A. B. Dobrovolskiy

INCREASE OF INFORMATION CAPACITY OF SIGNAL DEVICES, INTENDED FOR STATE FRONTIER PROTECTION

The paper considers the following problems: evaluation of information capacity of technical means of state border protection, ways of its improvement, techniques of trespasser motion parameters determination by means of two-positional radio-emission devices, method of distance to the trespasser determination by means of break type signal devices, based on the measurement of electric capacitance of sensitive element.

Key words: *information capacity, technical means of border protection, two-positional radio-emission signal defence device, break type signal device, detection zone, microcable.*

Introduction

Nowadays, rather wide range of technical means is used for the protection of state border. For instance, for signal blocking of local sections of state border two positional radio-emission signal defence devices (RESDD) — СС-84РЛБ («Vitim»), РЛД-73 («Georgin») and break type signal means — «Khmel-1», «Crystal-M», «Crystal-2», «Liana-1», «Tros». Two-positional RESDD, that can replace «VITIM» and «GEORGINA» are signal devices «FORTEZA-12» and «RADIY-БРК» [1 – 2]. Reading break type signal means, they can be replaced by such devices as «Crab-1» and «Cuvshinka-M» [3 – 4]. Characteristic feature of the existing signal devices for the protection of local sections of state border is their insufficient information capacity, because these devices can not determine the direction of motion and speed of the trespasser the distance to him. Information capacity of technical devices for border protection can greatly influence the efficiency of trespasser capturing process. If the above-mentioned conditions are realized in break type signal devices and RESDD, then, the information capacity will increase [5 – 6].

Results of research

For comparison of various technical means of border protection, the most universal criteria are information capacities, based on the volume of information regarding trespasser. In [6] evaluation of information capacity of the existing models of technical means, intended for border protection according to their tactical-technical characteristics has been performed, as well the change of information capacity of these technical means evaluation, if they possess such functional possibilities – storage of the information, regarding the fact of trespass, determination of trespasser motion direction and distance to him, his radioimage formation. To determine the information capacity of technical means of border protection the following expression is used:

$$I = K \log_2 (N_T N_W N_D), \tag{1}$$

where K — storing factor ($K = 1$ - information about the fact of trespass is stored; $K = 0$ — information is not stored); N_T — time degree of freedom; N_W — space degree of freedom; N_D — number of freedom degrees types.

The number of time degrees of freedom influences information capacity of technical means, but it must be taken into account in cases when for the formation of alarm signals, time parameters are used, for instance, delay time of the received signal relatively emitted signal. Part of existing technical means do not use time characteristics of the signal and time degrees of freedom for finding information capacity will be missing. Usage of space parameters regarding the information about trespasse fact is widely spread in technical means of protection [6].

Infra-red imaging means have highest information capacity among all technical means of protection but at the same time have some drawbacks — they can not be adapted to all types of terrain and have high cost (from tens thousands to several hundreds thousands of USD). In their turn other technical means have possibilities to increase their information capacity:

- at first, it is storage of the information obtained, if it is realized in the device «Khmel-1» the information capacity will equal 1 bit;
- secondly, if technical means of border protection have the possibility to determine the direction of trespasser motion, for instance, signal system «Vitim», then its information capacity will equal 5.3 bit;
- thirdly, if there is a possibility to determine the distance to the trespasser, for instance, in signal devices «Khmel-1», «Crystal-2» and in signal system «Vitim» (that already determines the direction of motion) with the errors of distance measurement — 5 m («Khmel-1»), 15 m («Crystal-2»), 1 m («Vitim»), then their information capacity will equal 10.2 bit, 7.2 bit, 13.1 bit, correspondingly;
- fourth, in the process of realization of radio-image formation function there appears the possibility to determine the cross-sectional dimensions of the trespasser and if for the system «Vitim» (that already determines the direction of motion and the distance to the trespasser) and radar units ПСНР-5 and СБР-3 we take by cross-sectional dimensions 0.5 at the the width of the controlled area 5 m and at the height of the controlled area 1.7 m their information capacity equals 18.9 bit, 19.3 bit, 14.27 bit.

Table 1 contains the data, regarding information capacity of technical means of border protection according to their tactic-engineering characteristics and evaluation of ways of its improvement while realization of the above-mentioned methods of improvement.

