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MONOLITHIC MICROWAVE BANDPASS FILTERS DESIGN FOR S- AND C-BANDS

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Abstract. This paper discusses the development of monolithic integrated circuits of S- and C-band bandpass filters from modeling to measurement of experimental samples within the pHEMT05D technology. Bandpass filters with central frequencies of 2.5, 3 and 5 GHz with a relative bandwidth of 40% and a rejection in the stop band of at least –30 dB have been developed. When developing the topology, optimization methods were used according to the requirements for frequency characteristics. Two variants of carrying out measurements of experimental samples are proposed: with welding on PCB using the Kulicke & Soffa 4256 station and from the plate using the Cascade Microtech EP6RF probe station. The measurements were carried out using the Rohde Schwarz ZVA40 vector network analyzer. The obtained samples showed deviations in frequency characteristics of approximately 10% and an increase in losses in the passband within 2 dB. High repeatability of the result within the manufactured plate is demonstrated, which confirms the stability of the obtained result.

Keywords: MMIC design, bandpass filters, S-band, C-band, GaAs pHEMT

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РАЗРАБОТКА МОНОЛИТНЫХ ИНТЕГРАЛЬНЫХ СХЕМ ПОЛОСОВЫХ СВЧ ФИЛЬТРОВ S- И С-ДИАПАЗОНОВ

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Аннотация. В данной статье рассматривается разработка монолитных интегральных схем полосовых фильтров S- и С-диапазона от моделирования до измерения экспериментальных образцов в рамках технологии pHEMT05D. Разработаны полосовые фильтры с центральными частотами 2,5, 3 и 5 ГГц с относительной шириной полосы пропускания 40% и подавлением в полосе заграждения не менее –30 дБ. При разработке топологии применялись методы оптимизации по требованиям к частотным характеристикам. Предложены два варианта проведения измерений экспериментальных образцов: с разваркой на платы посредством станции Kulicke & Soffa 4256 и с пластины посредством зондовой станции Cascade Microtech EP6RF. Измерения проводились при помощи векторного анализатора цепей Rohde Schwarz ZVA40. Полученные образцы показали отклонения по частотным характеристикам около 10% и увеличение потерь в полосе пропускания в пределах 2 дБ. Продемонстрирована высокая повторяемость результата в пределах изготовленной пластины, что подтверждает стабильность полученного результата.

Ключевые слова: проектирование MMIC, полосовые фильтры, S-диапазон, С-диапазон, GaAs pHEMT

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Introduction

In most modern telecommunication systems, microwave bandpass filters are used as a preselectors in front-end of the design. As system-on-chip concept is widely used, MMIC realization is of interest. In the last decade, a large number of works [1–9] have been devoted to the problems of designing MMIC filters.

In recent years, many restrictions have been introduced in Russia on the import of semiconductor components. In addition, cooperation with foreign semiconductor manufacturers has become difficult. These circumstances make the task of development of semiconductor integrated circuits using domestic technologies relevant.

In this work, S- and C- bands MMIC filter designs are presented from realization choice up to samples measurement. The GaAs pHEMT technological process of Svetlana-Rost JSC (pHEMT05D) was used for design and sample production [10–13].

Design parameters

For this work, a series of bandpass filters with a fractional bandwidth (FBW) of 40% were designed. They cover range from 2 to 6 GHz with center frequencies of 2.5, 3 and 5 GHz. Stopband attenuation is set to 30 dB as one of the typical parameters for general applications. Insertion loss (IL) is set to be up to 2 dB as desired parameter, expecting reasonable exceedances for real samples. Since the approximate dimensions of a microstrip realization, even a compact hairpin structure, are too large to consider (for a center frequency of 2.5 GHz, the topology area is 1560×10675 μm excluding contact pads and requirements for

