Russian Technological Journal. 2021;9(6):37–45

ISSN 2500-316X (Online)

Modern radio engineering and telecommunication systems

Современные радиотехнические и телекоммуникационные системы

UDC 621.396.621
https://doi.org/10.32362/2500-316X-2021-9-6-37-45

RESEARCH ARTICLE

Very high frequency radio receiver preselector design

Egor V. Gurov [1],
Saygid U. Uvaysov [2, @],
Victoria V. Chernoverskaya [2],
Ruslan M. Uvaysov [2]

[1] *Siemens LLC, Moscow, 115184 Russia*
[2] *MIREA – Russian Technological University, Moscow, 119454 Russia*
[@] *Corresponding author, e-mail: uvaysov@yandex.ru*

Abstract.
Objectives. The quality of a radio receiver preselector largely determines its main characteristics, including sensitivity. A preselector usually consists of linear elements: inductors, capacitors, low noise amplifiers, and switches. At high frequencies, the components cannot be considered as ideal ones, since active and reactive parasitic parameters significantly affect the frequency response of the components and, as a consequence, the network. Therefore, simulation of the networks requires more sophisticated component models, which take into account parasitic parameters. However, if refined components models are applied, it is still possible to obtain unsatisfactory results, since interconnections and footprints pads also affect the frequency response. This is true even if short traces with a length of about 5 mm are used at frequencies of about 100 MHz. These features must be taken into account for RF network design. The purpose of the work is to ensure the required characteristics of the preselector in the design process based on computer simulation.
Methods. Egor Gurov's methodology for analog VHF LC-filters was applied to radio receiver preselector design. The methodology contains the methods of discrete optimization, Monte-Carlo method, momentum analysis with Green's functions. Experimental results were obtained by prototype implementation and measurement with a vector network analyzer.
Results. The article presents the preselector design process. The preselector contains two analog switches, an analog band-pass filter, an analog high-pass filter, and a low-noise amplifier. Simulation and experimental results with their comparison are presented in the article.
Conclusions. Satisfactory results were obtained. It means that the Egor Gurov's method for analog filters design can be applied for more complex networks design such as radio receiver preselectors.

Keywords: radio receiver, preselector, SPICE model, scattering matrix, mathematical modeling, electronic component, microstrip line, frequency range, parasitic parameters

• **Submitted:** 28.09.2021 • **Revised:** 12.10.2021 • **Accepted:** 19.10.2021

For citation: Gurov E.V., Uvaysov S.U., Chernoverskaya V.V., Uvaysov R.M. Very high frequency radio receiver preselector design. *Russ. Technol. J.* 2021;9(6):37–45. https://doi.org/10.32362/2500-316X-2021-9-6-37-45

Financial disclosure: The authors have no a financial or property interest in any material or method mentioned.

The authors declare no conflicts of interest.

НАУЧНАЯ СТАТЬЯ

Проектирование преселектора радиоприемника в диапазоне метровых волн

Е.В. Гуров [1]**,**
С.У. Увайсов [2, @]**,**
В.В. Черноверская [2]**,**
Р.М. Увайсов [2]

[1] *ООО «Сименс», Москва, 115184 Россия*
[2] *МИРЭА – Российский технологический университет, Москва, 119454 Россия*
[@] *Автор для переписки, e-mail: uvaysov@yandex.ru*

Резюме.
Цели. Качество преселектора радиоприемника в значительной мере определяет его основные характеристики, в том числе чувствительность. Преселектор обычно состоит из линейных элементов – катушек индуктивности, конденсаторов, малошумящих усилителей и ключей. При работе на высоких частотах нельзя считать эти компоненты идеальными, так как активные и реактивные паразитные параметры вносят значительный вклад в частотную характеристику цепей. Поэтому для моделирования высокочастотных схем требуются более сложные модели компонентов, учитывающие паразитные составляющие. Однако при применении для всех компонентов уточненных моделей или S-параметров вероятность получения неудовлетворительных результатов сохраняется, поскольку соединительные линии и контактные площадки также вносят заметные искажения в частотную характеристику. Это наблюдается и для коротких линий длиной около 5 мм, которые оказывают влияние на частотах порядка 100 МГц. Поэтому подобные явления необходимо учитывать при разработке. Цель работы – обеспечение требуемых характеристик преселектора в процессе его автоматизированного схемотехнического проектирования на основе компьютерного моделирования.
Методы. Использована методика Гурова Е.В. для проектирования аналоговых фильтров диапазона метровых волн, но применительно к преселектору радиоприемника. Она включает в себя методы дискретной оптимизации, имитационного моделирования Монте-Карло, метод моментов для электромагнитного моделирования с использованием функции Грина. Экспериментальные результаты получены путем изготовления опытного образца и измерений с помощью векторного анализатора цепей.
Результаты. Представлен процесс проектирования преселектора радиоприемника диапазона метровых волн, состоящего из двух аналоговых ключей, полосового фильтра на сосредоточенных компонентах, малошумящего усилителя и фильтра высоких частот. Приведены результаты моделирования и экспериментальные результаты, их сравнение.
Выводы. Проведенные численные и натурные исследования позволяют говорить о том, что методика Гурова Е.В. для проектирования аналоговых LC-фильтров в диапазоне метровых волн применима и для более сложных цепей, таких как преселектор радиоприемника.

