DESIGN AND IMPLEMENTATION OF A CIRCUIT FOR ANALOG LINEAR REGRESSION

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Abstract : With the emergence of VLSI Technology in electronic industry, the numerous applications of integrated circuits in high-performance computing, consumer electronics, and telecommunications has been rising steadily, and at a very fast pace. The regression models play a key role in many application domains for analyzing or predicting a quantitative dependent variable based on one or more independent variables. The focus of this paper is to design and implementation of a circuit for analog linear regression which can be used as a wave shaper in signal processing. The analog linear regression model comprises of analog components like multipliers, adders, differentiators and analog memory circuit. The proposed architecture is designed using 180nm CMOS technology with Cadence virtuoso tool.

***IndexTerms*: Analog linear regression, wave shaper.**

I. INTRODUCTION

Many of the digital models have being replaced by the analog models in order to overcome the drawbacks of digital system and exploit the advantages of the analog system. The area of the analog system is less than the digital system, for example: the required area for analog multiplier is less than the digital multiplier [1].The digital systems requires analog to digital converters in addition to process the analog signals, but the analog systems can directly process the analog signals. Therefore real time processing can be achieved. All these advantages of analog circuits motivated to design and implement the linear regression model using analog circuits.

Machine learning (ML) is the scientific study of algorithms and statistical models that systems use to effectively perform a specific task without using explicit instructions, relying on patterns and inference instead. Machine learning is a subset of artificial intelligence. Machine learning algorithms build a mathematical model of sample data, known as "training data", in order to make predictions or decisions without being explicitly programmed to perform the task. Linear regression is supervised Machine Learning algorithm which is a linear approach to modelling the relationship between a dependent variable and one or more independent variables. Regression analysis is a statistical technique for modeling a quantitative dependent variable Y as a function of one or more continuous or categorical independent variables X_1 to X_n. Common applications of regression models include prediction and sensitivity analysis of Y with respect to changes of independent variables. The analog linear regression model proposed in this paper, learn from the training data which are continuous time signal.

II. PROBLEM STATEMENT

Design and implementation analog linear regression model. Simple linear regression is a type of regression analysis where the number of independent variables is one and there is a linear relationship between the independent(x) and dependent(y) variable. In the proposed work the first order linear equation is designed and implemented using analog circuit.

First order linear equation:

$$y = m.\, x + c \qquad (1)$$

where, y = output, x = input, m = coefficient of x, c = intercept

III. METHODOLOGY

Design of analog linear regression model:

First order linear equation:

$$y(t) = m \, . \, x(t) + c \qquad (2)$$

where, y(t)= output signal, x(t)=input signal, m= coefficient of x(t), c= intercept

The motive of the analog linear regression algorithm is to find the best values for m and c to have a best fit.

Error Function

The error function helps to figure out the best possible values for m and c which would provide the best fit line. In order to minimize the error between the predicted value and the actual value the error function shown below is used

$$Error\ Function = \frac{1}{t}\int_0^t (pred(t) - y(t))^2\, \mathrm{dt} \qquad (3)$$

The difference between the predicted values and required values gives error difference, it is then squared and summed over all data points and divided by the total number of data points. This provides the average squared error over all the data points. Therefore, this error function is also known as the Mean Squared Error (MSE) function. By, using this MSE function the values of m and c are changed such that the MSE value settles at the minima.

Gradient Descent Algorithm for Continuous Function:

The linear regression is gradient descent. Gradient descent is a method of updating m and c to reduce the error function (MSE). The idea is to start with some values for m and c and then change these values iteratively to reduce the error.

To update m and c, gradients from the error function is taken. To find these gradients, partial derivatives are taken with respect to m and c.

$$\mathrm{m} = \mathrm{m} - \frac{2}{t}\int_0^t \big(pred(t) - y(t)\big).\ x\,(t)\; d(t) \qquad (4)$$

$$\mathrm{c} = \mathrm{c} - \frac{2}{t}\int_0^t (pred(t) - y(t))\ \mathrm{d(t)} \qquad (5)$$

Proposed Model:

By using the equation (4) and (5) the m and c values are updated and the analog linear regression model is constructed as shown in figure 1. The proposed analog linear regression model will perform two task, learning and classification. During classification the input data is classified into different classes and during learning the input signal and the target signal are applied to the model, the proposed analog linear regression model will update the values of m and c by using Gradient Descent Algorithm as explained in designing section.

