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Cost Effective Design for Conductivity Measurement

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ABSTRACT
Recent technological research led to the development of compact device with ultra low power and cost effective solution. There are a lot of expensive standard conductivity products already available in the market but the small scale industries which need several conductivity transmitters cannot afford it. Many Indian make solutions are available with the economical price but they are not able to compete the standard one because of the method of conductivity measurement used which is as like measuring the resistance using multimeter with applied DC voltage. The prime objective of this research work is to design prompt, cost effective, online conductivity measurement and monitoring system. Conductivity Measurement is an extremely widespread and useful method, especially for quality control purpose. Electrical conductivity of the sample can be used as an indirect indicator of a number of physical and chemical properties. The hardware-developing of the system includes conductivity sensor, constant AC current source, a signal conditioning circuit, microcontroller, a data acquisition device and a PC. Here in the first part of this paper, we design the AC current source and signal conditioning circuit for conductivity measurement and indicate it using LabVIEW graphical environment as virtual instrument. The total number of components used in these circuits is less, compact, inexpensive and the designs for sine wave oscillator, current source, filter & signal conditioner is attractive.
Keywords— conductivity measurement, conductivity transmitter, Signal conditioning circuit, virtual instrument

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I. INTRODUCTION

Electrical conductivity is a key characteristic of all the chemical substances, there is a massive interest in measuring, analysing and controlling this parameter since it is indicative of ability of a solution to carry a current.

Electricity is the flow of electrons. This indicates that ions in solution will conduct electricity.

$\kappa = G \cdot K$

Where, κ = conductivity (S/cm)
G = conductance (S), where G = 1/R
K = cell constant (cm-1)

The cell constant is the ratio of the distance (d) between the electrodes to the area (a) of the electrodes.

K = d/a

Where, K = cell constant (cm-1)
a = effective area of the electrodes (cm2)
d = distance between the electrodes (cm)

Cell Constant is determine the amount of current that will flow through a known amount of liquid, the volume between the two electrodes must be exact and the current must be kept consistent and moderate. This is known as the cell constant. Any effective volume change changes the cell constant and current, too much volume will result in noise (low current) or too little volume in electrolytic effects (high current). The cell constant recommended will vary depending on the conductivity range of the solution. High conductivity requires a high cell constant and low conductivity requires a low cell constant.

Electrical conductivity is the reciprocal of electrical resistivity. The unit for electrical conductivity is Siemens per meter as an SI derived Unit.

Conductivity measurement is temperature dependent, if the temperature increases, conductivity increases. It is mandatory to always associate the temperature together with a conductivity result. If no temperature correction is applied, the conductivity is the value taken at measurement temperature.

The signal conditioner is the essential part in conductivity measurement, provides signal conditioning, signal conversion and re-transmission for continues conductivity measurement application. Here, in proposed design of signal conditioning circuit for conductivity measurement, following blocks are included.

- Constant value AC current source for conductivity sensor
- High Impedance Buffer Amplifier
- Precise Rectifier
- Butterworth lowpass filter

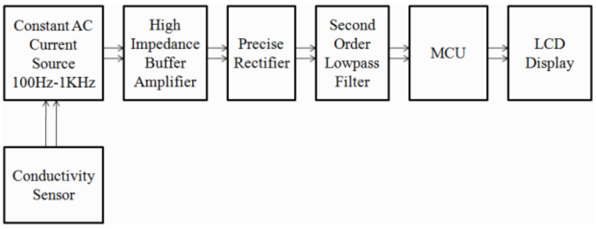

Fig.1.Block diagram of the proposed system

In signal conditioning circuit of conductivity measurement, high performance filters are required to remove undesired signals, such as noise from incoming signals that the sensor receives undesired signals at the sensing frequency, and harmonics after the mixing operation. All analog filters fall in one of two categories: passive or active. In this conductivity measurement system, active filters are used because of the following advantages:

- Active filter can generate a gain larger than one.
- higher order filters can easily be cascaded since each op-amp can be second order
- Filters are smaller in size as long as no inductors are used, which makes it very useful as integrated circuits.