Ключевые слова: радиоприемник, преселектор, SPICE-модель, матрица рассеивания, математическое моделирование, электронный компонент, микрополосковая линия, диапазон частот, паразитные параметры

• **Поступила:** 28.09.2021 • **Доработана:** 12.10.2021 • **Принята к опубликованию:** 19.10.2021

Для цитирования: Гуров Е.В., Увайсов С.У., Черноверская В.В., Увайсов Р.М. Проектирование преселектора радиоприемника в диапазоне метровых волн. *Russ. Technol. J.* 2021;9(6):37−45. https://doi.org/10.32362/2500-316X-2021-9-6-37-45

Прозрачность финансовой деятельности: Авторы не имеют финансовой заинтересованности в представленных материалах или методах.

Авторы заявляют об отсутствии конфликта интересов.

INTRODUCTION

The maximum sensitivity of a radio receiver is determined by its noise level. Careful design of radio receiver units is required to achieve high sensitivity [1, 2]. The preselector is connected directly to the antenna and has the greatest influence on the intrinsic noise. This follows from the Friis formula for the noise figure in the case of a series connection of several stages:

$$F_{\text{total}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots + \frac{F_n - 1}{G_1 G_2 \ldots G_{n-1}}, \quad (1)$$

where F_{total} is the total output noise; n is the number of stages; F_1 is the noise figure of the first stage; G_1 is the power gain of the first stage, etc. The values of the noise coefficients and gains are dimensionless quantities.

It can be noted that the noise figure of the first stage is completely presented in the total output noise, and the noise figure of the second stage is divided by the gain of the first stage [1]. Hence, for maximum sensitivity, it is necessary to place a low-noise amplifier next to the antenna. However, as it was shown in [3], this approach does not always provide the minimum intrinsic noise level. In an environment with a large number of powerful emitting radio stations, such as large cities, a wideband low-noise amplifier may produce higher output noise than expected. The solution to this problem is a bandpass filter installation before the low-noise amplifier.

In the frequency range from several tens of megahertz to gigahertz, to obtain an arbitrary frequency response (arbitrary bandwidth and stopband), it is suitable to use passive inductor–capacitor (LC) filters. The design process for such filters is fully automated at the moment (for example, using *Nuhertz Technologies FilterSolutions®* software). Here, the well-known frequency response approximation method is used, which provides an electrical circuit of the filter with nominal values of the components, as well as a transfer function [4–7].

This method assumes that ideal passive components (inductors and capacitors) are applied and traces between the components do not affect the transfer function of the designed filter. However, at frequencies above 10 MHz, non-ideal components and topology on a printed circuit board have a noticeable influence on the frequency response [8]. *Nuhertz Technologies FilterSolutions®* software can take a quality factor (Q-factor) of the components into account, and even replace them with S-parameters. However, it is not possible to take into account the printed circuit board topology influence. *Keysight Genesys* software tried to automate the filter design process, taking into account both parasitic parameters of the components and printed circuit board topology. The method for designing LC filters in *Keysight Genesys* software is presented in [9]. It takes into account parasitic parameters of the components, their tolerances, and printed circuit board topology.

A preselector of a radio receiver, besides the filter, may contain a low-noise amplifier, which usually has an uneven (slope-down) frequency response, and its input and output impedances may differ from the standard 50 Ohm. It can also be used different bandpass filters selectable by analog switches.

This article presents an example of a radio receiver preselector design. The preselector consists of analog switches that switch the bandpass filters, one bandpass filter, a low-noise amplifier, and one high-pass filter. Based on the simulation results, a prototype was implemented. Experimental results were obtained with a vector network analyzer [10]. The obtained data can be considered as an application extension of the method [9] for the synthesis of more complex circuits than LC filters.

PROBLEM STATEMENT

The preselector for the superhetherodyne radio receiver with an operating bandwidth of 114…122 MHz is under consideration. The maximum sensitivity is required at the frequency of 121.5 MHz, and an intermediate frequency of 87 MHz on the radio frequency (RF) input must be additionally suppressed. It is supposed to use three sub-bands, but within the framework of this article, only one sub-band is considered taking into account the effect of the analog switches. The block diagram of the preselector is shown in Fig. 1.

