ENGINEERING SCIENCES

THE STUDY OF DEPENDENCE OF THE RESONANCE FREQUENCIES OF DIFFERENTIAL SENSOR ON THE INTRUDER'S APPROACHING

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Abstract. *The article described the studies in laboratory and outdoor experiments the feasibility of use of two auto-generators with sensitive elements, which were built on the digital logic elements, in the security warning systems for guarding of the objects of civil aviation as capacitance differential sensors. In experiments, the frequency variations of auto-generators are studied depending on the distance of approaching and length of sensitive elements. It is found that when the length is less than 6 m, the sensitive elements are connected to the auto-generators as elements with lumped parameters, whereas of the length is more than 6 m - as elements with distributed parameters.*
Keywords: *Differential sensor, intruder's approaching, resonance frequency, aviation security, security warning system, sensitive element.*

Introduction. In modern times, the provision of stable operation and protection of strategically important civil aviation facilities that ensure the international air transportation, including the improvement of the aviation security against new manifestations of terrorism, and the promotion of the reputation of any state in this area in the international arena are of great importance [1, 2].

The timely, sustainable and reliable response to expected threats depends on the integration level of security-warning systems of strategically important facilities. Sustainable and reliable operation enables early detection of possible threats to the security-warning system, regardless of the environmental impact [3-5]. One of the various control facilities integrated into these systems, which detect the intruder (object) at an early stage, are the capacitance sensors [6].

The approaching of an object (for example, a human) can be detected through the sensors [7]. The sensitivity distance of the sensor, its adaptation to environmental changes, as well as the design of the used auto-generators [8, 9], the size of the sensitive elements (SEs), and the installation configuration have to be comprehensively studied [10].

The purpose of the article is to determine the feasibility of use of two auto-generators, which were built on digital logic elements, with SEs as differential sensors.

For this purpose, dependence of frequency changes of two auto-generators, build on digital logic elements, which was connected SEs, and of sensitivity distance of these auto-generators as differential sensors on SEs' length were studied.

Research methods. Two auto-generators are installed on the same printing board using two digital microcircuits the type of К155ЛА3. The logic elements contained in both microcircuits are symmetrically cross-distributed in the auto-generators circuits [9]. In all experiments, the metal case of the sensors, where auto-generators circuits and frequency measuring device are located, is grounded in accordance with real operating conditions [7] and additionally placed in a hermetic plastic container to be protected from rain during the implementation of outdoors experiments (Figures 1a, 1b). The figure shows the frequencies recorded with the video camera.

a) *b)*

Fig. 1. Differential capacitance sensor in metal case (a) and hermetic container (b).

The experiments were performed on the territory of the National Aviation Academy (NAA) and the facility where the VOR-DME (VOR - Omni-directional range; DME - distance measuring equipment) is located. In the experiments, the frequencies of the auto-generators were measured using two eight-digit frequency measuring devices of SKU00653 model. The accuracy of these frequency measuring devices was verified by “GW Instek GOS 620” oscillator, and their high accuracy (accuracy of 0.1 Hz at 1 MHz frequency) was defined [11]. GoPro video camera with 250 frames per second was used to record fast frequency variations.

The experiments performed on different days in laboratories and outdoor (in the territory of NAA and VOR-DME system facilities) are described below.

1. Dependence of frequency variation on the lengths of SEs. Dependence of the frequency variations on the length of SE was studied in three days in the environments provided in Table 1.

Table 1. Weather condition in three days experiments

Days	Weather Temperature, (°C)	Atmospheric pressure, (mm mercury)	Humidity, (%)	Source
I	22 - 24	750 - 758	50 - 60	[12]
II	21 - 23	761	45 - 50	[13]
III	26 - 28	757	45 - 50	[14]

During the study, SEs of 2 m, 5 m, 6 m, 10 m, 20 m, 30 m, 40 m and 50 m, as well as the copper wires of 4.5 m long are used to cover the sensor case with soil. The HEs are directly connected to each of the auto-generators separately. The experiments were performed on the territory of the navigation facility (Figures 2a, 2b).

