Realtime Measurement of Impedance Locus using Impedance Spectroscopy: How Many and How Low Frequencies Are Required ?

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ABSTRACT

High temporal-resolution and accurate measurement of skin impedance locus provides useful data for the identification of the physiological/psychological changes and also the identification of acupuncture point. An impedance spectroscopy method using digitally constructed current waveform consisting of many frequency components (multiples of 1Hz) was reported[3]. The time resolution of the method depends on the lowest frequency used in the waveform construction, and therefore, the measurement would be faster if the lowest frequency is the higher. However, it was not clear that how many and how low frequencies must be used for the estimation of the skin impedance parameters from which the impedance locus can be drawn. This study shows the relationship between the estimation error of the impedance parameters and the frequency coverage of the spectroscopy. The results of this study are expected to serve as the reference of the frequency selection in the impedance spectroscopy.

Key Words : Skin impedance (피부 임피던스), Spectroscopy (주파수영역 계측법), Constant Current (정전류), Impedance parameter (임피던스 특성치)

1. Introduction

High temporal-resolution and accurate measurement of skin impedance locus is essential for the identification of the phasic change due to electrodermal activity elicited by stress, acupuncture, emotional activity, sound, etc. The impedance locus also can be used in the localization of low impedance points e.g. acupuncture points.

DC square wave method[1] and AC current method[2,3] have been used for the measurement of skin impedance locus. Though the DC square wave method has good temporal resolution, it has poor accuracy at high frequencies because the high frequency components in the DC square is fundamentally small and can be degraded by the noise. In the AC current method, sequential application of current with several frequencies[2] or a digitally constructed current waveform consisting of many frequency components[3] was applied to the electrodes and the voltage was analyzed to derive the skin impedance.

Generally the AC current method has advantage of better accuracy of the impedance values at high frequencies because it can derive the impedance value for a specific frequency by adding the certain frequency in the applied current. However, the temporal resolution of the AC method is determined by the lowest frequency used in the applying current. Therefore, to improve the temporal resolution, it is desirable not to include low frequencies in the current.

If we can calculate the impedance parameters that feature the impedance locus of Fig. 1, the impedance value at any frequency can be calculated easily so that it is needless to measure the impedance at many frequencies. Yamamoto et al.[2] fully made use of this fact and estimated the impedance parameters from the 3 impedance values. Searl and Kirkup[3], on the other hand, used 30 frequencies evenly distributed in the impedance locus in terms of the phase angle.

The frequency distribution on the impedance locus is significantly depends on the measured object and the type and state of the electrode, and therefore, it is difficult to

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determine the needed frequency component to estimate the impedance parameters with acceptable accuracy. The motivation of this study is "How many and how low frequencies are required to estimate the impedance parameters well ?". As the first step for the solution of this question, we investigated the relationship between the estimation error of the impedance parameters and the frequency coverage through experiment with several RC network models.

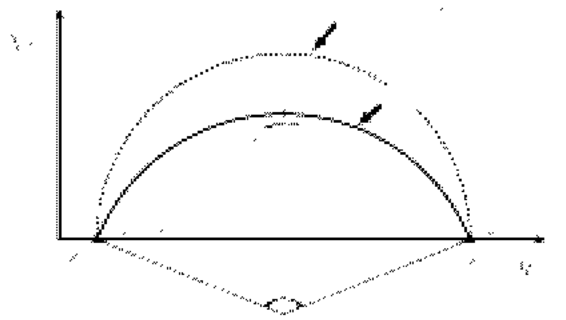

Fig. 1 General impedance locus and corresponding impedance parameters Z_0, τ_m, β

2. Methods

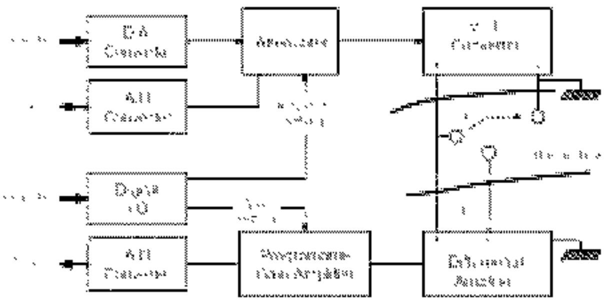

Fig. 2 Experimental setup

The experimental setup for the measurement of the skin impedance is shown in Fig. 2. Three-electrodes method was used that applies constant current and the voltage is measured. The current is constructed from multiple frequency components with the same intensity $|I_n|$ to guarantee the same S/N ratio for all the frequencies used. The applied current and the measured voltage can be described as equation (1). The skin impedance including the electrode-skin interface of one side is calculated from equation (2). One important fact is the spectral leakage can be avoided by using the frequency ω_n as the multiple of the lowest frequency and the windowing operation is not required. Therefore, we included only the multiples of the lowest frequency in the applied current.

[illegible] (1)

$$Z(j\omega_n) = V(j\omega_n) / I(j\omega_n) \quad (2)$$

The impedance locus follows the Cole-Cole's law[4] of equation (3). The impedance parameters Z_0, τ_m, β, which are the DC resistance, the time constant of medium frequency, and the distribution of τ_m, were derived through minimization of the measured impedance from experiment and calculated impedance from equation (3) values using the Levenberg-Marquardt method. The inefficiency of parameter estimation, i.e. the error between the actual and estimated impedance parameters, was calculated by eq (3), where N is the number of measurement and was set to 100 times.

