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Research Article

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A STUDY OF DEPENDENCE RESONANCE FREQUENCIES OF DIFFERENTIAL CAPACITIVE SENSOR ON TIME

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Abstract. *The article notes that airport perimeter security is considered one of the preventive measures in aviation security and the need to stimulate innovative devices led to the need to improve the sensors uses in perimeter security-warning systems. It emphasizes that the most widely used sensor in perimeter security-warning systems is the capacitive sensor and the importance of adapting to environmental changes is shown. Therefore, the article emphasizes that the purpose is to explore the environmental dependence of the frequency changes of two auto-generators built on digital logic elements applied as differential capacitive sensors. For this purpose, it is described the results from investigations of frequency variations of two auto-generators built on digital logic elements used as differential capacitive sensors in perimeter security-warning systems, as well as their synchronous operation in relation to each other's dependence on time. The mathematical expectation and dispersion of the variation values of the resonance frequencies of auto-generators which were connected to sensitive elements of different lengths were calculated in experiments, and it was found that the frequencies of the auto-generators changed more synchronously with each other. As a result, it is determined experimentally that, taking into account the time drift of the resonant frequency of auto-generators with sensitive elements of two meters length in laboratory conditions, the discreteness of the measured parameters allows us to determine the weight of the approaching object, and in all cases, the resonant frequencies of both auto-generators change approximately equally in both directions with a small difference depending on time.*

Keywords: aviation security, airport, perimeter, security-warning system, differential capacitive sensor, resonance frequency, sensitive element, dispersion

1. Introduction

Early detection of an intruder within the airport area is considered a significant issue from a aviation security perspective [1-3]. An intruder intending to unlawfully enter the area first crosses the physical guarding fence installed around the perimeter of the area [4, p. 182-183]. With this in mind, the project of the guarding fence, as well as the effectiveness and reliability of the security-warning system installed along the perimeter, must be commensurate with the assessed risk of acts of unlawful interference that may be directed against civil aviation [5, p. 16, 25].

It is possible to reduce the damage caused by acts of terrorism and unlawful interference by detecting the intruder through special sensors installed in the security-warning system, generating an alarm signal regarding the intrusion, and delaying the intruder for a certain period of time in the physical guarding fence [6-8]. At the same time, the maximum sensitivity distance of the perimeter security-warning system should be increased and the probability of generating false warning signals in the system should be reduced as much as possible [9-11].

One of the top five challenges for aviation security is the proper use of methods for the “expansion of technical resources and stimulation of innovation” [12, p. 23]. As preventive measures in aviation security start with perimeter protection, the stimulus of innovation results in improving the sensors used for the perimeter security-warning systems of the airport. There is an urgent need to improve capacitive sensors, which are increasingly used in warning and perimeter protection systems in order to adapt to the environment [13, 14]. Capacitive sensors used in airport perimeter security-warning systems consist of sensitive elements that have a certain capacitance relative to the ground. When sensitive elements are approached or touched, the change in capacitance causes the frequency of the sensor's auto-generator to change and it was generated warning signal [15]. Since the frequency variations of the auto-generator differ depending on the length of the sensitive elements and the weights of the intruders, the sensitivity distance of the capacitive sensor and the frequency of the auto-generator's output signal also differ [16, 17].

Work objective. The dependence of the frequency variations of two auto-generators built on digital logic elements applied as differential capacitive sensors on the environment has been determined. Therefore, the synchronous operation of two auto-generators, each of which has simultaneously connected HEs of equal length, and the time dependence of the frequency distance were studied under various conditions. A metal case with auto-generators built on logic elements was grounded. Experiments were carried out with the lengths of sensitive elements measuring 2, 5, 6, 10, and 50-m.

2. Problem statement

The experiments carried out in both indoor and outdoor spaces on different days are described below.

In Fig. 1, as indoor space there is a metal box and laboratory room [16]. As for outdoor space, the VOR-DME is used (VOR - Omni-directional distance; DME - distance measuring equipment) in Fig. 1a, 1b.

a) b)

Fig. 1. Experiments in outdoor territories: a) in the territory of NAA, b) in the territory of VOR-DME.

