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MEASURING FREQUENCY MARKS IN THE DEVICES ON THE BASE OF SWEEP-GENERATOR

The paper suggests method for determination the frequency of sweep-generator by formation of frequency marks by reference generators, analyses measurement error of frequency marks, caused by sweep-generator non-linearity.

***Key words**: sweep-generator, frequency mark, stroboscopic mixer, reference generator, factor of unrolling non-linearity, formation and analysis of time intervals, maximal and boundary harmonic number.*

Introduction

Definition of parameters of electronic devices and connection lines requires the knowledge of their frequency characteristics, the determination of which is quite a complex operation. Panoramic devices, based on sweep-generators, are used to simplify the measuring of frequency characteristics, bur it entails the problem of formation of grid of frequency marks and determination of their frequency.

There are some method for the determination of frequency marks, such as comparison of sweep-generator voltage control with its frequency, arrest of sweep-generator scanner and measuring its frequency by cymometer, use of direct digital synthesis [1, 2]. The first method ensures high productivity with the wide band of sweep-generator oscillation, but the exactness in frequency determination is low. Arrest of sweep-generator unrolling and measuring frequency marks by cymometer provides for exact results, but if requires much more time for the determination of frequency characteristics. Direct digital synthesis allows to compare the digital control code with the sweep-generator frequency, but the devises, made according to the technology of direct synthesis, have frequency limitations.

There appears the task in developing methods, which would allow to measure the frequency marks in panoramic devises with sweep-generators in UHF and microwave ranges with high exactness.

Methods for measuring frequency marks

The [3] suggests method for measuring frequency marks and device on the base of two reference generators which allow to solve the task set.

With the aim of decreasing the frequency mark measurement error, the third reference generator with frequency $f_0 - F$ is suggested to be installed into the device [3] (fig. 1).

