A comparison of modified Howland circuits as current generators with current mirror type circuits

This content has been downloaded from IOPscience. Please scroll down to see the full text.
2000 Physiol. Meas. 21 1
(http://iopscience.iop.org/0967-3334/21/1/301)

View the table of contents for this issue, or go to the journal homepage for more

Download details:
IP Address: 131.252.130.248
This content was downloaded on 26/04/2014 at 15:17

Please note that terms and conditions apply.
A comparison of modified Howland circuits as current generators with current mirror type circuits

P Bertemes-Filho, B H Brown and A J Wilson
Department of Medical Physics and Clinical Engineering, Royal Hallamshire Hospital, University of Sheffield, Sheffield S10 2JF, UK
E-mail: mpp98pb@sheffield.ac.uk

Received 16 July 1999

Abstract. Multi-frequency electrical impedance tomography (EIT) systems require stable voltage controlled current generators that will work over a wide frequency range and with a large variation in load impedance. In this paper we compare the performance of two commonly used designs: the first is a modified Howland circuit whilst the second is based on a current mirror. The output current and the output impedance of both circuits were determined through PSPICE simulation and through measurement. Both circuits were stable over the frequency ranges 1 kHz to 1 MHz. The maximum variation of output current with frequency for the modified Howland circuit was 2.0% and for the circuit based on a current mirror 1.6%. The output impedance for both circuits was greater than 100 kΩ for frequencies up to 100 kHz. However, neither circuit achieved this output impedance at 1 MHz. Comparing the results from the two circuits suggests that there is little to choose between them in terms of a practical implementation.

Keywords: current sources, impedance imaging, evaluation

1. Introduction

Electrical impedance tomography (EIT) systems have been constructed to measure sets of transfer impedance data from arrays of electrodes and the results used to produce images of electrical resistivity distribution (Brown et al 1994, Griffiths and Jossinet 1994).

Although EIT systems suffer from poor image resolution the transfer impedances must still be measured with high accuracy. The effect of unknown skin–electrode impedance on measurement errors can have a significant effect on image quality (Boone and Holder 1996). The data collection system can also limit the overall accuracy (Smith 1990). Errors arise in both current drive and voltage receive parts of the measurement system.

An ideal accuracy in transfer impedance measurements of 0.1% has been suggested by Brown and Seagar (1987). Many attempts have been made to obtain the best possible performance from the current generators used in multi-frequency EIT systems (Denyer et al 1994, Jossinet et al 1994a). Some EIT systems have used current measurement techniques to achieve 0.1% accuracy (Cook et al 1994) by adjusting the output amplitude of the current source under computer control in a trimming process. However, it is difficult to control the output current sufficiently rapidly in many situations (Blad et al 1994).

The simplest technique to obtain a constant current is to use a voltage controlled current source (VCCS), which can be defined as a combination of positive and negative feedback around a high gain operational or instrumentation amplifier. Four major configurations for a
VCCS have been used. These are: a feedback inverting amplifier; transformer coupled VCCS (Li et al 1994); positive feedback amplifier or a supply-sensing circuit. Oscillators have also been used in EIT systems by some workers (Murphy et al 1987, Van der Walt 1981) but they have frequency and amplitude stability problems.

These attempts show that it is very difficult to design a voltage controlled current source (VCCS) whose output impedance is greater than 1 MΩ at frequencies up to 1 MHz (Lu 1995).

We compare two designs for VCCS. One uses positive feedback in a modified Howland circuit (Cusick et al 1994, Jossinet et al 1994b) and the other a current mirror architecture (Casas et al 1996, Bragós et al 1994, Riu et al 1992).

In this paper we compare the Howland circuit with the one based on a current mirror (Casas et al 1996). In order to assess performance, the output current and output impedance have been measured over the frequency range 1 kHz to 1 MHz.

2. Method

The design specification was for a current generator which would have an output of 1 mA p–p. The circuit must operate over the frequency ranges 1 kHz to 1 MHz with a minimum output impedance of 100 kΩ. Also, the circuit should be stable for the range of loads likely to be encountered when collecting EIT data sets.

The two designs of current generator are shown in figures 1(a) and 1(b). In (a) the current mirror design is shown using a current feedback amplifier AD844 which is manufactured by Analog Devices. This circuit is fully described by Casas et al. The output current is defined by the first stage, which uses a transconductance amplifier MAX435 from Maxim Integrated Products. The modified Howland design is shown in (b). Output current $I_{out} = V_i/Z_4$ when $Z_1 = Z_3 = Z_5$ and $Z_2 = (Z_1 + Z_4)$.

Both the circuits were simulated in PSPICE and both were constructed using 1% tolerance components. The following measurements were made on the two circuits.

2.1. Output current magnitude

Figure 2 shows the schematic diagram that was used to measure the output current of the VCCS for both Casas et al and modified Howland designs.

The input voltage and the output current were measured five times by using an impedance/gain analyser (Solartron-1260) in a differential input configuration with floating screen. The frequency range 1 kHz to 1 MHz and 1 V p–p input voltage were used. The input voltage was averaged and normalized for both circuits. The normalized input voltage was used to compensate the frequency response of the output current, assuming 1 kΩ load.

2.2. Output impedance magnitude

The output impedance was measured using a multimeter. This technique (figure 3) used a DVM (Keithley 2000) to measure the output current under total loads of 200 Ω and 500 Ω.

