Journal of Electrical Engineering 5 (2017) 329-334
doi: 10.17265/2328-2223/2017.06.005

Minimal Electric Charge Detection Device for Perimeter Security Systems

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Abstract: Passive types of perimeter security systems based on the detection technique of minimal electric charge are developed and applied in the test fields. The detection technique of electric charge is based on the triboelectric effect. If two different types of materials are rubbed with each other, electric charges are generated at the friction surface. Simple telecommunication cable can be employed instead of the expensive sensor transducer for sensing the exterior intrusion. Minimal electric charges are generated between the cable conductors and isolator when little forces and impacts are applied to the cable. The developed charge detection device detects the generated minimal charges. The fixed long length of sensor cable is fastened on the various types of perimeter fences. It is a passive sensor fence based on the algorithm of electrostatic charge separation detecting the friction electromotive force. The guard alarm for perimeter fences is generated by signals on the local deformation of the fence and the sensor fastened to it at any unauthorized penetration by getting over the fence. Charge sensitivity of the developed experimental device is 1.6×10^{-16} coulombs. This system is expected to be applied widely in more field areas.

Key words: Triboelectric effect, sensor cable, alarm.

1. Introduction

The physical defense system has been developed from the first generation to the third generation using the latest technologies. The first generation was dependent on the barbed wire fence and guards' eyes and the second generation was based on electric fences and CCTV (closed-circuit television) cameras. The generation consists of a surveillance system based on GPS (global positioning system), cameras and the related wireless communication system, an alarm system with various sensor fences, an access control system from outside gates to the inside of the buildings and the systems are integrated into a central security control server. The purpose of the physical protection system is to detect an unauthorized intruder; whereas the perimeter intrusion detection sensor fence detects the intruder right away by a surveillance monitoring system which covers before and after the intrusion, and at the same time prevents the intruders by a sensor at the earliest time. There are several kinds of fences in the second generation such as a taut-wire, a vibration, an electromagnetic induction sensor and in the third generation including a fiber optic cable, a micro wave, and an electric charge sensor.

When classifying and comparing certain exterior perimeter systems, five methods are considered [1]. The first one is passive or active sensors. Passive sensors detect energy submitted by the target, or detect a change in the environment associated with the presence of the target. Active sensors transmit some forms of energy and detect a change in the received energy created by a disturbance caused by a target. The second type of comparison is a covert operation of sensor or its visibility to the intruder. The third type of method is the requirement for the sensors to have a LOS (line-of-sight) or follow the terrain. The fourth type of comparison is whether the sensors are volumetric (detect intrusions in a volume of space) or line detection (detect along a line). Finally, the

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application method classifies these systems into three modes: buried line, fence-associated, and freestanding.

The charge multiplying semiconductor detector has the unique characteristics as a charge amplifier in a circuit containing a tunnel diode biased for charge detection [2]. In Ref. [3], there is a poly electric polymer sensor with an integrated charge amplifier. First prototype device design of the security system based on the triboelectric effect was developed and investigated in the study [4].

The electric charge sensor fence is the unique system in this field as the first passive sensor in the world and it uses the special algorithm of electric charge displacement which is based on friction electromotive force change of the passive sensor cable. The electric charge technique is based on the triboelectric effect. If we rub two different types of materials with each other, electric charges are generated and these are called triboelectric effect. Physical protection security system can be realized using by triboelectric effect. Simple telecommunication cable is used in the protection systems instead of the sensor transducer that is fastened on the various types of perimeter fences. Electric charges are generated, when external force is applied to the sensor cable.

The charge detection device named as ASU (analog sensing unit) detects the generated minimal charges and rings an alarm. It does not generate any electric signals and electromagnetic fields. It only reacts against the change on electric charge in specific range. It is not affected by any external factors. Thus, there is no false alarm and perfect probability detection. Also the security detection device does not generate the false alarm signals on and after exposure to the outdoor environment factors such as humidity, rain, wind, fog, dust etc. Sensor cable reacts against the forced impact weighing 8-20 kg on the fence. It does not detect little forces, for example, small animals hit the fence. The system sensitivity can be regulated by switches. Electric charge sensor fences are not harmful to the human body. These types of security systems have much more advantages than any other systems. It has simple installation and easy maintenance and is (highly affordable) more economical than any other systems.

2. System Design and Solution

Simple shielded telecommunication 10~15 pair of cable is used instead of the sensor transducer for sensing the external force and impact. That cable does not connect to the power supply. Fig. 1 shows the main operation diagram of the system.

Electric charges are generated between the cable conductors and isolator when external force and impact are created by the intruder. The lengths of sensor cable are limited up to 1,000 m.