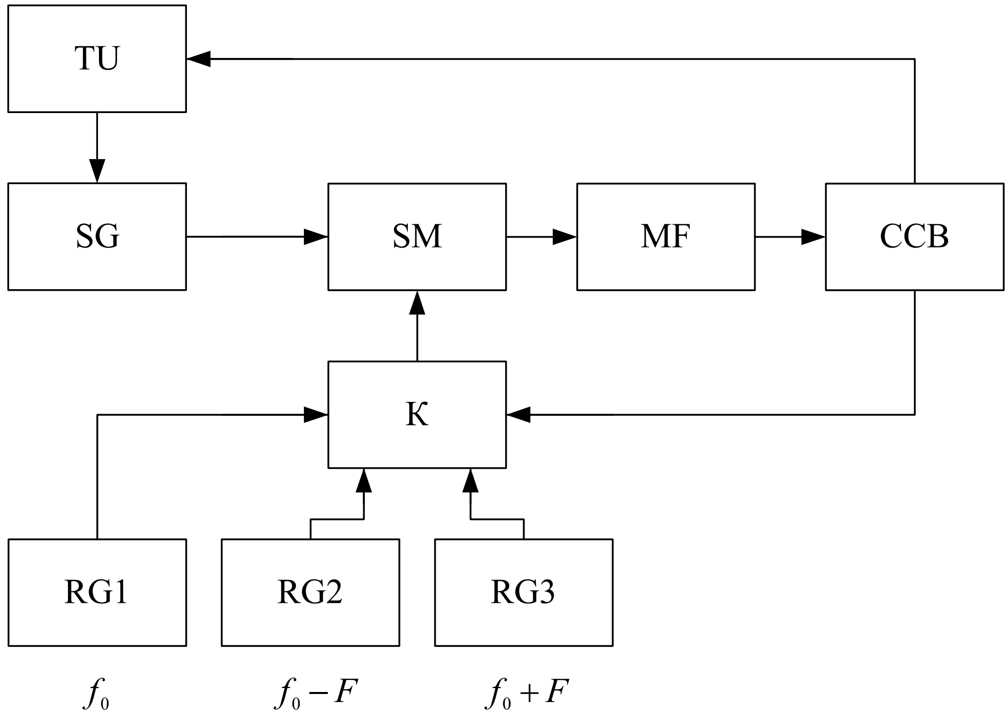


Fig. 1. Measuring device of frequency marks

Frequency f of output voltage of sweep-generator (SG), switched to the input of stroboscopic mixer (SM), is changed during the direct unrolling voltage run in the tuning unit (TU) according to the linear law. Voltage from one of the three references generators (RG) shall be supplied to the second input of mixer. Harmonics of output voltage of reference generators PG1 – RG3 shall be evenly distributed in the working frequency range with the space f_0, $f_0 - F$, $f_0 + F$ correspondingly. Consequently "zero beats" shall be observed on the mixer output, with the help of which the marks' former (MF) creates marks impulses on the input of control and calculation block (CCB). When the PG1 is switched, the first mark corresponds to the moment of time, when $f = (n-1) f_0$, where $n = 2,3,4...$ After the first mark the key (K) switches the mixer input to the generator RG2, therefore the second mark will appear when $f = n(f_0 - F)$. Than CCB switches the key in to the position, when the voltage from generator RG1 is switched to the mixer input and the following third mark will correspond to the moment of time when $f = nf_0$. Time interval between the second and the third marks

$$\tau_- = \frac{nf_0 - n(f_0 - F)}{\eta} = \frac{nF}{\eta},$$

where η – rate of frequency change in sweep-generator.

After the third mark is formed, the key, using CCB, connects generator RC3 to the mixer. The fourth mark will appear when $f = n(f_0 + F)$, time interval between the third and the fourth mark

$$\tau_+ = \frac{n(f_0 + F) - nf_0}{\eta} = \frac{nF}{\eta}.$$

Than CCB switches the key to the position, when the voltage from the generator RG1 shall be supplied to the mixer, and the appearance of the fifth mark will correspond to the time moment, when $f = (n+1) f_0$.

Interval between the first and the third marks, third and fifth marks will make up correspondingly

$$\tau_1 = \frac{nf_0 - (n-1)f_0}{\eta} = \frac{f_0}{\eta},$$

$$\tau_2 = \frac{(n+1) - nf_0}{\eta} = \frac{f_0}{\eta}.$$

The frequency of the third mark

$$f_M = nf_0 = \frac{\tau_+ + \tau_-}{\tau_1 + \tau_2}\frac{f_0^2}{F}.$$

Accuracy in measuring mark frequency increases due to the fact that in measuring device, unlike in [3], the influence of sweep-generator unrolling non-linearity on the result is compensated.

Sequence of the format marks is presented on fig. 2. All the control signals are formed by CCB in series by programming. Depending on sweep-generator frequency change rate and its non-linearity factor τ_-, τ_+, τ_1 and τ_2 acquire different values for one and the same mark f_M. In case of constant rate of sweep-generator frequency change η

$$\tau_+ = \tau_- = \tau,$$

$$\tau_1 = \tau_2 = \tau_0.$$

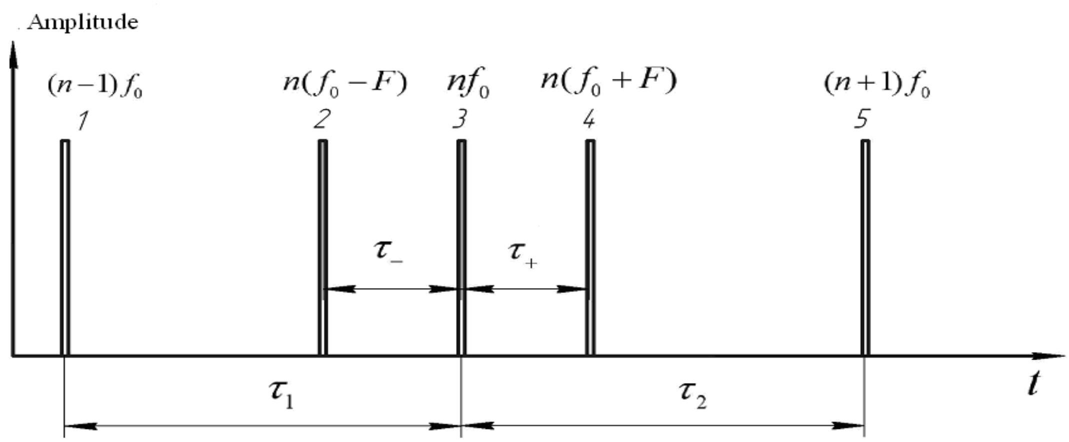


Fig. 2. Sequence of the formed marks

Formula for frequency of the third mark

$$f_M = \frac{\tau}{\tau_0}\frac{f_0^2}{F},$$

coincides with the formula according with which [3] the frequency marking [3] is determined. Sequence of marks in device [3] is presented in fig. 3.

