Low-Ripple Output Interface Circuit for Electrical Conductivity Measurement

Anucha Kaewpoonsuk[1] Suphawadee Suphramit[1] and Apinai Rerkratn[2]

Abstract— **In this paper, an interface circuit for measuring the electrical conductivity of electrolyte solution is described. It consists of a quadrature oscillator, a non-inverting amplifier, a voltage-to-current converter, a peak detector, a sample-and-hold circuit, and the designed control signal generator. The proposed technique is based on the use of peak-and-hold method to detect the amplitude of sinusoidal output signal instead of the traditional method that uses the rectifier circuit connected with low-pass filter. The proposed circuit provides the obtained output in the form of DC voltage with low ripple and fast response. Experimental results verifying the circuit performance are agreed with the theoretical values.**

Index Terms—**Electrical conductivity, Peak detector, Amplitude detector, Quadrature oscillator.**

I. Introduction

Measuring the electrical conductivity of fluid is used to determine the ability of ion conductivity. The electrical conductivity of fluid is used for many applications in industrial and food product such as quality monitoring and cleanliness of the water in the plants, measurement of amount of dissolvable substance in water, measurement of the nutrient concentration in plants, and water quality detection in the seawater desalination. The basic principle generally known for measuring the electrical conductivity is based on Ohm's law. Many researchers propose methods for measuring the electrical conductivity [1-7]. Haval Y. Yacoob Aldosky et al. have introduced the method by using four silver electrodes with different frequencies between 50 Hz and 100 kHz to measure admittance and conductivity of water [2]. Masato Futagawa et al. have reported the use of platinum electrodes and 10 kHz sine wave to measure the conductivity of the electrolyte solution [3]. Susan L. Schiefelbein et al. have presented the calibration-free technique to measure the electrical conductivity of liquids [4]. Shaopeng Hu et al. have proposed the method of electrical conductivity measurement in seawater desalination based on variable frequency excitation [5]. Rajendran A. et al. have reported the measurement of conductivity of liquids using AT89C55WD microcontroller [7]. From above discussion, the aim of this paper is to present a new interface circuit for measuring the electrical conductivity of electrolyte solution with improvement in DC output voltage. Moreover, the low-ripple behaviour and fast response operation are obtained.

Manuscript received January 13, 2016. ; revised January 25, 2016

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II. Circuit Description

From Fig. 1, the proposed interface circuit for measuring the electrical conductivity consists of quadrature oscillator circuit, non-inverting amplifier circuit, current-to-voltage converter circuit, peak detector circuit, sample and hold circuit and control signals generator circuit. The quadrature oscillator circuit is used as the signal generator for using measurement the electrolyte solution and also the reference signal of control signals generator circuit. Output signal from quadrature oscillator circuit is gained by non-inverting amplifier circuit before sent to measurement the electrolyte solution via electrodes in Fig. 2. The output voltage of quadrature oscillator circuit can be expressed as

$$V_{cos} = A_o \cos(2\pi f_o t) \tag{1}$$

$$V_{sin} = A_o \sin(2\pi f_o t) \tag{2}$$

where A_o and f_o are amplitude and frequency of the output signal of quadrature oscillator circuit, respectively. The output signal from quadrature oscillator circuit is amplified by non-inverting amplifier circuit. The output voltage from non inverting amplifier circuit can be stated as

$$V_{ex} = \left(\frac{R_5 + 1}{R_4}\right) A_o \cos(2\pi f_o t) \tag{3}$$

where V_{ex} defines the output voltage of non-inverting amplifier circuit. After that, the voltage V_{ex} is sent to measurement solution via electrodes. The current flow between electrodes can be calculated by

$$I_x = \frac{V_{ex}}{R_o + 1/G_x} = \frac{1}{R_o + 1/G_x}\left(\frac{R_5 + 1}{R_4}\right) A_o \cos(2\pi f_o t) \tag{4}$$

where I_x is the current flowing between electrodes. G_x, R_o denote the conductance and resistance of measurement solution, respectively.