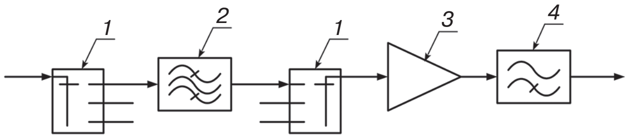


Fig. 1. Block diagram of the preselector: (*1*) analog switch, (*2*) bandpass filter, (*3*) low-noise amplifier, and (*4*) high-pass filter

Peregrine Semiconductor's (USA) PE42430 radio frequency switch was used for bandpass filter switching, and Qorvo's (USA) TQP3M9035 was used as a low-noise amplifier. A high-pass filter is required to suppress unwanted input signals at the intermediate frequency. It also increases the slope and improves the suppression of powerful broadcasting stations in the range of 88...108 MHz. The bandpass filter should also suppress the image frequency by at least 50 dB.

Thus, the requirements for the entire network can be described by the following expressions:

$$\begin{cases} A(f) > A_{\text{pass}}, & f_{\text{pass1}} \le f \le f_{\text{pass2}}, \\ A(f) < A_{\text{stop}}, & f < f_{\text{IF}},\ f > f_{\text{IM}}, \\ K(f) > 1, & \\ B_1(f) > 0, & \end{cases} \quad (2)$$

where $A(f)$ is the frequency response of the circuit (gain vs. frequency); f is the frequency; A_{pass} is the minimum allowable signal gain in the passband; A_{stop} is the maximum allowable signal gain in the stopband; f_{pass1} and f_{pass2} are the minimum and the maximum frequencies of the passband respectively, f_{IF} is the intermediate frequency; f_{IM} is the minimum frequency of the image signal; K and B_1 are the stability coefficients that are described on the Keysight Knowledge Center site[1]. Since the network has an active component, it is also necessary to make sure that self-oscillation will not occur; therefore, the extra stability requirements are imposed. Constraints on the stability coefficients must be met at all the frequencies. Here, considering the simulation frequencies only is enough, since there will be no self-oscillations of the networks if no signal gain. The stability coefficients application is limited by the networks with only one active amplifier stage.

SIMULATION OF THE PRESELECTOR

The preselector simulation was carried out in the *Keysight Genesys* 2018 software. The models of the RF switches and low-noise amplifier were downloaded from the manufacturer's official websites. The software allows network simulation with S-parameters, SPICE models, carrying out electromagnetic analysis of the printed circuit board topology using the method of moments. Thus, both the parasitic parameters of the components and the printed circuit board topology are taken into account.

The functional diagram of the preselector is shown in Fig. 2. To minimize the size of the preselector and meet the conditions (2), a third-order bandpass filter was applied. A signal with the intermediate frequency is suppressed using the LC-shunt connected between the capacitors at the output of the low-noise amplifier.

All the capacitors are of standard size of 0402, inductors are of the standard size of 0603 or 1206. Blocking capacitors C1 and C6 have a capacitance of 0.01 μF.

As the next step, the schematic and topology were set up in the *Keysight Genesys* environment. All the components were connected with microstrip lines. The topological model is shown in Fig. 3. In addition to metallization and contact pads, it also contains the contours of the components on the silkscreen layer.

