# Instantaneous measurement of electrical parameters in a palm during electrodermal activity

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# Instantaneous Measurement of Electrical Parameters in Palm During Electrodermal Activity

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*Abstract* – *The determination of impedance is performed by means of the frequency domain analysis or the time domain analysis. The latter has an advantage of being able to measure instantaneously the whole frequency characteristics of impedance. The method is hence powerful to obtain the biological impedance which changes with time. An instantaneous measuring method by using the time domain analysis has been then developed. Fast Fourier Transformation(FFT) of indicial response for current to the skin can determine the palm impedance. This method can carry out the determination of the parameters of the palm skin impedance during a galvanic skin reflex(GSR), which is impossible by means of the frequency domain analysis.*

## I. Introduction

The determination of impedance is performed by means of the frequency domain analysis or the time domain analysis. In the frequency domain analysis, since measurements are carried out with changing a frequency, it is difficult to obtain the whole frequency characteristics of impedance in an instant. In particular, skin impedance, which varies every moment, makes a restriction in measurement, and frequency characteristics of the skin impedance during a phasic electrodermal activity are very hard to determine[1].

By contrast, the time domain analysis has an advantage of being able to determine instantaneously the whole frequency characteristics of impedance[2]. This method which determines the impedance with the transient response for current to the skin can follow the rapid impedance variations. We next consider GSR(galvanic skin reflex) which is a transient variation of electrodermal activity. Since GSR is an attractive phenomenon which is connected with many kinds of external stimuli, researches into the phenomenon has been carried out in many fields. However, the variation of the frequency characteristics for the skin impedance during a GSR did not complete entirely satisfactory measurement. We have therefore developed a transient response measurement system which can determine impedance instantaneously by using the time domain analysis. This paper describes the complete measurement system, and investigates the problem relating to linearity of skin in its application. An example which the variation of the skin impedance during a GSR is presented.

## II. Materials and Methods

### A. Principle of Determining Impedance

Suppose that skin is a linear system, Fourier transformation of the current applied to the skin $i(t)$ and its voltage response $v(t)$ shown in Fig.1 are $I(j\omega)$ and $V(j\omega)$, respectively. Then the skin impedance $Z(j\omega)$ is expressed by the following equation:

$$Z(j\omega) = \frac{V(j\omega)}{I(j\omega)}. \quad (1)$$

When the current is unit impulse $\delta(t)$,

$$I(j\omega) = 1 \quad (2)$$

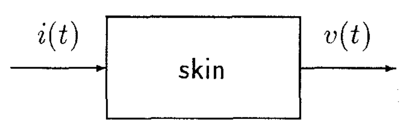


Fig. 1. Relationship between current $i(t)$ and voltage $v(t)$ of the skin.

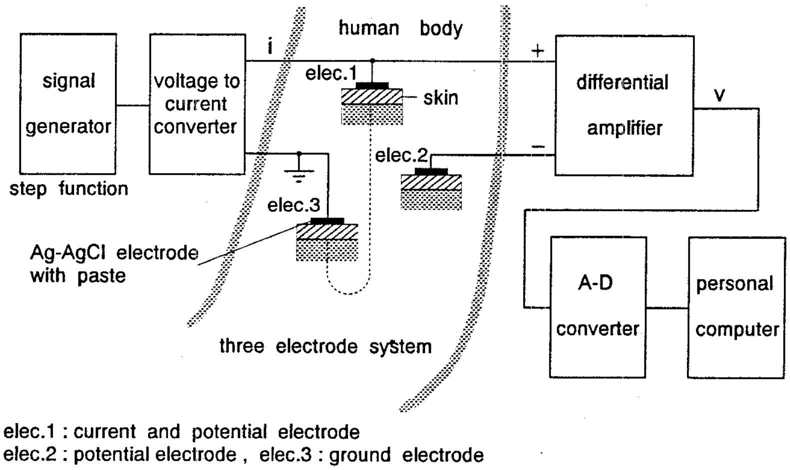


Fig. 2. Block diagram of measurement of electrical parameters in palm skin.