$$Z(j\omega) = \frac{Z_0}{1 + (j\omega\tau_m)^{\beta}} \quad (3)$$

$$E = \sqrt{\frac{1}{N}\sum_{i}^{N}\left|1 - \frac{p_e}{p_t}\right|} \quad (4)$$

Finally, to see the effect of frequency coverage on the parameter estimation error of eq. (4), we designed an experiment with RC parallel networks as a representation of the skin-electrode impedance. The test values for the RC networks are shown at Table 1. The frequencies included in the construction of current in equation (1) were 5, 10, 15, 20, 25,…, 195, 200, 250, 300, … , 500Hz. The impedance parameters and the corresponding error of eq. (4) were calculated for all the instances as we exclude one impedance value at a time. The exclusion started from the impedance of lower frequencies, because the lowest frequency determines the temporal-resolution. The degree of exclusion was described by the phase angle of the currently excluded impedance value.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 1. Test RC values and impedance parameters

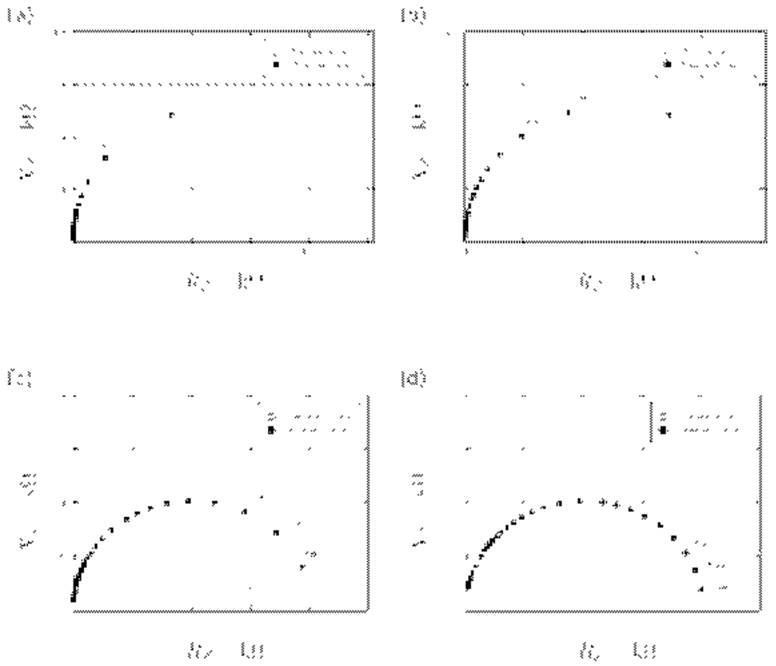

Fig. 3 Impedance locus for the circuit 1 (a), circuit 2 (b), circuit 3 (c) and circuit 4 (d)

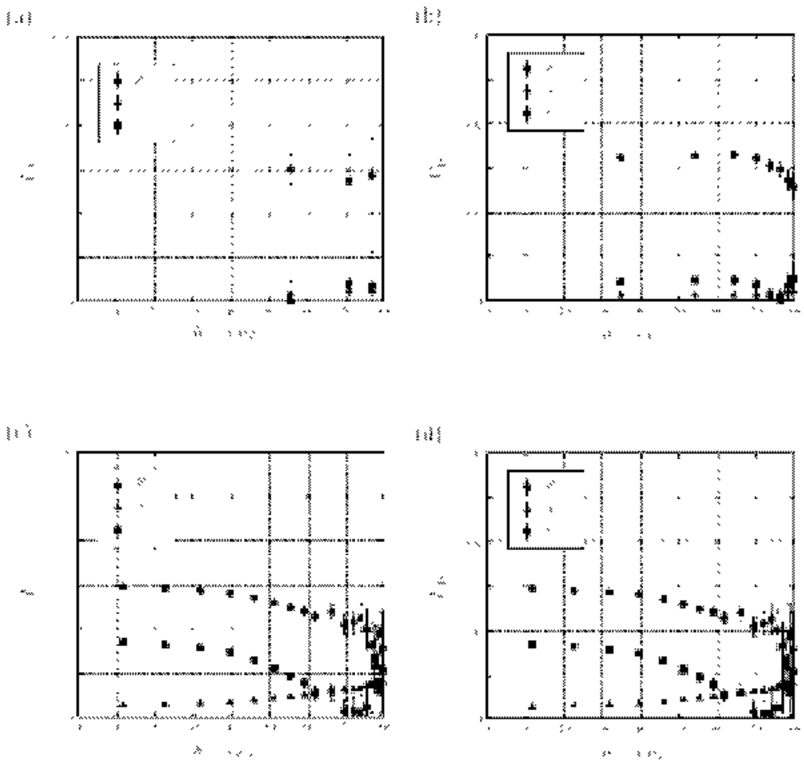

Fig. 4 Relationship between the parameter estimation error – the phase angle of the lowest frequency included in the current in the circuit 1 (a), circuit 2 (b), circuit 3 (c) and circuit 4 (d)

3. Results

Fig. 3 shows the impedance values measured at the circuit model 1~4 when all the pre-specified frequency components are included in the current waveform. As is obvious from the electronics, the circuit models with smaller RC values (c~d) had better distribution of impedance values for the applied frequencies.

The relationship between the parameter estimation error and the frequency coverage is shown in Fig. 4. Error less than 2% is guaranteed for all the circuit models when the included highest frequency components covers 80~90 deg phase angle of the impedance locus.

This result shows that the impedance parameters can be fairly well estimated only with relatively high frequencies, in which case the temporal-resolution can be greatly increased.

This study showed the possibility of impedance parameter estimation with few experimental impedance values in relatively low skin-electrode impedance model (R=203~517k**Ω**, C=14~89nF). A further study with greater value impedance model is planned in the future.

4. Conclusion

The relationship between the impedance parameter estimation error and the frequency coverage is investigated. It was shown that the impedance parameters could be fairly well estimated only with relatively high frequencies, in which case the temporal-resolution can be greatly increased.

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