SOFIA, 2011 VOLUME 5, NUMBER 2 ISSN 1313-1842

ANNUAL JOURNAL

OF

ELECTRONICS

Technical University of Sofia

Faculty of Electronic
Engineering and Technologies

ANNUAL JOURNAL OF ELECTRONICS

The Journal is issued by the FACULTY OF ELECTRONIC ENGINEERING AND TECHNOLOGIES, TECHNICAL UNIVERSITY of SOFIA, BULGARIA.

The Journal includes the selected papers from the International Scientific Conference Electronics ‘11, held on 14 – 16 September 2011 in Sozopol, Bulgaria.

CONTENTS

BOOK 1

BOOK 2

Rainfall Drops Measurements Using a Modified Lord Kelvin Generator

Petar Vasilev Sapundjiev, Georgi Genchev Zhelyazkov and Mityo Georgiev Mitev

Abstract - **this paper presents a method for rainfall measurements based on a well known electrostatic generator principle. The proposed method eliminates the need for mechanical moving parts, which are widely used in, volume and weight based, rainfall measurements. The measurement of the rainfall itself is realized by determining the electrostatic charge carried by the water drops. The aforementioned charge is induced to the drops by means of electrostatic induction while they travel through a high voltage potential induced volume. Thus ,measuring the total charge carried by the water drops, it is possible to derive the quantity of water that has passed through the polarizing volume.**

Keywords – **Electrostatic charge, droplet polarizing, Rainfall measurement**

I. INTRODUCTION

The process of measuring the rainfall is quite a specific process due to the influence of a number of dynamically changing factors, which could prove hard to compensate for. The measurements' accuracy depends largely on the strength and direction of the wind (if any is present at the time of measurement) and the height at which the opening of the water collecting tube is positioned. The errors associated with the uncertainties, caused by the aforementioned factors, could reach as high as 50%.

The quantity of rainfall drops for a given period of time is defined as the height of the water film, that would cover a flat surface, provided there is no present leakage out nor vaporization of the water. This height is usually given in millimeters (in SI) and is defined for a certain known surface in cm^2 or m^2.

The majority of the rainfall measuring apparatus operation is based on two widely used transform methods – one based on the mass of the accumulated water and another based on its volume. Both methods require periodically performed measurements of the gathered quantity of water as well as periodically emptying of the water container. This dictates the presence of mechanical moving parts, which complicate the overall design and worsen the reliability of the device (for example in case of icing). Furthermore, a rainfall-meter which behaves adequately in case of snowfall is not known to us. This research aims to find and describe a method which would allow the construction of a rainfall meter without the hindrances that a mechanical construction with moving parts necessitates.

P. Sapundjiev is a PHD student in the Department of Electronics and Electronics Technologies, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: vasilev_p@mail.bg

G.Zhelyazkov is a PHD student in the Department of Electronics and Electronics Technologies, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail: joro_zh@abv.bg

M. G. Mitev is with the Department of Electronics and Electronics Technologies, Faculty of Electronic Engineering and Technologies, Technical University - Sofia, 8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria, e-mail:mitev@ecad.tu-sofia.bg

II. THEORY OF OPERATION

Lord Kelvin's Electrostatic Generator, also widely known as Kelvin Water Dropper, is an apparatus that generates electric potential up to a certain known level (specified via electrical or mechanical means). Due to the principle of operation, the total power that is generated is quite limited, but on the other hand the voltage potential could reach as high as tens of kilovolts.

The original experiment, that Lord Kelvin performed, included two metal rings along with two metal containers (fig. 1). Each container is placed under its corresponding ring. Also, the aforementioned containers are cross wired with the rings i.e. the first one is connected to the ring above the second one and vice versa. It is mandatory that all electrostatic conducting parts are isolated one from another as well as from the ground potential. A separate water container is positioned above each ring. This water in these containers should fall as droplets through a suitable valve, but due to the physical principle of operation this condition may not be meat (the water could fall even in the form of a continuous current).

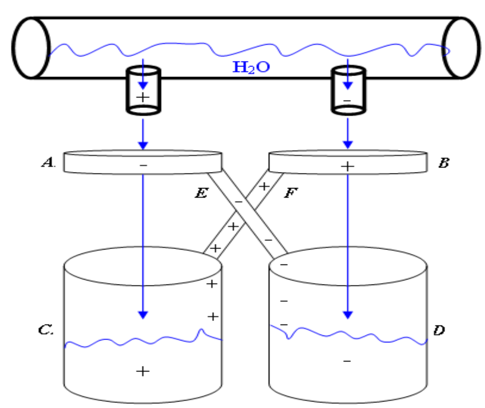

Fig. 1

In the figure above the letters correspond to:
A, B – metal (conducting) rings
C, D – metal (conducting) containers
E, F – metal (conducting) wires

If the two rings are positioned close enough, at some point of time, it is imminent that a voltage discharge will take place given that enough droplets have passed through both rings, thus accumulating the needed charge.

