Implementation of linear trace moisture sensor by nano porous thin film moisture sensor and NLAmp

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Abstract: Almost all type of moisture sensors has a non-linear response. With out linearization it is difficult to apply such a non-linear sensor in electronics circuits, specially in analog electronics. Non linear sensor and transducers characteristic can be linearized using analog electronics or digital electronics. In this paper a method of linearization of such non-linear sensors characteristics using analog electronics is described. Theoretical explanation of the methods and its verification by experiment is stated in this paper. It may possible to linearize any non linear characteristic using this method. We use thin film nano porous trace humidity sensor as a non linear device for the circuit justification. The fabrication process of the sensor is also described in this paper.

Keywords: Differential slope, Amplifier gain control, Analog multiplexer, Trace moisture sensor, PWM.

1. INTRODUCTION

Most of the transducers are non linear in character [1-5]. There are several methods employed for linearization of non-linear transducers characteristic both in digital and analog electronics. Microcontroller based digital linearization follows look up table which is one of the popular methods but lack in accuracy [1, 24, 25]. For better accuracy less table spacing is required. i.e. more memory is require for better accuracy. Analog linearization technique may be used to increase the sensor smartness [6]. We know that non linear curve is the summation of segmental linear curve with different slope. We have to convert these different slope linear parts into a constant slope. Non linear characteristic is divided into small segments and slope of the curve is calculated. Different slope of each segment is fed into an amplifier of variable gain to fit the formula y = mx + c. The non linear curve is divided into segments by means of comparator circuit. The amplifier gain is controlled by the digital circuit. The output of the amplifier is linear in nature as expected and verified by experiments. Capacitive type moisture sensor is easy to fabricate. A basic property of sensing moisture is the condensation of water molecule in the pore present at the surface of the sensor [7-13]. Thin film trace moisture sensor has a non linear response of capacitance with moisture as describe in [2, 3] and we have used this for our circuit justification. We extract the voltage signal from the thin film sensor by the means of pulse width modulation (PWM) control circuit and a low pass filter [14]. The voltage signal from the circuit is found to be non linear with the moisture. The linearization of this non-linear response is done by the proposed circuit.

2. THEORETICAL APPROACH

A non linear characteristic is shown in figure-1. This characteristic breaks into some segments as shown in figure-2. From this figure the slope of the each segment as ‘m1’, ‘m2’, ‘m3’, ….., ‘m11’ are measured. Consider a linear characteristic of slope ‘M’. Calculate the slope ratio for the each segment with the approximated linear curve and multiply the input signal with this ratio to achieve the constant slope. For each segment a segment corrector is added to achieve the continuous linear line. The complete discussion can be expressed as

$$Y(x) = \sum_{i=1}^{n} \left(y(x) \times \tfrac{M}{m_i} + Y_i \right) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where n is the number of segment

y(x) is the physical variable, have to be linearized.

m_i is the i-th segmental slope

M is the desired constant slope.

Y_i is the i-th segment corrector.

