Design and Development of a Capacitance-to-Voltage Conversion System for Measuring Moisture in Raw Cashew Nuts

EC 490 - PRACTICAL TRAINING

Submitted By-

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Project Report

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ABSTRACT

Moisture content is a critical parameter in the quality control and preservation of agricultural products. Accurate measurement of moisture content is particularly crucial in the case of raw cashew nuts, as it significantly affects the storage, processing, and shelf life of this valuable commodity. This project introduces a novel Capacitance-to-Voltage Conversion System (CVCS) that incorporates an all-pass filter, Zero-Crossing Detector (ZCD), XOR, and low-pass filter elements to achieve accurate moisture content measurement in raw cashew nuts.

The proposed CVCS leverages the principles of capacitance sensing and signal processing using an All-Pass Filter to achieve high-resolution, real-time moisture content measurement in cashew nuts. By monitoring changes in capacitance resulting from varying moisture levels, the system provides an efficient and non-destructive method for assessing the moisture content of raw cashew nuts, contributing to enhanced quality control and reduced economic losses in the cashew nut processing industry.

The project encompasses the development of a custom-designed capacitance sensor, optimized for sensitivity and resilience to environmental factors. The All-Pass Filter serves as a key component in the signal conditioning circuit, offering phase-shifting capabilities that enable precise moisture content determination. Followed by ZCD and XOR integrated into the signal conditioning circuit, work together to convert capacitance variations into voltage signals that represent moisture content and a Low-Pass Filter for noise reduction Both the input and the output of the all-pass filter are passed through the zero-cross detectors to convert sinusoids into square waves. The square waves are fed to an XOR gate to get a train of pulses and then to filter to get a DC component.

Preliminary testing and calibration of the CVCS indicate its potential for high accuracy and responsiveness to variations in moisture content. Further validation and calibration with a representative sample of raw cashew nuts will be conducted to ensure the system's reliability under practical conditions.

The project's overarching goal is to provide the cashew nut industry with a cost-effective, high-precision solution for moisture measurement, thereby minimizing product wastage and improving product quality. Moreover, the CVCS may find application in other agricultural and food processing domains where accurate moisture content measurement is pivotal. Additionally, the modification and integration of advanced filter techniques open up innovative possibilities for moisture measurement in various agricultural and food processing sectors. Thus, increases the measurement of the system, and accuracy, reduces power requirements, reduces noise, and is cost-effective. The successful implementation of this project helps the cashew nut industry's approach to moisture monitoring, ultimately leading to increased profitability and sustainability within the sector.

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1.1 Introduction and Objectives

The main aim of this project is to design and prototype a system to convert capacitance to voltage which can be used as a sub-system in the design of a system to measure the moisture content of raw cashew nuts in cashew processing industries. This idea replaces the traditional method of estimating the amount of moisture heuristically by measuring the percentage weight lost in the cashew as equivalent moisture lost while drying the cashews. Instead, a device measuring the moisture content and displaying it on the display board or grading the cashew based on moisture would have great utility value to the cashew processing industry. The device has been designed to make it portable (battery operated), field operable, and simple to use. A person with minimal knowledge of the device's functioning would be able to use it with ease. The cashew kernels need to retain about 7% moisture in order to maintain their flavor and also to prevent them from breaking up (cracking) during processing/ extraction.

Therefore, drying the cashew kernels to enable extraction of the edible part of the kernel without damage/ charring/ disintegration is a crucial step in the processing. The data obtained by the moisture meter can be analyzed by experts to make necessary changes in the drying process for more effective drying and also prevent excessive drying of cashews. The device has been designed indigenously to make the cashew moisture meter cost-effective and available to the cashew processing industry/ cashew growers all over India and the world.

This device is simple and durable. For a long time, there was no moisture meter for measuring the raw cashew nut moisture. The laboratory methods are based on destructive tests. Moreover, the test takes a long time to give results. It has rechargeable batteries integrated into the bottom of the device. Battery life is long enough for measuring raw cashew nut moisture in the deep farms of Africa, Indonesia, etc. where power is unavailable. It is made of stainless steel and literally as strong as steel.

1.2 Methodology

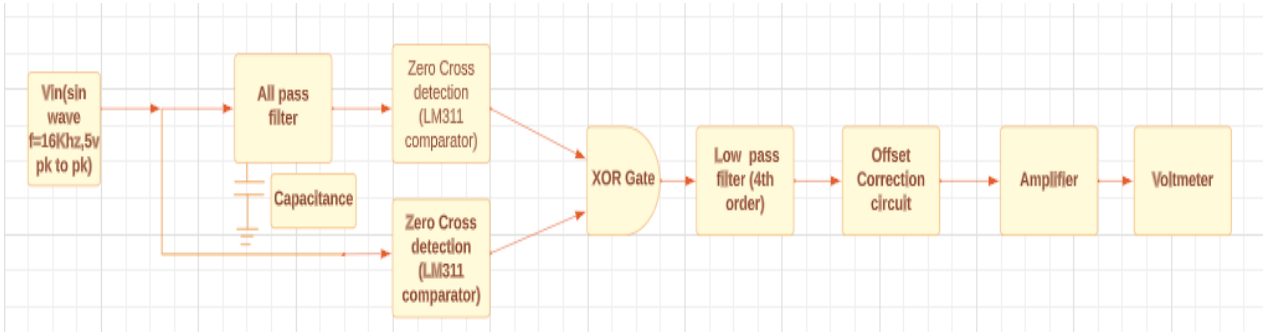


Fig: 1:- Block diagram

The block diagram in Fig 1 shows the proposed scheme of capacitance-to-voltage conversion and explains the internal architecture of the device. It consists of a sine wave generator (f = 16khz), an All-pass filter, ZCD, an XOR gate, a low-pass filter, an offset removal circuit, an amplifier, and a voltmeter.

The main aim is to make moisture equivalent to voltage i.e. moisture content is measured in terms of voltage or voltmeter. The moisture or humidity is affected by dielectric i.e. dielectric changes as the percentage of moisture is varied. So the idea is to sense the dielectric or indirectly moisture.

The sensor is located in the sensing head and it consists of two parallel plates that are separated by a fixed distance. When the sensor is exposed to material or cashew, it loses its dielectric properties and causes a change in capacitance between the electrodes. Thus, the problem of moisture measurement is brought into measuring capacitance. This project aims at designing a system to measure capacitance and give an equivalent voltage.

The Capacitance to be measured is made as a part of an all-pass filter circuit which passes all frequencies but with a fixed amount of phase change or delay. The phase change depends on the value of capacitance. The Input to the all-pass filter is a 16KHz sinusoid of 5V peak to peak.

Both the input and the output of the all-pass filter are passed through the zero-cross detectors to convert sinusoids into square waves. The square waves are fed to an XOR gate to get a train of pulses. The LM311 IC is used as a comparator and the CD4070 IC is in the XOR gate.

The pulse width is a measure of the amount of a phase shift which in turn has in it the information of capacitance. The higher the pulse width of XOR operation the higher the phase shift thus the capacitance. The XOR output is fed into a 4th order Butter-worth low filter to filter out all AC Components and give only the DC content.

The idea is to measure the change in capacitance from the box without cashews and with cashews. So it is important to remove the offset for better reliable detection.

