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SYNTHESIS AND IMPLEMENTATION OF A POLYNOMIAL NOTCH FILTER ACCORDING TO AN RF PROTOTYPE

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ABSTRACT

The use of modern methods of synthesis of electrical circuits makes it possible to create circuits with frequency characteristics of any complexity that do not require restructuring. However, when solving the problem of creating tunable filters, additional requirements arise for the filter and tuning technologies, especially if we are talking about creating systems in the frequency region bordering between frequencies, where implementation in the form of systems with lumped and distributed parameters is inconvenient in both cases. This article is devoted to the synthesis of a stop filter under such conditions. The goal of synthesizing tunable filters is to obtain either a constant absolute or constant relative bandwidth. The first requirement is typical for radio receiving devices, where it is necessary to ensure the minimum permissible bandwidth during tuning, the second – for radio transmitting devices, where minimum losses in the passband and a constant harmonic filtering coefficient are required. A modified method for the synthesis of rejection filters according to operating parameters is described, the synthesis of a specific filter and technological solutions for its implementation, the choice of a method for its electronic restructuring is described.

KEYWORDS: *Phase-Frequency Response, Signal, Prototype, Interference, Synthesis, Filter, Two-Port Network, Four-Port Network, Passband, Unevenness.*

1 Introduction

Frequency-selective circuits play a vital role in radio engineering. Their task is to separate the desired signal from a variety of signals and interference or, conversely, to suppress unwanted vibrations.

The use of modern methods of synthesis of electrical circuits makes it possible to create circuits with frequency characteristics of any complexity that do not require restructuring [1]. However, when solving the problem of creating tunable filters, additional requirements arise for the filter and tunability technologies [2], especially when it comes to creating systems in the frequency range bordering between frequencies, where implementation in the form of systems with lumped and distributed parameters is inconvenient in both cases. This article is devoted to the synthesis of a stop filter under such conditions.

2 Research results – synthesis and implementation of a high-order notch filter in conditions of problematic implementation

When synthesizing a tunable filter, it is necessary to set its key parameters [3,4]:

- Allowable changes in bandwidth when tuning from the lower frequency of the tuning range to the upper one;
- Permissible changes in the level of distortion during reconstruction;
- Permissible levels of loss in the passband and guaranteed attenuation in the stopband for the entire tuning range;
- Providing the required law for changing the tuning frequency in a given range when acting on the actuator that rebuilds the filter;
- Ensuring the optimal shape, dimensions, weight of the adjustment device [5,6];
- Resistance of the adjustment device to mechanical and climatic influences

The goal of synthesizing tunable filters is to obtain either a constant absolute or constant relative bandwidth. The first requirement is typical for radio receiving devices, where it is necessary to ensure the minimum permissible bandwidth during tuning, the second – for radio transmitting devices, where minimal losses in the passband and a constant harmonic filtering coefficient are required [7]

Filter synthesis based on operating parameters is used to create broadband filters, which, unlike narrowband filters, cannot be matched at the input and output, loaded with characteristic resistances, due to their pronounced dependence on frequency [8]. Typically, the filter has a resistive or complex load with a small reactive component, and matching is only possible in a narrow frequency band, where the filter's output resistance weakly depends on frequency. The same can be said about the input resistance of the filter and the internal resistance of the input oscillation source. The theory and practice of calculating filters loaded with characteristic resistance are represented by type “k” and type “m” filters, about which it is also known that in a wide frequency band their theoretical characteristics never coincide with the experimental ones (although the filtering effect takes place, but not can be assessed in advance) [9].

The fundamental difference between filters created taking into account operating parameters from filters calculated using characteristic parameters is that in the first case there is a synthesis of the optimal circuit of the device, the characteristics of which correspond to the technical specifications, and in the second, selection from a database of ready-made circuits without any guarantees of optimality selected scheme for a given technical problem. The synthesis of narrow-band filters based on operating parameters often leads to circuits with capacitance and inductance values that are unrealizable on lumped elements, and for this reason is not widely used. However, such calculations are known, in contrast to the calculations of stop filters, so it is worth paying attention to just such a filter and the case when the classical implementation is impossible on lumped elements, and the frequency range does not allow the use of elements with distributed parameters [10-14].

