DEVELOPMENT OF A CAPACITANCE SENSOR SYSTEM TO MEASURE ULTRA-LOW WATER CONTENT IN CRUDE OIL

By

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13857

Dissertation submitted in
partial fulfillment of the requirements
for the
Bachelor of Engineering (Hons)
(Electrical & Electronics)

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CERTIFICATION OF APPROVAL

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Approved by,

____

(AP Dr. Tang Tong Boon)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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LIM YEE LING

ABSTRACT

The capacitance sensor system had been applied in various applications including measurement of water content in crude oil. The purity of crude oil is graded based on the water content found in it. The lesser the amount of water detected, the higher the purity of crude oil. The determination of water content is crucial as it directly reflects the quality of crude oil. However, the capacitance sensor system is limited to a high water concentration measurement. In this project, a higher resolution measurement is introduced which utilizes the capacitance sensor system based on phase angle conversion. The presence of water inside the crude oil is indicated by the change in capacitance value and results in a phase shift. The sensor system is capable of detecting a very small change of capacitance, meaning it is able to measure ultra-low water content inside the crude oil.

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CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND OF STUDY

Grading the purity of crude oil is an important task at different stages of processing. The classification of crude oil depends on its physical characteristics and chemical composition. Water content in crude oil is a very important data in grading crude oil. The quality of crude oil is often associated with the amount of water content in it. The water found in crude oil actually originates from underground water when it is extracted from the reservoir. Since the underground water comprises of various minerals content, the mixture of water and crude consists of conductive ions which lead to its dielectric and electrical conductive properties.

The determination of water content in crude oil is vital in the processing, transport and marketing purposes as it measures and reflects the net volumes of actual crude oil in sales, taxation, exchanges and custody transfer. Besides that, it is significant in maintaining the quality control of crude oil and to meet trade specifications. In other word, the water content measured is a significant parameter in determining the net oil production.

In industrial processes, common methods such as distillation, centrifugation and electrical dewatering are used in the water content measurement in crude oil. These test methods often involves the usage of expensive tools and equipments and requires complicated procedures. This results in a time consuming and tedious processes.

In recent years, great interest is shown in developing water content measurement technologies. In order to measure ultra-low water content in crude oil, an accurate sensing measurement with a higher resolution is required. This project will focus on the development of a capacitance sensor system to measure ultra-low water content in crude oil based on phase shift conversion.

A capacitance contains two conducting plates separated by an insulating material or known as the dielectric. It is broadly used in various applications and fields such as in electronics, communications systems and power systems. The value of capacitance depends on the dielectric material placed in between them which is the measured parameter. The larger the permittivity of the dielectric material between the plates, the greater will be the capacitance. Besides that, the capacitance values are also affected by the surface areas of the plate and the spacing distance between the plates.

To measure ultra-low water content in crude oil, the sensor system should be able to detect a very small change in capacitance value. Capacitive sensors are noncontact devices capable of high-resolution measurement. The sensor system designed will be able to detect a small change in capacitance value. The phase difference reflects on the capacitance changes which represent the amount of water found in crude oil.

1.2 PROBLEM STATEMENT

There are various conventional methods used in grading purity of crude oil but the methods often involve pricey equipments and require complex procedures. The determination of water content in crude oil is essential as it reflect actual net production of crude oil. Therefore, it is crucial to develop a simpler and economic sensor system for grading the purity of crude oil. Capacitance sensor system is useful in a wide range of applications in the industry especially in the measurement of water content in crude oil. However, the sensor system is limited to high water content measurement. Therefore, a higher resolution capacitive sensing system is required to measure ultra-low water content in crude oil. The sensor system should be able to detect a very small change in capacitance value.

1.3 OBJECTIVE

The main objective is to develop a simpler and economic sensor system for grading crude oil. Under the main objective, the followings are the sub-objectives for this project:

- To develop a high resolution measurement of water content in crude oil.
- To design and implement capacitance sensor system based on phase shift conversion

1.4 SCOPE OF STUDY

The design and implementation of the sensor system is studied. There are various ways to measure water content in crude oil and most of them are expensive and involve complicated procedures. Therefore, the aim of this project is to develop a high resolution measurement of water in crude oil using capacitance sensor which is a simpler and less expensive option than the industrial conventional methods. Next, it is important to understand how the capacitance sensor system based on phase shift conversion is able to measure water content in crude oil. For example, how the phase difference is related to the water content found in crude oil. Lastly, the whole capacitance sensor system is set up and measurements will be done using crude oil samples.

CHAPTER 2

2. LITERATURE REVIEW

The determination of water content in crude oil is essential in the petroleum industry as it reflects the actual net volume of crude oil production. The amount of water content is directly related to the quality of the crude oil. The lower percentage of water content found defines a better quality of crude oil. The applied method commonly used in measuring water content in crude oil in the industry is divided into two types which consist of artificial sampling and on-line measurement.

The test methods widely used in the industry comprises of centrifugation, distillation and Potentiometric Karl Fischer Titration method [1]. A laboratory centrifuge is a piece of equipment driven by electric motor that spins liquid samples at a high speed and works by sedimentation principle where centripetal acceleration is used to separate substances of greater and lesser density. For the centrifugation method, the crude oil is first heated before being mixed with solvent (water saturated toluene). In certain cases, de-emulsifier is also added. The crude oil is then centrifuged at a very high speed of 500X gravity and the centrifugal force causes more dense particles to migrate away from the axis of rotation and lighter particles to move toward it. These particles will eventually settle and the amount of water can be read at the bottom of the tube. The distillation method involves boiling of the mixture of crude and water immiscible solvent (xylene) which forces the water and solvent overhead. The solvent and water will be condensed into trap and the trap circulates the solvent back to crude while retaining the water. The Potentiometric Karl Fischer Titration method utilizes the quantitative reaction of water with iodine where water in the crude oil sample reacts with iodine from the Karl Fishcer (KF) solution. This results in an increase of cell resistance and fresh KF solution is added to restore the original resistance. Thus, the amount of KF solution added is directly proportional to the water content in crude oil. All the test methods above generally display precise results. However, these methods require expensive equipments and tools and often require tedious laboratory procedures which involve a lot of time.

On-line measurement such as density method, ray method, short wave, microwave method and capacitance method are also used in determining water content in crude oil [2]. Ultrasonic measurement technique [3, 4] is also used in determination of water content in crude oil and it does not pose health risks as compared to methods using radiation attenuation like x-ray or gamma ray. Recent research had use the method of impedance spectroscopy for online assessment of water concentration where the dielectric property of the liquid phase is proportional to the electrical impedance [5]. However, when it comes to measuring ultra-low water content, the methods mentioned above are restricted to a higher water concentration measurement.

The usage of capacitance sensors are acknowledged in various applications such as proximity sensing [6], position sensing [7], humidity sensing [8] and etc. A proximity sensor can detect the presence of nearby objects without physical contact by emitting electromagnetic field or radiation and detecting the change in the field or the returning signal. When a target object comes closer to the capacitive type proximity sensor, the controller unit will detect a change of electric field distributed around the capacitor. Position sensors can be used to measure linear and angular position and it is widely used in industrial applications such as liquid level measurement, shaft angle measurement, gear position sensing and etc. Capacitive humidity sensor detects changes in the dielectric material between the capacitor plates since the dielectric of air is influenced by the humidity. These sensors are commonly made of aluminum, tantalum, silicon and polymer types.

A capacitor is made up of two conducting electrodes separated by an insulator or a non-conducting material known as dielectric. These dielectric materials have their own respective dielectric constant. The capacitance value differs depending on the physical quantity placed between the capacitor plates where the capacitance is proportional to the value of dielectric constant. When the dielectric constant of the material placed between the capacitor plates increases, the capacitance value increases as well. In terms of parameters such as design simplicity, cost, reproducibility and output response, the capacitance sensor system is proven to be a better choice among other measurement methods [9]. There are various types of designs presented for the capacitance sensor system such as concave and ring-types [10], uniform circular cylinder made up of insulating material such as glass, ceramic and plastic [11], semi-cylindrical [12] and etc.

The small change in capacitance value (<100ppm) is difficult to be detected by a typical LCR meter where the LCR meter is an electronic tool used in measuring the resistance, inductance or capacitance of a component [13]. Parts per million or ppm refer to out of a million and represent the concentration of something in a liquid. Since the high accuracy LCR meter is only available for laboratory usage, it is vital for the capacitance sensor system to be equipped with an interface circuit with high sensitivity to accurately measure the change in capacitance value.

There are various types of interface circuit used for the capacitance sensing system. In [14], the capacitance sensors are connected directly to a microcontroller without using any analog circuit between them. This method can only measure low capacitance value with low sensitivity due to its simplicity in design. Switched capacitor signal-conditioning circuit [15] and Modified Schering Bridge network circuit [16] were also used as interfacing circuit for the capacitance sensor system.. In [17] , the interface circuit detect the capacitances by sensing the current flowing through the transducer and convert it to an output voltage. The output voltage produced is proportional to the transducer capacitance. All the circuits mentioned above are sufficient for the usage of general measurement. When it comes to determination of ultra-low water content in crude oil, these interface circuits are not adequate enough for a high resolution measurement. Therefore, it is necessary to have a readout circuit that is reliable and precise.

Based on these findings, it is necessary to develop a high resolution measurement of water content in crude oil. For this project, a capacitance sensor system based on capacitance to phase angle conversion is proposed [18]. The circuit is able to detect very small changes in capacitance values which represent the water content in crude oil and sensitive to changes in femto farads. This circuit is only made up of single stage capacitance to phase conversion circuit which results in unstable outputs caused by presence of jitter noise. In Figure 1, the single stage capacitance to phase conversion circuit is shown.

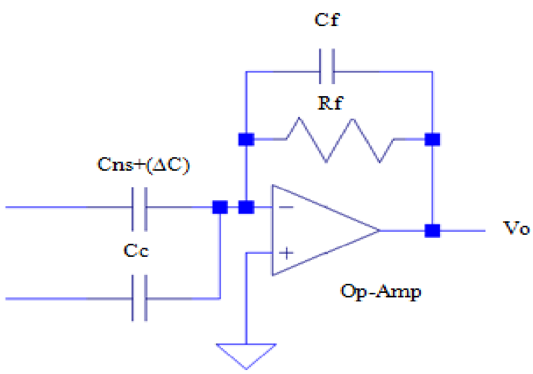


Figure 1: Single stage capacitance to phase conversion circuit [18]

