Instrumentation Amplifier design: Comparison of CMOS-memristive to CMOS design

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Abstract—An instrumentation amplifier (InAmp) is an electronic device used in many applications, where test and measuring accuracy is required. However, one of the drawbacks of an InAmp is limited operation gain range. In this paper, we investigate the possibility of replacing CMOS transistors in InAmp with memristive devices. The application of memristors in CMOS instrumentation amplifier design has lead to reduction of on-chip area and power consumption, comparing to the original design. The memristor based implementation of InAmp design has an improved gain. The advantages of memristor application are shown, and DC and operation gain range are discussed in this paper. Furthermore, variability analysis and performance variation with respect to the temperature variation is provided. In addition, the noise sensitivity analysis is performed. Moreover, varying values of resistance levels of memristors, the operation gain range, gain accuracy as well as a the noise reduction can be improved.

Index Terms—CMOS, memristor, Instrumentation amplifier, Operational Amplifier

I. INTRODUCTION

An InAmp is known for its high controlled gain and high common mode rejection ratio. In addition, there is no need in input impedance matching, which makes an InAmp useful for testing and measurements of a variety of equipments. The characteristics such as high gain, high common mode rejection ratio and absence of input impedance matching make an InAmp accurate and sensitive to input changes [2]. However, operation range and DC precision can be improved. Furthermore, temperature and noise analysis of CMOS-memristor InAmp circuit design need to be performed, to make further improvement of InAmp design.

In this paper, we proposed the CMOS-memristive design of instrumentation amplifier. There are several recent works that illustrate the advantages of memristive circuits [11], [14], [10], [3] in terms of power and area consumption; however, the memristor-based instrumentation amplifier is an open problem. Therefore, in this paper we investigate the possibility of replacing resistors in the conventional instrumentation amplifier by memristive devices and show the advantages that can be achieved in terms of the amplifier performance, on-chip area and power consumption.

II. BACKGROUND

Instrumentation amplifier (InAmp) is a differential amplifier consisting of three operational amplifiers (OpAmp): two buffer input OpAmps and one output OpAmp. Two buffer OpAmps are used to avoid impedance matching and increase input impedance significantly, this makes an InAmp be especially useful in measurement and testing [2].

Fig. 1: InAmp circuit.

There are numerous advantages of InAmp: high accuracy, high gain, relative independence from external factors and stability. However, there is a limitation in operation range. For instance, the operation range of op-Amp is larger than the one of InAmp.

The methods to enlarge an operation range, as well as to increase gain by implementing memristors in the InAmp circuit will be discussed further in this paper. Moreover, area and dissipated power calculation will be performed.

III. METHODOLOGY

A. Simulation circuits

An InAmp CMOS design consisting of three stage CMOS-memristive Op-Amps is to be considered, as illustrated in Figure 1. The Design of InAmp [5] shown in Figure 3 contains three OpAmps of design [5].

Initially, transistors in Op-Amps are to be checked for saturation. That is, if the $I_{ds}$ of the transistor is constant, regardless the value of $V_1$, the transistor is in its saturation region. This means the transistor imitates a short circuit between a collector and an emitter. Therefore these transistors can be replaced with the memristors. Firstly, transistor will be replaced in the OpAmps, and after that in InAmps, which consist of these OpAmps. Obtained CMOS-memristive circuit of OpAmp can be seen in Figure 2, whereas CMOS-memristive circuit of
InAmp is illustrated in Figure 3. It should be noticed that the subcircuits of OpAmp are denoted with rectangular boxes.

Thus, the current is:

\[ I = \frac{V_1 - V_2}{R_g} \quad (4) \]

Voltage between node a and b can be expressed as:

\[ V_a - V_b = \frac{V_{in} * (2*R_1 + R_g)}{R_g} = \frac{V_{in} * (2*R_1/R_g + 1)} {R_g} \quad (5) \]

The output voltage of InAmp is determined as:

\[ \frac{V_0}{V_{in}} = \frac{(2*R_1/R_g + 1) * (2*R_1)} {R_2} \quad (6) \]

**C. Small Signal Model Analysis**

Op-Amp can be represented as following small-signal model shown in Figure 4.

\[ V_{in2} = R_{in} * (G_{m1} * V_{in} - i_x) \quad (7) \]

\[ i_x = (G_{m2} * V_d - g_{m2} * V_{in}) \quad (8) \]

\[ V_{out} = R_{out} * (G_{m2} * V_{in2} + i_x) \quad (9) \]

**IV. SIMULATION RESULTS**

**A. Memristor simulations**

Memristor is a passive circuit element, where the ratio of a derivative of magnetic flux linkage to a derivative of charge flowing through a memristor is determined as memristance. Moreover, a dependence of current on voltage across a memristor can be illustrated as a hysteresis. The form of hysteresis depends on such parameters of a memristor model as \( R_{on}, R_{off}, \) throughput voltage, etc. The parameters of the memristor model used in design of the OpAmps and the InAmp are as follows: \( R_{on}=3k, R_{off}=62k, V_{th}=1, a=10, \) and \( R_{ini}=10k. \) The IV characteristics of the memristor model are presented in Figure 5.
B. Gain

One of the main operation parameters of the InAmp is differential gain which can be calculated as follows:

\[ \text{Gain} = \frac{V_{\text{out}}}{(V_1 - V_2)} \]  

(10)

For the brevity of calculations, the simulations were performed for \( V_1 \) equal to 1 Volt and \( V_2 \) equal to 0 Volt. So, for this case \( \text{Gain} = V_{\text{out}} \). The graph representing output and input voltage relations for CMOS InAmp circuit is illustrated in Figure 6; whereas for CMOS-memristive InAmp circuit the relations are shown in Figure 7. From Figure 6 and 7, a directed relation between output and input voltage magnitudes can be observed. In addition, the output voltage magnitude starts to saturated at about -1.5315 V for CMOS InAmp design and at -1.7920 V for CMOS-memristive design. This means the gain magnitude of CMOS-memristive circuit is higher than the one of the original circuit.