The DC voltage is available at the output of the filter and, after offset removal, is measured using a 10V Voltmeter

1.3 Design of the system

1.3.1 All-pass Filter

An all-pass filter is a signal processing filter that passes all frequencies equally in gain but changes the phase relationship among various frequencies. Most types of filters reduce the

amplitude (i.e. the magnitude) of the signal applied to it for some values of frequency, whereas the all-pass filter allows all frequencies through without changes in level.

We have taken a Resistance of R =22KΩ for our circuit. LM741 op-amp is used with a Supply Voltage of ± 12V. The capacitance shown in this filter is actually measured between two Parallel plates in which cashew is placed thus capacitance is dependent on the moisture content or dielectric which we have to measure.

Fig 2 shows the circuit diagram of the filter:-

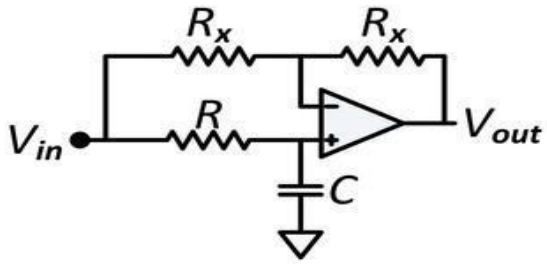


Fig 2: All pass filter

Here R =Rx = 22KΩ, Vin = sin(2*pi*16Khz) i.e. f= 16Khz.

The transfer function of all-pass filters is:-

$$H(s) = -\frac{s - \frac{1}{RC}}{s + \frac{1}{RC}} = \frac{1 - sRC}{1 + sRC},$$

The magnitude and phase response are the following:-

$$|H(iw)| = 1 \text{ and } \angle H(iw) = -2 \arctan(wRC).$$

The filter has a unity-gain magnitude for all ω. The filter introduces a different delay at each frequency and reaches input-to-output quadrature at ω=1/RC (i.e., the phase shift is 90°).

This implementation uses a low-pass filter at the non-inverting input to generate the phase shift and negative feedback. At high frequencies, the capacitor is a short circuit, creating an inverting amplifier (i.e., 180° phase shift) with unity gain. At low frequencies and DC, the capacitor is an open circuit, creating a unity-gain voltage buffer (i.e., no phase shift). At the corner frequency ω=1/RC of the low-pass filter (i.e., when the input frequency is 1/(2πRC)), the circuit introduces a 90° shift (i.e., the output is in quadrature with input. The output appears to be delayed by a

quarter period from the input). In fact, the phase shift of the all-pass filter is double the phase shift of the low-pass filter at its non-inverting input.

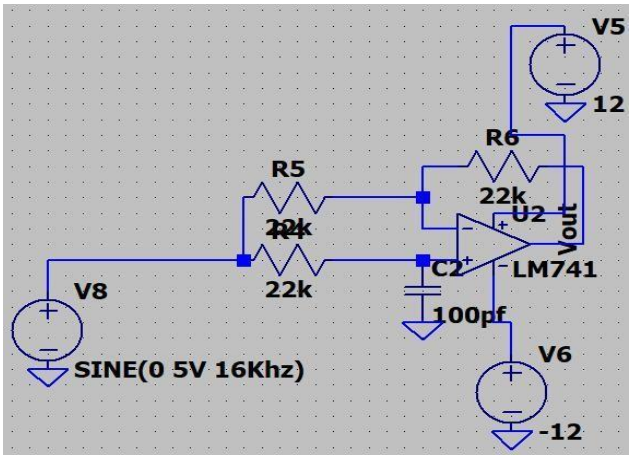


Fig 3: All pass filters (designed in Ltspice)

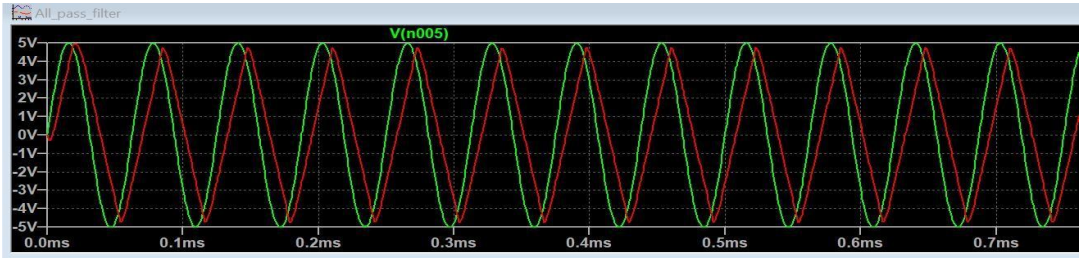


Fig 4: Phase shift of -2arctan(wRC); for C=100pF Vin in green color, Vout in red color.

1.3.2 Zero Cross Detection

The zero-crossing detector circuit changes the comparator output state when the AC input crosses the zero reference voltage. A Zero Crossing Detector Circuit is a useful application of Op-amp as a Comparator. It is used to track the change in the sine waveform from positive to negative or vice versa while it crosses Zero voltage. It can also be used as a Square Wave Generator. Zero Crossing Detector has many applications like a time marker generator, phase meter, frequency counter, etc. A Zero Crossing Detector can be designed in many ways like using a transistor, using an op-amp, or using an op-to-coupler IC.

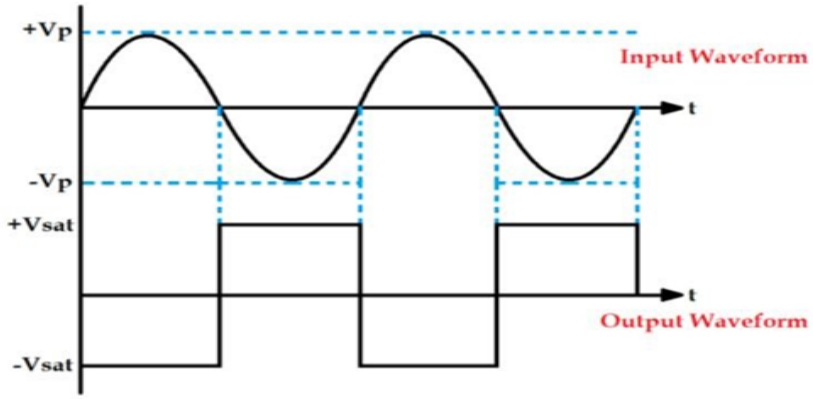


Fig 5: ZCD Output

LM311 op-amp has been used as a comparator. Voltage comparators like the LM311 offer a fast response. The LM311 is designed with versatility in mind as it can operate from a range of supply voltages, including +/- 15V DC, and +5V DC for logic circuits.

