Indirect Measurement of the Time Constant of Phase – Shifting Elements from Resistive – Coaxial Microwires

Dimitrachi S., Dimitrachi N.,
Technical University of Moldova,
Chisinau, Republic of Moldova

***Abstract*–One of the ways to create $\overline{RC}$ structures of big time constants for the range of low and infra-low frequencies and small size is using in the construction of these structures the coaxial micro-cable, obtained by casting the micro wire from liquid phase straight in glass insulation with a subsequent deposition of the metallic layer onto the glass insulation. This type of micro-cable has high chase parameters, resistance r with values of hundreds of kΩ/m, and even units of MΩ/m and capacitance C up to hundreds of pF/meter. The high value of r and C of micro-cable gives the possibility to produce $\overline{RC}$ structures of big time constants of a very small size.**

***Key words*– structures, coaxial, glass, filter, temperature**

I. INTRODUCTION

Purpose - The development of $\overline{RC}$ structures from coaxial micro-cable with high quality factor and thermal stability for ranges of low and infra-low frequencies; the development of the method of measuring the time constant of a given value of structures during the manufacturing process with high accuracy.

Due to the microminiaturization of electronic equipments in generators, selective amplifiers, spectrum analyzers, for the synthesis of complicated filters and other devices, range of low and infralow frequencies a strong necessity appeared in elaboration of phase – specifying and selective massive circuits, which in literature are called structures of type $\overline{RC}$ (notched filters, filters of high and low frequency and others), small size, weight, and qualitative electrical parameters.

The solution of this problem became possible only with elaboration of resistive – coaxial microwire [1, 2] static time constant for one meter that can be 1-40 and more microsec [2]. Using resistive coaxial microcable made possible the construction of phase-shifting elements in the sequel - structures for medium, low and even infra-low frequencies [4]. However, the high resistance passage (tens and hundreds of MΩ [3]) and fabrication of modern elements makes single microcable introduce a large loss of useful signal that need to be used in circuits with high resistances of approximately two orders of magnitude higher than the value $\overline{R}$, technology of their production is sufficient. This limits their widespread application, particularly at subsonic and low frequencies.

II. THEORETICAL PART

At the department of telecommunications from Technical University of Moldova was elaborated a method of construction of elements described above, which lack those shortages [5], providing at the same time the reduction of weight and mass dozens of times and in particular cases hundreds of times.

The purpose of this work consists of elaboration of methods for measuring time constant for these elements as the main factor that determines the degree of measured phase of the signal at the specified frequency.

The definition of time constant structure, after quantity of microcables, because of the inhomogeneity of its linear parameters, linear resistance *r* and linear capacity C [4] is conjugated with big errors in measures till tens and more per cents.

Method of measuring the time constant number of micro cable laid in the element at the manufacturing process does not require consequential damage continuity as coaxial cover and the name of the insulation.

Errors do not exceed hundredths or even thousandths of a percent, regardless of the time constant.

The basis of this method include fusion properties of the zero (notch) filter at the resonant frequency [5] $\overline{RC-0}$ - length of the line structure as a distributed-constant on the open end of the filter. Here the resonance frequency f_0 of the filter output voltage vector $\overline{RC-0}$ - structure is in anti-phase with the current vector at the filter input, and the time constant $\tau_S=\overline{RC}$ - structure resonant frequency f_0 filter connected unambiguous relationship: $\tau_S \cdot f_0 = 1.78$.

