Abstract: Latest advances in development of current mode signal processing have made it possible to realize high resolution lock-in signal processing in lock-in instruments having operating frequency of 1 MHz or even a decade or more higher. This enables to use PC-based lock-in instruments for many biomedical experiments, including electrical bio-impedance measurements, where formerly valuable desktop equipment of great price was used to reach high level results.

INTRODUCTION

Electrical bio-impedance measurements can find much more extensive use in a lot of experiments made in biomedical research, if the frequency range would be widened towards the higher frequencies [1]. Latest advances in development of current mode signal processing have made possible to realize high resolution lock-in signal processing even in the PC-based lock-in instruments that can have operating frequency higher than 1 MHz. This enables to use simple and cheap lock-in instruments for many biomedical experiments, where formerly very expensive equipment was needed to reach the results of high quality. It has made possible to use the PC-based measurement units in impedance spectroscopy and also in impedance tomography, where operating in a wide frequency range is needed [1, 2, 3].

To measure the real and imaginary parts I and Q or modulus and phase M and θ of the electrical impedance in a wide frequency range and with high resolution of the vector components I and Q at the frequencies over 1 MHz is not an easy task. But application of the modern current mode components enables to improve substantially the high frequency behaviour of the instruments.

CURRENT MODE SIGNAL PROCESSING

The structure of a lock-in measurement unit for PC-based electrical bio-impedance measurement accomplished on the basis of current mode components, is shown as a block diagram in Figure 1.

Actually current mode signal processing has enabled to design the wide frequency range lock-in instruments more than 10 years already. The limit of 50 MHz has been reached, but only in the large size desktop instruments [4, 5].

Modern current mode components, like transconductance amplifiers, current mode amplifiers (diamond transistors), current switches, and also high speed CMOS circuits, give a possibility to create PC-card size high frequency measurement units. The current mode electronic circuits, developed for high frequency operation, can be used at the frequencies much higher than 1 MHz, only assurance of the measurement accuracy will cause serious problems.

![Block diagram of a electrical bio-impedance measurement unit](image-url)

Figure 1. Block diagram of a electrical bio-impedance measurement unit accomplished on the basis of current mode components.
SOLUTIONS AND RESULTS

Commonly the current $I_S$ is passed through the bio-object, so that it causes the voltage drop $V_i$ passing through the impedance $Z_S$ to be measured. Thus one can avoid several electrode problems. And commonly the operational amplifier based Howland current pump circuit is used to accomplish the stimulation current $I_S$ source. Unfortunately this circuit is based on the voltage amplifier having a deep feedback according to the output current, and thus can not be used successfully even at the frequencies below the 1 MHz. This problem is solved by using the current-to-current converter CCC to convert the signal $S_F$ into the stimulation current $I_S$.

To generate the sine wave excitation signal $S_F$ for a multifrequency measurement commonly a digital synthesis is used. Using direct digital waveform synthesis of the excitation signal by means of binary D/A converters, the frequency range up to 1 MHz or higher can not be easily achieved, because the well defined phase relationships are needed for complex impedance measurements [6, 7].

The receiving part of the measurement unit has the controllable gain voltage-to-current converter VCC at the input. The output current $I_{AMP}$ of the VCC is detected by means of synchronously operating n-MOS induced channel current switches, providing less than 5 ns switching time that is short enough for operating frequencies up to 10 MHz. Detected currents are converted into the output current $I_{DB}$ by the differential-input (subtracting) current-to-current converter CCC, that is lead through the low-pass filter LPF, where the slew rate of the response signal $U_{SN}$ is reduced to be low enough for handling by the voltage mode analog-to-digital converter, like the 16 bit AD7715 sigma-delta ADC.

So, using of the current mode analogue signal processing techniques, combined with the digital postprocessing in PC, has made it possible to widen the operating frequency range of the electrical bio-impedance measurement instrument up to 10 MHz, and the input dynamic range up to 20 bits.

DISCUSSION

Due to linearity of the current mode circuits, like the Burr-Brown OPA660 current mode amplifiers, the input dynamic range achieved can be far wider than 16 bits, about 20 effective bits or even more. To get equivalent results in the case of direct digitizing of the input signal $V_{in}$ the sampling rate must exceed 20 MHz to cover the frequency range up to 10 MHz. This is not the state-of-the-art today.

But the situation has changed after the synchronous (lock-in) detection of the signal has been done, because the conversion is accompanied by some smoothing. Though the time constant $T = RC$ of this smoothing LPF is relatively small, the sampling rate of the order of 10 kHz can be used. Of course, the switching synchronous detection itself also causes very rapid changes of the current $I_{SN}$ at the moments of switching. But after passing the LPF all these stepwise changes are turned into slopes having a limited slew rate.

CONCLUSION

The improved results have been achieved thanks to reasonable use of current mode techniques, and thanks to availability of the modern current mode components, applied as the basic elements in all the circuits, where the high impedance current output and low impedance current input are needed.

Taking advantage of the current mode analogue signal processing techniques, combined with the digital postprocessing in a PC, has made it possible to widen the operating frequency range of the electrical bio-impedance measurement instrument up to 10 MHz, and to increase the input dynamic range up to 20 bits. These features have not been still achievable simultaneously in the fully digital or fully analogue instruments.

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REFERENCES