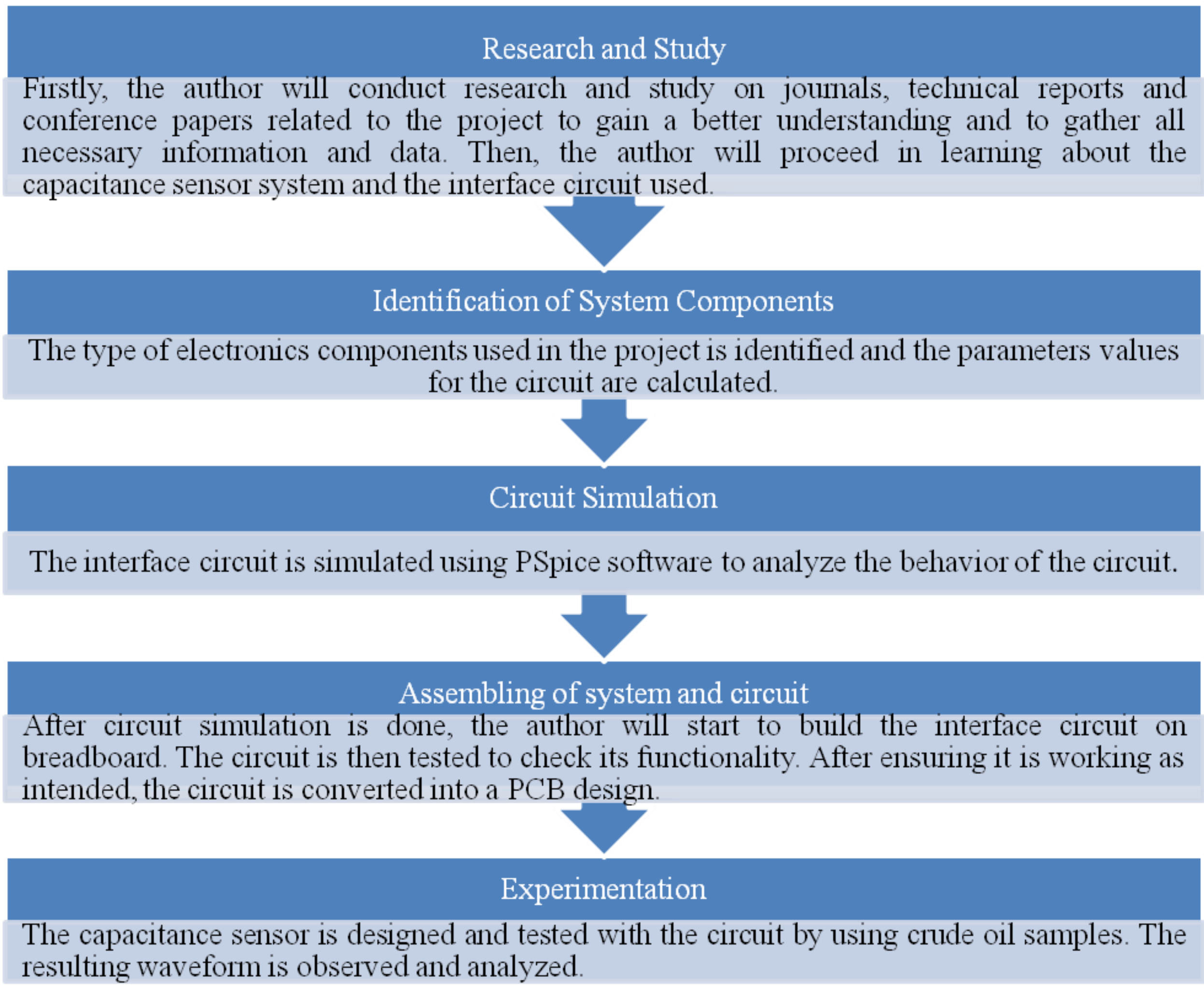
Therefore, in this project, differential sensing technique is used in the capacitive sensing system to overcome the limitation and to produce more stable output readings. Therefore, by utilizing the differential sensing technique, comparison can be made between the measurement and reference sensor. Being able to detect a small change in capacitance value, it is a promising method for a high resolution measurement of water content in crude oil.

CHAPTER 3

3. METHDODLOGY

3.1 RESEARCH METHODOLOGY

The capacitance sensor system used in measuring ultra-low water content in crude oil is based on the phase angle conversion method. The following flowchart displays the approaches and methods that are going to be used in this project for the entire FYP. FYP I will only cover from literature review until circuit simulation while FYP II covers from assembling of system and circuit until experimentation.



Project Design

Capacitance Sensor

The capacitance sensor is designed by using a glass tube and copper foil that act as the two electrodes. The copper foil is attached to both sides of the glass tube, creating a capacitor with two parallel conducting plates separated by an insulating material or dielectric where in this case is the crude oil samples. Therefore, the capacitance of the sensor depends on the dielectric permittivity of the medium between the two electrodes.

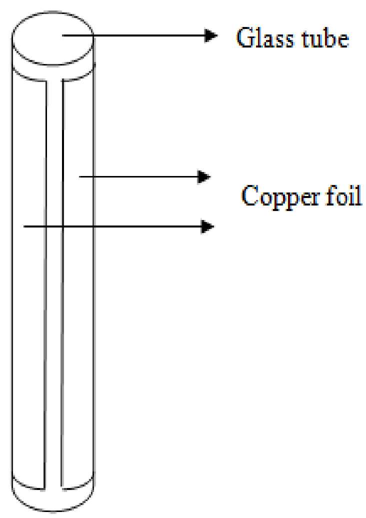


Figure 2: Design of the capacitance sensor

Interface Circuit

Figure 3 display the proposed interface circuit diagram of the capacitance sensor system. The interface circuit consists of three parts: Capacitance to phase conversion, Sinusoidal to digital conversion and Comparison. The circuit uses differential sensing technique where the upper part is the measurement signal flow path and the bottom part is the reference flow signal path. Figure 4 shows the circuit diagram for the generation of compensating driving signals. The compensating signal is introduced to permit gradual phase shift in response to change of capacitances.

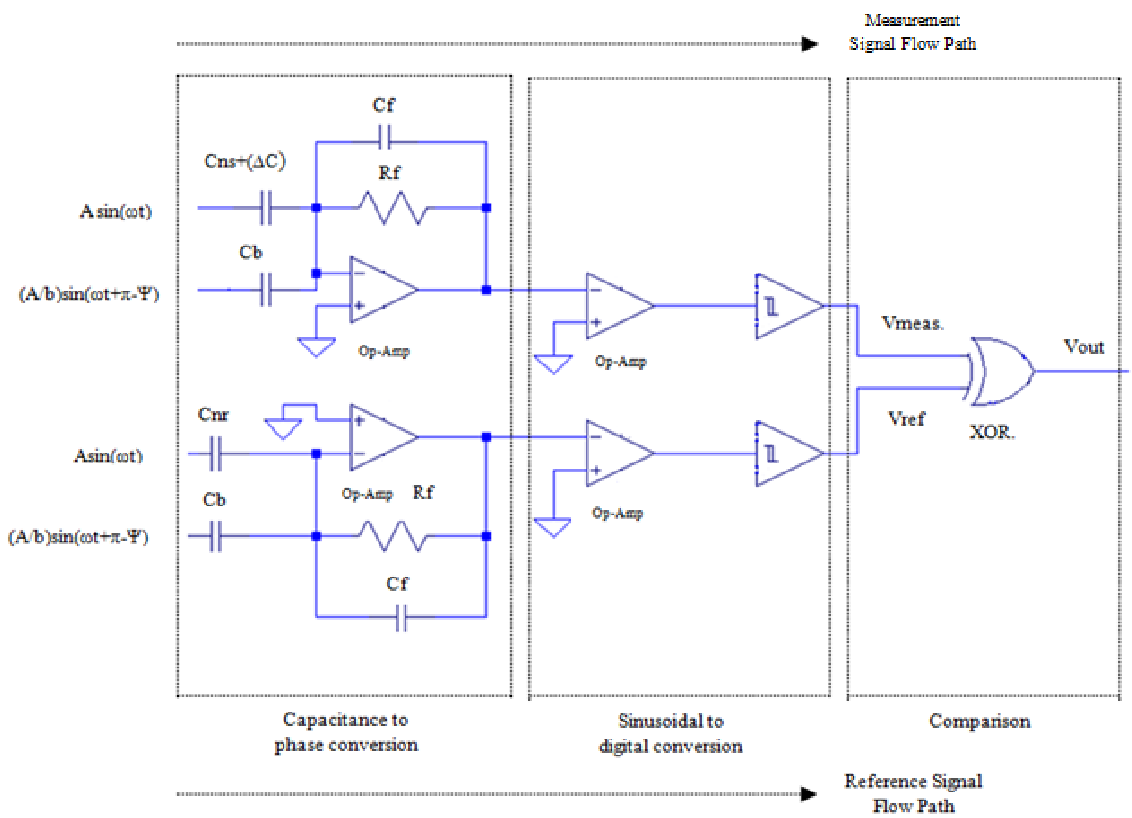


Figure 3: Interface Circuit Diagram

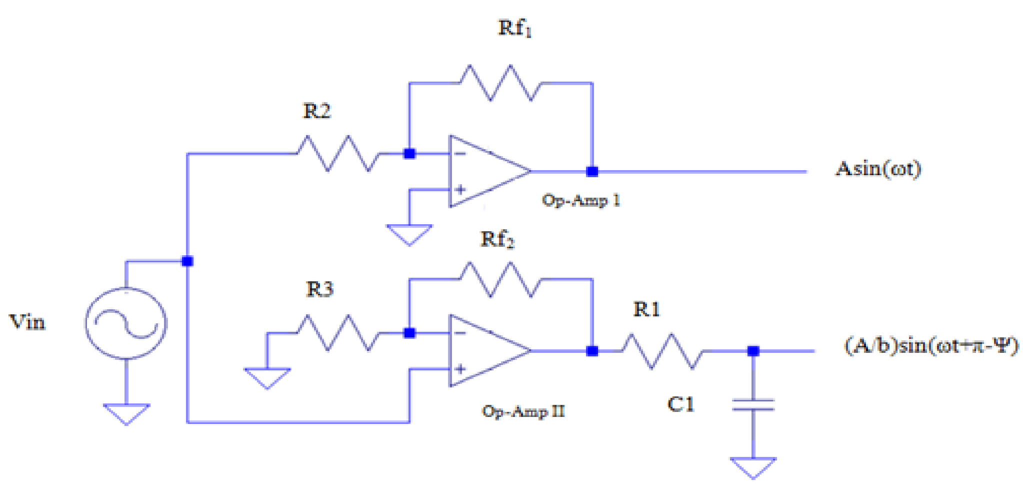


Figure 4: Circuit to generate compensating driving signals

Part 1-Capacitance to phase conversion

In this section, two stages of capacitance to phase converters are used where parameter C_{ns} represents the measurement sensor and C_{nr} act as the reference sensor. The main reason for using two stages of capacitance to phase converters is comparison can be done between the measurement and reference value so that the phase difference can be determined where it represents the amount of water content in crude oil. The two input driving compensating signals $A\sin(\omega t)$ and $(A/b)\sin(\omega t+\pi-\Psi)$ is generated by the circuit shown in Figure 4. Op-amp 1 produce the phase shift of 180^o and the RC low pass filter will shift the output signal of Op-amp II. The parameter Ψ represents the sensitivity and operating region where the value of Ψ affects the angle of phase shifted signal. The value of Ψ can be calculated by using the RC low pass formula: $\Psi=-\arctan(\omega R1C1)$.

Part 2- Sinusoidal to digital conversion

The Op-amp will generate a square wave from the output sine wave from circuit in Part 1. The Schmitt Trigger will then convert it into a digital signal.

Part 3- Comparison

Both the digital output is fed into the XOR gate to show the phase difference between both sensor signals. The pulse width generated will be bigger if there is larger phase difference which indicates higher water content in crude oil. The point output of XOR gate will be zero when water content is 0ppm because both capacitance sensors measurements are the same.

3.2 PROJECT ACTIVITIES

Below displays the project activities that are used to achieve the objectives of this project. The projects activities basically cover from FYP 1 to FYP 2.

1) Interface circuit simulation (FYP 1)

   The interfacing circuit for the capacitance sensor system is simulated using PSpice to evaluate the performance of the circuit. By varying the capacitance values, the phase difference produced is observed where it actually reflects the amount of water in crude oil.

2) Design Implementation (FYP 2)

   The interface circuit is built and tested to ensure it is working accordingly. After that, it is converted into a PCB design. The whole capacitance sensor system is then assembled together and implemented.

3) Experimentation (FYP 2)

   After the capacitance sensor system is implemented, measurements will be done using crude oil samples. Safety precaution must be taken when handling the crude oil as they are flammable in nature. The experiment should be conducted in an environment with good ventilation and no source of ignition. When not in used, the crude oil must be stored in a closed container to avoid spillage. Measurements are first conducted with both sensors using pure crude oil and water is gradually added in by using a micro syringe. The results from the experiment will indicate the capacitance changes due to the water content in crude oil.

3.3 LIST OF TOOLS AND EQUIPMENT USED

The following shows the list of tools and equipments needed for this project:

1) Materials
- Crude oil sample
- Glass tube
- Copper foil

2) Software
- PSpice
- EAGLE

3) Components
- Operational Amplifiers (CA3140)
- HEX Schmitt-Trigger Inverters (SN74LS14)
- Quadruple 2-Input Exclusive-Or Gates (GD74LS86)
- Capacitors
- Resistors
- Breadboard

4) Equipments
- Digital Multimeter
- Logic Analyzer
- Oscilloscope
- AC Signal Generator
- DC Power Supply
- LCR Meter

3.4 GANTT CHART AND PROJECT KEY MILESTONES

<u>FYP I</u>

Week

No	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project Title Selection														
2	Literature review														
3	Submission of Extended Proposal														
4	Interface Circuit Simulation														
5	Proposal Defense and Progress Evaluation														
6	Interface Circuit Implementation and Characterization														
7	Completion of Interface Circuit Simulation														
8	Submission of Interim Draft Report														
9	Submission of Final Interim Report														

Process

Suggested Milestone

FYP II

Week

No	Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Build Interface circuit	■	■	■	■	■	■	■								
2	Implementation of PCB								■	■						
3	Submission of Progress Report								●							
4	Experimentation									■	■	■	■			
5	Electrex										●					
6	Submission of Draft Report													●		
7	Submission of Final Report and Technical Paper														●	
8	Viva															●

■ Process

● Suggested Milestone

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 CIRCUIT SIMULATION

For this project, capacitance sensor system based on phase angle conversion will be used for the high resolution measurement of water content inside crude oil. Circuit simulation using PSpice is conducted to show that interface circuit for the capacitive sensing system is working as intended. The simulation of the circuit is done by using the software PSpice. Figure 5 shows the schematic diagram of the interface circuit drawn using PSpice. Before that, a thorough understanding of how the circuit works is important and the parameter values for the circuit is determined.

