.

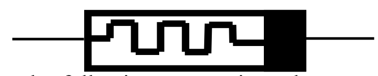

Fig.1 We use the following convention when possible: when a positive voltage is applied to the second (plain without lining) terminal with respect to the terminal denoted by the black thick line, the memory device goes into a state of high resistance.

Since the initiation of memristors, a great deal of work has been stated in the science and engineering fields due to their unpredictable behaviours [4]. The low power consumption and non-volatile nature of memristor makes it an attractive candidate for the next-generation memory technology [5]. Due to its characteristics, the memristors are likely to play a major role in many of the applications [6], [7] mutually with crossbar arrays [8], chaotic circuits [9,10], Emulator circuits [11] , non-volatile memory [12-14] neural networks [15], material implication logics[16], Magic logic gates [17] and circuit modeling [18]. In addition, novel analog circuits can be made using memristors [19, 20]. Itoh and Chua [21] anticipated several nonlinear memristor oscillators according to some of Chua's well studied circuits, in which the Chua diodes were substituted by the monotonically increasing piecewise-linear (PWL) memristors.

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In this work, a memristor based Wein Oscillator (WO) is proposed. The Wien oscillator

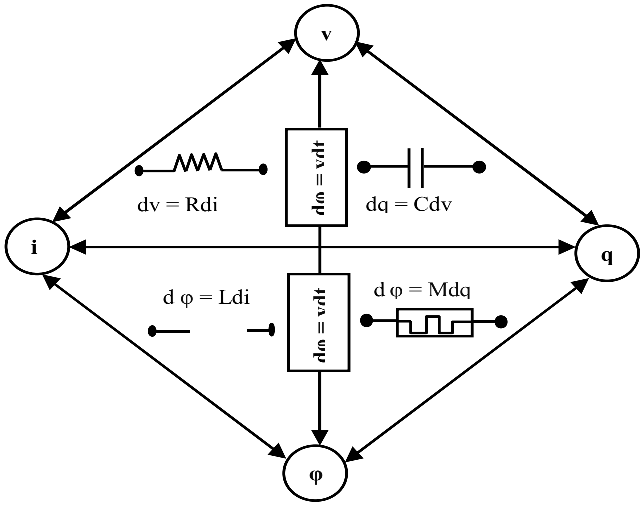

Fig.2. Relationship between Four Fundamental Quantities.

[22] is one of the simplest and best recognized oscillator and seize benefit of two RC circuits, one in series and the other in parallel.

The following is a brief description of the structure of the paper. Section II, which follows this Introduction, précis the information about the physical and mathematical models of the memristor. Section III describes the conventional Wein Oscillator. Section IV postulates the proposed Wein Oscillator using Memristor. Section V shows the evaluation of different parameters and their results and at last the paper is concluded.

II. THE PHYSICAL AND MATHEMATICAL MODELLING OF MEMRISTOR

There are four circuit variables voltage v, current i, magnetic flux φ and charge q, and three known circuit elements, resistor R, capacitor C and inductor L. Memristor provide a functional relationship between the charge and flux as shown in Fig. 2.

The lot of mathematical and simulative modeling and related work regarding with the memristor is carried out by Strukov. D. B [23] and Prof. L. Chua and is shown in Fig. 3. The memristor is a very small device that can be split into two main parts: a low doped region with high resistance (R_{OFF}) and a high doped region with low resistance (R_{ON}). The width of the high doped region (R_{ON}), which is w, defines the state variable of the memristor and the value of its resistance. The total resistance of the two-terminal device depends on the electric current (induced flux) that passes through it. The doped region has a low resistance while that of the un-doped region is much higher. When the external voltage bias is applied across the device, the length D will change owing to charged dopant drifting [24]. Toggling the memristor depends on the bias of the applied voltage across the device. ON- switching, or switching the device to ON-state, requires a positive bias across the device. While OFF- switching, or switching to OFF state requires negative bias [25].

Thus, the mathematical model for memristive device resistance is described as –
The memristor is formally defined as a two-terminal element in which the flux linkage φ_m between the terminals is a function of the amount of electric charge q that has passed through the device. Each memristor is depicted by its memristance function relating the rate of change of flux w.r.t charge.

$$\mathbf{M(q)} = \frac{\mathbf{d\varphi_m}}{\mathbf{dq}} \tag{1}$$

Observing from Faraday's law of induction that magnetic flux is basically the time integral of voltage and charge is the time integral of current, we may note down the more convenient form.

$$\mathbf{M(q(t))} = \frac{\frac{\mathbf{d\varphi_m}}{\mathbf{dt}}}{\frac{\mathbf{dq}}{\mathbf{dt}}} = \frac{\mathbf{V(t)}}{\mathbf{I(t)}} \tag{2}$$

It can be inferred from this that memristance's resistance is simply charge-dependent.

