Designing a Low Frequency Delay Line

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Tatiana Shkvarnitskaya
Institute of Aerospace Control Systems NAU,
Kyiv, Ukraine
e-mail: fsu@nau.edu.ua

Mariia Kataieva
Institute of Aerospace Control Systems NAU,
Kyiv, Ukraine
e-mail: kataeva.mariia@gmail.edu.ua

Volodymyr Kvasnikov
Institute of Aerospace Control Systems NAU,
Kyiv, Ukraine
e-mail: kvp@nau.edu.ua

Abstract— **Expressions were obtained for the phase characteristic of the delay line with active losses. Linearity of the phase characteristic is estimated. The experimental results are presented.**

Keywords— delay line, electrical filter, bridge circuit, phase response, delay time.

I. INTRODUCTION AND SETTING A TASK

Delay lines are intended to shift the time of impulse signals. Mostly, the delay line is a low pass filter (LPF) type K [1]. The delay time of such filters is inversely proportional to the cutoff frequency and is essentially frequency dependent. Therefore, only the initial bandwidth is used for operation, where the delay is small.

To increase the delay, it is necessary to increase the number of links, which significantly increases the size and weight of the product. Therefore, delay lines on LPF type K are rationally used in the high frequency region with low requirements for the delay time (microseconds), which is typical, for example, for radar.

In the low frequency range, the required delay time is up to milliseconds and even seconds, so using a K type LPF in this frequency range is unrealistic. In [2], it is proposed to use a m type LPF and a combination of the specified filter with a T-bridge link as a delay line. These options allow you to use a wider bandwidth, which reduces the cutoff frequency, thus increasing the delay by one section.

However, in [2] the effect of active losses in the elements on the characteristics of the scheme is not taken into account. The proposed article analyzes the characteristics of the delay line section on the low-pass filter type m and the T-bridge link taking into account the active losses in the circuit elements, evaluating the quality of the delay line, and provides experimental data.

II. ANALYSIS OF THE DELAY LINE SCHEME.

Analysis of the characteristics of LPF type m and T-bridge can be combined by submitting them as a generalized link of the delay line (Fig. 1).

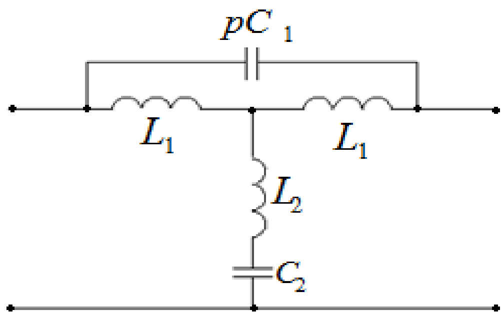

Figure 1. Generalized delay line link

At p = 0 we have a LPF type m link, at p = 1 we get a T-bridge.

The elements of the scheme are calculated by the ratios:

$$L_1 = 0,5\mathrm{m}L,$$

$$C_1 = \frac{C}{4\mathrm{m}}, \qquad (1)$$

$$L_2 = \frac{1-\mathrm{m}^2}{4\mathrm{m}}L,$$

$$C_2 = \mathrm{m}C,$$

where and - the inductance and capacity of the prototype K:

$$L = \frac{2R}{\omega_з};$$

$$C = \frac{2}{\omega_з R};\tag{2}$$

where is the cutoff frequency; R is the nominal impedance (actually the impedance on which the circuit is loaded). Having transformed the scheme of Fig. 1, we obtain the T-shaped scheme (Fig. 2).