The C_{ns} represent the capacitance value of the measured crude oil sample while C_{nr} is the capacitance value of pure crude oil samples which act as a reference. Therefore, the value of C_{nr} is kept constant. As the value of C_{ns} increases, meaning an increase in water content in crude oil, the waveform generated will have greater phase shift. This results in a larger phase difference and this is reflected by the pulse width produced by the XOR gate. If the output of XOR gate displays a straight line without the presence of pulse width, it indicate the measured crude oil sample has zero water content as there is no phase difference when compared to the reference value.

The interface circuit simulation is carried out to prove this by using different capacitance values. The simulation is started off with capacitance value of 5pF for both C_{ns} and $C_{nr.}$ Subsequently, the parameter value of C_{ns} is increased gradually in femto farad ranges. The change in capacitance values will be denoted as ΔC. This shows that the interface circuit is able to detect a very small change in capacitance values which represent the ultra-low water content in crude oil. Therefore, it is adequate for a high resolution measurement. By varying the capacitance values of C_{ns} , the output of the XOR gate is observed to see the resulting pulse width.

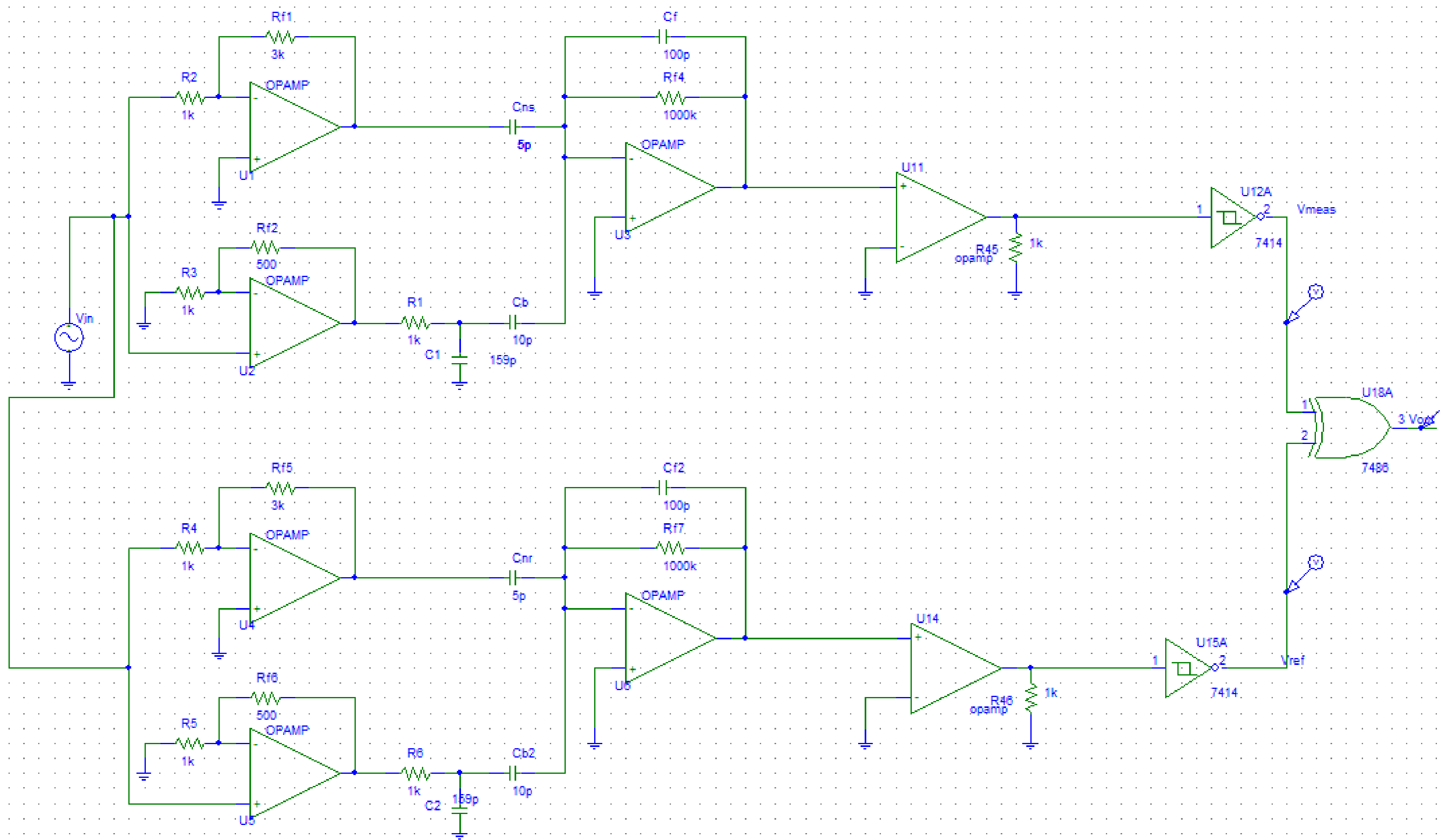
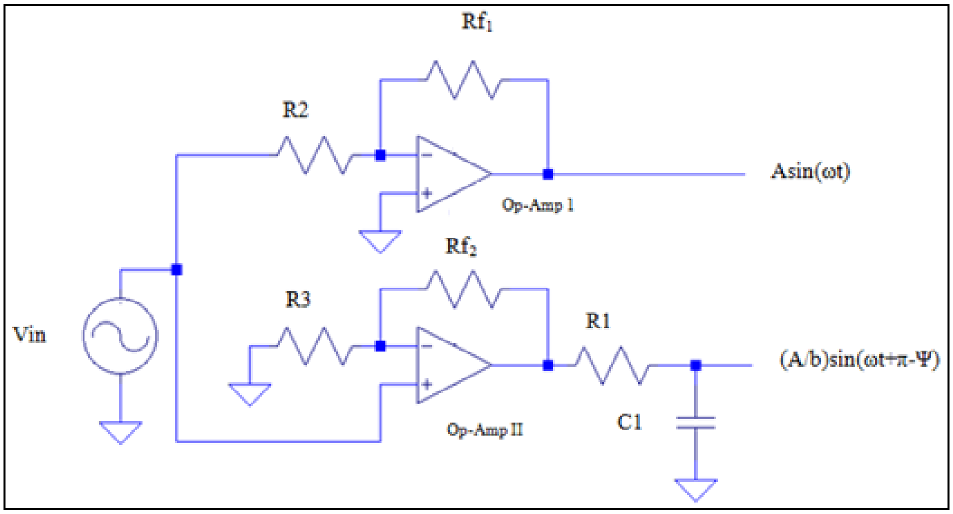


Figure 5: Schematic Diagram of Interface Circuit

4.1.1 CALCULATION OF PARAMETER VALUES

1) Circuit to generate compensating driving signal



For V_{in} , the amplitude is set to be 1V and its frequency is 10 kHz.

The amplitude, A is adjusted by varying the values of resistors R2 and Rf_1. The chosen value for A is 3. Therefore, by choosing R2 = 1kΩ, Rf_1= 3kΩ.

$$A = -\frac{Rf_1}{R2} \times V_{in}$$

$$-3 = -\frac{Rf_1}{1k} \times 1$$

$$Rf_1 = 3k\Omega$$

The output signal will be $-3\sin(\omega t)$ as a result of phase shift of 180°

The amplitude (A/b) is chosen to be 1.5 and it is also adjusted by varying the values of resistors R3 and Rf_2. By choosing R3= 1kΩ, Rf_2=500Ω.

$$\left(\frac{A}{b}\right) = (1 + \frac{Rf_2}{R3}) \times V_{in}$$

$$1.5 = \left(1 + \frac{Rf_2}{1k}\right) \times 1$$

$$Rf_2 = 500\Omega$$

Thus, the resulting signal will be $1.5\sin(\omega t + \pi - \Psi)$.

The value of Ψ determines the sensitivity and affects the angle of phase shifted signal. Ψ can be calculated using the formula of RC low pass filter.

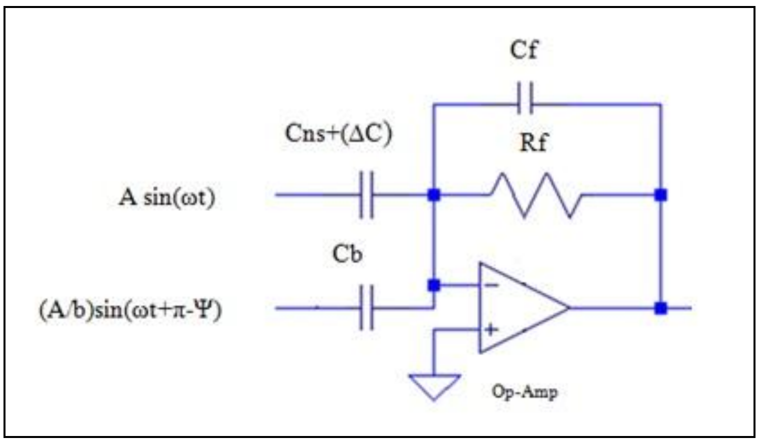
$$\Psi = \arctan(\omega R1C1)$$

By selecting R1=1kΩ and Ψ=0.01, C1= 159.16pF.

$$0.01 = \arctan(2\pi \times 10k \times 1k \times C1)$$

$$C1 = 159.16pF$$

2) Capacitance to phase conversion circuit



For this part of the circuit, the following conditions are to be fulfilled:

$$C_b \approx bC_{ns}$$

$$\omega R_f C_f \gg 1$$

From the previous calculations, the value of b is 2 and by choosing the value of C_{ns} to be 5pF, the value of C_b is 10pF.

For $\omega R_f C_f \gg 1$, the selected values of R_f is 1000kΩ and C_f is 100pF.