To determine the dependence of frequency variations of auto-generators on time, the frequency variation diapasons within five- and one-hour durations were explored. Each of the first of five experiments lasted five hours; four of them were carried out in laboratory and one in the territory of of NAA (Table 1).

Table 1. Experiments to study the frequency variations of auto-generators.

Experiments	**Location**	**Antenna length, m**	**During five hours with hourly -intervals**	**During one hour with five- minute – intervals**
1	Case	-	+	+
2	Lab.	-	+	+
3	---	2	+	+
4	---	5	+	+
5	in the territory of NAA	10	+	+
6	in the territory of VOR-DME	50	-	+

3. Experimental technique

The values of the auto-generators frequency variations were measured using two eight-digit devices with the model number "SKU00653" and recorded with a video camera (Fig. 2).

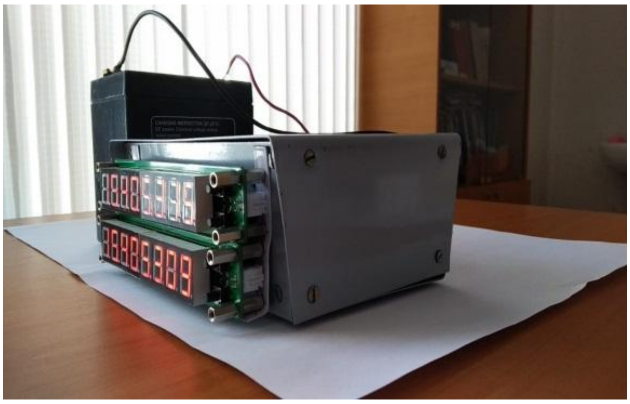


Fig. 2. Auto-generators in a metal case

The accuracy of frequency counters has been tested with a "Tektronix AFG3102C" Function Generator and they were found to have high accuracy [18].

4. Results and discussion

4.1. Experiments lasting five hours

These experiments were carried out by registering the frequencies with an hourly interval during five hours.

In order to determine the individual resonance frequency diapasons of auto-generators in the 1st and 2nd experiments, the sensitive elements were not connected to them. In order to eliminate side effects in Experiment 1, the auto-generators are placed in a metal (screened) case. Under the same conditions, Experiment 2 was carried out without the use of a metal case.

The graphs in Fig. 3a and Fig. 3b illustrate the frequency variations of auto-generators according to Experiments 1 and 2, respectively. Although the frequency values slightly differ, in some graphs they are the same for both auto-generators (-1st auto-generator, - 2nd auto-generator). In circles within the Fig.3, certain parts of the graphs are enlarged to show the direction of the frequency axes.

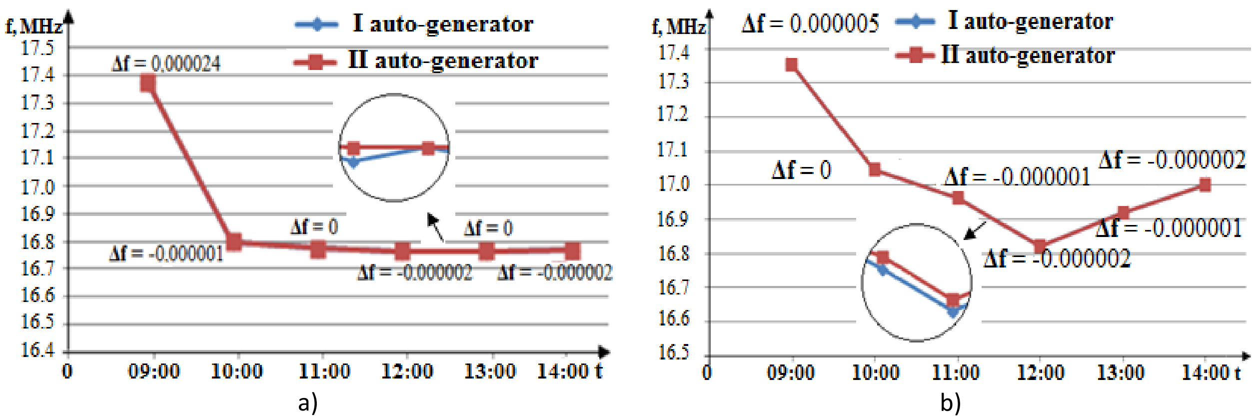


Fig. 3. Frequency variations of auto-generators:
a) in a metal case under laboratory conditions, b) under laboratory conditions.