Conductivity measurement is a low frequency signal. So for designing of Signal conditioning circuit, low pass filter design is must. In conductivity measurement, for selecting a low signal frequency, butterworth low pass filter having sallen key topology with non inverting gain is used. Here for proposed second order active lowpass filter (100 Hz with ± 3db slope) design, OP-AMP LMC6044 is used. At last we design signal conditioner circuit using op-amp that convert available signal into pure DC signal so one can able to proceed further with microcontroller unit.

Here, we use the Multisim (NI) software which is a circuit simulator based on SPICE (standard for circuit simulation). It contains a database of components that you can use to build a circuit and many of these components are simulatable. You can also find virtual instruments (scope, signal generators, and so on) that you can connect to your circuit in order to take measurements. So it gives prompt output and gets an idea for further improvement. All this can be achieved without advanced knowledge of SPICE, which is a major plus. NI Multisim is an excellent environment to design, analyse and create electronic circuits. It is a powerful, essential tool for electronic engineers or technicians.

LabVIEW (Laboratory Virtual Instrument Engineering Workbench), based on Graphic Language, is a type of opening platform and establishing tool for Virtual Instruments （VI）. The software unit of the system can acquire, control and interfacing the data. Also it can analyse and process the measured signals. Due to its influential function module and communication protocol, LabVIEW significantly diminishes the software development period. Especially in measuring and controlling systems, it can acquire and analyse data expediently. We can have the further analysis and processing with the acquired data in LabVIEW. In this paper, input signal coming from the sensor is processed with a Butterworth low-pass filter in Lab VIEW program. As a result, measured conductivity waveform chart, its value and averaged value are gained in microsiemens.

II. SOFTWARE SIMULATION

For designing and simulation of signal conditioning circuit for conductivity measurement, we select the prominent software "Multisim".

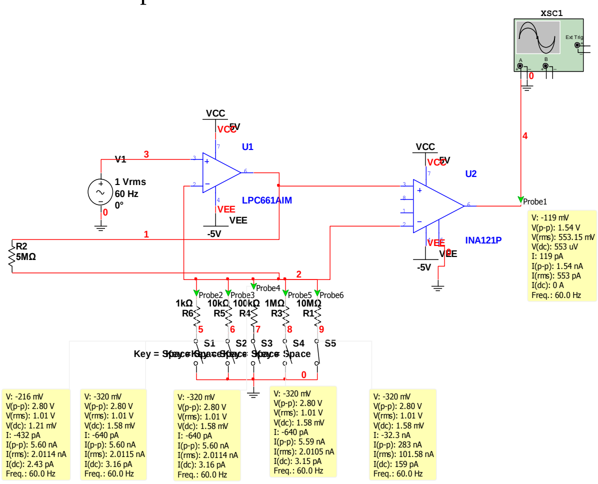

Fig.2. Constant value AC current source design

For conductivity measurement we have to design constant value AC current source having variable frequency range 100Hz-1 KHz. This proposed design shown in fig. is used for whole range (0.200µS/cm- 20.0mS/cm) of conductivity measurement and which is having autorange selectable feature. This is design by our self and its manufacturing cost is very low because of basic electronic components are used and thus, compare to

other manufactures our exciter cost is less, so we reduce the overall cost of the signal conditioner.
As shown in above fig five probes are connected and their values shown in pale yellow background
Probe1: indicates 1mA, 500Ω
Probe2: indicates 100µA, 5K Ω
Probe3: indicates 10µA, 50K Ω
Probe4: indicates 1µA, 500K Ω
Probe5: indicates 0.1µA, 5M Ω
All above uses 0.5 V because we have a 16 bit ADC operated on 0.6 V max. The virtual oscilloscope shows Conductivity output.

