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# РАДІОЕЛЕКТРОНІКА ТА ТЕЛЕКОМУНІКАЦІЇ

# RADIO ELECTRONICS AND TELECOMMUNICATIONS

UDC 621.317

## PHASE FREQUENCY INTERPRETATION OF THE COINCIDENCE METHOD FOR FREQUENCY TO CODE CONVERSION

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### ABSTRACT

**Context.** The problem of fast conversion of radio signal frequency for monitoring the radial velocity of a moving object. The object of the study was the process of converting frequency into a code based on the coincidence method.

**Objective.** The goal of the work is to improve the coincidence method for creating a new signal-to-code frequency converter without fixing the conversion time interval.

**Method.** The coincidence method for converting the signal frequency into a code has been improved. The improved frequency conversion method, unlike the existing ones, consists in counting the number of complete phase cycles of the known and unknown signals during the time of double coincidence and asynchronous mode of hardware determination of the particle. The improved method has advantages in comparison with the method of an electro-counter frequency meter when determining the radial speed of objects and does not have a methodical error, which in an electro-counter frequency meter increases as the unknown frequency approaches the reference to 100%. However, the improved coincidence method compared to other versions has a hardware scheme for tracking the moments of coincidence and determining the fraction and does not require expensive and high-speed microprocessors to calculate the conversion results.

**Results.** Based on the phase-frequency interpretation and the derived conversion equation and the proposed frequency-to-code conversion scheme using the coincidence method, a functional scheme of the frequency converter was developed. This made it possible to implement a 16-bit frequency converter in code on Intel's MAX V series CPLD.

**Conclusions.** The coincidence method for converting the signal frequency into a code received further development, which, unlike the existing ones, consists in counting the number of complete phase cycles of the known and unknown signals during the time of double coincidence and the asynchronous mode of hardware determination of the fraction.

The influence of the frequency of signals on the time of a single measurement was studied using the coincidence method, as a result of which it was found that with an increase in the difference between the reference and unknown frequency, the time of a single measurement decreases.

The obtained research results can be used for the development of high-speed means of converting the signal frequency into a binary code: in industrial tomography, radar and radio navigation for monitoring moving objects.

**KEYWORDS:** frequency, coincidence, electronic counter frequency meter, full phase shift, phase cycle, industrial tomography, radar, internet of things, unmanned aerial vehicle, complex programmable logic device.

### ABBREVIATIONS

CPLD is a complex programmable logic device;

FPHSH is a full phase shift;

UAV is a unmanned aerial vehicle.

### NOMENCLATURE

$T_0$ is a periods of a known signal;

$T_X$ is a periods of a unknown signal;

$d\varphi$ is a full phase shift;

$N_0$ is a number of periods of the known signal during the entire time interval of the coincidence;

$N_x$ is a number of periods of the unknown signal during the entire time interval of the coincidence.

### INTRODUCTION

The efforts of outstanding scientists are aimed at improving the metrological and technical indicators of existing measuring devices, in particular at developing new methods for correcting the characteristics of the transformation of the measuring channel, which is their main component [1]. Means of measuring various parameters and technical characteristics of radio equipment have always occupied leading positions in science and technology. Without an accurate definition of the relevant values, it is impossible to build modern high-quality radio communication systems, radar, navigation ground and satellite systems. Accordingly, the improvement of known methods for creating new high-speed converters of the frequency of high-frequency signals into a code is a promising task at today's stage of development of measuring technology [10].

**The object of study** is the process of converting frequency into a code based on the coincidence method. The

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process of converting a frequency into a code using an electro-counter frequency meter usually takes a long time. This is caused by the fact that the measurement time is always fixed, usually one second. At the same time, there is an additional methodical error inherent in the method of the electro-counter frequency meter. Therefore, to increase the speed of frequency conversion, it is necessary to improve the coincidence method for this problem.

**The subject of study** is the coincidence method for converting the signal frequency into a code.

The known sampling methods of frequency conversion [1, 3] are low-speed, and are also characterized by the presence of methodological error, which can reach 100% as the reference frequency approaches the unknown.

**The purpose of the work** is to improve the coincidence method for creating a new converter frequency to code without fixing the conversion time interval.