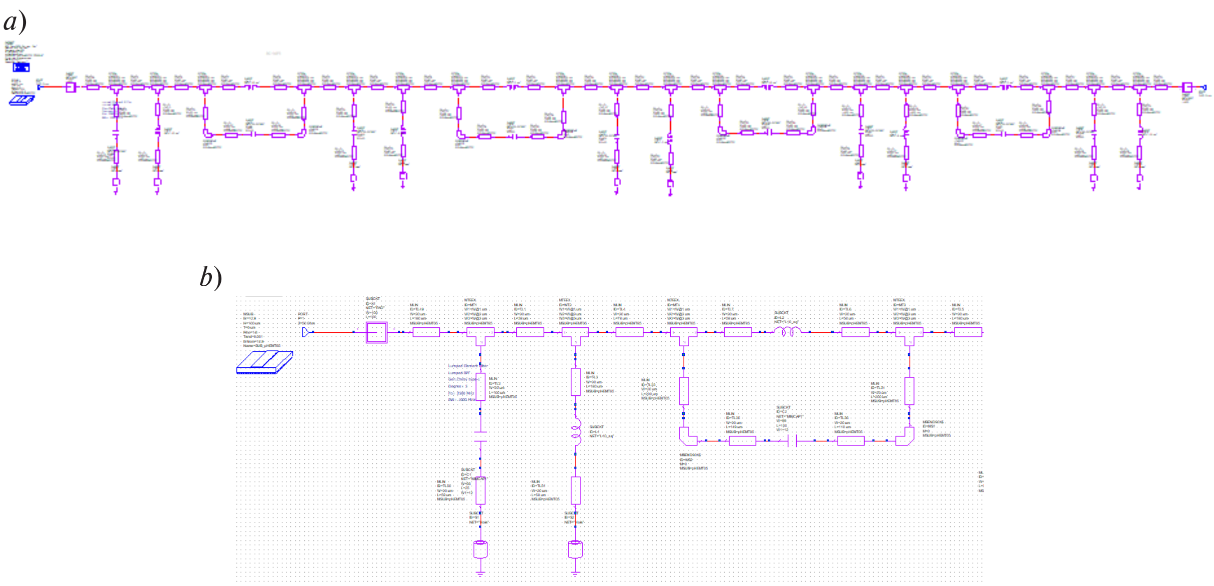

Fig. 1. Structure of a lumped element filter (*a*) with first two resonators in an enlarged scale (*b*)

the crystal boundary), lumped element structure is used in this work. The parameters for filter design are summarized in Table 1.

Table 1

Filter design parameters

Center frequency, GHz	Passband, GHz	Stopband, GHz	Insertion Loss, dB	Stopband attenuation, dB
2.5	1	2.5	2	30
3	1.2	3		
5	2	5		

For filters based on lumped elements, a structure based on the Type 1 generalized Chebyshev approximation with a passband ripple of 0.011 dB was selected. The structure of the prototype for the case of a center frequency of 2.5 GHz is shown in Fig. 1. The remaining filters have a similar structure; only the capacitance and inductance values differ proportionally to the frequency change.

Simulation and optimization

The S-parameters simulation results of the filter based on lumped elements with a center frequency of 2.5 GHz before optimization, after optimization and after rounding the values for production are shown in Fig. 2.

Similarly, Fig. 3 and 4 show the S-parameters simulation results for filters with center frequencies of 3 and 5 GHz, respectively. It should be noted that with increasing frequency, the influence of the inaccuracy of the implemented nominal values and microstrip lines on the frequency characteristics becomes greater, while the passband shifts below the target.

Filter topologies

Fig. 5–8 show the developed topologies of bandpass filters on lumped elements, in order of increasing central frequency. The sizes of the topologies (excluding the requirements for the crystal boundary) are given in the figure captions.