In fig. 1, 2 and 3 are shown diagrams illustrating the principle of indirect measurement of the time constant of the set value $\tau_S=\overline{RC}$. The time constant τ_S of the structure during its manufacture is continuously measured by measuring the phase shift between $\vec{I}_1$, the vector value 180° that flows in a specific area micro cable shell

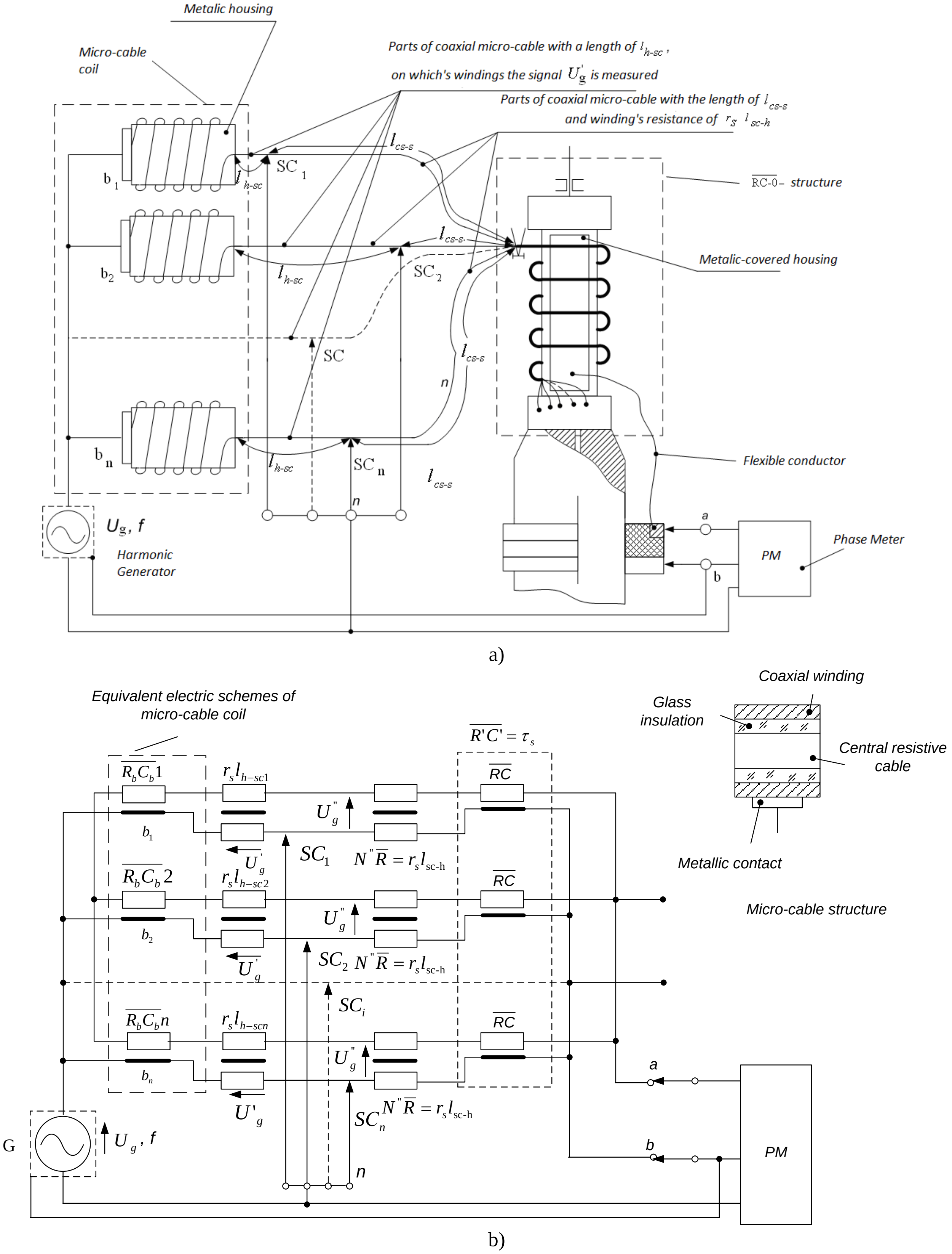


Fig. 1. Structural (a) and electrical equivalent (b) schemes showing the principle of producing and measuring the $\overline{RC-0}$ - structures.

indicated in figure 1 by l_{CS-S}, and the vector of the output voltage $\vec{U}_2$ being produced - at the end of an open structure.

