A MEASURING DEVICE FOR WEAK SIGNALS WITH A HIGH-IMPEDANCE INPUT - SPCE METER 1

M.Sc. Eng. Jordan Popov[1], Assoc. Prof. Ognyan Ivanov PhD[1], Prof. José L. Pérez-Díaz PhD[2]
Institute of Solid State Physics, Bulgarian Academy of Sciences, 1784 Sofia, Bulgaria[1]
Escuela Politécnica Superior, Universidad de Alcalá, 28805 Alcalá de Henares, Madrid, Spain[2]

ogi124@yahoo.com

Abstract: *Measurement device, specifically developed to capture and quantify low-amplitude surface photo-charge effect signals. It can also modulate and power a laser in various modes, and extract the processed signal as an output. The device is compatible with all of our surface photo-charge effect-based systems. The device is part of a portable system for detection of pollution in fogs or aerosols.*

Keywords: OPTICAL SENSORS, FOG DETECTION, PHOTOELECTRIC EFFECT, AIR POLLUTION, SECURITY

1. Introduction

Contamination of the environment as a result of industrial accidents, disasters, terrorist attacks, wars, etc., is in a lot of cases spread to large areas due to atmospheric dispersion. This is possible as the harmful agents - chemical, biological, radiological and nuclear agents, are usually dispersed as aerosol mixed with a carrier liquid [1]. One of the most efficient ways to decontaminate the polluted areas (indoors and/or outdoors) is through the spraying of fog with specific pressure and composition. Fog is an aggregation of a large number of microscopic water droplets spread in the air. The specifically controlled fog has the potential to sweep along a large number of impurities in the air, i.e. small particles, dust particles, chemical compounds, etc. and facilitate their condensation on the ground together with the water droplets. In such way, the fog effectively decontaminates the air. For more efficient decontamination, specific neutralizing substances are added to the fog. As these substances can also be potentially hazardous to human health, the spraying of fog needs to be optimized.

The application of this technique for decontamination with fog requires sensors for continuous monitoring of fog and its admixtures. Such detectors should be triggered on when the harmful substance appears in the environment and triggered off when the concentration of this substance falls below a threshold value. The perfect sensor will be with small size, rather inexpensive, with a simple construction, stable in the various conditions and portable. It should also be capable of online monitoring of small and large areas.

To address these needs, we have developed portable sensors [2] and monitoring devices for contamination in fog in the framework of EU FP7 Security project COUNTERFOG [3]. Most of the developed sensor systems operate on the basis of the Surface photo-charge effect (SPCE).

The SPCE is registered during the interaction of any solid with an electromagnetic field and is described as the induction of an alternating electric potential difference in the solid with the frequency of the incident field [4], [5]. The SPCE response has a significant dependence on the characteristic properties of the studied sample. This gives rise to opportunities for rapid and contactless analysis of solids, liquids, and gasses [6], [7], [8] and chemical agents dispersed in aerosols [2]. The sensors based on this effect have demonstrated good analytical capabilities [7], [9].

Here, we present a portable device for measuring the SPCE signals – SPCE Meter 1. The device allows different experiments to be conducted by irradiation of samples with laser pulses and the measurement of the associated photoelectric effects. The experiment is done with a fixed frequency of 28.5 kHz. The control of the laser, with respect to its specification, can be done with the passing of sinusoidal or square signal with given frequency.

2. Experimental setup.

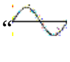
The device is designed for conducting experiments with a semiconductor laser influencing a sample made of semiconductor material. During the experiment on the sample, an impulse is being created with amplitude from tens up to hundreds of microvolts. The lower amount of the accumulated charge and amplitude of the voltage demand the usage of a preamplifier with large input impedance and low level of external interference and internal noises.

The device has the following technical parameters: supply voltage (220 +/– 10) V; (50 +/–1) Hz; Operating frequency (28,5 +/– 0,5) kHz; input impedance – over 100 MΩ. Output signal is: a) sinusoidal, with adjustment of the amplitude and the operating frequency; b) square, with TTL level, duty cycle (50 +/– 3) % with operating frequency; c) square, with TTL level and manually adjustable duty cycle /PWM/ in the approximate range of 3.5 – 86.5 %, with operating frequency. d) DC voltage proportional to the amplitude of the sample signal received in parallel to the measuring digital voltmeter; e) pulse signal with square form and manually adjustable amplitude (0 – 12) V, duty cycle (50 +/-3) % and with operating frequency.