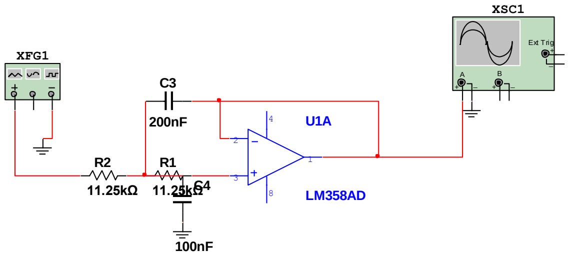

Fig 3. Simulation of active Butterworth lowpass filter (100 Hz)

Fig.3 shows the simulation of active lowpass Butterworth filter with cutoff frequency 100 Hz with ±3 db attenuation rate. Here, we choose LM358AD OP-AMP of Texas instruments because it is advantageous over others,

- The Input Bias Current and unity Gain cross frequency is Temperature Compensated.
- Two Internally Compensated Op Amps.
- Eliminates Need for Dual Supplies.
- Allows Direct Sensing near GND and VOUT also goes to GND.
- Compatible with All Forms of Logic.
- Power Drain Suitable for Battery Operation

For measurement of conductivity, as discussed earlier first we have to design the sine wave oscillator. Here for research purpose the sine wave oscillator of the frequency 100 Hz and 1000Hz is designed using 12 bit DAC of microcontroller MSP430F477. Available signal from the oscillator is discrete time sine wave or can said stepped one so output signal is filtered using AC coupled amplifier of time constant of 250 µs. Here we select LMC6044AIM OP – AMP IC which is the best suitable with the proposed signal conditioner design. After the AC coupled amplifier two lowpass filter with the cutoff frequency 100 Hz and 1000 Hz is used which provide the perfect sine wave of the frequency 100 Hz and 1000 Hz accordingly. For selecting the frequency 2×1 multiplexer is used, output from the same is given to the constant value AC current source which provides the output voltage according to the measured conductivity range. Then the available signal is given to the differential instrument amplifier and precise rectifier cum filter as shown in fig.5 which convert the AC

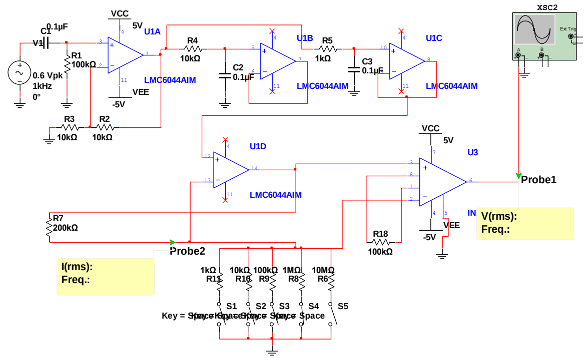

Fig.5. Signal conditioning circuit design

output signal to DC which is given to the microcontroller unit for further processing.

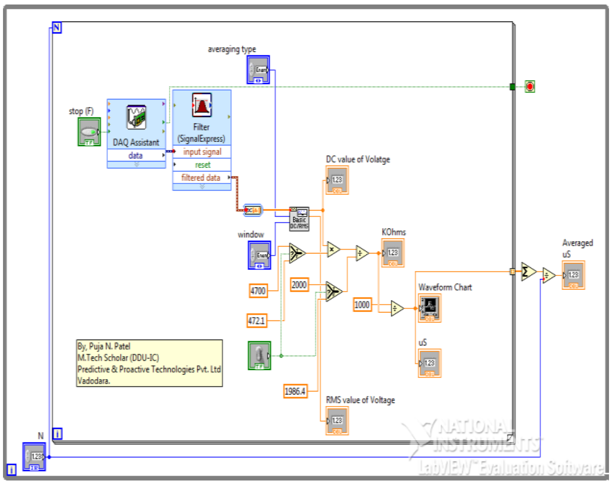
Fig 6. Block diagram of virtual instrument for conductivity measurement

For indicating the conductivity value , here We simulate the VI in LabVIEW graphical environment (fig. 6), which is a powerful and very accurate software with various tool. We can provide more cost effective solution by using the microcontroller and display unit but the accuracy, resolution and real time display is further need more research.

