A comparison of different Current Sources for multi-frequency Impedance Spectroscopy
Preliminary results

Xiaosha Zhao, Steffen Kaufmann and Martin Ryschka
Centre of Excellence in Medicine and Engineering (TANDEM), Lübeck University of Applied Sciences
Lübeck, Germany
kaufmann@fh-luebeck.de, ryschka@fh-luebeck.de

Abstract—Typical applications of impedance spectroscopy in both medical and industrial settings require a high quality current source, which maintains a high output impedance over a large bandwidth. The common build-up of the current generation is normally realized with a waveform generator in combination with a Voltage Controlled Current Source (VCCS). This work presents a comparison of different VCCS used for impedance spectroscopy in a frequency range of 100 Hz to 500 kHz. The studied current sources are the well-known enhanced Howland current source, a two op-amps based current source and a current source based on the AD8130 from Analog Devices. The current sources are compared in terms of their output impedances, their compliance-ranges and their build-up complexities.

Keywords- Voltage Controlled Current Source (VCCS), high output impedance, constant output current

I. INTRODUCTION

This work describes the analysis and comparison of different current sources. The current sources are compared in terms of their output impedances, their compliance-ranges and their build-up complexities. In order to get a comprehensive understanding and comparison among the different current sources, this analysis is based on both SPICE simulation and PCB measurements. This includes investigation of the output impedances and the output currents, as well as the compliance range in a frequency range from 100 Hz to 500 kHz.

II. BASIC AND METHODS

One of the most interesting parameter of a current source is the output impedance. Ideally, the output impedance should be infinite; however, in practice all current sources have finite and complex output impedance, which decreases with increasing frequency [1] [3]. Figure 1 shows a principle equivalent circuit of a Voltage Controlled Current Source (VCCS).

In this work the circuits are simulated with LTSpice IV from Linear Technology. For the output impedance estimations in the simulation the load impedance $Z_L$ is exchanged with a voltage source, additionally the input nodes are short circuited to ground. With $I_0 \approx 0$ follows with Ohm’s law:

$$Z_{out} = \frac{V_{test}}{I_{test}}$$  (1)

The output impedance estimation on the PCB measurements is based on the approximation that the output impedance is much larger than the load. This estimation results in the following formula:

$$I_L = I_0 \frac{Z_{out} + Z_L}{Z_{out}} \Rightarrow I_L' = \frac{dI_L}{dZ_L} = \frac{-I_0}{(Z_{out} + Z_L)^2} \approx \frac{-I_0}{Z_{out}} \Rightarrow Z_{out} = -\frac{I_0}{I_L'}$$  (2)

Where $Z_{out}$ is the output impedance of the circuit, $I_0$ is the ideal current provided by the current source and $I_L'$ is the differential coefficient of the current through the load.

III. SCHEMATICS

The enhanced Howland current source is build-up with an OP2134 from Texas Instruments. The schematic is shown in figure 2.

One of the two op-amps based current source [1] is also build-up with the same op-amp. Figure 3 shows the schematic.

Figure 1. The schematic of the enhanced Howland current source.

Figure 2. The schematic of the two op-amps based current source.
The third investigated current source is based on the AD8130 from Analog Devices, as shown in figure 4 [2].

Figure 3. The schematic of the AD8130 based current source (based on [2])

IV. RESULTS

Figure 5 shows the simulated output impedances of the three different current sources. It can be seen that the enhanced Howland current source shows the best overall performance.

Figure 4. The simulated output impedance of the three different current sources

The PCB measurements are done by measuring the output voltage over known 1% tolerance resistors, the needed input voltages for the VCCS are provided by an arbitrary signal generator. Figure 6 shows the measured output impedances of the three different current sources.

Figure 5. The output impedances of the three different current sources based on PCB measurements

Figure 6 shows that the output impedance difference below 50 kHz is small. Starting at about 80 kHz the output impedance starts to differ significantly for the three current sources. In contrary to the simulation the enhanced Howland current source has the smallest output impedance at higher frequencies. This can be caused by unpredictable errors like non-perfect simulation models, components tolerances or stray capacitances. The most stable output impedance shows the AD8130 based current source.

Table 1 shows a comparison of the different compliance ranges of the current sources, as well as their efficiency at different frequencies.

<table>
<thead>
<tr>
<th>Freq.</th>
<th>1 kHz</th>
<th>10 kHz</th>
<th>100 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vout / V</td>
<td>η / %</td>
<td>Iout / mA</td>
<td>Vout / V</td>
</tr>
<tr>
<td>enhanced Howland</td>
<td>1.92</td>
<td>38.4</td>
<td>1.93</td>
</tr>
<tr>
<td>Two op-amps</td>
<td>1.95</td>
<td>39.0</td>
<td>1.96</td>
</tr>
<tr>
<td>AD8130</td>
<td>3.75</td>
<td>75.0</td>
<td>3.76</td>
</tr>
</tbody>
</table>

The efficiency of the different current sources at different frequencies

\[ R_L = 1 \text{kΩ} \pm 1\%; V_{CC} = \pm 5 \text{V}; T = 23^\circ\text{C} \]

According to the table 1, the enhanced Howland current source and the two op-amps current source have almost the same efficiency \( \eta = \frac{V_{out}}{V_{CC}} \) of \( \approx 40\% \), whereby the current source based on the AD8130 is with more than 55% much more efficient.

V. CONCLUSION

In conclusion, the current source based on AD8130 shows the best performance. It has the largest output impedance at higher frequencies, combined with the best efficiency. On the other hand the build-up complexity of the AD8130 circuit is slightly higher than of the Howland circuit, but no matched low tolerance resistors are needed.

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REFERENCES