Current source for bioelectrical impedance measurements

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The bioelectrical tissue impedance is measured by the voltage drop across a body segment, created by injecting a high-frequency current (1÷500 kHz) with stabilised amplitude and frequency.

The non-linear distortions and the instability of the amplitude of the current source signal introduce errors, that should be taken in consideration in precise measurements of bioelectrical impedance.

A circuit of voltage to current converter that allows a relatively high current through the body segment is presented. The circuit offers a high output impedance in a wide frequency range. This is accomplished by a transistor output stage. As positive polarity components of the current are generated only, a full-wave rectification of the input voltage is combined with an output current commutation..

The use of higher but safe patient current improves the signal/noise ratio. The output impedance of the proposed circuit is investigated. The results obtained show a measurement accuracy of approximately 0.03%.

Introduction

The use of bioelectrical methods for studying the properties of tissues and their changes as a result of different disease states or for assessment of total body water changes, requires an accurate measurement of the constant impedance component [4].

Usually the bioelectrical tissue impedance is measured by injecting through the body a high-frequency sinewave current (1÷500 kHz) with stabilised amplitude and frequency. The impedance of the body corresponds to the acquired voltage obtained from two take-off electrodes. Therefore, current source properties are very important for the total measurement accuracy. Many studies on bioimpedance measurement accuracy deal with the problems of current sources stability [3]. There are many known voltage to current converters for bioimpedance measurements, but most are designed for specific purposes and others do not meet the requirements for high accuracy, especially when working with high amplitude and frequency [1].

Main theoretical preconditions

There are many known voltage to current converter, of various circuit configurations. The best results known are obtained with circuits which using bipolar transistors. The load resistance is inserted in the collector circuit and negative current feedback is provided. A circuit of this type is shown in *Fig.1*. Its characteristics are near ideal for the purpose in consideration.

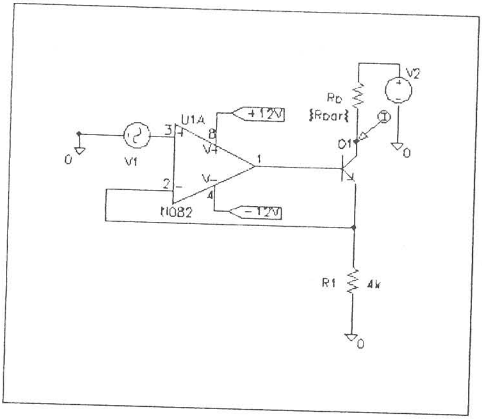


Fig.1.

However, circuits like this can not be used directly for bioimpedance measurements, because a constant current component in the input signal is needed, which results in an unallowable constant current component through the body. There were attempts for use of this circuit for bioimpedance measurements. A constant voltage source is connected to the input and by switching the load resistance the output signal is convert into bipolar pulses, thus obtaining a square-wave patient current. Due to capacitance bioimpedance components it may be smoothed or even transformed in a triangular-like waveform. This unavoidably would results in non-linear distortion errors, when detecting the impedance signal. Usually phase-sensitive detectors are used for obtaining low noise sensitivity of bioimpedance measurement modules. In such cases the non-linear distortions influence would be considerable [2].

Method for improving the non-linear distortions factor

To reduce or avoid non-linear distortion influence, a sinewave current should be passed through the patient body. This can be implemented by feeding the circuit by a sinewave voltage generator (Fig.1). The normal operation of the output transistor requires a constant current offset. As mentioned above, this would result in passing a constant current through the patient. To avoid this inconvenient the circuit of *Fig.2.* is proposed.

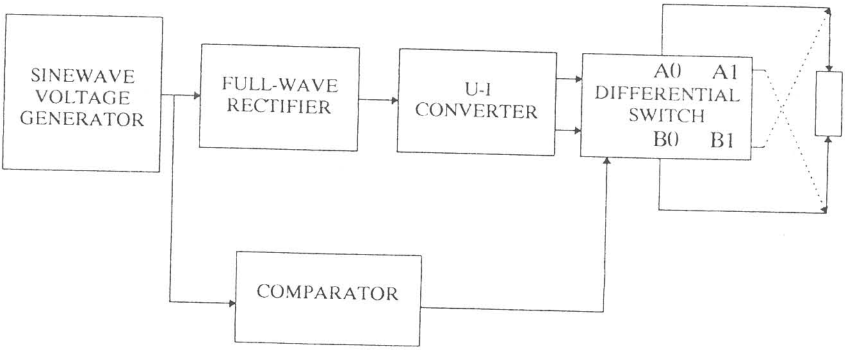
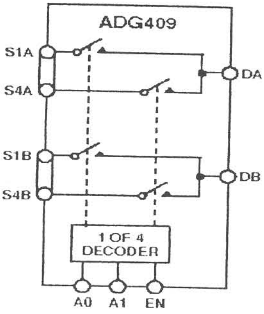


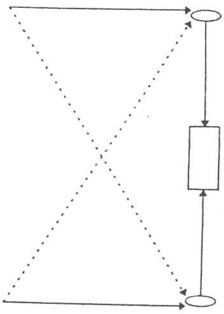
Fig.2.

