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THE CALIBRATION OF A BIOELECTRICAL IMPEDANCE SPECTROSCOPY DEVICE

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ABSTRACT

A Calibration is one of the key processes to design and implement of Bioelectrical Impedance Spectroscopy. Through the simulation, the specification of hardware can be determined and examined in the ideal condition. After the implementation of the device, the theoretical and measured values are different due to the uncertainties and noises from the environment. In this paper, the calibration procedure will be introduced and discussed for the different sets of electrodes. By adjusting the different values of the active electrodes and applying for the active shields, the measured value will be compared and discussed. Active electrodes and active shields will be a very effective way to isolate and minimize the noises and avoid unwanted stray capacitance values. Further investigations need to be followed to ensure the proposed way to reduce the noises and stray capacitances.
Keywords: Bioelectrical Impedance Spectroscopy, Calibration, and Compensation, Active Electrode.

INTRODUCTION

Bioelectrical Impedance Spectroscopy (BIS) is the most advanced method which can accurately measure the impedance values for the different range of frequencies [1]. The relatively large number of frequencies are introduced and filtered out the outliers to overcome the possible errors and increase the accuracy of the measurement [2]. The measuring range of impedances is usually from 10 to 1500 ohms and the range of frequencies starts from 3 or 4 kHz to 500 kHz or 1Mhz. Less than 3KHz or more than 1MHz will come up with small phase angles and it will be very difficult to acquire the exact values without the software compensation [3]. The accurate sinusoidal signal need to be supplied into the current pump. For the accuracy and safety features, Voltage Controlled Current Source circuits (VCCS) are preferred for the current pump [4,5]. The maximum current of the controlled device will be limited to the magnitude of the sinusoidal input function. The controlled current is usually between 100 to 300 μA for the commercially available BIS devices. After the implementation of the BIS device, a calibration for the different load (10 to 1000 ohms) for the range of the frequency (3 kHz to 1 MHz) will show the functionality of the device. Through the hardware correction, the device needs to be tuned for maximum accuracy. Software compensation can cover up the rest of the errors.

METHODS

The length of the signal line between the electrode and the device itself is 1 meter each. An active electrode is placed and it is connected with an electrode [6]. The active electrode is a kind of buffer, which can efficiently transmit the voltage measured through the electrode to minimize the unwanted noises [7]. The line between the active electrode and the device is connected and the active shield technology has been applied for the best performances.

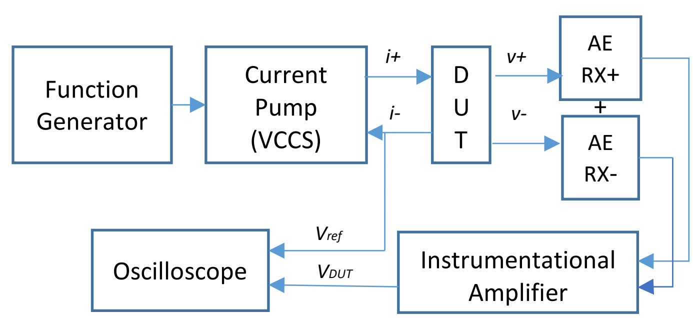

Figure 1 The schematic diagram of Bioelectrical Impedance Spectroscopy Device

Figure 1 shows the schematic diagram of the Bioelectrical Impedance Spectroscopy device. One meter long cable is placed between DUT and VCCS. The active electrode and

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instrumentational amplifier are also connected by one-meter shield cable. Figure 2 shows the printed circuit board of VCCS, and the instrumentational amplifier. Two active electrodes are placed and the active shield circuit is also in the small printed circuit board.

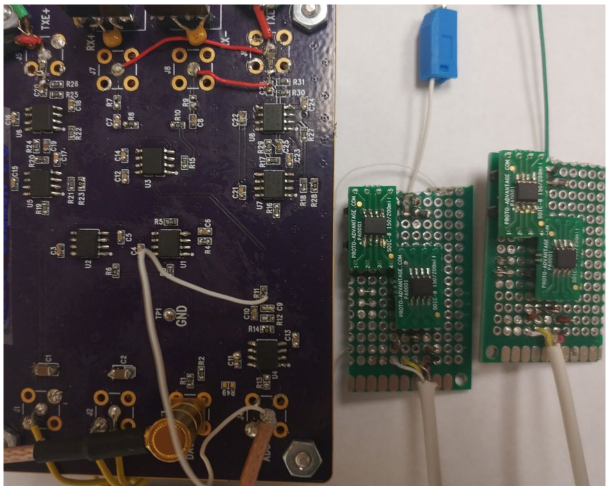

Figure 2 PCB board of Bioelectrical Impedance Spectroscopy Device and Active electrodes

Nine resistance values are connected at DUT terminal and ten different frequencies have been applied. The voltage of DUT and the reference resistor connected right after VCCS i+ and i- terminals are measured through the output of the instrumentational amplifier.