4.1.2 SIMULATION RESULTS

1) ΔC=0fF

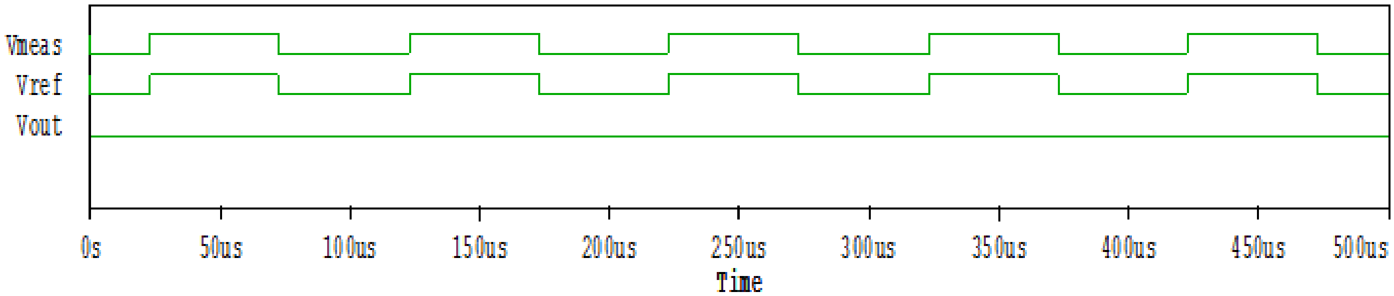


Figure 6: Resulting waveform for ΔC=0fF

2) ΔC=5fF

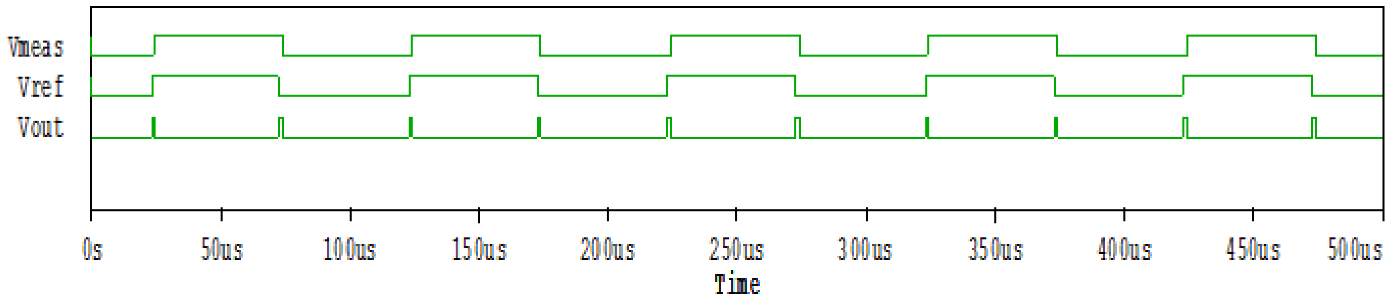


Figure 7: Resulting waveform for ΔC=5fF

3) ΔC=10fF

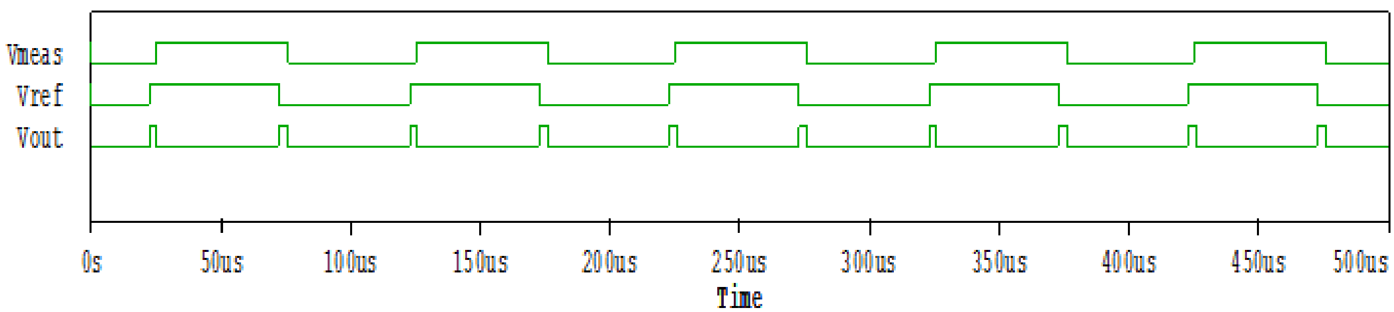


Figure 8: Resulting waveform for ΔC=10fF

4) ΔC=15fF

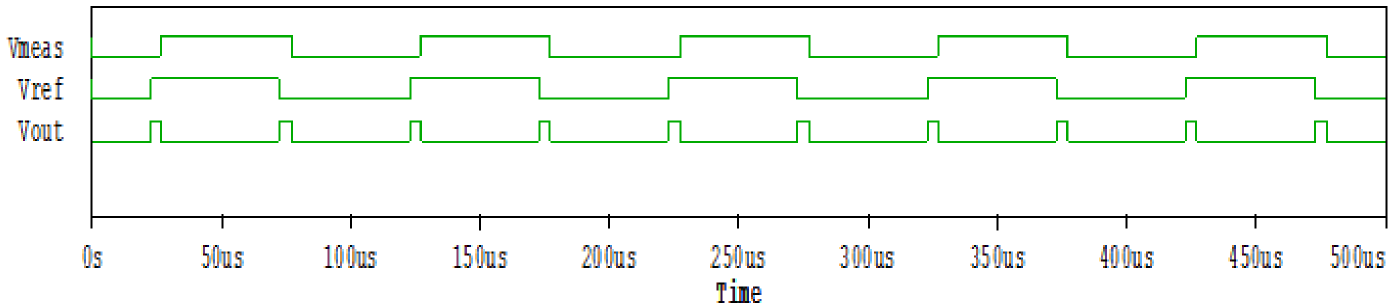


Figure 9: Resulting waveform for ΔC=15fF

5) ΔC=20fF

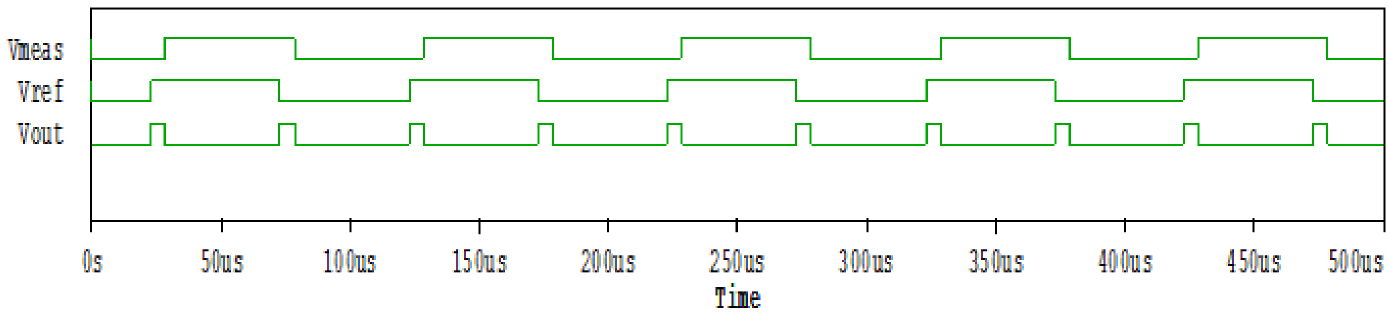


Figure 10: Resulting waveform for ΔC=20fF

6) ΔC=25fF

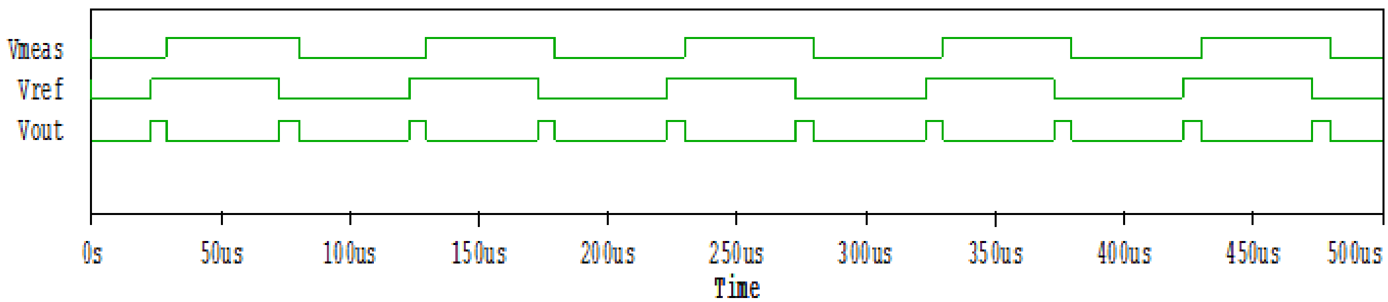


Figure 11: Resulting waveform for ΔC=25fF

From the simulation results of PSpice, it can be seen that as the ΔC increases, the resulting pulse width increases as well reflecting higher water content in crude oil. The results displayed here shows that the interface circuit is indeed working and suitable to be used as a high resolution measurement. The graph below shows the linear relationship between the change of capacitance (ΔC) and pulse width (represented by the phase difference, θ).

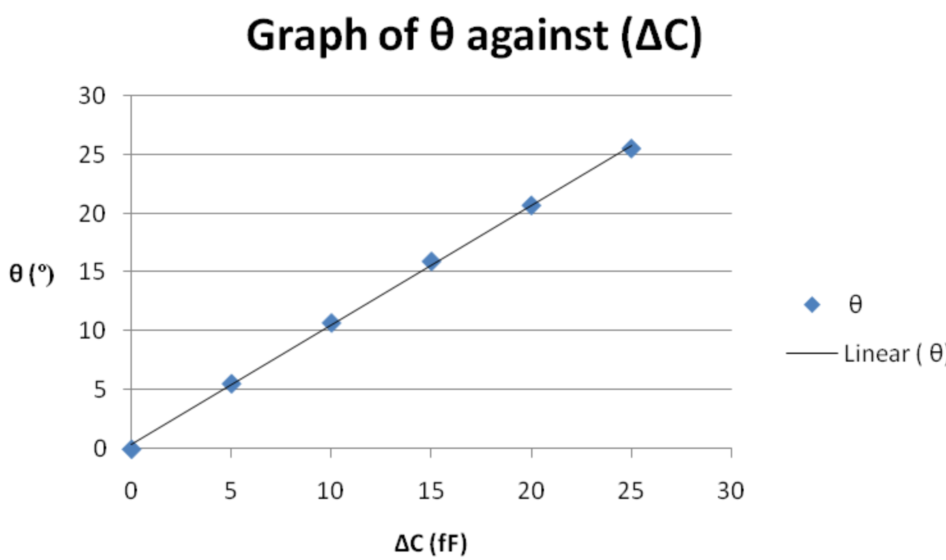


Figure 12: Graph of θ against ΔC

4.2 CIRCUIT IMPLEMENTATION

4.2.1. USING BREADBOARD

After circuit simulation is done, the circuit is built on breadboard. The circuit is tested using different values of capacitances of 0pF and 1pF to check its functionality and sensitivity.

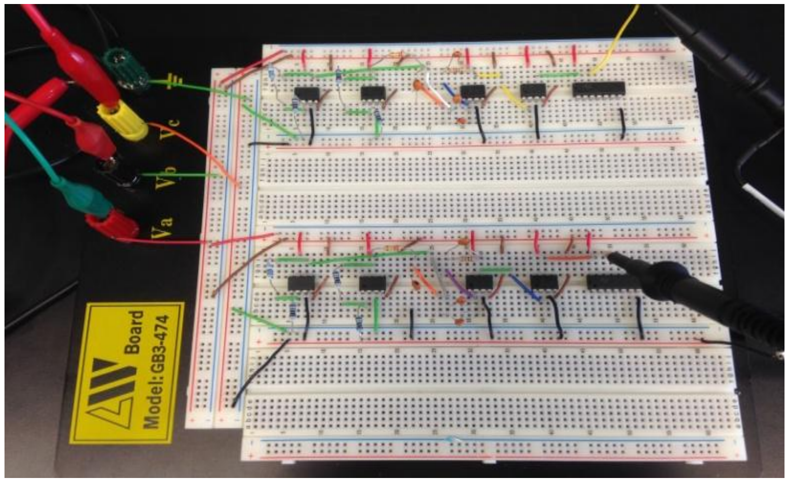


Figure 13: Circuit built on breadboard

The resulting output waveform is observed by using the logic analyzer.

1) ΔC=0pF

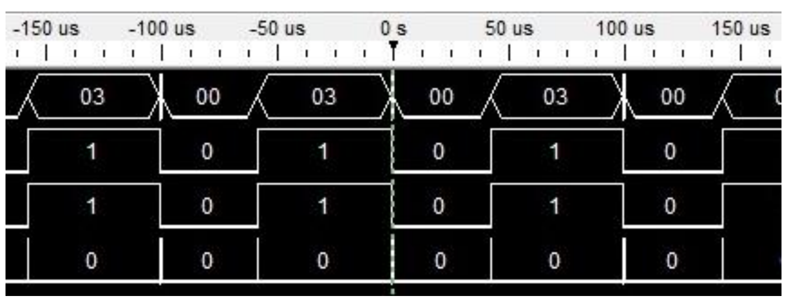


Figure 14: Resulting waveform for ΔC=0pF

2) ΔC=1pF

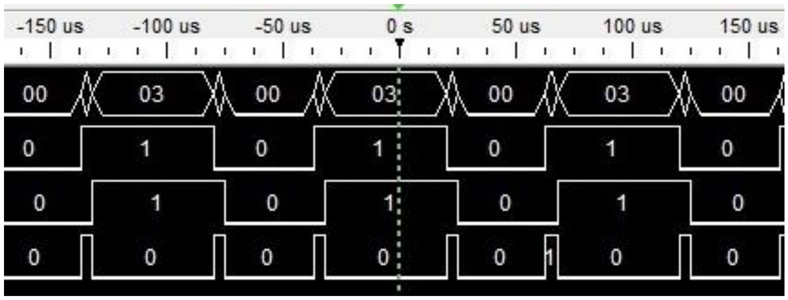


Figure 15: Resulting waveform for ΔC=1pF

In ideal case, there is no phase difference when ΔC=0pF and the resulting output waveform should depict a straight line because both capacitance values of C_{ns} and C_{nr} are the same. However, in practical, there is a very slight difference in values between the two capacitors and the capacitances of wires that are causing a very tiny pulse observed at the output. The resulting pulse width increases when the value of capacitance increases to 1pF. This shows that the circuit is working as there is a phase shift when the value of the capacitance changes. However, the performance of the circuit in terms of sensitivity is not satisfying as the results obtained do not match with the simulation results. According to the simulation results below, the phase difference is 25us when ΔC=1pF.