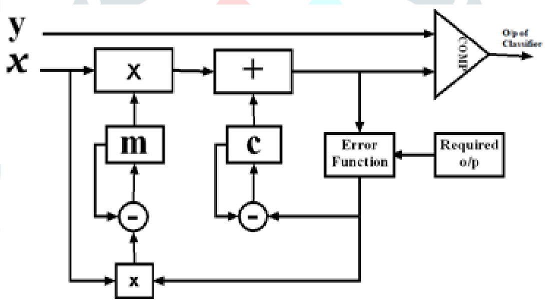


Figure 1: Proposed Analog Linear Regression Model

Implementation of Proposed Analog Linear Regression model Using MATLAB Simulink

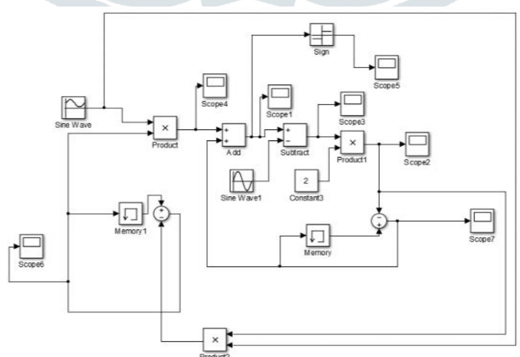
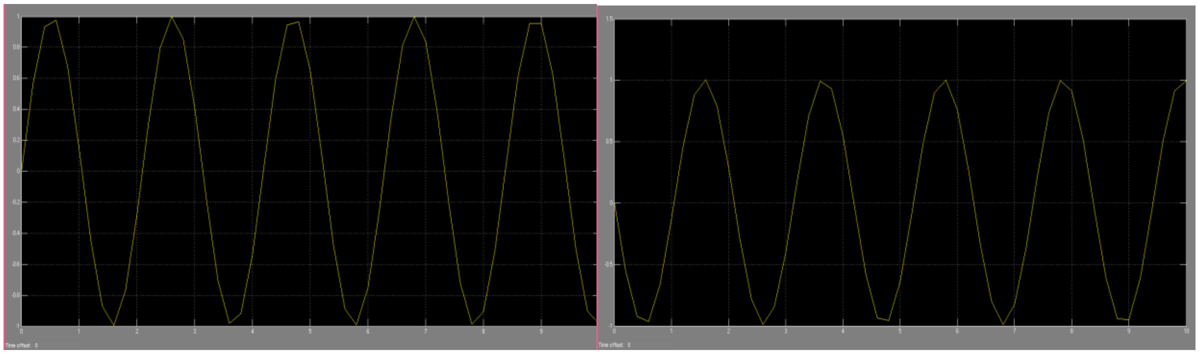


Figure 2: Implementation of Proposed Analog Linear Regression Algorithm Using MATLAB

The circuit in the figure 2 shows the implementation of the linear regression algorithm using MATLAB tool. The proposed analog linear regression model is implemented using the functional blocks.

Training of the Designed Analog Linear Regression model:

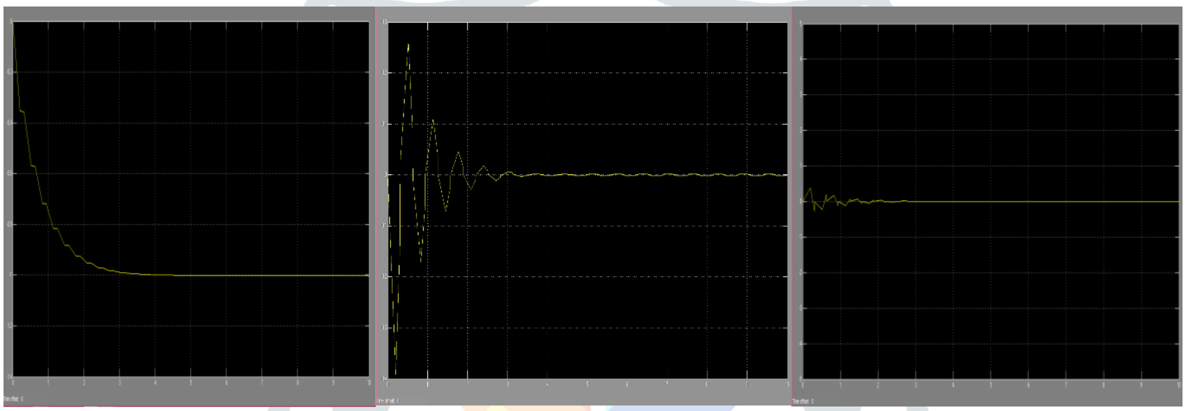
The inputs are given to the designed analog linear regression model shown in the figure 2, the input signals are shown in figure 3.