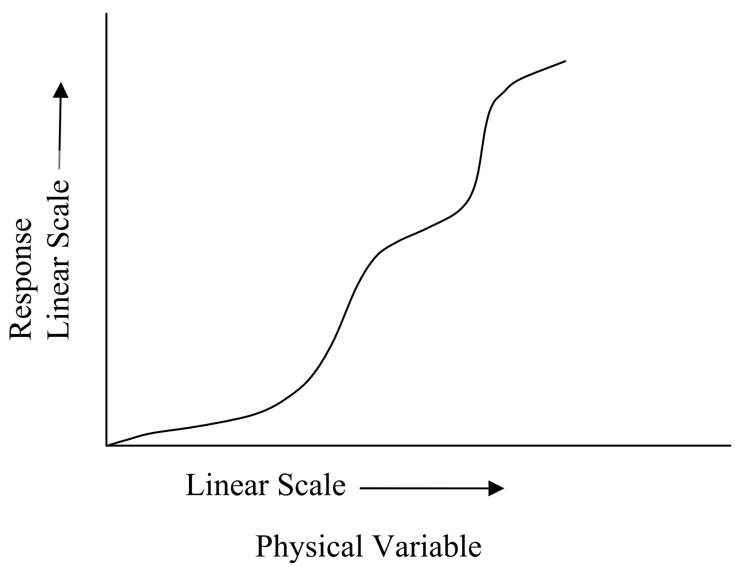


Fig-1: A Non-Linear Response with Physical Variable

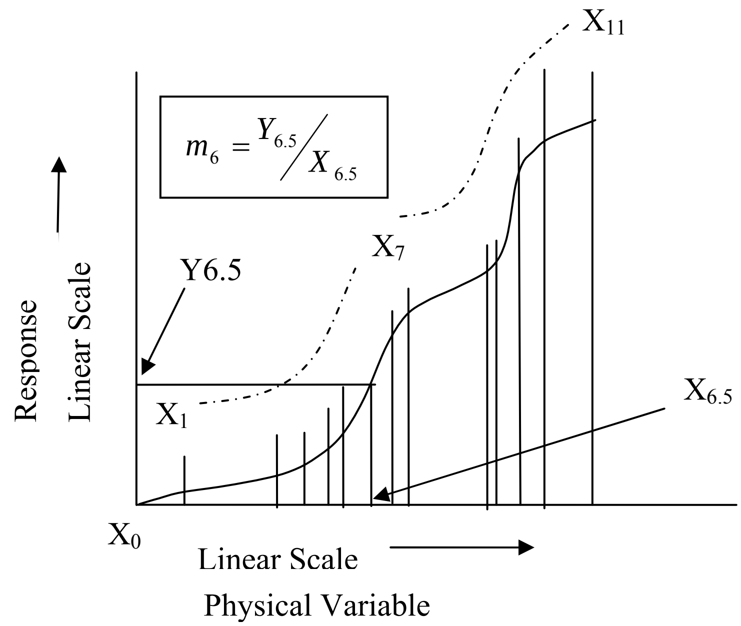


Fig-2: Segmental Graph with Slope Calculation

3. CIRCUIT DESCRIPTION

Schematic diagram of the proposed non linear amplifier (NLAmp) circuit is show in figure-3. Here we consider the circuit for only eight segments. For more accuracy the segmental strength is increased. The circuits mainly have four parts

1. Reference voltage generator
2. Segmentation of the analog signal
3. Gain control of the amplifier
4. Step error corrector.