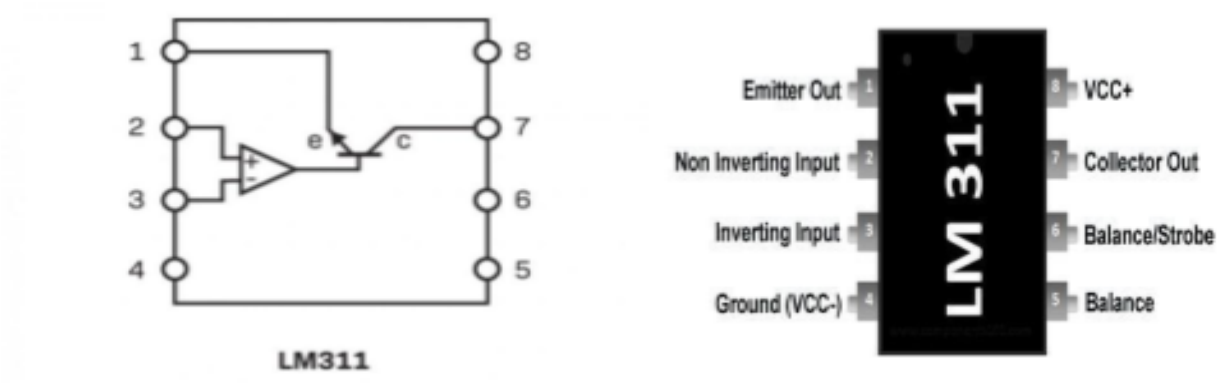


Fig 6: LM311 internal architecture and IC Pins. (Ref: https://components101.com)

The schematic of ZCD is shown in Fig 7:

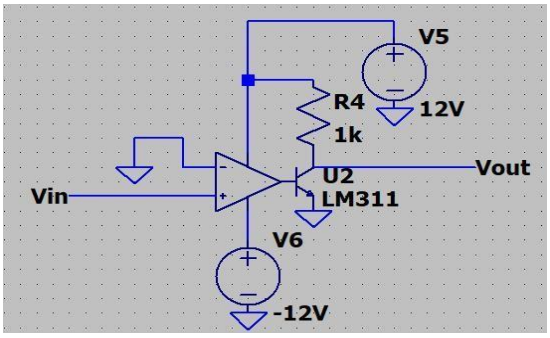


Fig 6: LM311 based Zero crossing detector

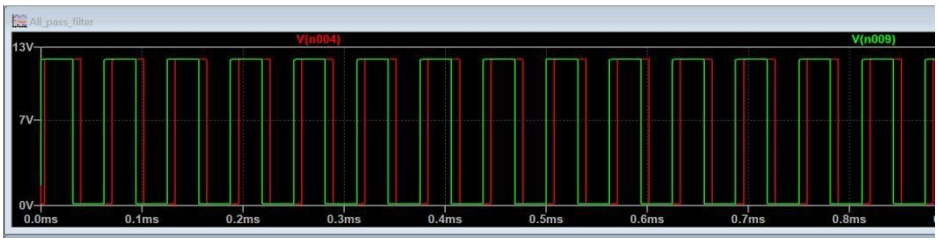
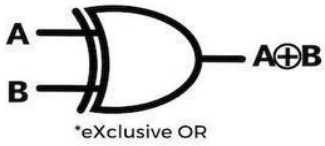


Fig 7: LTspice simulated result, Vin(ZCD) in green, Vout(ZCD) in red; for C=100pF

1.3.4 XOR Operation

XOR gate (sometimes EOR, or EXOR and pronounced as Exclusive OR) is a digital logic gate that gives a true (1 or HIGH) output when the number of true inputs is odd. An XOR gate implements an exclusive from mathematical logic; that is, a true output result if one, and only one, of the inputs to the gate is true. If both inputs are false (0/LOW) or both are true, a false output results. XOR represents the inequality function, i.e., the output is true if the inputs are not alike otherwise the output is false. A way to remember XOR is "must have one or the other but not both".



2 input XOR gate

A	B	A⊕B
0	0	0
0	1	1
1	0	1
1	1	0

Fig 8: XOR gate symbol and truth table of XOR gate

We have used a CD4070 IC as an XOR gate. The supply voltage is 12 V at pin 14 and ground pin 7. We downloaded a lib and asy file of CD4070 and used it in Ltspice for our simulation

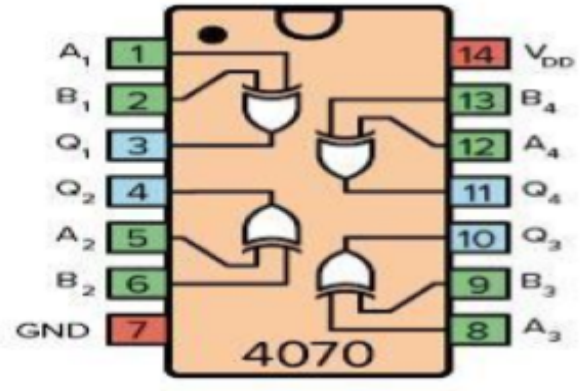


Fig 9: Internal Structure of CD4070 and CD4070 IC (Ref: https://robocraze.com)

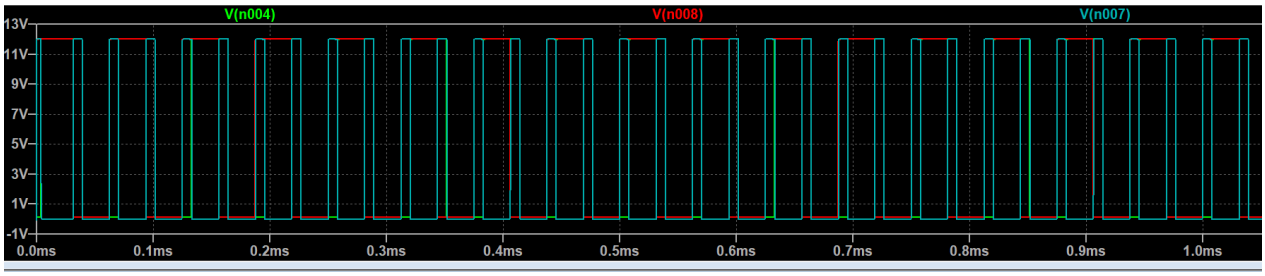


Fig 10: LTspice simulated result:- XOR operation (Blue color), Vin(Green color), Vout (red color). ; for C=100pF.

1.3.5 Fourth Order Butterworth filter (Sallen key Architecture)

The Butterworth filter is a type of signal-processing filter designed to have a frequency response that is as flat as possible in the passband. It is also referred to as a maximally flat magnitude filter. The Sallen–Key topology is an electronic filter topology used to implement second-order active filters that is particularly valued for its simplicity.[1] It is a degenerate form of a voltage-controlled voltage-source (VCVS) filter topology.
The Butterworth filter is an analog filter design that produces the best output response with no ripple in the pass band or the stop band resulting in a maximally flat filter response but at the expense of a relatively wide transition band.

nth Order Butter-worth filter, the frequency response is given as:

$$H_{(j\omega)} = \frac{1}{\sqrt{1+\varepsilon^2\left(\frac{\omega}{\omega_p}\right)^{2n}}}$$

For Butterworth epsilon **(ε) = 1**
Where: n represents the filter order, ω is equal to $2\pi f$ and Epsilon ε is the maximum passband gain, (Amax). If Amax is defined at a frequency equal to the cut-off -3dB corner point (fc), ε will then be equal to one, and therefore ε2 will also be one.

NUMERICAL CALCULATION
Transfer function and constant calculation of 4th order Butterworth filter design.

The Normalised Denominator Polynomials in Factored Form are obtained from the standard filter table. (Ref:- https://en.wikipedia.org/wiki/All-pass_filter)

For the 4th order Butterworth filter the Denominator is:-

$$(1+0.765s + s^2)(1+1.848s+s^2)$$

Scaling Frequency to required let (w):

$$(1+0.765\ \frac{s}{w}+(\frac{s}{w})^2)\left(1+1.848\ \frac{s}{w}+\left(\frac{s}{w}\right)^2\right)$$

Clearly from above equation **Q1 = 1.31** and **Q2 = 0.54**

1.3.6 Sallen key architecture

The generic gain Sallen–Key filter topology implemented with an operational amplifier is shown in Figure 11. The following analysis is based on the assumption that the operational amplifier is ideal.