## 1 PROBLEM STATEMENT

It is known that to convert the frequency of a signal into a code, an electronic counter frequency meter uses a time interval equal to one second [1, 3]. This limits its use in radio communication systems with pseudo-random reconfiguration of the operating frequency. Because in such systems, the period of changing the operating frequency can be from several seconds to several minutes. In addition, there are limitations regarding the use of this method and for measuring the speed of UAV movement. Because two UAVs moving towards each other at a speed of 200 km/h will travel more than 100 meters in one second.

Therefore, in order to prevent emergency situations and obtain timely information about the operating frequency or the speed of UAV movement, it is necessary that the time of converting the signal frequency into a code is less than one second.

An alternative to an electronic counter frequency meter can be a converter based on the coincidence method. However, the imperfect theoretical justification of the transformation process and the use of a microprocessor to track the moments of coincidence and determine the share nullifies all the advantages of this method. Accordingly, the improvement of the coincidence method and the development of a frequency conversion device that would perform a single measurement of the frequency of a signal in a time of less than one second is a priority task for this research work.

## 2 REVIEW OF THE LITERATURE

The modern world does not stand still. The constant development of the radio engineering industry requires more high-speed means of converting the frequency of the radio signal to monitor the speed of a moving object. In ultrasound diagnostics, which are used in medicine, the speed of blood flow in vessels is studied by determining the frequency of the reflected signal [12]. In industrial tomography and radar, the speed of movement of the object depends on the frequency of the reflected signal [1, 5, 6, 11, 12]. At the same time, it is necessary to use high-speed frequency measurement tools in systems with active sensors used in telecommunication networks and UAVs based on the Internet of Things technology [2, 9]. In addition, UAVs need a quick response in the environment.

Among the methods of converting the frequency of a radio signal into a code, the leading place is occupied by the method of an electro-counter frequency meter [1, 3]. This method has a simple hardware implementation, which in the simplest version requires: a reference generator, a logical AND2 multiplication scheme and a counter. At the same time, the method of the electro-counter frequency meter has a low speed of single measurement, usually 1s. In addition, this method has a methodical error, which increases as the unknown frequency approaches the reference frequency to 100%.

There are attempts to implement the coincidence method for frequency conversion [4, 5, 13]. However, all these attempts have an imperfect coincidence tracking scheme and require expensive and high-speed microprocessors to calculate the conversion results. All this leads to the appearance of additional errors and increases the time of converting the frequency into a code.

## 3 MATERIALS AND METHODS

The essence of the coincidence method for measuring the signal frequency consists in the double coincidence of the fronts of the known and unknown signals at a certain time interval [13]. The graphic interpretation of the double coincidence of the fronts of the known and unknown signals at a certain time interval is presented in fig. 1. From the point of view of phase-frequency theory[8], both frequencies of periodic signals can be expressed in terms of their FPHSH. At the same time, the frequency of a known periodic signal can be represented as:

$$F_0 = \frac{d\varphi_0}{dt}. \quad (1)$$

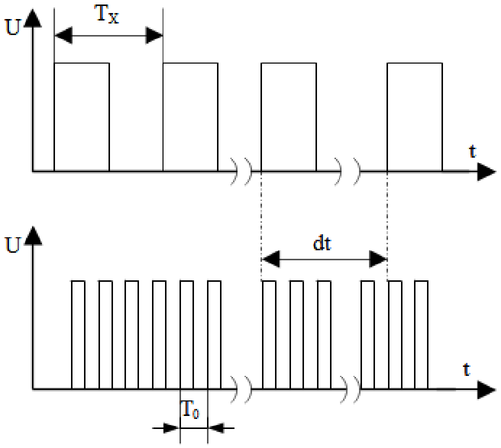

Figure 1 – Graphical interpretation of the coincidence method

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Accordingly, the frequency of an unknown periodic signal can be determined by the formula (2):

$$F_X = \frac{d\varphi_X}{dt}. \tag{2}$$

Let's imagine that the time interval during which a double coincidence of the fronts of signals of known and unknown frequency occurs is dt. Let's express this time interval from formulas (1) and (2). For a known periodic signal, we will have:

$$dt = \frac{d\varphi_0}{F_0}. \tag{3}$$

For an unknown periodic signal, we will have:

$$dt = \frac{d\varphi_X}{F_X}. \tag{4}$$

Since in one period there is a phase shift of 2π, then for the entire time interval of coincidence, FPHSH for a known periodic signal will be defined as:

$$d\varphi_0 = 2\pi \cdot N_0. \tag{5}$$

Accordingly, FPHSH for an unknown periodic signal will be defined as:

$$d\varphi_X = 2\pi \cdot N_X. \tag{6}$$

Since the coincidence of the signal fronts of a known and an unknown periodic signal occurs in one time interval, we equate expressions (3) and (4), we will have:

$$\frac{d\varphi_0}{F_0} = \frac{d\varphi_X}{F_X}. \tag{7}$$

Substitute expressions (5) and (6) into expression (7) to determine FPHSH and shorten the left and right parts by 2π, then we will have:

$$\frac{N_0}{F_0} = \frac{N_X}{F_X}. \tag{8}$$

From formula (8), we express the frequency of the unknown periodic signal and obtain the conversion equation:

$$F_X = F_0 \cdot \frac{N_X}{N_0}. \tag{9}$$

In accordance with the transformation equation (9), to measure the frequency, it is necessary to count the number of phase cycles of the known and unknown signals during the time of coincidence and find their proportion.

## 4 EXPERIMENTS

At the same time, to determine the frequency of a periodic signal, it is necessary to count the number of periods of a known and unknown signal during the time interval when the fronts of these signals coincide twice. Schematically, such a process is presented in Fig. 2.

In accordance with the scheme presented in Fig. 2, it is necessary:

1. Form pulses with minimum duration for signals of known and unknown frequency.
2. Determine the moments of matching signal fronts.
3. Calculate the moments of matching signal fronts.
4. Count the number of pulses of the known and unknown signals during the time of two matching signal fronts.
5. Find the share of the number of pulses of the known and unknown signals during the time of two coincidences of the signal fronts.

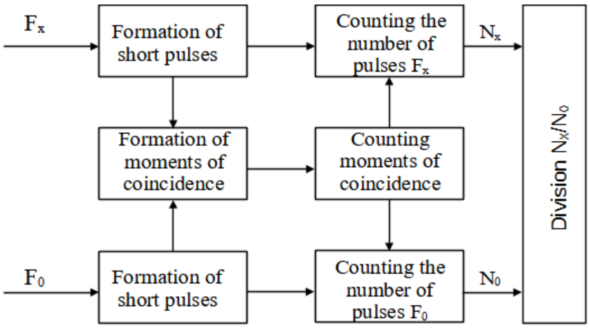

Figure 2 – Scheme of the process of converting the frequency of a periodic signal into a code by the method coincidence

Since most of the blocks of this scheme are related to digital signal processing, the hardware implementation of such a converter is better to be implemented on the basis of CPLD. The use of CPLD in radio equipment allows you to arrange the entire digital part in the middle of one microcircuit and improve the immunity of the circuit. Accordingly, the processing time of the frequency conversion results can be reduced. To form pulses with a minimum duration for signals of known and unknown frequency, it is advisable to use the shaper described in [10]. In this case, the period will remain constant, and the duration of the pulse will be equal to 2 time delays of the basic logic element. For CPLDs of the MAX V family from Intel, the delay is 7ns [7]. Accordingly, the duration of the pulse will be 14ns. Determination of the moments of coincidence of the signal fronts can be implemented with the help of the logic element AND2. To count the moments of coincidence of the signal fronts, we will use a two-digit counter based on the D-trigger. With the help of 8-bit counters, we will calculate the number of pulses of known and unknown signals during the time of two coincidences of signal fronts. We will determine the share using the DIVIDE megafunction. In addition, it will allow to separate the whole and fractional part of the division results. The functional scheme of the frequency to code converter based on the coincidence method is presented in Fig. 3.

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Rectangular pulses of an unknown frequency are received at the FX input of the circuit (Fig. 3), and at the F0 input – of the reference frequency. With the help of fi short pulse generators, the duration of input pulses of unknown and reference frequency becomes equal to 14 ns. At the same time, the period of the unknown and reference signal remains unchanged. Through 2AND logic multiplication circuits, short pulses are sent to the inverse exclusive OR element, which captures the moments of coincidence. At the same time, the cnt2 counter counts the moments of coincidence. Blocks ff, built on the basis of a D-trigger and a logic multiplication scheme 2AND, included in series. These blocks are intended for fixing the leading edges of pulses. The first moment of coincidence enables the operation of the LPM_COUNTER counters. These counters count pulses of the unknown and reference signal. After the second moment of coincidence, the counters are blocked. After that, the counter outputs have a binary code corresponding to the number of periods of the unknown $N_x$ and the reference $N_0$ signal, for the entire time period of the double coincidence. From the outputs of the counters, an 8-bit binary code is sent to the input of the DIVIDE division block. In asynchronous mode, the division block DIVIDE defines an integer quotient (cile) of 8 bits and a remainder (ostacha) of 8 bits. Thus, we have a 16-bit code at the output of the frequency converter. If the binary 16-bit code from the DIVIDE block is multiplied by the value of the reference frequency, then we will have the frequency of the unknown signal.