Table 1

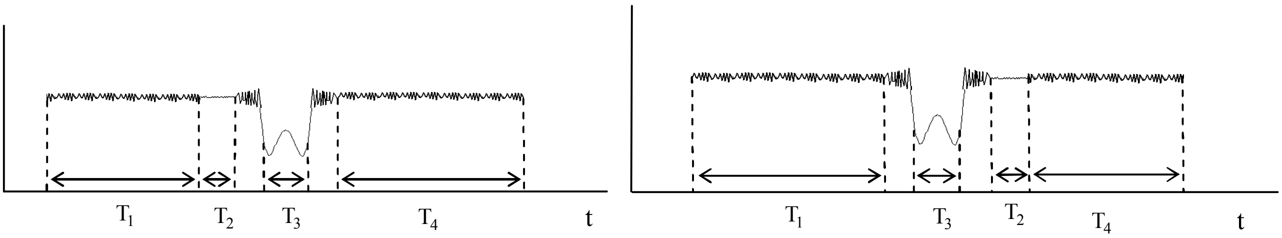
Information characteristics of technical means of border protection

Information characteristics	Signal means				Radar installation		Infra-red means	
	breaking type			two-position radio emission				
	«Khmel-1» (Ukraine)	«Crystal-2» (USSR)	«Crab-1» (Russia)	«Vitim» (USSR)	СБР-3 (USSR)	ПСНР-5 (USSSR)	Vario View™150 (Germany)	Carl Zeiss (Germany)
N_W	1	1	50	1	7,8 $\left(\frac{L}{\Delta L}\right)$ 20 $\left(\frac{\beta}{\Delta\beta}\right)$	15 $\left(\frac{L}{\Delta L}\right)$ 40 $\left(\frac{\beta}{\Delta\beta}\right)$	640 (N_X) 420 (N_Y) 7000 $\left(\frac{L}{\Delta L}\right)$	640 (N_X) 512 (N_Y) 3600 $\left(\frac{L}{\Delta L}\right)$
N_D	2	2	2	2	3	3	3	3
I, bit	1/0*	2	6,6/0*	4,3	8,4**	13,5**	32,8**	32,1**
Possible ways of improvement: 1). Information storage. $I_з$, bit	+ 1	—	+ 6,6	—	—	—	—	—
2). Determination of	—	—	—	+ 5,3	—	—	—	—
	+	+	—	+	—	—	—	—

Information characteristics	Signal means: breaking type «Khmel-1» (Ukraine)	Signal means: breaking type «Crystal-2» (USSR)	Signal means: breaking type «Crab-1» (Russia)	Signal means: two-position radio emission «Vitim» (USSR)	Radar installation СБР-3 (USSR)	Radar installation ПСНР-5 (USSSR)	Infra-red means Vario View™150 (Germany)	Infra-red means Carl Zeiss (Germany)
direction I_d, bit	10,2	7,2		13,1				
3). Randing I_r, bit	—	—	—	+ 18,9	+ 14,27	+ 19,1	—	—
4).Formation of radioimage. I_r, bit								

Note: * - value of information power / but the information is not stored; ** - value of information power corresponds to transport means (automobile).

In [7] the possibility to determine the motion direction and speed of the trespasser by means of two-position RESDD, and his classification by the type-man or large animal is noted. To determine the direction of object motion by two-position RESDD, the reflector is used in the detection area. If the reflector is located in the detection area, the determination of motion direction is performed as a result of tailing of the received signal sequences change: overlapping by the object the beam to the reflector, then direct beam, or inverse sequence occurs, as it is shown in Fig. 1.



a) b)

Fig. 1. Signal being registered at the output of the receiver: a) when the object moves in the direction "to us"; b) when the object moves in the direction "from us"; T_1, T_4 - time interval, when interference occurs; T_2 - time interval, when interference is missing; T_3 - time interval, when the object intercept the direct beam

The drawback of the given method is that for its operation, the reflector must be accurately located on the edge of the detection area. That is why such method is suitable for two-position RESDD, located stationary, for instance, signal system «Georgin». Besides, if trespasser overcomes the detection area near the transmitter or receiver, this will result in rapid decrease of the amplitude of the received signal. That is the trespasser by his body will block simultaneously both direct beam and beam the reflector, and it will be impossible to determine the direction of trespasser motion. To determine the direction of motion by means of signal system «Georgin» the trespasser must overcome the detection area at the distance not less than 12 m from the receiver or the transmitter [8].