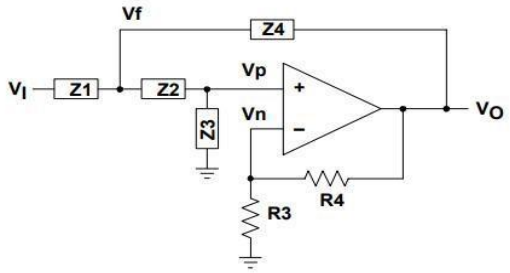


Fig 11: Generalized Sallen - key circuit

To find the circuit solution for this generalized circuit, find the mathematical relationships between Vi, Vo, Vp, and Vn, and construct a block diagram.

Apply KCL at Vf and Vp and substitute equation to each other and solve for Vp:-

KCL at Vf:

$$Vf(\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_4}) \ = \ Vi(\frac{1}{Z_1}) \ + \ Vp(\frac{1}{Z_2}) \ + \ Vo(\frac{1}{Z_4})$$

KCL at Vp:

$$Vp(\frac{1}{Z_2}+\frac{1}{Z_3}) \ = \ Vf(\frac{1}{Z_2}) \ \Rightarrow \ Vf \ = Vp(1+\frac{Z_2}{Z_3})$$

Substitute equations and solve for Vp:-

$$Vp = Vi(\frac{Z_2Z_3Z_4}{Z_2Z_3Z_4 + Z_1Z_2Z_4 + Z_1Z_3Z_2 + Z_2Z_2Z_4 + Z_2Z_2Z_1}) + Vo(\frac{Z_2Z_3Z_1}{Z_2Z_3Z_4 + Z_2Z_1Z_4 + Z_2Z_3Z_1 + Z_2Z_2Z_4 + Z_2Z_2Z_1})$$

KCL at Vn:-

$$Vn = Vi(\frac{1}{R_3} + \frac{1}{R_4}) = Vo(\frac{1}{R_4}) \Rightarrow Vn = Vo(\frac{R_3}{R_3 + R_4})$$

Application: low-pass filter

The standard frequency-domain equation for a second-order low-pass filter is:

$$H_{LP} = \frac{K}{-\left(\frac{f}{f_c}\right)^2 + \frac{jf}{Qfc} + 1}$$

Where fc is the corner frequency (note that fc is the breakpoint between the pass band and stop band and is not necessarily the -3 dB point) and Q is the quality factor. When f<<fc Equation reduces to K, and the circuit passes signals multiplied by a gain factor K. When f=fc, the Equation reduces to-jKQ, and signals 2 are enhanced by the factor Q. When f>>fc, the Equation reduces to -k(fc/f)^2, and - signals are attenuated by the square of the frequency ratio. With attenuation at higher frequencies increasing by a power of 2, the formula describes a second-order low-pass filter.

The Sallen-Key circuit configured for low-pas

Replace Impedance with the following values:-

$Z1 = R1,\ Z2 = R2,\ Z3 = \frac{1}{sC1},$

$Z4 = \frac{1}{sC2},$ and $K = 1 + \frac{R4}{R3}.$

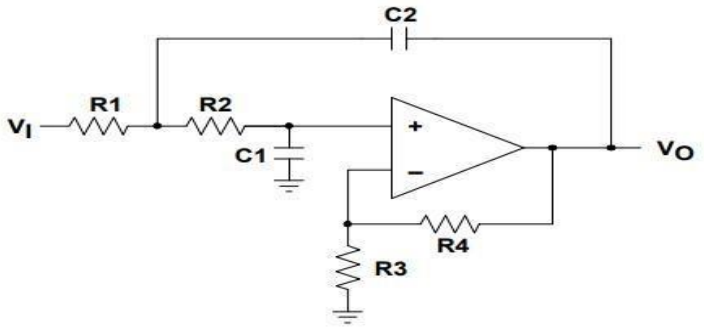


Fig 12: Low-Pass Sallen-Key Circuit

$$\frac{Vo}{Vi}(Ip) = \frac{K}{s^2(R1R2C1C2) + s(R1C1 + R2C1 + R1C2(1-K)) + 1}$$

By letting

$$s = j2\pi f,\ fc = \frac{1}{2\pi\sqrt{R1R2C1C2}},\ \text{and}\ Q = \frac{\sqrt{R1R2C1C2}}{R1C1 + R2C1 + R1C2(1-K)},$$

Letting R1=R2=R, and C1=C2=C, results in: $fc = \frac{1}{2\pi RC}$ and $Q = \frac{1}{3-K}$.

The new equation becomes;-

$$\frac{K}{s^2 R^2 C^2 + sRC(3-K) + 1}$$

Where Q = 1 / (3-k) and K = 1 + R2 / R1

Transforming Sallen key architecture into a butter-worth response.

So comparing 4th order butter-worth response with Sallen key equation above. We get

$$Q_1 = \frac{1}{3-K_1} \quad Q_2 = \frac{1}{3-K_2}$$

Where **Q1 = 1.31** and **Q2 = 0.54**

On solving we get **K1 = 2.214** and **K2 = 1.153** also at a same time
K = 1 + R2 / R1
So, on putting values we ratio of R2/R1
(R2/R1) = 0.153 and (r2/r1) = 1.214

Choosing R1 = 22kΩ , R2 = 3.3kΩ , r2 = 5.6kΩ and r1 = 4.7kΩ to satisfy conditions.

We have to filter the DC component so the required frequency cut-off of the filter is ω < 1.6Khz. So we chose a cut-off frequency is 1khz. Here in the Sallen key filter equation cut-off frequency is 1/RC

$$w = \frac{1}{RC} \quad w = 2 \times \pi \times f$$

Choosing R = 16kΩ we get C = 0.01μF

The Final Circuit diagram of the filter is shown below:-

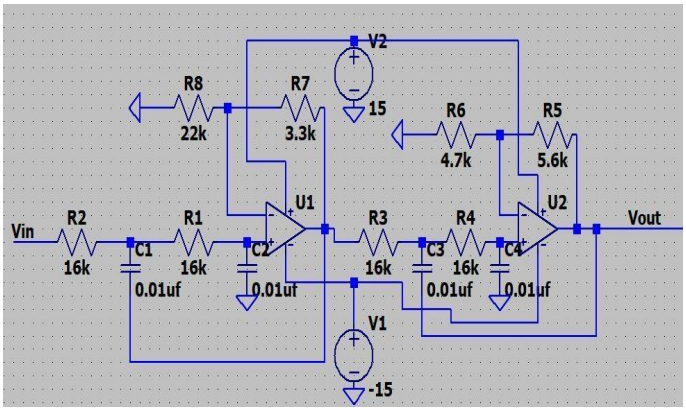


Fig 13: 4th Order Butter-worth Low-Pass filter (Sallen Key Architecture)