and $v(t)$ is equal to an impulse response $h(t)$. Hence, the skin impedance $Z(j\omega)$ can be determined by performing the Fourier transformation of the impulse response as following equation:

$$Z(j\omega) = \int_0^{\infty} h(t) e^{-j\omega t} dt. \quad (3)$$

Using the discrete style, we can obtain the impedance as follows:

$$Z(j2\pi n\Delta f) = \Delta t \sum_{m=0}^{N-1} h(m\Delta t) e^{-j2\pi \frac{nm}{N}} \quad (4)$$

where $\Delta t$ = sampling time, $N$ = data points and $\Delta f = 1/(N\Delta t)$.

However, it is difficult to generate an impulse signal and then obtain the impulse response. Consequently, we measured an indicial response since the impulse response $h(t)$ can be expressed by using the indicial response $A(t)$, which is easily measured, as follows:

$$h(t) = \frac{dA(t)}{dt}. \quad (5)$$

### *B. Measurement System*

Fig.2 is a block diagram of the complete system of measuring the transient response. The output step voltage from the generator is converted into a current of the same phase angle and waveform by a voltage to current converter, and this current flows through the skin via electrode 1 and 3. The voltage drop, which is a indicial response, of impedance of skin under the electrode 1 is amplified by a differential amplifier. The response waveform which is quantized by A/D converter is inputted to a personal computer. The sampling interval is 50 $\mu$s or 200 $\mu$s. The data are saved in a floppy disk and analyzed by a personal computer after measurement. The sequence of the analysis by the computer are as follows : •(1) 512 sampling points are picked up from quantized response waveform in floppy disk. Those data are differentiated numerically. The numerical difference method is central differences. Those data are treated as impulse response. •(2) The impulse responses are calculated by means of Fast Fourier Transformation (FFT). The impedance of skin is determined. •(3) The parameters of Cole-Cole arc are calculated using determining impedance.

We adopted a three-electrode technique as an electrode system. An Ag-AgCl electrode (Skin surface electrode, Nihon Kohden Co.Ltd, Japan), which is an unpolarizable electrode, 10mm in diameter, was used. The electrode paste was redux cream (Electrode electrolyte, Hewlett Packard, U.S.A)

## III. Results and Discussions

### *A. Nonlinear Electrical Property of the Skin*

In transient response, the object must be a linear system. We therefore need to investigate the linearity of the skin impedance, which essentially has a nonlinear system.

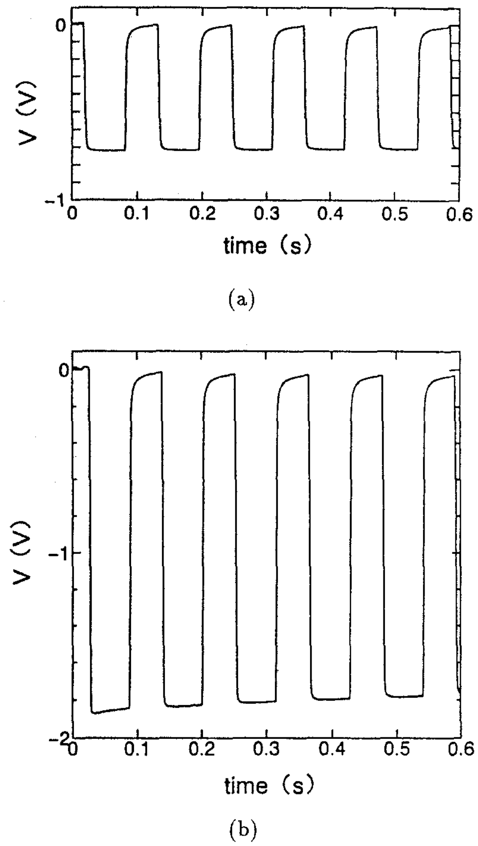


Fig. 3. Waveforms of repetitive indicial responses. (a) I = $-10\mu A/cm^2$; (b) I = $-50\mu A/cm^2$