While registration of the start of beam blocking on the reflector(from the reflector) and beginning of direct beam blocking or while registration of time indices in inverse order it becomes possible to determine such parameter of motion as trespasser speed. The speed is found by the following formula:

$$V_n = \frac{2R_m \lambda r_r}{(8r_r^2 + R_m \lambda)(t_2 - t_1)} \tag{2}$$

where t_1, t_2 - moments of time of beams blocking in the direction of the reflector and direct beam; r_r - distance from the middle line (direction of the direct beam) to the reflector, located at the edge of detection area; R_m - distance between the transmitter and receiver; λ - length of the wave, generated by the transmitter.

Classification of the trespasser is carried out by the following features:

- by registration of the change of complex amplitude modulus under the impact of lateral dimension of the object, Lateral dimension of large animals is greater than the lateral dimension of a man ($a > 0.25$ m). In [9] the model of signal formation in two-position RESDD as a result of diffraction of electromagnetic waves on the trespasser, is presented. According to the given model the range of complex amplitude module change at the point of reception increases at the growth of lateral dimension of the trespasser.
- by the duration of the beam overlap on the reflector (from the reflector) or direct beam.

Table 2 contains the features of identification and corresponding criteria.

Table 2

Characteristics of impact identification of object violation

Characteristic of identification	Criterion of identification
Change of signal (X_1) amplitude is registered first as a result of overlapping of violation object of the beam on the reflector (from the reflector)	Criterion of motion direction determination – the object moves «to us»
Considerable decrease of signal (X_2) amplitude as a result of the overlap by the object direct beam violation	Criterion of motion direction determination – the object moves «from us»
Change of complex amplitude modulus at lateral size is more than 0.25 m (X_3)	Criterion of object type determination (man/animal)
Time of beam overlap duration on the reflector (from the reflector) (X_4)	Criterion of object type determination (man/animal)

Similarly to the process of signals evaluation in radiolocation [10], additional features of signal identification can be considered as parallel detection of the signal by corresponding feature. The structure of signal processing algorithm, taking into account identification criteria consists of several parallel channels of signals identifiers by corresponding feature, as it is shown in Fig. 2.

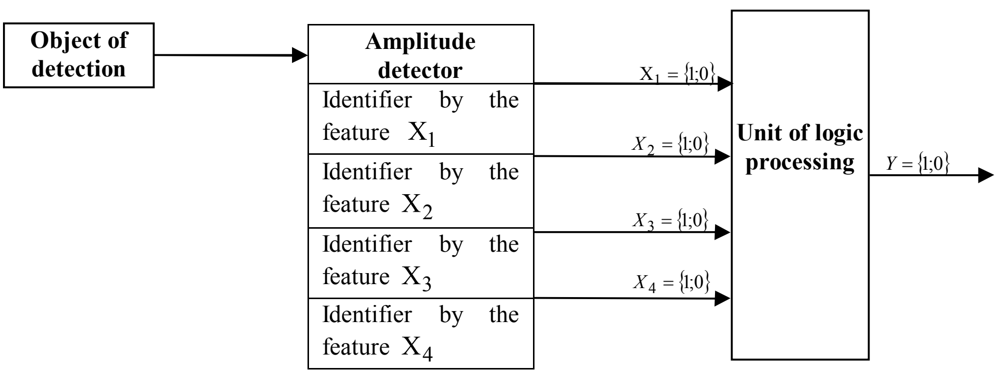


Fig. 2. Structure of signal processing algorithm

As it is shown in Fig. 2, amplitude detector besides boundary detection, processes signal by means of additional processing channels, which include identifiers by the features X_1, X_2, X_3, X_4, by which unit of logic processing determines the direction of the motion and the type of trespasser (man or animal).

To understand how logic processing unit operates, it is necessary to understand the logic of its operation, that is, to find correspondence between input and output signals, the following actions should be done:

first – we compose the truth table (Table 3);

second – according to the Table we will write down logic function (formula) by means of the method, called «expanded disjunctive normal form»:

- in the given Table only the sets of variables, at which the value of function equals «1» are selected;
- for each set the conjunctions of all input variables, having value «1» are written, variables, having value «0» are written as inversions of these variables;
- all the obtained conjunctions are united by the signs of disjunction, this will be logic function, that can be minimized, applying the laws of Booleam algebra;

third – we construct logic scheme by minimized logic function.