Resistance micro cable said shell portion l_{CS-S}, fig. 1b indicated by NR, is the resistance of the notch filter and manufactured in cooperation with - the structure of the virtual image of the zero notch filter (Fig. 2b).

As for measuring the signal structure used by the voltage drops on the other shell portion micro cable, fig. 1 and the voltage across it by $U_g^{'}$ (Fig. 1 b and 2 a, b).

Using as a measuring signal voltage $U_g^{'}$ that occurs on the shell l_{h-sc} micro cable file allows the virtual measuring signal input of the filter without destroying the continuity of the coaxial micro cable coating and insulation, thereby providing the same phase shift of the voltage vectors at the input of the current $\vec{I}_1$ structure $\vec{U}_1$ (Fig. 2). We will demonstrate this.

The relationship between the voltage at the exit of $\overline{R'C'}-0$ - structure $\vec{U}_2$ and the vector of the current at the entrance of notch filter $\vec{I}_1$ and the passive $\overline{R}'$ and $\overline{C}'$ values of the structure $\overline{R'C'}-0$ type is given by relation:

$$U_2 = I_1 \frac{\overline{R}}{\theta}\cdot\frac{1}{sh\theta}, \tag{1}$$

where $\theta=\sqrt{2\pi frCl}=\sqrt{2\pi f\overline{CR}}=\sqrt{2\pi f\tau}$,

f - frequency of the measured signal, l - the length of micro-cable stacked in the structure.

Separating in (1) the real part from the imaginary one we get:

$$U_2 = I_1\frac{R}{\gamma}e^{-j\frac{\pi}{2}}\times \times\left[\frac{sh\gamma l\cos\gamma l}{ch^2\gamma l+\cos^2\gamma l} - j\frac{ch\gamma l\sin\gamma l}{ch^2\gamma l+\cos^2\gamma l}\right], \tag{2}$$

where $\gamma=\sqrt{\pi fCr}$.

From (2) we can find the angle between the vector of input current $\vec{I}_1$, and the output voltage $\vec{U}_2$ of the structure $\overline{CR}-0$ - type:

$$\varphi = \angle\vec{U}_2\vec{I}_1 = arctg\frac{ch\gamma l\sin\gamma l}{sh\gamma l+\cos\gamma l}. \tag{3}$$

When $\angle\vec{U}_2\vec{I}_1 = 180°$, (3) becomes:

$$th\gamma l = -tg\gamma l. \tag{4}$$

Solving (4) depending on γ, we get:

$$\gamma=\sqrt{\pi frlCl}=\sqrt{\pi fr\overline{RC}}=\sqrt{\pi f\tau_S}=\left(k-\frac{1}{4}\right)\pi, \tag{5}$$

From which: $$\tau_S = \frac{(k-0.25)^2\pi}{f}. \tag{6}$$

The value of "k" is an integer and can take values 1,2,3 ...

The first value of γ (when k = 1), and the vectors $\vec{I}_1$ and $\vec{U}_2$ are in opposite phase equal to 2.365, and the constant τ and the frequency f_r at which the phase shift takes place between them, are related by:

