Uncertainty Determination in Measurements Using a Gerdien Tube

Z. Roubal, Z. Szabo, and M. Steinbauer
Department of Theoretical and Experimental Electrical Engineering
Brno University of Technology, Technicka 12, Brno 616 00, Czech Republic

Abstract— Light negative air ions demonstrably exhibit positive influence on the human organism. The concentration of these ions can be effectively used as the integral criterion for the evaluation of air purity, and there also exists a multitude of other applications. The presented aspiration method enables us to establish the concentration of air ions in the atmosphere. In a Gerdien tube fitted with a one-piece inner electrode, measurement of the saturation characteristics must be performed to facilitate the determination of the air ion mobility spectrum. This method is very sensitivity to noise and leakage current. In this paper is determination uncertainty of type B in Gerdien tube and electrometric amplifier. This method is very sensitive to noise and leakage current. In this paper, the determination of uncertainty B in a Gerdien tube and an electrometric amplifier is presented. The uncertainty depends on the input bias current and input noise current of the applied operational amplifier. Another significant source of B uncertainty is the temperature and time instability of the Teflon insulator.

1. INTRODUCTION

In industrial zones, where the environment air is often polluted with dust and smog, the concentration of air ions can be regulated or measured only with difficulty. Any thus impaired area shows an inherent deficiency of negative ions and, conversely, an abundance of positive ions complementing the nano and microscopic dust particles. Significantly, the described aspects have a markedly negative effect on the overal degree of fatigue and professional performance of a human being [1, 2]. The impact of environment on a human organism has been analyzed in studies [1, 2]. In the DTEEE laboratories, the methodology supporting the measurement of air ions concentration and mobility spectrum utilizes an aspiration condenser [3–9], this method is dependent upon a suitable approximation of saturation characteristics.

2. GERDIEN TUBE

A Gerdien tube (GT) is an instrument used for the measurement of air ions concentration assuming that the volume of tested air has not been limited or the ions are continuously generated. In the time domain, it is possible to measure by means of an GT only ions of one polarity; then, following a certain interval, ions of the other polarity can be measured. Ionized air is sucked into the GT by a ventilator. The homogeneous electric field is set between the inner and the outer electrode. If an electric ion shows a negative electric charge and the collecting inner electrode has a positive electric potential, the ion is progressively attracted to the inner electrode. Provided that the ion impinges upon the electrode, it will induce an electric current that is measured by the help of a sensitive electrometric picoampermeter [4]. The velocity of the ions motion in the electric field can be described by mobility $k\,[\mathrm{m}^2 \cdot \mathrm{V}^{-1}\,\mathrm{s}^{-1}]$.

It is possible to determine boundary mobility k_m for every GT configuration.

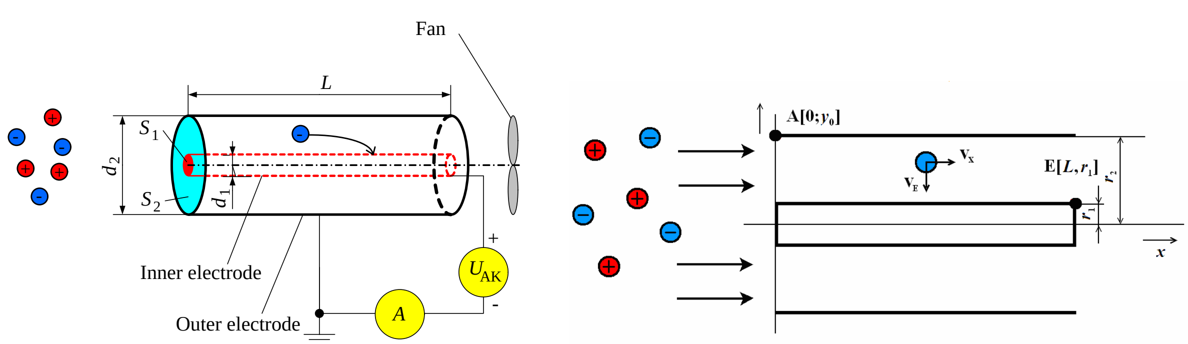


Figure 1: The basic principle of a Gerdien tube.