The graphs show that the difference between the resonance frequencies decreases over the time and becomes quite small, even zero in some cases.

Resonance frequency values for the 1st and 2nd auto-generators while running are respectively: in Experiment 1, f_1 = 17.374754 MHz, f_2 = 17.374778 MHz (Fig. 3, a): in Experiment 2: f_1 = 17.354630 MHz, f_2 = 17.354635 MHz (Fig. 3, b). In Experiments 3 and 4, for determination of - the effects of SEs on resonance frequencies, they were not initially connected to auto-generators. In this case, the recorded values of the frequencies are respectively: in Experiment 3, f_1 = 16.615353 MHz and f_2 = 16.615354 MHz; in Experiment 4, f_1 = 16.333898 MHz and f_2 = 16.333913 MHz.

In turn, two wires were connected separately to the auto-generators as SEs. In all experiments carried out with connected SEs, the lengths of the wires by which they consist were identical. The wires were attached to the dielectric supports in parallel to each other and to the floor. The distance between them was 10 cm, the altitude from the floor was 1 m, and the lengths were 2 m and 5 m in Experiments 3 and 4, respectively. After connecting the SEs: in Experiment 3, f_1 = 13.599993 MHz and f_2 = 13.599989 MHs and in Experiment 4, f_1 = 10.459934 MHz and f_2 = 10.459942 MHs. Such frequency variations were expected; adding the capacitance of SE to input capacitance will result in a reduction in the frequency of auto-generators. The graphs of the frequency variations according to Experiments 3 and 4 are illustrated in Fig. 4a and Fig. 4b respectively.

In the first four experiments, the maximum values of the variations of the resonance frequencies of the 1st and 2nd auto-generators are:

in Experiment 1, 0.605620 MHz and 0.605646 MHz;
in Experiment 2, 0.351823 MHz and 0.351830 MHz;
in Experiment 3, 0.113939 MHz and 0.1131936 MHz;
in Experiment 4, 0.1119920 MHz and 0.1119911 MHz, respectively.

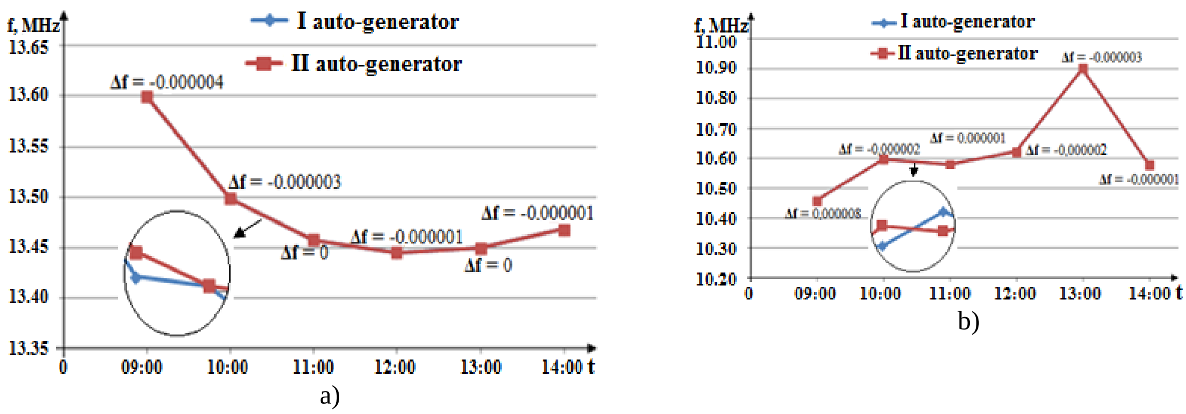


Fig. 4. Frequency variations of SE connected auto-generators of 2 m (a) and 5 m (b) lengths.