The way that the apparatus works is identical to the two-transistor flip-flop trigger circuits, in the meaning that, both processes unfold avalanche-like over time and are also similar in the fact that an asymmetry of the starting conditions is available (in the case of the generator – a charge asymmetry).

As was mentioned, in order to give start to the physical process, an electrical asymmetry in the electrical charge between the two, electrically linked metal containers, should exist. For example, let, in concordance to the charge polarity showed on fig.1, container C and ring B have had accumulated less positive total charge than container D and ring A. With these starting conditions in mind if water droplets start to fall through the rings, the two electrostatic "branches" will begin to polarize, gathering charges of different polarity. The droplets, going through the negatively charged ring A, are being polarized positively according to the law of electrostatic induction. Thus, carrying positive charge, they end in container C, which is already positively polarized and add their charge to its own. That way container C and its corresponding ring F are being polarized even more positively. This further polarizing of ring F causes the negative polarization of the drops, that pass through it, analogical to the way that ring A charges its droplets positively. These droplets (passing through ring F) deliver their charge to the connected container D and ring A thus polarizing them even more negatively. In its nature this process is essentially a positive feedback and leads to an avalanche-like process similar to that in flip-flop trigger circuits as was mentioned above.

The quantity of charge delivered by each drop is proportional to the total difference in electrical charge between the wired "branches" container D – ring A and container C- ring F. This difference is, on the other hand, proportional to the voltage potential difference V between them. If the water is falling monotonously (i.e. the number of drops per unit of time is constant) the speed with which the potential difference V will change will be proportional to itself – V:

$$\frac{dV}{dt} = K * V \qquad (1)$$

In equation (1) K is a constant positive parameter factoring the construction of the apparatus and the parameters of the water current. The above equation could be solved and has a solution presented as:

$$V(t) = V_0 * e^{K*t} \qquad (2)$$

In equation (2) Vo represents the voltage potential at the beginning of the process i.e. in t=to – that is the starting moment of non-equilibrium. In theory if the starting conditions include Vo=0 and the starting condition of the water current is non-segmented (continuous flow) the process should never start, but in practice there are a couple of factors that allow the system to begin operation. Some of them are:

1. The water itself may not be purely electro-neutral as it may (and as it in practice – does) contain some solvents that increase its conductivity. This imbalance is further amplified by the electrostatic charge on the rings once the initial charge is delivered.

2. During its free falling to the water container, due to its friction with the air, the droplet may gather free electrostatic charges.

3. Due to its movement in the Earth's electrical field, it is quite often the case that a polarized local region is formed at the bottom of the drop. This causes the opposite charge to be relocated on the surface of the droplet.

As was already mentioned the system can start even if the water falls in the form of water current. This is due to the nature of the water current itself to fracture itself and the further the location in a current from the source the more possible it is that droplets will break due to the following forces:

1. At the places where the "would-be-droplets" connect, the circumference of the current is less than that at other locations. This leads to a heightened water pressure effect at these locations in comparison to the pressure in the droplets themselves.

2. As a result of the above the odds that a outside force could cut the current at these location are heightened as per the following equation:

$$F = p * \sigma = 2 * \pi * r * \sigma \qquad P = \frac{F}{S} = \frac{F}{\pi * r^2} = \frac{2 * \sigma}{r} \qquad (3)$$

In which F is the total force applied by the surface tension of the water σ, S is the surface of the droplet, P is the pressure in the droplet and r is its radius. As is evident greater radius leads to greater pressure and the odds that the droplet will form are heightened.

3. An oscillating force is apparent due to the effect gravity has on the water current. In other words the longer the water current becomes the greater the number of possible cut sites becomes and the greater the force that separates them thus ensuring that after certain length water drops will be formed.

4. During the process of acquiring water in the containers the water current drifts towards the edge of the rings due to the electrostatic forces of attraction. This force combined with the effects above works to cut droplets from the water current at the places where the circumference is at its minimum.

The physical principal of operation of the Kelvin water dropper leads to the conclusion that it could be effectively used to measure the rainfall for a given period of time – this could be achieved by simply letting the rain drops through the charging rings. The first way to achieve this is to measure the charge delivered by the water drops in the system. In this case the sensitivity of the system drops due to the amount of rain needed to cause the electrical discharge. Furthermore the uncertainty errors are high because the initial starting conditions, which strongly affect the operation of the system, such as air volume charge, are not known. Another possibility is to measure the voltage potential between the two electrically isolated parts of the Kelvin water dropper. Unfortunately, as can be seen from equation (1), the voltage potential dependency upon the rainfall is of highly nonlinear nature (exponential). An additional factor to be considered is that the proportional coefficients are highly dependent on the ambient environment and the present weather conditions.

