

Comparison of Howland and General Impedance Converter (GIC) circuit based current sources for bio-impedance measurements

Article (Published Version)

Qureshi, Tabassum-Ur-Razaq, Chatwin, Chris, Huber, Nicolas, Zarafshani, Ali, Tunstall, Benjamin and Wang, Wei (2010) Comparison of Howland and General Impedance Converter (GIC) circuit based current sources for bio-impedance measurements. *Journal of Physics: Conference Series*, 224 (1). 012167. ISSN 1742-6588

This version is available from Sussex Research Online: <http://sro.sussex.ac.uk/id/eprint/40504/>

This document is made available in accordance with publisher policies and may differ from the published version or from the version of record. If you wish to cite this item you are advised to consult the publisher's version. Please see the URL above for details on accessing the published version.

Copyright and reuse:

Sussex Research Online is a digital repository of the research output of the University.

Copyright and all moral rights to the version of the paper presented here belong to the individual author(s) and/or other copyright owners. To the extent reasonable and practicable, the material made available in SRO has been checked for eligibility before being made available.

Copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.

Comparison of Howland and General Impedance Converter (GIC) circuit based current sources for bio-impedance measurements

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2010 J. Phys.: Conf. Ser. 224 012167

(<http://iopscience.iop.org/1742-6596/224/1/012167>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 139.184.30.133

This content was downloaded on 10/06/2014 at 14:56

Please note that [terms and conditions apply](#).

Comparison of Howland and General Impedance Converter (GIC) circuit based current sources for bio-impedance measurements

T R Qureshi, C R Chatwin, N Huber, A Zarafshani, B Tunstall and Wei Wang

Biomedical Engineering, School of Engineering and Design, University of Sussex,
Brighton BN1 9QT, UK

Email: wei.wang@sussex.ac.uk

Abstract: The current source is a key component in bio-impedance measurement systems. The accuracy of the current source can be measured in terms of its output impedance together with other parameters, with certain applications demanding extremely high output impedance. This paper presents an investigation and comparison of different current source designs based on the Enhanced Howland circuit combined with a General Impedance Converter (GIC) circuit using both ideal and non-ideal operational amplifiers. Under differing load conditions two different settings of the GIC are evaluated and the results are compared to show its performance settings. Whilst the study has shown that over a wide bandwidth (i.e. 100Hz – 100MHz) the output impedance is limited, operation over a more limited range offers output impedance in the Giga-ohm range, which can be considered as being infinite.

1. Introduction

In any bio-impedance measurement system, 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 low output impedance. Therefore we must preferably use the second method – to inject current and measure voltage across the object [1].

An important parameter of a current source is its output impedance which is frequency dependent. Ideally the output impedance should be infinitely large; so primarily this paper will investigate ways to achieve the highest possible value of output impedance of current source. Bandwidth of the current source is also an important factor. EIT systems require a wide range of frequencies. Apart from output impedance this paper will also investigate the bandwidth of current source under different loads.

The current source which is mostly used in bio-impedance measuring systems is the Enhanced Howland circuit. According to the available literature [2] [3], the Enhanced Howland circuit has limited output impedance which is consistent across a wide bandwidth. At higher frequencies, the output impedance degrades due to the presence of output capacitance and by cancelling this output capacitance higher output impedance can be achieved. The placement of a GIC in parallel with an Enhanced Howland circuit is known to improve the output impedance of the circuit [4].

In this paper, the Enhanced Howland-GIC circuit is simulated with ideal and non-ideal operational amplifiers. This paper is a comparison and simulation of the Enhanced Howland-GIC circuit with

different devices currently available in the market to find the theoretically maximum achievable output impedance. To reduce the output capacitance of the system, different settings of the GIC are simulated, and its output impedance and bandwidth performance are established.

2. Current Source Architecture

2.1. Enhanced Howland Circuit

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 (see fig. 1). This Enhanced Howland circuit is used as a current source in most EIT systems due to its simple architecture and better performance [1][2][3][5][6]. In terms of output impedance, the Enhanced Howland circuit does not give our desired high output impedance due to the presence of output capacitance. The Output current of the Enhanced Howland circuit for an ideal op amp is given as,

$$I = -V_i \cdot \frac{R_2}{R_5 \cdot R_1} + \frac{R_3}{R_5 \cdot (R_3 + R_4)} \left(\frac{R_2}{R_1} \frac{R_4 + R_5}{R_5} \right) \cdot V \quad (1)$$