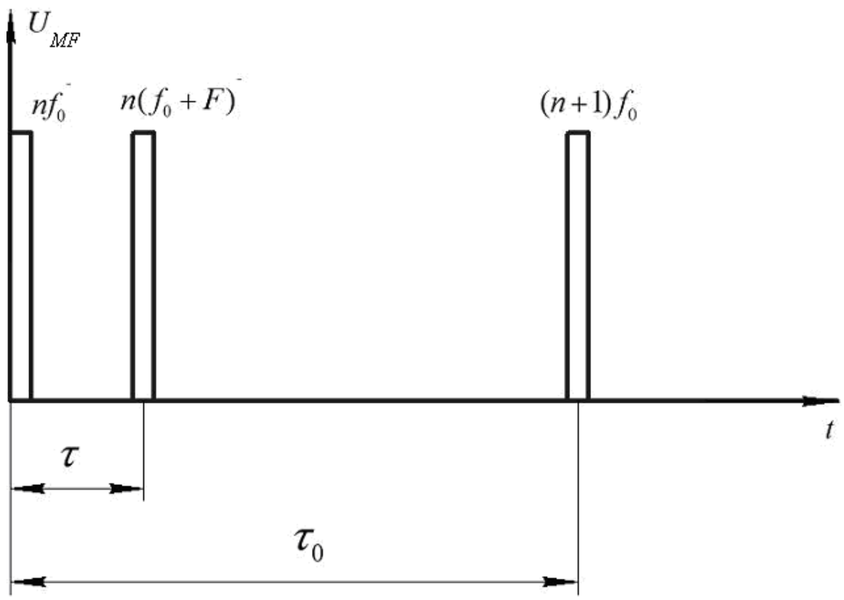


Fig. 3 Sequence of marks in device [3].

Let us perform the normalization of time dependence of frequency f of sweep-generator on the ordinate axis to $y = f/f_{\mathrm{m}}$, on the abscissa axis – to $x = t/T_P$, where f_{m} – maximum frequency, and T_P – period of sweep-generator frequency unrolling. The worst case from the point of view of influence of unrolling non-linearity on the exactness of frequency determination – frequency change f during the unrolling period from $(n-1)f_0$ to $(n+1)f_0$ (fig. 4).

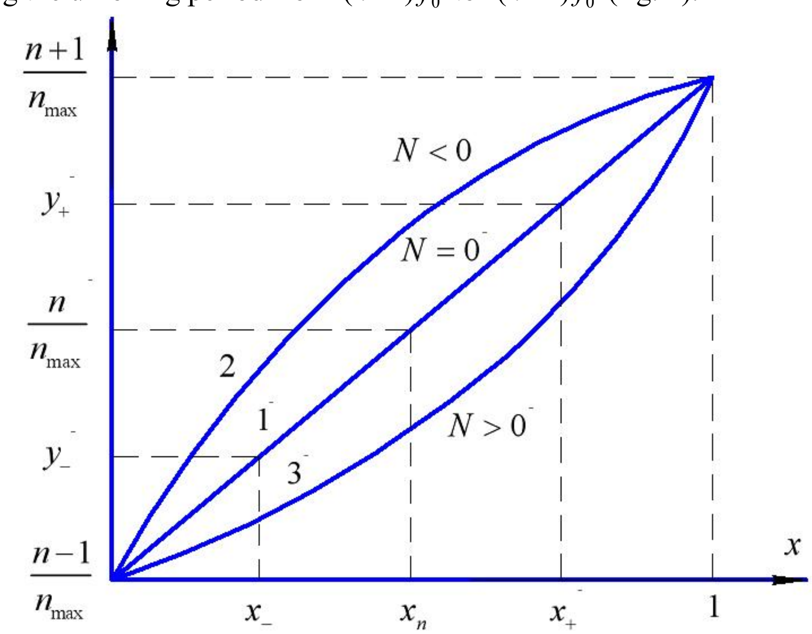


Fig. 4. Linear and non-linear change of sweep-generator frequency

For the linear measuring of frequency f (fig. 4, curve 1) in measuring device with two reference generators [3] the number of harmonics.

$$n = n_{\max}\frac{\tau}{\tau_0} = n_{\max}\frac{x_+ - x_n}{1 - x_n}, \tag{1}$$

where $n_{\max} = \frac{f_0}{F}$ – maximum number of harmonics, which corresponds to the maximum frequency of sweep-generator $f_{\max}$. For measuring devised (fig. 1)

$$n = n_{\max} \frac{\tau_- + \tau_+}{\tau_1 + \tau_2} = n_{\max}(x_+ - x_-). \tag{2}$$

Only theoretically sweep-generator frequency time change takes place according with the linear law. Therefore the frequency mark shall be found from (1, 2) with error, which depends on the non-linearity factor of the real sweep-generator. The method of capacitor overcharging with direct current is used to create voltage which is linearly changing in the tuning block [4]. Despite of special circuit solutions (application of the initial section of exponential curve, negative feed-back in integrator, compensation e.m.f. etc.), zero factor of nonlinearity cannot be found.