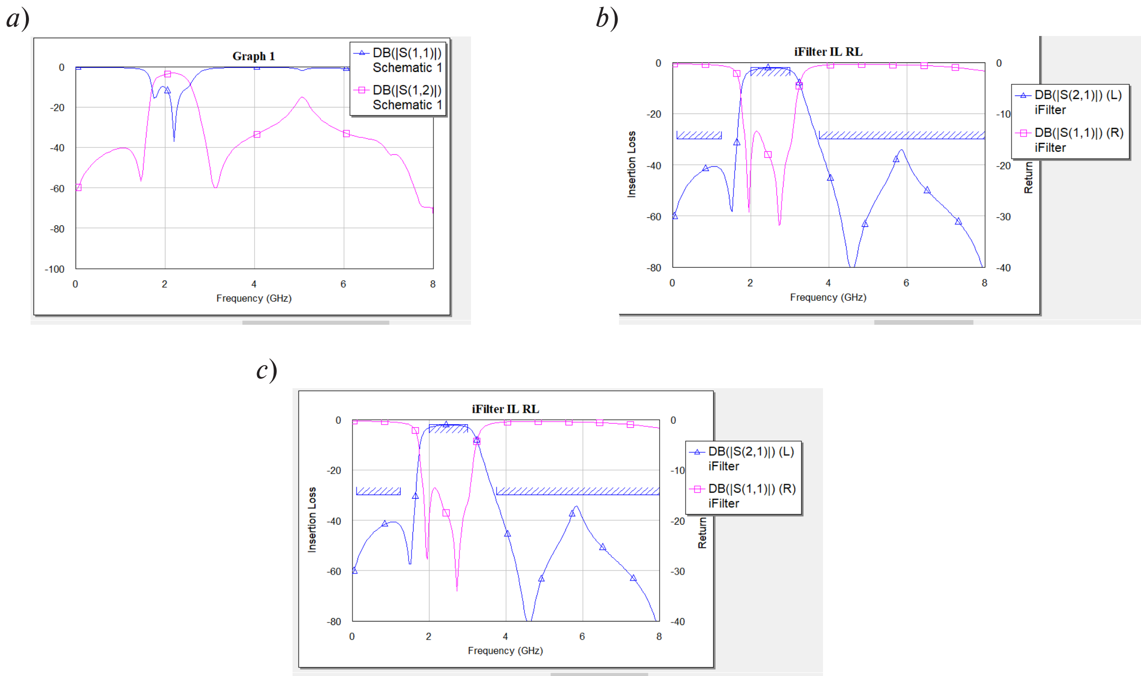

Fig. 2. S-parameters simulation results of the bandpass filter based on lumped elements with a center frequency of 2.5 GHz: before optimization (*a*), after optimization (*b*), after rounding the values (*c*)

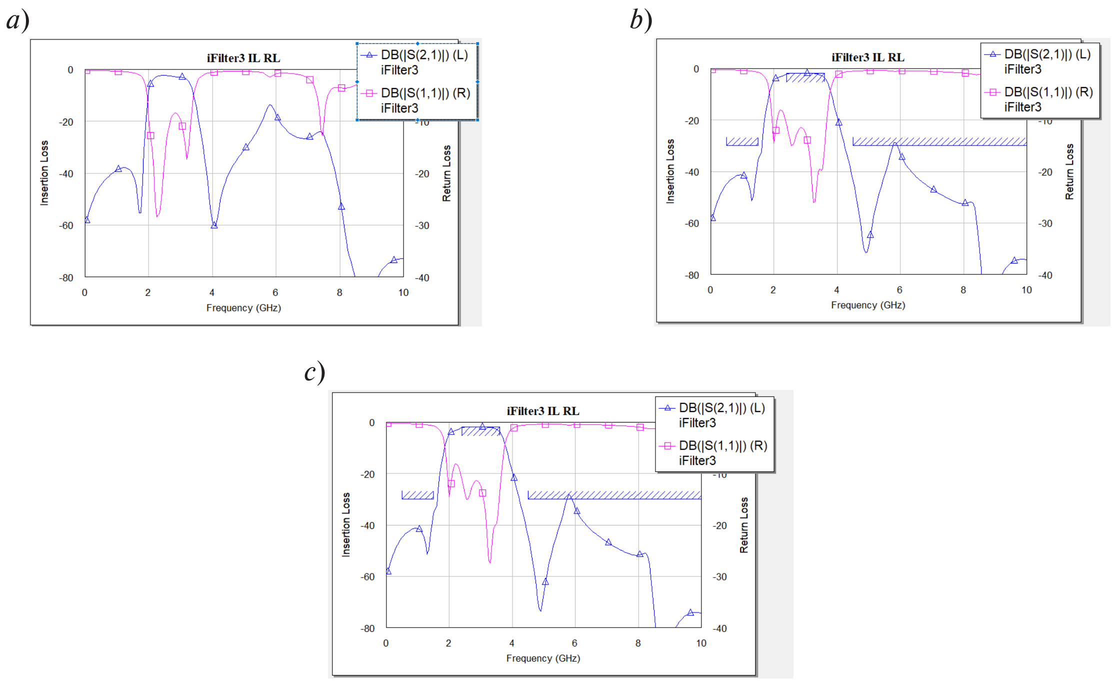

Fig. 3. S-parameters simulation results of the bandpass filter based on lumped elements with a center frequency of 3 GHz: before optimization (*a*), after optimization (*b*), after rounding the values (*c*)

The description of the contact pads is given in Table 2. The contact pads by inputs and outputs are grouped in a GSG formation, which means that there is one signal pad (S) and two ground pads (G), symmetrically located relative to the signal pad.