(a) (b)

Figure 3: (a) Input Signal, (b) Target Signal

The figure 4 shows the obtained m, c and error when the input signals are given to the analog linear regression model.



(a) (b) (c)

Figure 4: (a) Obtained m value from the proposed model, (b) Obtained c value from the proposed model, (c) Output of Error Function

Verification Circuit:

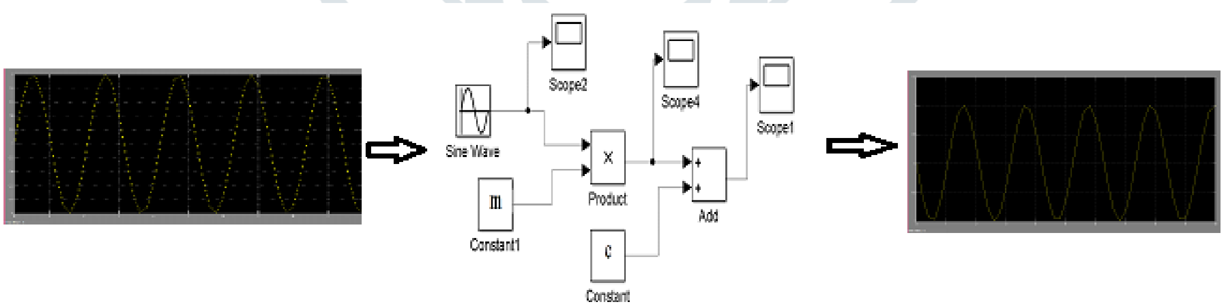


Figure 5: Verification Circuit

Verifying the designed analog linear regression circuit by applying input signal, m and c value obtained to the circuit shown in figure 5, the output signal obtained from the verification circuit will be 180 degree out of phase with respect to input signal.

Realization of the Proposed Analog Linear Regression Model Using Analog Component

1 Gilbert Multiplier

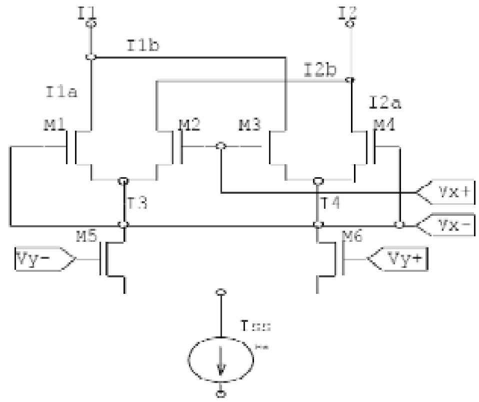


Figure 6: Gilbert Multiplier

In figure 6 the basic Gilbert cell structure is presented [6]. Assuming all transistors are biased in the saturation region and obey the ideal square law equation and that devices are sized and matched so that the transconductance parameters satisfy K1=K2=K3=K4=Ka and K5=K6=Kb.

Defining the output current $I_0=I_2-I_1=-(I_{2b}+I_{2a})-(I_{1a}+I_{1b})$, it can be shown that

$$I_o=\sqrt{2Ka}\ Vx\left[\sqrt{I3}\sqrt{1-\frac{Ka\ Vx^2}{2\ I3}}-\sqrt{I4}\sqrt{1-\frac{Ka\ Vx^2}{2\ I4}}\right] \quad (6)$$

If we demand

$$\frac{Ka\ Vx^2}{2\ I3} \ll 1\ \ and\ \ \frac{Ka\ Vx^2}{2\ I4} \ll 1 \quad (7)$$

It follows that Io depends linearly on Vx

$$I_o \cong \sqrt{2Ka}\ (\sqrt{I3}-\sqrt{I4})\ Vx \quad (8)$$

While the currents I_3, I_4 can be expressed as by

$$Vy = \frac{1}{\sqrt{Kb}}\left(\sqrt{I3}-\sqrt{I4}\right) \quad (9)$$

Substituting Vy and Io expression, it follows that

$$I_o = \sqrt{2KaKb}\,Vx\ Vy \quad (10)$$

The output current yields an ideal analog multiplier. Notice that since both I_3 and I_4 are I_{SS} and V_Y dependent, both V_Y and V_X must be kept small to maintain good linearity.