Coaxial cable is used for transferring generated minimal electric charge between the sensor cable and ASU. Because of the very high input impedance of the charge amplifier, the sensor must be connected to the amplifier input with low-noise cable. This cable is specially treated to minimize triboelectric noise which is generated within the cable due to physical movement of the cable. The coaxial cable is necessary to affect an electrostatic shield around the high impedance input lead, precluding extraneous noise pickup.

ASU is connected to the data center through the TCP/IP protocol. ASU includes the TCP/IP module. The data center registers fence alarms and ASU's status when some problems occurred on the perimeter

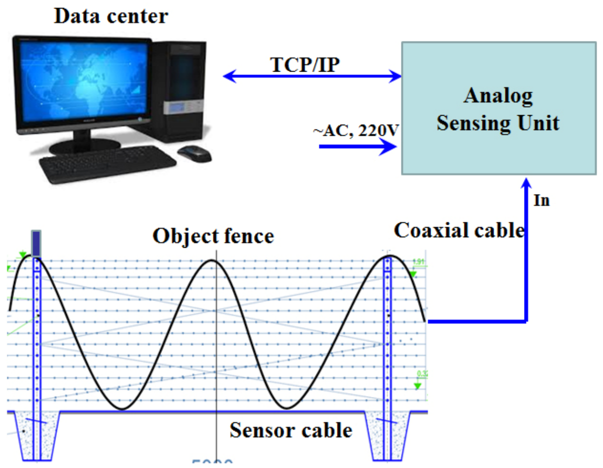

Fig. 1 Main operation system diagram of the system.

security fence. For example, there are generated alarms when the sensor or coaxial cable is cut or short.

Fig. 2 shows functional internal diagram of ASU.

The ASU detects the generated charges on the passive sensor cable by intruder and ring the alarm. The ASU contains a charge sensitive device, voltage amplifier, signal shaping, filtering, and comparator. The charge sensitive preamplifier is the main part of the charge detection device. The charge sensitive device consists of the charge preamplifier and filters. There are two basic types of preamplifiers that can be used for sensing charge difference.

(1) Charge preamplifiers;

(2) Voltage preamplifiers.

The cable capacitance has a little effect on the overall sensitivity of the system when it uses charge preamplifier. Charge preamplifiers can be used with various cable lengths without the need for recalibration due to cable capacitance. Voltage preamplifiers require recalibration when different cable lengths are used because the sensitivity is directly related to cable capacitance.

Charge preamplifiers produce an output voltage that is related to the charge input and other parameters of preamplifier. Fig. 3 shows a schematic of a charge sensitive preamplifier.

Input charge of the sensor cable is expressed by Eq. (1).

$$q_{IN} = q_{SC} + q_{CC} + q_F \tag{1}$$

$$q = V * C$$

$$q_{IN} = V_{IN}(C_{SC} + C_{CC}) + V_{OUT} * C_F \tag{2}$$

Voltage difference of positive and negative inputs is zero (Vin = 0) during normal mode of the operation amplifier.

$$q_{IN} = V_{OUT} * C_F$$

$$V_{OUT} = V_F = \frac{q_{IN}}{C_F} \tag{3}$$

The output voltage is dependent on the ratio of the only input charge to the feedback capacitance as shown in Eq. (3) when Vin is zero.

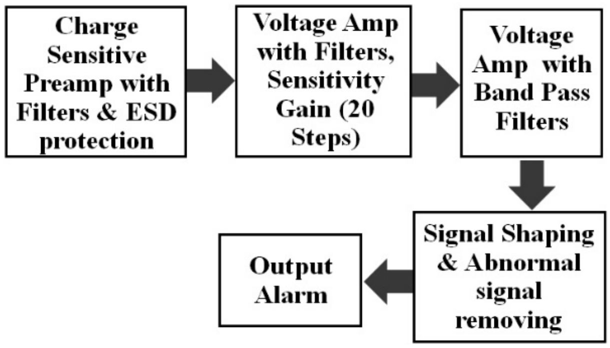

Fig. 2 Functional diagram of ASU.

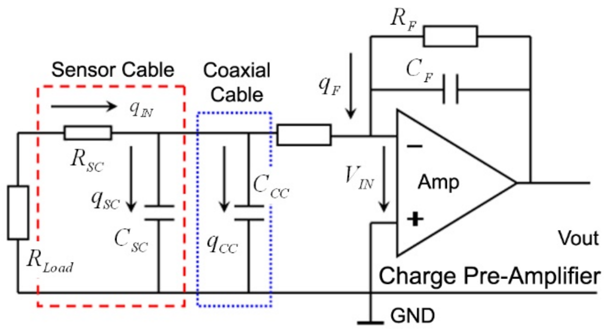

Fig. 3 Charge sensitive preamplifier with sensor and coaxial cable.

