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Transformerless High-quality Electrocardiogram and Body Impedance Recording by an Amplifier with Current-Driven Inputs

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Summary: Measurement and recording of changes in bioelectrical impedance in vivo has become a widely used method with various clinical applications. It includes basal impedance Z_o, relative changes ΔZ or its derivative dZ. Many applications related to cardiac and respiratory function require simultaneous electrocardiogram, impedance-cardiogram and/or respiration signals recording and analysis. Accurate recording of body impedance is limited by high common mode voltages at the amplifier inputs combined with the influence of the output impedance of the used current source. A circuit concept for a simultaneous high-quality electrocardiogram and bioimpedance acquisition is proposed, profiting from advantages offered by a previously specially designed amplifier with current-driven inputs, yielding to low common mode and high differential mode input impedances.

Keywords: Bioimpedance monitoring, ECG amplifier, Power-line interference

1. INTRODUCTION

Bioelectrical impedance methods have found wide acceptance in various physiological and clinical applications. Basal impedance (Zo) is measured and its relative change (ΔZ) or derivative (dZ). The measurement consists of injecting high frequency current in a selected body segment or organ and taking-off a voltage proportional to the impedance [3].

One of the most widespread applications is patient monitoring, using simultaneous electrocardiogram (ECG) and impedance-cardiogram (ICG) recording, for assessment of cardiac output changes. In neonatal care, ECG and respiration impedance acquisition and analysis has been a routinely accepted modality.

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This paper presents an application of a Current Driven Input Amplifier (CDIA) [1] approach for high-quality simultaneous body impedance and electrocardiogram recording.

2. BIOIMPEDANCE MEASUREMENT WITH TRANSFORMER INTERFACE

Usually, a high-frequency sinusoidal reference current in a frequency range from 30kHz - 300kHz is used for bioimpedance measurement. The current is injected into the body by a pair of electrodes called 'current electrodes'. The generated voltage drop due to this current is sensed by another pair of high-impedance or 'voltage electrodes'. In practice this implements the so-called 'four wire Kelvin connection' or 'force-sense connection', in which the impedance influence of the current electrodes is eliminated and does not introduce an error.

In some cases when only the relative impedance changes ΔZ is needed to be registered, e.g. in respiration monitoring, both pairs of electrodes could be connected in parallel, thus only one pair of electrodes for a current-force-voltage-sense could be used.

The common practice for injecting the current into the body is by a transformer interface as shown in Fig. 1.

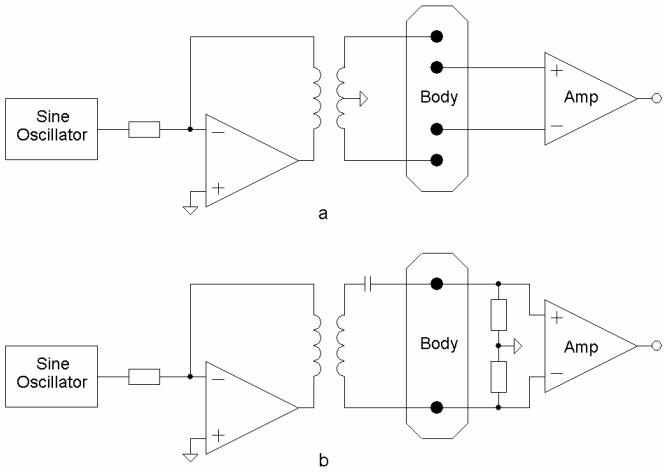

Fig. 1 Transformer interface for bioimpedance measurement a) 'four wire' connection, b) 'two wire' connection

The secondary coil in Fig. 1a is normally built from two sections to have a middle point connected to circuit ground. This connection ensures very low common mode impedance of the 'current electrodes' keeping the body potential close to circuit ground and in the amplifier common mode input range. The power-line (PL) interference currents, typically in a range from 200nA to 2μA, flow only into 'current electrodes' and do not create a voltage drop over an impedance of 'voltage electrodes'. The middle point of the transformer secondary coil can be connected also in a negative common mode shunt-shunt feedback loop similar to 'driven right leg', for additional lowering of the amplifier input common mode voltage.

If only two electrodes are used, the secondary coil must be connected via capacitor to ensure sufficiently high impedance for the ECG frequency band - see Fig. 2b. The amplifier inputs are usually kept in their common mode range by two highohmic resistors (10MΩ), and there is a risk for saturation of the amplifier input stage at high level common mode interference, because if the supply voltage is 5V, the maximum tolerated PL interference current is below 0.5μA.

3. RESULTS AND DISCUSSION ON TRANSFORMERLESS CONCEPT FOR BIOIMPEDANCE MEASUREMENT

The presence of the transformer is the main drawback of the transformer interface. It is a custom designed and manufactured part of relatively high cost. That is why the whole circuit will greatly benefit if the transformer can be omitted without degradation in the final performance.

The proposed architecture is shown in Fig. 2. It consists mainly of a CDIA described in [1] and, additionally, a sine oscillator and an amplitude demodulator. Owing to CDIA structure, the circuit offers the same or better performance as a transformer interface, but without using transformer. Similarly to 'four electrodes' transformer connection, CDIA provides low common mode impedance of the 'current electrodes', which from one side fixes the body potential into an amplifier input common mode range, and from the other side it makes the PL interference currents flow only into the 'current electrodes'.