Measurement error, caused by sweep-generator nonlinearity

Retuning voltage and, accordingly, frequency f of sweep-generator are changed according to exponential law (fig. 4, curves 2, 3)

$$y = \frac{n-1}{n_{\max}} + \frac{2}{n_{\max}} \cdot \frac{e^{Nx} - 1}{e^N - 1}, \tag{3}$$

where N –is factor of nonlinear unrolling.

Let us find expressions for x_n, x_-, x_+ in case of sweep-generator nonlinearity. Substituting in (3) value $y(x_n) = \frac{n}{n_{\max}}$, we receive:

$$\frac{n}{n_{\max}} = \frac{n-1}{n_{\max}} + \frac{2}{n_{\max}} \cdot \frac{e^{Nx_-} - 1}{e^N - 1},$$

whence

$$x_n = \frac{1}{N} \ln\left(\frac{e^N - 1}{2} + 1\right). \tag{4}$$

The value of y in the time moment x_- equals

$$y(x_-) = \frac{n(f_0 - F)}{n_{\max}} = \frac{n}{n_{\max}}\left(1 - \frac{1}{n_{\max}}\right)$$

or

$$\frac{n-1}{n_{\max}} + \frac{2}{n_{\max}} \cdot \frac{e^{Nx_n} - 1}{e^N - 1} - \frac{n}{n_{\max}^2} = \frac{n-1}{n_{\max}} + \frac{2}{n_{\max}} \cdot \frac{e^{Nx_-} - 1}{e^N - 1}.$$

After transformation we receive

$$x_- = \frac{1}{N} \ln\left[\frac{e^N - 1}{2}\left(2\frac{e^{Nx_n} - 1}{e^N - 1} - \frac{n}{n_{\max}}\right) + 1\right]. \tag{5}$$

Analogically time moment

$$x_+ = \frac{1}{N} \ln\left[\frac{e^N - 1}{2}\left(2\frac{e^{Nx_n} - 1}{e^N - 1} + \frac{n}{n_{\max}}\right) + 1\right]. \tag{6}$$

Substituting (4 - 6) in (1), (2), we have the calculated formulas for finding the number of harmonica n_p, and, correspondingly, frequency mark f_M.

The exact value of harmonica number is determined according to the formula $n = n_{\max} y(x_n)$, than the error of determining the number of harmonica $\Delta n = n_p - n$.

Fig. 5, 6 present the dependence of absolute error Δn of determining the number of harmonics from $z = \frac{n}{n_{\max}}$ for different values of sweep-generator nonlinearity factor in case of using in measuring device the frequency marks of two [3] and three (fig. 1) reference generators.

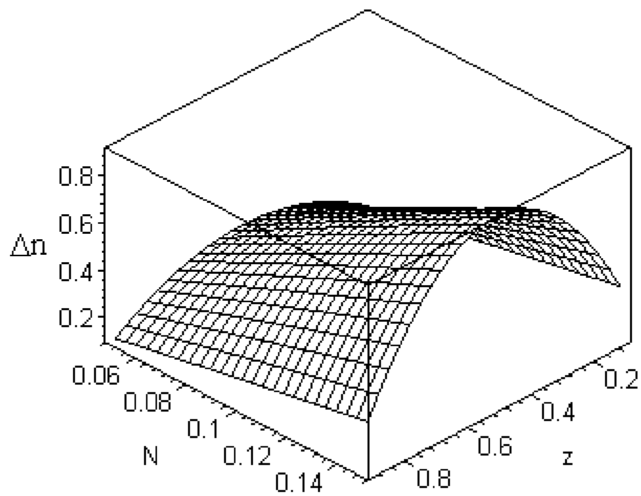


Fig. 5. Absolute error of determining the number of harmonics of measuring device with two reference generators

Number of harmonics will be determined correctly, when the condition $\Delta n < 0{,}5$ is met. It is due to the fact that the number of harmonic must be only a whole number. After measuring time intervals x_n, x_-, x_+ and calculating n_p the exact number of harmonic n will be found by rounding.