All ions showing an index of mobility greater than k_m will impinge upon the inner electrode; however, only a proportionate part of them will impinge in ions which mobility is smaller than k_m. Based on the aspiration condenser parameters, the air flow volume rate is defined as

$$M = \left(r_2^2 - r_1^2\right) \cdot \pi \cdot v_x, \tag{1}$$

where M, r_2, r_1, v_x, ... are the air flow volume rate, the outer electrode radius, the inner electrode radius, and the air flow velocity, respectively.

The main parameter applied for the definition of air ions mobility consists in boundary mobility k_m,

$$k_m = \frac{\varepsilon_0 \cdot \varepsilon_r \cdot M}{C_{\mathrm{AK}} \cdot U_{\mathrm{AK}}}, \tag{2}$$

where ε_0, ε_r, C_{AK}, U_{AK}, ... are the vacuum permittivity, the relative permittivity, the GT capacity, and the GT polarization voltage, respectively. Then, for current I measured by the electrometric picoampermeter, we can define

$$I_{k<k_m} = \frac{k}{k_m} \cdot n \cdot q \cdot M, \quad I_{k \geq k_m} = n \cdot q \cdot M, \tag{3}$$

where n, q, ... are the volume concentration of ions and the elementary charge, respectively.

3. THE EQUIVALENT CIRCUIT OF THE MEASUREMENT EQUIPMENT

The measured current I_{IONT} is measured with a high-quality picoampermeter, namely an electrometer. However, we must consider the fact that high-impedance measurement is performed, and therefore the structure and insulation of the component will influence the measured current. The equivalent circuit of the measuring equipment is shown in Fig. 1. At the DTEEE, an older GT manufactured by the Brno Institute of Scientific Instruments (ISI) is used together with a new type designed at the department (DTEEE). By constructing a new electrometric amplifier, we recently modernised the older GT.

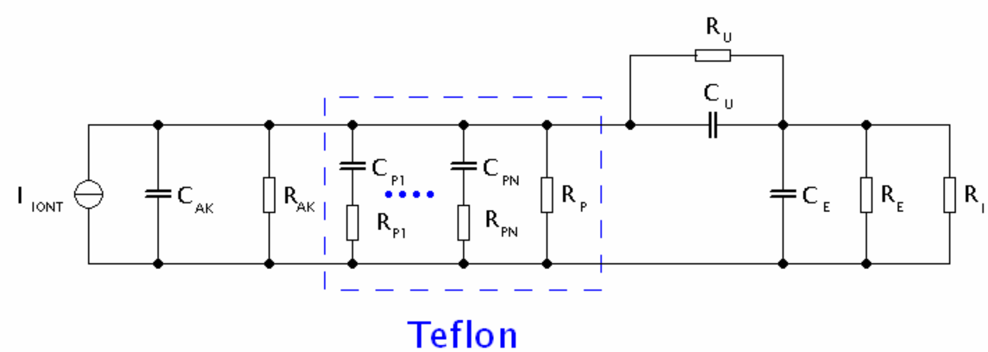


Figure 2: The equivalent circuit of the measuring equipment using the Gerdien tube.

Table 1: The value of elements in the equivalent circuit.

	ISI GT	DTEE GT
C_{AK}	15,06 pF	7,72 pF
$R_{\mathrm{AK}} \parallel R_P$	910 TΩ	5889 TΩ
C_U	1 μF/250 V	1 μF/250 V
R_U	10 TΩ	10 TΩ
C_E	6 pF	3 pF
R_E	100 TΩ	100 TΩ

In both GTs, we measured the insulation resistance R_{AK} in parallel with the R_P and the capacitance C_{AK}. The values of other elements in the equivalent circuit are indicated in Table 1. Here R_{AK}, R_P, C_U, $R_U, C_E, R_E, \ldots$ are the insulation resistance of the GT, the insulation resistance of the teflon duct, the charge capacitor, the insulation resistance of the charge capacitor, the input capacity of the electrometer, and the input insulation resistance of the electrometer.

The dielectric absorbtion of the Teflon material (represented in the equivalent circuit by the elements R_{P1}, C_{P1}, …, R_{PN}, C_{PN}) causes leakage current changes during the measurement. Thus, when measuring AV characteristics of the leakage current (from which the parallel values $R_{\mathrm{AK}} \parallel R_P$, are subsequently determined), we need to wait for the end of the transient process. The measurement time dependence of the leakage current is presented in Fig. 3.