Once enabled, the frequencies of both auto-generators account, are 17.12 MHz without SEs and grounding, 17.01 MHz after 60 seconds, and 16.82 MHz when their case was grounded.

a) *b)*

Fig. 2. Experience in VOR-DME area: a) rear view, b) side view.

Graphic depictions of the average values of frequency variations recorded for three different days, depending on the lengths of the SEs were provided in Figure 3. Since the frequencies are repeated with 0.01 MHz accuracy, the frequencies of both auto-generators are shown as one curve.

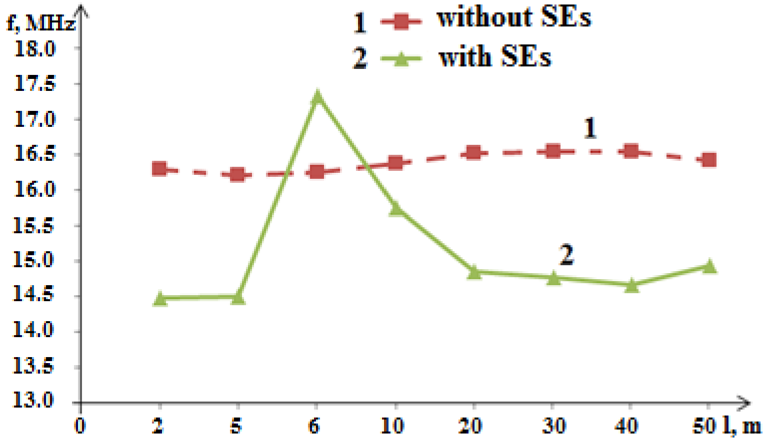

Fig. 3. Graphical representation for the average values of the frequency variations of the auto-generators in three different days depending on the lengths of the SEs

As seen from the figure, the frequencies of both auto-generators without SEs vary around 16.5 MHz at a range of less than ± 0.5 MHz (Figure 3, 1st curve).

With the exclusion of 6 and 10 m, the frequencies of both auto-generators vary around 14.5 MHz at all other lengths of the SEs. Here, the case of the SE of 6 m is specific. In this case, in all experiments performed in three different days, the frequencies of both auto-generators are often higher than those without SE, accounting for $f_{I\ mid.}$ = 17.345066 MHz and $f_{I\ mid.}$ = 17.345066 MHz (Figure 3, 2nd curve) respectively.

2. Experiments performed with approaching. The dependence of sensitivity distance of the sensors on the length of the SEs has been studied. In this regard, the frequencies of the auto-generators were recorded when a person with weight m (the researcher's weight is 93 kg) approached to SEs of 2 m, 5 m, 10 m and 50 m.

2.1. Experiments conducted in laboratory conditions. The auto-generators are connected to two wires as the SEs, each of which is 2 m in length, as well as parallel to each other and to the floor. The wires are fastened to the dielectric supports, at a distance of 0.1 m from each other and 1 m from the floor.

During the study, the approaching was performed perpendicularly to the midpoint of the SE starting at a distance of 3 m, and the frequency values were recorded for the approaching at each meter (l = 3; 2; 1; 0 m) (Table 2). l = 0 is the value when a person touches the SE.

Table 2. The frequencies values of two auto-generators when approaching to SE at 2 m

l (m)	I auto-generator, f_1 (MHz)	II auto-generator, f_2 (MHz)
0	13.661799	13.661016
1	13.781477	13.778263
2	13.811120	13.811674
3	13.813097	13.813492

The difference between the resonance frequencies (Δf_{ob}) at zero (when touching) and 3 m distance from a person to SE accounts for Δf_{ob} = 0.1151298 MHz for the 1st generator, and Δf_{ob} = 0.1152476 MHz for the 2nd generator, respectively.