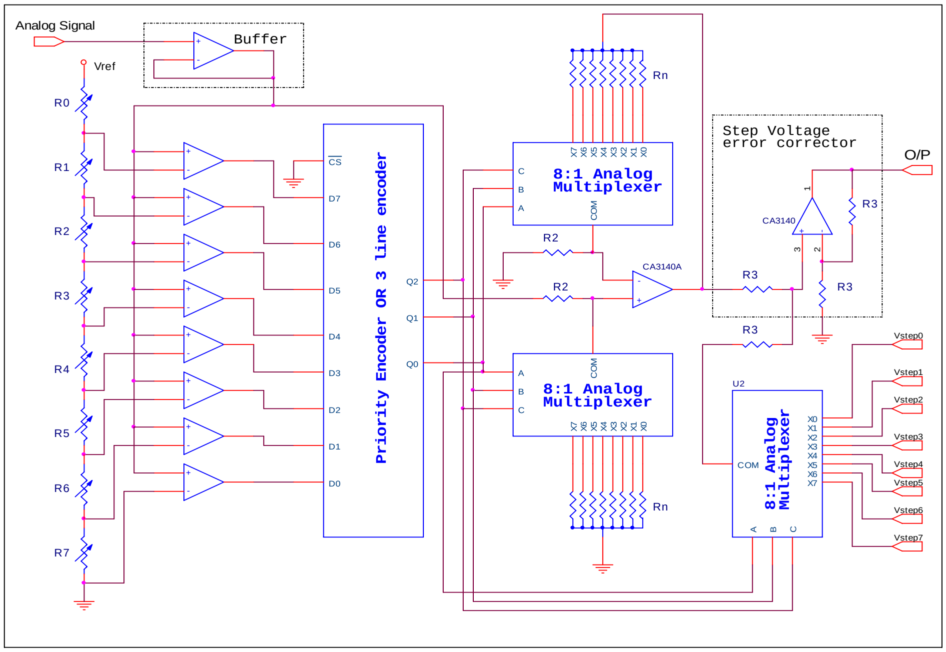


Fig-3: Non-Linear Amplifier Circuit Details

The step-reference voltage is regenerated by the divider network and a constant voltage source. The characteristic is segmented by the comparator and the step-reference voltage. Comparator produces the signal for the 3-bit encoder. The encoder then encodes the signal to multiplexer which controls the appropriate gain of the amplifier according to signal strength. The step corrector circuit corrects the offset part by adding the offset voltage.

4. EXPERIMENT

4A: SENSOR PREPARATION

The most common techniques for the preparation of sol gel films involve primarily spin coating [8,10,15-17], dip coating [18-20], spray pyrolysis [21] etc. Crack free thin-film preparation is challenge [22]. In sensor technology it is an important aspect. Here porous gel samples of oxide were prepared by technique of Yoldas [23]. Hydrolysis was performed by introducing Al-sec.-butoxide ($AlC_{12}H_{27}O_3$) into excess amount of water and solution was peptized by adding 1.6(N) NHO_3 acid and the solution was kept at

90^{o}C under stirring for 1 hr. Solution was added with binder and coated five times on a gold coated α-Alumina Substrate of size (10 mm x 20 mm x 1 mm). Second electrode was formed on film coated substrates. It was then finally fired at 950^{o}C for cuing the electrodes (Fig. 5). The following procedure was adapted for preparation of films. The binder mixed sol was important for reproducible film. The films were deposited on gold coated α-alumina substrate by dipping them in the prepared sol, then pulling out with a speed of 10 cm/min. 4 times with sol of Higher Surface tension. This was followed by drying and then sintering the films between 450^{o}C – 500^{o}C for a period ranging from 4 to 5 hrs.

For obtaining higher thickness films, the sequence of dipping, drying and then dipping again was performed a number of times. The sintering was done only after the final dipping. The thickness of the film increased almost linearly with respect to a number of dipping. Film thickness ranging 3-10 μm was subjected to microstructural and morphological measurements and characterizations of electrical properties.

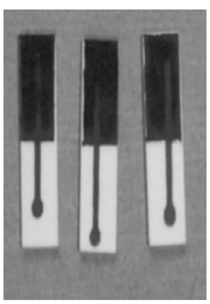


Fig.4: Before Sintering

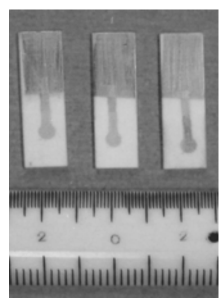


Fig.5: After Sintering At 950^{0}C

4B: CHARACTERIZATIONS OF THE THIN FILM TRACE MOISTURE SENSOR

The measurement set-up for trace moisture response analysis is shown in figure-6a and the picture of the complete set-up is shown in figure-6b. Dry nitrogen gas is mounted with trace moisture in a closed chamber. SHAW moisture meter is used for monitoring the trace moisture. The sensitivity of the sensor is plotted in figure-7. It shows the change in capacitance with the moisture which is a non linear curve.