3 Replacing a reactive two-terminal network with a resonant circuit built on magnetically coupled inductive coils

At the resonance frequency (29.93 MHz), the reactance of coil L_1 is 3.5 Ohms. The frequency dependence of the resistance module of the L_1C_1 circuit is shown in Figure 1.

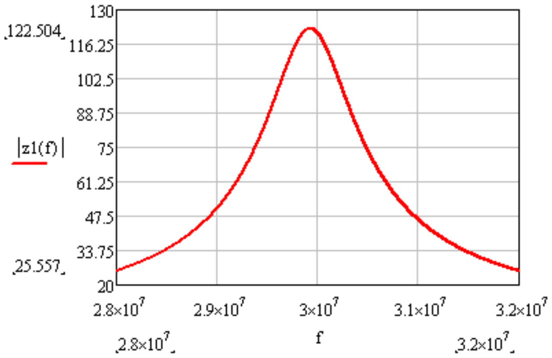
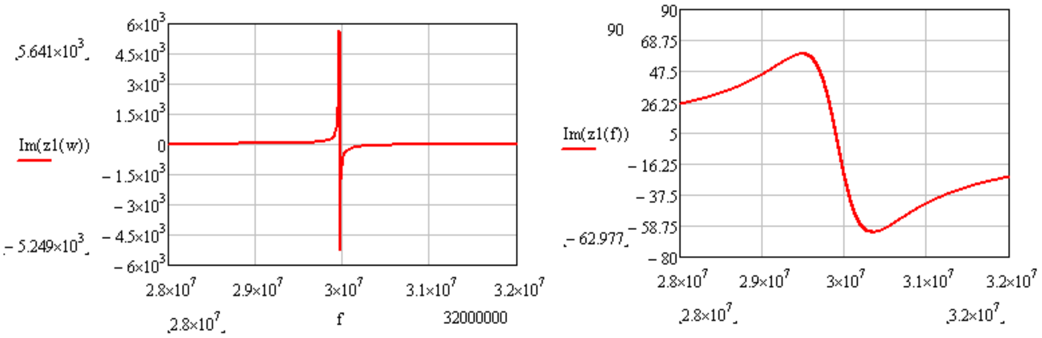


Fig. 1: Resistance module frequency dependence of the L_1C_1 circuit

Accordingly, the phase-frequency characteristic of the L_1C_1 circuit is shown in Figure 2. Note that the phase-frequency characteristic of an ideal two-terminal network without losses is a discontinuous function and is of little use for comparing two-terminal networks (Fig. 2,a), therefore, when constructing a graph (Fig. 2,b) we introduced losses equivalent to a quality factor of 200, which is considered sufficient for filter synthesis without taking losses into account.



a) b)

Fig. 2: Phase-frequency characteristic of circuit L_1C_1

Thus, to implement a band-stop filter with given characteristics, it is necessary to synthesize a two-terminal network that can be implemented in practice and that the frequency response and phase response coincide with the corresponding frequency response and phase response of the theoretical prototype in the operating frequency range - from 25 to 35 MHz.

The simplest way to implement a selective link with an inductive element with very low inductance is shown in Figure 3.

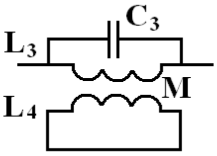


Fig. 3: Selective link with an inductive element

The equivalent inductance of the circuit in this case is determined by the introduced resistance, which is capacitive in nature and, therefore, the total inductance decreases. By selecting the values of inductances L1, L2 and mutual inductance M, we achieve the required value of the total inductance of the circuit:

$$L = L_3 - \frac{M^2}{L_4} \quad (1)$$

Implementing the calculated inductances in the above manner, we obtain a filter circuit whose characteristics are completely identical to those obtained by synthesis:

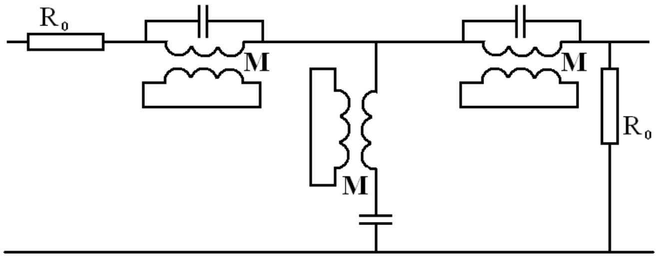


Fig. 4: Circuit diagram of a filter whose characteristics are completely identical to those obtained by synthesis

Such an implementation solves the issue of low inductance, but will not help in any way if the synthesis has given very small values of the capacitance of the corresponding elements.