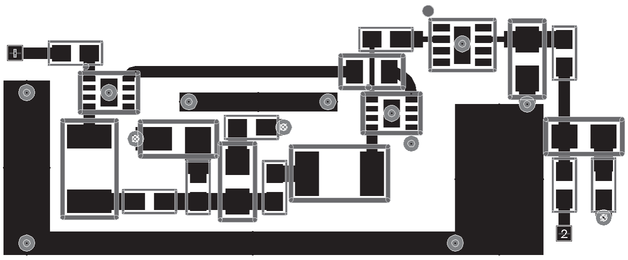


Fig. 3. The topology of the preselector

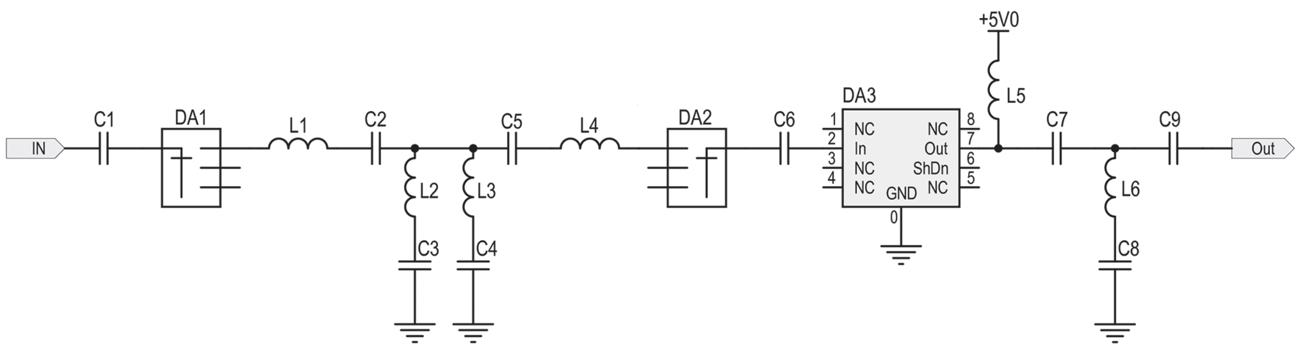


Fig. 2. Functional diagram of the preselector

[1] URL: https://edadocs.software.keysight.com/genesys2018/simulation/getting-started-with-genesys-simulation/getting-started-with-measurements/stability-factor-and-measure. Accessed October 25, 2021.

Table. Preselector bill of components

Components	Nominal value	Part number	Manufacturer
C1, C6, C9	0.01 μF 5%	GRM1555C1E103JE01	Murata (Japan)
C2	3.9 ± 0.1 pF	GJM1555C1H3R9BB01	Murata
C3, C4, C8	43 pF 2%	GJM1555C1H430GB01	Murata
C5	3.3 ± 0.05 pF	GJM1555C1H3R3WB01	Murata
C7	33 pF 5%	GJM1555C1H330JB01	Murata
DA1, DA2	–	PE42430	Peregrine (USA)
DA3	–	TQP3M9035	Qorvo (USA)
L1	390 nH 2%	1206CS-391XGEB	Coilcraft (USA)
L2	75 nH 2%	LQW18AN75NG80	Murata
L3	8.2 ± 0.2 nH	LQW18AN8N2C80	Murata
L4	470 nH 2%	1206CS-470XGEB	Coilcraft
L5	47 nH 5%	LQW18AN47NJ80	Murata
L6	82 nH 2%	LQW18AN82NG80	Murata

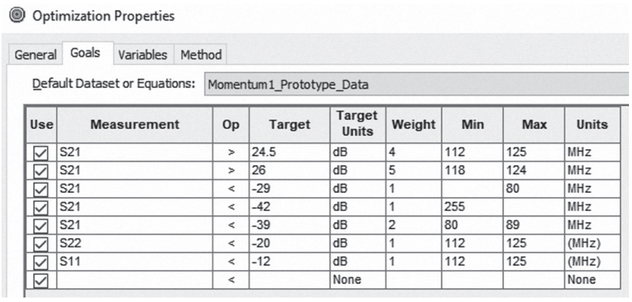
The models with Q-factor were initially chosen as the models of inductors and capacitors. The Q-factor model consists of an ideal capacitor or ideal inductor (for a capacitor and inductor, respectively) with a series connection of an ideal resistor (i.e., active resistance), it is also known as equivalent series resistance (ESR). This allows tuning the nominal values of the component, which may not be possible for the more complex and accurate models. Different components have different ESR values. At the current stage, it was assumed that the ESR is constant during the variation of the component's nominal values[2, 3] [11, 12]. The initial values of the components were obtained using the *Keysight Genesys* built-in automatic filter synthesis tools.

The nominal values of the components were calculated by optimization in accordance with the methodology [9]. This methodology first employs simple component models and selects component values. After the optimization, sensitivity analysis is conducted and the least sensitive component is replaced with the more complex model, which does not allow freely changing the value of the main parameter in a wide range. Then the optimization must be repeated. And so on until all the components are replaced with more complex models.

[2] Ceramic capacitors MLCC: application features. URL: https://www.compel.ru/lib/56541. Accessed October 25, 2021. (in Russ.).

[3] The physical meaning of the group delay of the filter. Digital filters with a linear phase-frequency characteristic. Theory and practice of digital signal processing. URL: http://www.dsplib.ru/content/filters/linphase/linphase.html. Accessed October 25, 2021. (in Russ.).

As a result, all models of the inductors and capacitors were replaced with the corresponding S-parameters provided by the manufacturers. The boundary conditions (2) were set up in the *Keysight Genesys* software, as shown in Fig. 4. Weights have been introduced to get the desired shape of the frequency response. Initially, they were all equal to 1 but then were manually changed during the optimization process. The criterion error was multiplied by the corresponding weight. The optimization goal was to minimize the total error.