Let us research the dependence of maximum possible number of harmonics $n_{\max}$ of reference generator with frequency f_0 from z for different factors of sweep-generator nonlinearity, when measuring devices of frequency marks with two (fig. 7) and three (fig. 8) reference generators are used. Analysis of dependences will help connect the following main parameters of sweep-generator as working frequency range, frequency pitch of marks, dispersion.

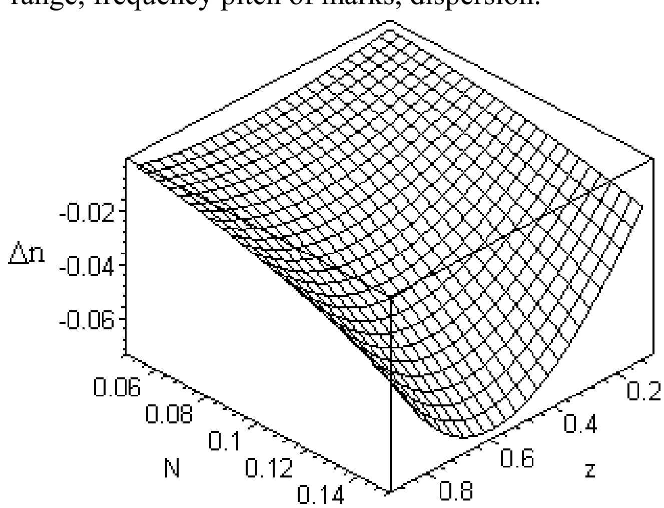


Fig. 6. Absolute error of determining the number of harmonic of measuring device with three reference generators

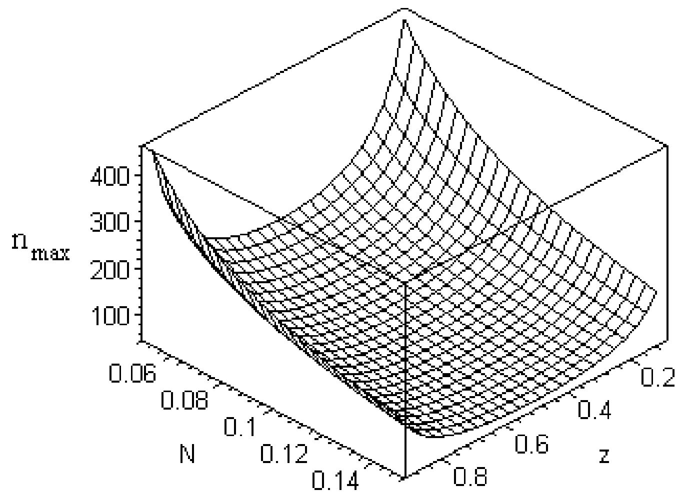


Fig. 7. Maximum number of harmonics of measuring device with two reference generator

Let us conduct the normalizing of error Δn to $n_{\max}$, then the condition of correct determination of frequency will look like

$$\frac{0,5}{n_{\max}} > \frac{|\Delta n|}{n_{\max}}.$$

Then for the measuring device with two generators [3] we will receive the following expression for maximum number of harmonic

$$n_{\max} = \frac{1}{2}\left(\frac{x_{+} - x_{n}}{1 - x_{n}} - z\right)^{-1},$$

and for measuring device with three reference generator (fig. 1)