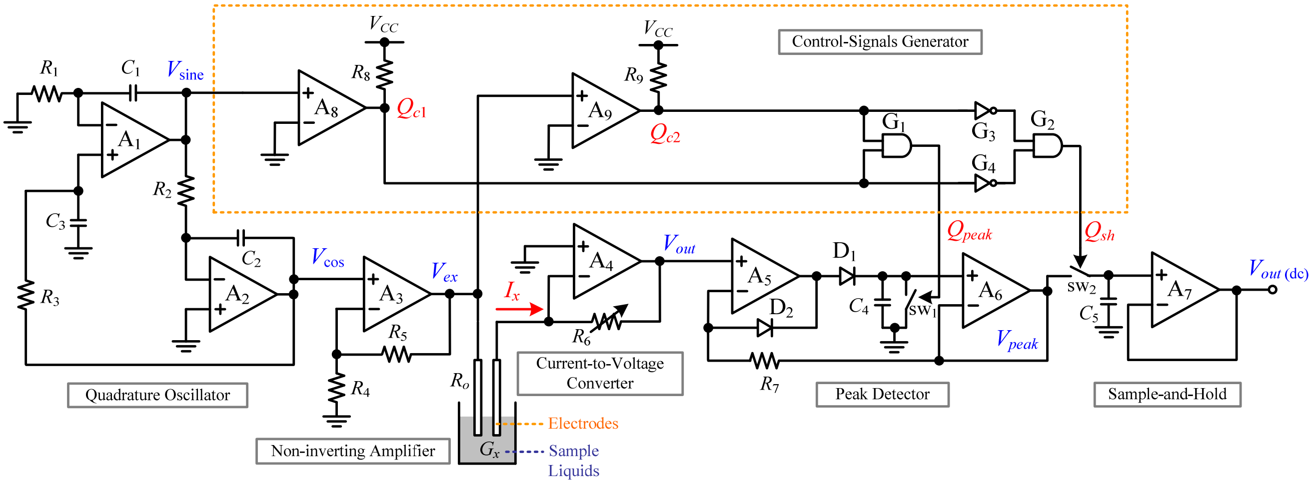


Fig. 1 Proposed interface circuit for measuring the electrical conductivity.

Fig. 2 The electrode used in the experiment.

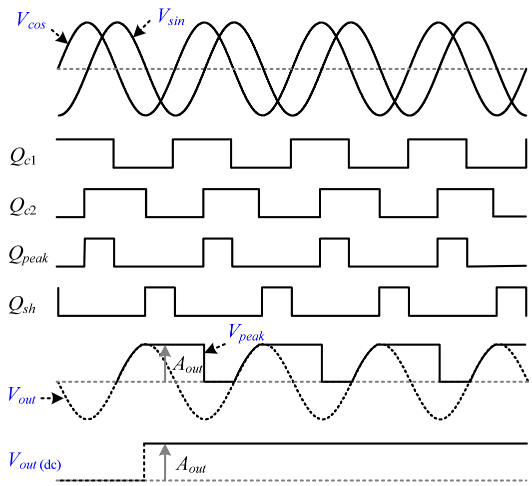


Fig. 3 Waveform sketches of proposed interface circuit for measuring the electrical conductivity.

The current flowing between electrodes is converted to voltage by current-to-voltage converter circuit. The output voltage from current-to-voltage converter circuit can be expressed as

$$V_{out} = -R_6 I_x = \frac{-R_6}{R_o + 1/G_x}\left(\frac{R_5+1}{R_4}\right)A_o\cos(2\pi f_o t) \tag{5}$$

or

$$V_{out} = -A_{out}\cos(2\pi f_o t) \tag{6}$$

where A_{out} is peak amplitude of output voltage V_{out}.

The output voltage from current-to-voltage converter circuit is sent to peak detector circuit. Peak detector circuit is controlled by Q_{peak} from control signals generator circuit for detecting peak amplitude of output voltage V_{out}. The output voltage of peak detector circuit V_{peak} is sent to sample and hold circuit for generating the output $V_{out(dc)}$ of proposed circuit by using Q_{sh}, signal from control signals generator circuit, for control the hold state.