From the AV characteristics of the GTs manufactured by both the DTEEE and the ISI, the relevant are determined. After charging the capacitor C_U, it is suitable to observe a delay of approximately 2 minutes, as shown in Fig. 3. Using Pspice, we simulated the equivalent circuit and defined the charging interval of the capacitor C_U. This recharge time interval depends on the air ion concentration n. The result is obvious from Fig. 5. Near strong ion fields, such as those

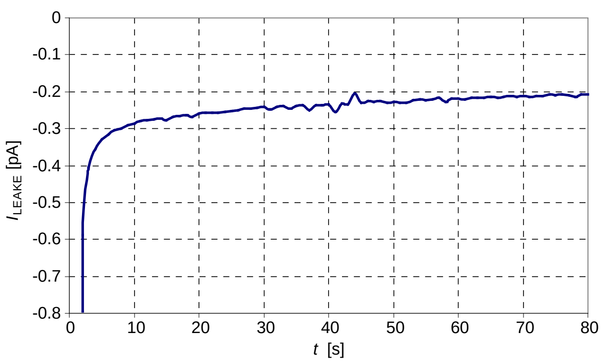


Figure 3: The time dependence of the leakage current after polarisation voltage changes.

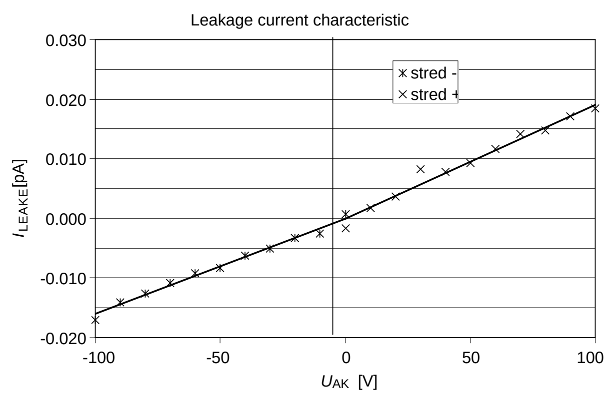


Figure 4: The AV characteristics of the GT by the DTEEE.

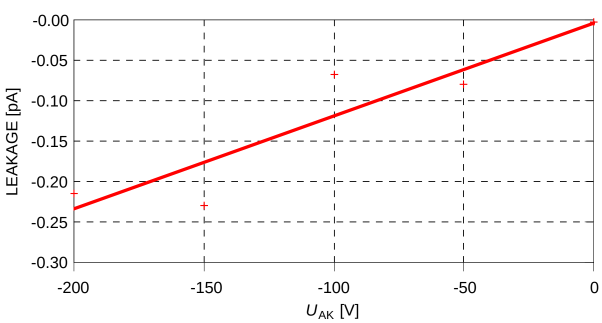


Figure 5: The AV characteristics of the GT by the ISI.

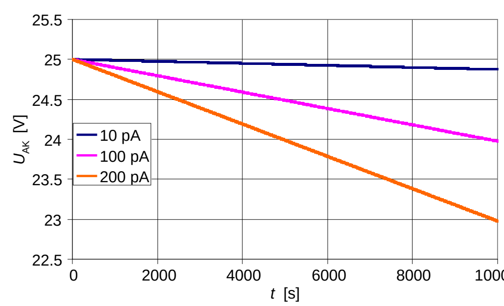


Figure 6: The discharge capacitor C_U.

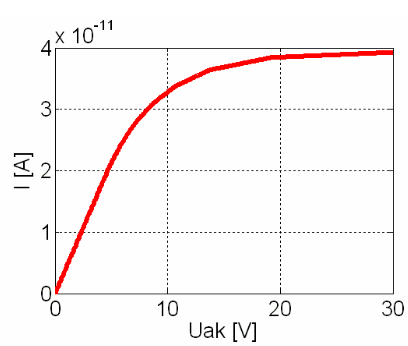
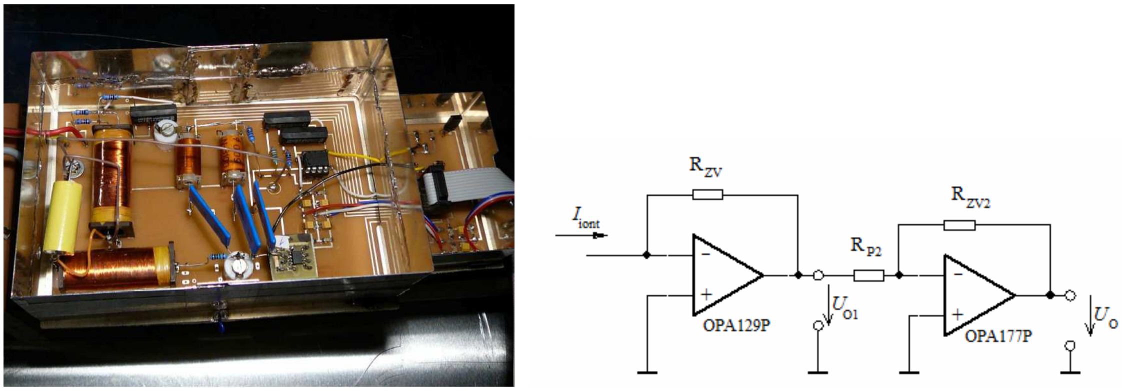