The lengths for SEs were selected 5 m. During the study, the approaching is performed perpendicular towards SEs from three different points starting at a distance of 3 m (in the 1st case, from the point connected to the auto-generator; in the 2nd case, from the midpoint; in the 3rd case, from the edge) (Table 3).

Table 3. The frequencies values of two auto-generators when approaching to SE at 5 m

l (m)	**I auto-generator, f_1 (MHz)**			**II auto-generator, f_2 (MHz)**		
	I case	**II case**	**III case**	**I case**	**II case**	**III case**
0	11.238468	11.207155	11.209304	11.238467	11.207335	11.209322
1	11.240973	11.238147	11.238210	11.240965	11.238169	11.238253
2	11.241044	11.241434	11.242047	11.241045	11.241435	11.242048
3	11.241095	11.241639	11.242341	11.241093	11.241640	11.242341

The variation in frequency relative to the moment of touching to SE when the object approaching, are:

on the 1st auto-generator,
I case Δf_{ob} = 0.002627 MHz,
II case Δf_{ob} = 0.034484 MHz,
III case Δf_{ob} = 0.033037 MHz;

on the 2nd auto-generator
I case Δf_{ob} = 0.002626 MHz,
II case Δf_{ob} = 0.034305 MHz,
III case Δf_{ob} = 0.033019 MHz.

The graphs of frequency variations are illustrated in Figure 4. Apparently, the resonance frequencies of the auto-generators when approaching to SEs vary in the same way and decrease.

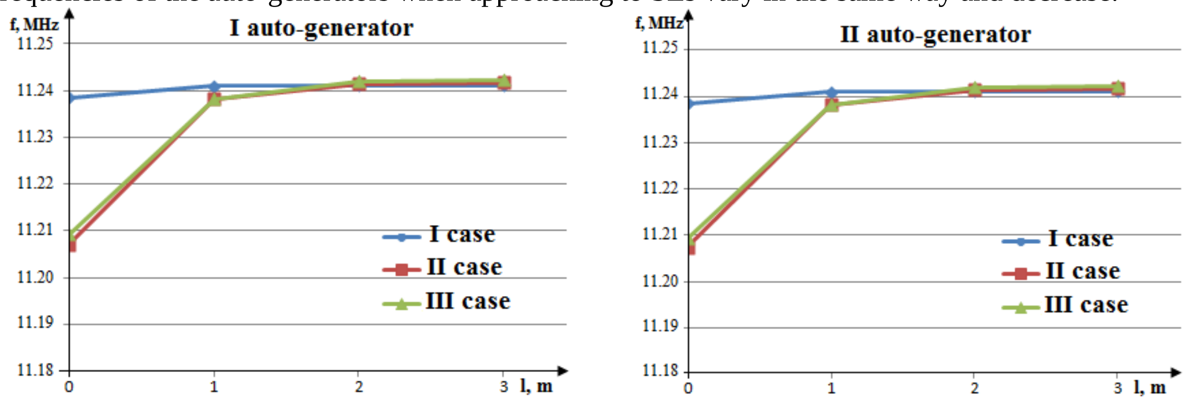

Fig. 4. Dependence of resonance frequencies on human approaching distance to SEs, which are 5 m lengths of each and were connected to the auto-generators

2.2. Experiments performed in an open area. Two wires, each 10 m length, are connected to the auto-generators as SEs via coaxial cables of 5 m (Figure 2 a, 2 b). The wires are fastened to dielectric supports at distance and height of 1 m, in parallel to each other and to the surface of the Earth. The experiments were performed in the same sequence as stated in 2.1, and the recorded values of the frequency variations were provided in table (Table 4).