Fig. 3 shows waveform sketches of the proposed interface circuit for measuring the electrical conductivity. The output voltage of peak detector circuit V_{peak} and sample and hold circuit $V_{out(dc)}$, respectively, can be given by

$$V_{peak} = A_{out} = \frac{R_6 A_o}{R_o + 1/G_x}\left(\frac{R_5+1}{R_4}\right) \tag{7}$$

$$V_{out(dc)} = V_{peak} = \frac{R_6 A_o}{R_o + 1/G_x}\left(\frac{R_5+1}{R_4}\right) \tag{8}$$

The output voltage from sample and hold circuit $V_{out(dc)}$ is used to calculate electrical conductance G_x and electrical conductivity σ_x, respectively, which can be stated as

$$G_x = \frac{V_{out(dc)}}{R_6(A_o(R_5+1)/R_4) - V_{out(dc)}R_o} \tag{9}$$

$$\sigma_x = \frac{V_{out(dc)}}{R_6(A_o(R_5+1)/R_4) - V_{out(dc)}R_o}\left(\frac{L}{A}\right) \tag{10}$$

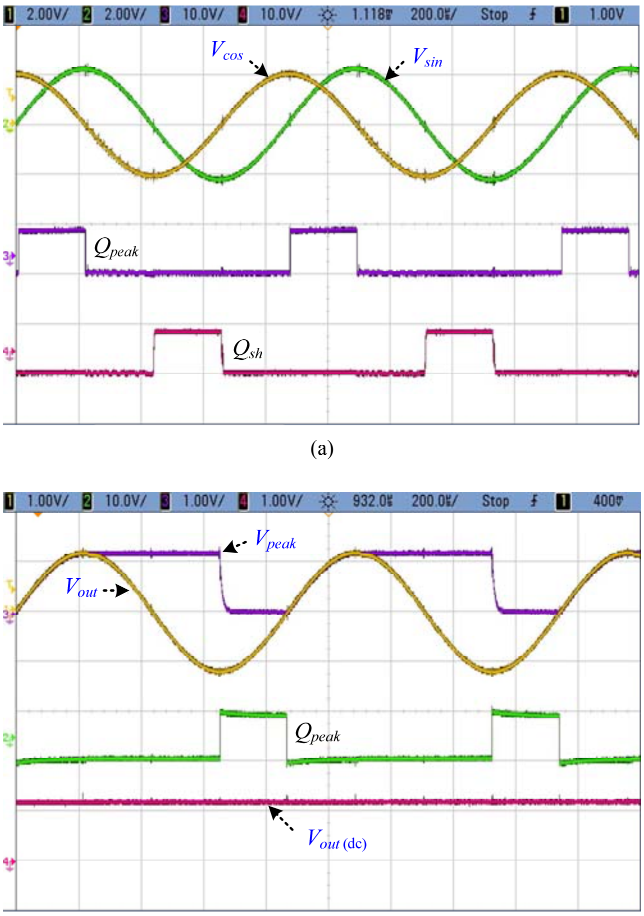
ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

III. Experimental Setup

To verify the performance of the proposed synthesis method, the circuit as shown in Fig. 1 was experimentally implemented using analog and discrete components. The LF351, LM319, and 1N4148 devices were used for op-amp A_1-A_7, A_8-A_9, and diode, respectively. The MC14066BCP, HEF4081BP, and HD14069UPB devices were used as analog switches, AND gate, and inverter, respectively. The 5% tolerance capacitors and 1% tolerance resistors were used in the proposed circuit. The values of device components used are set as follows: $C_1 = C_2 = C_3 = 4.7$ nF, $C_3 = 2.2$ nF, $R_1 = 4.3$ kΩ, $R_2 = 200$ kΩ, $R_3 = 6$ kΩ, $R_4 = R_5 = 1$ kΩ, $R_6 = 2$ kΩ, and $R_8 = R_9 = 5$ kΩ. The supply voltages used for the scheme were set to ± 10V.

IV. Experimental Results

From the experimental setup, the experimental results are shown in Fig.4 - Fig.6.