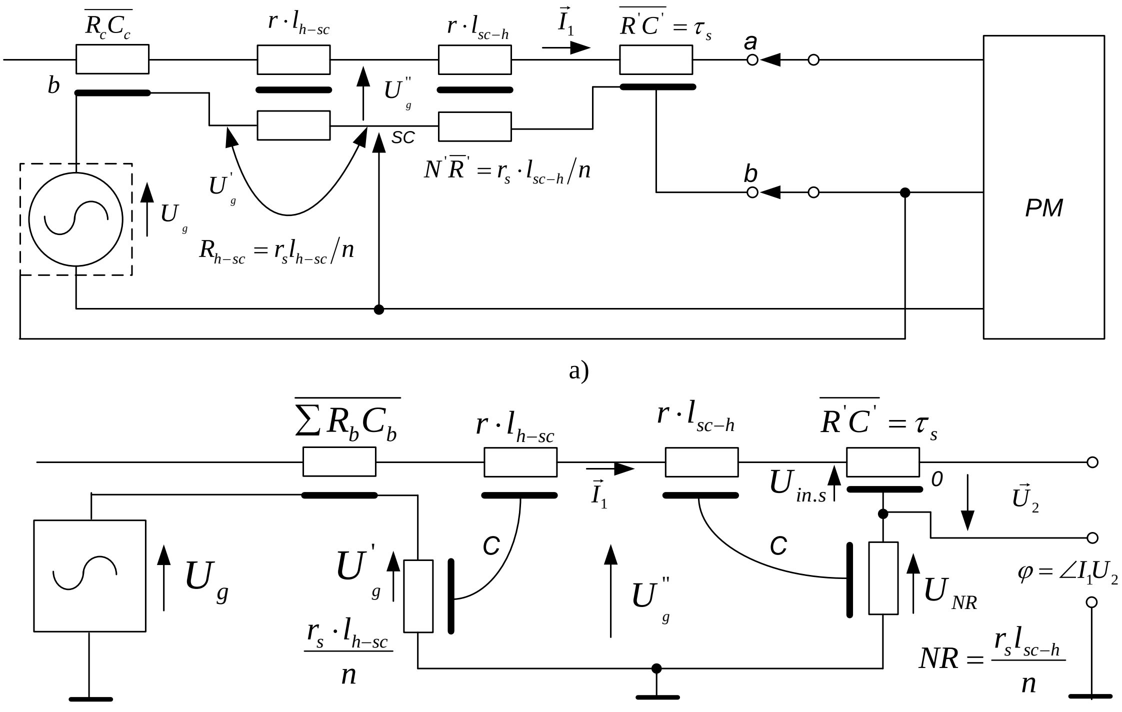
$$\tau\cdot f=\tau_S f_r=1.78=const. \tag{7}$$

where f_r - the frequency at which in the notch filter, using $\overline{RC}$-0 – structure as a phase-rotating chain occurs a resonance.

From (7) follows that when $\varphi=\pi$ between the time constant τ of the structure and the frequency of the measuring signal f equal to the resonance frequency f_r ($f=f_r$) in the filter where $\tau=1.78/f_r$ there is a clear dependence. Using this dependence is made the method of playback the time constant τ_S of fixed value structures type $\overline{R^{'}C^{'}-0}$ during their manufacturing. In the diagrams (Fig. 2) explaining the principle of the method are adopted the following notations: $\overline{R_{bi}C_{bi}}-0$ - the equivalent electrical values off micro-cable on the giving coils b$_i$; SC – sliding electric contact, PM - phase meter, G - generator of harmonic signals, r and r_s - respectively the resistance per unit length of the central conductor and the conductive cover (coil) of the micro-cable; l_{h-sc} and l_{cs-s} respectively the length of micro-cable sites that are between the giving coil b and a sliding contact SC and respectively between the sliding contact and the structure C. The resistance of coaxial shells of these sites of micro-cable forms the resistances: of the harmonic generator $r_s l_{h-sc}$ and the load resistance of the notch $r_s l_{cs-s}$ formed by the notch filter (Fig. 2b).

The originality of the method and the schemes implementing the method of measurement is:

- in the same phase shifts introduced by the values of the micro-cable coils in vectors of the voltage $\vec{U}_g^{''}$ and the current $\vec{I}_1$;
- in the use of hybrid notch filter’s properties;
- in artificial creation of zero hybrid notch filter (Fig. 2);
- in the use of the produced $\overline{R'C'}-0$ – structure as phase rotating chain that is component of hybrid notch filter (Fig. 2);



a)

b)

Fig. 2 Electrical equivalent common scheme (a), and the scheme of the formed notch filter (b).

