ELECTRICAL PROPERTIES OF THE SKIN FOR AC VOLTAGES OF VARYING FREQUENCY

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ABSTRACT

The resistivity of human skin depends on the layer within which it is measured. The DC characteristics are fairly well known; here, an experiment that measures the transport of AC signals through the skin is described.

Human skin resistivity

Human skin has three major layers whose electrical properties vary. Any electrical current applied to the skin is transported by charged water-soluble molecules contained in the skin. What is important here is the resistivity, measured in ohm-meters. The range of resistivity of the skin layers is shown in Fig. 1.

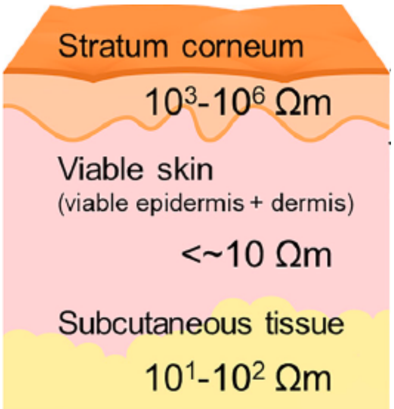

Figure 1. The resistivity of human skin layers. [Abstracted from the Review Article by Abe and Nishizawa.] The thickness of the stratum corneum is about 20 μm and of the viable skin about 1.2 mm.

As pointed out by Abe and Nishizawa,[1] the skin has a dielectric property. For alternating current measured on the skin surface, its resistivity is high at low frequencies and decreases at high frequency due to its capacitive characteristics. The magnitude of the low frequency resistivity of the stratum corneum has been estimated to be 10^3–10^6 Ωm.

The experiment described here is to determine the alternating current conductivity at frequencies from 1Hz to 1.5 MHz.

[1] Y. Abe and M. Nishizawa, "Electrical aspects of skin as a pathway to engineering skin devices", *APL Bioeng* **5**, 041509 (2021). This review paper has an extensive list of references covering the literature.

Experimental Configuration

The experiment involved a sitting figure with the output of a signal generator applied to the left wrist and the voltage measured at the right index finger and the right ankle. Only the output of the generator was applied to the subject and its ground was not applied. The signal was then measured with a Tektronix oscilloscope with an input impedance of 1 MΩ paralleled by 20 pF and the grounds of the signal generator and oscilloscope connected. The input to the oscilloscope was set to DC. The experimental setup is shown in Figure 2. Note that the figure in the figure was not an actual person or subject in the experiment. The actual subject was the author of this paper.

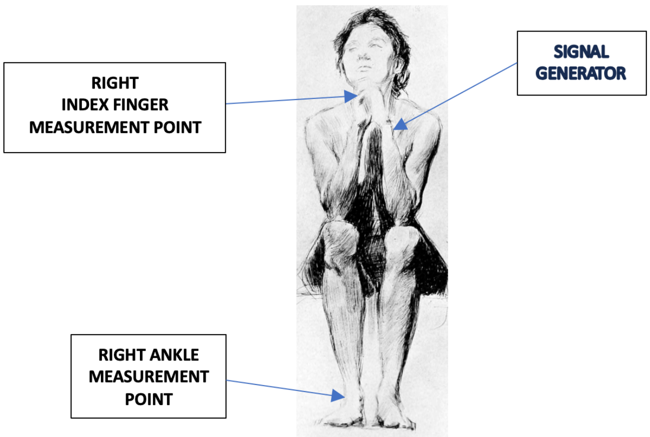

Figure 2. The experimental configuration showing the application point of the output of the signal generator to the left wrist and the two measurement points on the figure (not an actual person who participated in the experiment).

To be clear, the complete circuit is the signal from the signal generator connected to the subject via the left wrist and exiting from one of the measurement points, passing into the probe of the oscilloscope. The ground of the oscilloscope is connected to the ground of the signal generator.

The shape of the AC signal from the signal generator is shown in Fig. 3.