Table 4. The frequencies values of two auto-generators when approaching to SE at 10 m

l (m)	**I auto-generator, f_1 (MHz)**			**II auto-generator, f_2 (MHz)**		
	I case	**II case**	**I case**	**II case**	**I case**	**II case**
0	19.420569	19.461813	19.428018	19.420550	19.461812	19.428026
1	19.443941	19.461900	19.440790	19.443925	19.461904	19.440768
2	19.462565	19.462243	19.455898	19.462567	19.462248	19.455902
3	19.461537	19.458791	19.454895	19.461540	19.458793	19.454899

According to Table 4, the resonance frequencies of both auto-generators vary in all cases, increasing when approaching towards SEs at the distance from 3m to 2 m, and decreasing when approaching towards SEs at the distance of 2 m to touching point. On the I auto-generator, in the I case, Δf_{ob} = 0.041996 MHz, in the II case, Δf_{ob} = 0.003452 MHz, and in the III case, Δf_{ob} = 0.02788 MHz; On the II auto-generator, in the I case, Δf_{ob} = 0.042017 MHz, in the II case, Δf_{ob} = 0.003455 MHz, and in the III case, Δf_{ob} = 0.027876 MHz.

Two wires of 50 m were connected directly to the auto-generator as the SEs (Figure 2 a, b). The wires are fastened as in the abovementioned cases.

Experiments were performed in the sequence shown in Experiments 2.1 and 2.2, and the recorded values of the frequency variations were presented at Table 5.

Table 5. The frequencies values of two auto-generators when approaching to SE at 50 m

L (m)	**I auto-generator, f_1 (MHz)**			**II auto-generator, f_2 (MHz)**		
	I case	**II case**	**I case**	**II case**	**I case**	**II case**
0	14.993379	14.937367	14.937740	14.993377	14.937355	14.937738
1	14.990632	14.974322	14.973409	14.990640	14.974321	14.973408
2	14.987608	14.986177	14.983077	14.987605	14.986175	14.983071
3	14.986868	14.986205	14.983303	14.986866	14.986203	14.983301

The variation in frequency relative to the moment of touching to SE when the object approaching, are:

on the 1st auto-generator,
I case Δf_{ob} = 0.006511 MHz,
II case Δf_{ob} = 0.048838 MHz,
III case Δf_{ob} = 0.045563 MHz;

on the 2nd auto-generator
I case Δf_{ob} = 0.006511 MHz,
II case Δf_{ob} = 0.048848 MHz,
III case Δf_{ob} = 0.045563 MHz,

The graphs representing the frequency variations were presented in Figure 5. Apparently, when approaching the SEs, the resonance frequencies of the auto-generators change in the same way, increasing in the I case and decreasing in the II and III cases, respectively.

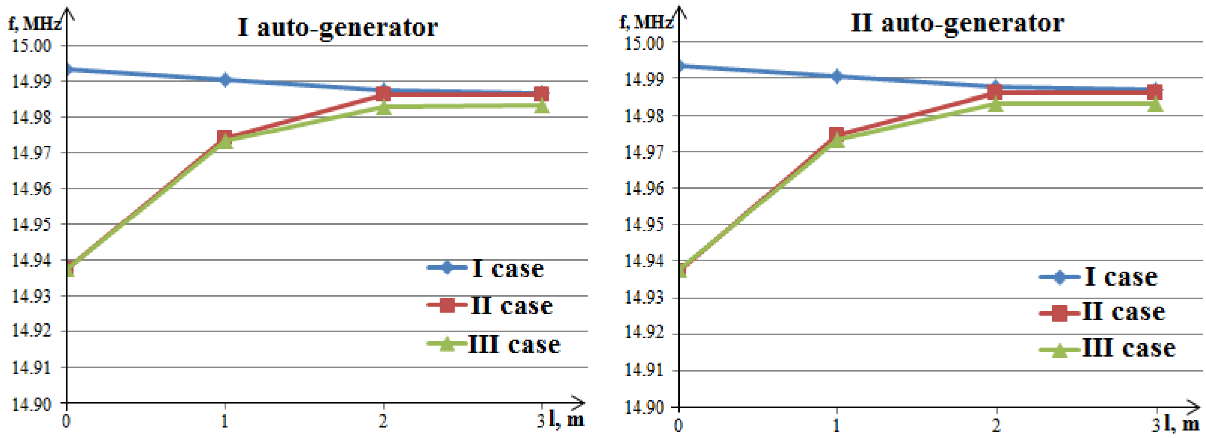

Fig. 5. Dependence of resonance frequencies on the distance of a human approaching the SE of 50 m connected to the auto-generators