Experiment 5 was carried out in the NAA territory, at an environment of temperature 8ºC, atmospheric pressure of 775 mm of mercury, and relative humidity of 70-80%, according to the report of the Ministry of Ecology and Natural Resources, February 5, 2019. Two wires each 10 m in length as SEs, were connected to the auto-generators and attached to dielectric supports in parallel to each other and to the surface of the Earth. The distance between the wires and their altitude from the surface of the Earth was equal to 1 m (Fig. 5). Each SE was connected to the auto-generators via a coaxial cable of 5 m in length. Screen coverage of coaxial cables was grounded, on the side where they are connected to auto-generators.

When the SEs were not connected, the values of the resonance frequencies of the auto-generators were f_1 = 17.709108 MHz and f_2 = 17.709110 MHz, respectively, and f_1 = 19.353318 MHz and f_2 = 19.353322 MHz after connection of the SEs. As seen, the frequency variation is not as expected. Such variations in frequency (i.e., increases) when connecting SEs may occur due to various reasons.

For example, SEs may increase the input potential of an auto-generator by receiving electromagnetic waves as an antenna in an outdoor space and by collecting electrical charges in the total input capacity. This corresponds to the reduction of the value of the total input capacity which in turn increases the frequency of the auto-generator. The total input capacitance of the auto-generator is determined by the capacitances of auto-generator input, the coaxial cable, and SEs. The experiments outlined below, which were carried out in the territory of VOR-DME, indicate that when the SE is 6 m in length and the frequency of the auto-generator is repeatedly higher than the value without SE, we can suggest that this is related to the resonance phenomena. Since it is not the object of our research, however, we have not carried out its analysis is not carried out.

Fig. 5 shows the graphs of frequency variations after connecting the SEs. As seen from the graphs, during the five-hour experiments and with regard to the initial values, the final value of the frequency increased by 0.095692 MHz in the 1st auto-generator and 0.095689 MHz in the 2nd auto-generator. The difference in frequencies is quite small at different hours, and the maximum difference (at 09:00) is 0.000004 MHz.

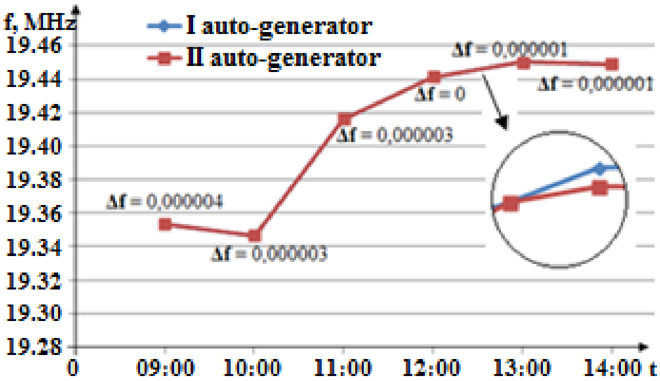


Fig. 5. Frequency variation of the 10m long SE connected auto-generators during five hours.

In all experiments, the recorded values of the resonance frequencies of the auto-generators are random. Comparison of the recorded values shows that the difference between the resonance frequencies of the auto-generators at the beginning of the experiment (09:00) were: in Experiment 1, Δf = 0.000024 MHz; in Experiment 2, Δf = 0.000005 MHz; in Experiment 3, Δf = 00.000004 MHz; in Experiment 4, Δf = 0.000008 MHz; and in Experiment 5, Δf = 0.000004 MHz which is more than the differences that occurred in other hours. These values can be ignored as the rough error that occurred at the beginning of the experiment. The estimated values of the mathematical expectation, dispersion and mean quadratic deviation of possible values of random numbers Δf for the five experiments during five hours, excluding initial values are provided in the following table (Table 2):