III. System Design

To deal with the aforementioned factors we suggest a modified variant of the Kelvin water dropper. In this variant one of the electrostatic branches is removed leaving the system with only one conducting ring and one water container. The conducting ring itself is replaced with a grounded conducting plate. An external source is used to create a voltage potential difference between the ring and the grounded plate thus ensuring that the voltage difference between them is of a constant value (fig. 2).

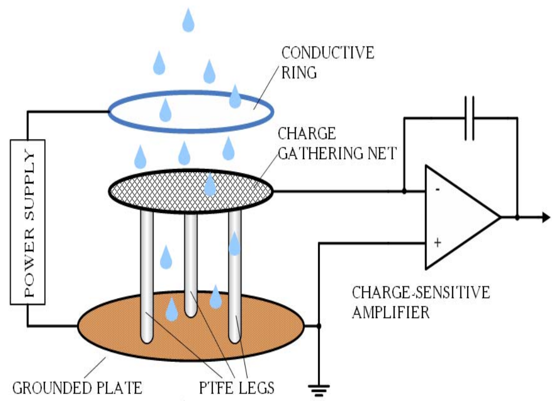

Fig. 2

Therefore the charge that every water drop delivers is relatively constant and is dependent only on the size of the water drop, which is directly proportional to the measured quantity of rainfall. The volume between the ring and the grounded plate is separated by a conductive charge gathering net isolated from the grounded plate by means of 3 PTFE polymer legs. The charge gathering net is wired to the input of a charge sensitive amplifier. The high voltage source is used to set the voltage potential of the ring relative to the grounded plate to a certain value. Each water drop passing through the ring is polarized by the ring to the same degree, relative to the grounded plate. The water drops then fall upon the charge gathering net, giving up their induced charge, which is amplified by the charge sensitive circuit which acts effectively as a charge to voltage transducer. From the above said, the charge amplifier's output signal should be proportional to the net charge delivered by the water drops and thus indirectly dependent upon the net quantity of water, that has passed through the polarizing ring. To decrease the uncertainty of the charge carried by the water drops they should enter the system (i.e. the ring) with a charge that is well defined. One solution could be the depolarization of the water drops

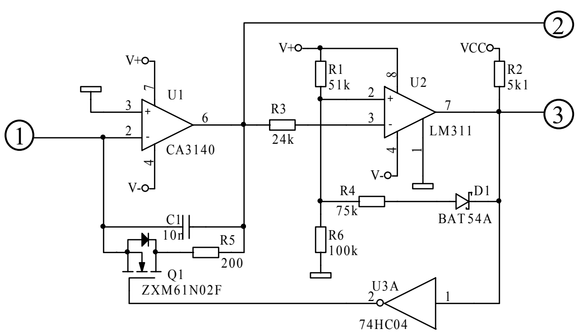

Fig. 3

prior to their entrance in the system. This could be achieved by the addition of conducting net in the way of the water drops. This second net should be grounded to the bottom plate so that every drop entering the system should give its initial charge to the depolarizing net and thus travel through the ring having zero voltage potential (compared to the grounded plate and the actual ground of the system). This allows the setting of the initial starting conditions to zero and escape any static error.

In order to put the aforementioned principle and modified system to the test, the electronic circuit shown on figure 3 was designed and experimented with. The charge-sensitive amplifier was designed using IC CA3140 which possesses high input resistance, Ri>1.5TΩ, which is required in order to lower the error from reduced charge gathering (input charge leakage). The experiments were performed with two parameters in mind – one being the ring polarizing voltage and the second being the rate at which water drops pass through the ring. The polarizing voltage was modified in the 200V-500V range. At all times the supply current drawn from the voltage source didn't exceed 1μA thus staying sufficiently low. As could be expected, raising the polarizing voltage resulted in better overall sensitivity in the context of achieved better water drop polarization. On the other hand the sensitivity depends also on the charge-gathering capacitor C1 which value is most effectively chosen empirically as any calculated time-constant may be contaminated by the size of the drops or the rate of arrival or even by the solvents on the water itself. The system principle of operation is as follows: when the threshold voltage is reached, the comparator U2 sets its output at low voltage level. Its output signal is inverted by U3A which governs the switching off and on of the FET transistor Q1 (now switched on) through which the feedback capacitor C1 is periodically drained of charge. Vice versa, when the lower threshold is reached, the comparator switches off the FET transistor and the charge gathering begins anew.