## 5 RESULTS

Modeling of the functional scheme of the frequency converter into code based on the coincidence method (Fig. 3) was carried out in the automated design environment Quartus Prime from Intel. In fig. 4 presents an oscillogram explaining the operation of the functional circuit (Fig. 3). The first two signals correspond to the reference F0 and the unknown Fx signal. The other two signals are data from the counters of the reference N0 and measuring NX channels. The last two signals are the result of dividing the data from the counters. Accordingly, cile[7..0] is an integer value, the result of division, ostacha[7..0] is a fractional value, the result of division.

In order to determine the time of a single conversion of the frequency into a code, by the method of coincidence, it is necessary to estimate the difference in the duration of the signal periods. The difference in the duration of the periods can be written in the following way:

$$\Delta T = \left| \frac{1 - F_0/F_x}{F_0} \right| . \qquad (10)$$

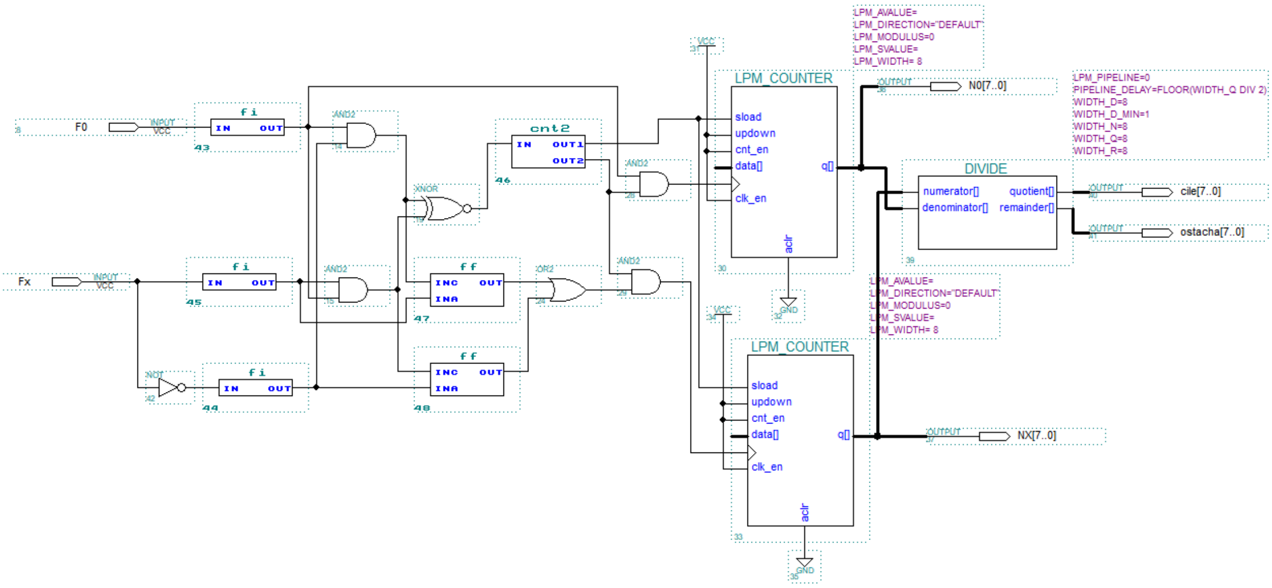

Figure 3 – Functional scheme of the frequency converter to the code based on the coincidence method