Use	Measurement	Op	Target	Target Units	Weight	Min	Max	Units
☑	S21	>	24.5	dB	4	112	125	MHz
☑	S21	>	26	dB	5	118	124	MHz
☑	S21	<	-29	dB	1		80	MHz
☑	S21	<	-42	dB	1	255		MHz
☑	S21	<	-39	dB	2	80	89	MHz
☑	S22	<	-20	dB	1	112	125	(MHz)
☑	S11	<	-12	dB	1	112	125	(MHz)
☑		<		None				None

Fig. 4. Boundary conditions for the optimization

The simulation results are presented below. Figure 5 shows the frequency response (S21) and the return losses (S11, S22). The shaded areas display the boundary conditions indicated in Fig. 4. Figure 6 shows the stability coefficients (K, B1) and the group delay (GD) of the entire network[3]. In this case, there were no requirements imposed for the GD, and it is noted just for information.

The applied components for the simulation are listed in Table.

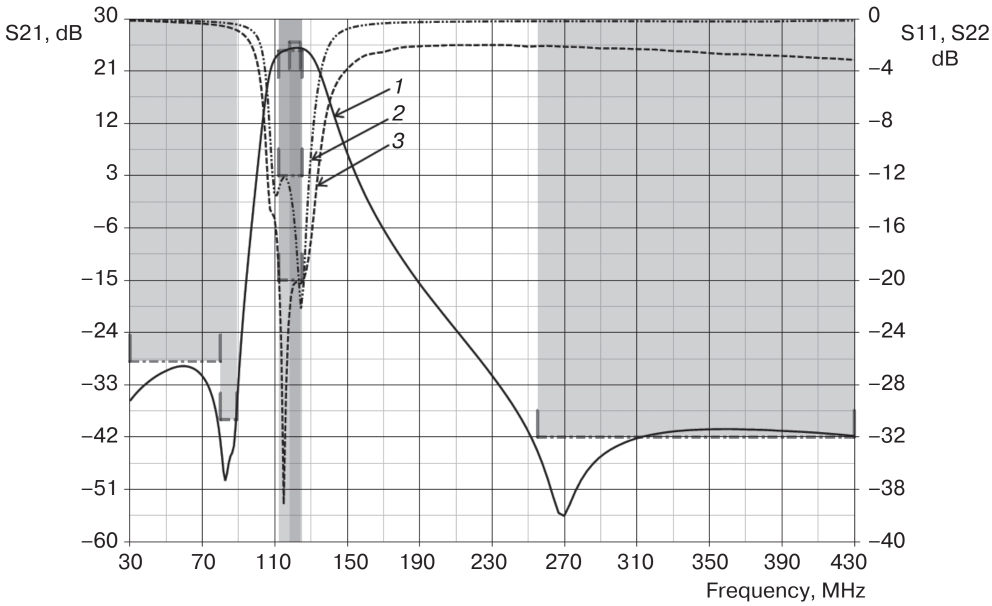


Fig. 5. Frequency response and return losses of the preselector: (*1*) frequency response, (*2*) return losses (S11), and (*3*) return losses (S22)

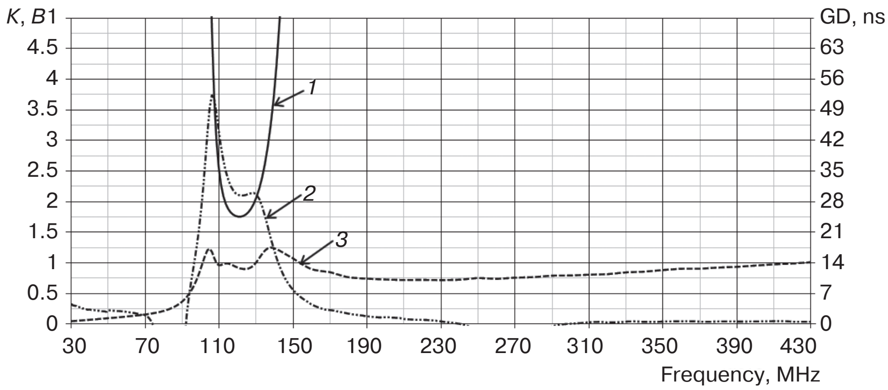


Fig. 6. Stability coefficients and GD of the preselector: (*1*) stability coefficient K (must be greater than 1), (*2*) GD, and (*3*) stability coefficient B1 (must be greater than 0)

EXPERIMENTAL RESULTS

The preselector was implemented on the 4-layer printed circuit board made of FR-4 fiberglass. The topology in Fig. 3 was performed on the top layer, the nearest inner layer was a solid polygon connected to the "ground" reference layer [8]. The input signal was delivered from the SMA connector mounted on the printed circuit board, the output signal was taken through the U.FL-R-SMT connector. The frequency response was obtained using Rohde and Schwarz ZVA8 vector network analyzer.