IV. RESULTS AND DISCUSSION

RESULT OF SINE WAVE OSCILLATOR

For conductivity measurement, first we have to consider the whole range of conductivity measurement that is from conductivity of pure water to conductivity of high concentrated solution and design the current source which is basically used here for the selection of the conductivity measurement range.

For giving the excitation here two types of sources can be used. DC current source may provide the jerk when the circuit is going to initiate. Because of the disadvantages of DC here constant value AC current source is designed. For giving the excitation sine wave oscillator (Generator) is designed using the microcontroller MSP430f477 which is give the sin wave with the frequency 100Hz or 1KHz according to the distance between number of samples selected per second.

Because microcontroller is unipolar we cannot generate bipolar sine wave using microcontroller. So here because of reference voltage of 16 bit ADC is 1.2V, initial value of amplitude of designed sine wave is 0.6V. Then by the use of AC coupled Amplifier, DC components from the output waveform is removed. So we can get the perfect sine wave as shown in figure.

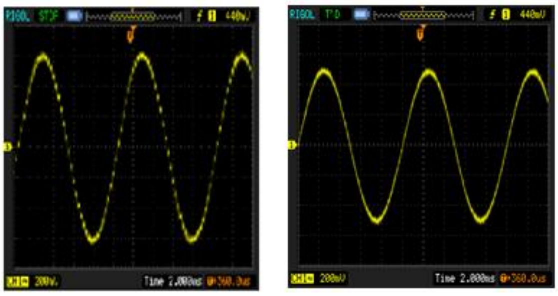

Fig. 7 (a) 100 Hz sine wave (DAC output) and (b) 100 Hz sine wave (filtered output)

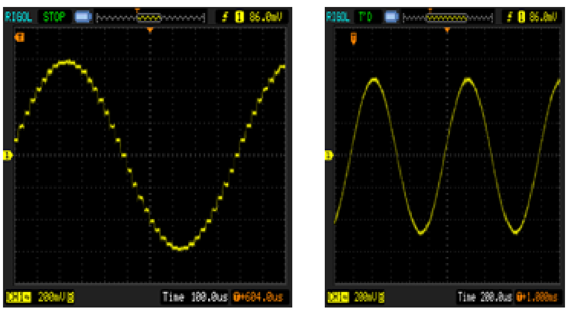

Fig. 8 (a) 1000 Hz sine wave (DAC output) and (b) 1000 Hz sine wave (filtered output)

As shown in Fig 7(a) and fig. 8(a), proposed oscillator design gives the discrete sine wave output with the frequency 100Hz and 1 KHz accordingly.

As shown in Fig 7(b) and fig. 8(b), proposed oscillator design gives the continuous sine wave output with the frequency 100Hz and 1 KHz accordingly with the use of second order low pass filter with time constant of 250 µs.

Fig 9 (a) shows that with the fix number of sample we have distance between the samples is 25 µs. That is total time period of complete one cycle is 50 µs so we get the

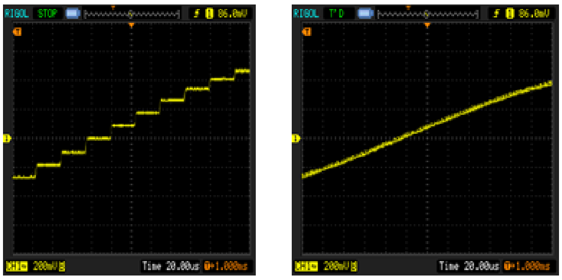

Fig. 9 (a) Step size of 25 µs for sine wave (DAC output) and (b) Step size of 25 µs for sine wave (filtered output)

frequency of 20 KHZ. Fig 9 (b) shows the filtered output of the same.