Figure 7: The typical saturation characteristic the GT DTEEE.



(a) (b)

Figure 8: The new electrometric amplifier for (a) the GT ISI and (b) its simplified circuit.

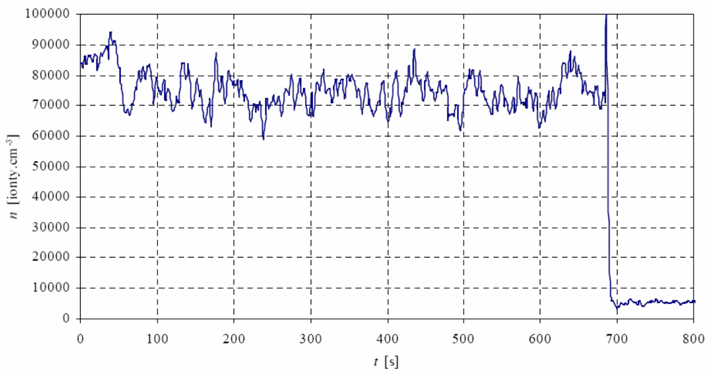


Figure 9: The time dependence of the air ion concentration measured with the new electrometric amplifier near the ioniser BIV-06.

Table 2: The relative uncertainty of type B for several variant electrometric amplifier.

	R_I	uncertainty of type B
ISI GT with electrometric amplifier WSH223	100 GΩ	10%
ISI GT with electrometric amplifier OPA129	10 MΩ	1%
DTEEE GT with electrometric amplifier INA116	10 GΩ	1%
DTEEE GT with electrometric amplifier OPA129	10 MΩ	0.25%

created by an ioniser or a waterfall, it is important to recharge the capacitor C_U. If the saturation characteristic [11] used for the determination of the air ion mobility spectrum is measured, the above-shown decrease in the polarisation voltage U_{AK} causes a rapid increase of the saturation characteristic slope. This results in erroneous estimation of the air ion mobility spectrum.

The measured current is given by the equation

$$I = I_{\mathrm{ions}} \cdot \frac{G_I}{G_I + G_{\mathrm{AK}} + G_P + G_E}. \tag{4}$$

where the conductivities correspond to individual elements in the equivalent circuit, and G_I is the input conductivity of the electrometric amplifier.

4. THE MODERNISATION GT ISI

If we need to minimalise the systematic error of the measurement, it is suitable to decrease the input resistance value of the electrometric amplifier. For this purpose, a feedback ammeter performs better than the shunt amplifier used in electrometers with INA116. When modernising the GT manufactured by the ISI, we designed a new electrometric amplifier with an OPA129 operation amplifier [12]. The result is presented in Fig. 9.

5. CONCLUSION

The GT manufactured by the DTEEE exhibits smaller uncertainty B than the older GT supplied by the ISI. The sensitivity of the former device is nevertheless worse than that of the GT ISI; thus,the team at our department eventually modernisedthe GT ISI. In the measurement configuration, we decreasedthe input resistance of electrometric amplifier, andthis change then improved the features of the GT ISI. During the simulation in Pspice, the recharge interval of the capacitor C_U was determined to be 3 hours. In the course of this time, the polarisation voltage U_{AK} near the ioniser decreases (in the GT UTEEE) to 2,5 V. In the GT ISI, this interval is longer.

ACKNOWLEDGMENT

The research described in the paper was financially supported by a grant of the BUT science fund, No. FEKT-S-14-2545/2014, and the authors also received assistance from projects within the Education for Competitiveness Operative Programme, Nos. CZ.1.07.2.3.00.20.0175 and CZ.1.07/2.3.00/3-0.0005.

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