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# High accurate and wideband current excitation for bioimpedance health monitoring systems

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ABSTRACT

Current sources are critical for the performance of bioimpedance health monitoring device. The challenging features for a high accuracy and wide bandwidth voltage controlled current source are stable and safe current magnitudes. Corresponding to the typical measurement requirements, it should allow typical load impedances in the range from 100 Ω to 10 kΩ and have high output impedance of approximately 10 MΩ at 5 kHz and 1 MΩ at high frequencies up to 1 MHz without harmonics and influence of stray capacitances. Generalized impedance converters and negative impedance converters help to reduce the influence of stray capacitances. In this study, we compare between two types of voltage controlled current sources for grounded loads: Howland and Tietze circuits. Based on this study, we suggest an improved Howland circuit in inverting dual configuration with a negative feedback using the high bandwidth amplifier AD8021. With this configuration, a better accuracy is reached at higher frequencies up to 1 MHz. With the addition of compensation capacitor to the operational amplifier, this circuit configuration is capable to maintain approximately constant current amplitude within an accuracy of less than 0.022% at both low and high frequencies up to 1 MHz.



## 1. Introduction

For non-invasive tissue characterization, pathological health status investigation and diseases diagnosis, electrical impedance spectroscopy is gaining increasingly importance [1]. Comparing to non-invasive techniques used in clinical research such as optical spectroscopy, ultrasound and X-ray, bioimpedance spectroscopy is easy to use, safe and low-cost method [2]. The typically used frequency range, for investigation of tissue's electrical properties and separation of different effects in the impedance spectrum, is from 5 kHz up to 1 MHz corresponding to the β-dispersion [3,4]. For measuring bioimpedance, it is preferable to choose a current injection to avoid the influences of voltage source degradation, contact impedance between the electrode and the tissue [5] and high currents through the tissue due to the temperature-dependence of tissue electrical conductivity [6]. To maintain the medical requirements, the current should be below the perception threshold (0.5 mA) at 5 kHz [7] imposed by the standard IEC-60601. The perception threshold increases when the frequency increases following the equation ($I_{max} = 10^{-7} * f$); where the current is in rms value and the frequency in Hz [8]. To keep the output current stable over the working frequency range independently of the load changing, the output impedance $Z_{out}$ should be maintained much higher (>1000) than the load impedance $Z_{load}$. The load impedance does not consist only of the measured tissue but also of electrodes impedances and contact effects. According to [9], the high frequency impedance at 1 MHz varies from 100 Ω to 1 kΩ, whereas

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low-frequency impedance at 5 kHz varies from 2 kΩ to 10 kΩ. Therefore, it is important to consider output impedance which is higher than 10 MΩ and 1 MΩ respectively at 5 kHz and 1 MHz. The majority of voltage controlled current sources studied in literature do not fulfil the target output impedance's requirements. The aim of this study is to design a voltage controlled current source with output impedance higher than 10 MΩ at 5 kHz and higher than 1 MΩ until 1 MHz. The paper is structured in four sections. In section 2, a literature review of some voltage controlled current sources in current-mode and voltage-mode approaches are analyzed concerning their output impedance. In section 3, different voltage controlled current sources for grounded loads (Tietze and Howland topologies) are described and compared considering output current and output impedance in order to choose the suitable configuration. In section 4, the chosen configurations are simulated in order to decide about suitable circuit element values and to analyze their influence. In section 5, in pursuance of improving the stability of the output current at high frequencies up to 1 MHz, methods eliminating the influence of stray capacitances are expounded and the external compensation is proposed. Also, the experimental investigations are carried out and results concerning voltage controlled current source are discussed.

## 2. Literature review of voltage controlled current sources

Voltage controlled current sources can be based on a voltage-mode approach or a current-mode approach (Fig. 1). In the voltage-mode approach, the output current is generated by the voltage in one or more nodes of the active circuit, such as the Howland topologies, Tietze topology and the load-in-the-loop. In the current-mode approach, the output current is generated by an active device, such as operational transconductance amplifier, current mirror and current conveyors [10]. Both approaches can have floating or grounded load.

Different current sources have been studied in literature. The supply-current sensing current source based on current mirrors [11] shows a dramatically decrease of the output impedance at 1 MHz about 30 kΩ. Even, if the output impedance at high frequencies increases by introducing a current conveyor (CCII) [12], it remains lower than 700 kΩ. The limitations are due to the mismatch between transistors and coming out of saturation i.e. the collector and emitter are at higher potential than the base. In this case, the current driven into the base is not enough to forward bias the base–collector and the base–emitter junctions. These restrictions influence the accuracy of circuit by increasing its current noise and reducing the output impedance. Table 1 shows that only the current conveyor (CCII) and the operational transconductance amplifier (OTA) of class-AB have reached the requirements. They have output impedance higher than 10 MΩ and 1 MΩ respectively at 5 kHz and 1 MHz [13]. Because the development of current-mode approaches is expensive and requires custom fabrication, the interest in this study remains on voltage-mode approach. Each current source approach has two possibilities of load connection: floating loads (load-in-the-loop) and grounded loads (Howland circuit). In the load-in-the-loop structure, the output impedance is dependent on the feedback resistor ($R_f$) connected in parallel with the load. If $R_f$ increases, the output impedance increases to around 1.5 MΩ at both low and high frequencies. The reason behind the higher the value of $R_f$ the higher the output impedance, is that $R_f$ acts like a current divider. When connecting the load-in-the-loop to the current conveyor, the output impedance at 1 MHz increases slightly but remains low [14]. The floating load in the feedback loop has a significant effect on stability. In case of complex loads, which are not purely resistive, additional components are required to insure stability. For grounded loads, no additional components are needed [15]. In addition to that, a comparison, made between floating load (load-in-the-loop) and grounded load (Howland circuit) [16], shows that the floating loads degrade severely comparing to Howland topologies when changing the load. As a conclusion, the floating load is instable and not sufficiently preferment comparing to Howland when using complex loads, depending on the feedback resistor connected in parallel with the load. That is why we are focusing in this study on grounded loads. For voltage controlled current sources for grounded loads, different topologies have been studied in literature. Mirrored Enhanced Howland circuit [13,17], inverting and non-inverting enhanced Howland in single and dual configuration with negative or positive feedback [18], Howland configurations and Tietze circuit [19] have output impedance all lower than 110 kΩ at 1 MHz. In [18], all configurations of Howland do not fulfil the output impedance's requirements. Tietze circuit is compared to Howland configurations [19] and only dual configuration with negative feedback in inverting and non-inverting configuration have output impedance higher than 10 MΩ at low frequency but at high frequency is lower than 1 MΩ even lower than 15 kΩ.

Based on these results, we decide to investigate current sources for voltage-mode approach with grounded loads,

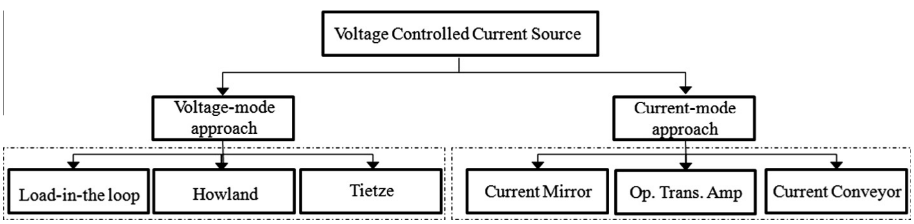


**Fig. 1.** Classification of different approaches for voltage controlled current souces.