The linearity of the skin impedance in indicial response depends on flow current. Fig.3 shows the waveform of indicial response, when the rectangular current continuously flows to skin. The period is 1 s. The flowing period is 0.5 s. When current density is $-10$ $\mu A/cm^2$ as shown Fig.3(a), peak-to-peak values are constant. The potential level (SPL) in the repetitive response do not change before and after flow. On the other hands, when flow current density is $-50$ $\mu A/cm^2$ as shown Fig.3(b), The potential level of the repetitive response becomes gradually smaller. The skin impedance is not influenced by the countinous flow current $-10$ $\mu A/cm^2$. Steady waveforms of indicial responses can be sufficiently obtained during several seconds of GSR appearance.

Fig.4(a) shows indicial response of skin impedance on forearm using several kinds of current values. There is a linear relationship between flow current and voltage of response when the current is smaller than $-10$ $\mu A/cm^2$.

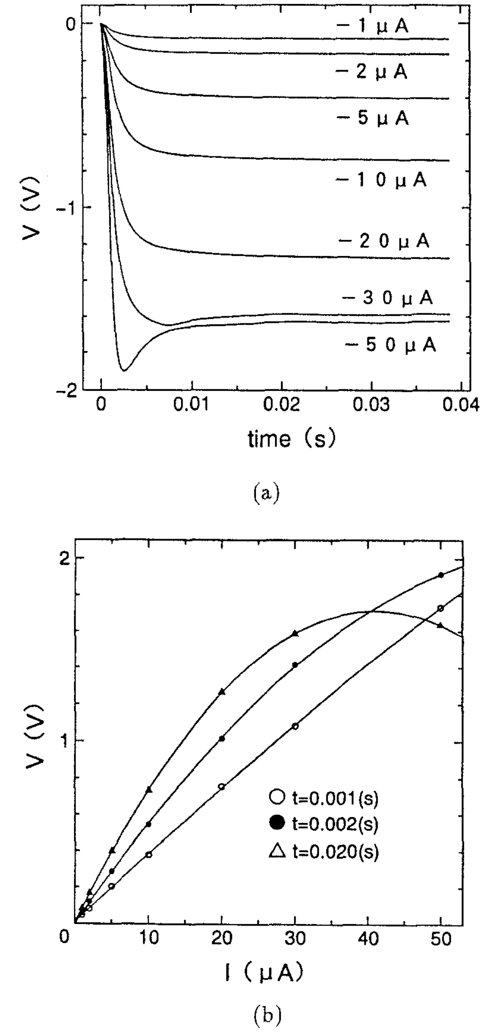


Fig. 4. Nonlinearity of indicial response of the skin. (a) responses for various current values; (b) linearity of response

The linear relationship disappears in current of larger value. Fig.4(b) shows the relationship between flow currents and voltages which are the values at the time t = 0.001s, 0.002s, 0.020s in each waveform of respose of Fig. 4(a). If skin impedance has a linear system, there is a linear relationship between current and voltage using a parameter of time t. We accordingly find there is a linearity at $-10$ $\mu A/cm^2$ and the nonlinearity appears above $-20$ $\mu A/cm^2$. Skin impedance is greatly influenced by measurement conditions. The current of small value should not be used in order to avoid the influences caused by noize from the standpoint of measurement. Then appropriate current value also changes in every cases.