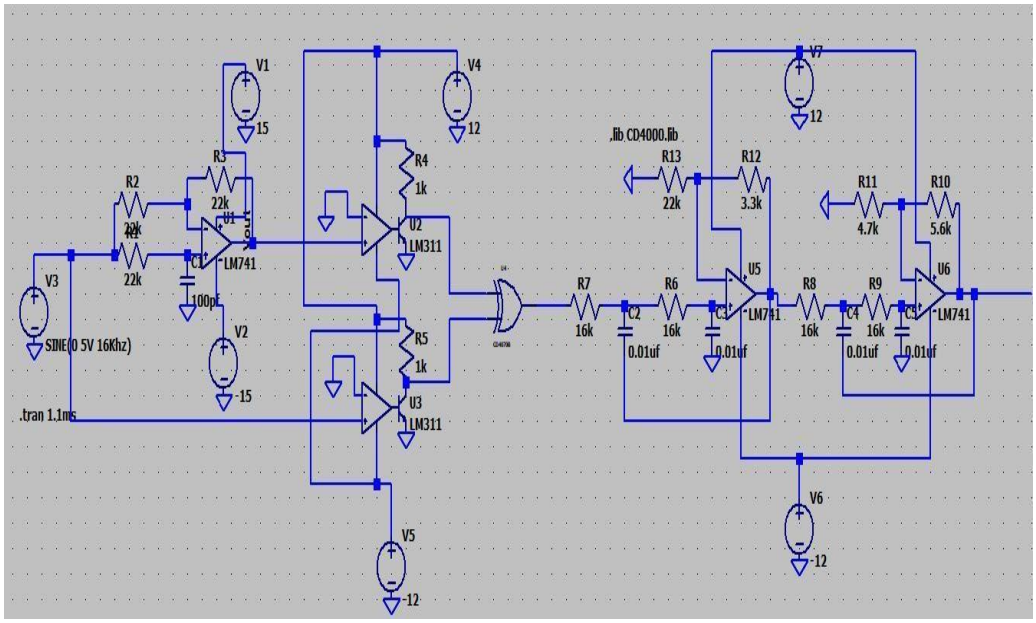


Fig 14: Overall Circuit Diagram of the system:- Consists of all-pass filters, ZCD, and filter(4th order).

1.4 Practical Implementation Of Circuit

This is done in two phases:-
First phase:-

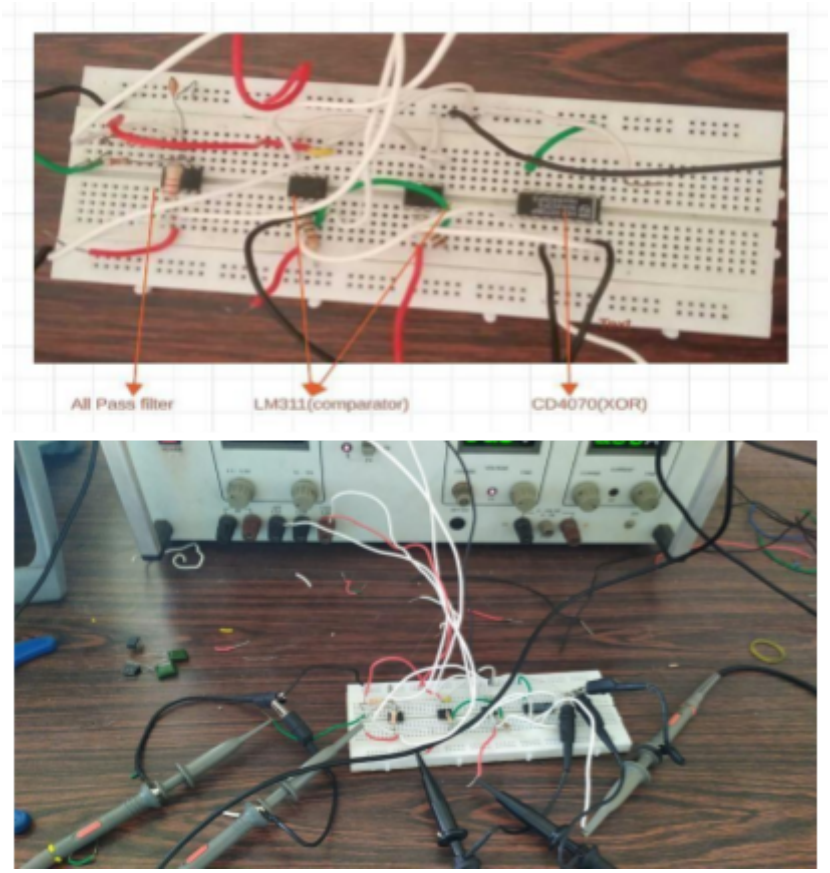


Fig 15: Breadboard Implementation and Connections

This figure shows a circuit implementation up to the XOR gate from all-pass filters. The sinuous is provided through a waveform generator and voltage is from a voltage source (available in the lab).

The output is taken from ▬

- Pin No. 6 of LM741 (op-amp) i.e. all-pass filter which shows phase shift of -arctan(wRC)
- Pin No. 7 of LM311 Comparator which converts sinusoid into digital waveform. (sinusoid without phase-shift).
- Pin No. 7 of LM311 Comparator which converts sinusoidal into digital waveform. (sinusoid after getting out from all pass filters i.e. phase-shift).
- Pin No. 10 of CD4070 in which LM311 output is fed at pin 8 and pin 9 and output is generated at 10 i.e. XOR of two signals or pulses.

The full setup is shown in the figure below:-

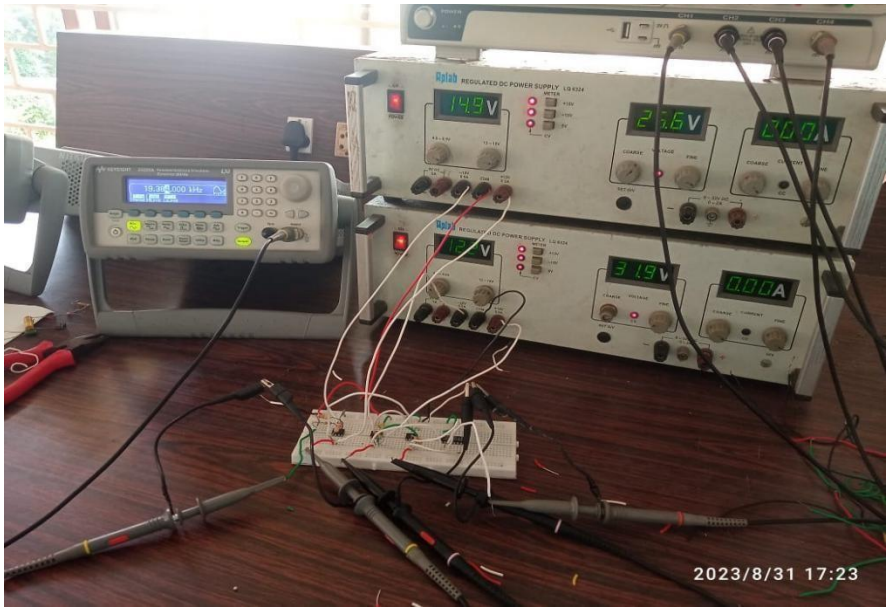


Fig 16: Circuit Implementation, Power Supply, and Wave Generator.

