Automated synthesis of band-pass filters with current to voltage conversion with given transfer gain in the Simone circuit designer

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Abstract. The iterative method for automated synthesis of band-pass filters with current to voltage conversion with a given transfer gain is developed. The structure of the synthesis system of LC circuits with a given voltage transfer coefficient is presented. The implementation of the proposed method in SimOne Circuit Designer plugin is shown. Further ways for method development are suggested.

1. Introduction
One of the possible implementation for filtering in the input circuits of the receiving devices is to connect passive band-pass LC filters directly to the output of the antenna feeder which, in turn, are loaded with a broadband amplifier in their output. In the case when the resistance of the antenna feeder is equal to the input resistance of the amplifier, the signal attenuation equal to 6 dB, making it comparable to intrinsic noise of the amplifier. At the same time, there is the current to voltage conversion to increase the level of the received signal, which is currently not explicitly used. To obtain a positive effect from the conversion of current into voltage passive voltage-boosting LC- circuits can be loaded with high-impedance inputs of the control electrodes of field-effect transistors and their and their various variations. One of the variation for such a connection scheme is presented on the figure 1.
The intrinsic noise of the circuit shown in the figure 1 mainly caused by the intrinsic noise of the active parasitic resistance of capacitors and inductors, so it is logical to assume that the noise of such circuits is small. The ability to obtain a higher voltage transfer coefficient will allow you to control the operating point of the active element, providing a minimum of nonlinear distortion and noise. To do this, it is necessary to do the implementation of the higher voltage transfer coefficient \( H_0 \) (see figure 2)

\[
|H(j\omega)| \rightarrow H_0 = \text{const} |\omega \in \omega_m \ldots \omega_m \delta < \delta_m^\omega ; ,
\]

where \( H(j\omega) \) - is the transfer function of the LC-circuit, \( H_0 \) - is the desired value of voltage transfer coefficient, \( \delta_{mis} \) - is the tolerance of the approximation \( H_0 \) by physically implemented function defined by the expression

\[
\delta_{mis} = 20 \log \left( \frac{H_0 + \Delta}{H_0} \right).
\]
where \( \Delta = \max \left( H_0 - |H(j\omega)| \right) \) \( \omega \in \omega_1, \omega_2, \ldots, \omega_m \) – is the maximum absolute deviation \( H_0 \) from \( |H(j\omega)| \) (see figure 2).

The physical implementation (1) is practically possible using ladder LC-circuits with current to voltage conversion, shown in figure 3.

![Figure 3. Implementations of the passive LC-circuits with voltage level increasing.](image)

The advantage of ladder LC-circuits in relation to other implementations is the minimum number of used capacitive and inductive elements for a given accuracy of reproduction transfer function magnitude. However, in known sources [1-6] LC-circuits, shown in the figure 3 are traditionally considered as matching devices, while the calculation of the components parameters is made for two resistances: input \( R_0 \) and output \( R_H \), which does not provide for the calculation of a given value of the transmission coefficient \( H_0 \). Thus, for instance in [1, 2] tables with normalized components parameters of matching filter proposed. The parameters in [1] are calculated up to 10 orders of magnitude for relative bands from 0.1 to 1 in increments of 0.1 and discrete transfer coefficient values up to 50, while all calculations are aimed at obtaining the required ratios of input and output resistances. In addition, tables contain only a limited number of solutions, significantly narrowing the scope of the resulting technical implementations. In other works based on traditional calculation methods also only the problem of matching impedances is considered and the deviation from a constant value \( H_0 \delta_{mis} \) taken into account, while the voltage gain \( H_0 \) as a result of calculations is arbitrary.

In summary we can conclude that automated calculation of the desired voltage transfer gain \( H_0 \) for LC-circuits, shown in the figure 3 was not considered at least in publications known to authors and is not automated.

### 2. Theoretical backgrounds and calculation methods

To calculate the voltage transfer coefficient of ladder LC-circuits we will use transfer functions from the theory of two-port networks (TPN) [4]. To do this, we present a mathematical model of the transfer function of the LC-circuit (see figure 3) by voltage in the following form
\[
|H(j\omega)| = \frac{b(j\omega)^n}{(j\omega)^N + a_{N-1}(j\omega)^{N-1} + \ldots + a_2(j\omega)^2 + a_1(j\omega) + a_0} > H_0 \quad \text{for all } \delta < \delta_{mis}; \quad (2)
\]

where \(a_i\) are positive coefficients of the Hurwitz polynomial when replaced \(j\omega = p\), \(i = 1, \ldots, N - 1\), \(N\) is the order of the approximated function equal to the number of reactive components, \(b\) is the positive coefficient determining the magnitude of the transfer function in the passband, \(n_\omega\) is the number of poles of the transfer function with \(j\omega = p \rightarrow 0\).