For the design of the active electrode, a low pass filter and feedback resistor and capacitor are tested in four different cases. In general, the active electrode is comprised of a buffer circuit and its feedback path is venerable for the inside or outside noises. Once noises are into the feedback path, the output of the buffer becomes oscillating and the measurement values are incorrect. In this study, four pre-determined cases are tested and the results will be compared for the maximum performances.

RESULTS

Since the phase angle is the main factor that can alter the signal, figure 3 shows the frequency versus phase angles of nine different resistance values. Obviously, a large value of resistance and frequency can alter more phase angles. The linear trend is stronger at the high frequency throughout the resistance values. Additional measurement was performed at the frequency range of 3 to 50 kHz due to the evaluation of the linearity of the output. This frequency range covers almost half of the Cole-Cole curve for BIS measurement and the detailed evaluation is very crucial for the accuracy of the measurement. From figure 3, linear trend can be easily compensated using software algorithm with desirable accuracy.

Figure 4 shows the changes of phase angles throughout the frequency of 100 to 1000 kHz. Four different sets up of the active electrodes were tested. The combination of a low pass filter with the placement of 20 pF at the feedback loop of the buffer showed the largest change of the phase angle, however, the linearity is slightly above the case of a low pass filter with 10 pF.

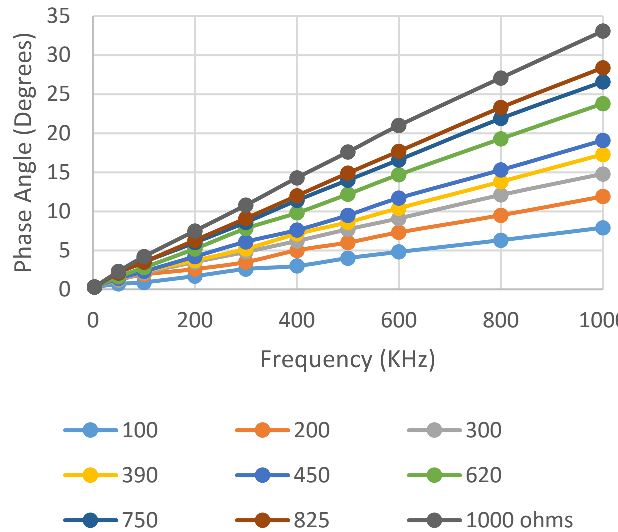

Figure 3. Frequency versus Phase Angle for the Device Under Test. The Range of Device is from 100 TO 1000 Ohms.

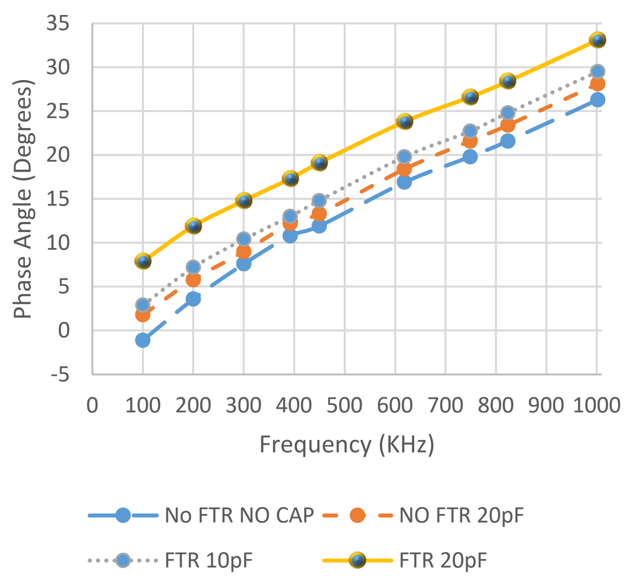

Figure 4. Frequency versus Phase Angle of Four Different Active Electrode Set up (a combination of with/without low pass filter and capacitors)

From figure 4, displaying more linearity means it will be more easy and accurate to perform the compensation using the software. It will also save the computational power in case of using the embedded micro-processor based platform.