The waveform generated in each pin described above is seen in the Oscilloscope in the lab. The below picture shows the desired waveform:-

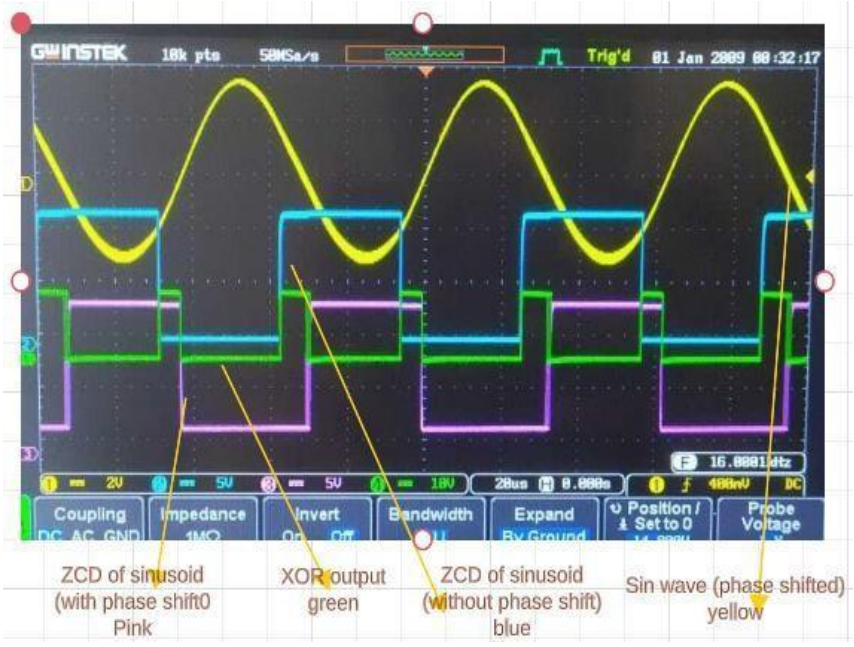


Fig 17: Waveforms (In Oscilloscope)

The below diagram shows full implementations and oscilloscope-

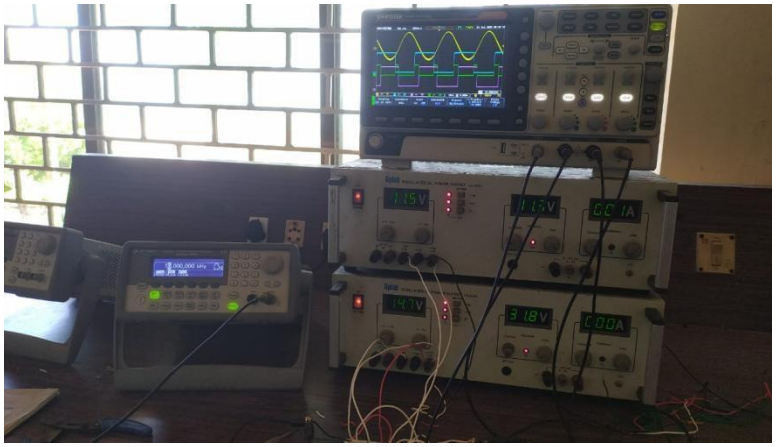


Fig 18: Oscilloscope, Voltage Regulator and Wave generator

Second Phase:-

Butterworth filter implementation

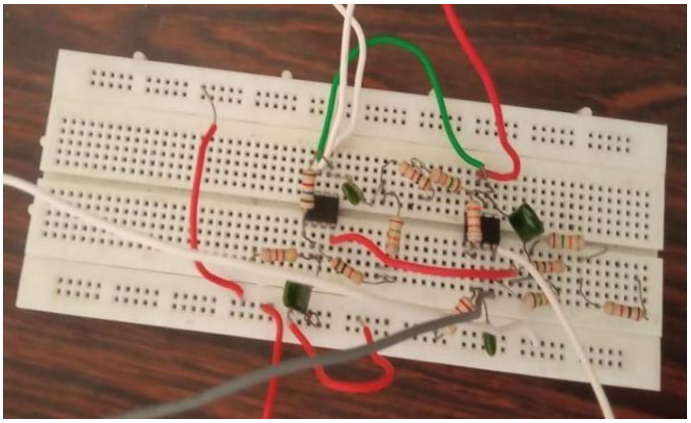


Fig 19: Filter Implementation in the breadboard

The output is taken from Pin 6 of the op-amp. The output of the XOR gate which is Pin 10 of CD4070 is fed to the 16kΩ resistor filter as input. The filter filtered the DC component of the pulse and gave a DC component with a DC gain of K1*K2 i.e. DC gain.

The output is measured on a multimeter and using an Oscilloscope for comparison purposes.

Table 1 shows the changing of output voltage with a changing capacitance in all-pass filters. This observation shows the variation of voltages in changing capacitance. It consists of measurement from a multimeter and oscilloscope of the output of 4th order Butterworth Low-Pass filter and mean value of pulse i.e. is of XOR operation.

Capacitance (in pf)	Multimeter Value (XOR)	Oscilloscope Value (XOR)	Multimeter Value (filtered)	Oscilloscope Value (filtered) (gain=k1k2)	Phase shift In degrees
Open circuit	0.417V	0.4V	1.159V	1.16V	≈0
10pf	0.532V	0.53V	1.40V	1.43V	2.52
22pf	0.65V	0.627V	1.75V	1.77V	5.567
47pf	1.05V	1V	2.7V	2.6V	12.19
100pf	1.924V	1.82V	4.81V	5.04V	24.92
147pf	2.67V	2.88V	6.66V	6.75V	35.99
200pf	3.52V	3.34V	8.82V	8.91V	47.69

Table 1: Voltage Measurement For Different Capacitance

Observation:-

As the value of capacitance increases, we can see that the voltage is increasing. This indicates that as voltage increases capacitance increases means dielectric increases hence moisture content or humidity increases between capacitance or electrodes or block.

1.5 Offset correcting (Zero-setting) Circuit

To remove the offset from the above design for an open circuit or parasitic capacitance of about 1.16V. For this purpose a variable voltage to cancel the offset and incorporated into the butter-worth filter such that the overall output for the open circuit is zero. The offset removal circuit consists of a potentiometer which is used to vary the voltage to finally get an output from the op-amp as zero for open capacitance.

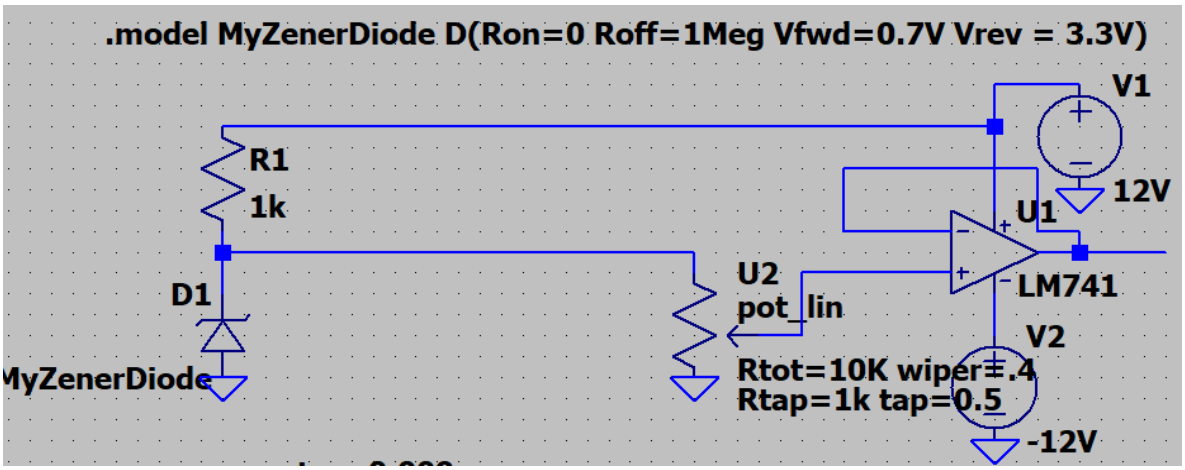


Fig 20: Offset Correction Circuit

Offset correction circuit range: -0 to 3.3(R5/R6)

The circuit consists of a zener diode (3.3V breakdown voltage).op-amp 741 potentiometers of 10k for varying voltage in range.