IV. Experimental Results

During the initial stage of the experiments the achieved sensitivity was of the magnitude of 10-20mV/ml. This leads to the saturation of the charge-sensitive amplifier which on the other hand demands some design means of returning the system to its normal mode of operation. One possible way is to constantly monitor the output voltage of the system and, when it exceeds some predefined point, to switch the ring polarizing voltage's polarity thus forcing the output to swing in the opposite direction. Unfortunately this requires the commutation/reversal of up to 500V power supply. Another way to resolve the saturation problem is to periodically zero the output of the amplifier. Since its output voltage is effectively the voltage across the feedback capacitor, this could be achieved by implementing a circuit for shorting out the capacitor. Using this method, an additional data type output could be obtained – the time interval at which the capacitor is being shorted. This is a digital signal, which is proportional to the quantity of rainfall given that the rate of arrival of drops remains relatively constant. By integrating this signal for a given period of time or measuring the time, during which the shorting transistor is switched on we could obtain an analogue value representing the quantity of rainfall. At the same time it is possible to monitor the analogue voltage across the feedback capacitor thus increasing the overall accuracy of the system.

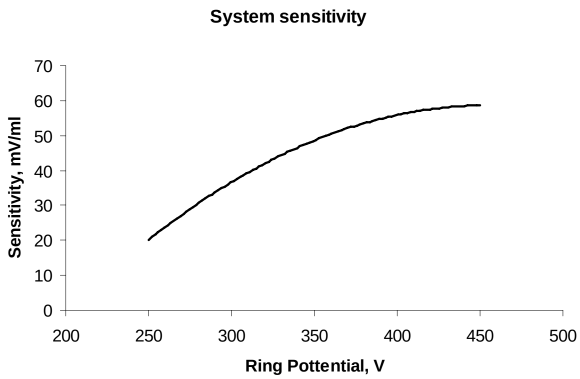

Fig. 4

The first experiment was performed with the ring voltage potential as a parameter (Fig. 4). The ring's voltage with respect to ground was swept through the range 250-450V. The output signal was recorded and the sensitivity of the system was derived based on it and quantity of water that has flown through the ring. The second experiment was performed as the rate at which the water drops traveled ($V_1<V_2<V_3<V_4$) through the sensitive element (ring). Based on the different amounts of water collected for the gathering period the "sensitivity" upon the rainfall rate was derived (this is not true sensitivity however because this is already covered by the first experiment since the amount of rain and thus the drops per square cm per a second is in fact unknown). This "sensitivity" in fact shows the dependency on the different gathered masses of water.

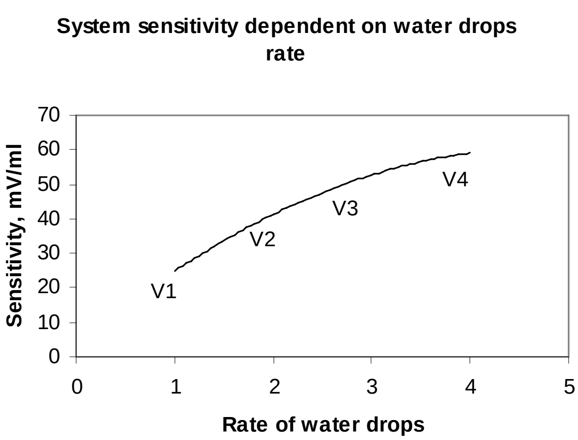

Fig. 5

V. CONCLUSION

The system's lack of mechanical parts remains its biggest advantage. The experiments show that the proposed principle is indeed applicable but there are many issues left to clear off. First off, the effect of the ring's circumference on the system's sensitivity and its optimal size should be experimentally found. The distances between the charge gathering net and the ring, on one hand and between the gathering net and the grounded plate on another, should be researched in search of an optimal placement. Another possibility to explore could be the inclusion of different value capacitors corresponding to different rates of raining and water drops sizes.

ACKNOWLEDGEMENT.

The present research is supported by the Technical University - Sofia under Contract 102ПД210-3.

REFERENCES

[1] J.Chang, A. Kelly. *Handbook of Electrostatic Processes, ISBN 0-8247-9254-8,* Marcel Dekker Inc.

[2] T. Gemci, R. Hitron. D*etermination of Individual Droplet Charge in Electrosprays From FPDA Measurements*, ILASS-Europe 2002 Zaragoza 9 –11 September 2002

[3]G. Planinsic, T. Prosen. *Conducting rod on the axis of a charged ring: The Kelvin water drop generator,* Am. J. Phys., Vol. 68, No. 12, December 2000

[4]L. Santos, T. Ducati. *Water with Excess Electric Charge,* Proc. ESA Annual Meeting on Electrostatics 2011

[5] http://www.intersil.com