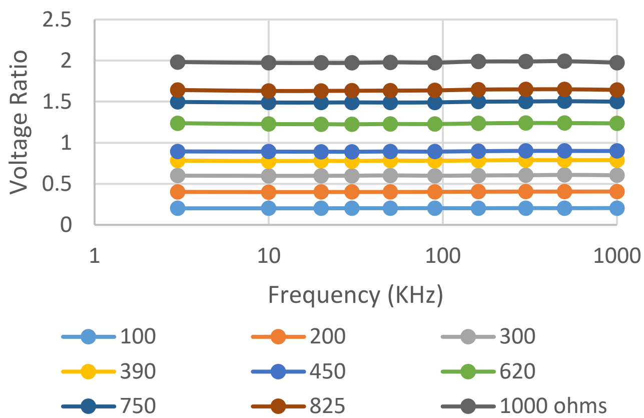

Figure 5. The Voltage Ratio between Device Under Test and The Reference Resistor.

Figure 5 shows the voltage ratio between the DUT and the reference resistor (475 ohms). The linear trend is very obvious for the low value of the DUT and the distortion of the voltage ratio is high for the large value of DUT. Also, regardless of the DUT values, the high frequency shows more distortion and the voltage ratio reduces at the high frequency.

INTERPRETATIONS

The measurement of the difference of the phase angle between the reference resistor and DUT determines the accuracy of the BIS measurement. A small change of the phase angle results in a large deviation in the Cole-Cole curve. Especially at the low frequency, the noises from a DC power supply with unstable ground conditions will affect the phase angle of DUT and the output will become highly unstable. A spectrum analyzer can display the unwanted frequency oscillation and intermodulation. The oscillation will make the current unstable and it has to be avoided by using the clean source of a power supply with a proper ground.

Another source of the oscillation factor can be located in the active electrode. The active electrode uses a feedback loop for the buffer and the oscillation can happen if the feedback loop is agitated by the external noises. Once the buffer in the active electrode is in oscillation, excessive power consumption can happen and the system needs to be shut down to kill the oscillation. The placement of a resistor and a capacitor can avoid the oscillation and figure 4 shows the combination of the different combinations of a low pass filter and a capacitor in the feedback loop. A low pass filter can take care of noises and unwanted DC offset which makes distortions to the instrumentational amplifier. The active shield is one of the key components to avoid external noises [8]. Both outputs (i+ and i-) from the current pump are passed through the reference resistors and the clean signal is essential to increase the accuracy of the magnitude and phase angle. The active shield around the current outputs is a very effective way to reduce the noise. If the signal ground is applied as the shielded source around the current outputs, it will slightly diminish the magnitude of the constant current output. The active shield for the active electrode side of the cable is also crucial to block the noises and transmit the clearly measured voltage to the instrumentational amplifier. Due to the power sources for the op-amp used in the active electrode, the multiple cables (±5V or ±12V, GND, and output from the active electrode) need to be placed from the body of the BIS device to the active electrodes. The placement of the coupling capacitors is necessary and the long ground line can also cause the low-frequency oscillation which can turn out the intermodulation or corssmodulaiton to the BIS system. The low gain setting of the instrumentational amplifier can be helpful to minimize the chance of the oscillation mentioned above, but the original sources of the oscillations need to be secured first.

The distortion of the magnitude and phase at the high frequency is the natural phenomenon for VCCS current pump system and even a simulation shows the decrement of the magnitudes and phases at the high frequency near 1MHz. If the distortion displays the linear trend, it will be beneficial for software compensation. A linear compensation will save the computational power and the memory space, especially for the embedded system. Also, an interpolation between DUT needs to be calculated to cover all range of resistance values and linear outputs will make the interpolation easy and exact. For the software compensation, the magnitude compensation has to be taken first by using the previously measured data. After the magnitude compensation, the phase angle compensation needs to be followed by using the measured data such as Figure 3. For the human body measurement of BIS, Cole-Cole curve shows the hookup effect in which the high-frequency components of resistance and reactance values go higher due to the stray capacitances of a human body [9]. The hookup effect can be compensated by multiplying the equation and R_0 and R_∞ can be interpolated by applying a circular fit.

CONCLUSION

The BIS system has been implemented and the calibration for the magnitude and the phase angle have been performed. For the different range of resistances (100- 1000 ohms), the output voltages are linear and it made software compensation easier. For the magnitude ratio between the reference and DUT resistors, the results show strong linearity. The minimum use of filters and active components make the signal path of measurement optimal and the active shields around output cables of the current and the receiving cables blocked the possible noises for the linear outputs. For future works, a more adaptive design of the active electrodes can increase the linearity and accuracy of the measurement.

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