The above circuit is attached to a filter as shown below; The range for offset correction is also increased.
This changes the final value as:-

$$Vout(new) = Vout(old) - Vdc(R5/R6)$$

Vdc such that for an open circuit the Vout becomes Zero.

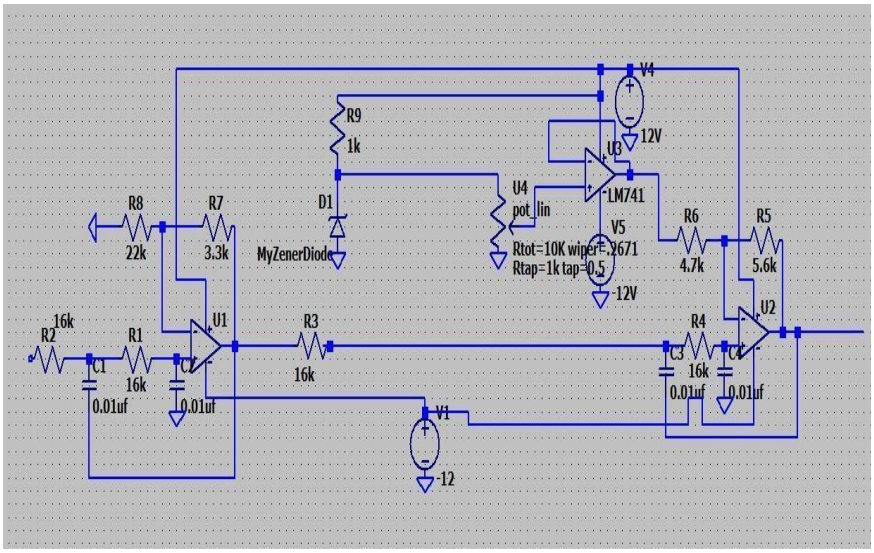


Fig 21: Filter with zero setting circuit

Circuit Implementation:-

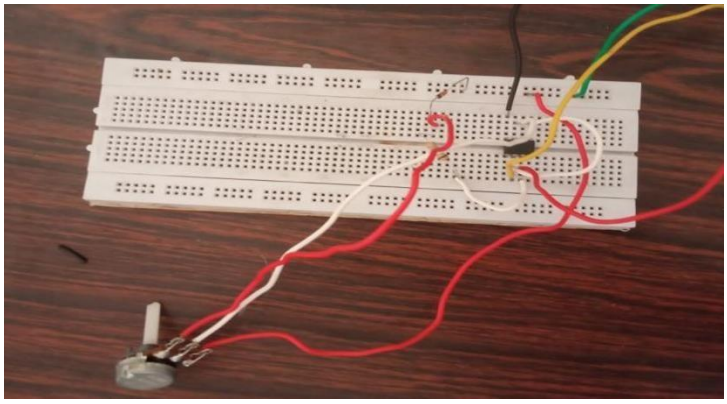


Fig 22: Breadboard implementation

The overall circuit is now as follows:-

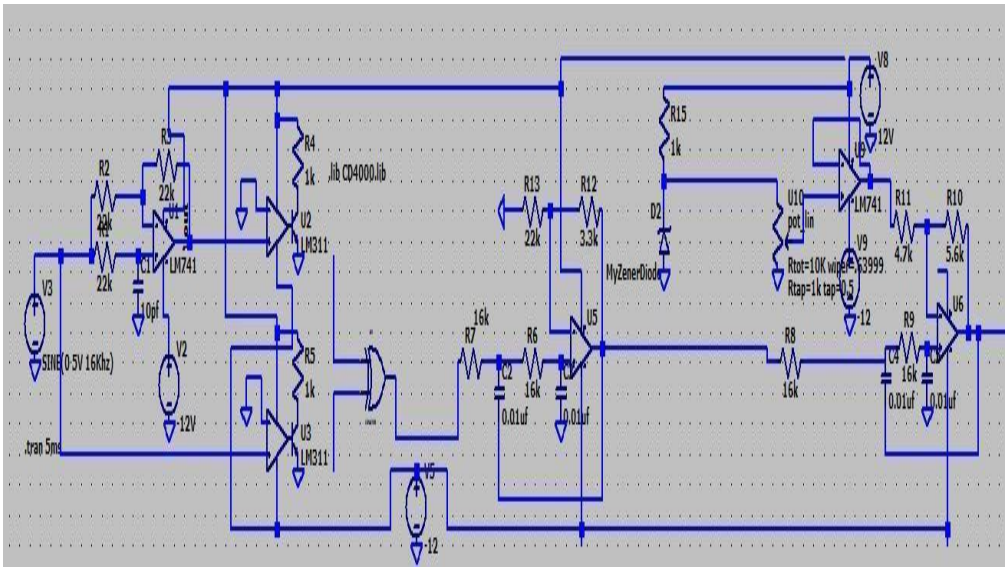


Fig 23: Complete Circuit Consists of All pass filter, ZCD, XOR, and Low-Pass Filter with Zero Setting Circuit.

The output from the offset circuit is fed to the 4.7kΩ resistance end of the filter so that vd with a gain of (R5/R6) can be subtracted from the final value. The potentiometer is set to a position where for no capacitance in the filter the voltage is zero.

Vout (for open circuit) = 1.16V (as in Table 1)
For getting Vout zero we set Vdc = 0.88V which is subtracted from the final value.

Table 2 shows the voltage measurement using a multimeter of output voltage after the offset was corrected.

Capacitance (in pF).	Multimeter Measurement (V)
Open circuit	-0.011 ≈ 0
10	0.228
22	0.591
47	1.49
100	3.618
147	5.429
200	7.47

Table 2: Voltage Measurement For Different Capacitance

Now Capacitance in all-pass filters is replaced by a parallel-plate capacitor box used to measure the moisture of the cashew.

Fig 24: parallel plate capacitor box used to measure the moisture of the cashew

1.6 Further Modifications

In the above circuit, we have used a butter-worth filter which had a DC gain of k1*k2 i.e. 2.5226, which increases the voltage that gets from the xor gate so much that it reduces the measurement range for capacitance or moisture content. We now use another circuit or filter with less gain such that the range of the Overall circuit is increased so that it can measure capacitance or moisture in a higher range.

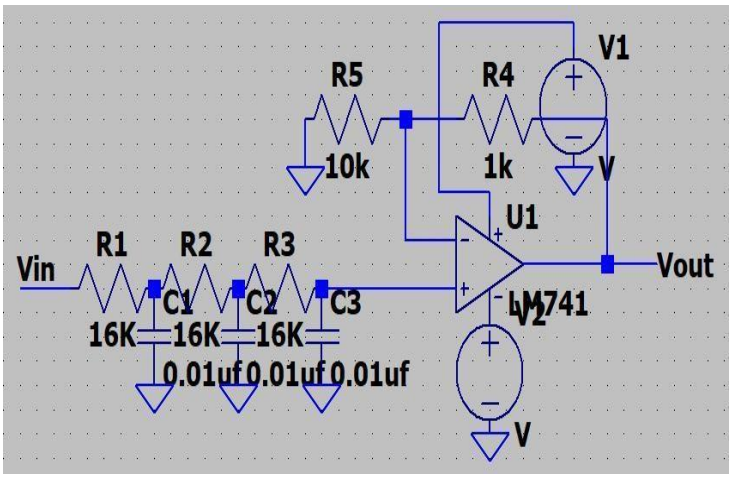


Fig 25: 3rd order Filter with DC gain of 1.1

We have used this circuit that has a DC gain of 1.1 which reduces the range of final voltage so we can measure more range of capacitance.