A universal method is the replacement of oscillatory systems in a filter with similar but practically implementable systems, according to the criterion of identical (within certain limits of the frequency range) complex input impedance. One of the possible two-terminal networks of this type is the circuit shown in Figure 5.

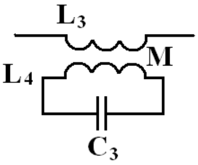


Fig. 5: Two-terminal circuit

The input impedance of the circuit shown in Figure 4 is:

$$Z_{\textit{вх}} = j\omega L_3 + \frac{\omega^2 M^2}{j\omega L_4 + \frac{1}{j\omega C_3}} \quad (2)$$

Let's add small losses to the inductive reactances to make the resistance graph more convenient for analysis, we get the following expression:

$$Z_{\text{вх}} = j\omega L_3 + R_{03}\frac{\omega^2 M^2}{j\omega L_4 + R_{04} + \dfrac{1}{j\omega C_3}} \tag{3}$$

Figure 6 shows the frequency dependence of the reactance obtained from expression (3) – blue curve. In the same figure, the frequency dependence curve of the reactance of a classical parallel oscillatory circuit with losses from the synthesized filter circuit is shown in red.

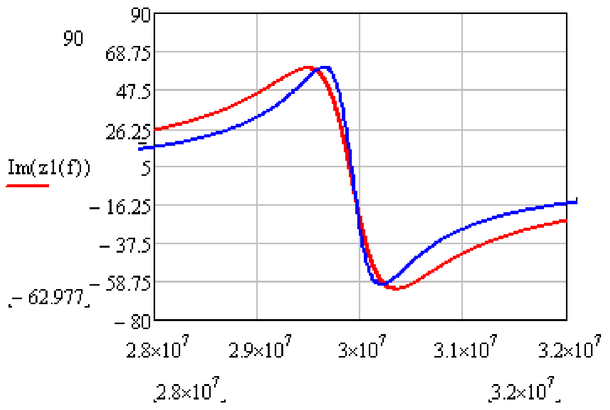


Fig. 6: Frequency dependence of reactance

As can be seen from Figure 6, with the same losses in the inductive elements, the circuit whose circuit is shown in Figure 4 has a slightly higher selectivity, but in general, the characteristics can be considered close, that is, the replacement is legitimate. More noticeable are the differences in the frequency dependences of the resistance modules of the circuit in Fig. 5 and the classic parallel circuit (Fig. 7).

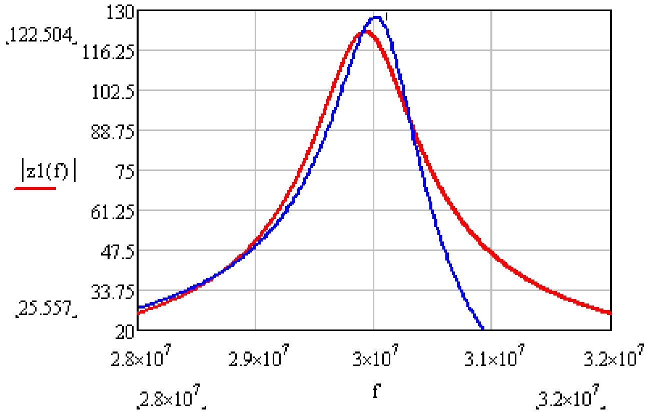


Fig. 7: Frequency dependences of system resistance modulus and the classical parallel circuit

In Figure 7, the asymmetry of the frequency response of the input impedance of an oscillatory system with mutual inductance and a capacitive element in the additional circuit is noticeable. Such a difference in characteristics can even lead to better filtering, but the characteristic will no longer be an analytical function of a given type (Butterworth, Chebyshev, Cauer-Zolotarev). This circumstance allows us to conclude that it is admissible to use a replacement of the classic selective link with a link like Figure 5, however, some additional filter adjustment will be required to level the response and suppress unwanted resonances. Despite these difficulties, this method is practically the only way to create a bandpass selective device based on lumped elements in the higher part of the HF range.