2.2. Generalized Impedance converter (GIC)

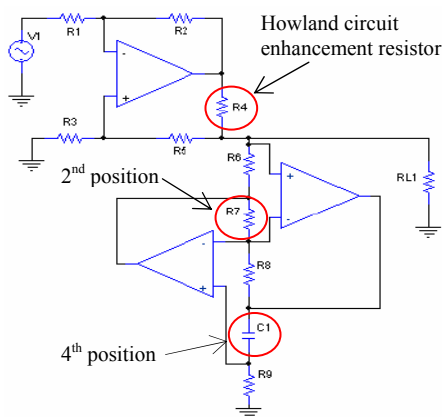


Figure 1: Enhanced Howland-GIC circuit, highlighting possible capacitor positions

GIC circuit is from Northrop [7]. 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. In our case, we want to cancel the output capacitance of the current source circuit by configuring the GIC to effectively produce inductance. Therefore, for inductive output the GIC should have two operational amplifiers, four resistors and one capacitor [7]. The inductance produced will have the value:

$$L = \frac{R_1 R_3 R_5 C_2}{R_4} \quad (2)$$

$$L = \frac{R_1 R_3 R_5 C_4}{R_2} \quad (3)$$

3. Methodologies

A GIC circuit is placed in parallel with Enhanced Howland circuit for output capacitance cancellation as shown in figure 1. The circuit is simulated using PSpice over a wide range of frequencies i.e. up to 1GHz. Output impedance of the circuit is calculated up to 10MHz over different loads i.e. 1k, 2k, 4k, 10k, 20k, 40k. Initially, the Enhanced Howland-GIC circuit is tuned to a single resistor and capacitor setting to achieve maximum possible performance with a single configuration. It is noticed that this configuration will have high output impedance at lower frequencies but the output capacitance degrades the performance at higher frequencies. On the other hand, it covers a wide range of frequencies, as defined by the amplifier bandwidth specifications. This design is called the *single network configuration* (see figure 2).

The Enhanced Howland-GIC circuit can also be tuned to achieve higher output impedance, but over a limited frequency range. This kind of design we have named *multiple network configuration* (see figure 3 for a 1MHz spot frequency performance).

4. Results and Discussion

The circuit was simulated using an ideal operational amplifier present in PSpice libraries. This paper gives simulation results to show maximum output impedance achieved from group of selectable devices. Either 2nd or 4th component in GIC can be a capacitor. In this paper we had placed capacitor at both location and have noticed its results.

Non-ideal operational amplifiers (OPA656, THS4304 and THS3201 by Texas Instruments and AD8055 by Analog Devices) are simulated using single & multiple circuit configurations as well as different capacitor configurations. These operational amplifiers are selected due to wide bandwidth, higher slew rate, low distortion and simple pin configuration. Table 1 shows the maximum output impedance achieved from all selected non-ideal devices at a particular frequency. e.g. Table 1 shows that maximum output impedance of 4GΩ at 100Hz is achieved using OPA656 device for 2nd position of capacitor, while at same frequency 26GΩ output impedance is achieved using AD8055 for 4th position of capacitor. This difference in output impedance is due to characteristics of operational amplifier used and tuning of GIC until we achieve maximum current injection. Using single network configuration gives us better bandwidth but the output impedance decreases at 1MHz and above. Table 1 shows the output impedance achieved using different non-ideal amplifiers. Multiple circuit configurations can be used to achieve high output impedance at higher frequencies. Both possible capacitor settings highlighted in figure 1 can be individually used because the system is tuned for very

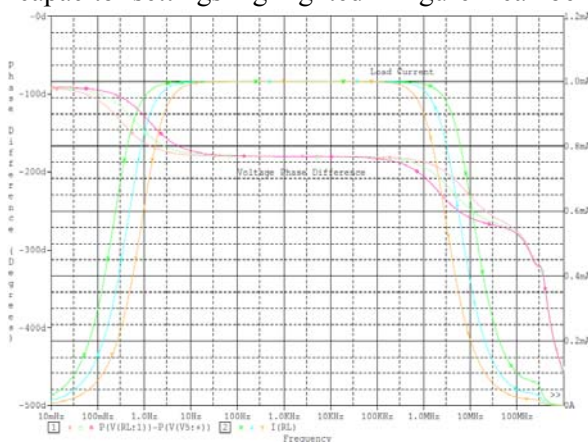


Figure 2: Current and phase difference curves for Enhanced Howland-GIC circuit at 10k, 20k and 40k loads

