

# A COMPARATIVE STUDY OF CURRENT SOURCES USED IN BIOIMPEDANCE MEASUREMENT SYSTEMS

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**Abstract**—The current source circuit is one of the most important parts in the bioelectrical impedance devices and Bio Impedance Tomography (BIT). There are many types of circuits like the Howland Current Source, Improved Howland Current Source, General Impedance Converter, Wien Bridge circuit etc. This paper presents the comparative analysis of the available current sources and study of the best suited ones for the bioimpedance measurement and its various applications.

**Keywords**—*bio impedance, generalised impedance converter, howland current source, current source.*

## I. INTRODUCTION

As all the matter, the human body has a number of electric features; the group of properties related with the opposition against an alternating current flow, is known as bioimpedance[1]. The way to measure is not different from the conventional impedance measurement technique, which consists of applying a small alternating current signal and measuring the variations in the voltage, and then the impedance is calculated with the amplitude and phase changes between the original signal and the recorded one.

In any bio-impedance measurement system, the unknown impedance can be measured by two possible methods: either by the application of a known voltage across the subject and then measuring the current through it or by injecting a known current into the subject and measuring the voltage across it.

Unknown contact impedance exists between the electrode and the subject. It will degrade the operation of voltage source having a low output impedance. Therefore we preferably use the second method – to inject current and measure voltage across the object. A current source is the most important part in this method and should have the following characteristics:

- 1) Very good stability in providing current and whose value should be between 700uA and 1mA.
- 2) Very high output impedance.
- 3) Can cover low and high frequencies.

This paper analyses the different current sources that can be used for the current injection purpose and presents their comparative study.

In this paper, section II explains the different types of current sources that can be used in bioimpedance measurement. In section III a comparative analysis of the different current sources has been done. Then in Section IV, a comparative analysis of the different current sources is given.

## II. DIFFERENT CURRENT SOURCES

In this section, the different types of current sources used for bioimpedance measurement have been explained along with the calculative equations and the required circuit diagrams.

### A. The Howland Current Source

The Howland Current Source is a well known and widely used circuit for realizing voltage controlled current sources for loads with one end connected to the ground. Several variants of the original circuit which are often referred to as the modified Howland circuits have already been proposed. The circuit discussed in this paper in one of these circuits. The essential features of the original Howland circuit have been preserved [2]. A block diagram of modified Howland circuit is given below:

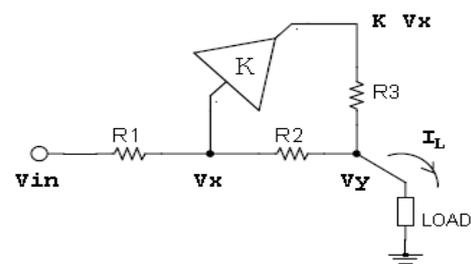


Fig 1. Schematic diagram of Howland Current Source

By inspection assuming an ideal amplifier with voltage gain  $k$ , the current across the grounded load is given by:

$$I_L = K \cdot \frac{V_x - V_y}{R_3} + \frac{V_x - V_y}{R_2}$$

At the node that connects R1 and R2

$$\frac{V_{in} - V_x}{R_1} = \frac{V_x - V_y}{R_2}$$

From the above equations the following expression for the load current can be easily derived:

$$I_L = \left[ \frac{R_1(K - 1) - (R_2 + R_3)}{R_1.R_3} \right] V_x + \left( \frac{R_2 + R_3}{R_1.R_3} \right) V_{in}$$

Consequently for  $I_L$  to be dependent on  $V_{in}$  only, the following condition must be met:

$$R_1.(K-1) = R_2 + R_3$$

The usually suggested value of  $K$ , in most appearances of the Howland Circuit is 3. This number is attractive because it allows the use of simple ratios for the involved resistors. That is, making  $R_3=R_2=R$ , yields  $R_1=R$ . Notice, however, that when  $R_2=R_3$  the voltage swing across  $R_1$  will be reduced due to the voltage drop across  $R_3$ . As a result, more suitable values should be chosen for  $K$ , as well as for associated resistances, provided  $R_3$  is small enough not to compromise voltage swing across the load.