The capacitors of the GRM series were installed on the prototype instead of the GJM series capacitors because the right capacitors had not been purchased at that moment. GRM series capacitors have the status "not recommended for new designs." These capacitors have a lower Q-factor; therefore, it could be expected more attenuation in the passband rather than in the simulation results, but without significant distortion of the frequency response curve.

The experimental results and their comparison to the simulated ones are presented in Fig. 7. The figure shows only the frequency response (S21). Return losses (S11 and S22), as well as stability factors, satisfied the required values.

The passband gain in the experimental curve was about 1 dB lower than in the simulation results, as was expected due to the lower Q-factor of the capacitors. In general, both results are in good agreement, especially at low frequencies. In the method [9], it is noted that a better frequency response can be achieved by tuning (i.e., replacing with another one with different nominal value) the most sensitive components on the prototype. It has not been done here, since the frequency response

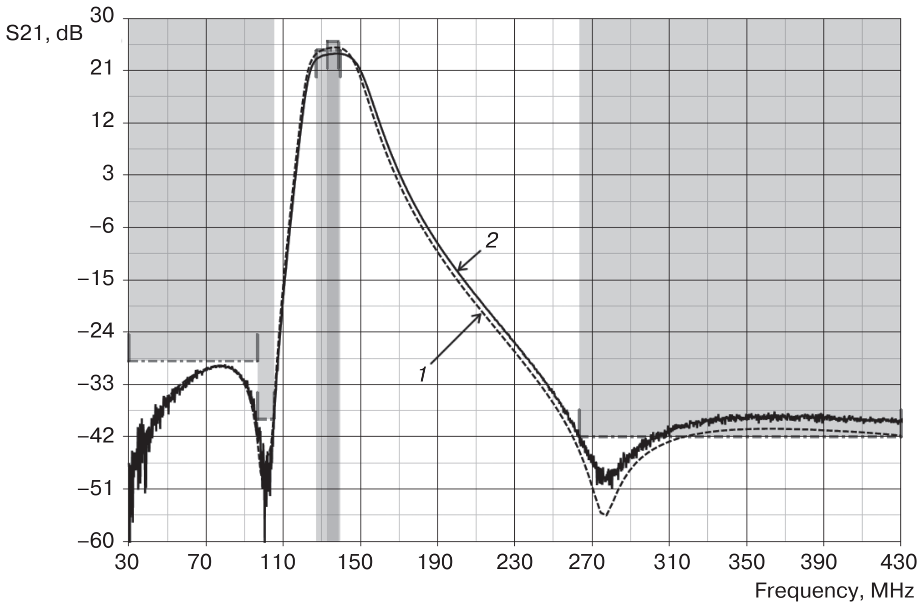


Fig. 7. Frequency response of the preselector: (*1*) simulation and (*2*) experimental data

of the preselector meets the specified requirements. Careful selection of components can be useful as part of a release device.

CONCLUSIONS

The radio receiver preselector is the most important part since it significantly affects its sensitivity. The article describes the design process of the radio receiver preselector in the very high frequency (VHF) range. The preselector consists of analog switches, one bandpass filter, a low-noise amplifier, and an additional high-pass filter. The design takes into account input and output impedances and slope-down frequency response of the analog switches and low-noise amplifier.

The designed preselector was implemented in the prototype, and the experimental data was obtained with the vector network analyzer. The simulated and experimental results are in good agreement. This is shown in Fig. 7. The discrepancy between the gain in the passband of about 1 dB is caused by the capacitors on the prototype with the lower Q-factor than in the model since the capacitors in the model were not available at the time of printed circuit board assembly. In addition, the frequency response can be improved by selecting the most sensitive components directly on the prototype. This operation has not been done, because it was only the prototype, and such selection is reasonable in the release device device.

In [9] it is shown that in the VHF range the frequency response of analog filters is significantly affected by parasitic parameters of the components and interconnection on the printed circuit board topology.

Following the LC-filter design method [9], the radio receiver preselector has been designed. It is shown that the method also allows taking into account the frequency responses of analog switches and low-noise amplifiers, as well as checking the stability of amplifying cascades.

In conclusion, the results presented in the article extend the applicability of the analog LC-filters design method of Egor Gurov for analog filters design [9]. It also allows the design of more complex networks, which can include active components as well.

Authors' contribution. All authors equally contributed to the research work.