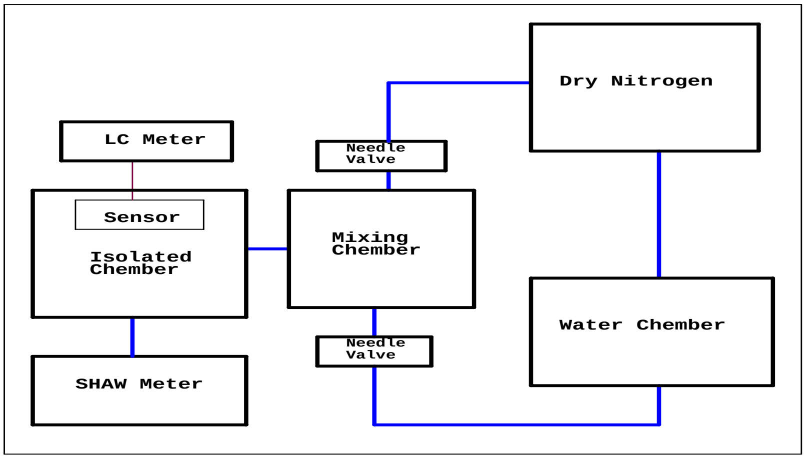


Fig-6a: Trace Moisture Measurement Set-Up

Fig-6b: Experimental set-up for sensor characterization

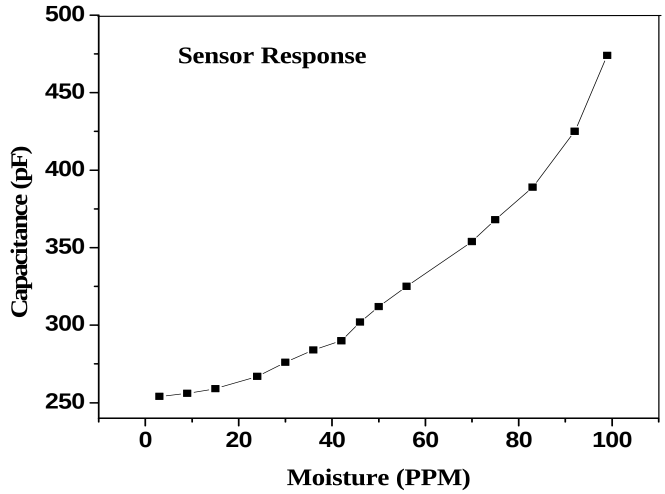


Fig-7: Sensitivity of the Sensor

4C: EXTRACTION OF ELECTRICAL SIGNAL FROM SENSOR

Pulse width modulation and a low pass filter, shown in figure-8 is used to extract the signal from the sensor, which is a response of capacitance with ambient change. The response of the circuit is also shown in fig-8a and output of the PWM circuit is shown in figure-8b. Circuit's operation is simple. A constant trigger source triggers the monostable multi-vibrator with a constant frequency. The unstable state of the monostable multi-vibrator is controlled by charging resistance and sensor capacitance and hence the desired modulation is achieved. RC low pass filters then filter out the ripple and produces a DC level. PCB version of PWM circuit, RC filter and amplifier is shown in fig-8c.

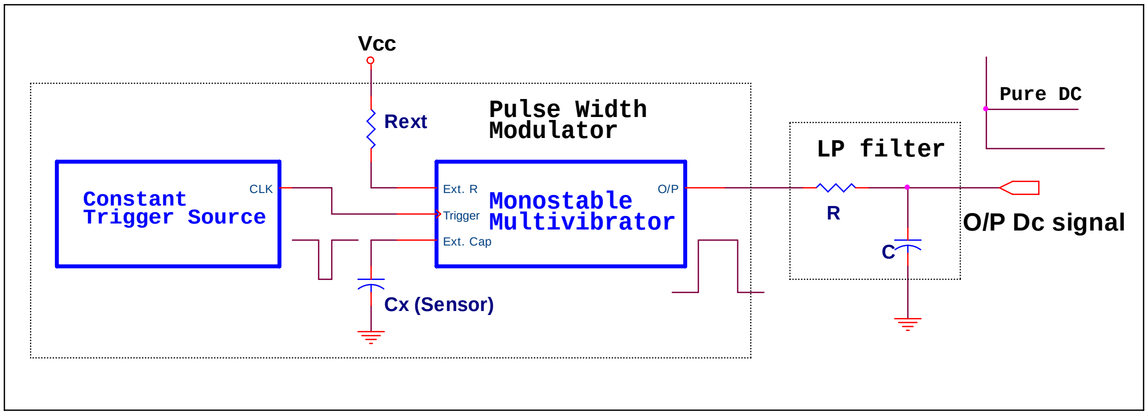
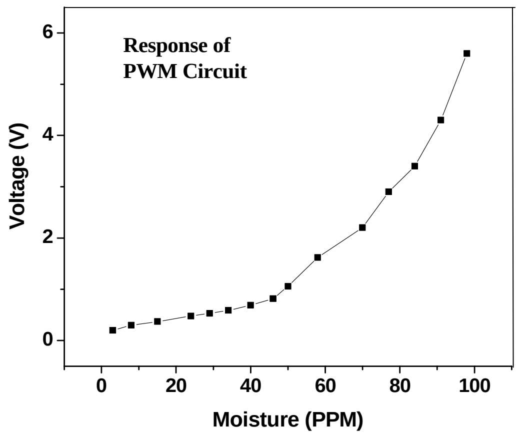