2. Summing amplifier and Differential amplifier:

The Summing amplifiers are used to add two signals which is shown in figure 10, the unit gain summing amplifiers are used in the proposed model.

The Differential amplifiers are used to take the difference of two signals which is shown in figure 11. The unit gain differential amplifiers are used in the proposed model.

3 Sample and Hold Circuit

Sample & Hold Circuit is employed to sample the given signal and to hold the sampled value. Sample and hold circuit is employed to sample an analog signal for a short interval of time in the range of 1 to 10μS and to hold on its last sampled value until the input signal is sampled again. The holding period may be from a few milliseconds to several seconds.

The figure 7 shows the block diagram of a typical sample and hold amplifier.

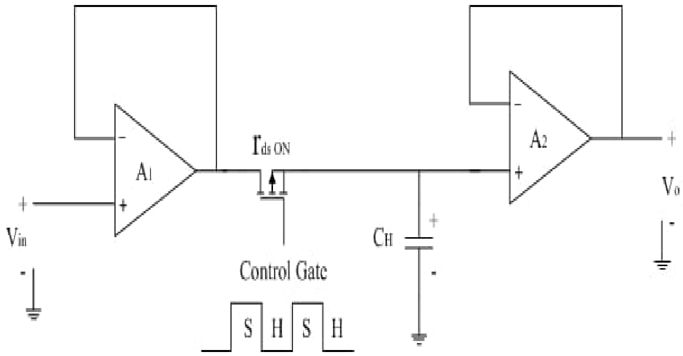


Figure 7: Sample and Hold Circuit

IV. RESULTS

The following figure 8 shows the circuit schematic of a Gilbert Multiplier designed using cadence virtuoso tool and Transient Response. The entire circuit design is carried out using 180nm VLSI technology. Figure 9 shows the transfer characteristic of Gilbert Multiplier.

(a) (b)