(a)

(b)

Fig. 4 Measured results of the proposed interface circuit for measuring the electrical conductivity.
(a) The signals V_{cos}, V_{sin}, Q_{peak}, and Q_{sh}
(b) The signals V_{peak}, V_{out}, Q_{peak}, and $V_{out(dc)}$

Fig. 4 shows the measured waveform of the signals V_{cos}, V_{sin}, V_{peak}, V_{out}, $V_{out(dc)}$, Q_{peak}, and Q_{sh} . It is evident that the proposed circuit functions correctly and provides a dc output voltage $V_{out(dc)}$ in close agreement with the expected values. To demonstrate the performances of the proposed circuit, electrolyte solution with the electrical conductivity in the range 0.5-4.0 mS/cm were set in experiment. Fig. 5 shows the measured results for the electrical conductivity in the range 0.5-4.0 mS/cm. Fig. 6 shows the linear relation between the measured and input of electrical conductivity values. Fig. 7 demonstrates the error between the measured and input of electrical conductivity values.

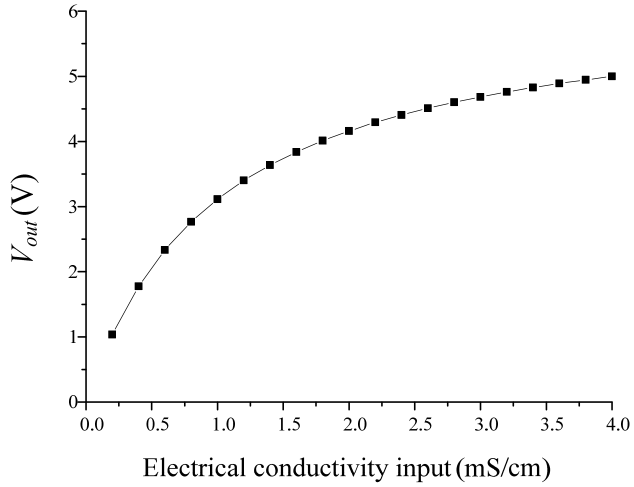


Fig. 5 The measured results for the electrical conductivity in the range 0.5-4.0 mS/cm.

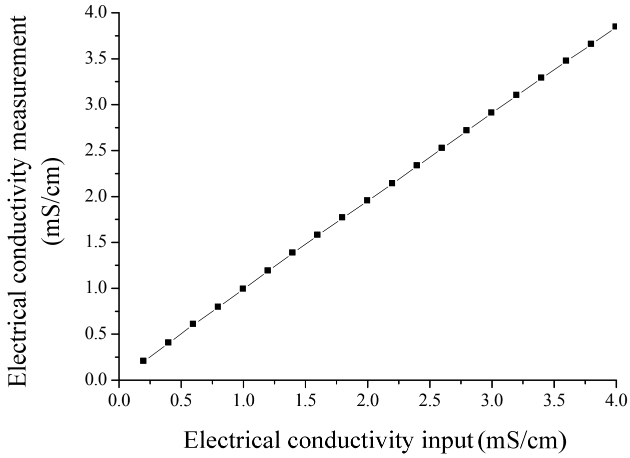


Fig. 6 The relation between the measured and input of electrical conductivity values.

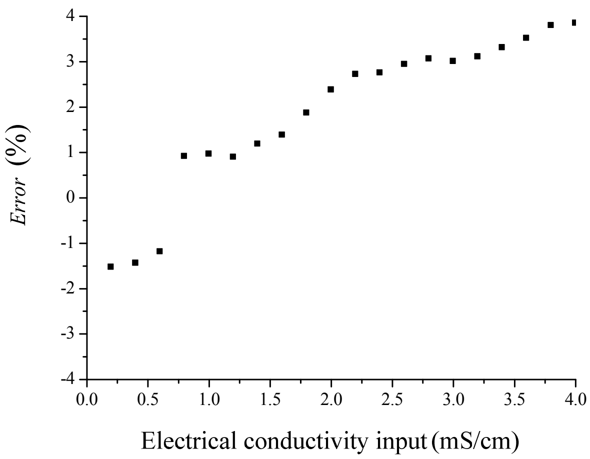


Fig. 7 Error between the measured and input of electrical conductivity values.

ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

V. Conclusion

The proposed interface circuit for measuring the electrical conductivity has been detailed in the paper. The proposed interface circuit comprises quadrature oscillator circuit, non-inverting amplifier circuit, current-to-voltage converter circuit, peak detector circuit, sample and hold circuit and control signals generator circuit. The experimental results using electrolyte solution with the electrical conductivity in the range 0.5-4.0 mS/cm confirmed the sensitivities, linearity, resolution and stability of the proposed interface circuit are agreed with the expected values.

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