Table 3

Truth table

Variables				$Y(X_1,X_2,X_3,X_4)$
X_1	X_2	X_3	X_4	
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	1	1	1	1
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	1
1	1	0	0	0
1	1	0	1	0
1	1	1	0	0
1	1	1	1	1

Logic function for the case, when the type of the object (man) and the direction of its motion to be determined, will have the following form:

$$Y = \overline{X}_1 \cdot X_2 \cdot X_3 \cdot X_4 + X_1 \cdot \overline{X}_2 \cdot X_3 \cdot X_4 + X_1 \cdot X_2 \cdot X_3 \cdot X_4 . \quad (3)$$

Having reduced the expression (3) we obtain:

$$Y = X_3 \cdot X_4 (\overline{X}_1 \cdot X_2 + X_1 \cdot \overline{X}_2 + X_1 \cdot X_2) = X_3 \cdot X_4 \cdot (\overline{X}_1 \cdot X_2 + X_1) . \quad (4)$$

Logic scheme of processing unit is shown in Fig. 3. When constructing logic scheme, based on the above-mentioned logic function we take into account the established procedure of logic operations execution: inversion, product, addition, we should not forget about the priority of brackets.

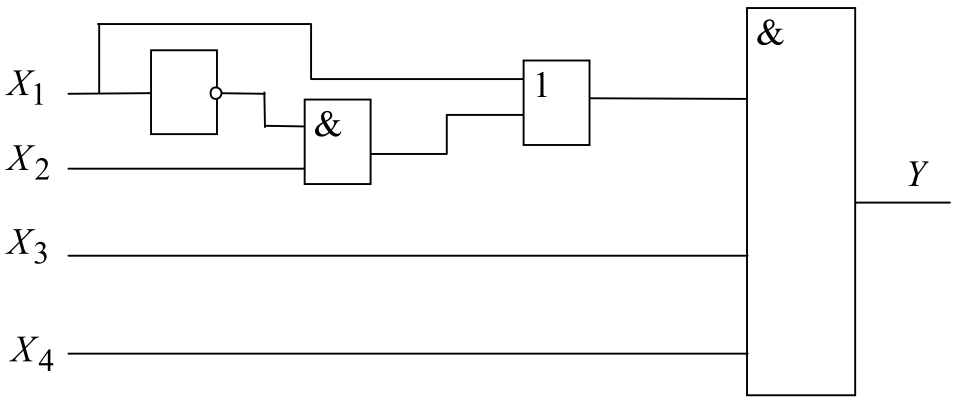
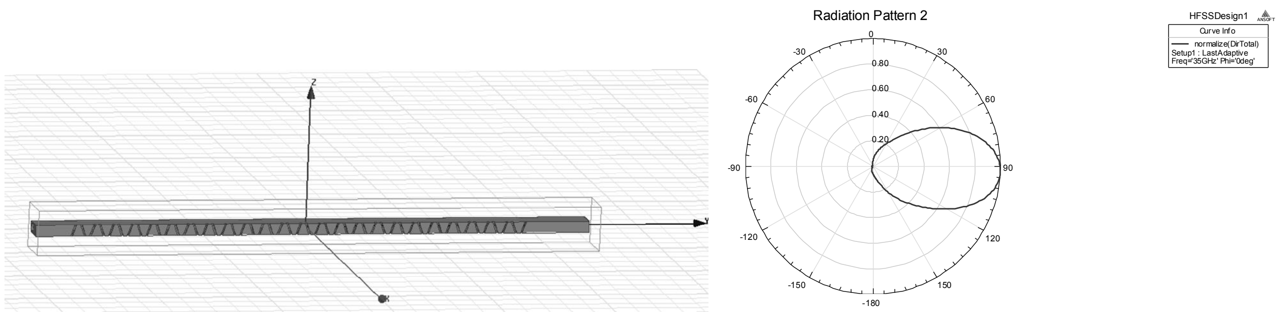


Fig. 3. Logic scheme of processing unit

In [11] another method of trespasser motion determination by means of two position РПСЗО is suggested. The necessary condition, is the formation of asymmetric zone of detection. To create asymmetric zone of detection it is sufficient to have asymmetric directional pattern of the transmitter or the receiver, that would be narrowed from one of the sides to its middle line. For modeling of slotted-guide aerial of signal system «Vitim» transmitter programme HFSS v. 13.0 was used. The process of modeling in HFSS is shown in [12].