Besides the above-mentioned pulse signals, a manually regulated DC voltage (2 - 12) V can be generated from the device, which can be controlled with a digital voltmeter. Maximum current which can be produced with the built-in stabilizer is 200 mA.

The device for conducting experiments is made of the following blocks and nodes, shown in the block diagram of the device (Fig. 1): Input matching block (1); High-frequency filter (2); Resonance differential amplifier (3); Matching HF transformer (4); Power supply filters circuit. The above blocks are located in different shielding housing provided with BNC type connector; Sinusoidal generator (5); Shaper of TTL signal (6); PWM regulator (7); Output TTL drivers (8); Fast-acting transistor switch (9); Amplitude detector for the acting signal – sinusoidal or pulse (10); Amplitude detector for the sample signal (11); Power supply +/– 12 V (12); Power supply + 5V (13); Adjustable power supply + (2 – 12) V (14); Galvanic isolated power supply 9V for the digital voltmeters (15).

To expand the potential of the device, a few types of changes (modulation) of the controlling signal are provided. If the output power of the laser is proportional to the instantaneous value of the control voltage, it is possible the value to be with controllable form, as the power of the irradiation is linear or close to a linear function of the controlling signal. The possible changes of the signal are as follows:

A) Adjustment of the amplitude of the sinusoidal voltage. It is possible to be used if the structure of the laser allows control (modulation) of the irradiation with a signal which has an arbitrary linear function for the control voltage. The voltage of the output of the device to the control input of the laser is adjusted with potentiometer on the front panel, noted with the symbol "

”(Fig. 2, Pos. 2). The output signal is received from the connector type BNC, noted with the label “sin 28.5”, which is on the back panel (see Fig. 3).

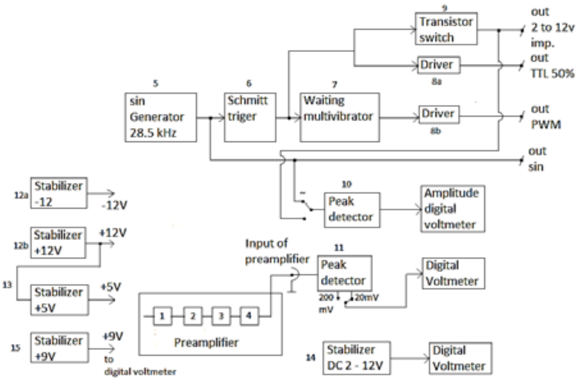


Fig.1 *Block diagram of SPCE Meter 1*

B) Adjustment of the amplitude of the sinusoidal voltage. It is possible to be used if the structure of the laser allows control (modulation) of the irradiation with a signal which has an arbitrary linear function for the control voltage. The voltage of the output of the device to the control input of the laser is adjusted with a potentiometer on the front panel, noted with the symbol “∿” (Fig. 2, Pos. 2). The output signal is received from the connector type BNC, noted with the label “sin 28.5”, which is on the back panel (see Fig. 3).

C) Adjustment of the amplitude with a square voltage with duty cycle 50 %. It is regulated with a potentiometer on the front panel with a label “⎍” (Fig. 2, Pos. 4). The signal for control of the laser is drawn-out to the connector type BNC on the back panel with label “imp. 2 – 12 V” (see Fig. 3).

The amplitude of the voltage from point A to point B can be measured when we use the switch located between the two potentiometers (Fig. 2, Pos. 3) and we choose the respective symbol of the voltage. The reading is done on the display over the potentiometer (Fig. 2, Pos. 1).

It is important to take into account a number of issues.

1) The signals from the potentiometers are submitted directly to the output connectors. The load which is added to the connectors must be with impedance 50-100 kΩ.

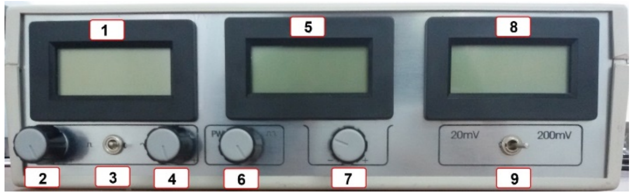
2) When the sinusoidal voltage is measured the display shows its amplitude and not the effective value.

3) When the laser is controlled with a TTL signal and the relation between the investigated effect and the duty cycle of the pulse is not under investigation, an output labeled “TTL 50%” on the back panel is used. In this case, the intensity of the laser radiation can be changed in different ways one of which is the change in the power voltage.