Fig-8: PWM and Low Pass Filter



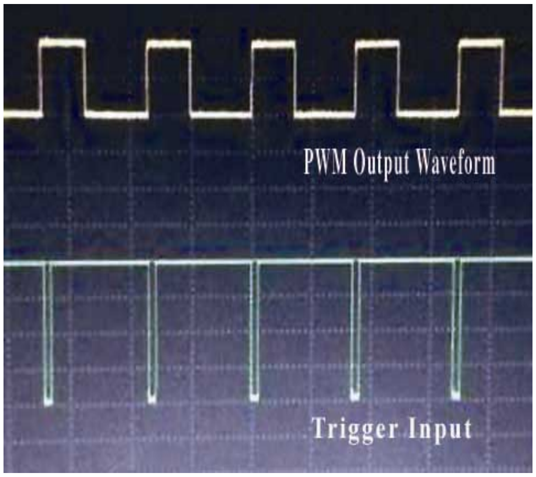


Fig-8a: Response of the PWM Circuit

Fig-8b: O/P of PWM Circuit

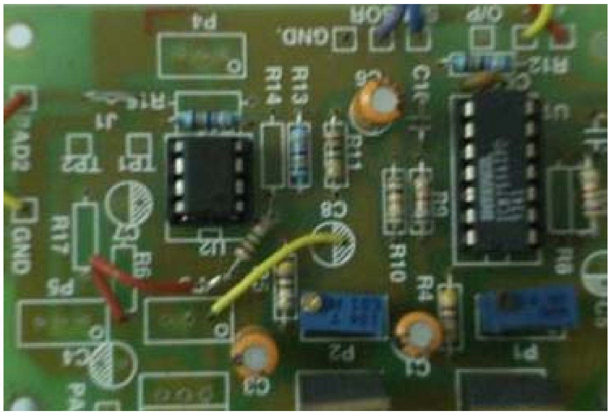


Fig-8c: PWM Circuit with RC Filter and Amplifier in PCB

5. LINEARIZATION WITH NLAMP: IMPLEMENTATION WITH THIN FILM SENSOR: CASE STUDY

A demonstrative application of the NLAmp to linearize a non linear characteristic is implemented with the thin film moisture sensor. Circuit for this purpose is shown in fig-9. The transfer characteristic of the NLAmp is shown in figure-10 which is non linear as proposed. The overall response of the circuit and the sensor response are shown in figure-11. The response shows that it is almost linear with moisture.