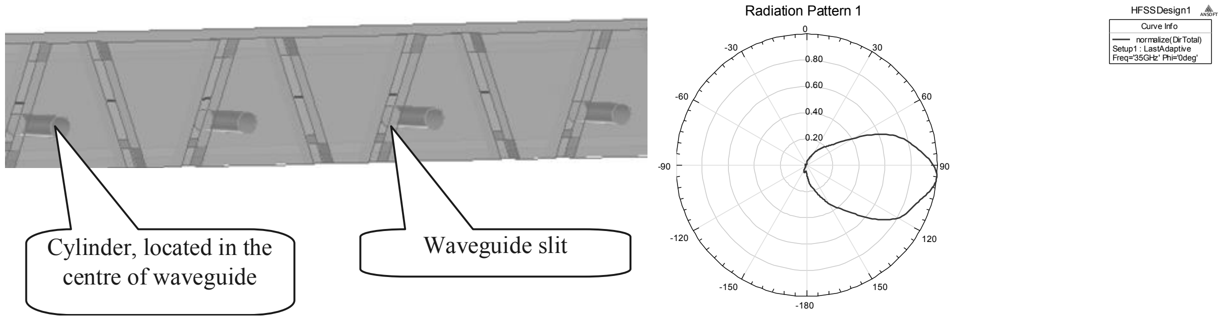
Output data for modeling are dimensions of the aerial and wave length, that corresponds to operating frequency 35 GHz. As a result of modeling of the aerial, used in the transmiiter of two-positional РПСЗО «Vitim» (Fig. 4 a), its directional pattern, shown in Fig. 4 b, is obtained .



a) б)

Fig. 4. Waveguide-slit aerial of “VITIM” system in HFSS v. 13.0: a) external view; b) directional pattern

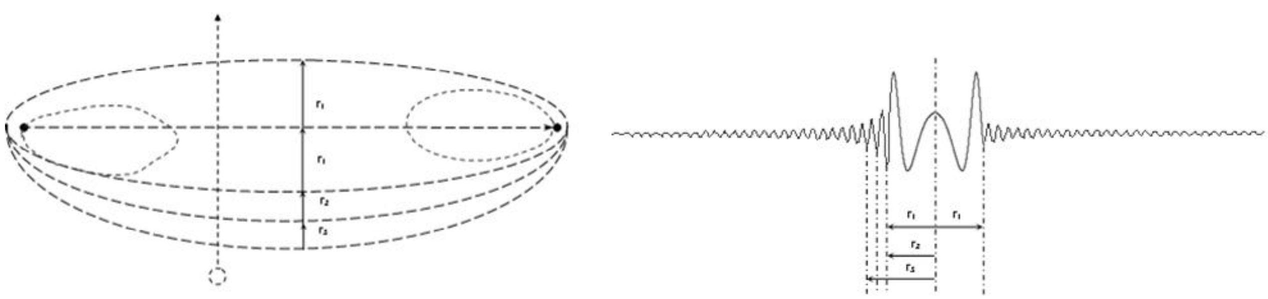
As a result of modeling in HFSS the construction of transmitter aerial was changed. The essence of construction changes is the following: small metal cylinders are located in the middle of wave-guide, as it is shown in Fig. 5 a. As a result, directional pattern of the aerial changes, it narrows from one side to its middle line and, vice versa, widens from the other side. The form of such directional pattern is shown in Fig. 5 b. Hence, placing metal cylinders of different dimensions in the middle of the wave guide and changing the coordinates of their location, the directional pattern of the required form, can be obtained.



a) b)

Fig. 5. Waveguide-slit aerial transmitter with changed construction (cylinders in the centre of waveguide): a) external view; b) directional pattern

Determination of the direction of motion of the trespasser is realoized by the analysis of received signal sequence as a result of asymmetric signal sequence. As a result of asymmetric form of the detection area, the trespasser, who is from the wider side of detection area (relatively the middle line), emits and forms in the receiver higher level of the signal, than being from the narrow side of detection area. Formation of asymmetric detection area is explained at Fig. 6 a, where directional pattern of the transmitter is asymmetric Fig. 6 b explains how the received signal will change, if the trespasser performs tangential (transversal) motion across asymmetric area of detection from wide side to the narrow side.



