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Grounded Meminductor Emulator Using Operational Amplifier-Based Generalized Impedance Converter and Its Application in High Pass Filter

Anshul Gupta[1], Shireesh Kumar Rai[2] and Maneesha Gupta[3]

[1,3]ECE Department, Netaji Subhas University of Technology, Delhi, India, [1]anshulg.ev20@nsut.ac.in, [3]maneeshapub@gmail.com
[2]ECE Department, Thapar Institute of Engineering and Technology, Punjab, India, shireesh.rai@gmail.com

***Correspondence:** Anshul Gupta; Email: anshulg.ev20@nsut.ac.in

ABSTRACT- This paper exhibits a grounded meminductor emulator designed using an operational amplifier generalized impedance converter (GIC) and a memristor. One of the resistors of GIC has been judiciously replaced by memristor to convert active inductor circuit into meminductor emulator circuits. For the proposed grounded meminductor emulator, pinched hysteresis loops of up to 5kHz have been produced. The simulation findings were obtained using the LTspice simulation tool. The pinched hysteresis loops are shrinking when the frequency is varied from 100 Hz – 5 kHz. A high pass filter has also been constructed and simulated using the proposed meminductor emulator to validate its performance.

General Terms: Memelements, Signal Processing.

Keywords: Memristor, Meminductor, High Pass Filter, Generalized Impedance Converter (GIC)

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1. INTRODUCTION

L. O. Chua proposed the presence of a fourth fundamental circuit element, the memristor, in 1971, in addition to the existing three [1]. Its generalized concept was later discussed by him in 1976 [2]. The memristor, however, was only a theoretical concept until 2008, when, Williams and his team in the HP labs realized it physically using TiO_2 [3]. With the successful development of the memristor, researchers extended the notion of memristors to include capacitors and inductors as well i.e., memcapacitors and meminductors. In this way, they developed the electrical relationship between charge(q) and the time-integral of flux(ρ) with the meminductor, and between flux(φ) and the time-integral of charge(σ) with the memcapacitor (*Figure 1*). These devices possess memory storage capabilities and therefore their past values affect their current performance.

However, due to the unavailability of these devices in a physical form, various emulators have been researched for converting the memristor into memcapacitor and meminductor circuits [4][5]. Many memcapacitor and meminductor emulators have also been realised using different passive and active components.

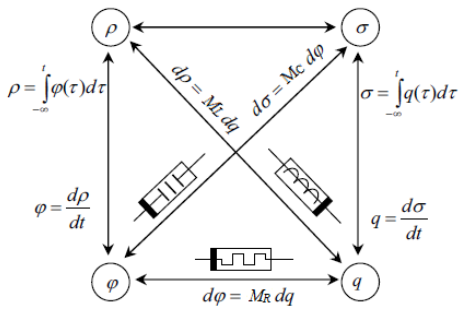

Figure 1: The relationship between circuit elements [4]

This paper aims to design a meminductor emulator using passive and active components that are easily and cheaply available in the market and obtain a circuit that is both simpler in design as well as reliable in operation.

The meminductor emulators found in the existing research that have been designed using a memristor usually employ components that are not easily available in the market as well as multiple active and passive components that complicates the circuit and as such it becomes quite difficult to realize that circuit on a breadboard. The proposed meminductor emulator is designed using op-amps which can be easily and cheaply obtained. The Generalized impedance converter is also a simple circuit that has been used in many applications and hence this circuit can easily be implemented on a breadboard for further understanding. Moreover, the approach used in this paper can be further employed in other circuits and lead to the simplification of many complex circuits.

The introduction is the first of five sections of this paper. The mathematical analysis of the proposed meminductor emulator has been shown in *Section 2*. The proposed meminductor emulator's simulation results are shown in *Section 3*. An

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application of the proposed meminductor emulator is covered in *Section 4* while *Section 5* contains the conclusions.

2. LITERATURE REVIEW

Various emulators have been researched for conversion of memristor into memcapacitor and meminductor circuits [4][5]. Many memcapacitor and meminductor emulators have also been realised using different passive and active components. A memristor, an op-amp, a capacitor, and a resistor were used to realize memcapacitor and meminductor emulators in [6]. A memristor-less floating and grounded meminductor emulator is designed in [7] using a VDTA, a CDBA and 2 grounded capacitors. A floating meminductor emulator without using a memristor has been realized that contains four CCIIs, three op-amps, a multiplier, a capacitor, and eight resistors [8].