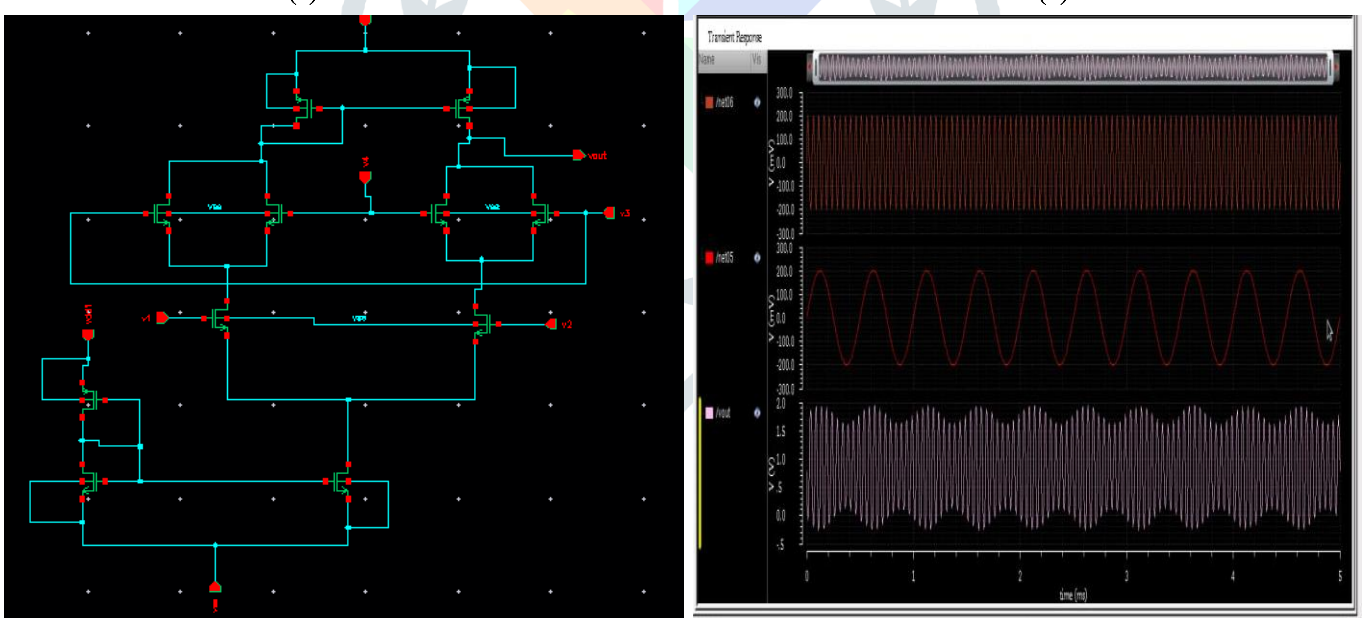


Figure 8: (a) Schematic of Gilbert Multiplier (b) Transient Response

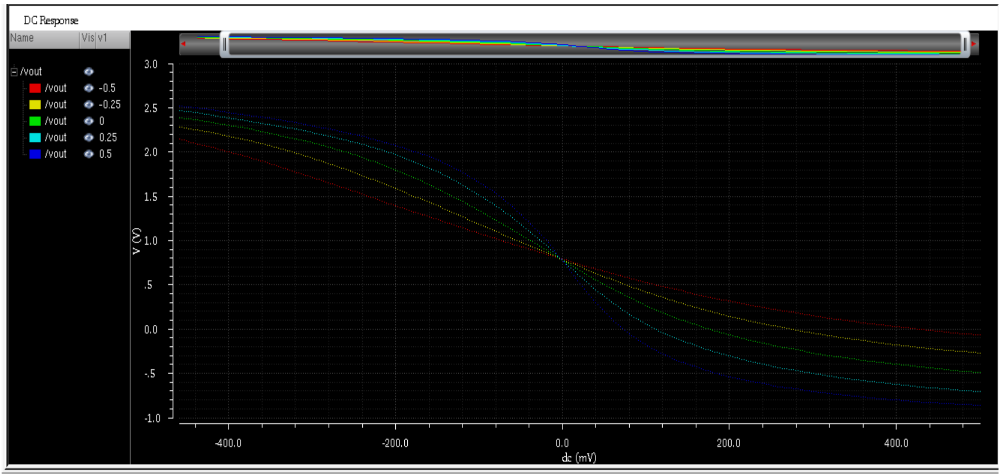


Figure 9: Transfer Characteristic of Gilbert Multiplier

Figure 10 and 11 shows the circuit schematic and Transient Response of summing and differential amplifier respectively.