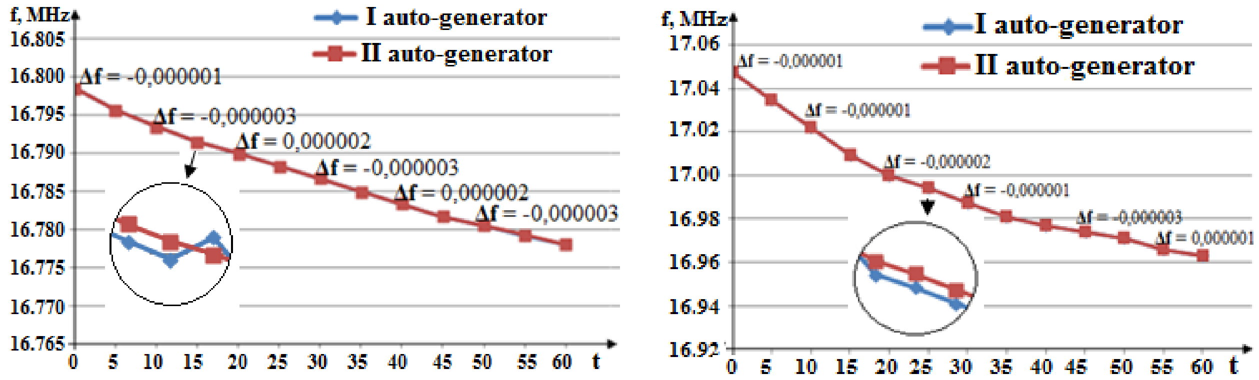
Table 2. The values of the mathematical expectation, dispersion and mean quadratic deviation of random numbers Δf.

No.	$M_N(\Delta f)$	$D_N(\Delta f)$	$\sigma_N(\Delta f)$
1	-10^{-6}	$8\cdot10^{-13}$	$89\cdot10^{-7}$
2	$-1.2\cdot10^{-6}$	$5.6\cdot10^{-13}$	$7.48\cdot10^{-7}$
3	-10^{-6}	$12\cdot10^{-13}$	$10.95\cdot10^{-7}$
4	$-1.4\cdot10^{-6}$	$18.4\cdot10^{-13}$	$13.56\cdot10^{-7}$
5	$1.6\cdot10^{-6}$	$14.4\cdot10^{-13}$	$120\cdot10^{-7}$

4.2. One-hour experiments

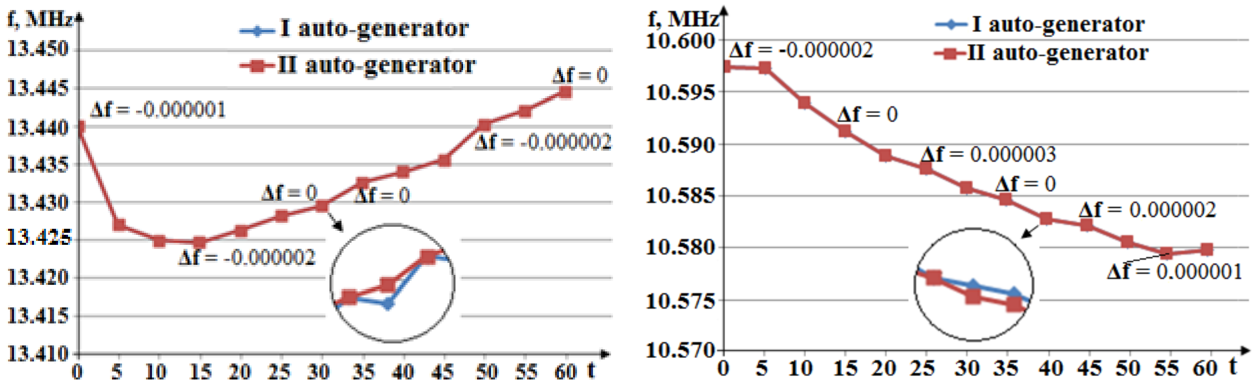
The frequency values in these experiments were recorded during one hour with five-minute of intervals. All conditions remained the same as in the five-hour experiments. In addition, one experiment was carried out with 50 m length wires in the territory of VOR-DME (Fig.1b). On that day, the environment was at a temperature of 22-24°C and there was atmospheric pressure of 758 mm of mercury and relative humidity of 50-60 %. Values are based on data from the press service of the Ministry of Ecology and Natural Resources of May 5, 2019. The frequency variations of the auto-generators are illustrated in graphs in Fig.6a and Fig. 6b, in accordance with the 1st and 2nd Experiments. As seen from the graphs, the resonance frequencies of the auto-generators decreased during an hour at an approximately equal rate (Fig.7). The difference between the frequency values is significantly small (Δf ≤ 0.000003 MHz). This difference even accounts for Δf = 0.000001 MHz.