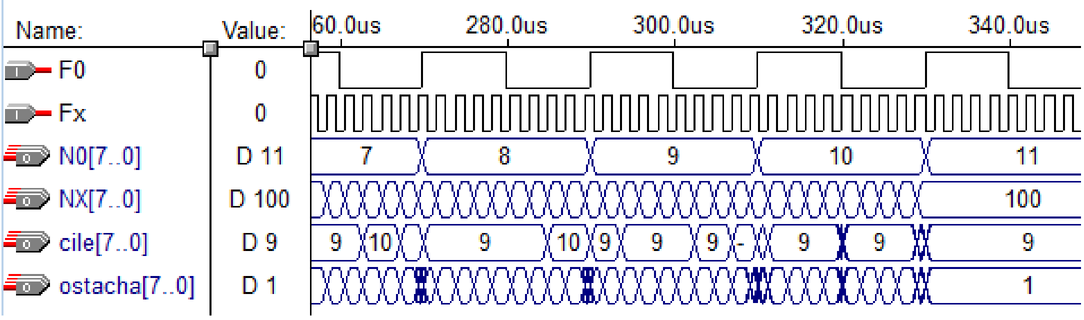

Figure 4 – Oscillograms of the operation of the frequency converter to the code based on the coincidence method

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The time between two coincidences of signal edges, taking into account expression (10), will be determined as:

$$T_i = \frac{T_x \cdot T_0}{\Delta T} = \frac{1}{|F_x - F_0|}. \qquad (11)$$

The modulo value in the denominator assumes no negative time. In this way, the moments when the unknown frequency may be lower than the reference frequency are taken into account. In fact, expression (11) is a formula for determining the time of a single transformation. Graphical interpretation of expression (11) for three reference frequency values: 10KHz, 100KHz and 1MHz is presented in Fig. 5. On the vertical axis, the measurement time is indicated in seconds, on the horizontal axis - the value of the unknown frequency in hertz.

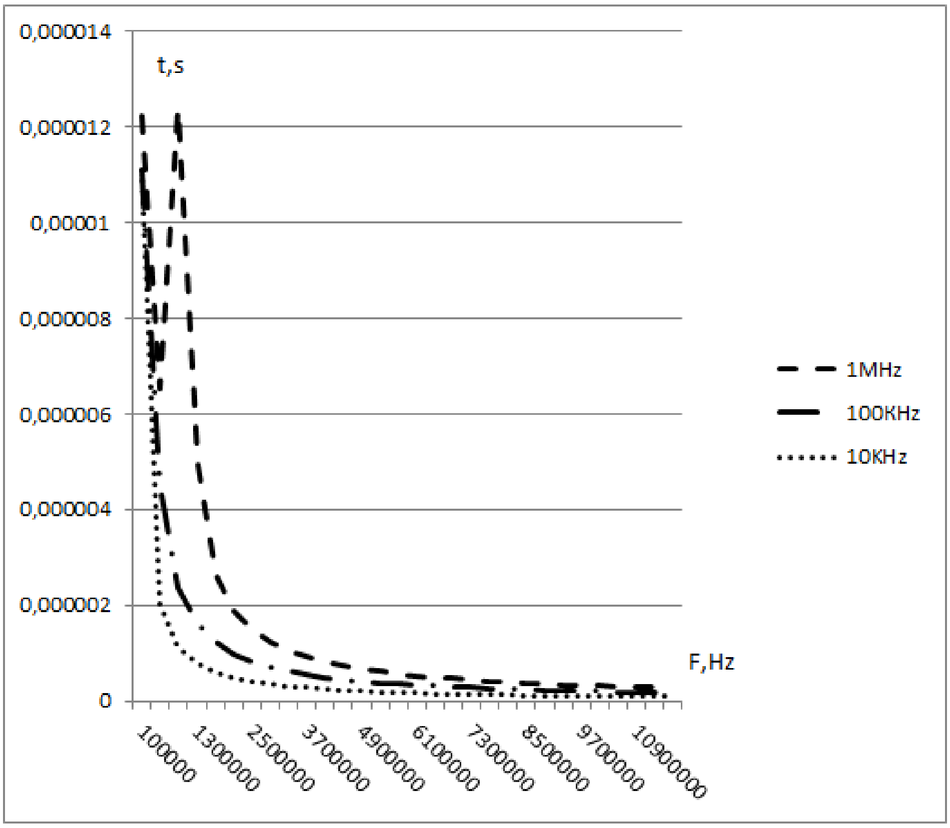

Figure 5 – Time dependence of a single frequency measurement by the coincidence method

## 6 DISCUSSION

Signal oscillograms obtained during modeling in the Quartus Prime automated design environment from Intel (Fig. 4) confirm the validity of the proposed theoretical solutions: expression (9), scheme (Fig. 2) and the functionality of the functional scheme (Fig. 3).