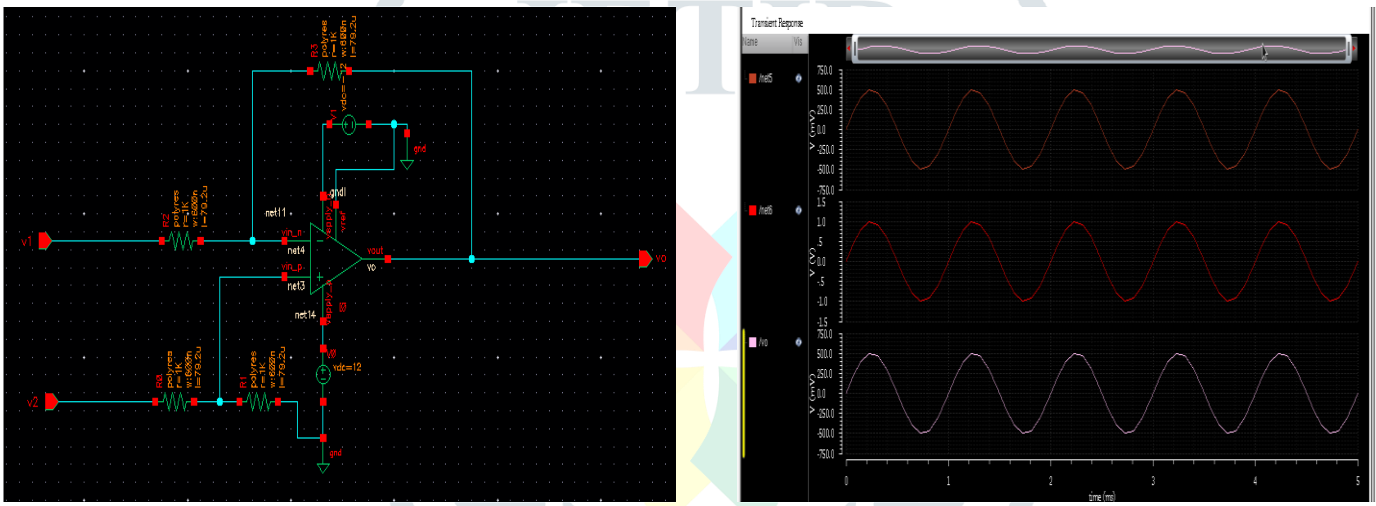


Figure 10: Summing Amplifier circuit and its Transient Response

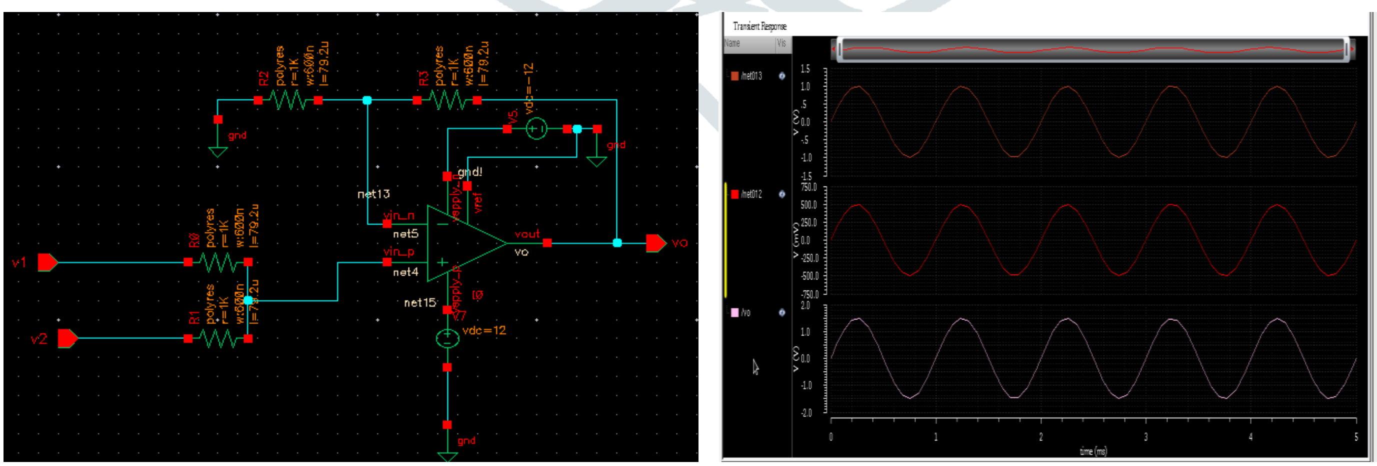


Figure 11: Differential Amplifier circuit and its Transient Response

Figure 12 shows the circuit schematic and Transient Response of Sample and Hold Circuit