If M(q(t)) is a constant,

then we obtain Ohm's Law i.e.

$$\mathbf{R(t) = V(t)/\ I(t)} \tag{3}$$

If M (q (t)) is important, however, the equation is not alike because q(t) and M(q(t)) will differ with time. Resolving for voltage as a function of time we obtain

$$\mathbf{V(t) = M(q(t)) * I(t)} \tag{4}$$

where

$$\mathbf{M(t)} = \frac{\mathbf{R_{ON}\ w(t)}}{\mathbf{D}} + \mathbf{R_{OFF}} \frac{\mathbf{1 - w(t)}}{\mathbf{D}}$$

where R_{OFF} is the resistance when w(t) = 0 and R_{ON} is the resistance when w(t) = D [26]. This equation reveals that voltage $V(t)$ is depending on both the resistance and actual current [27].
Therefore, the power consumption attribute recalls that of a resistor i.e. I^2R.

$$\mathbf{P(t) = I(t)V(t) = I^2(t)M(q(t))} \tag{5}$$

As long as M(q(t)) varies little, such as in alternating current, the memristor will emerge as a resistor. If M(q(t)) increases quickly, however,

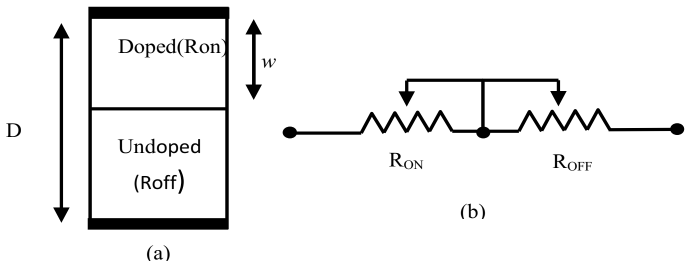

Fig. 3(a & b) Memristor Physical Models.

current and power consumption will rapidly stop. Furthermore, the memristor is static if no current is applied. If I(t) = 0, we uncover V(t) = 0 and M(t) is constant.

III. CONVENTIONAL WEIN OSCILLATOR

The Wien Oscillator is one of the simplest and best known oscillators and is used extensively in circuits. The Wien bridge oscillator is one of electronic oscillators that generate sine waves. It is the standard RC oscillator circuit for a large range of frequencies. The bridge circuit comprises of four resistors and two capacitors. As said, the Wien oscillator takes benefit of two RC circuits, in which one is parallel and the other is in series. The RC network applies an attenuated, but not phase shifted version of V_{out} to the negative input terminal, while receives attenuated and an phase-shifted version of V_{out} to the positive input terminal. The schematic of a Wein Oscillator is shown in Fig. 4.

IV. WEIN OSCILLATOR WITH MEMRISTOR

The conventional PSO makes use of resistances that requires more power. Hence, the resistor R2 in parallel RC is replaced by memristor in the Wein oscillator as shown in Fig. 5. Here, R_M represents the resistance of memristor. A parametric study of the initial Resistance (R_{init}) is introducing to validate the concept for different cases. For this oscillatory system, R_M is expressed as:

$$\mathbf{R_{max} - R_{min} \cong \frac{V_M K(R_{OFF} - R_{ON})}{\pi R_{init}\, f_m}} \qquad (6)$$

Where, $K = \frac{\mu_v R_{on}}{D^2}$

f_M is the frequency of oscillation,

V_M is the voltage across R_M,

R_{max} is the maximum of R_M and

R_{min} is the minimum value of $_{RM}$.

RC Oscillators are stable and provide a well-shaped sine wave output with the frequency being proportional to 1/RC. Usually in oscillators, the parameters are applied periodically to instigate oscillations but in this memristor-based Wein oscillator, no external means are required to have

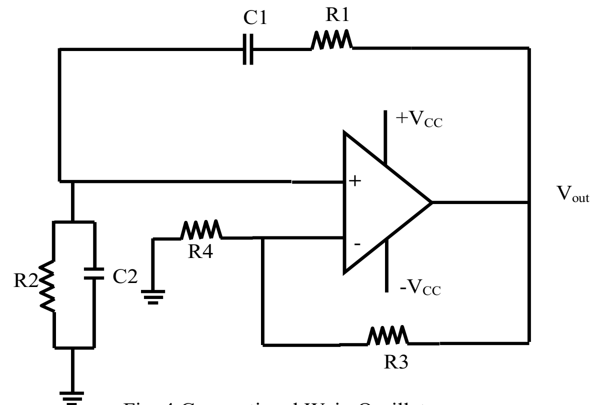

Fig. 4 Conventional Wein Oscillator

the parameter (R_M) oscillating with time. This new circuit element shares many of the properties of resistors and shares the same unit of measurement (ohms). However, in contrast to ordinary resistors, in which the resistance is enduringly fixed, memristance may be programmed to different resistance states based on the history of the voltage applied to the memristance material.