a) b)

Fig. 6 Asymmetric zone of detection: a) external view of detection zone, formed due to asymmetric form of of direction diagram of the transmitter ; b) signal diagram in reception channel while trespasser motion across asymmetric detection zone from wide side to the narrow side

Concerning signal devices of break type, the above-mentioned devices «Crab-1» and «Kuvshinka-M» have the possibility to determine the approximate length of sensitive element. The given functional possibility is realized on the basis of the method of pulse reflectometry. However, the given method has some drawbacks:

– maximum length of sensitive element can not be more than 500 m, because in the process of propagation of electro-magnetic wave in waveguide line its attenuation in the earth occurs;

– for operation its signal device must be grounded, as a result of its properties the soil can limit the length of wire, being controlled, for instance, if the soil is dry or rocky;

– using the method of pulse reflectometry signal device is active, that, in its turn, leads to decrease of operation, if self-contained power supply is used.

It is possible to overcome such a drawback as the necessity of grounding using in signal devices the cassettes with microcable, and determination of microcable length, based on measurement of its capacitance can be the alternative to the method of pulse reflectometry.

Cassettes with microcable are used in the following signal devices of break type – «Khmel-1», «Liana-1», «Tros». Microcable comprises two conductors, 0.05 mm of diameter. Operation principle of signal devices, using cassettes with microcable is the control of microcable integrity by means of registration of its resistance change. Electric circuit, being controlled, is formed as a result of fusion of microcable end. The above-mentioned devices do not possess the function of determination of the distance to the place of sensitive element break.

Measurement of the distance to the place of microcable break by means of measurement of capacitance can be reduced to the following technique, that comprises the following actions:

– measurement of capacitance value of the control length of the broken microcable and calculation of the value of the linear capacitance, as it is shown in the formula:

$$C_{\text{lin}} = \frac{C_c}{\mathrm{L_c}}, \tag{5}$$

where C_c – capacitance of the control length of microcable; L_c - control length of microcable.

– realization of permenant control over the values of initial and final values of voltages in microcable;

– measurement of microcable capacitance charging time;

– calculation of residual capacitance of microcable by the formula (3):

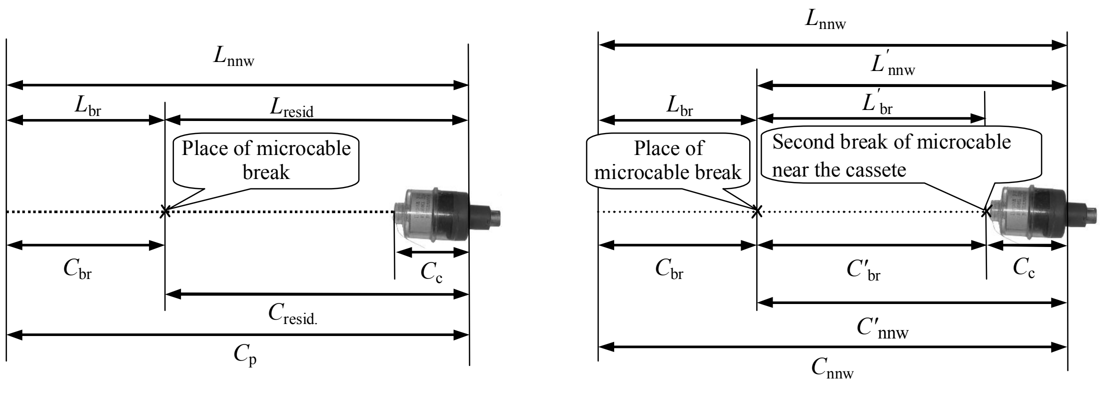
$$C_{\text{lin}} = \frac{t}{R \cdot \ln\left(1 - \frac{U}{U_0}\right)}, \tag{6}$$

where R – resistance of microcable, across which the charging of the capacitance of the rest of microcable occurs; U – initial value of voltage in microcable; U_0 – final value of voltage in microcable; t – time of capacitance charging of the rest of microcable from U_0 до U.