REFERENCES

1. Brannon B. Basics of designing a digital radio receiver (Radio 101). *Analog Devices*. 1998. URL: https://www.analog.com/en/technical-articles/basics-designing-digital-radio-receiver.html. Accessed October 25, 2021.
2. Gurov E.V., Rotkevich A.S. Experimental evaluation of the sensitivity of a radio receiver for varios structures of the input circuit. In: *Mezhvuzovskaya nauchno-tekhnicheskaya konferentsiya studentov, aspirantov i molodykh spetsialistov imeni E.V. Armenskogo: materialy konferentsii* (*Collection of materials of the Interuniversity scientific and Technical Conference of students, Postgraduates and Young Professionals named after E.V. Armensky*). Moscow: MIEM NIU VShE; 2018, p. 135–136. (in Russ.).
3. Gurov E.V. The influence of radio frequency filter on a low-noise amplifier signal to noise ratio degradation: experimental assessment. *Tekhnologii elektromagnitnoi sovmestimosti = Technologies of Electromagnetic Compatibility*. 2017;2(61):49–55 (in Russ.).
4. Paarmann L.D. *Design and Analysis of Analog Filters*: *A Signal Processing Perspective*. NY: Kluwer Academic Publishers; 2001. 440 p.
5. Gurov E.V., Uvaisov S.U., Uvaisova A.S., Uvaisova S.S. Discrete parametric optimization for very high frequency analog filters synthesis. *Kachestvo. Innovatsii. Obrazovanie. = Quality. Innovation. Education*. 2019;2(160):53–63 (in Russ.). https://doi.org/10.31145/1999-513x-2019-2-53-63
6. Smirnov A.V. Method of simultaneous optimization of radio devices performance in frequency and time domains. *Rossiiskii tekhnologicheskii zhurnal = Russian Technological Journal*. 2018;6(6):13–27 (in Russ.). https://doi.org/10.32362/2500-316X-2018-6-6-13-27
7. Hassan A.H. *Design and Size Reduction Analysis of Micro Strip HBP Filters*. Master's Thesis in Electronics. Master's Program in Electronics/Telecommunications. Sweden, Gävle: University of Gävle. January 2015. 68 p.
8. Kechiev L.N. *Proektirovanie pechatnykh plat dlya tsifrovoi bystrodeistvuyushchei apparatury* (*Design of printed circuit boards for digital high-speed equipment*). Moscow: Gruppa IDT; 2007. 616 p. ISBN 978-5-94833-024-2
9. Gurov E., Uvaysova A.S., Uvaysov S.U., Uvaysov R.M. Design Method for Non-Tunable LC-Filters. In: *2020 Moscow Workshop on Electronic and Networking Technologies (MWENT)*. 2020. https://doi.org/10.1109/MWENT47943.2020.9067472
10. Hiebel M. *Fundamentals of Vector Network Analysis*. 3rd ed. München: Rohde & Schwarz GmbH & Co.; 2008. 420 p.
    [Hiebel M. *Osnovy vektornogo analiza tsepei*. Moscow: Izdatel'skii dom MEI; 2009. 501 p. ISBN 978-5-383-01305-2]
11. Gurov E.V., Uvaysov S.U., Uvaysova A.S., Uvaysova S.S. Nominal and actual values of inductor and capacitor parameters at high frequencies. *Rossiiskii tekhnologicheskii zhurnal = Russian Technological Journal*. 2019;7(4):44–53 (in Russ.). https://doi.org/10.32362/2500-316X-2019-7-4-44-53