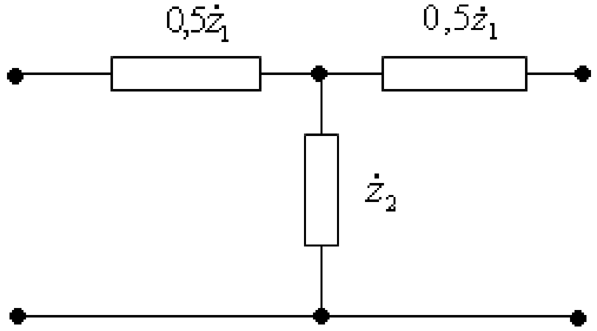

Figure 2. T-shaped diagram of a generalized link of the delay line

The elements of this scheme are as follows:

$$\dot{z}_1 = j\frac{m\omega Lk}{1 - p\eta^2 kt},$$

$$\dot{z}_2 = \frac{pm^4\eta^4k^2t^2 + \left(1 - p\eta^2 kt\right)\left[1 - \eta^2\left(1 - m^2\right)kt\right]}{j\omega mct\left(1 - p\eta^2 kt\right)}\tag{3}$$

Where $\eta = \frac{\omega}{\omega_з}$; $k = 1 - jd_L$; $t = 1 - jd_c$; $d_L -$ active losses in inductors; - active capacitor losses (and this is the ratio of active resistance to reactance of the respective element).

Analysis of the quality of the delay line is carried out, as a rule, on the basis of the behavior of its phase-frequency characteristic (FCH). The delay time is derived from the FCC of the circuit:

$$t_з = -\frac{d\phi}{d\omega},\tag{4}$$

where - FCC of the circuit If the frequency response is a linear function of frequency:

$$\phi = \alpha\omega,\tag{5}$$

Then

$$t_з = \alpha = \text{const},\tag{6}$$

that is, the delay of the circuit is independent of frequency, and the impulse signal passes this circuit without distortion with delay. Thus, the quality of the delay line depends on the linearity of the frequency response and is estimated by the deviation of the frequency response from the linear dependence. This is practically the only way to control and adjust the delay line.

In this regard, we obtain an expression for the FC of the generalized delay line. According to (3), the expression for the FCH is:

$$\phi(\omega) = \arccos\frac{1}{2}\left[\sqrt{(1+A)^2 + B^2} - \sqrt{\left(1 - A^2\right) + B^2}\right],\tag{7}$$

where to link with $p = 0$ (LPF type m)

$$A = \frac{\eta^4\left(1\text{-m}^4\right)\left(a^2 + b^2\right) - 2\eta^2 b + 1}{\eta^4\left(1\text{-m}^2\right)^2\left(a^2 + b^2\right) - 2\eta^2\left(1\text{-m}^2\right)b + 1},$$

$$B = \frac{2\text{m}^2\eta^2 a}{\eta^4\left(1\text{-m}^2\right)^2\left(a^2 + b^2\right) - 2\eta^2\left(1\text{-m}^2\right)b + 1},\tag{8}$$

where to link with $p = 1$ (T-bridge scheme)

$$A = \frac{\left[\left(1 - \eta^2 b\right)^2 - \eta^4 a^2\right]^2 + 4\eta^4 a^2\left(1 - \eta^2 b\right)^2 - \eta^4 m^4\left(a^2 + b^2\right)}{\left[\left(1 - \eta^2 b\right)^2 + \eta^2\left(m^2 b - \eta^2 a^2\right)\right]^2 + \eta^4 a^2\left[m^2 - 2\left(1 - \eta^2 b\right)\right]^2},$$

$$B = \frac{2\eta^2 m^2 a\left[1 - \eta^4\left(a^2 + b^2\right)\right]}{\left[\left(1 - \eta^2 b\right)^2 + \eta^2\left(m^2 b - \eta^2 a^2\right)\right]^2 + \eta^4 a^2\left[m^2 - 2\left(1 - \eta^2 b\right)\right]^2}\tag{9}$$

In expressions (8) and (9) $a = d_L + d_c$; $b = 1 - d_L d_c$.

As follows from [2], the highest linearity of the frequency response is achieved with the combination of LPF type m and T-bridge at m = 1,49. However, according to (1), the inductance of the circuit becomes negative.