### B. Enhanced Howland Current Source

To remove the common mode voltage or loading effects in the Basic Howland circuit a resistor is added between the non-inverting and the output terminals to improve the performance of the circuit. This Enhanced Howland circuit is used as a current source in most bioimpedance measurement systems due to its simple architecture and better performance. In terms of output impedance, the Enhanced Howland circuit [3] does not give our desired high output impedance due to the presence of output capacitance. The load in the howland circuits is grounded load that means one side of the load is tagged to ground. Fig. shows Enhanced Howland circuit configuration. There is one important condition in this circuit is

$$\frac{R_2}{R_1} = \frac{R_4 + R_5}{R_3}$$

It is very important to achieve above equation to get very high output impedance. The  $R_o$  will be very big value if the percentage of the equation is achieved. The output current can be calculated:

$$i_0 = -V_1 \left( \frac{R_2}{R_1.R_4} \right)$$

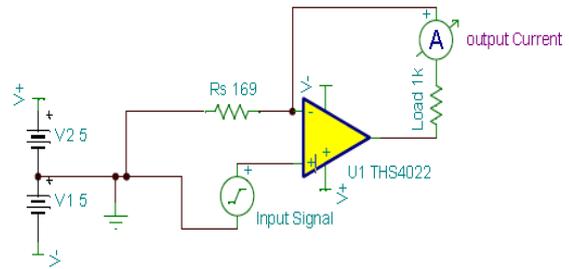


Fig 2. Enhanced Howland Circuit

### C. Generalised Impedance converter

Generalised impedance converters (GICs) [4] are active circuits that can be synthesized using impedances and operational amplifiers (op amps) or operational transconductance amplifiers (OTAs). In both cases, they form, with other two-port circuits such as gyrators and negative or positive impedance converters (NIC or PIC), the building blocks of active filter design.

It consists of two operational amplifiers and five discrete components which can be used to synthesize various impedances. These components are either resistors or capacitors. There are several topologies to implement this circuit. The circuit representation is as shown:

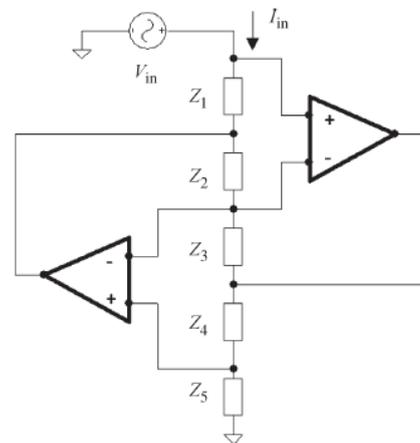


Fig 4. Generalised Impedance Converter

$$Z_{inp} = \frac{Z_1.Z_3.Z_5}{Z_2.Z_4}$$

Figure above shows the GIC circuit in its original form. The structure has been widely used to synthesize inductors using passive  $RC$  components and op amps in active filter circuits. In these cases, all GIC currents and voltages are of the ac type. The

impedance behavior depends on which resistances and capacitances are assigned to impedances  $Z1-Z5$ . If in the above circuit impedances are resistances and ac input voltage  $V_{in}$  is replaced by a precision dc reference voltage  $V_{ref}$ , then the GIC works in a dc regime for all its currents and voltages (dc GIC, Fig. 3). Considering ideal op amps, voltage  $V_{ref}$  appears at all the op amp inputs, and then, it is transferred by op amp action from the GIC input terminal to resistance  $R5$ . Once  $V_{ref}$  and  $R5$  are selected, current  $I_o$  through

$R5$  is well defined. Because the lower op amp is considered to be ideal, all the current through  $R5$  circulates through  $R4$ , and then

$$I_{R4} = I_o = \frac{V_{ref}}{R5}$$

An interesting property of the GIC is one related to the load current supplied by reference voltage  $V_{ref}$ . To prevent an undesirable  $V_{ref}$  thermal drift, input current  $I_{in}$  from  $V_{ref}$  to the GIC must be kept as low as possible. This could be accomplished by selecting high values for resistances  $R1$  and  $R3$  and a low value for resistances  $R2$  and  $R4$  but taking into account that the resistances seen by the op amp input terminals would be matched.