$$n_{\max} = \frac{1}{2(x_{+} - x_{-} - z)}.$$

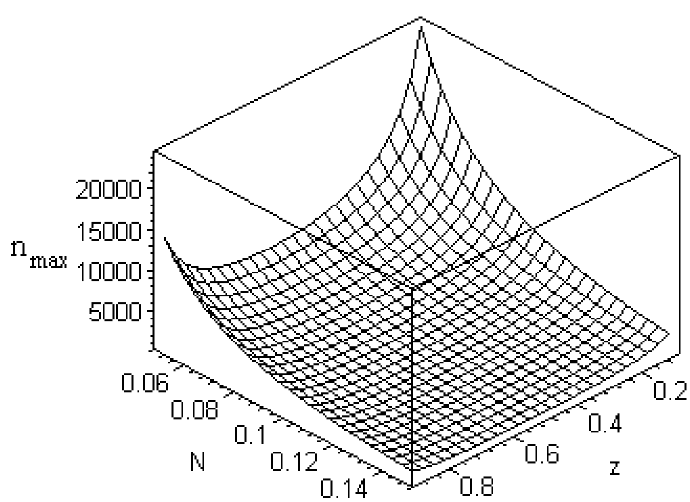
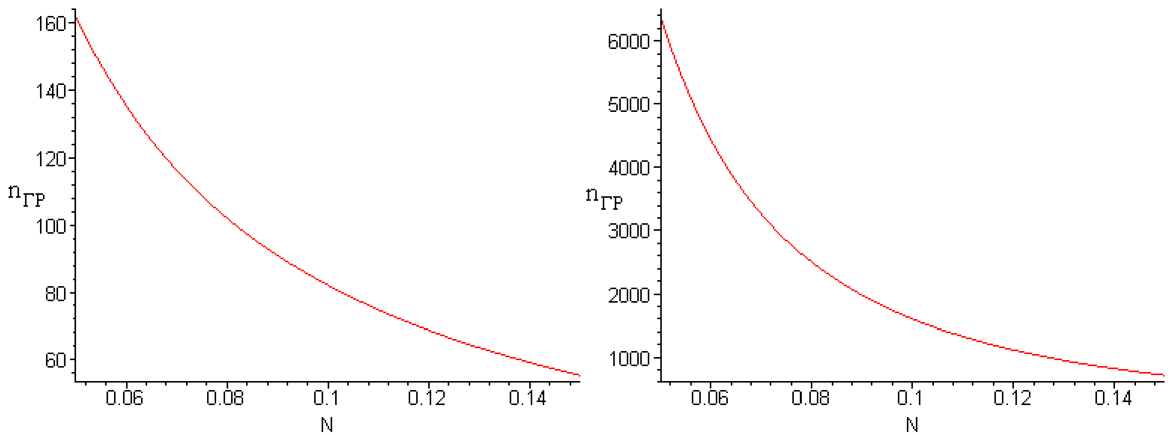


Fig. 8. Maximum number of harmonics of measuring device with three reference generators

Received curves have minimums, which correspond to the condition $\frac{\partial n_{\max}}{\partial z} = 0$. It is possible to say that for each sweep-generator nonlinearity factor there is its own boundary number of harmonics $n_{ГР}$. If the maximum number of harmonics $n_{\max}$ exceeds the boundary vary, then in the whole frequency range of sweep-generator together with the correctly formed marks there will be those, frequency of with is determined with absolute error f_0 or higher. Fig. 9 presents the dependence of boundary number of harmonic $n_{ГР}$ of factor of sweep-generator nonlinearity.



a) b)

Fig. 9. Boundary number of harmonic of reference generator with frequency f_0 (a – two reference generator, b – three reference generator)

Such an application of the considered dependences may be suggested for designing devices on the base of sweep-generator. According to the known factor of sweep-generator nonlinearity N we find the boundary number of harmonic $n_{ГР}$. Then, following the known maximum operating frequency f_{MAX} we calculate frequency $f_0 = f_{MAX}/(0{,}8 \cdot n_{ГР})$ and shift frequency in which frequencies of reference generators differ, $F = f_{MAX}/(0{,}8 \cdot n_{ГР}^2)$. Thus, the minimum allowed pitch of frequency measuring device f_0 as well as minimum dispersion of sweep-generator $3f_0$ become known. For instance, let the maximum operating frequency of sweep-generator $f_{MAX} = 10$ GHz, and nonlinearity factor $N \le 0{,}1$. We find $n_{ГР} = 84$ (fig. 9, a). We determine marks pitch $f_0 = 10 \cdot 10^3/(0{,}8 \cdot 84) \approx 150$ MHz, shift frequency $F = (10 \cdot 10^3)/[0{,}8 \cdot (84)^2] \approx 1{,}7715$ MHz. Minimum dispersion of sweep-generator makes up $П_{MIN} = 3f_0 = 450$ MHz.

Conclusions

1. There had been considered the principal methods for determining frequency marks in devices on the base of sweep-generator. There had been suggested methods for building measuring device with two and there reference frequencies. Measurings are conducted within the unrolling period, that is within much time. The determination of frequency marks in sweep-generators with significant speed of frequency change is possible.

2. There had been analyzed the errors of measurings, caused by nonlinearity of frequency unrolling of sweep-generator. There had been suggested a way for calculating the main parameters of devices on the base of sweep-generator, such as mark pitch, frequency pitch, dispersion. It had been proved that the measuring device with three reference frequencies under equal nonlinearity factors, has less mark pitch, that is, less error in determining sweep-generator frequency in comparison with the measuring device with two reference frequencies.

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