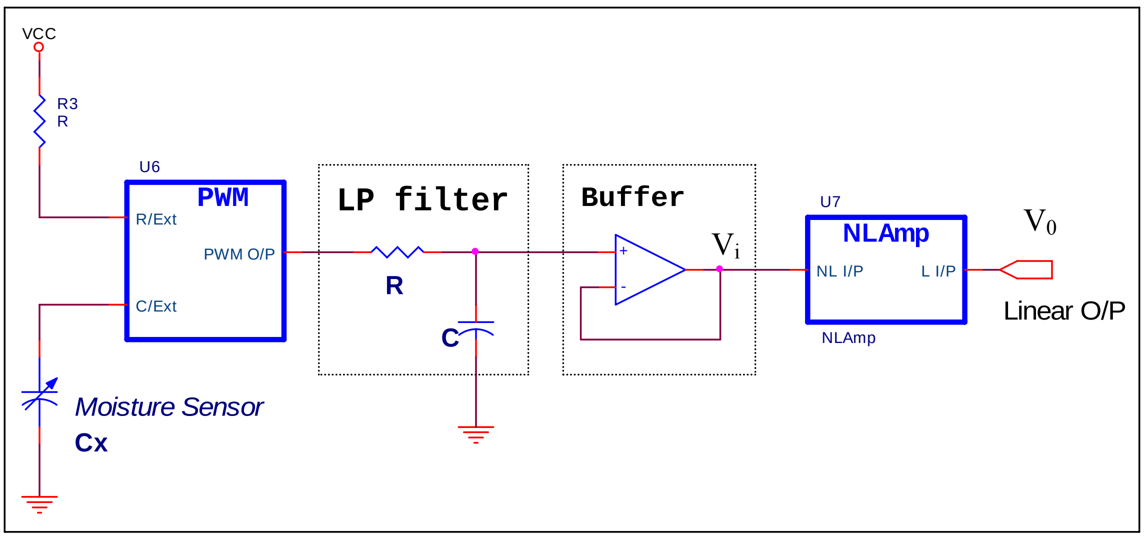


Fig-9: Linearization Circuit by NLAmp

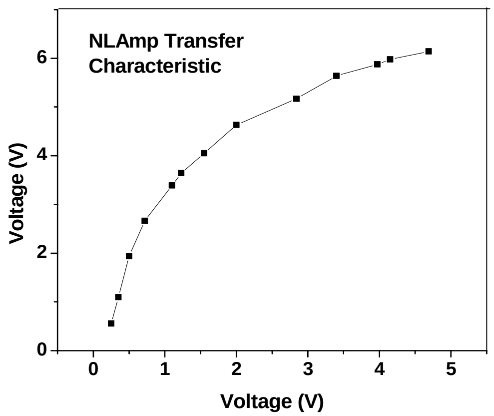


Fig-10: NLAmp Transfer Characteristic

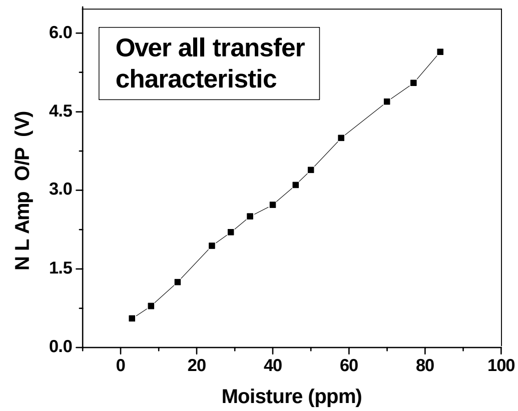


Fig-11: Overall Transfer Characteristic of the Circuit

6. MODIFICATION OF THE NLAMP CIRCUIT

The proposed NLAmp circuit can be modified to improve for the better performance specially in the step region. To improve that region NLAmp circuit is modified as shown in figure-12 where the amplifier is used in differential mode. The amplifier amplifies the differential segment voltage. The response of this circuit follows the equation-2. The over all response of the circuit is shown in figure-13, which has a better response than the previous circuit as shown in fig-11.

$$Y(x) = \sum_{j=1}^{p} \left(\left(y(x) - y_j \right) \times \tfrac{M}{m_j} + Y_{j0} \right) \text{.....................(2)}$$

Where is the number of segment

y(x) is the physical variable, have to be linearized.

m_j is the j-th segmental slope.

M is the desired constant slope.