The charge-controlled meminductor reported in [9] uses a multiplier, three op-amps, MOSFETs, inductor, capacitor, and resistor. A floating memristor was converted into a meminductor in [10] using a multiplier, a CCII, operational amplifier with three capacitors and resistors. The memristor-less voltage and current controlled meminductor reported in [11] employs multipliers, current conveyors and few capacitors and resistors. A meminductor emulator has also been emulated using an op-amp, a VDTA along with some capacitors and resistors [12]. A high frequency meminductor using two VDTAs and a capacitor is presented in [13] along with an application of the same.

A memcapacitor using a memristor and an op-amp in connection to a resistor and a capacitor in [14]. A memristor, a CBTA, and a capacitor are used in [15] to create a global mutator circuit. In [16], five multipliers, nine op-amps, many resistors and capacitors were used to create a meminductor emulator. To create chaos, the meminductor emulator with a capacitor in parallel is used. Another configuration uses an OTA, a CFOA, two CCIIs, an analogue multiplier, two capacitors and eight resistors to realize a floating flux controlled meminductor emulator [17]. A DVCCTA, a resistor and two capacitors have been utilized to realize a memcapacitor emulator in [18]. In [19], four AD844s, an op-amp, a varactor diode, a capacitor and a few resistors were used to transform memristor, memcapacitor, and meminductor.

In [20], off-the-shelf components (AD633, AD844), a capacitor and a few resistors were used to create a universal charge-controlled emulator. Three trans-impedance operational amplifiers, a floating memristor, buffers, capacitors and resistors were used to create a global mutator in [21]. In [22], a memristor, a voltage differencing current conveyor (VDCC), and a capacitor were developed as floating meminductor and memcapacitor emulators. The current mode approach is used in [23] and a CCII, an OTA, a resistor, and a capacitor were used to create a memristor, memcapacitor, and meminductor emulation circuit. Operational amplifier based meminductor emulators have been reported in [24] [25] and their applications in chaotic oscillators are given.

By extensive literature survey it has been observed that mainly two techniques have been used to realize meminductor and memcapacitor emulators. For the first, meminductor emulators have been obtained by transforming memristors into meminductor emulators using mutator circuit. Most of the meminductors in the literature have been obtained using this method. On the other hand, meminductor emulators have also been designed without using memristors but using a number of active and passive components.

3. THE PROPOSED GROUNDED MEMINDUCTOR EMULATOR

The proposed circuit has been designed using a generalized impedance converter circuit [26], in *Figure 2*, and a memristor. The proposed circuit has been shown in *Figure 3*.

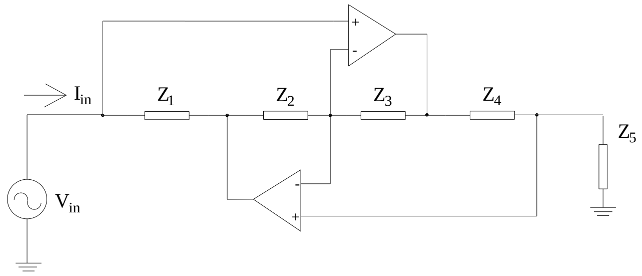
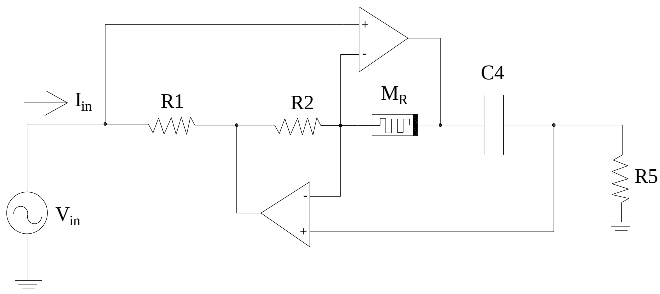


Figure 2: A General Impedance Converter [26]

By replacing the resistors in place of impedances Z_1, Z_2, and Z_5; using a memristor instead of impedance Z_3 and using a capacitor as Z_4, the generalized impedance converter shown in *Figure 2* is converted into a grounded meminductor as shown in in *Figure 3.*