The voltage difference of positive and negative inputs is nonzero (Vin! = 0) when there is deformation on the cable. As shown in Fig. 3, gain of the amplifier is expressed as Eq. (4).

$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_F}{R_{MAIN}} \tag{4}$$

$$R_{MAIN} = R_{LOAD} + R_{SC}$$

As shown in Eqs. (2) and (4), dependence of the output voltage and input charge is related by Eq. (5).

$$V_{OUT} = \frac{q_{IN} * R_F}{(R_{LOAD} + R_{SC}) * (C_{SC} + C_{CC}) + R_F * C_F} \tag{5}$$

KSC 3603 0.5mm×15P cable was used for doing system experiment. By specification of the cable, capacitance and resistance is approximately $70nF/km$ and $94\Omega/km$ [5]. And 500 m sensor cable was used in this experiment. Thus, the cable capacitance and resistance is approximately $C_{SC} = 35nF$ and $R_{SC} = 47\Omega$. The capacitance of coaxial cable is 101.05 pF/m [6]. The capacitance is approximately $C_{CC} \approx 1pF$ when 100 m coaxial cable was used in this experiment. Because it is estimated that 100 capacitors are connected by series.

As shown above parameters of charge preamplifier are:

(1) $R_{LOAD} = 200K\Omega$
(2) $R_F = 14.1M\Omega$
(3) $R_{SC} = 47\Omega$
(4) $C_F = 6.8nF$
(5) $C_{SC} = 35nF$
(6) $C_{CC} \approx 1pF$

Eq. (6) shows the relation of the input charge and output voltage which are estimated as in the above parameters and Eq. (5).

$$q_{IN} = \frac{V_{OUT}}{0.137} \quad (6)$$

The voltage amplifier amplifies and shapes the generated signal from the charge preamplifier stage. Filtering is the most important part of system because there is much more external noise to affect the normal operation. In this system, filtering circuits are used in all the stages. Analog comparator was used to compare the generated signal by the intruder with the reference value then raise the alarm.

3. Experiment and Results

Fig. 4 shows experimental charge detection device named as ASU. The ASU includes the surge protection elements and sensitivity control switches.

Sensitivity levels are depended on perimeter fence types and environmental conditions.

Fig. 5 shows the sensor cable output signal level when cable does not connect to the ASU. Low level signal is mixed with high frequency noise.

As shown in Fig. 6, noise of the sensor cable was removed perfectly after passing the stages of the voltage amplifier, shaping and filtering parts.

As shown in Fig. 7, there is generated voltage difference on the sensor cable, when a person gives a light touch by hand approximately 2-3 kg. It can be estimated the generated electric charges by Eq. (6). The generated voltage difference was approximately $1\mu V$ after estimating charge and voltage amplifier gain

Fig. 4 Experiment device.

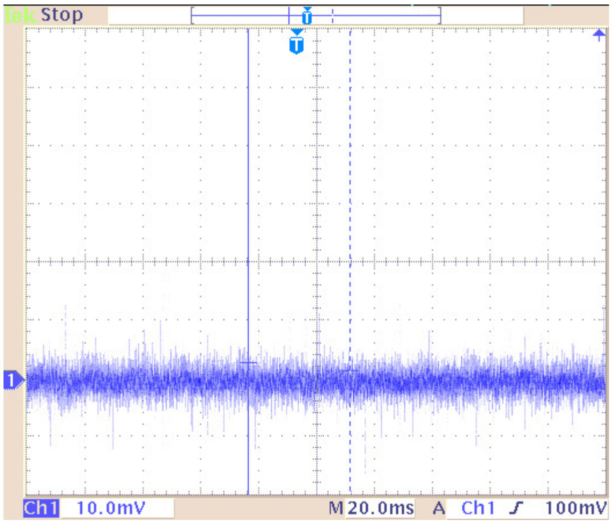

Fig. 5 Output signal of sensor cable.

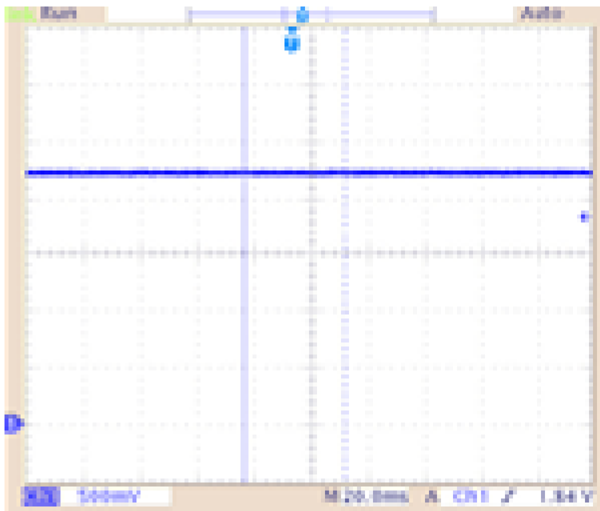

Fig. 6 Output signal of sensor cable.