The frequency variations of the auto-generators in 3rd and 4th Experiments are illustrated in the respective graphs (Fig. 7a and Fig. 7b). As seen in the graphs, the resonance frequencies of the auto-generators vary over time. Comparison of the values shows that the difference between the values of the auto-generator resonance frequencies is quite small, i.e., Δf ≤0.000002 MHz in Experiment 3, Δf ≤ 0.000003 MHz in Experiment 4. This difference even equals zero in some cases.



a) b)

Fig.6. Variations of resonance frequencies of the auto-generators within one hour: a) in a metal case, b) in a room.



a) b)

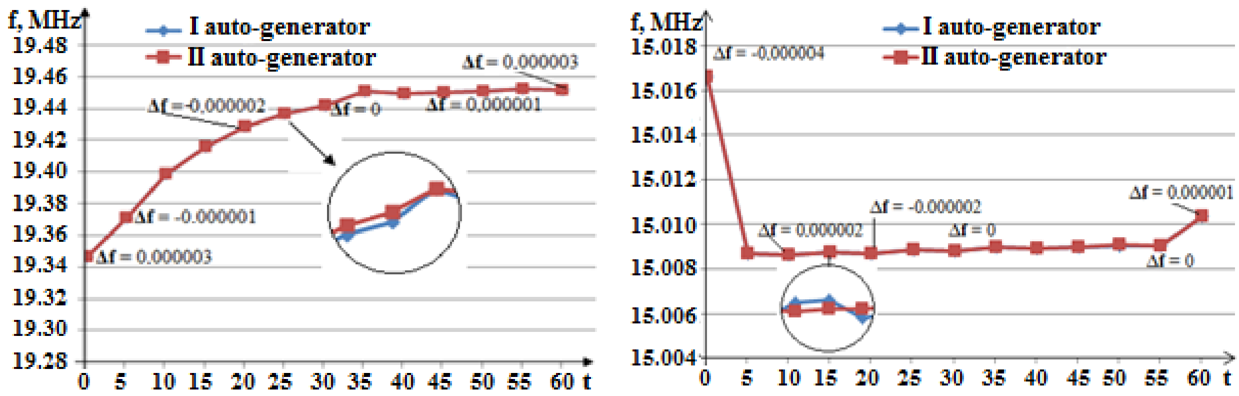
Fig.7. Variations of resonance frequencies of the auto-generators within one hour connected to SEs with lengths 2 m (a) and 5 m (b).

The drift of frequency values on time during one hour is:

In Experiment 3, for the 1st auto-generator, Δf_{zI} = ± 0.009965 MHz (13.429734 MHz ÷ 13.449664 MHz); for the 2nd auto-generator, Δf_{zII} = ± 0.009966 MHz (13.429732 MHz ÷ 13.449664 MHz);

In Experiment 4, for the 1st auto-generator, Δf_{zI} = ± 0.0090275 MHz (10.579381 MHz ÷ 10.597436 MHz); for the 2nd auto-generator, Δf_{zII} = ± 0.009026 MHz (10.579382 MHz ÷ 10.597434 MHz). The variation diapason - Δf_z determines the degree of discreteness of the measurement system.