The meminductor can be described by the equation:

$$\phi_{in} = \mathrm{M_L I(t)} \tag{1}$$

and it can also be represented as,

$$\mathrm{I(t)} = \mathrm{M}_L^{-1}\phi_{in} \tag{2}$$

For a generalized impedance converter (GIC) circuit, depicted in *Figure 5*, the input impedance is represented as,

$$Z_{in} = \frac{V_{in}}{I_{in}} = \frac{Z_1 Z_3 Z_5}{Z_2 Z_4} \tag{3}$$

From this circuit a meminductor can be modelled by replacing the impedance Z_3 with a memristor and the impedance Z_4 with a capacitor while keeping the rest of the impedances as resistors which makes the eq. (3) as,

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$$Z_{in} = \frac{V_{in}}{I_{in}} = j\omega \frac{R_1 M_R(\rho) R_5}{R_2 C_4} \tag{5}$$

Therefore, the inductance will be,

$$M_L(\rho) = \frac{M_R(\rho) R_1 R_5}{C_4 R_2} \tag{6}$$

This inductance can be proven as the meminductance by using the constitutive equation of the inductor:

$$V_{in}(t) = \frac{d(M_L(\rho)\, i_{in}(t))}{dt} \tag{7}$$

This can be further expressed as,

$$\frac{d\rho_{in}(t)}{dt} = \phi_{in}(t) = \int V_{in}(t)\, dt = \frac{d(M_L(\rho)\, i_{in}(t))}{dt} \tag{8}$$

The first term of eq. (8) can be further expanded as,

$$\frac{d\, \rho_{in}(t)}{dt} = \frac{d\, (\rho_{in}(q))}{dq} \times \frac{d\, q(t)}{dt} \tag{9}$$

Combining eq. (5), with eq. (8) and eq. (9), we get the resulting meminductance as,

$$M_L = \frac{d\rho_{in}(t)}{dq(t)} = \frac{M_L(\rho).\, i_{in}(t)}{dq(t)/dt} = \frac{M_R(\rho) R_1 R_5 i_{in}(t)}{C_4 R_2 i_{in}(t)} = M_L(\rho) \tag{10}$$

The proposed grounded meminductor has been designed by modifying a generalized impedance converter and using a memristance instead of resistor R_3 in an inductor made using a GIC. This memristance provides the inductor with a memory component which changes its value based on the previous value of the charge passing through it. This in turn changes the value of our inductor based on the previous charge and thus realizes a meminductor.

4. RESULTS AND DISCUSSION

Analog Devices' LTspice simulation program was used to simulate the proposed meminductor emulator. The simulation employed the AD711 op-amp with bias values of 9V. The resistors R_1, R_2, and R_5 have values of 1kΩ, 1kΩ, and 0.5kΩ, respectively, while the capacitor C_4 has a value of 1nF. The HP memristor's SPICE model [27] was used to model the memristor.

4.1 Transient Analysis

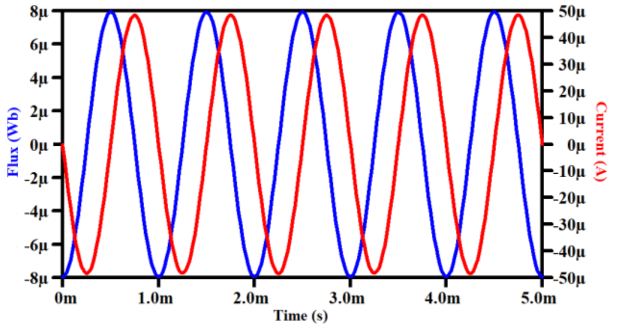

Figure 4: Transient analysis for the proposed meminductor emulator

The pinched hysteresis loops (PHLs) for the proposed meminductor emulator have been achieved using a sinusoidal signal of 50mV amplitude and varying frequency from 100Hz to 5kHz. By monitoring the value of flux (ϕ) on the x axis of *Figure 5*, we can see that on increasing the frequency of operation, the loop area decreases. It can be concluded that at higher frequencies, the pinched hysteresis loop begins deforming. Hence, after 5kHz, the pinched hysteresis loop deforms. Thus, we can say that the maximum frequency of operation for this meminductor emulator is 5kHz. *Figure 5* presents the PHLs for the proposed meminductor emulator.