– determination of the distance to the place of break by the formula (7):

$$L_{rest} = \frac{C_{rest}}{C_{lin}}. \tag{7}$$

However, the given technique of measurement of the distance to the place of break, using cassettes with microcable is impossible to use, because linear capacitance will be stable value only for the section of the broken microcable without cassette (L_{br}), as it is shown in Fig. 7 a.



a) b)

Fig. 7. Cassette with unreeled microcable

Accordingly, it is possible to find the distance L_{br}, as it is shown in the expression:

$$L_{br} = \frac{C_{br}}{C_{lin}} = \frac{C_{un} - C_{rest}}{C_{lin}}. \tag{8}$$

Linear capacitance can not be used for determining the length of the rest of microcable (L_{res}) and unreeled microcable (L_{ur}), because the capacitance of the rest of microcable (C_{rest}) and capacitance of unreeled microcable (C_{ur}) is influenced by interbranch capacitance of the cassette it self with microcable (C_c).

To find out the length L_{rest} the possible variant is to break microcable directly before the cassette, as it is shown in Fig. 7 b. Thus, the distance to previous place of microcable break equals:

$$L'_{br} = \frac{C'_{ur} - C'_{br}}{C_{lin}} . \tag{9}$$

But it is not expedient to use the given method, as it does not result in more rapid usage of microcable, contained in the cassette, but it does not allow to realize tactical advantage, when similar devices are used — determination of motion direction in case of blocking of the area.

To realize in signal device of break type such functions as determination of the distance to the object and direction it is necessary to apply another method of microcable capacitance determination. The alternative method may be processing of experimental data of microcable cassette capacitance in two cases — when it is unreeled or when it is broken.

By the results of the experiment capacitance of microcable cassette «Tros» was measured by means of digital multimeter M890G. Total length of microcable of the cassette «Tros» is 2000 m [13]. By the results of the experiment it was revealed that while unreeling of microcable from the cassette the capacitance gradually decreases, although the total length of microcable does not change. By experimental data the equations of regressive polynomials for two above-mentioned cases were found. Coefficients of the equations and degrees of polynomials are determined by means of MathCAD programme. Listing of MathCAD programme for these regressive polynomials is shown in Fig. 8. Where n – degree of polynomial. $L1, C1$ – length and capacitance of unreeled microcable, $L2$, $C2$ – length and capacitance of broken microcable. In vectors of the results $V1$ and $V2$ first three lines are service and other indicate the values of polynomial coefficients.

```
n := 2
v1 := regress(L1,C1,n)              v2 := regress(L2,C2,n)

z := 0,0.1..2000                    z := 0,0.1..2000
re1(z) := interp(v1,L1,C1,z)        re2(z) := interp(v2,L2,C2,z)
```

$$v1 = \begin{pmatrix} 3 \\ 3 \\ 2 \\ 271.604 \\ -0.081 \\ -2.865 \times 10^{-5} \end{pmatrix} \qquad v2 = \begin{pmatrix} 3 \\ 3 \\ 2 \\ 274.144 \\ -2.902 \times 10^{-3} \\ -1.494 \times 10^{-5} \end{pmatrix}$$

Fig. 8. Listing of MathCAD program for two regressive polynomials

The value of the capacitance while unrolling of the cassette will correspond to regressive polynomial, that has the following form:

$$C_{unr}(L_{unr}) = -2.825 \cdot 10^{-5} L_{unr}^2 - 0.081 L_{unr} + 271.604 , \tag{10}$$

where L_{unr} - length of unrolled microcable from the cassette.

The value of the capacitance, if microcable from the cassette is broken, is described by the following polynomial:

$$C_{br}(L_{br}) = -1.494 \cdot 10^{-5} L_{br}^2 - 2.902 L_{br} + 274.144 , \tag{11}$$

where L_{br} - length of broken microcable from the cassette.

Form of the functions (10) and (11) is shown in Fig. 9.

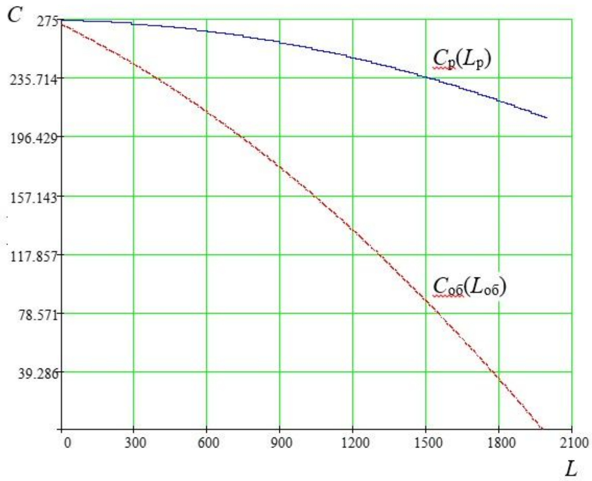


Fig. 9. View of regressive polynomials by experimental data

By means of equation (10) the length of unreeled microcable from the full cassette:

$$L_{unr} = 179.1 \cdot \sqrt{0.037 - 1.13 \cdot 10^{-4} C_{unr}} - 1433.6\,, \tag{12}$$

where C_{unr} - capacitance of the full cassette with unreeled microcable.