The above circuit is attached with an offset correction circuit and then replaced in place of a 4th order butter-worth filter to get an updated circuit of more range. The offset is corrected such that the value of voltage for the open circuit is zero.

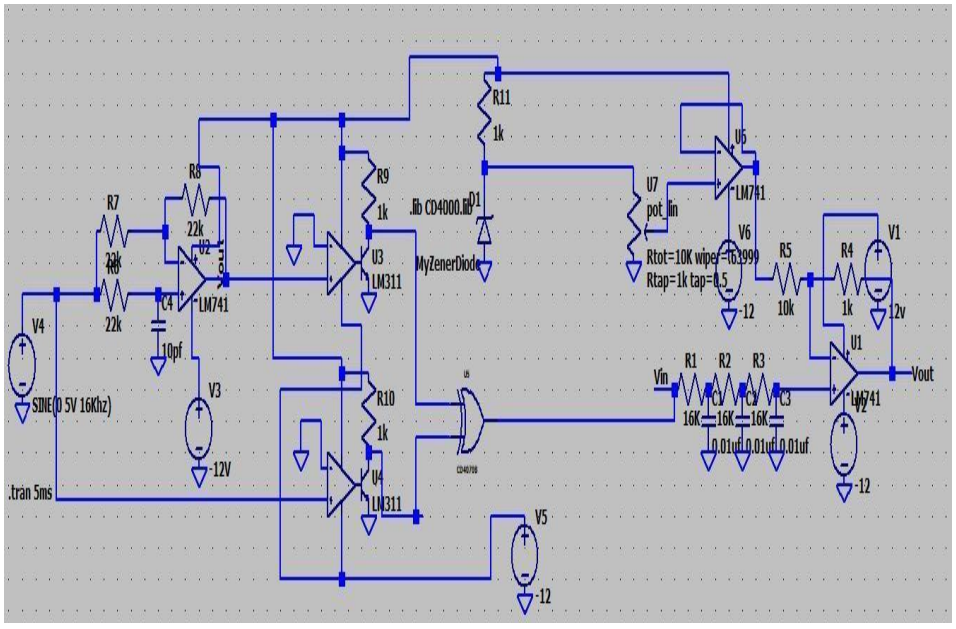


Fig 26: Overall circuit with new filter + offset corrected

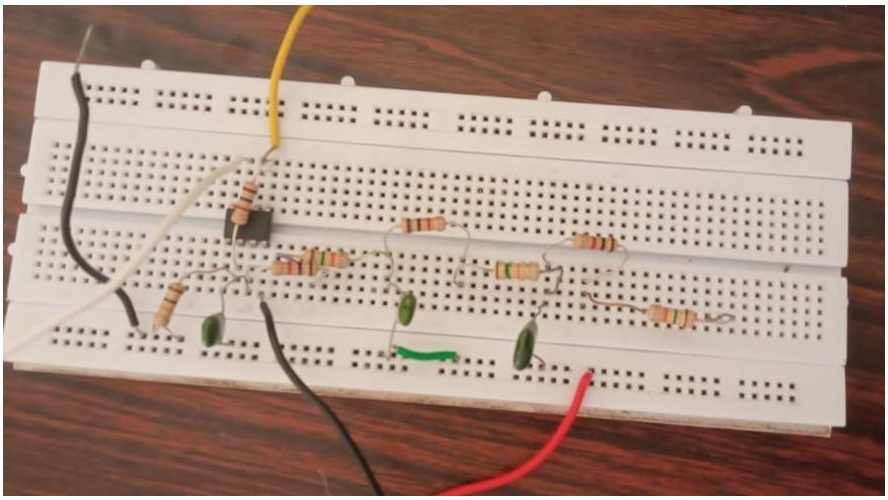


Fig 27: Implementation of Breadboard

Measurement for different values of capacitance:-

Without offset **Vout(open circuit) = 0.437v**; The offset is set such that this value of Vout becomes zero.

Table 3 shows Vout for different values of capacitance:-

Capacitance (in pF).	Multimeter Measurement (V).
Open circuit	0.025 ≈ 0
10	0.214
22	0.326
47	0.808
100	1.732
147	2.505
200	3.36

Table 3: Voltage Measurement For Different Capacitance

Observation:-

We can observe that the voltage for 200pF capacitance is now 3.36V which is 7.47V for the previous circuit. So the range is increased for measurement so that the filter will not saturate for higher values of capacitance. Along with it reduction in power in the circuit as fewer resistors and op-amp are used.

1.7 Conclusion -

The "Design and Development of Capacitance-to-Voltage Conversion System for Measuring Moisture in Raw Cashew Nuts" project represents a significant advancement in the field of moisture measurement for agricultural products, with a particular focus on raw cashew nuts. By integrating advanced capacitance sensing techniques and a combination of innovative filters, the project has successfully developed a robust and precise Capacitance-to-Voltage Conversion System (CVCS) tailored for moisture assessment in raw cashews.

Key achievements of the project include:

1. The creation of a customized capacitance sensor optimized for sensitivity and environmental resilience.
2. Integration of an All-Pass Filter to capture phase changes, a Zero-Crossing Detector (ZCD) XOR filter for precise moisture content quantification, and a Low-Pass Filter for noise reduction in the signal conditioning circuit.
3. The modification of a low-pass filter to measure the higher values of moisture content.

Preliminary testing and calibration have demonstrated the CVCS's potential for high precision and sensitivity to moisture variations. Further validation with a representative sample of raw cashew nuts will verify the system's reliability under practical conditions.
The project offers significant promise to the cashew nut industry by providing a cost-effective and highly accurate solution for moisture measurement. This innovation will help reduce product wastage, enhance product quality, and contribute to increased profitability and sustainability within the sector. Furthermore, the integration of advanced filter techniques holds potential for broader applications in moisture measurement across various agricultural and food processing sectors.

1.8 Future Scope:-

The success of this project opens several avenues for future research and development:-

1. Advanced Calibration: Conduct further calibration with a larger and more diverse sample of raw cashew nuts to refine the system's accuracy and reliability.
2. Real-Time Processing: Explore the possibility of real-time data analysis and processing to provide instant feedback to cashew nut processing units.
3. Wireless Connectivity: Integrate wireless communication capabilities to enable remote monitoring and control of moisture measurement systems in processing facilities.
4. Data Analytics: Develop advanced data analytics and machine learning algorithms to analyze the collected moisture data and provide predictive insights for quality control and decision-making.

5. Cross-Industry Applications: Investigate the adaptability of the CVCS and advanced filter techniques for moisture measurement in other agricultural and food processing applications, such as grain storage and fruit preservation.
6. Commercialization: Explore opportunities for commercializing the CVCS as a standalone product or as an integrated component in existing moisture measurement systems.

The "Design and Development of Capacitance-to-Voltage Conversion System Using All-Pass, ZCD, and Low-Pass Filters for Measuring Moisture in Raw Cashew Nuts" project not only holds immense promise for the cashew nut industry but also for broader applications in the field of moisture measurement. This innovation opens doors to improved quality control, reduced wastage, and sustainable practices across various industries, ultimately benefiting both producers and consumers.

1.8 References

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