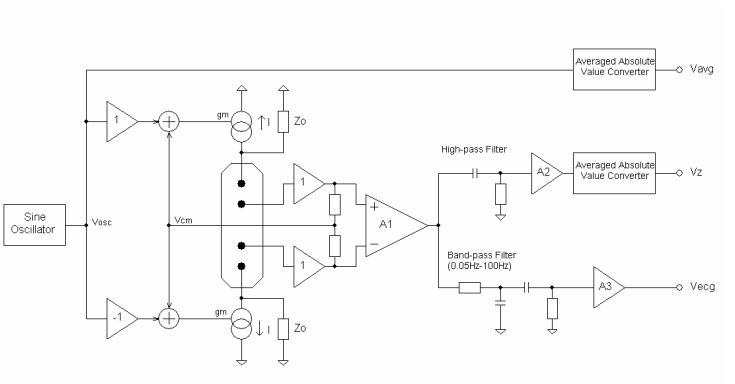

Fig. 2 Transformerless circuit concept for a high-quality simultaneous bioimpedance and ECG measurement

Thus, the PL interference currents do not create a voltage drop over impedance of sensing electrodes, body common mode voltage is reduced, the amplifier CMRR is increased and saturation problems do not exist. The circuit is applicable equally in four or in two electrodes configuration. Of course, in 'two electrode' configuration the flowing common mode current multiplied by electrode impedance difference will create a differential input voltage drop, which will be amplified together with the useful signal independently of the amplifier CMRR value.

The needed sine voltage can be generated by Wien bridge, other RC or LC oscillators or digitally synthesized by DAC. If a 'four electrode' configuration is used, the generated sine wave should be selected to be in a lower frequency range from 30kHz to 100kHz. If a 'two electrode' connection is used the generated sine wave should be in the upper frequency range from 100kHz to 300kHz, for lowering the electrode impedance influence which have dominantly capacitive nature. The current source amplitude is selected in the range from 100μA to 1mA.

The voltage drop proportional to the body impedance (20Ω to 200Ω) is amplified by A1 (see Fig. 2), high-pass filtered, additionally amplified by A2, and amplitude demodulated by an asynchronous detector; or in other words it is amplified, rectified and averaged. One example of a simple averaged absolute value converter is

described in [2] and it can be successfully implemented. A synchronous demodulation [4] can be used as well, and it is a must if complex impedance (real and imaginary part) has to be recorded, otherwise it only additionally increases the circuit complexity.

For precise results, additional amplitude demodulator (averaged absolute value converter) can be used for amplitude measurement of the reference sine wave, see Fig. 2.

If the current sources have a transconductance *gm*, the absolute value of the body impedance Z_{body} is:

$$Z_{body} = \frac{V_z}{V_{avg}} \cdot \frac{1}{gm \cdot A_1 \cdot A_2}$$

If V_{avg} = 1V, then:

$$Z_{body} = \frac{V_z}{gm \cdot A_1 \cdot A_2}$$

The differential mode and common mode impedances as seen from the 'current electrodes' are:
$Z_d = 2Z_o$, $Z_{cm} = 1/2gm$

The lowering of the current sources common mode output impedance leads to self balance in their output voltages. For example, let us assume that the transconductance *gm* is changed within 1%. If the generated current is 1mA this means a mismatch current of 10μA, which must flow via common mode impedance Z_o. If the common mode output impedance Z_o is 1MΩ, the common mode voltage will have amplitude of 10V, and the current source output will be saturated. If the common mode impedance Z_o has a reduced value of 1k, the common mode amplitude will be only 10mV, and will not play a role.

The power line interference currents can also lead to saturation, because the current source output impedance at low frequency is much higher, and can be in range of about 50MΩ. The reduced common mode impedance solves this problem, and if the PL interference current has amplitude of 5μA (per input), the body common mode voltage amplitude will be only 5mV (if Z_o = 1k).

The ECG channel consists of a band-pass filter with a fist order high-pass and a second order low-pass roll-offs and an additional amplifier A3.

4. CONCLUSIONS

The presented approach can be used in all cases when bioimpedance and ECG monitoring needs to be simultaneously registered. Its advantages could be summarized as:

- Better performance without usage of a transformer;
- Circuit asymmetries due to unequal characteristic of the implemented current sources: transconductance *gm* and output impedance Z_o are selfcompensated. Their adjustment is not needed, and a sure operation is guarantied.
- Relatively low common mode impedance of the 'current electrodes', in comparison to 'voltage electrodes', makes the power-line interference currents flow in these electrodes only, decreases the body common mode voltage amplitude, increases the total CMRR and finally ensures a high-quality ECG.
- The approach can be implemented in four or in two electrode configurations.

REFERENCES

1. Dobrev D., I. Daskalov, Two-electrode biopotential amplifier with current-driven inputs, *Med. Biol. Eng. Comp.* 2002, 40, 122–127.
2. Dobrev D., Two op amps provide averaged absolute value, *EDN - Design Ideas*, 2003, 24, 98.
3. Patterson R., Bioelectric impedance measurements, in Bronzino J (Ed): *The Biomedical Engineering Handbook*, 2nd ed., 2000, CRC Press
4. Petrova G., Improvement of common mode rejection ratio in bioimpedance measurement using differential synchronous demodulation, *Proc. ET1998, b2*, 1998, 71–75.