Equation (2) can be considered as a problem of approximating a function, and numerical methods should be used to solve it. The formulation of the problem is: find the vector of varied parameters \(A = \{A_{0i}, A_{ii}, B_{0i}, B_{li}, \Delta, H_0\}\) for a given relative irregularity in the passband \(\delta_{mis}\) in the range of normalized frequencies \([\Omega_{-\infty}, \Omega_{\infty}]\) satisfying the next conditions:

\[
\min_{A} \max_{\Omega} \left( H_0 - H(A, \Omega) \right) \leq \Delta, \quad (3)
\]

where \(\Omega = \{\Omega_j\} \in [\Omega_{-\infty}, \Omega_{\infty}]\) is frequency vector of the maximum deviations \(H(A, \Omega)\) from \(H_0\), \(j = 1, \ldots, N - 1\), \(A_{0i}, A_{ii}, B_{0i}, B_{li}\) - transfer function coefficient (2) in the range of normalized frequencies, \(\Delta\) - relative tolerance - approximation error \(H(A, \Omega)\) from \(H_0\).

Finding a solution to inequality (3) encounters difficulties in choosing a good initial approximation. To solve the problem when designing CAD systems, the following structure proposed in [8] and shown in figure 4 can be used:

**Figure 4.** Structure of the system of the synthesis LC-circuits with a given voltage transfer coefficient.

A stable search for solutions (3) is based on three interconnected components. Firstly, a database of initial approximations for various frequency overlap coefficients, which are determined by the following boundary frequencies ratio:

\[
k_{\omega} = \frac{\omega_\infty}{\omega_{-\infty}} \quad (4)
\]

The database contains LC-circuits coefficient vectors (2) for the range of normalized frequencies \(A_{0i}, A_{ii}, B_{0i}, B_{li}\), given for different orders of approximation functions.

Secondly, input data analysis and decision control module. This is the main component that defines the CAD system user interface and includes elementary functions of the input data
initial processing for calculating LC-circuits, for instance, for computing (4). Moreover, this module controls the physical implementation of the resulting approximation. For instance it controls positive sign conditions of the coefficients $A_{0i}, A_{ii}, B_{0i}, B_{ii}$, for different stages of the iterative solution (3).

Third components is function-files module that includes sets of voltage transfer functions (2).

All modules in the figure 4 interact with each other during CAD system operation, besides there is feedback from database in the CAD system, which allows to expand the sets of coefficients $A_{0i}, A_{ii}, B_{0i}, B_{ii}$.

The main problem in the automated synthesis of ladder LC-circuits with a given voltage transfer coefficient is the absence of the analytical solution in which the value of the transfer function and the real voltage transfer coefficient of LC-circuits are interconnected, defined as

$$K_U = \frac{U_2(\omega)}{U_1(\omega)},$$

where $U_{1,2}(\omega)$ - the amplitudes of voltages harmonic of the input and output of the LC-circuits.

In [7] was proposed additional special coefficient $H'_0$ which used in considered CAD system:

$$H'_0 = \frac{K_U}{H_0}.$$  (6)

The purpose of including equation (6) in the numerical algorithm of the LC-circuit with given $K_U$ is to obtain equal-wave approximation shown in figure 2 taking into account (3) and the interacting components of the CAD system shown in figure 4. In SimOne Designer the calculation of the $L_i$ and $C_i$ proceeds using decomposition in the chain fraction [7, 8]. After that, a non-visual AC analysis is performed for the generated LC circuit and the average level in given frequency range is calculated. If the obtained $K_U$ less or bigger of the desired, then $H'_0$ increases or decreases. Such variation of the $\delta_{mis}(\Delta)$ is possible due to directly proportionality of the level and the approximation error: with $H'_0$ increased then $\Delta$ increased and vice versa. After that the next iteration running (3). Iterations are repeated until the real $K_U$ is obtained with given accuracy.

3. Implementation of the developed synthesis method in the SimOne Designer plugin

The developed synthesis method of LC-circuits with given $K_U$ is implemented in the plugin SimOne Designer to the russian circuit simulation software SimOne. The main window of the plugin is presented in figure 5. The synthesis of the desired circuits begins with the selection of the required settings, which include the operating frequency range, the order of the circuit and voltage transmission coefficient.
As output information user can see the magnitude of the circuit transfer function, rectangularity coefficients at a given level and so on. The synthesis LC-circuits supplemented with stability analysis tools provided by SimOne. Thus, in the preview mode, the user can quickly check the stability of the developed circuit by switching to the corresponding tab (see figure 6).

By pushing “Ok” button user activates the generation of a band-pass filter device with current into voltage conversion with a given voltage transfer coefficient. The generation result is shown in figure 7.
4. Conclusion

The result of the circuit generation shown in figure 7 confirms the correctness of the evolution of the previously proposed approach to circuit simulation CAD [8, 9] by expanding its application area, proving his theoretical generality. Using the proposed method in an automated mode opens up a new field of application of LC-circuits as devices providing a given voltage transfer coefficient in a wide frequency band. Synthesized band-pass filters can be used in the input circuits of radio receivers in common with low-noise active elements, which allows you to flexibly control the operating point of devices.

The practical significance of the proposed method concludes in the stable automated synthesis of ladder LC-circuits with a given voltage transfer coefficient, which does not require special knowledge from engineers in a sufficiently high-tech specific field of filter design, which ensures a reduction in labor costs and accelerates the development process.

Further development of the method includes the research of the proposed combination of "LC-circuit-active device" in the interests of improving the quality of the input circuits of the receiving devices and reducing the intrinsic noise of the combined circuit and reducing the negative effect of non-linear distortions in the amplifier as well.

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