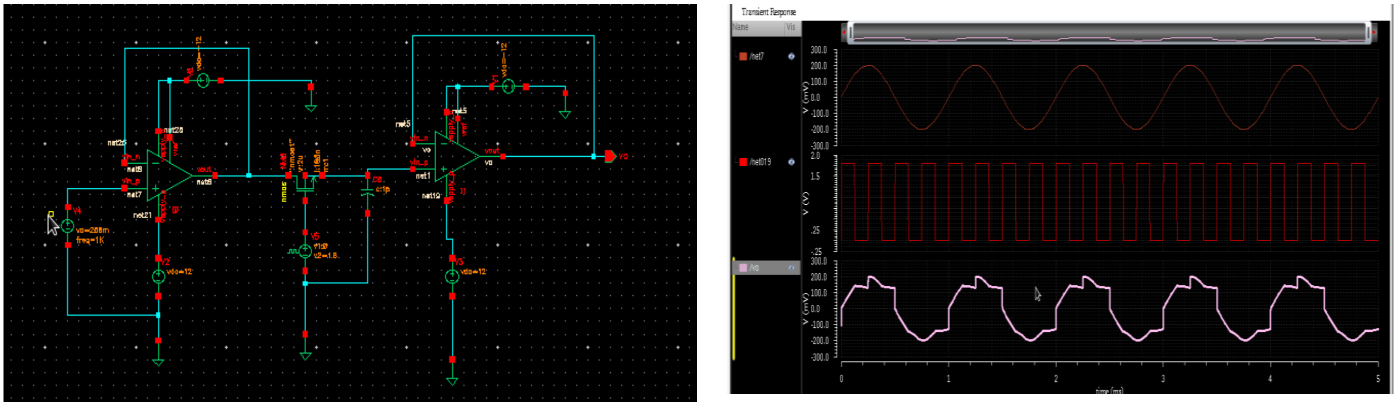


Figure 12: Sample and Hold Circuit and its Transient Response

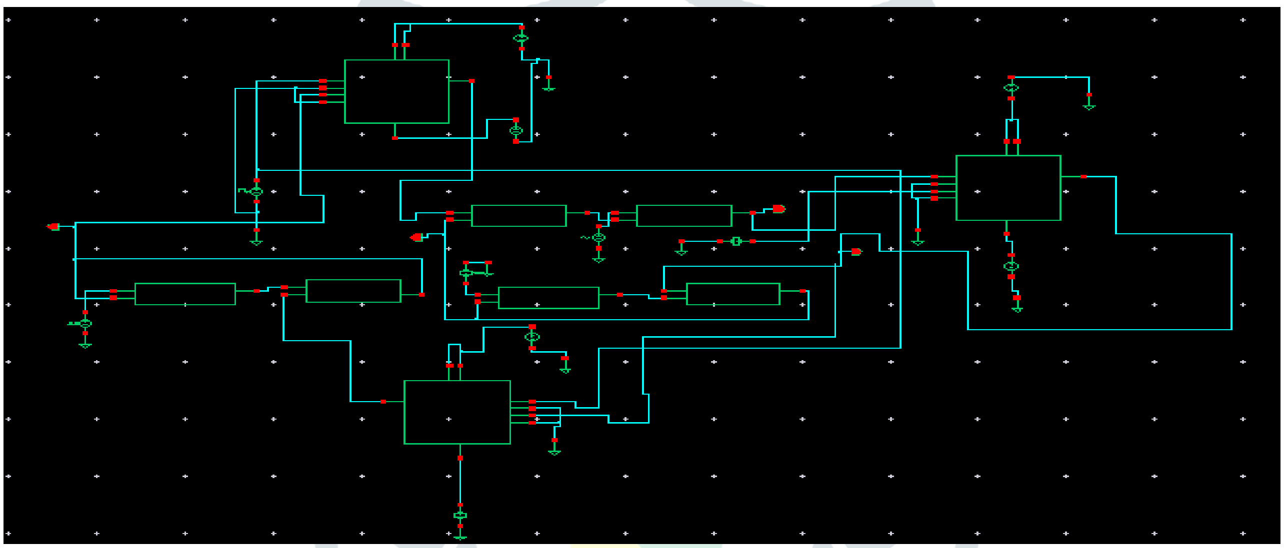


Figure 13: Implemented analog linear regression circuit

The figure 13 shows the implementation of the proposed analog linear regression model using cadence virtuoso tool and figure 14 shows the output obtained from the model when the input and the target signals are applied to the model.