When the complete cassette with microcable is used the distance to the break (distance to the trespasser) can be determined by means of the expressions (5) and (9):

$$L_{rest} = L_{unr} - L_{br}\,. \tag{13}$$

However, it is not expedient to determine the distance to the trespasser, using the expression (12), as, every time while blocking the area complete (new) cassette with microcable must be unreeled.

That is why, the necessary precondition, regarding the development of the method of distance to the object (break of microcable) determination is the realization of the possibility of using incomplete cassette with microcable. For this purpose a number of steps must be taken, the explanation of these steps is shown in Fig. 10:

1. Measure the capacitance of incomplete non-unreeled cassette (C_{nur}).

2. Determine the length of microcable in incomplete non-unreeled cassette by the expression (11):

$$L_k = 33467 \cdot \sqrt{0.016 - 5.9 \cdot 10^{-5} \cdot C_{nur}} - 97.12\,, \tag{14}$$

where C_{nur} - capacitance of incomplete non-unreeled cassette.

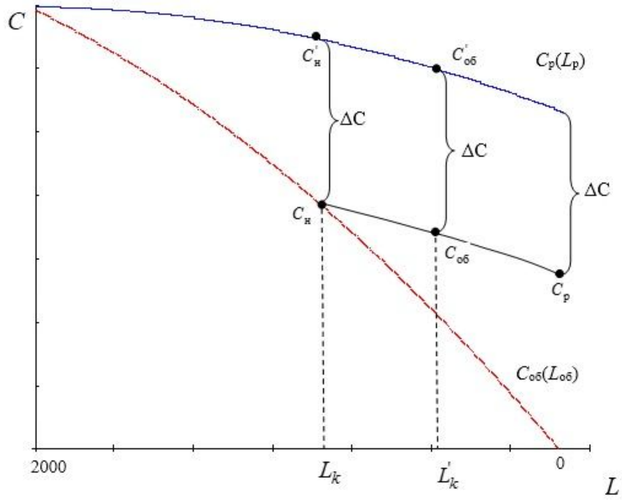


Fig. 10. Dependences of electric capacities of the complete unreeled cassette, incomplete unreeled cassette, complete cassette with broken microcable on the length of microcable

3. Determine, by the formula (12) the capacitance of the complete cassette, unreeled on the length of $2000 - L_k$ ($C_{nur}^{'}$).

4. Determine $\Delta C = C_{nur}^{'} - C_{nur}$.

5. Measure the capacitance of unreeled incomplete cassette (C_{unr}).

6. Measure the capacitance of unreeled, incomplete cassette after microcable break by the trespasser at the length $L_k^{'}$ (C_{br}).

7. Determine the forecast capacitance of complete, unreeled cassette after microcable break by the trespasser at the length $L_k^{'}$:

$$C_{br}^{'} = C_{br} + \Delta C. \quad (15)$$

8. Determine by the expression (12) the length of microcable of new unreeled cassette after the break:

$$L_k^{'} = 179.1\sqrt{0.037 - 1.13 \cdot 10^{-4} \cdot C_{br}^{'}} - 1433.6. \quad (16)$$

9. Determine the length of microcable for incomplete unreeled cassette after its break, taking into account the expressions (14), (16):

$$L_{rest} = L_k - L_k^{'} - \frac{C_{unr} - C_{br}}{C_{lin}}. \quad (17)$$

Conclusions

By the results of the research, carried out, the methods of enhancement of information capacity of signal devices, intended for protection of local sections of state boarder are substantiated. The development of new or improvement of existing signal devices with new functional possibilities intended for protection of local sections of state boarder is expedient.

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Dobrovolskiy Andriy – Adjunct.

Bogdan Khmelnytsiy National Academy of State Frontier Guard of Ukraine.