СПИСОК ЛИТЕРАТУРЫ

1. Brannon B. Basics of designing a digital radio receiver (Radio 101). *Analog Devices*. 1998. URL: https://www.analog.com/en/technical-articles/basics-designing-digital-radio-receiver.html, дата обращения 25.10.2021
2. Гуров Е.В., Роткевич А.С. Экспериментальная оценка чувствительности радиоприемника при различных структурах входной цепи. В сб.: *Межвузовская научно-техническая конференция студентов, аспирантов и молодых специалистов имени Е.В. Арменского*: *материалы конференции*. М.: МИЭМ НИУ ВШЭ; 2018. С. 135–136.
3. Гуров Е.В. Влияние радиочастотного фильтра на ухудшение соотношения сигнал/шум малошумящего усилителя: экспериментальная оценка. *Технологии электромагнитной совместимости*. 2017;2(61):49–55.
4. Paarmann L.D. *Design and Analysis of Analog Filters*: *A Signal Processing Perspective*. NY: Kluwer Academic Publishers; 2001. 440 p.
5. Гуров Е.В., Увайсов С.У., Увайсова А.С., Увайсова С.С. Алгоритм дискретной параметрической оптимизации для решения задач синтеза аналоговых фильтров диапазона очень высоких частот. *Качество. Инновации. Образование*. 2019;2(160):53–63. https://doi.org/10.31145/1999-513x-2019-2-53-63
6. Смирнов А.В. Метод одновременной оптимизации характеристик электрических фильтров в частотной и временной областях. *Российский технологический журнал*. 2018;6(6):13–27. https://doi.org/10.32362/2500-316X-2018-6-6-13-27
7. Hassan A.H. *Design and Size Reduction Analysis of Micro Strip HBP Filters*. Master's Thesis in Electronics. Master's Program in Electronics/Telecommunications. Sweden, Gävle: University of Gävle. January, 2015. 68 p.
8. Кечиев Л.Н. *Проектирование печатных плат для цифровой быстродействующей аппаратуры*. М.: Группа ИДТ; 2007. 616 с. ISBN 978-5-94833-024-2
9. Gurov E., Uvaysova A.S., Uvaysov S.U., Uvaysov R.M. Design method for non-tunable LC-filters. In: *2020 Moscow Workshop on Electronic and Networking Technologies (MWENT)*. 2020. https://doi.org/10.1109/MWENT47943.2020.9067472
10. Хибель М. *Основы векторного анализа цепей*: пер. с англ. М.: Издательский дом МЭИ; 2009. 501 с. ISBN 978-5-383-01305-2
11. Гуров Е.В., Увайсов С.У., Увайсова А.С., Увайсова С.С. Номинальные и эффективные значения параметров катушек индуктивности и конденсаторов на высоких частотах. *Российский технологический журнал.* 2019;7(4):44–53. https://doi.org/10.32362/2500-316X-2019-7-4-44-53
12. Cain J. Parasitic Inductance of Multylayer Ceramic Capacitors. KYOCERA AVX Components Corporation. February 2002. URL: https://www.avx.com/docs/techinfo/CeramicCapacitors/parasitc.pdf

12. Cain J. Parasitic Inductance of Multylayer Ceramic Capacitors. KYOCERA AVX Components Corporation. February 2002. Available from URL: https://www.kyocera-avx.com/docs/techinfo/CeramicCapacitors/parasitc.pdf

About the authors

Egor V. Gurov, Cand. Sci. (Eng.), Leading Engineer (Research and Design), Siemens LLC (9, ul. Bolshaya Tatarskaya, Moscow, 115184 Russia). E-mail: gurov.yegor@gmail.com.

Saygid U. Uvaysov, Dr. Sci. (Eng.), Professor, Head of the Department of Design and Production of Radio-electronic Means, Institute of Radio Engineering and Telecommunication Systems, MIREA – Russian Technological University (78, Vernadskogo pr., Moscow, 119454 Russia). E-mail: uvaysov@yandex.ru. Scopus Author ID 55931417100, ResearcherID H-6746-2015, https://orcid.org/0000-0003-1943-6819

Victoria V. Chernoverskaya, Cand. Sci. (Eng.), Associate Professor, Department of Design and Production of Radio-electronic Means, Institute of Radio Engineering and Telecommunication Systems, MIREA – Russian Technological University (78, Vernadskogo pr., Moscow, 119454 Russia). E-mail: chernoverskaya@mirea.ru.

Ruslan M. Uvaysov, 2nd year Undergraduate Student, Department of Design and Production of Radio-electronic Means, Institute of Radio Engineering and Telecommunication Systems, MIREA – Russian Technological University (78, Vernadskogo pr., Moscow, 119454 Russia). E-mail: uvajsov.r.m@edu.mirea.ru.

Об авторах

Гуров Егор Владимирович, к.т.н., ведущий инженер (Исследования и разработки) ООО «Сименс» (115184, Россия, Москва, ул. Большая Татарская, д. 9). E-mail: gurov.yegor@gmail.com.

Увайсов Сайгид Увайсович, д.т.н., профессор, заведующий кафедрой конструирования и производства радиоэлектронных средств Института радиотехнических и телекоммуникационных систем ФГБОУ ВО «МИРЭА – Российский технологический университет» (119454, Россия, Москва, пр-т Вернадского, д. 78). E-mail: uvaysov@yandex.ru. Scopus Author ID 55931417100, ResearcherID H-6746-2015, https://orcid.org/0000-0003-1943-6819

Черноверская Виктория Владимировна, к.т.н., доцент, кафедра конструирования и производства радиоэлектронных средств Института радиотехнических и телекоммуникационных систем ФГБОУ ВО «МИРЭА – Российский технологический университет» (119454, Россия, Москва, пр-т Вернадского, д. 78). E-mail: chernoverskaya@mirea.ru.

Увайсов Руслан Магомедович, магистрант 2-го года обучения, кафедра конструирования и производства радиоэлектронных средств Института радиотехнических и телекоммуникационных систем ФГБОУ ВО «МИРЭА – Российский технологический университет» (119454, Россия, Москва, пр-т Вернадского, д. 78). E-mail: uvajsov.r.m@edu.mirea.ru.

Translated by E. Shklovskii