The filter circuit based on selectivity elements with inductive coupling and a capacitive element in an additional circuit is shown in Figure 8.

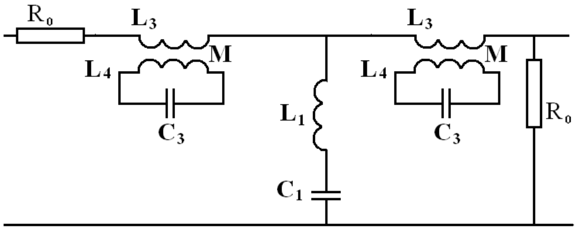


Fig. 8: Filter circuit based on selectivity elements with inductive coupling and a capacitive element in an additional circuit

Note that in the parallel branch the use of a selective link with mutual inductance was not necessary; the values of capacitance and inductance turned out to be realizable.
The expression for the transfer function of the circuit in Figure 8 has the form:

$$H(j\omega)=\frac{\dfrac{1}{\dfrac{1}{j\omega L_1+\dfrac{1}{j\omega C_1}}+\dfrac{1}{R_0+j\omega L_3+\dfrac{\omega^2M^2}{j\omega L_4+\dfrac{1}{j\omega C_3}}}}}{R_0+j\omega L_3+\dfrac{\omega^2M^2}{j\omega L_4+\dfrac{1}{j\omega C_3}}+\dfrac{1}{\dfrac{1}{j\omega L_1+\dfrac{1}{j\omega C_1}}+\dfrac{1}{R_0+j\omega L_3+\dfrac{\omega^2M^2}{j\omega L_4+\dfrac{1}{j\omega C_3}}}}}*\frac{R_0}{R_0+j\omega L_3+\dfrac{\omega^2M^2}{j\omega L_4+\dfrac{1}{j\omega C_3}}} \qquad (4)$$

It is quite easy to introduce losses into this expression; it is necessary to add a resistive loss resistance to each inductive reactance [15]. Figure 9 shows the frequency dependence of the filter transfer function calculated using (4) (Fig. 8):

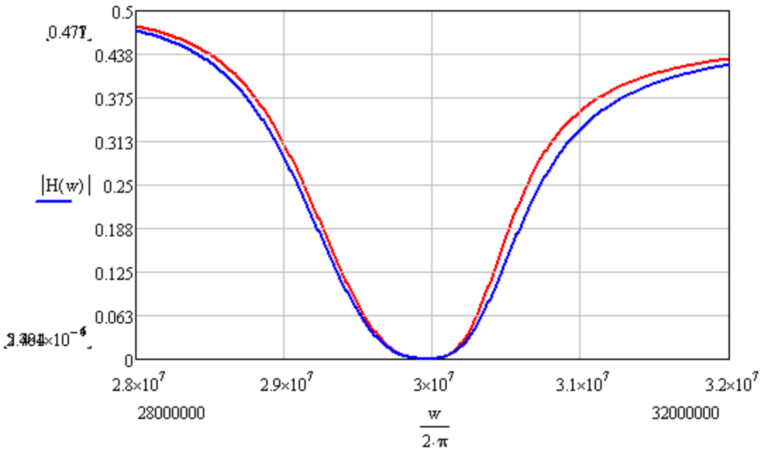


Fig. 9: Frequency dependence of the filter transfer function

The introduction of active losses leads to a change in the characteristics (blue curve), the stopband expands somewhat, but the nature of the curve and its asymmetry remain the same. To equalize the characteristic, one capacitive element was added during the tuning process (Fig. 10), another resonance appeared in the system and the characteristic was balanced by selecting the capacitance of this capacitor (Fig. 11).