Y_{j0} is the j-th initial segment value.

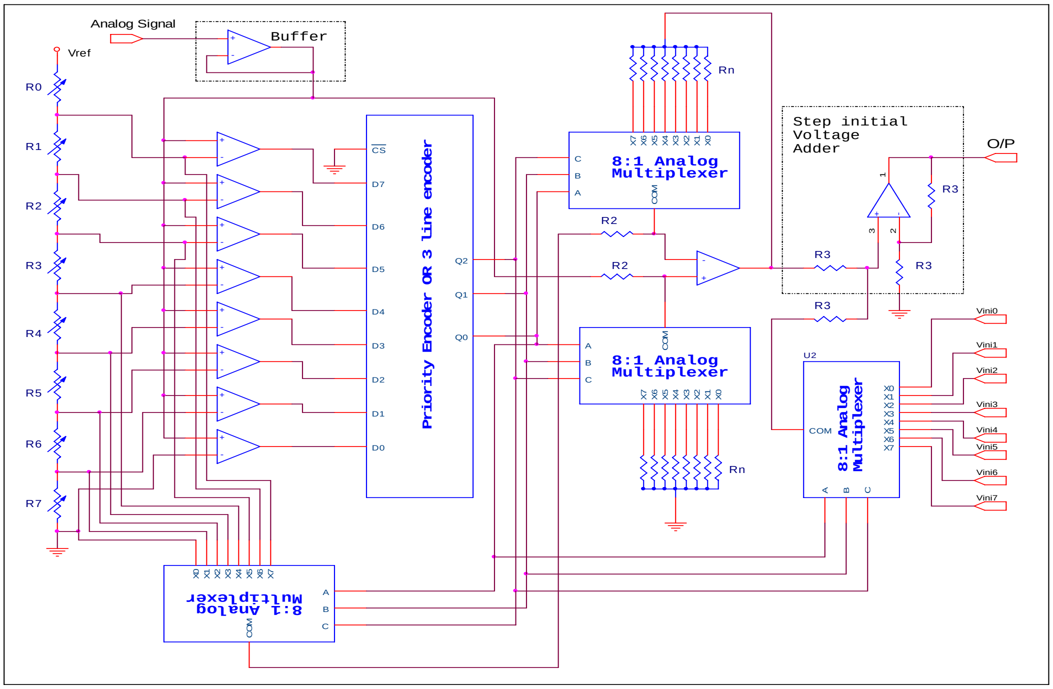


Fig-12: Modified NLAmp Circuit

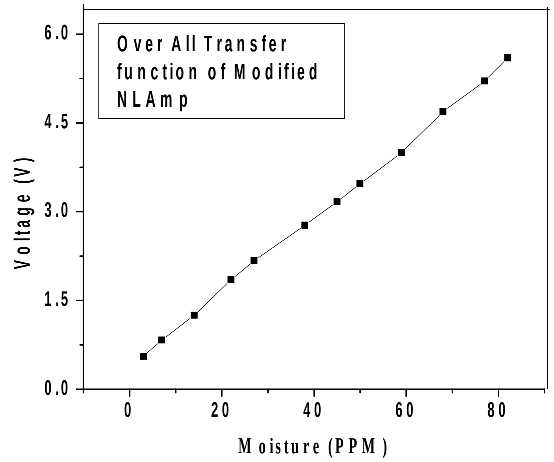


Fig-13: Overall Response of Modified Nlamp Circuit

7. CONCLUSIONS

The present paper investigates the suitability of nanoporous alumina oxide capacitive sensor for detecting the trace moisture in gases. The change in capacitance with moisture is quasi-linear in character. The sensor character is linearized with the NL amplifier which was further modified with an improved NLAmp circuit for better performance.

ACKNOWLEDGEMENT

The authors are thankful to Department of Science, Govt. of India for financial support and also to Dr. H. S. Maiti, Director, Central Glass and Ceramic Research Institute, Kolkata for rendering all sorts of cooperation for conducting the research work.

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