*B. Accuracy of the Measurement Method*

In order to investigate the accuracy of impedance measurement by a transient response method, RC parallel circuit is measured. It is well known that equivalent elctrical model of simple RC parallel circuit approximately represents electrical characteristics. Considering the property of real skin impedance, the value of circuit elements were given as 50 kΩ resistance and 0.022 $\mu$F capacitance. The indicial response of this model circuit by flow current $-10$ $\mu$A/cm$^2$ was recorded. Sampling interval $\Delta$t is 50 $\mu$A, sampling number is 512. The impedance was determined the method as previously stated. Fig.5 shows vector loci of theoretial values and measured values by transient response method. The vector locus of measured value is well similar to that of the theoretial values. It shows arc locus of perfect semi-circle. The determination of impedance means the determination of arc locus. The measured value has some dispersion differences in frequency range above 1 kHz. It is not serious problem because differences in high frequency range do not influence to the determination of arc locus. It is difficult to obtain accurate value in the area of high frequency by calculating FFT. But considering following two points : measured frequency points from 0 Hz to 400 Hz plot about 3/4 arc and the vector locus of skin impedance pass the origin, the arc locus can be determined accurately in measurement conditions with a little errors in that frequency range. The results of the measurement tell us that the relative error of measured value to theoretical value is less than 2 %. The accuracy is enough to measure impedance.

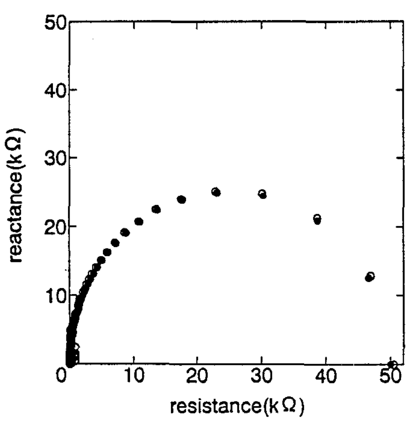


Fig. 5. Measurement result of equivalent circuit. o : measured value; • : theoretical value; $\Delta$f = 39.1Hz

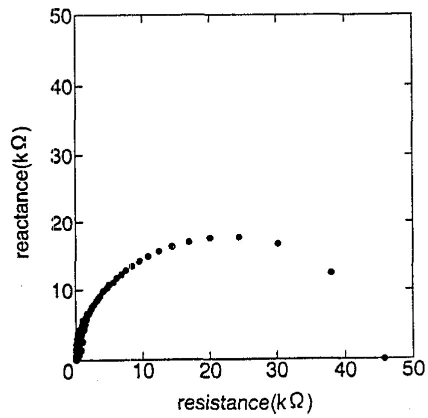


Fig. 6. Skin impedance on the palm site.

Fig.6 shows the results of the measurement of skin impedance. The flow current is $-10$ $\mu$A/cm$^2$, indicial response is measured with 50 $\mu$s sampling interval and 512 sampling point. Although there are differences in high frequency range compared with in low frequency range, the arc locus can be determined.

*C. Determination of the impedance during a GSR*

GSR is a phenomenon which the electrical property of skin varies instantaneously. The duration time of variations is for 3–5 s. Hence it is difficult to obtain the change of the frequency characteristics of impedance by a frequency domain analysis. On the other hand, impedance can be measured by a transient response method. Impedance during GSRs appearance is analyzed by that.

Fig.7 shows changes of impedance during GSRs appearance. The time elapses are in order $t_1, t_2, t_3, t_4$. Indicial responses are measured with 200 $\mu$s sampling interval and 512 sampling points. The arc locus changes with passage of time. The property of skin impedance is presented using parameters of Cole-Cole arc ($Z_0$ : impedance value at frequency 0 Hz, $f_m$ : frequency which shows reactance maximum, $\beta$ : coefficient of arc's angle). Those parameters are calculated using each arc. We find that $\beta$, which is about 0.86, hardly changes. The skin impedance during GSRs appearance, which has been made a guess with insufficient results of measurement, is confirmed using transient response methods.