RESULT OF CURRENT SOURCE

For conductivity measurement we have to design constant value AC current source having variable frequency range 100Hz-1 KHz. This proposed design shown in fig.5.2 is used for whole conductivity range (0.200µS/cm- 20.0mS/cm) measurement and which is having autorange selectable feature.

As discussed above constant value AC current Source is designed which is shown in fig. 2 and the result of proposed design is shown below in fig 10 in virtual oscilloscope.

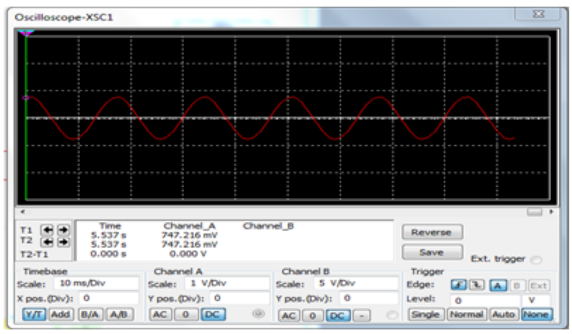

Fig. 10 Output from current source

Here for testing purposes, probe no.5 (0.1µ A, 5M Ω) is connected but the design provides autorange selectable feature for whole conductivity range measurement. The very basic electronic

components are used, so it is very cost effective design & it helps to reduce system overall cost.
The unique feature of the design is, user can use the same source for all different types of conductivity cell and range of measurement.

RESULT OF LOW PASS FILTER

Conductivity measurement is a low frequency signal. So for designing of Signal conditioning circuit, low pass filter design is must. For Conductivity signal conditioner, we require low pass filter, Differential instrument amplifier, Precise Rectifier & AC coupled Amplifier. Result of proposed lowpass filter design is discussed below.

In conductivity measurement, for selecting a low signal frequency, second order butterworth lowpass filter having sallen key topology with non inverting gain is used. Here for proposed design, the 2nd order Butterworth lowpass filter with cutoff frequency 100 Hz is used, result for the same is showing below in fig. 11.

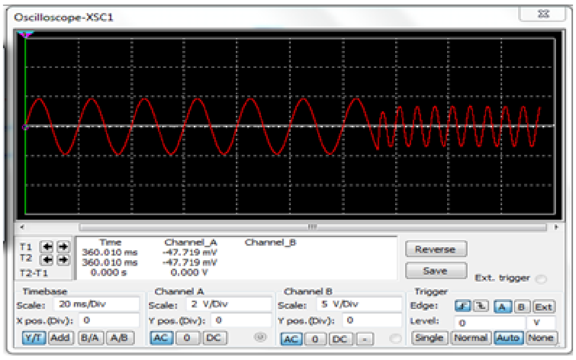

Fig. 11 Output waveform of Lowpass filter

For designing of low pass filter, we select the passive components and also verify the results of analog circuit with the help of filterpro software.

SIMULATED RESULTS OF SIGNAL CONDITIONING CIRCUIT USING NI-MULTISIM

Probe Connected	Excitation Current (RMS)	Voltage Drop (RMS)	Max. Resistance	Conductivity Range
1	721.34 µA	541.00mV	50Ω -500Ω	2.000mS to 20.000mS
2	72.048 µA	540.36mV	500Ω-5KΩ	200.0µS to 2000µS
3	7.2039 µA	540.28mV	5KΩ -50KΩ	20.00µS to 200.0µs
4	720.47nA	540.34mV	50KΩ-500KΩ	2.000µS to 20.00µS
5	72.669nA	544.99mV	500KΩ-5MΩ	0.2µS to 2.000µS

Table 6.1 Results of signal conditioning circuit.

Table 6.1 shows the Results of signal conditioning circuit of fig.2. So in this proposed solution we measure the conductivity with autoranging feature.