– in the use of the resistance of a defined part of coaxial winding of micro-cable $r_s l_{cs-s}/n$ as resistance of the notch filter (Fig. 1,a and 2,a);

– in the use of the voltage on a defined part of coaxial winding of micro-cable as measuring $U_g^{'}$ (Fig. 2,a);

– in the elimination of micro-cable coil $\overline{R_c C_c}$ influence on the precision of measurement τ_S of the structure by including them in the scheme of measurement as elements of electrical connection of the structure with voltage $U_g^{'}$;

– in the use of coaxial shell of micro-cable as the load of harmonic measuring generator;

This method is applicable for the playback of structures $\overline{CR-0}$ - type for any purpose, any values of time constants τ_S of fixed value, regardless of the phase shifts made by the mentioned elements of connection.

Lets see the possibility of the method on the example of reproducing time constant τ_S of a fixed value of structures $\overline{R^{'}C^{'}-0}$ – type for low-pass filters LPF (Fig. 3,a), high HPF (Fig. 3,b) frequencies, and also the zero notch filters ZNF (Fig. 3,c). The method is also applicable to reproduce the structures of time constant of fixed value in the manufacturing of phase-shifting circuits $\overline{C^{'}R^{'}-0}$ - type of any phase values operating in the frequency range up to the infra-low.

- reproduction of structures $\overline{RC-0}$ *- type for HPF of a fixed low-pass filter cutoff frequency* f_c, Fig. 3,a.

Transfer coefficient of voltage for low-pass filter at idle is defined by [6, 7]:

$$K_{U.LPF} = 1/\mathrm{ch}\,\theta. \qquad (8)$$

Separating in (8) the imaginary part of the real, we define the modulus of $|K_{U.LPF}|$:

$$K_{U.LPF} = \frac{\mathrm{ch}\gamma\cos\gamma}{sh^2\gamma+\cos^2\gamma} - j\frac{sh\gamma\sin\gamma}{sh^2\gamma+\cos^2\gamma},$$

From where $|K_{U.LPF}| = \sqrt{2}/\sqrt{ch2\gamma+\cos 2\gamma}$. (9)

Equating (9) to the value $1/\sqrt{2}$, we can establish the connection between the filter cutoff frequency $f_{C.LPF}$ and it's time constant $\tau_{s.LPF}$:

$$|K_{U.LPF}| = \sqrt{2}/\sqrt{ch2\gamma+\cos 2\gamma} = 1/\sqrt{2},$$

From where $ch2\gamma+\cos 2\gamma = 4$,

And respectively

$$\tau_{s.LPF} = \overline{R^{'}C^{'}} = 2.43/2\pi f_{C.LPF.} = 1.215/\pi f_{C.LPF.}. \qquad (10)$$

Then equating (7) and (10), we obtain the equation establishing the relationship between the voltages frequency

f at which is measured the constant $\tau_{\text{s.LPF}}$ and a cutoff frequency $f_{C.LPF}$ of filter:

$$f = 4.6 f_{C.LPF} \,. \tag{11}$$

— the reproduction of structures $\overline{R'C'} - 0$ *– type for HPF of fixed frequency* $f_{C.HPF}$, Fig. 3, b.

HPF transfer coefficient at the idle is defined by [6]:

$$K_{HPF} = (ch\theta - 1)/ch\theta \,. \tag{12}$$

Separating in (12) the imaginary part of the real, we define the transfer coefficient's modulus of the filter:

$$|K_{U.LPF}| = \sqrt{1 - \frac{4\text{ch}\gamma \cos\gamma}{sh 2\gamma + \cos 2\gamma}} \,. \tag{13}$$

Equating (13) to the value and the time constant of specified value: $1/\sqrt{2}$ we can establish a connection between the filter cutoff frequency $f_{C.HPF}$ and the time constant of specified value $\tau_{s.HPF}$:

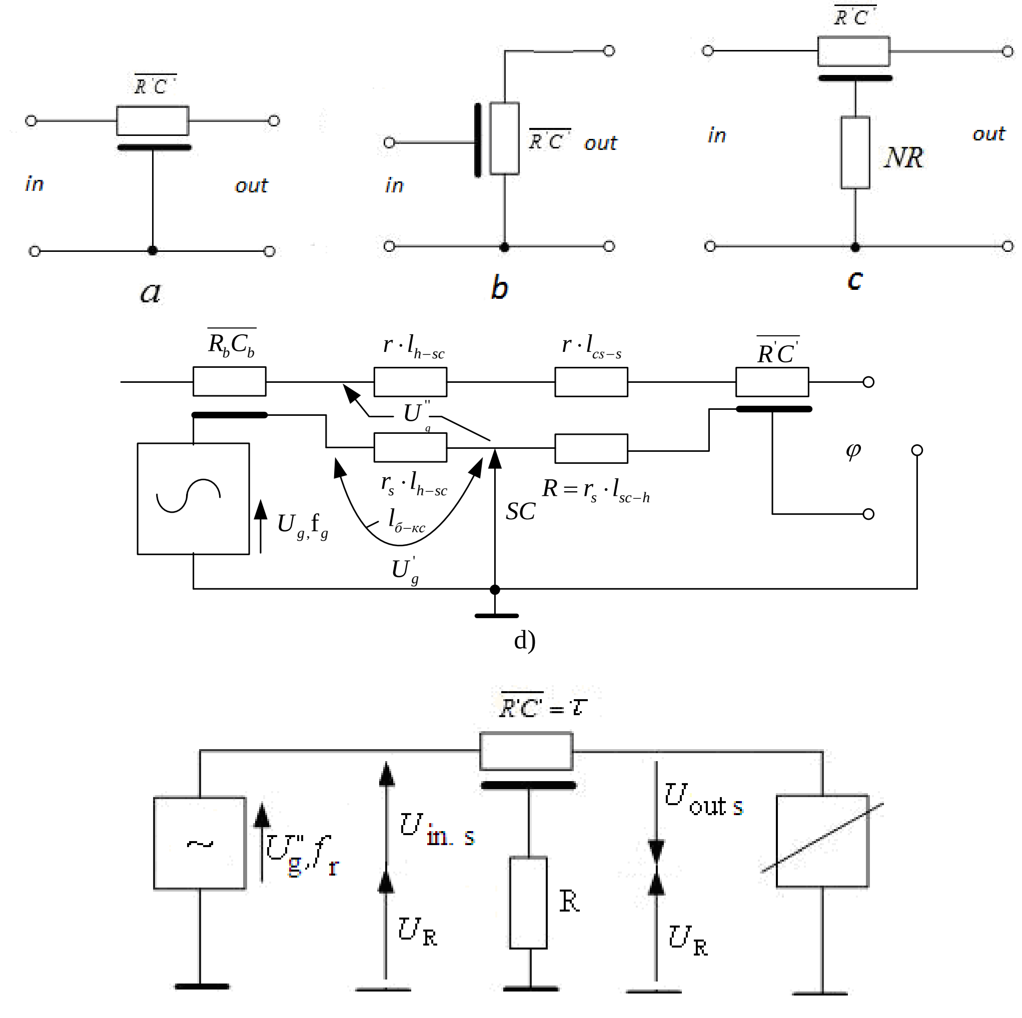
$$\tau_{s.HPF} = \overline{R'C'} = 1.318 / f_{C\Phi B Ч} \,. \tag{14}$$

From (7) and (14) we find the relation between frequency $f_{C.HPF}$ and signal frequency f which according to this method should be measured the constant $\tau_{s.HPF}$

$$\tau_{s.HPF} = \frac{1.78}{f} = \frac{1.318}{f_{C.HPF}} ,$$

From where $$f = 1{,}34 f_{C.HPF} \,. \tag{15}$$

— reproduction of $\overline{R'C'} - 0$ *- structures of the time constant for the zero notch filters of a fixed frequency of rejection* f_r, fig. 3, c.



d)

e)

Fig. 3 Structure of the R - C - 0 - type as: a) low-pass filter LPF, and b) high pass filter HPF, c) as phase-switching chain in the notch (zero) filter.