4) In order to explore the dependence of the researched impact of the duty cycle of the control pulse, the signal that controls the laser can be taken from “TTL PWM”. With the help of the potentiometer (Fig. 1 Pos. 6) with constant operating frequency, the duty cycle can be varied within approximately 4÷85%. The control of this parameter can be performed by an additional instrument, for example, oscilloscope connected to the output.

5) If the laser permits, the intensity of its radiation can be adjusted manually by varying the supply voltage. For this purpose, an additional galvanically separated supply voltage is provided. This voltage can be adjusted manually with a potentiometer (Fig. 1 Pos. 7), and the result is displayed in volts (Fig. 2, Pos. 5). This power supply is obtained from a separate connector on the back panel, labeled “DC 2-12V” (Fig. 3).

Methods 3) and 4) can be combined with method 5) to build groups of characteristics of the effect. In methods 1) and 2) where the radiation of the laser is adjusted with the amplitude of the input



voltage, the DC source can be used by setting it to the prescribed power-supply voltage of the laser.

Fig. 2 *Front panel of SPCE 1 device.*

Fig. 3 *Back panel of SPCE 1.*

3. Experimental procedure

When the appropriate method for supplying the laser is chosen, we can proceed with measurement of the SPCE impact effect. In the preamplifier, a trimmer-potentiometer is provided for correction of the gain. It is located next to the BNC connector. In the right-most position (CW) of this potentiometer, the meter is calibrated and the reading on the display (Fig. 1, Pos. 8) is in μV. The switch under the display (Fig. 1, Pos. 9) must be in position “20 mV”. Then the maximum display value of the voltage can be 199.9 μV. If the supply to the display voltage is over this value, the switch must be changed to “200 mV”. Then the maximum display value of the voltage will be counted to 199.9 mV. The measurement must be done in the following order: 1) connection of all the necessary circuits; 2) turning on the power supply unit; turning on the power supply to the laser and choose of operating mode; 3) the switch under the display is placed in position “20 mV”; 4) positioning an opaque barrier in the way of the laser beam and without disconnection of the laser, shifting the reading on the display as close as possible to 0 mV. The potentiometer for the signal shift is on the back panel, over the connector type “DB-9”; 5) removing the opaque barrier and check if the display is not overloaded. In case of overload switch to “200 mV” and the procedure of the reset is repeated.

From the experiments is established, that the voltage on the device input, does not have sinusoidal form. It closely resembles a saw. So as to secure sufficient enough protection from disturbance, in the preamplifier, a resonant filter is used. It is set to the first harmonic of the operating frequency. Therefore, the reading on the display is proportional to the amplitude of this harmonic and do not take into account the impact of the second, third, etc. harmonics.

The calibration of the device is done as the input is submitted with a sinusoidal voltage with low-frequency generator with an effective value of 100 μV.

The device for experiments works as follows: the signal is fed to the matching block, which has very high input impedance. Its output is connected to high-frequency active filter with slope 12db/oct and a cutoff frequency of 10 kHz. This filter eliminates the noise to a great extent with the frequency of 50 Hz from the surrounding network. The output of the filter is connected with an inductive connection to the differential amplifier. The coil of the resonant circuit is wound bifilarly and connected in series, which puts the AC voltage into antiphase. The differential amplifier has the capability of manual adjustment of the limits (10 ÷ 500) times. The output via broadband transformer is connected to the main block.

In the main block, this signal is detected and its amplitude is shown with the digital voltmeter. The same voltage appears in BNC type connector for connection to an additional external device.

The operating frequency of the device is made of RC sinusoidal generator with Wien bridge. It is implemented via a powerful integrated circuit – final low frequency (LF) amplifier. The shaping of the square signal is done with CMOS Schmitt – trigger. The regulation of the width of the pulse is made with the help of a waiting multi-vibrator made with schemes with hysteresis. These two signals are supplied to separate outputs through drivers, each containing three parallel connected CMOS inverters. With this, we secure amplitude of the output voltage to almost 5V, which enables the outputs to connect devices with CMOS or TTL input.

A square signal with filling 50% and adjusting the amplitude is obtained from a fast transistor switch. With the switch for choice of source of the signal (sinusoidal or pulse) these voltages are fed to the amplitude detector and are reported with a separated digital voltmeter. The outputs with adjustable amplitude (sinusoidal and square signal) require load resistance over 50 kΩ. Keep in mind that the sinusoidal voltage is shown as amplitude and not as effective value.