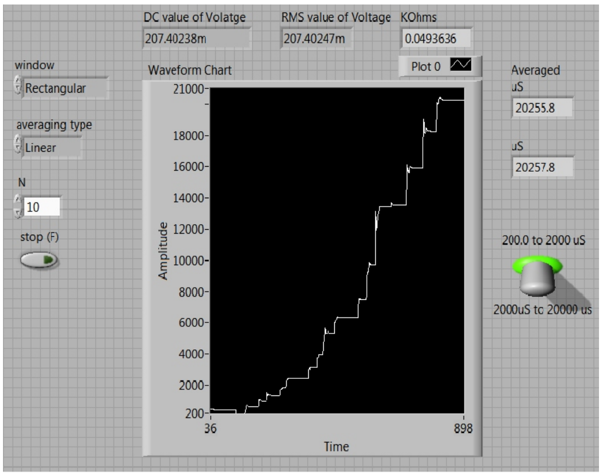

Fig 12 LabVIEW front panel

Fig.12 shows the front panel diagram of the virtual instrument of fig.6. We can know the DC value of voltage in mV and Conductivity value in uS. Here the experimental result is shown. We can see that as the salt (Kcl) concentration in distilled water increases the conductivity increases which can be recorded in real time chart as shown in the above diagram. We can take number of samples using numerical entry(N).so we can averaging the readings and get the average conductivity value which is useful in other means like analysis and controlling the parameter.

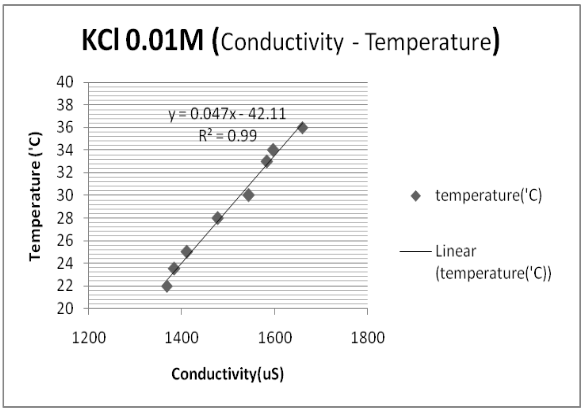

Fig 13 0.01M Kcl conductivity Vs Temperature

Using the above setup We can measure the conductivity value of 0.01M Kcl solution. Here fig.13 shows the graph of measured conductivity value of 0.01M Kcl with different temperature and fig.14 shows the graph of measured conductivity value of 0.05 % Nacl with different temperature.

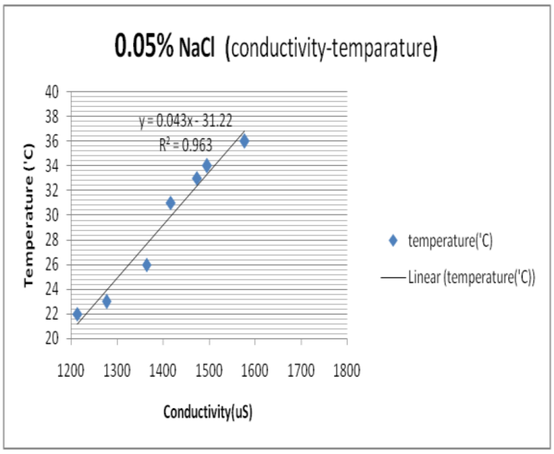

Fig 14 0.05 % NaCl conductivity Vs Temperature

V. CONCLUSION

Recent technological research led to the development of compact device with ultra low power and cost effective solution. Proposed design of constant Ac current source can be used for any type of conductivity sensor and for conductivity range from 0.200 µS/cm to 20.00 mS/cm. As conductivity is low frequency signal, active low pass filter (2nd order) is used to implement antialiasing filter in data acquisition system. Conductivity transmitter design has been proposed and implemented. Result of this have been noted and recorded in graphical plot which form the useful baseline for future analysis. Proposed design measure the conductivity at the measurement temperature. Temperature compensation techniques can be used to measure the conductivity value at reference temperature.

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