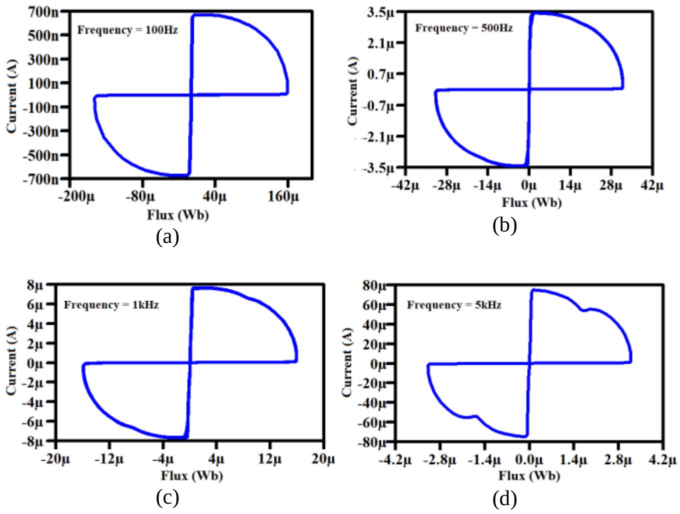

Figure 5: PHLs of proposed meminductor emulator at different frequencies (a) 100Hz (b) 500Hz (c) 1kHz (d) 5kHz

4.2 Temperature Analysis

In order to test its stability, the circuit was simulated at different temperatures varying from −40°C to 40°C. A sinusoidal input wave with 50mV amplitude and 1kHz frequency was applied as the input for this analysis. The results obtained in *Figure 6*, show us that temperature has no effect on the pinched hysteresis loops. Thus, we can conclude that the proposed decremental/incremental meminductor can work in extreme temperatures satisfactorily.

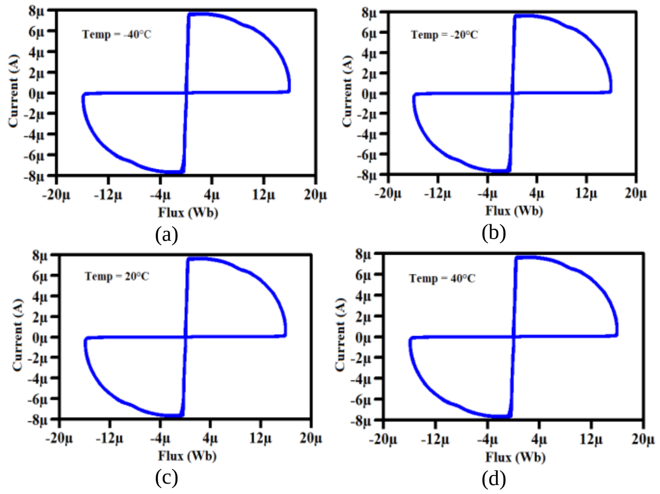

Figure 6: Temperature analysis of proposed meminductor

4.3 Non-Volatility Test

To verify the memory retaining quality of the proposed meminductor emulator, we applied a pulse waveform with amplitude 100mV, pulse width 1ms and time period 4ms. *Figure 7* shows the non-volatility test, and it can be clearly observed that during the time when the input is high, the meminductance value changes, while it retains its value in the non-pulse period.

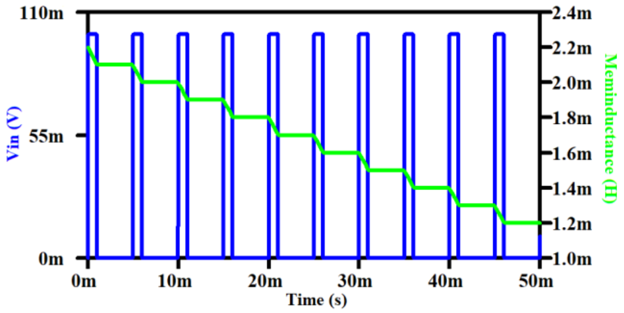

Figure 7: Non-Volatility test for proposed grounded meminductor

5. COMPARISON WITH EXISTING MEMINDUCTORS

Table 1, shows the analogy of the proposed meminductor emulator with existing emulators in the literature. Below is the summary of *Table 1*.