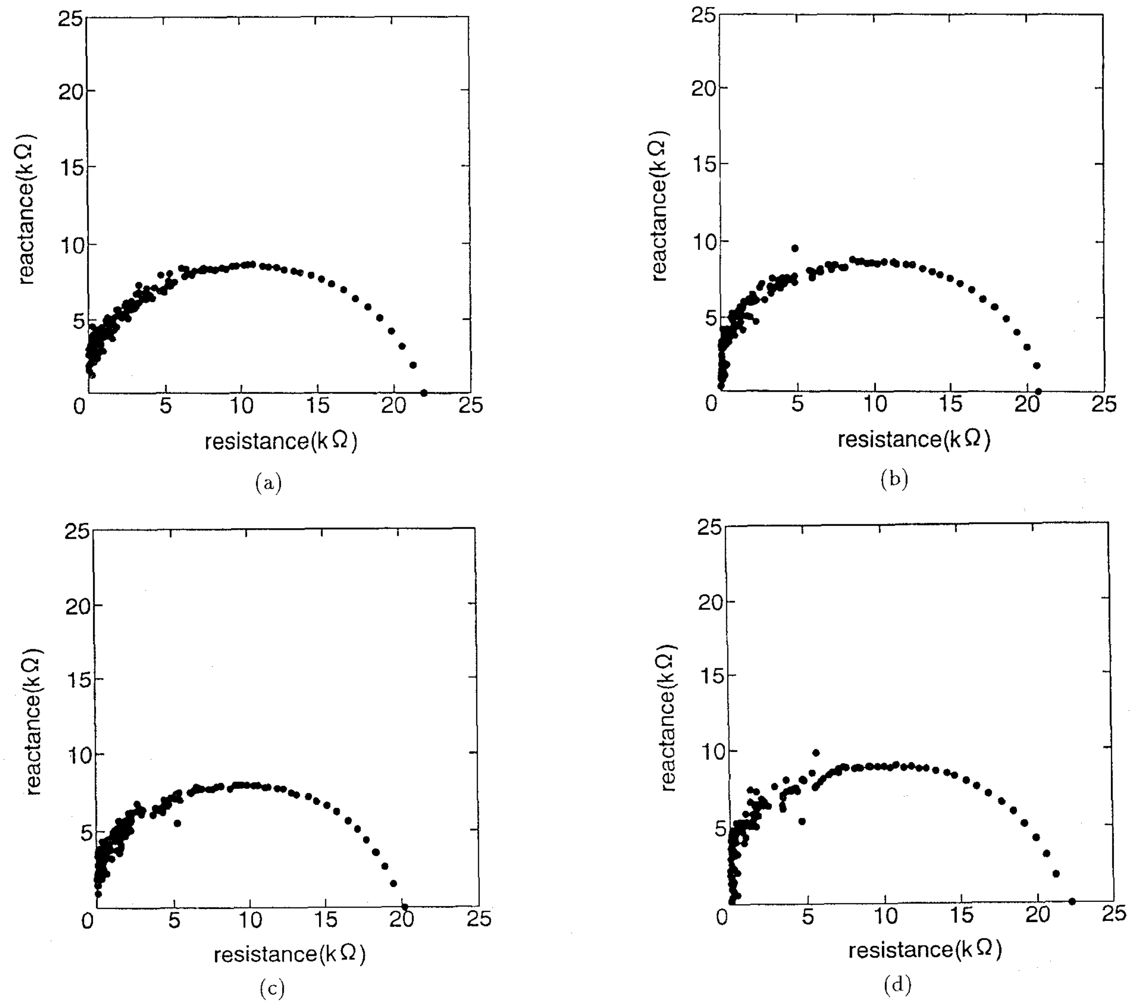


Fig. 7. Impedance during a GSR. (a) $t_1$; (b) $t_2$; (c) $t_3$; (d) $t_4$

## IV. Conclusion

A new method determining instantaneously the impedance which changes trasiently with time has been developed. The total frequency characteristics of skin impedance is determined using time domain analysis. The method has an advantage of instantaneous determination of impedance compared with conventional methods using frequency domain analysis. The skin impedance during GSRs appearance, which is difficult to measure using a conventional frequency domain analysis, can be determined using time domain analysis.

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