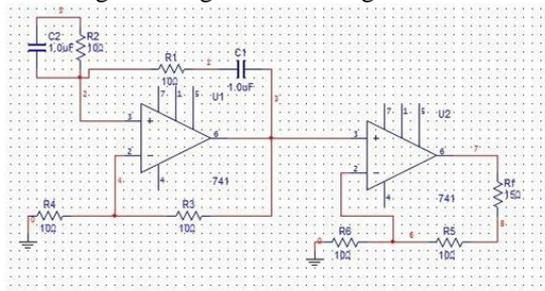
#### D. Wein Bridge with V-I Converter

A Wein Bridge Oscillator is a type of electronic oscillator that generates sine wave. It can generate a large range of frequencies. The frequency of oscillation is given by:

$$f = \frac{1}{2\pi RC}$$

This bridge can also be viewed as a positive feedback system combined with a band pass filter. A current source using wein bridge consists of resistors  $R_1, R_2, R_3, R_4$  and capacitors  $C_1$  and  $C_2$ , which are connected in a bridge formation utilizing a 741-opamp IC and followed by a V-I converter.

The following is the circuit diagram of the current source designed using the wein bridge oscillator:



The values of  $R1, R2$  and  $C1, C2$  is adjusted to get the required value of frequency. The gain of wein bridge oscillator is adjusted by  $R3$ . The voltage produced by oscillator is given to V-I converter which is simply an opamp. The voltage is applied to its positive terminal and receives current from feedback path.

#### IV. COMPARISON OF THE DIFFERENT CURRENT SOURCES

The DC polarized GIC circuit has some improved properties with respect to other current sources [5]. Particularly, in the well-known Howland current source, an op amp follower is needed at its input only to prevent input loading due to its finite input impedance. In the GIC circuit, input reference voltage  $V_{ref}$ , which is needed to select the value of the current source ( $I_o = V_{ref}/R5$ ), only drives a small current due to the high input resistance value selected by resistances  $R1-R4$ . Only adjusting the GIC resistance values is enough to have a high input resistance and a very low output current driven from the input reference voltage. Additionally, the efficiency of the GIC current source is better than that of the Howland topology. This circuit needs a modification in its structure, because only a small fraction of the op amp output current is delivered as an output load current.

Considering the simplified Howland current source, its efficiency was not good, with typical values of about 10%. The modified Howland circuit improves the current efficiency, reaching values in the range of 20%–30%. In the GIC-based current source, all the current delivered by the upper op amp circulates through the load, except for some quantity that is needed to bias the non inverting input of the lower op amp. In the GIC circuit, only selecting the  $R3$  value to be high enough assures good efficiency between the upper op amp output current and the current source. On the other hand, the GIC circuit does not need resistance matching like the Howland pump, improving the current adjustment process. Without an op amp follower at its input (inverting or non-inverting), the balance that the Howland circuit requires has to be corrected each time an input voltage is connected, particularly if this one (the input voltage) does not have a very low output impedance. However, the GIC current source cannot avoid the requirement that the load must be floating.

An improved or modified Howland current source is preferred over the Howland current source. It is seen that for frequencies up to 1 MHz the measured maximum variation of the output current for the modified Howland circuit is around 1.5%.

The current source design using Wein Bridge Oscillator has several advantages over the other designs. Firstly, the circuit implementation is quite simple and can be easily designed. Also, it can be

used for the bio impedance measuring devices that measure values over a wide range of frequencies. This is possible because the wein bridge oscillator circuit provides a stable and low distortion sinusoidal output for a wide frequency range. Moreover the frequency of oscillation can be easily varied by varying capacitances  $C_1$  and  $C_2$  simultaneously. The overall gain of the circuit is high. This makes the Wein Bridge oscillator a preferable choice over the other sources.

## V. CONCLUSION

Thus we discussed the various current sources that can be used for the purpose of bio-impedance measurement. The bio impedance measurement systems require a current source which is stable, has a high output impedance and can cover a wide range of frequency; for the sake of designing a multi frequency current source. The different current sources that we have studied have certain advantages and disadvantages over one another which have already been mentioned above. Among all the current sources, the Wein Bridge Oscillator circuit for current source design has the most simplified implementation. Although a disadvantage is that its maximum frequency output is limited because of amplitude and phase shift characteristics of the amplifier, yet its numerous advantages outweigh its disadvantages. So accordingly depending upon the required features the choice of the most suitable current source can be made.



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