A few stabilized power sources are used to make the power supply of the device. The analog part (sinusoidal generator and operational amplifiers) require voltage +/- 12V. They are received from the network transformer with the middle point of the secondary winding, symmetric rectifier, and two integral stabilizers – for positive and negative voltage. The necessary 5V for the digital integrated circuits are produced from the stabilized positive voltage using a linear integrated circuit. Although the bigger heat losses the preferred solution is with linear stabilizers and not with pulsed, so to avoid the possibility of penetration of noises in the circuits of the power supply.

The three digital voltmeters which are located on the front panel require galvanic separated power supply voltage 9V. It is obtained from the separated winding of the second transformer and is also stabilized with the linear integrated circuit.

The manually adjustable DC voltage for the power supply of the semiconductor laser is also galvanically separated from the measuring part with the purpose to lower the internal noises. It is secured in a separated winding in the second transformer, rectifier, and linear stabilizer.

Constructively the device is installed into two housings – main and supporting, which are connected with a flexible multicore cable via a DSUB-9 connector. The supporting housing is mode out of a metal casting, to provide shielding of the sensitive to noises input circuits.

For heat dissipation, the linear integrated circuits for power supply and sinusoidal generator are installed on the radiators. The upper cover of the main housing is with openings for ventilation

4. Results and discussion.

The SPCE was applied for measurements of the cleaning properties of fog created by the full-scale Fog Dynamics Laboratory, in CIEMAT, Madrid designed in the framework of project COUNTERFOG. The special design of the SPCE meter allowed for it to be installed in the Laboratory and measurements with different types and concentrations of pollutants to be performed.

The most numerous measurements were made with the chemical contaminator: potassium dihydrogen phosphate (KH_2PO_4). Potassium dihydrogen phosphate (KH_2PO_4) was chosen as a harmless simulant of the highly lethal class of nerve chemical warfare agents from the G- and V-series. In solution, KH_2PO_4 dissociates to give phosphate ions which are very similar to the behavior of the mentioned class of chemical agents' molecules. In Fig. 4 is presented the signal obtained from the SPCE meter at spraying of fog containing KH_2PO_4 as a function of time. It can be seen that according to time the evolution of the SPCE signal can be divided into four groups – before the start of spraying (before point A), during spraying (between point A and B), signal build-up (between point B and D) and relaxation of the signal (point D). It is seen that in the before the start of spraying, the SPCE signal is rather constant due to the lack of pollutant on the sensor surface. With the start of fog spraying (point A), there is characteristic peak which is formed (between point A and B). This peak is due to the influence of the fog particles that alter the effective surface of the sensor. After the initial peak, there is a significant change in signal amplitude for the duration of tens of seconds (B-D). This is the period in which the pollutant sprayed in the environment interacts with the surface of the sensor and the signal is accumulated. After the relaxation of the fog, the amount of pollutant decreases and so thus the measured signal (point D and beyond).

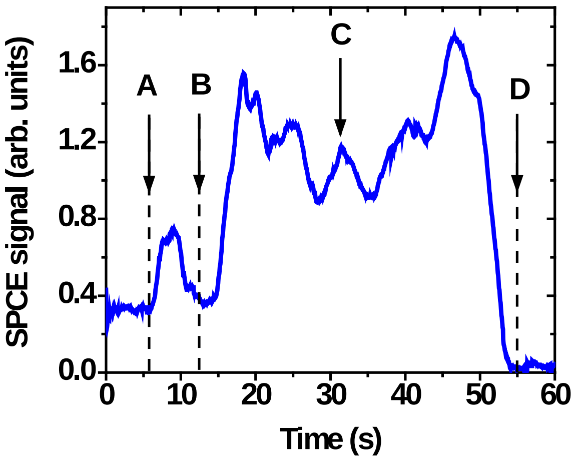


Fig. 4 *Surface phot-charge effect signal measurement during spraying of fog with admixture of potassium dihydrogen phosphate (KH_2PO_4).*

5. Conclusion

A portable device capable of measuring the surface photo-charge effect is demonstrated. The design, the principles of work and the capabilities of the device SPCE Meter 1 are described in this report. It relies on selection and amplification of the weak SPCE signal from the sensor. The capabilities of the device are demonstrated in real on-site measurements of pollution decontamination with fog.

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