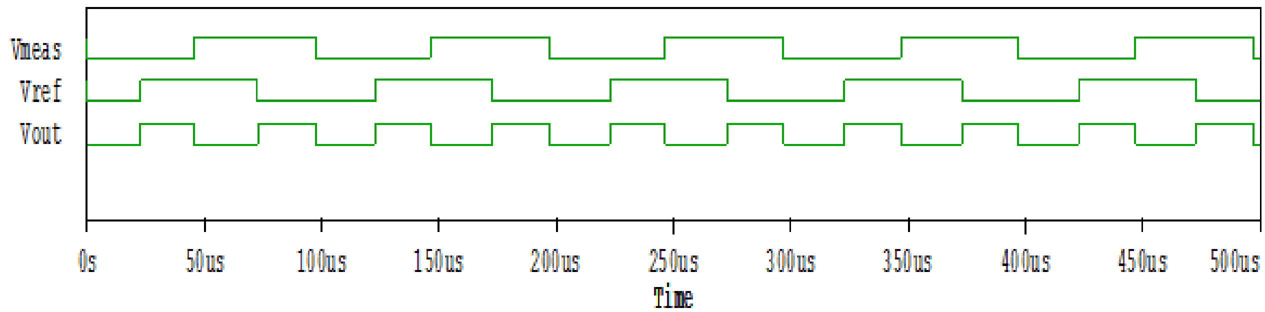


Figure 16: Resulting waveform for ΔC=1pF

4.2.1.1. ANALYSIS ON REDUCTION IN CIRCUIT SENSITIVITY

There are few reasons that may cause the performance of the sensitivity to drop.

a) The limitations of using breadboard

   Breadboards are only useful for simple experiments with few components. Besides that, breadboards are noisier than other circuit boards and this may affect the performance of the circuit. There is also presence of stray capacitance that is caused by the parallel nature of the rows of contacts which is around 2-25pF for every contact point that contribute to the sensitivity problem.

b) The chosen component values

   The chosen values for resistors and capacitors are important as operational amplifiers will only work in a certain reasonable range of component values depending on the datasheet. In addition, the resistances and capacitors available from the EE Store have tolerance where the tolerance percentage reflects how much the electronic component can deviate in terms of percentage from its stated nominal value. For instance, a 1kΩ resistor with 10% tolerance can deviate 10% from its 1kΩ resistance value and 10% of 1kΩ is 100Ω. Therefore, the resistance value can vary between 900 Ω and 1.1 kΩ.

   The circuit is sensitive to different component values. This is validated through the simulation results. A study of circuit sensitivity with respect to choice of resistor values had been conducted. Based on Figure 17, as the resistance value deviates from its stated nominal value (in this case is 1kΩ), the sensitivity represented by the pulse width reduces. This shows that very accurate electronics component values are needed to improve the sensitivity of the circuit. Besides that, all the capacitors available have tolerance of 10% which will cause the values of capacitances to deviate 10% from its stated nominal values. This may affect the performance of sensitivity of the circuit.

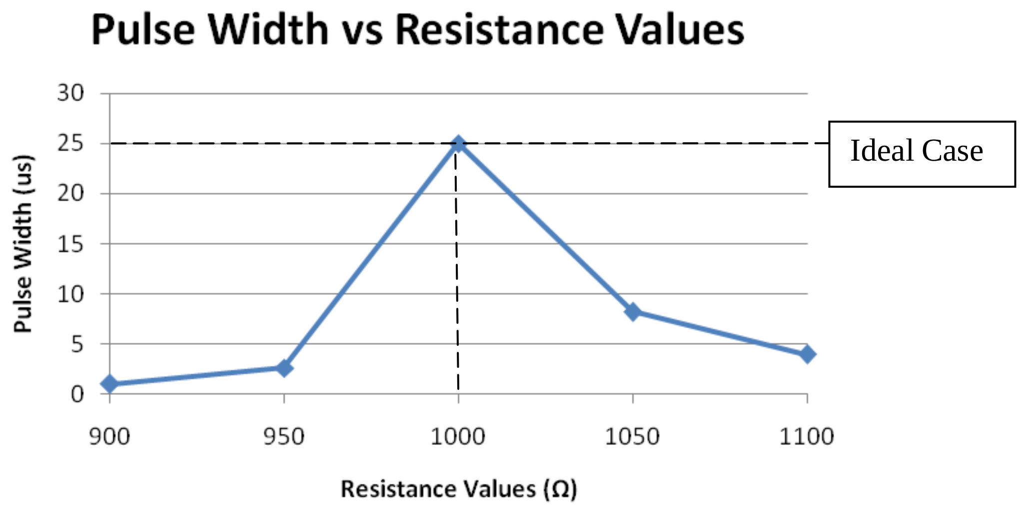


Figure 17: Graph of pulse width vs. resistance values showing circuit sensitivity with different choice of resistor values

4.2.2. USING PRINTED BOARD CIRCUIT (PCB)

In terms of functionality, the circuit is working as there is phase difference observed when the value of capacitances changes. However, the performance of sensitivity need to be further improved. One of the ways to do that is to convert the circuit into a Printed Circuit Board (PCB). A proper design of PCB will lead to reduction of electronics noise as the electronics components are assembled in a manner where the path lengths of electrical current between them decreases which results in lower radiation and pickup of electromagnetic waves. Another thing is that PCB ensures there is no introduction of parasitic capacitance into the circuit. Since noise and parasitic capacitance is causing the degradation of the performance of the circuit, PCB is a good alternative to replace the breadboard to improve the sensitivity of the circuit.

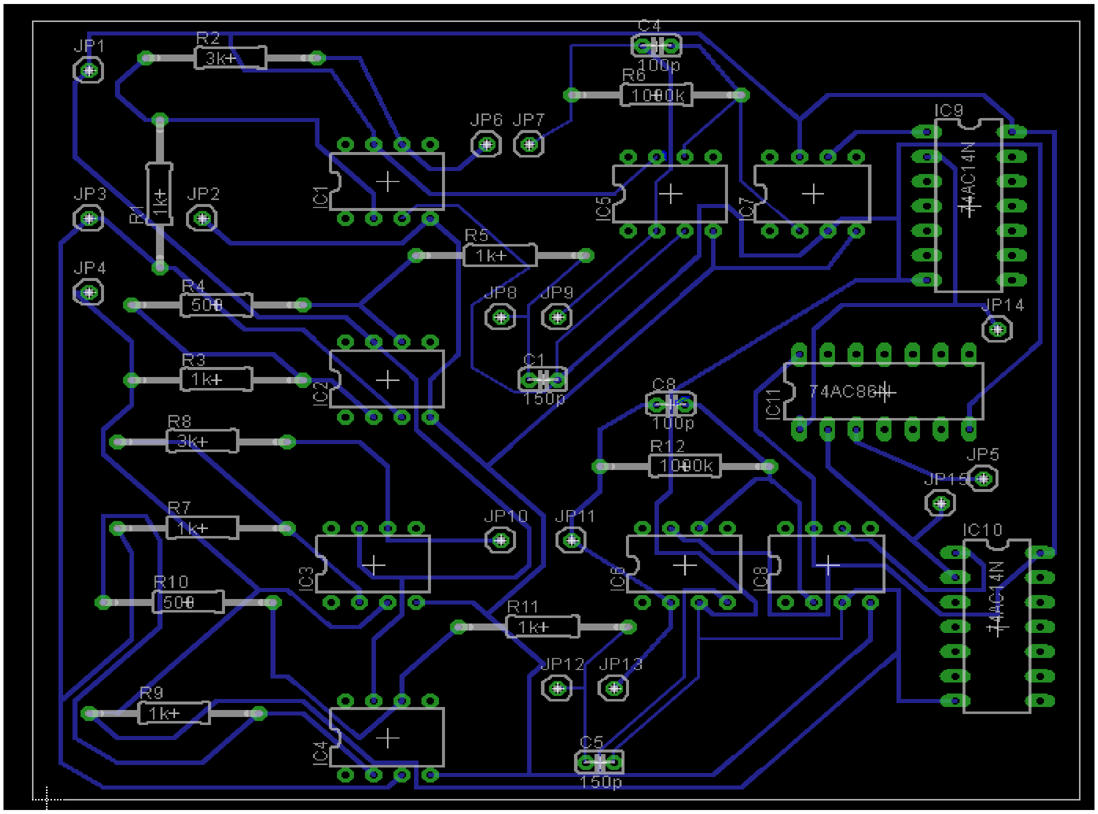


Figure 18: PCB Design using Eagle Software

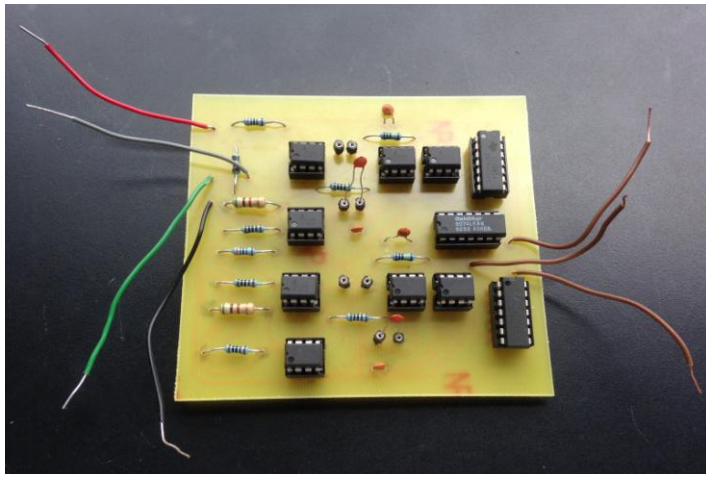


Figure 19: The completed PCB design

The PCB design is done by using Eagle Software. After it had been completed, the PCB is tested with different values of capacitances of ΔC=0 and ΔC=1pF to check the functionality and sensitivity of the circuit. The resulting output waveform is as shown.

1) ΔC=0pF

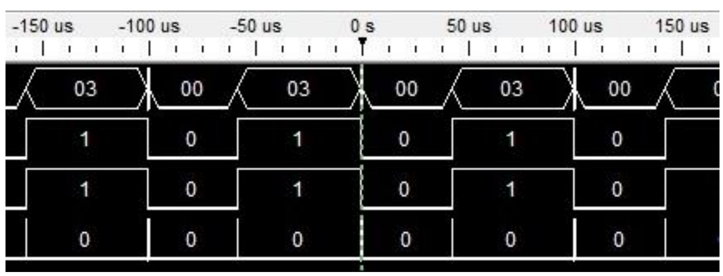


Figure 20: Resulting waveform for ΔC=0pF

2) ΔC=1pF

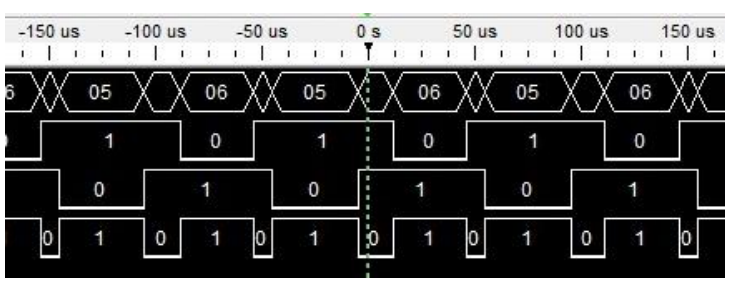


Figure 21: Resulting waveform for ΔC=1pF

Compared to breadboard, PCB implementation displays improvement in terms of sensitivity. The phase shift of 41us is quite large for ΔC=1pF. Note: This may differ compared to the simulation results because it is operating in a non-linear region. This is due to the lower value of Ψ used which is 0.01 that gives higher sensitivity but reduced linearity. Based on the results obtained using PCB, it can be seen that PCB gives a better performance in sensitivity when compared to breadboard as it overcome the problem of parasitic capacitance that affects the sensitivity of the circuit.