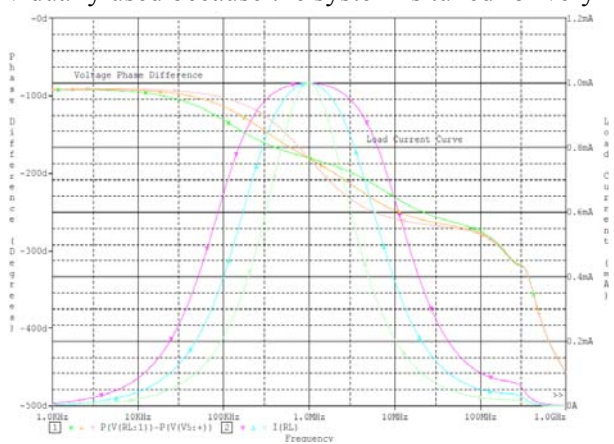


Figure 3: Current and phase difference curves for Enhanced Howland-GIC circuit at 1MHz using 10k, 20k, and 40k loads

narrow frequency bands at which we achieve maximum current injection. Table 2 shows the output impedance possible using non-ideal amplifiers.

For single network configuration, there is also some phase difference between the load voltage and input voltage. From 100Hz to 100kHz phase difference is 180°. Above 1MHz, phase difference increases and the maximum phase difference at 40k load is 259°. For multiple network configurations, phase difference is 180° at 1MHz. When this design is implemented in practice, the phase differences introduced need to be taken into consideration during reconstruction, or calibrated out of the measurements.

5. Conclusion

In this paper, Enhanced Howland-GIC circuit has been simulated using ideal and non-ideal operational amplifiers. Both possible capacitor positions in GIC circuit are simulated. Two different configurations are discussed to cover maximum number of frequencies. Multiple network configurations can be helpful to achieve higher output impedance at higher frequencies, tuned to a narrow band. Results show that, most non-ideal devices can give an acceptable level of output impedance, but THS3201 only achieves low output impedance. However, this same device gives

better bandwidth as compared its counterparts. If we want to achieve higher output impedance (i.e. in the GΩ range) with a single configuration at higher frequencies (i.e. > 1MHz), then we have to sacrifice circuit bandwidth.

As mentioned earlier, this paper only gives the simulation results to find maximum achievable output impedance from a specific group of devices while ignoring the parasitic effect of cables, capacitors, resistor, inductor etc. Once the device which gives acceptable output impedance is decided, this circuit will be simulated including the parasitic effects and will be tested practically. These approaches can further be improved using better operational amplifiers when available.

Table 1: Enhanced Howland-GIC output using the single network configuration at different loads

Frequency (Hz)	Maximum Output Impedance (Z_o) (Ω)							
	Ideal		Non Ideal (OPA656, THS4304, THS3201, AD8055)					
	Using capacitor on 2 nd Position	Using capacitor on 4 th Position	Using capacitor on 2 nd Position		Using capacitor on 4 th Position			
			Max Z_o & Corresponding Load	10k Load	Max Z_o & Corresponding Load	10k Load		
100	6.25G	16.66G	4G	40k	24M	26G	40k	23M
10k	33G	33G	13G	40k	23M	4G	40k	22M
100k	33G	33G	400M	4k	12M	6.15G	4k	13M
1M	33G	33G	20M	4k	2.06M	18.32 M	4k	2.1M
5M	33G	33G	672k	4k	286k	734k	4k	300k
10M	33G	33G	204k	2k	81.26k	188k	2k	85k

Table 2: Enhanced Howland-GIC output using multiple network configurations at different loads

Frequency (Hz)	Maximum Output Impedance (Z_o) (Ω)				
	Ideal		Non Ideal (OPA656, THS4304, THS3201, AD8055)		
	Using capacitor on 2 nd Position	Using capacitor on 4 th Position	Using Capacitor on 4 th Position		
			Max Z_o & Corresponding Load		10k Load
100	6.25G	16.66G	4G	40k	25M
10k	33G	33G	4G	40k	25M
100k	33G	33G	4G	40k	25M
1M	33G	33G	4G	40k	20M
5M	33G	33G	1.2G	10k	1.2G
10M	33G	33G	500M	10k	500M

References

- [1] Yang J 2006 *The Investigation and Implementation of Electrical Impedance Mammography Hardware System* PhD Thesis, De Montfort University, UK
- [2] Wang W 2007 *ICEBI, IFMBE Proceedings* **17** 213-216
- [3] Alexander S R 2003 *Physiol. Meas.* **24** 509-516
- [4] Franco S 2002 *Design with operational analog integrated circuits* (New York: McGraw-Hill)
- [5] Bertemes-Filho P, Brown B H and Wilson A J 2000 *Physiol. Meas.* **21** 1-6
- [6] Oh T I, Lee K H, Kim S M, Koo H, Woo E J and Holder D S 2007 *Physiol. Meas.* **28** 1175-88
- [7] Northrop R B 1997 *Introduction to Instrumentation and measurements* (Florence: CRC)