Taking into account the time-dependent drift of the resonance frequency of the auto-generators ($\Delta f_{t.\,I}$ = ± 0.004001 MHz and $\Delta f_{t.\,II}$ = ± 0.003998 MHz), the sensitive elements of which are 50 m length of each, the discreteness value of the measured parameters $n_{d.v}$ for the I auto-generator is $n_{d.v} \approx 2$ in the I case, $n_{d.v} \approx 12$ in the II case, and $n_{d.v} \approx 11$ in the III case, and for the auto-generator is $n_{d.v} \approx 2$ in the I case, $n_{d.v} \approx 12$ in the II case, and $n_{d.v} \approx 11$ in the III case, which enables determining the weight of the approaching object at a distance of more than 3 m.

Research results. When a person of 93 kg weight perpendicularly approached the SEs at a distance of 3 m, the frequency of the auto-generators changed. These variations accounted for as follows:

- if the length of the SEs was 2 m - Δf_{ob} = 0.1151298 MHz for the I auto-generator; Δf_{ob} = 0.1152476 MHz for the II auto-generator;
- if the length of the SEs was 5 m, then for the I auto-generator Δf_{ob} = 0.002627 MHz in the I case, Δf_{ob} = 0.034484 MHz in the II case, Δf_{ob} = 0.033037 MHz in the III case; for the II auto-generator Δf_{ob} = 0.002626 MHz in the I case, Δf_{ob} = 0.034305 MHz in the II case, Δf_{ob} = 0.033019 MHz in the III case;

- if coaxial cables of 5 m length were connected to the SE of 10 m - for the I auto-generator Δf_{ob} = 0.041996 MHz in the I case, Δf_{ob} = 0.003452 MHz in the II case, Δf_{ob} = 0.02788 MHz in the III case; and for the II auto-generator Δf_{ob} = 0.042017 MHz in the I case, Δf_{ob} = 0.003455 MHz in the II case, and Δf_{ob} = 0.027876 MHz in the III case.

Taking into account the time-dependent drift ($\Delta f_{t.\ I} = \pm$ 0.004001 MHs and $\Delta f_{t.\ II} = \pm$ 0.003998 MHs) of the value of the resonance frequency of auto-generators, the sensitive element of which was 50 m length, the discreteness value of the measured parameters $n_{d.v}$ for both auto-generators was $n_{d.v}$ = 2 in the I case, $n_{d.v}$ = 12 in the II case, and $n_{d.v}$ = 11 in the III case which allowed determining the weight of the approaching object at a distance of more than 3 m.

When reviewing the resonance frequency variations depending on the length of the SEs, we saw that the lowest values of the auto-generators' frequencies were recorded when the length of the SEs was 2 m ($f_{I\ mid.}$ = 14.479189 MHz and $f_{II\ mid.}$ = 14.479186 MHz). It should be noted that the values of the resonant frequencies on both auto-generators were less than those without SEs, however greater than those with the SEs of 6 m ($f_{I\ mid.}$ = 17.345066 MHz and $f_{II\ mid.}$ = 17.345066 MHz).

Conclusions. The SEs of 6 m were connected to the auto-generator as the sensors with an lumped parameter, whereas the SEs of greater than 6 m were connected to the auto-generator as the sensors with distributed parameters (long line).

Thus, based on the mentioned features and the results of approaching experiments, we can conclude that the auto-generator circuits with sensitive element built on logic elements in differential sensors used in the security and warning systems of the territories of facilities are applicable. In this case, regardless of the length of the SEs, the differential sensors are automatically adapted to the environmental changes.

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