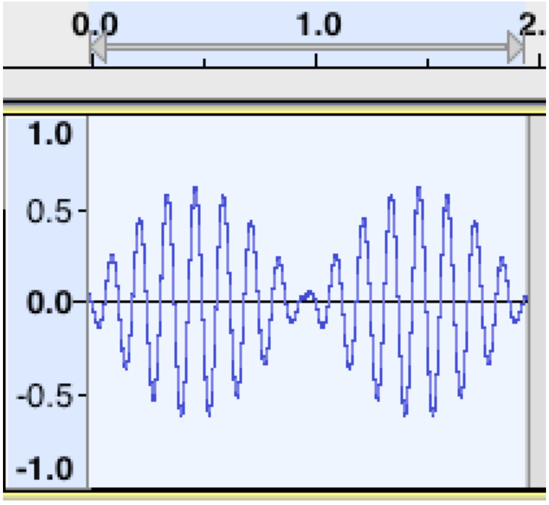

Figure 3. Output of the signal generator. The upper scale is in seconds and vertical scale is notional. The maximum magnitude of the peak-to-peak AC voltage used in the experiment is ~20 V. Two full cycles of the signal are shown. Here the frequency of the signal generator was set to 1 Hz, which–as can be seen–corresponds to a period of one second. The higher frequency wave within each cycle has a frequency of 8 Hz, or a period of 0.28 s.

The spectrum of the signal shown in Fig. 3 can be seen in Fig. 4. The 8Hz peak in the spectrum corresponds to the higher frequency component of the signal and has a period of 0.28 s.

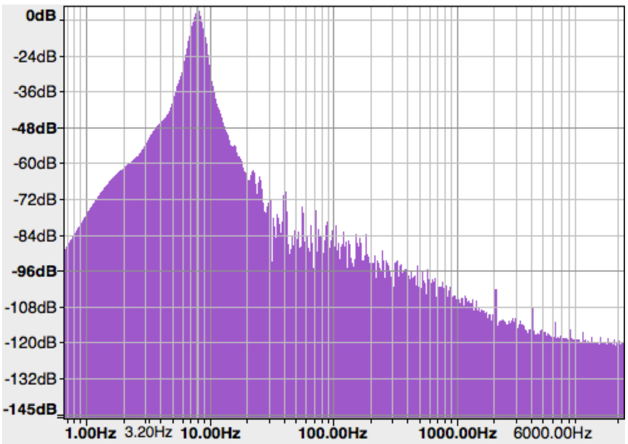

Figure 4. The spectrogram of the signal shown in Fig. 3. The peak of the spectrum at 8 Hz clearly stands out.

Results

An EKG monitoring electrode with foam tape and sticky gel was used to connect the output from the FeelTech FY3200S signal generator to the skin. This signal generator has an output impedance of 50 Ω.

The complete circuit for the experiment is shown in Fig. 5.

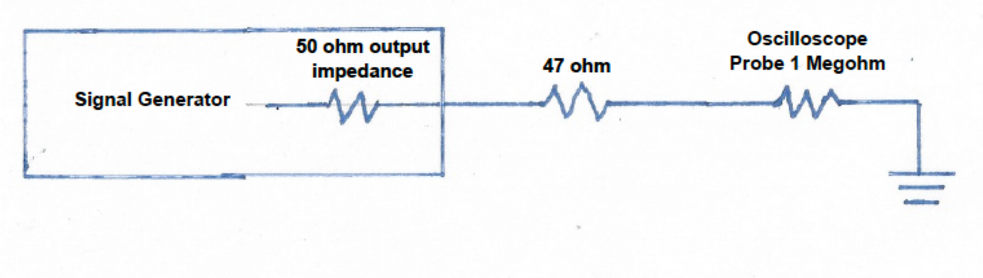

Figure 5. Experimental wiring diagram. The 47 Ω resistor corresponds to the resistance of the human body treated as a cylinder (see Fig. 6).

The current through the circuit shown in Fig. 5 is ~2 X 10^{-5} Amp. This gives a voltage drop across the 47 Ω resistor of 1.8 X 10^{-2} V. This is the voltage drop through the visible skin layer. If the resistance of the stratus corneum was measured to be ~250 kΩ.

The resistivity ρ is defined as

$$\rho = R\frac{A}{l}, \tag{1}$$

where R is the resistance of the material, l is the length of the specimen, and A is its cross-sectional area. Here, the specimen is the human body. Note that Eq. 1 can be rearranged to give $R = \frac{l\rho}{A}$. The human body will be treated here as a cylinder as shown in Fig. 6.