In [7] is found the resonance condition of this filter. Transfer coefficient for notch (zero) filter at the idle $\left(R_L = \infty\right)$ is defined by [7, 5]:

$$K_n = \frac{1 + \mathrm{N}\theta sh\theta}{\mathrm{ch}\theta + Nsh\theta}. \qquad (16)$$

Considering the resistance $\left(R_L \neq \infty\right)$:

$$K_n = \frac{m\theta\left(1 + \mathrm{N}\theta sh\theta\right)}{m\theta\left(\mathrm{ch}\theta + N\theta sh\theta\right) + sh\theta + 2N\theta\left(ch\theta - 1\right)}, \qquad (16')$$

where $m = R_L/R$, $N = R_m/R = 0.0562$,

$\theta = \sqrt{2\pi frC}\, l = \sqrt{2\pi f\, \overline{RC}} = \sqrt{2\pi f\tau}$, $\tau = \overline{RC}$,

R_m - the resistance of the rejection.

At the filter's frequency of rejection (resonance) f_r the transmission coefficient is equal to zero, which occurs when:

$$1 + \mathrm{N}\theta sh\theta = 0. \qquad (17)$$

Separating in (17) imaginary component of the real and, after appropriate transformations, we obtain:

$$\begin{cases} 1 + N\gamma sh\gamma \cos\gamma - N\gamma ch\gamma \sin\gamma = 0; & (18) \\ th\gamma = -tg\gamma. & (19) \end{cases}$$

Equation (19) coincides with equation (4). Consequently, for reproduction of time constant for the structures $\overline{RC - 0}$ - type for zero notch filters, measuring the time constant of the structure should be carried out at a frequency f of measuring signal, equal to the frequency of notch filter f_r, meaning at the frequency $f = f_r$.

III. CONCLUSION

Considered in the indirect method of measurement of electrical parameters, such as time constants $\overline{RC}$ of the coaxial structures micro wires is original in its meaning in the decision. It provides high accuracy measurement time constant - determines the value of the phase shift of the signal regardless of the value of constant, can provide high performance manufacturing structures, regardless of the number of resistive coaxial micro cable of them simultaneously made structure.

REFERENCES

[1] Трескин С.А., Шпирнов В.А. Разработка способа получения коаксиального микропровода. Сб. Микропровод и приборы сопротивления, вып. IV. Кишинев, Картя Молдовенеаскэ, 1966.

[2] Дегтярь Л.Э. Электрические параметры и свойства коаксиального микропровода – В сб.: Микропровод и приборы сопротивления. - Кишинев, Молдова: Картя Молдовенеаскэ, 1970, вып.VII, с. 131-139.

[3] Л.Э. Дегтярь, Л.М. Зафрипа, М.С. Цимерман. Расчет параметров $\overline{RC}$ – структур из коаксиального микропровода, Молдова: Картя Молдовенеаскэ, 1970, вып.VII, с. 159-269.

[4] С.Н. Димитраки. Автореферат докт. дис. Технологические методы и приборы для измерения и воспроизведения параметров микропровода резистивных и резистивно-емкостных элементов из микропровода. Кишинев, 1986

[5] Койзер, Кастро, Николсб, Схемы с распределенными постоянными на тонких пленках, Зарубежная радиоэлектроника, 1964, №4.

[6] В.В. Виноградов, А.Н. Савенков, М.Л. Фрухтман. Температурная зависимость сопротивления микропроводов из сплава 72НХГС – В сб: Микропровод и приборы сопротивления.-Кишинев, Молдова: Картя Молдовенеаскэ, 19 , вып. , с. 293-296

[7] W.M. Kaufman. Theory of Monolithic Null. Device and some Novel circuits. Proceedings of the I.R.E., 1960, №9 .