As can be seen from Fig. 5: as the difference between the reference and the unknown frequency increases, the time of a single measurement decreases. Thus, it can be noted that even with a frequency difference of 1Hz, the time of a single measurement will be one second, which corresponds to an electric counter frequency meter. On the basis of the developed functional scheme (Fig. 3), a high-speed frequency converter can be developed into a code for industrial tomography or radar reconnaissance. The proposed version of the frequency to code converter (Fig. 3) based on the Intel MAX V family CPLD can measure the frequency of an unknown signal up to 100 MHz.

## CONCLUSIONS

The urgent problem of developing a coincidence method for converting the signal frequency into a code is solved.

**The scientific novelty** of the obtained results is that the coincidence method for converting the signal frequency into a code was further developed, which, unlike the existing ones, consists in counting the number of complete phase cycles of the known and unknown signals during the coincidence time and the asynchronous mode of hardware determination of the division result.

The influence of the frequency of signals on the time of a single measurement was studied by the coincidence method, as a result of which it was established that with the increase in the difference between the reference and

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unknown frequencies, the time of a single measurement of the measurement decreases.

**The practical significance** of obtained results is that based on the derived conversion equation and the proposed scheme of frequency conversion to code using the coincidence method, a functional scheme of the frequency converter was developed. This made it possible to implement a 16-bit frequency converter in code on Intel's MAX V series CPLD.

**Prospects for further research** are to study the obtained research results can be used for the development of high-speed means of converting the signal frequency into a binary code: in industrial tomography, radar and radio navigation for monitoring the radial speed of moving objects.

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# ФАЗОЧАСТОТНА ІНТЕРПРЕТАЦІЯ МЕТОДУ КОІНЦИДЕНЦІЇ ДЛЯ ПЕРЕТВОРЕННЯ ЧАСТОТИ В КОД

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## АНОТАЦІЯ

**Актуальність.** Розглянуто проблема швидкого перетворення частоти радіосигналу для моніторингу швидкості рухомого об'єкту. Об'єктом дослідження є процес перетворення частоти в код на базі методу коінциденції.

**Мета роботи** – удосконалення методу коінциденції для створення нового перетворювача частоти сигналу в код без фіксації часового інтервалу перетворення.

**Метод.** Удосконалено метод коінциденції для перетворення частоти сигналу в код. Удосконалений метод перетворення частоти, на відміну від існуючих, полягає у підрахунку кількості повних фазових циклів відомого і невідомого сигналів за час подвійного збігу і асинхронного режиму апаратного визначення частки. Удосконалений метод має переваги в порівнянні з методом електролічильного частотоміра під час визначення радіальної швидкості об'єктів і не має методичної похибки, яка у електролічильного частотоміра збільшується з наближенням невідомої частоти до опорної до 100%. Разом з

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тим, удосконалений метод коінциденції в порівнянні з порівнянні з іншими версіями має апаратну схему відслідковування моментів збігу та визначення частки і не потребує дорого вартісних і високошвидкісних мікропроцесорів для обрахунку результатів перетворення.

**Результати.** На основі фазочастотної інтерпретації і виведеного рівняння перетворення та запропонованої схеми перетворення частоти у код методом коінциденції, розроблено функціональну схему перетворювача частоти. Це дозволило реалізувати 16-розрядний перетворювач частоти в коді на CPLD серії MAX V компанії Intel.

**Висновки.** Отримав подальший розвиток метод коінциденції для перетворення частоти сигналу в код, який, на відміну від існуючих, полягає у підрахунку кількості повних фазових циклів відомого і невідомого сигналів за час подвійного збігу і асинхронного режиму апаратного визначення частки.

Досліджено вплив частоти сигналів на час поодинокого вимірювання за допомогою методу коінциденції, в результаті чого з'ясовано, що зі збільшенням різниці між опорною і невідомою частотою час поодинокого вимірювання зменшується.

Отримані результати досліджень можуть бути використані для розробки високошвидкісних засобів перетворення частоти сигналу у двійковий код: у промисловій томографії, радіолокації та радіонавігації для моніторингу рухомих об'єктів.

**КЛЮЧОВІ СЛОВА:** частота, коінциденція, електронно-лічильний частотомір, повний фазовий зсув, фазовий цикл, промислова томографія, радіолокація, інтернет речей, безпілотний літальний апарат, програмована логічна інтегральна схема.

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