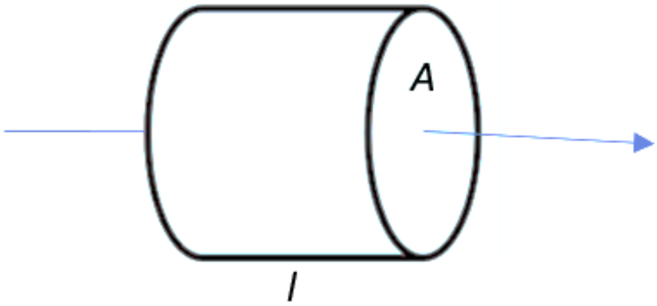

Figure 6. The human body treated as a cylinder. A is given by 0.085 $m^2$and l = 2m. For ρ = 2 Ωm, Eq. 1 gives R = 47 Ω. The radius of the cylinder is 0.16 m and the surface area of the cylindrical surface is very close to that of a tall adult female. The arrow corresponds to a current flow.

The resistivity of the stratum corneum, given a skin resistance of 250 kΩ and the dimensions in the caption of Fig. 6, comes out to be 10^4 Ωm, well within the range given for the low frequency resistivity of the stratum corneum shown in Fig 1.

The fact that the signal does not decrease at any measurement point on the body implies that the signal is not traveling along the stratum corneum but rather through the viable skin layer generally having a resistivity of <10 Ωm. This is also true for signal being a D.C. voltage. The voltage drop passing through the SC to the VS layer of the skin is very small, ~0.2V. The real question is then: What is the frequency response of the viable skin layer?

This was measured for the frequency range of 1Hz to 1.5 MHz. The results are shown in Figure 7. As can be seen from this figure, the corner frequency is considerably lower than 1 Hz.

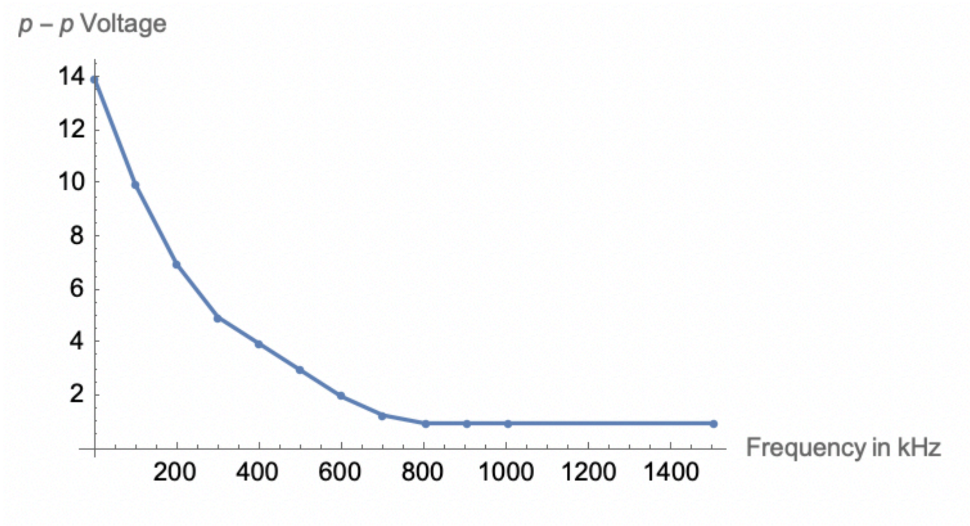

Figure 7. Measured frequency response of the viable skin layer from 1Hz to 1.5 MHz. There is no significant difference between measurements taken from the right index finger or right ankle.

Summary

Experiments on the electrical properties of skin are generally done using two electrodes on the surface of the skin. In the cited Review Article by Abe and Nishizawa, for example, the electrodes were two parallel strips having a width of 2 mm and a spacing of 1 cm, which were laid on the surface of the stratum corneum. An electrical signal having a magnitude of 1 V and a frequency of 100 kHz was then put across these electrodes. In the experiment described here, the applied signal was measured at two points on the subject's body after being applied to the left wrist (see Fig. 2). The important results of the experiment are that the current is carried by the viable skin and did not decrease in magnitude over the distance between the applied signal and the measurement point for any given frequency. The frequency response of the viable skin was then determined over the frequency range of 1Hz to 1.5 MHz. The result is shown in Fig. 5.