It is possible to obtain negative inductance by applying mutual induction. The presence of reciprocal inductance between the inductors of the consecutive arm is equivalent to the negative inductance in the parallel arm. That is, the scheme of the generalized link of the delay line at m> 1 will have the following form (Fig. 3):

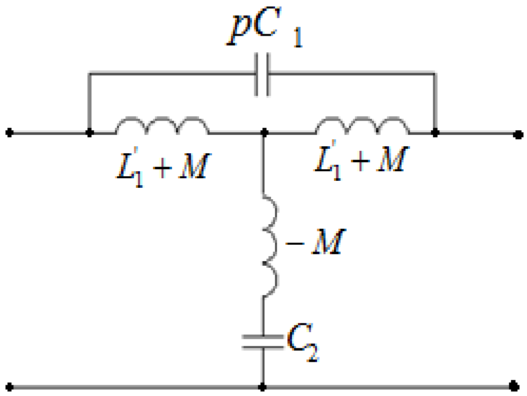

Figure 3. Generalized link of the delay line at m> 1.

Comparing this scheme with the scheme in Fig. 1, we can note:

$$L_1 = L_1' + M = 0,5mL\,;\, L_2 = -M = \frac{m^2-1}{4m}L$$

where L is the inductance of the prototype K, which is in accordance with (2).

The capacitors of the capacitors remain the same as in the scheme of Fig. 1.

At low inductance frequencies, as a rule, are performed on the toroidal nuclei, in which the magnetic flux is practically concentrated inside the nucleus. In this case, the mutual inductance is ensured by winding a portion of the inductance of one coil of magnitude M at the core of the second coil.

Comparisons were made of CFM type m and *T*-bridge at *m*=1.49 for the ideal variant (without active losses) and in the presence of losses. The corresponding practical values of active losses ($d_L = 0,02$; $d_c = 0,01$) were used in the calculations. The deviations of these FCCs from perfectly linear were determined.

III. Experimental studies of this delay line have been conducted

Figure 4 shows the absolute deviations of the phase-frequency characteristics of the combined link from the ideal linear for the lossless variant, taking into account the active losses in the circuit elements, as well as for the frequency response obtained experimentally for the links with $\omega_з = 6280\frac{rad}{\sec}\ (f_з = 1000\ hz)$.

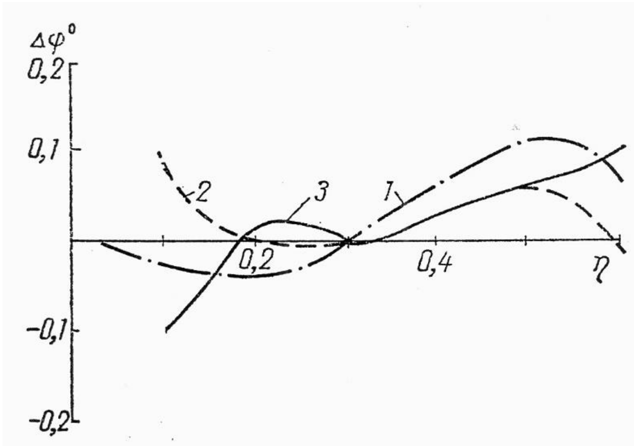

Figure 4. Deviation of frequency response of the combined delay line from the ideal linear: 1- without losses; 2- with active losses; 3- experimental

IV. Conclusions.

The calculations and experimental results indicate the possibility of producing a delay line with a nonlinearity of the phase-frequency characteristic not more than 0.1° per combined pair of units in the range up to 0.6. The experimental data are slightly different from the calculated data. The results obtained allow us to reasonably design delay lines with a long delay time.

References

[1] Basharin SA, Fedorov VV Theoretical foundations of electrical engineering. The theory of electrical circuits and electromagnetic field. - M .: Academy, 2004.- 304 p.

[2] Aizinov MM Transitions in elements of radio devices.-M .: Maritime transport, 1988.- 492 p.