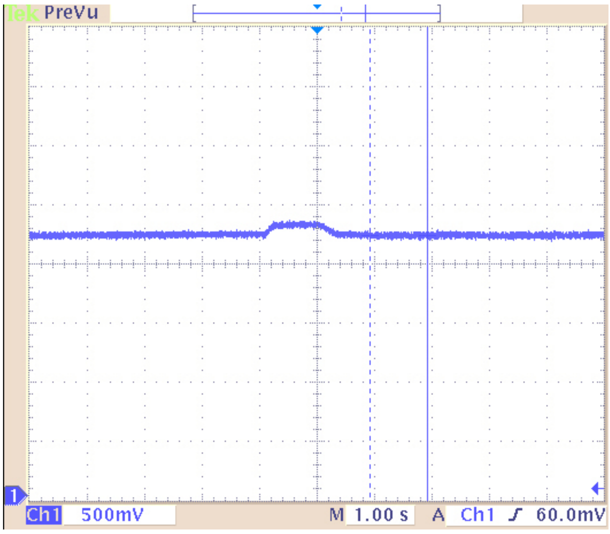

Fig. 7 Output signal of sensor cable when minimal force is applied on the cable.

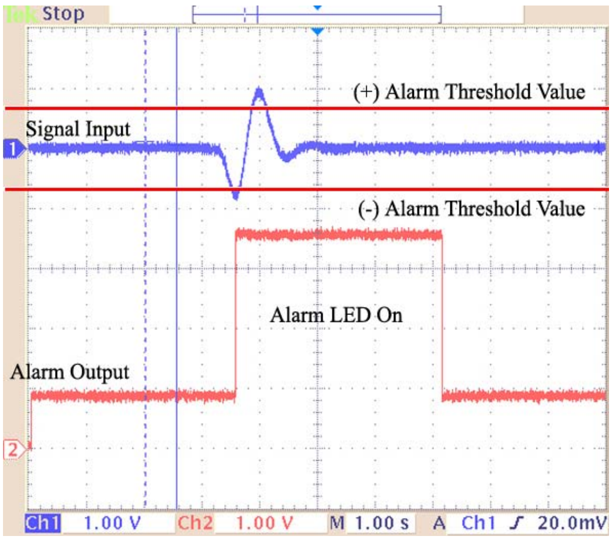

Fig. 8 Output signal of sensor cable (signal input) and alarm signal shapes.

using Eq. (6). That $1\mu V$ value means only output of the charge sensitivity preamplifier.

$$q_{IN} \approx 7.3 * 10^{-15} C$$

Fig. 8 shows the alarm signal (LED on) output when normal human force (approximately 6~8 kg) is applied on the sensor cable fastened fence. Signal input means output signal of the sensor cable while passing all ASU's stages such as voltage amplifiers and filters. It is generated alarm when value of signal input exceeded the threshold value.

As shown in the experiment results, the generated charges increase when applied exterior force on the cable increases. It can be regulated the sensitivity of system. As shown in the experiments, the charge sensitivity of experimental detection device is about $1.6 * 10^{-16}$ coulombs.

4. Conclusions

The proposed minimal charge detection device named as the ASU detects and rings alarms for all types of sensor cable cutting and forced impact on the fence. Perimeter security system consists of ASU, coaxial and sensor cable, security fence and data center. There are generated alarms on the data center when intruders touch and try to pass over the sensor cable fastened security fence. The sensor cable reacts against 8~20 kg forced impact on the fence. The device sensitivity can be regulated by switches. In addition, the system works without influences of soil, water and freezing conditions, as well as temperature and climate changes. Passive sensor cable does not generate any electric signal and electromagnetic fields. The charge sensitivity of the proposed device was about $1.6 * 10^{-16}$ coulombs. The charge sensitivities of the existing charge amplifier devices [2, 3] are lower than the proposed device.

As shown in the experiment results, ASU has generated the false alarms during high wind. Therefore, it has to analyze input analog signal of the sensor cable for reducing false alarms due to high wind effect. It has been seen that we need to improve the ASU hardware design and develop new device for reducing false alarms in further work.

Acknowledgment

This research was financially supported by the Project No. COR_01/2015 "High Sensitive and Errorless Security Fence System" of the Mongolian Foundation for Science and Technology and by the Project No. 2016952895 "Sensitive and Errorless Electrical Security Fence by Using Minimal Friction Electricity in Coaxial Cable" of the National Research

Foundation of Korea.

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