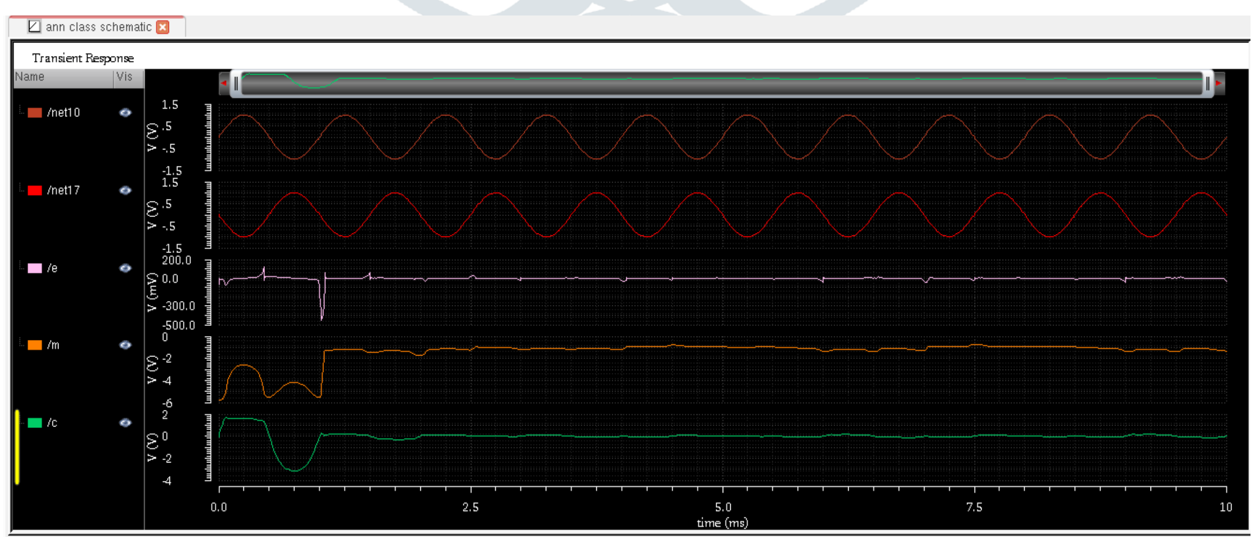
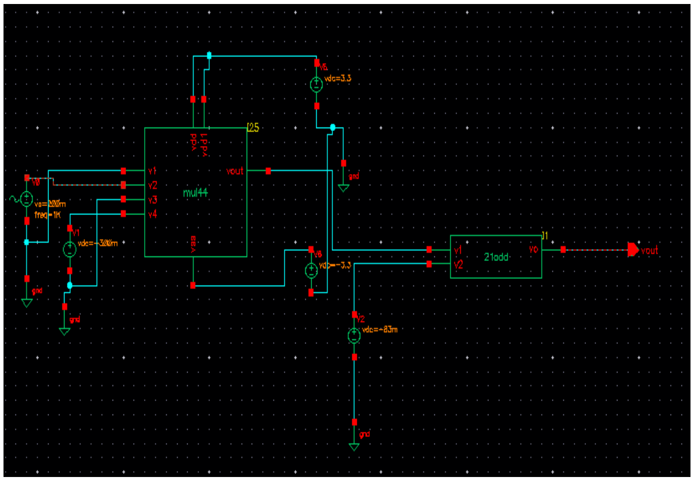


Figure 14: Transient Response of Analog Linear Regression model



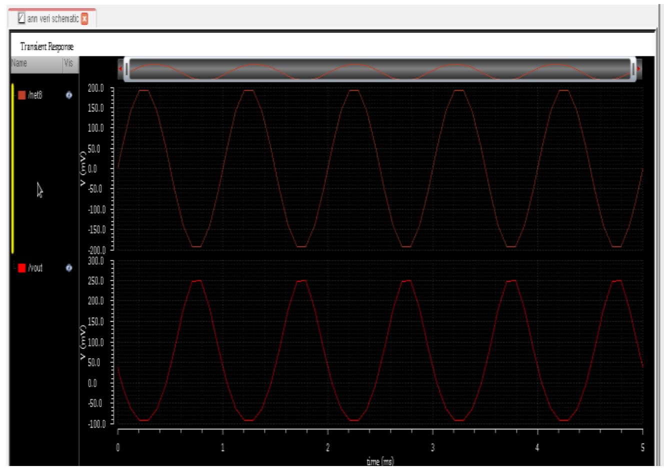


Figure 15: Verifying Circuit and its Output

The designed analog linear regression circuit is verified by applying input signal, m and c values obtained to the circuit shown in figure 15.

V. CONCLUSION AND FUTURE WORK

Design and simulation of analog linear regression of first order using MATLAB tool has been successfully done and also implemented the analog linear regression circuit using Electronic circuit simulator tool like Cadence. The proposed analog regression model in this paper can be used as wave shaper in signal processing. , further work could be done to implement the higher order linear regression models.

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