From the diagram shown in figure 3, it is clear that for two different loads the following two equations can be obtained:

$$i_S = i_{Z1} + I_1$$

$$i_S = i_{Z2} + I_2.$$ (1)

The equations (1) and (2) can be combined to obtain the following equations (3) and (4).

$$I_1 - I_2 = i_{Z2} - i_{Z1}$$ (3)
Comparison of current generators

Figure 1. (a) Diagram of the current mirror circuit. $Z(= R_t C_t)$ is the trans-impedance of the AD844 integrated circuit. $|$ denotes the parallel between $R_t$ and $C_t$. $+V$ and $-V$ are non-inverting input voltage and inverting input voltage, respectively. $R_{in}$ represents the input resistance of the IC AD844. (b) Schematic of the modified Howland circuit, where $V_I$ is the regulated input voltage and $I$ is the constant output current.

Figure 2. Diagram schematic of the impedance/gain analyser set used to measure the output current, where $I_L$ is the current through the load $R_L$.

\[
I_1 - I_2 = (V_{Z2} - V_{Z1})(1/Z_S). \tag{4}
\]

Since the voltage across the output impedance ($Z_S$) of the VCCS is equal to the voltage across the total load ($R_L + P$), equation (4) can be written as:

\[
Z_S = \Delta V_L/\Delta I \tag{5}
\]
Figure 3. Schematic diagram used to measure the output impedance $Z_S \approx \Delta R_L (I/\Delta I)$. $Z_S$ is the output impedance of the VCCS, $P$ is a variable resistance and $R_L$ is the load.

Table 1. A comparison for both designs of the output impedance, assuming a load variation from 200 $\Omega$ to 500 $\Omega$.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>$Z_{out}$ (\Omega)</th>
<th>$Z_{out}$ (\Omega)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PSPICE</td>
<td>Measured</td>
</tr>
<tr>
<td>1k</td>
<td>3.0M</td>
<td>&gt; 1.0M</td>
</tr>
<tr>
<td>10k</td>
<td>2.0M</td>
<td>&gt; 1.0M</td>
</tr>
<tr>
<td>100k</td>
<td>288.0k</td>
<td>700.0k</td>
</tr>
<tr>
<td>300k</td>
<td>96.0k</td>
<td>400.0k</td>
</tr>
<tr>
<td>1M</td>
<td>29.0k</td>
<td>70.0k</td>
</tr>
</tbody>
</table>

For small changes in $I$, $I_1$ can be considered to equal to $I_2$ (i.e. $I \approx I_1 \approx I_2$) and then the equation (6) can be finally approximated as:

$$Z_S \approx \frac{\Delta R_L I}{\Delta I}$$

(7)

where $\Delta R_L$ is the difference between $P_2$ and $P_1$ which are two different settings of the variable resistance $P$.

In other words, the output impedance can be calculated from the difference in the current flowing by using a fixed resistor ($R_L$) of 200 $\Omega$ and a variable resistance of 500 $\Omega$.

3. Results

The output impedance for the two circuits is presented in table 1. It can be seen that both circuits meet the design specification of 100 k$\Omega$ output impedance over most of the frequency range but both fail at 1 MHz.

The technique utilized in this paper could not measure impedance over 1 M$\Omega$, as shown in table 1, because of the accuracy of the digital multimeter.

It was observed that the output impedance is a function of load in both cases.

The PSPICE simulation and measured output currents are given in figure 4. It can be observed in figure 4 that the maximum errors were $+3.8\%$ for the Casas et al design and $-1.7\%$ for the modified Howland design. However, the high output current for the Casas et al circuit could obviously be scaled with appropriate choice of component values. The deviation
Comparison of current generators

Figure 4. Comparison of the compensated output current magnitude, assuming 1 kΩ load. The Howland circuit is within 2.0% and the Casas et al circuit is within 1.6% over the whole frequency range.

over the complete bandwidth was 1.6% for the Casas et al circuit and 2% for the modified Howland circuit. The errors were greater than those found in the PSPICE simulations in both cases. Errors will arise from the tolerance of real components across the full frequency range and the effects of parasite capacitances at the high frequencies.

4. Discussion and conclusions

The fact that both circuits failed to achieve 100 kΩ output impedance at 1 MHz is almost certainly due to the output resistance having a parallel output capacitance which reduces the output impedance at high frequency.

Both circuits exhibit quite large changes in output impedance with changes in load resistance. This is an important factor in assessing the actual performance of a VCCS in a particular measurement situation. The output impedance should be measured under the actual load conditions. The effects of related circuits in the EIT system should also be considered when measuring the output impedance.

The measurements of the modified Howland design, which are shown in the table 1, can be reproduced. However, the level of noise in the VCCS circuits is an important factor to be considered when very high output impedances are to be measured.

Both circuits were stable over a range of load resistances from 50 Ω to 1 kΩ. There does not appear to be a clear case to favour one or other of the two designs.

Acknowledgments

I would like to thank the Brazilian Government, through the National Council for Scientific and Technological Development—CNPq, for financial support through a grant.
References


Boone K G and Holder D S 1996 Current approaches to analogue instrumentation design in electrical impedance tomography Physiol. Meas. 17 (suppl 1A) A229–A247


Griffiths H and Jossinet J 1994 Bioelectrical spectroscopy from multifrequency EIT Physiol. Meas. 15 (suppl 2A) A59–A63


——1994b Active current electrode for in vivo electrical impedance tomography Physiol. Meas. 15 (suppl 2A) A83–A90


Lu L 1995 Aspects of an electrical impedance tomography spectroscopy (EITS) system PhD Thesis University of Sheffield


Smith R W M 1990 Design of a real-time impedance imaging system for medical applications PhD Thesis University of Sheffield