4.3 EXPERIMENTATION

The experimentation is conducted by using diesel oil due to unavailability of crude oil samples from the Petroleum Engineering Department. The setup of the experimentation is as shown as Figure 22. A micro syringe is used to add in drops of water into the diesel oil. Safety precaution must be taken when conducting the experiment due to the highly flammable properties of diesel oil. The oil samples must not be exposed to a high temperature and kept in a closed container when not in used.

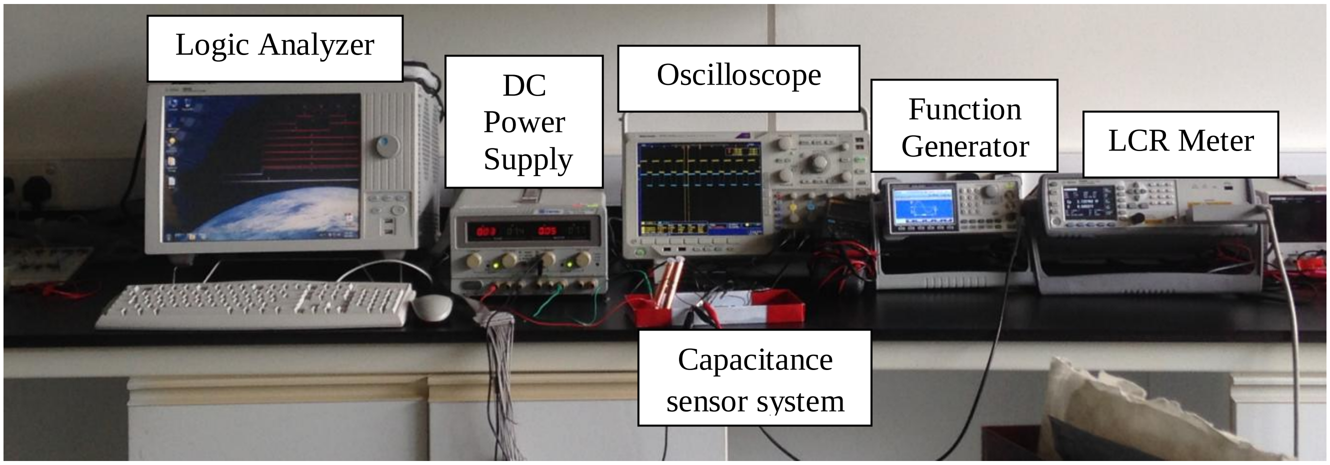


Figure 22: Setup of Experimentation

Figure 23: Capacitance Sensor

Water concentration of 0%, 1% and 5% is added in and the resulting output waveform is observed through the logic analyzer and evaluated.

1) 0% of water

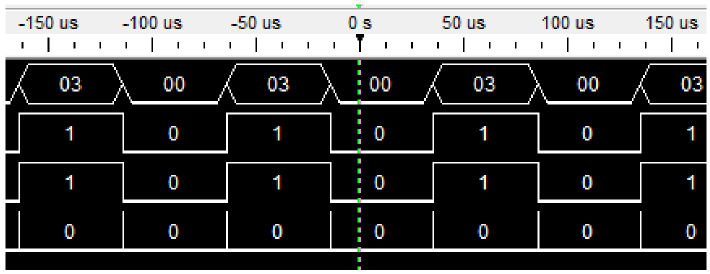


Figure 24: Resulting waveform when no water is added

2) 1% of water

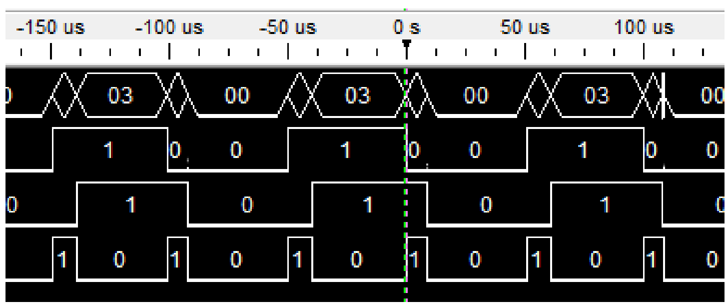


Figure 25: Resulting waveform when 1% of water is added

3) 5 % of water

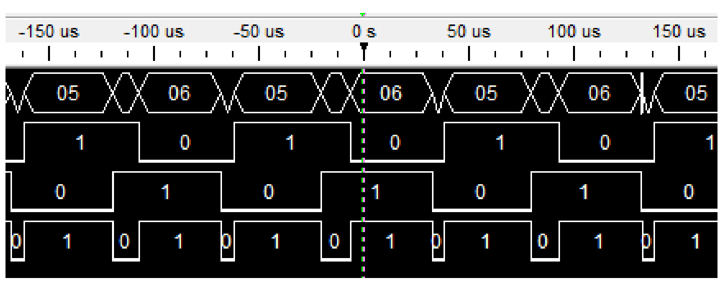


Figure 26: Resulting waveform when 5% of water is added

The purpose of the experimentation is to show the behavior of the circuit when it is tested with the oil samples. When both sensors are filled with diesel oils, both waveforms are the same as there is no phase shift. A phase shift can be seen when 1% of water is added and the pulse width is larger when 5% of water is added. Water has a much higher dielectric constant than diesel oil which causes a large capacitance change when it is added into the oil. The table below shows the dielectric constant of different types of materials and substances at room temperature.

Table 1: Dielectric constant of different types of materials [19]

Material	Dielectric Constant
Vacuum	1.0
Air	1.0006
Oil	2.2
Polyethylene	2.26
Beeswax	2.8
Fused Quartz	3.78
Water	80
Calcium Titanate	168
Barium Titanate	1250

Therefore, the phase shift is greater when water concentration is higher which results in larger pulse width. Based on the results of the experiments, the circuit respond well when it is tested with the diesel oil samples as there is phase difference when the value of capacitance changes. This confirms the functionality of the interface circuit and the capacitance sensors when it is tested with the real oil samples.

4.4 NOISE REMOVAL ANALYSIS

In general, analog circuits are more susceptible to noise (small and undesired variation in voltage). The noises that arise result in the response of the circuit to external input less than ideal. Even a small change in the signal may cause a significant change in the signal, producing error when being processed and result in certain information present to be lost. To investigate the stability of the system, a high frequency noise is introduced at the input source through circuit simulation by using PSpice. With the addition of the noise source, it causes spiking noise or jitter at the circuit output. To remove the noise, a type of low pass filter known as the Sallen-Key Low Pass Filter is introduced to filter out the high frequency noise.

A low pass filter allows low-frequency signals to pass through but attenuates the signals with frequency greater than the cut-off frequency. Sallen-Key Low Pass Filter is a simple active filter based on op-amp stages and one of the most widely used filter topologies in many applications. It is reasonably tolerant of component variations and the performance of the filter is the least dependence on the performance of the op-amp. Besides that, the filter is good for manufacturability due to the low ratio of the largest resistor value to the smallest resistor value and the ratio of largest capacitor value to the smallest capacitor.