V. SIMULATIONS AND RESULTS-

Power consumption is now the major technical difficulty facing the semiconductor industry [28].With the growing use of portable and wireless electronic systems decrease in power consumption has become one of the main concerns in today's and system design. With the help of these values following parameters are calculated:

1. *Average Power*

With the rising use of portable and wireless electronic systems, decrease in power has become one of the main concerns in today's VLSI circuit and system design.

Table I.

S. No.	Parameters	Notation	Value
1	Process Technology	-	45nm
2	Supply voltage	V_{dd}	0.7v
3	Resistance of the un-doped region	R_{off}	1600
4	Resistance of the doped region	R_{on}	100
5	Dopant mobility	μ	10e-14
6	Length of the memristor	D	10e-9
7	Temperature	T	27^{o}C

Table 1 represents the following model parameters (of Memristor) for simulations.

Power is the product of applied voltage to the circuit and current flow through the circuit due to applied voltage source through the circuit due to

$$\textbf{Power (P)} = \textbf{Voltage } (V_{dd}) * \textbf{Current } (I_{dd}) \quad (7)$$

"Energy consumed in unit time by circuit is known as Average Power"[29], which is shown in Table II and in Graph 1.

2. Peak Power

Rate of energy flow in every pulse is called as Peak Power [30] .

$$P_{Peak} = \frac{E}{\Delta t}$$

For our simulations we have used R1=6.5kΩ, R3=2R4, R4=1.6kΩ, C1=C2=10nF, R2 is replaced with Memristor (R_M) and the supply voltage (V_{dd}) of 0.7 v.

VI. CONCLUSION

In this work we illustrated that the Memristor is the best choice to be used in place of resistors, as ordinary resistor's resistance is permanently set but memristor's memristance may be switched or programmed to different resistance state's based on the history of the voltage applied. Usually in parametric oscillators, the parameters are externally applied periodically to initiate oscillation but in this memristor-based Wein oscillator, no external means is required. In addition, it consumes less power and is non-volatile in nature and supports the circuitry even in the case of sudden power failure.
A series of simulation were performed for power minimization including Average power and Peak power of the circuit and reductions in these parameters are noticed in our proposed Memristor

Table II.

S.No.	Average Power	
	Conventional Wein Oscillator	Memristor Based Wein Oscillator
1	292.9 nW	69.93 nW

Table II showing Average Power in nano-Watt(nW) for both the circuits.

Table III.

S.No.	Peak Power	
	Conventional Wein Oscillator	Memristor Based Wein Oscillator
1	293.1 mW	213.8 nW

Table II showing Peak Power in milli-Watt (mW) and nano-Watt(nW) for both the circuits.

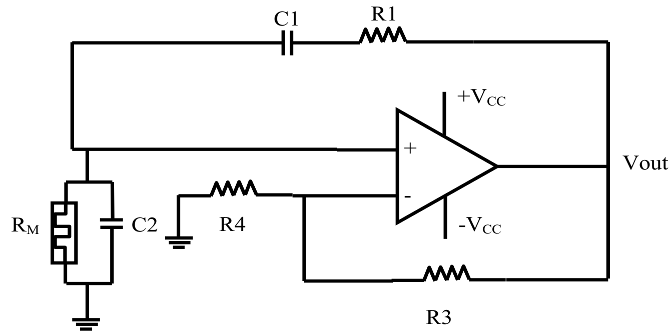

Fig.5 Wien Oscillator with Memristor (R2 replaced by R_M)

based Wein Oscillator cell in comparison with the conventional Wein Oscillator. Thus, it can be said that Memristor offers ten-folds or even more, improvement in terms of performance, power and scalability. The circuit was simulated under ideal conditions using Cadence virtuoso tool in 45 nm technology at 27^o temperature.

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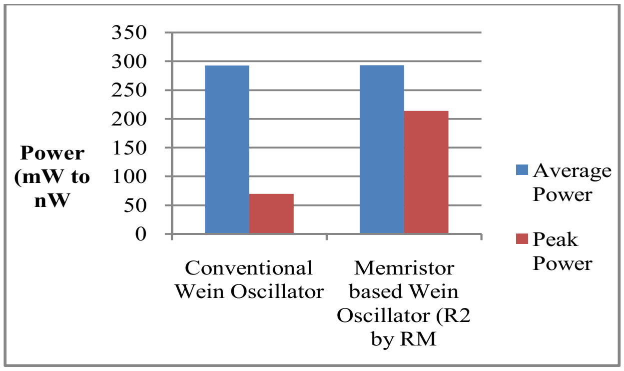

Graph 1. It shows the Power Parameters (which goes from mW to nW).

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