The sinewave voltage signal from the generator is full-wave rectified and converted into current, which goes in opposite directions through the patient during adjacent periods of the rectified input signal. This is implemented by switching over the current electrodes between the two voltage to current converter output leads. The current through the body is then bipolar and of sine waveform. This allows the high performance characteristics of the voltage to current converter to be used. The two main problems of this circuit - constant current through the body and high non-linear distortions - are thus avoided.

The switching of the current electrodes makes use of the ADG409 switch, shown in *Fig.3a*.



a



b

Fig.3.

The operation of the switch is shown in *Fig.3b*. Point A is connected to the supply source and point B to the transistor collector. The patient is connected to the current source as shown by full lines during one period of the rectified signal and during the next period the connection is shown by dashed lines.

ADG409 switches four differential inputs to one differential output. The inputs switching depends of the signal on A1 and A0. The above mentioned switching can be obtained by connecting S1A and S2B to point A, and S2A and S1B to point B.

The rectangular control signal for ADG409 must be of the same phase as the output signal of the voltage generator. It can be obtained by a comparator from the sinewave voltage input signal. The comparator output may be used for phase-sensitive detection, which ensures lower noise sensitivity.

Fig.4. shows the sinewave voltage signal from the generator, the full-wave rectified current, the rectangular control signal and the bipolar current through the patient.

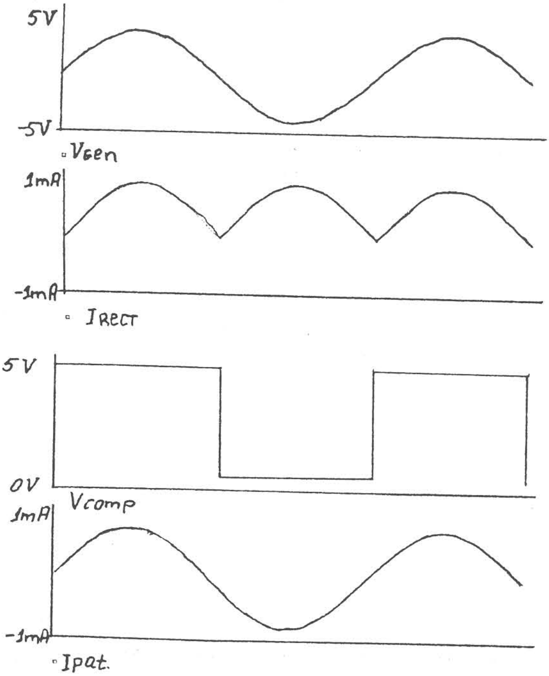


Fig.4.

Investigation of the voltage to current output resistance and it's influence on the measurement accuracy.

The error, introduced by the output impedance must be evaluated. A parametric frequency analysis with DESIGN CENTRE is made. The load resistance changes from 30Ω to 1kΩ, simulating different tissue impedances. The general purposes amplifier TL082 is used. Results from this analysis are shown in *Fig.5*.

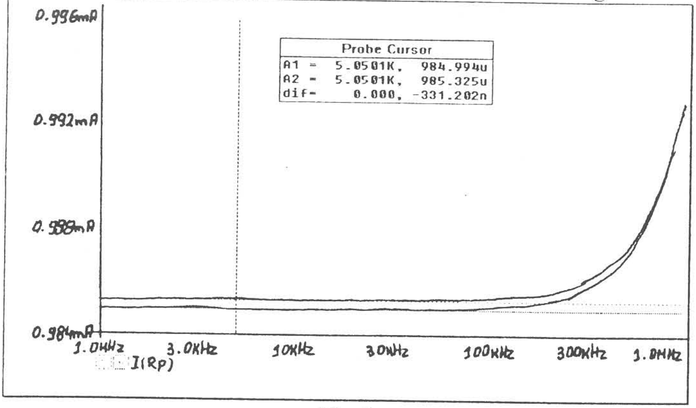


Fig.5.

Using the results from the analysis, the output circuit resistance can be obtained from the equation:

$$Z_{OI} = \frac{R_{T1}.I_1 - R_{T2}.I_2}{\Delta I} = \frac{R_{T1}.I_1 - R_{T2}.(I_1 + \Delta I)}{\Delta I}$$

where

- Z_{OI} - the output voltage to current converter resistance;
- I_1 - the current with load resistance 1kΩ;
- I_2 - the current, with load resistance 30 Ω;
- ΔI - the difference between I1 and I2 (Fig.5.).

An output resistance of nearly 3MΩ is obtained, which results in a measurement error lower than 0.03% for the maximum load resistance of 1kΩ.

As it can be seen from Fig.5, the output resistance is relatively constant in the frequency range of 1÷100kHz. Therefore, the circuit is suitable for two-frequency measurement or impedance spectroscopy monitoring of body compartmental volume changes.

Conclusions

The proposed voltage to current converter ensures high output current source impedance and high measurement signal/noise ratio. The latter is due to the possibility of passing higher but safe currents through the patient. The stability of the output impedance between 1kHz and 100kHz makes the circuit suitable for two-frequency measurements and impedance spectroscopic monitoring in this frequency range.

References

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