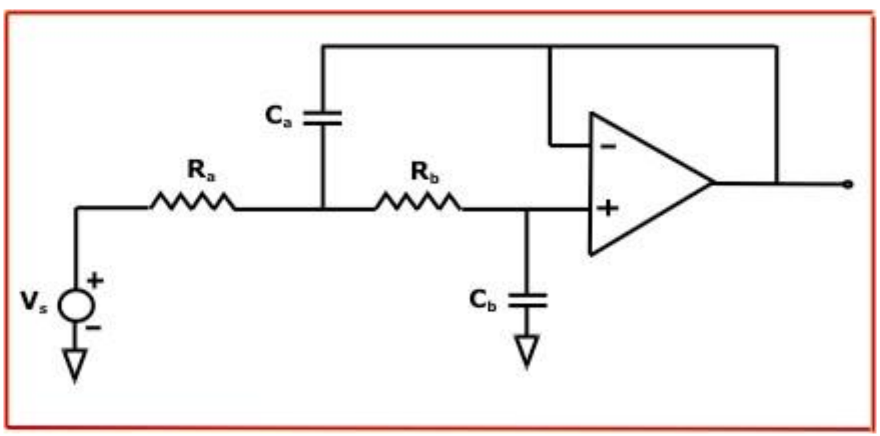


Figure 27: Sallen-Key Low Pass Filter

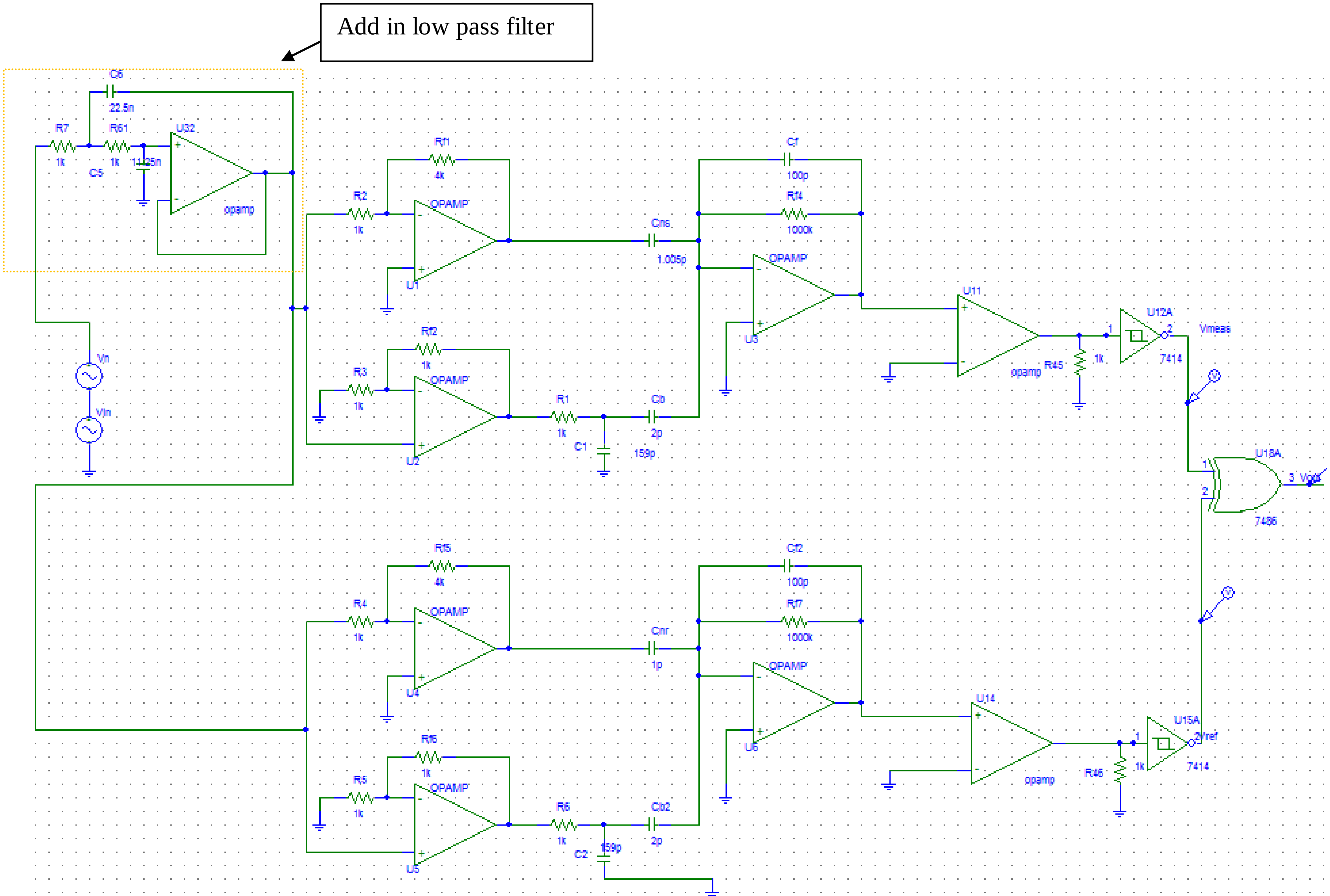


Figure 28: Schematic diagram of circuit with the addition of low pass filter

Simulation Results

Case 1: Without noise source

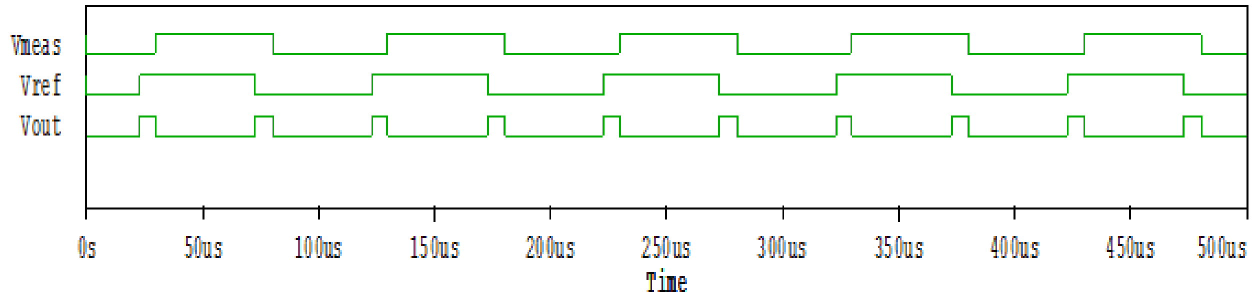


Figure 29: Resulting waveform without noise source

Case 2: With added noise source

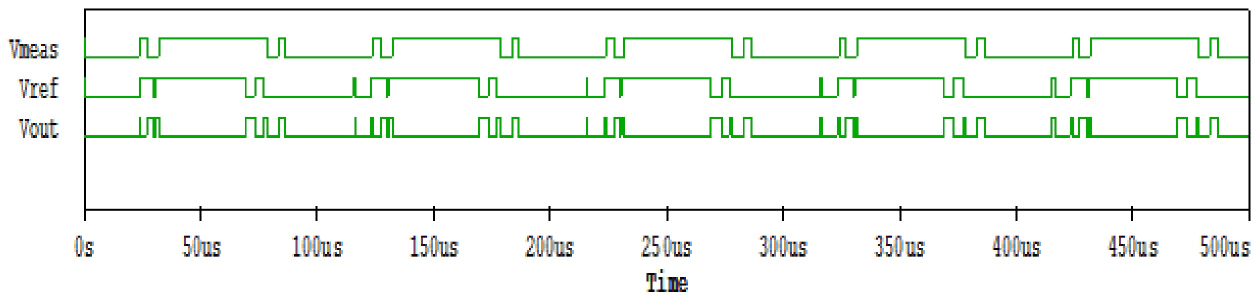


Figure 30: Resulting waveform with added noise source

Case 3: With added noise source + introduction of Sallen-Key low pass filter

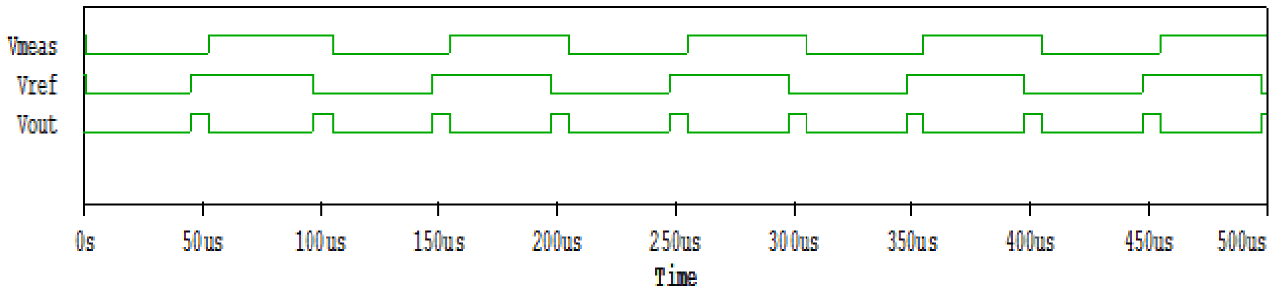


Figure 31: Resulting waveform with added noise source and introduction of Sallen-Key low pass filter

From the simulation results, it can be observed that with the addition of the low pass filter, the circuit produces a more stable output. The Sallen-Key Low Pass Filter manages to filter out the high frequency noise.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

Determination of water content in crude oil is significant in various processes such as manufacturing, purchase, sale or transfer of petroleum products because they help in predicting and evaluating the quality and performance characteristics. The presence of water displaces crude which cost money and the amount of moisture may lead to corrosion of equipment and problems in processing. In the industry, the test methods used in measuring water content involve costly equipments and tedious laboratory procedures.

In this project, a capacitive sensing system based on phase shift conversion is introduced to accomplish this due to its simplicity in design and economic price. The capacitance sensor system is tested with real oil samples to evaluate the behavior of the sensor system. Experimentations are conducted and based on the results obtained, it can be observed that the phase shift is greater when there is higher concentration of water added into the oil samples. This confirms the functionality of the circuit as the phase difference gets larger when there is higher water content.

For future work, there are several recommendations that can be implemented to the capacitance sensor system.

1) Calibration of the sensor system

   In this project, the capacitance sensor system is tested with real oil samples to prove that the circuit responds well and there is phase difference observed when there is an increase in water content or capacitance changes. The sensor system can be calibrated so that the exact amount of water found in the oil samples can be accurately determined.

2) Addition of low pass filter to remove noise

   Simulation using PSpice had been conducted to evaluate the effect of noise to the interface circuit. By adding the Sallen-Key Low Pass filter, the circuit is able to produce a more stable output.

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APPENDICES

Appendix A: Datasheet of CA3140

intersil

CA3140, CA3140A

Data Sheet | November 2002 | FN957.7

4.5MHz, BiMOS Operational Amplifier with MOSFET Input/Bipolar Output

The CA3140A and CA3140 are integrated circuit operational amplifiers that combine the advantages of high voltage PMOS transistors with high voltage bipolar transistors on a single monolithic chip.

The CA3140A and CA3140 BiMOS operational amplifiers feature gate protected MOSFET (PMOS) transistors in the input circuit to provide very high input impedance, very low input current, and high speed performance. The CA3140A and CA3140 operate at supply voltage from 4V to 36V (either single or dual supply). These operational amplifiers are internally phase compensated to achieve stable operation in unity gain follower operation, and additionally, have access terminal for a supplementary external capacitor if additional frequency roll-off is desired. Terminals are also provided for use in applications requiring input offset voltage nulling. The use of PMOS field effect transistors in the input stage results in common mode input voltage capability down to 0.5V below the negative supply terminal, an important attribute for single supply applications. The output stage uses bipolar transistors and includes built-in protection against damage from load terminal short circuiting to either supply rail or to ground.

The CA3140A and CA3140 are intended for operation at supply voltages up to 36V (±18V).

Ordering Information

PART NUMBER (BRAND)	TEMP. RANGE (^oC)	PACKAGE	PKG. NO.
CA3140AE	-55 to 125	8 Ld PDIP	E8.3
CA3140AM (3140A)	-55 to 125	8 Ld SOIC	M8.15
CA3140E	-55 to 125	8 Ld PDIP	E8.3
CA3140M (3140)	-55 to 125	8 Ld SOIC	M8.15
CA3140M96 (3140)	-55 to 125	8 Ld SOIC Tape and Reel	

Features

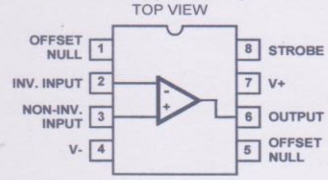
- MOSFET Input Stage
  - Very High Input Impedance (Z_{IN}) -1.5TΩ (Typ)
  - Very Low Input Current (I_I) -10pA (Typ) at ±15V
  - Wide Common Mode Input Voltage Range (V_{ICR}) - Can be Swung 0.5V Below Negative Supply Voltage Rail
  - Output Swing Complements Input Common Mode Range
- Directly Replaces Industry Type 741 in Most
- Applications

Applications

- Ground-Referenced Single Supply Amplifiers in Automobile and Portable Instrumentation
- Sample and Hold Amplifiers
- Long Duration Timers/Multivibrators (µseconds-Minutes-Hours)
- Photocurrent Instrumentation
- Peak Detectors
- Active Filters
- Comparators
- Interface in 5V TTL Systems and Other Low Supply Voltage Systems
- All Standard Operational Amplifier Applications
- Function Generators
- Tone Controls
- Power Supplies
- Portable Instruments
- Intrusion Alarm Systems

Pinout

CA3140 (PDIP, SOIC)
TOP VIEW



1

CAUTION: These devices are sensitive to electrostatic discharge; follow proper IC Handling Procedures.
1-888-INTERSIL or 321-724-7143 | Intersil (and design) is a registered trademark of Intersil Americas Inc.

Absolute Maximum Ratings

DC Supply Voltage (Between V+ and V- Terminals) 36V
Differential Mode Input Voltage 8V
DC Input Voltage . . . . (V+ +8V) To (V- -0.5V)
Input Terminal Current. 1mA
Output Short Circuit Duration∞ (Note 2) . . . . Indefinite

Operating Conditions

Temperature Range. . . . . -55^oC to 125^oC

Thermal Information

Thermal Resistance (Typical, Note 1)	θ_{JA} ($^oC/W$)	θ_{JC} ($^oC/W$)
PDIP Package	115	N/A
SOIC Package	165	N/A

Maximum Junction Temperature (Plastic Package) . . . . 150^oC
Maximum Storage Temperature Range . . . . -65^oC to 150^oC
Maximum Lead Temperature (Soldering 10s) . . . . 300^oC
(SOIC - Lead Tips Only)

CAUTION: Stresses above those listed in "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress only rating and operation of the device at these or any other conditions above those indicated in the operational sections of this specification is not implied.

NOTES:

1. θ_{JA} is measured with the component mounted on a low effective thermal conductivity test board in free air. See Tech Brief TB379 for details
2. Short circuit may be applied to ground or to either supply.

Electrical Specifications $V_{SUPPLY} = \pm15V$, $T_A = 25^oC$

PARAMETER	SYMBOL	TEST CONDITIONS		TYPICAL VALUES CA3140	CA3140A	UNITS
Input Offset Voltage Adjustment Resistor		Typical Value of Resistor Between Terminals 4 and 5 or 4 and 1 to Adjust Max V_{IO}		4.7	18	kΩ
Input Resistance	R_I			1.5	1.5	TΩ
Input Capacitance	C_I			4	4	pF
Output Resistance	R_O			60	60	Ω
Equivalent Wideband Input Noise Voltage (See Figure 27)	e_N	BW = 140kHz, R_S = 1MΩ		48	48	µV
Equivalent Input Noise Voltage (See Figure 35)	e_N	R_S = 100Ω	f = 1kHz	40	40	$nV/\sqrt{Hz}$
			f = 10kHz	12	12	$nV/\sqrt{Hz}$
Short Circuit Current to Opposite Supply	$I_{OM}+$		Source	40	40	mA
	$I_{OM}-$		Sink	18	18	mA
Gain-Bandwidth Product, (See Figures 6, 30)	f_T			4.5	4.5	MHz
Slew Rate, (See Figure 31)	SR			9	9	V/µs
Sink Current From Terminal 8 To Terminal 4 to Swing Output Low				220	220	µA
Transient Response (See Figure 28)	t_r	R_L = 2kΩ C_L = 100pF	Rise Time	0.08	0.08	µs
	OS		Overshoot	10	10	%
Settling Time at $10V_{P-P}$, (See Figure 5)	t_S	R_L = 2kΩ C_L = 100pF Voltage Follower	To 1mV	4.5	4.5	µs
			To 10mV	1.4	1.4	µs

Electrical Specifications For Equipment Design, at $V_{SUPPLY} = \pm15V$, $T_A = 25^oC$, Unless Otherwise Specified