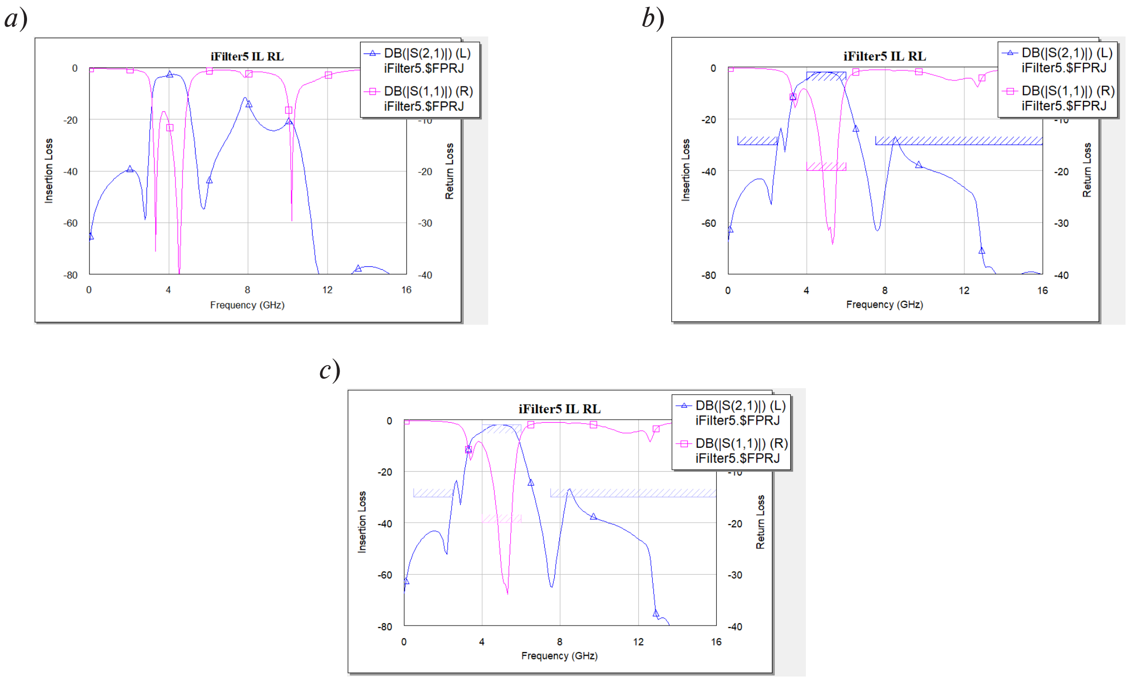

Fig. 4. S-parameters simulation results of the bandpass filter based on lumped elements with a center frequency of 5 GHz: before optimization (*a*), after optimization (*b*), after rounding the values (*c*)

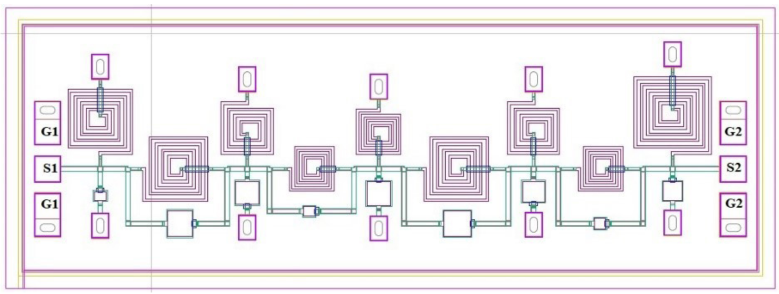

Fig. 5. Topology of the bandpass filter crystal with a center frequency of 2.5 GHz. Cell size 3100×1130 μm