C. Operation range

Another parameter of InAmp which needs to be improved is operation range. The operation range analysis can be performed by plotting gain-frequency graph for both InAmp designs.

Figure 8 and Figure 9 represent gain vs frequency graphs for CMOS and CMOS-memristive designs of InAmp respectively. From Figure 8 it can be noticed that the operation range of CMOS InAmp design is about 10 MHz. In comparison, the operation of CMOS-memristive design is larger than 10 THz and is predicted to be infinite from Figure 9. Moreover, the gain increased significantly from about -32 dB to -8 dB. This verifies result obtained from Figure 6 and 7, that gain of CMOS-memristive InAmp design is higher than for the original circuit.
D. Area and Power Calculation

Area of instrumentation amplifiers was calculated for the both cases: CMOS and CMOS-memristive InAmp designs. (0.6μm*0.18μm size CMOS transistors and 0.185μm*0.112μm size memristors are used in the designs). As for power calculation, it is known that the magnitude of dissipated power is equal to the magnitude of supplied power in an electronic circuit. Therefore, average dissipated power for both designs is calculated by summing power provided by each voltage source. The computations were performed by LTspice Software. The computation results both for area and power are shown in Table 1.

| TABLE I: Area and Power Calculation | Area ($Pm^2$) | Power (W) |
|------------------------------------|--------------|-----------|
| CMOS InAmp design                  | 3.348        | 3.33064   |
| CMOS-memristive InAmp design       | 2.910        | 0.36536   |

From Table 1, it can be clearly seen that the circuit area of CMOS-memristive InAmp is noticeably less than the one of CMOS design (2.910 $Pm^2$ compared to 3.348 $Pm^2$).

Regarding the power, it can be clearly seen that the average dissipated power of CMOS-memristive is 9.12 less than the one of CMOS design being 0.36536 W and 3.33064W respectively.

E. Total Harmonic Distortion (THD)

Total harmonic distortion for the InAmp designs were computed by the means of MATLAB software. From data presented in Table 4, THD increased from 29.4 percents to 48.3 percents.

| TABLE II: Output voltage THD Calculation | THD (percents) |
|----------------------------------------|----------------|
| CMOS InAmp design                      | 29.4           |
| CMOS-memristive InAmp design           | 48.3           |

F. Temperature analysis

In addition to the parameters analyzed, the influence of environment temperature on InAmp should be determined. To compare the operation of the designs, the simulation were implemented for temperature increasing from 0 to 100 Celsius degrees, with a step of 10 Celsius degrees. From Figure 10 and Figure 11, it can be observed that the gain for both for CMOS and CMOS-memristive design remain constant, regardless of the environment temperature. In addition, the operation range of CMOS-memristive is larger than the one of CMOS design, being above 1THz (and approaching infinity) and 10 MHz respectively. The same result has been obtained in the Operation range section and shown in Figures 8 and 9.

G. Noise analysis

Furthermore, output noise voltage need to be considered. The results of noise analysis performed in LTspice software are illustrated in Figure 12 and Figure 13. From Figure 12 and 13, it can be seen that output noise voltage is approximately 12 higher in CMOS circuit rather than in CMOS-memristive circuit, being 1.2 $uV/Hz^{1/2}$ and 100 $nV/Hz^{1/2}$ respectively. Furthermore, the point where the noise saturates to 0 for CMOS design is about 100KHz, whereas the saturation point for the CMOS-memristive design is above 100 GHz.

V. DISCUSSION

After numerous parameter analyses have been performed, advantages and disadvantages of CMOS-memristive InAmp
design can be discussed. From one hand, CMOS-memristor design has higher gain as compared to the original CMOS design. Moreover, it should be noticed that the operational range of CMOS-memristive circuit is higher than that of the CMOS design, being above 1 THz; further study on operational range behavior is suggested to be performed. Furthermore, from Table 1 it can be clearly seen that usage of memristors in In Amp circuit design makes the area of the circuit approximately 1.15 smaller. In addition, there is 9.12 times less dissipated power in CMOS-memristive design than in CMOS design. Less amount of dissipated power and less operation space make CMOS-memristive design more effective in terms of speed and heat dissipation. In addition to that, there is approximately 12 times less output noise in the CMOS-memristive circuit, comparing to the original CMOS circuit. Moreover, both CMOS-memristive and CMOS In Amp circuits are found to be resistant to environment temperature changes.

On the other hand, for CMOS-memristive circuit design, THD is increased from 29.4 percents to 48.3 percents when memristors have been implemented in the design. Further study on THD should be done, to analyze the influence of memristor presence on total harmonic distortion.

VI. CONCLUSION

Having implemented a variety of simulations, it can be concluded that CMOS-memristor circuits makes the design of instrumentation amplifiers more efficient by decreasing the area occupied and power dissipated. In addition, CMOS-memristive In Amp design has significantly higher gain and is not sensitive to temperature changes. Furthermore, it is shown that CMOS-memristive circuits introduce about 12 times less noise voltage than the original circuits. It is suggested to study the influence of memristance values on such parameters of CMOS-memristive In Amp design as gain, operational range, power dissipation and temperature changes. Especially, operational range and THD analysis should be studied further.

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