PARAMETER	SYMBOL	CA3140 MIN	TYP	MAX	CA3140A MIN	TYP	MAX	UNITS
Input Offset Voltage	$\lvert V_{IO}\rvert$	-	5	15	-	2	5	mV
Input Offset Current	$\lvert I_{IO}\rvert$	-	0.5	30	-	0.5	20	pA
Input Current	I_I	-	10	50	-	10	40	pA
Large Signal Voltage Gain (Note 3) (See Figures 6, 29)	A_{OL}	20	100	-	20	100	-	kV/V
		86	100	-	86	100	-	dB

Electrical Specifications For Equipment Design, at $V_{SUPPLY} = \pm15V$, $T_A = 25^oC$, Unless Otherwise Specified **(Continued)**

PARAMETER	SYMBOL	CA3140 MIN	CA3140 TYP	CA3140 MAX	CA3140A MIN	CA3140A TYP	CA3140A MAX	UNITS
Common Mode Rejection Ratio (See Figure 34)	CMRR	-	32	320	-	32	320	µV/V
		70	90	-	70	90	-	dB
Common Mode Input Voltage Range (See Figure 8)	V_{ICR}	-15	-15.5 to +12.5	11	-15	-15.5 to +12.5	12	V
Power-Supply Rejection Ratio, $\Delta V_{IO}/\Delta V_S$ (See Figure 36)	PSRR	-	100	150	-	100	150	µV/V
		76	80	-	76	80	-	dB
Max Output Voltage (Note 4) (See Figures 2, 8)	$V_{OM}+$	+12	13	-	+12	13	-	V
	$V_{OM}-$	-14	-14.4	-	-14	-14.4	-	V
Supply Current (See Figure 32)	I+	-	4	6	-	4	6	mA
Device Dissipation	P_D	-	120	180	-	120	180	mW
Input Offset Voltage Temperature Drift	$\Delta V_{IO}/\Delta T$	-	8	-	-	6	-	µV/^{o}C

NOTES:

3. At $V_O = 26V_{P-P}$, +12V, -14V and $R_L = 2k\Omega$.
4. At $R_L = 2k\Omega$.

Electrical Specifications For Design Guidance At V+ = 5V, V- = 0V, $T_A = 25^oC$

PARAMETER		SYMBOL	TYPICAL VALUES CA3140	TYPICAL VALUES CA3140A	UNITS
Input Offset Voltage		$\|V_{IO}\|$	5	2	mV
Input Offset Current		$\|I_{IO}\|$	0.1	0.1	pA
Input Current		I_I	2	2	pA
Input Resistance		R_I	1	1	TΩ
Large Signal Voltage Gain (See Figures 6, 29)		A_{OL}	100	100	kV/V
			100	100	dB
Common Mode Rejection Ratio		CMRR	32	32	µV/V
			90	90	dB
Common Mode Input Voltage Range (See Figure 8)		V_{ICR}	-0.5	-0.5	V
			2.6	2.6	V
Power Supply Rejection Ratio		PSRR $\Delta V_{IO}/\Delta V_S$	100	100	µV/V
			80	80	dB
Maximum Output Voltage (See Figures 2, 8)		$V_{OM}+$	3	3	V
		$V_{OM}-$	0.13	0.13	V
Maximum Output Current:	Source	$I_{OM}+$	10	10	mA
	Sink	$I_{OM}-$	1	1	mA
Slew Rate (See Figure 31)		SR	7	7	V/µs
Gain-Bandwidth Product (See Figure 30)		f_T	3.7	3.7	MHz
Supply Current (See Figure 32)		I+	1.6	1.6	mA
Device Dissipation		P_D	8	8	mW
Sink Current from Terminal 8 to Terminal 4 to Swing Output Low			200	200	µA

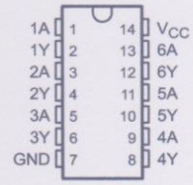
Appendix B: Datasheet of SN74LS14

SN5414, SN54LS14, SN7414, SN74LS14
HEX SCHMITT-TRIGGER INVERTERS

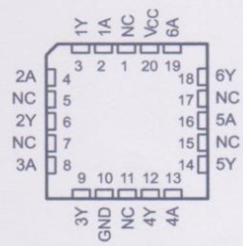
SDLS049B – DECEMBER 1983 – REVISED FEBRUARY 2002

- **Operation From Very Slow Edges**
- **Improved Line-Receiving Characteristics**
- **High Noise Immunity**

SN5414, SN54LS14 . . . J OR W PACKAGE
SN7414 . . . D, N, OR NS PACKAGE
SN74LS14 . . . D, DB, OR N PACKAGE
(TOP VIEW)



SN54LS14 . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

description

Each circuit functions as an inverter, but because of the Schmitt action, it has different input threshold levels for positive-going (V_{T+}) and negative-going (V_{T-}) signals.

These circuits are temperature compensated and can be triggered from the slowest of input ramps and still give clean, jitter-free output signals.

ORDERING INFORMATION

T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP – N	Tube	SN7414N	SN7414N
		Tube	SN74LS14N	SN74LS14N
	SOIC – D	Tube	SN7414D	7414
		Tape and reel	SN7414DR	
		Tube	SN74LS14D	LS14
		Tape and reel	SN74LS14DR	
	SOP – NS	Tape and reel	SN7414NSR	SN7414
	SSOP – DB	Tape and reel	SN74LS14DBR	LS14
–55°C to 125°C	CDIP – J	Tube	SN5414J	SN5414J
		Tube	SNJ5414J	SNJ5414J
		Tube	SN54LS14J	SN54LS14J
		Tube	SNJ54LS14J	SNJ54LS14J
	CFP – W	Tube	SNJ5414W	SNJ5414W
		Tube	SNJ54LS14W	SNJ54LS14W
	LCCC – FK	Tube	SNJ54LS14FK	SNJ54LS14FK

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

TEXAS INSTRUMENTS
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absolute maximum ratings over operating free-air temperature (unless otherwise noted)†

Supply voltage, V_{CC} (see Note 1) .... 7 V
Input voltage: '14 .... 5.5 V
'LS14 .... 7 V
Package thermal impedance, θ_{JA} (see Note 2): D package .... 86°C/W
DB package .... 96°C/W
N package .... 80°C/W
NS package .... 76°C/W
Storage temperaturerange, T_{stg} .... –65°C to 150°C

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. Voltage values are with respect to network ground terminal.
2. The package termal impedance is calculated in accordance with JESD 51-7

recommended operating conditions

		SN5414			SN7414			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
V_{CC}	Supply voltage	4.5	5	5.5	4.75	5	5.25	V
I_{OH}	High-level output current			–0.8			–0.8	mA
I_{OL}	Low-level output current			16			16	mA
T_A	Operating free-air temperature	–55		125	0		70	°C

electrical characteristics over recommended operating free-air temperature range (unless otherwise noted)

PARAMETER	TEST CONDITIONS‡			SN5414 SN7414 MIN	TYP§	MAX	UNIT
V_{T+}	V_{CC} = 5 V			1.5	1.7	2	V
V_{T-}	V_{CC} = 5 V			0.6	0.9	1.1	V
Hysteresis ($V_{T+} - V_{T-}$)	V_{CC} = 5 V			0.4	0.8		V
V_{IK}	V_{CC} = MIN,	I_I = –12 mA				–1.5	V
V_{OH}	V_{CC} = MIN,	V_I = 0.6 V,	I_{OH} = –0.8 mA	2.4	3.4		V
V_{OL}	V_{CC} = MIN,	V_I = 2 V,	I_{OL} = 16 mA		0.2	0.4	V
I_{T+}	V_{CC} = 5 V,	$V_I = V_{T+}$			–0.43		mA
I_{T-}	V_{CC} = 5 V,	$V_I = V_{T-}$			–0.56		mA
I_I	V_{CC} = MAX,	V_I = 5.5 V				1	mA
I_{IH}	V_{CC} = MAX,	V_{IH} = 2.4 V				40	µA
I_{IL}	V_{CC} = MAX,	V_{IL} = 0.4 V			–0.8	–1.2	mA
I_{OS}¶	V_{CC} = MAX			–18		–55	mA
I_{CCH}	V_{CC} = MAX				22	36	mA
I_{CCL}	V_{CC} = MAX				39	60	mA

‡ For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.
§ All typical values are at V_{CC} = 5 V, T_A = 25°C.
¶ Not more than one output should be shorted at a time.

Appendix C: Datasheet of GD74LS86

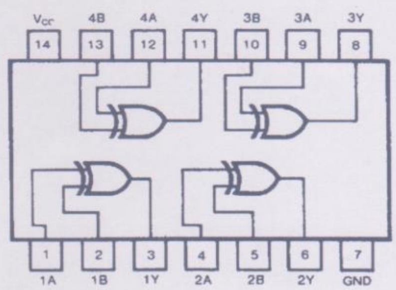
GD54/74LS86

QUADRUPLE 2-INPUT EXCLUSIVE-OR GATES

Description

This device contains four independent 2-input Exclusive-OR gates. It performs the Boolean functions $Y = A \oplus B = \bar{A}B + A\bar{B}$ in positive logic.

Pin Configuration

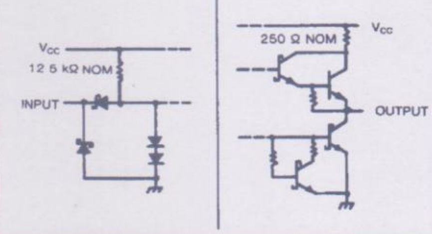


Suffix-Blank. Plastic Dual In Line Package
Suffix-J Ceramic Dual In Line Package

Function Table (each gate)

INPUT		OUTPUT
A	B	Y
L	L	L
L	H	H
H	L	H
H	H	L

Schematics of Inputs and Outputs



Absolute Maximum Ratings

- Supply voltage, Vcc 7V
- Input voltage 7V
- Operating free-air temperature range 54LS .... −55°C to 125°C
  74LS .... 0°C to 70°C
- Storage temperature range .... −65°C to 150°C

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Recommended Operating Conditions

SYMBOL	PARAMETER		MIN	NOM	MAX	UNIT
V_{CC}	Supply voltage	54	4.5	5	5.5	V
		74	4 75	5	5 25	
I_{OH}	High-level output current	54,74			−400	μA
I_{OL}	Low-level output current	54			4	mA
		74			8	
T_A	Operating free-air temperature	54	−55		125	°C
		74	0		70	

Electrical Characteristics over recommended operating free-air temperature range (unless otherwise noted)

SYMBOL	PARAMETER		TEST CONDITIONS			MIN	TYP (Note 1)	MAX	UNIT
V_{IH}	High-level input voltage					2			V
V_{IL}	Low-level input voltage				54			0.7	V
					74			0.8	
V_{IK}	Input clamp voltage		V_{CC}=Min, I_I=−18mA					−1.5	V
V_{OH}	High-level output voltage		V_{CC}=Min	V_{IL}=Max	54	2.5	3 4		V
			I_{OH}=Max	V_{IH}=Min	74	2 7	3 4		
V_{OL}	Low-level output voltage		V_{CC}=Min, V_{IL}=Max, V_{IH}=Min	I_{OL}=4mA	54,74		0.25	0 4	V
				I_{OL}=8mA	74		0 35	0.5	
I_I	Input current at maximum input voltage		V_{CC}=Max, V_I=7V					0.2	mA
I_{IH}	High-level input current		V_{CC}=Max, V_I=2.7V					40	μA
I_{IL}	Low-level input current		V_{CC}=Max, V_I=0 4V					−0.8	mA
I_{OS}	Short-circuit output current		V_{CC}=Max (Note 2)			−20		−100	mA
I_{CCH}	Supply current	Total with outputs high	V_{CC}=Max				6.1	10	mA
I_{CCL}		Total with outputs low	V_{CC}=Max				9	15	mA

Note 1 All typical values are at V_{CC}=5V, T_A=25°C
Note 2 Not more than one output should be shorted at a time, and duration should not exceed one second

Switching Characteristics, V_{CC} = 5V, T_A = 25°C

PARAMETER*	FROM (INPUT)	TEST CONDITION#		MIN	TYP	MAX	UNIT
t_{PLH}	A or B	Other input low	C_L=15 pF, R_L=2KΩ		12	23	ns
t_{PHL}					10	17	
t_{PLH}	A or B	Other input high			20	30	ns
t_{PHL}					13	22	

* t_{PLH} = propagation delay time low to-high-level output
* t_{PHL} = propagation delay time high to-low level output

#For load circuit and voltage waveforms, see page 3-11

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