1. Various meminductor emulators use multiple operational amplifiers, multipliers, current conveyors as well as a large number of passive components in [6][8-11][16][17][19][21]; on the other hand, the proposed circuit is extremely simple in design and uses only a small number of components.
2. For the meminductors stated in [6] [8-12] [16-21], the maximum frequency of PHLs is in the range of Hz only while the operating frequency for the PHLs obtained in the proposed meminductor emulator is 5KHz.

Table 1: Comparison of proposed meminductor emulator with other emulators in the literature

Reference	Active components	Passive Components	Memristor-less	Operating Frequency
6	8 CCII+s, 1 AD633, 5 opamps,1 memristor	11R, 3C	No	8Hz
7	1 VDTA, 1 CDBA	2C	Yes	2MHz
8	4 CCII+, 1 multiplier, 3 op amps	8R, 1C	Yes	36.9Hz
9	1 multiplier, 3 op-amps, 10 MOS	2R, 2C, 1L	Yes	300Hz
10	3 CCII+, 3 op amps, 1 multiplier, 1 memristor	3R, 1C	No	21.1Hz
11	3 CCII+, 1 adder, 1 multiplier	3R, 2C	Yes	10Hz
12	1 integrator, 3 op amps	3R, 2C	Yes	10Hz
13	2 VDTA	1R, 2C	Yes	1MHz
14	1 op amp,1 memristor	1R, 1C	No	-
15	1 memristor, 1 CBTA	1C	No	250kHz
16	7 multipliers, 9 op amps	26R, 2C	Yes	200Hz
17	1 CFOA, 1 OTA, 1 multiplier, 2 CCII	7R, 2C	Yes	5kHz
18	1 DVCCTA	1R, 2C	Yes	900kHz
19	1 op-amp, 4 CFOA, 1 Varactor Diode	5R, 3C	Yes	22kHz
20	1 op-amp, 5 CCII+, 1 multiplier	4R, 3C	Yes	5kHz
21	3 op-amps, 3 AD844, 1 AD633,1 memristor	10R, 2C	No	16Hz
Proposed Work	2 op-amps, 1 memristor	3R, 1C	No	5KHz

6. APPLICATION OF PROPOSED MEMINDUCTOR

A high pass filter was created utilising the proposed meminductor emulator, as illustrated in *Figure 8*, to verify its rise time, fall time, stability, and overall functioning. The resistor and capacitor values are set to 0.5kΩ and 2μF, respectively.

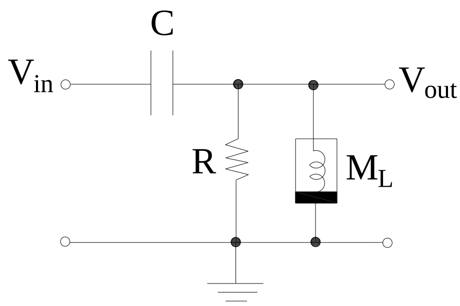

Figure 8: High Pass Filter using proposed meminductor emulator

The AC response in *Figure 9(A)* clearly shows that the circuit behaves as a high pass filter with a 3dB frequency of 360Hz. The *Figure 9(B)* shows the step response of the filter and it can be observed that there is no overshoot and ringing in the output. The proposed meminductor emulator's performance has thus been validated.

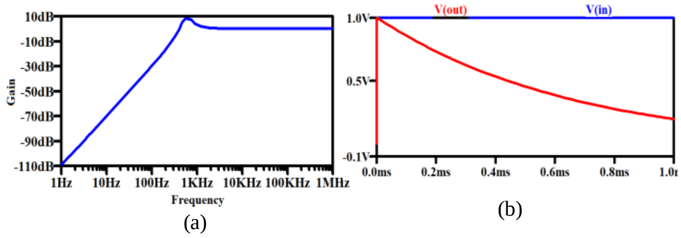

Figure 9: Responses of high pass filter (a) AC response (b) step response

7. CONCLUSION

A meminductor emulator was created using a generalised impedance converter and a memristor. Because the pinched hysteresis loops are undistorted up to 5kHz, this emulator operates over a frequency range of 5kHz. The proposed emulator has been found to work well across a wide temperature range by temperature analysis. The proposed circuit is simple to build and uses inexpensive off-the-shelf components. In order to test the circuit's performance, a high pass filter has also been implemented. It can be concluded that the approach used in this

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paper is viable and can be used in many other circuits to simplify them. This will allow many students to understand their workings more easily and in turn boost the development and interest of electronics in the students.

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