The graphs for frequency variations of the auto-generators in accordance with Experiments 5 and 6 are shown in Fig. 8a and Fig. 8b, respectively.



a) b)

Fig.8. Variations of resonance frequencies of the auto-generators during one hour connected to Ses with lengths 10 m (a) and 50 m (b).

Comparison of these values shows that the difference between the frequencies is quite small, and they are $\Delta f \leq 0.000003$ MHz in Experiment 5 (Fig. 8a) and $\Delta f \leq 0.000004$ MHz in Experiment 6 (Fig. 8b). This difference equals zero in both experiments at the half hour. As seen from the graphs, the resonance frequencies of the auto-generators vary in the same way.

Fig. 8a shows that the resonance frequencies of both auto-generators increase for 35 minutes after being turned on and subsequently, they vary up until the end of the hour with small differences, by increasing or decreasing. Within an hour, the resonance frequencies increase by 0.105322 MHz on both auto-generators. Fig. 8b shows that the resonance frequencies of both auto-generators decrease for five minutes after turning on and subsequently, they vary up until the end of the hour for 55 minutes with small differences, by increasing or decreasing. During one-hour experiment, the final values of the frequencies of the 1st and 2nd auto-generators decreased by 0.006271 MHz and 0.006266 MHz, respectively, with regard to the initial values. The maximum value of the variations of resonance frequencies of the auto-generators during one hour are:

1) On the 10 m length of SEs, $\Delta f_{zI} = \pm$ 0.052964 MHz (19.346528 MHz ÷ 19.452456 MHz) for the 1st auto-generator, and $\Delta f_{zII} = \pm$ 0.0529635 MHs (19.346531 MHs ÷ 19.452458 MHs) for the 2nd auto-generator;

2) On the 50 m length of SEs, $\Delta f_{zI} = \pm$0.004001 MHs (15.008618÷15.016619 MHs) for the 1st auto-generator, and $\Delta f_{zII} = \pm$0.003998 MHs (15.008620÷15.016615 MHs) for the 2nd auto-generator.

5. Conclusion

Taking into account the time-dependent drift ($\Delta f_{zI} = \pm$ 0.009965 MHz and $\Delta f_{zII} = \pm$ 0.009966 MHz) of resonance frequencies values of auto-generators with sensitive elements of 2 m in length, under laboratory conditions, the discreteness value of the measured parameters on both auto-generators was $n_m = 15$, which allowed for determination of the weight of the approaching object.

Comparisons of the dispersions ($D_1(\Delta f) = 8 \cdot 10^{-13}$; $D_2(\Delta f) = 5.6 \cdot 10^{-13}$; $D_3(\Delta f) = 12 \cdot 10^{-13}$ $D_4(\Delta f) = 18.4 \cdot 10^{-13}$ and $D_5(\Delta f) = 14.4 \cdot 10^{-13}$) of random values Δf_i showed that, in the experiments carried out, the value of the dispersion calculated in Experiment 2 was much smaller than in others. The calculated ratio between the dispersions in Experiments 4 and 2 ($D_4 (\Delta f) / D_2 (\Delta f) \approx 3.3 \cdot 10^{-13}$) was approximately 3. This also indicates that frequency variations of auto-generators in Experiment 2 were more synchronous.

The results of the experiments showed that, in all cases, the resonance frequencies of both auto-generators varied with a small difference in both sides (either increasing or decreasing) depending on time. The difference in resonance frequencies decreased over the time, accounting for a quite small value, even zero. In all experiments, the recorded values of the resonance frequencies of the auto-generators were random.

Conflict of interest statement

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

CRediT author statement

Nabiyev R.N.: Conceptualization, Methodology, Supervision; **Qarayev Q.I.:** Software, Writing-Original draft preparation, Validation; **Rustamov R.R.:** Data curation, Investigation, Visualization, Writing- Reviewing and Editing. The final manuscript was read and approved by all authors.

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