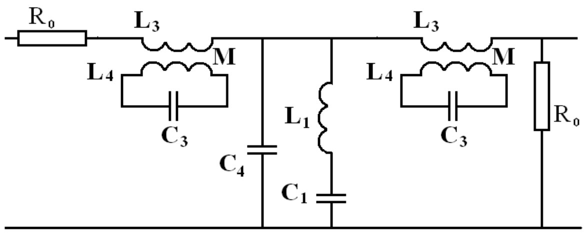


Fig. 10: Adding a capacitive element to a filter circuit

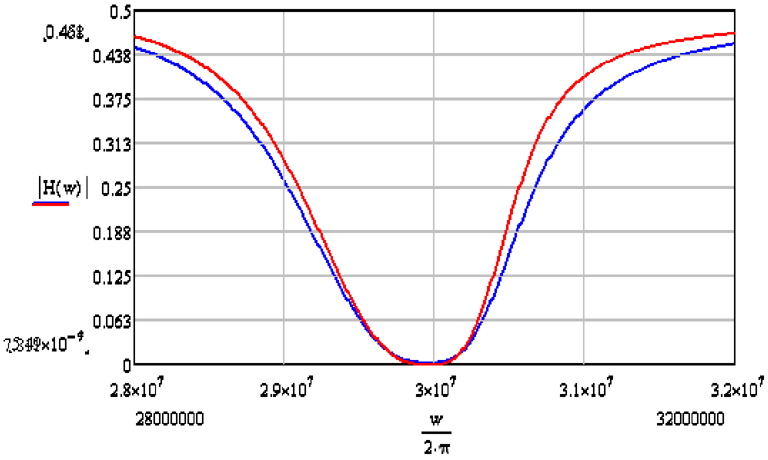


Fig. 11: Filter frequency response after adding a capacitive element

When synthesizing electrical circuits, including electrical filters, the operating attenuation parameter is used. This is the ratio of the power in the load of a four-port network to the power in the load matched to a given source, expressed in dB. The operating attenuation is related to the transmission coefficient of the quadrupole network by the expression:

$$A = -10\log\left(\frac{1}{4\left|H(j\omega)\right|^2}\right) \tag{5}$$

Figure 12 shows the frequency dependence curves of the operating attenuation of a classical synthesized filter with the Butterworth characteristic (blue curve) and a filter implemented on selective elements with coupled coils and a capacitive element in the secondary circuit.

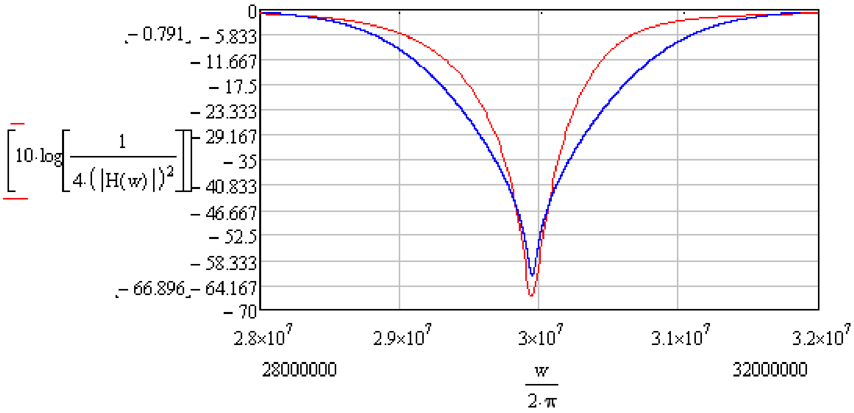


Fig. 12: Operating attenuation frequency dependences of a classical synthesized filter with a Butterworth characteristic (blue curve) and a filter implemented on selective elements with coupled coils and a capacitive element in the secondary circuit (red curve)

As one would expect, the frequency dependence of the operating attenuation did not retain the analyticity of the description, the slope of the characteristic in the transition region changed, however, in general, we can say that such an implementation is effective and can even be considered as a means of improving the characteristics of the filter (the resulting dependences of the operating attenuation are somewhere in the middle between the Butterworth and Chebyshev curves).

The filter is adjusted by electronically switching the matrix of capacitive elements.

4 Conclusion

As a result of the study of the synthesis of a stop filter, we can conclude that it is convenient to synthesize a stop filter using the method proposed above, using as a prototype not a low-pass filter, as usual, but a high-pass filter, which significantly saves time and simplifies computational procedures in calculations.

The use of a closed system of inductively coupled coils as an additional small capacitive element makes it possible to implement the filter characteristic at frequencies that do not allow the use of lumped elements, but low enough that the implementation can be carried out using systems with distributed parameters.

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