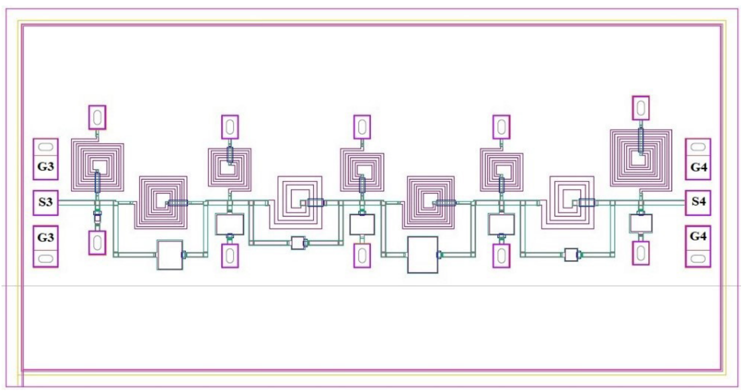

Fig. 6. Topology of the bandpass filter crystal with a center frequency of 3 GHz. Cell size 3100×1600 μm

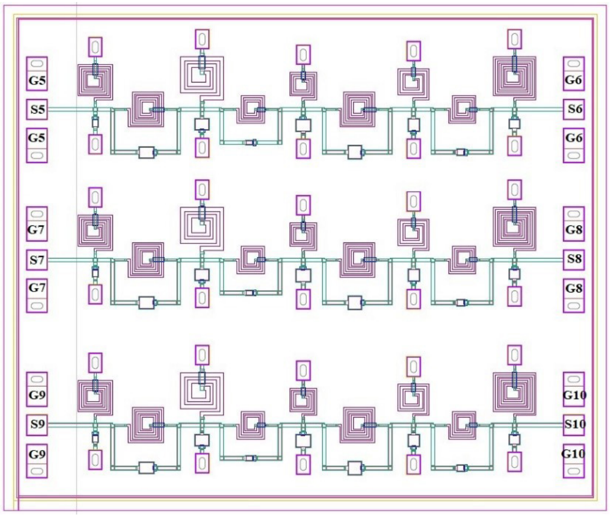

Fig. 7. Topology of the bandpass filter crystal with a center frequency of 5 GHz, repeated three times. Cell size 3100×2600 μm

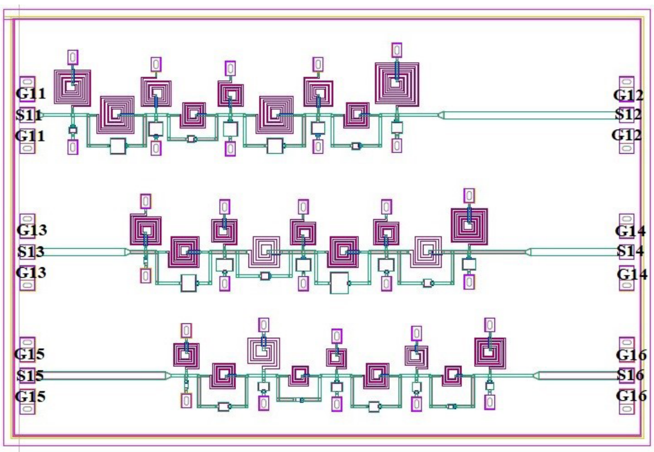

Fig. 8. Topologies of three filters (2.5, 3 and 5 GHz) in one cell. Cell size 4600×3100 μm

Table 2

Description of contact pads of filter crystals

Output name	Purpose
G1...G16	Ground pads are repeated to the left and right of each signal pad.
S1...S16	Signal pads correspond to the inputs and outputs of each topology. Each filter topology corresponds to one pair of odd Si and even S(i+1) inputs and outputs.

Measurement results

For connection to contact pads, test samples can be welded onto test PCB boards using a Kulicke & Soffa 4256 wedge micro welding machine. In this case, connection to the vector network analyzer is made via SMA connectors, which are soldered to a conductive line matched to 50 Ohm. For the samples in Fig. 7 and 8, three pairs of connectors are required, or three pairs of samples with welding of the corresponding pairs of inputs and outputs 5–6, 7–8, 9–10, 11–12, 13–14, 15–16.

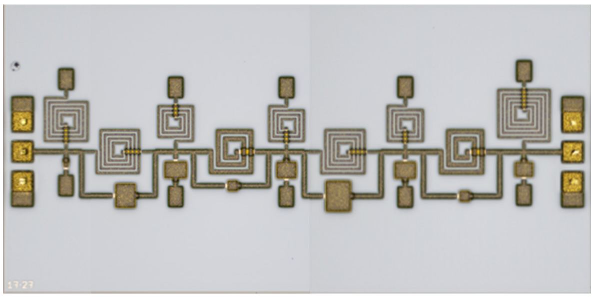

Fig. 9. Test sample microphotography (2.5 GHz center frequency)

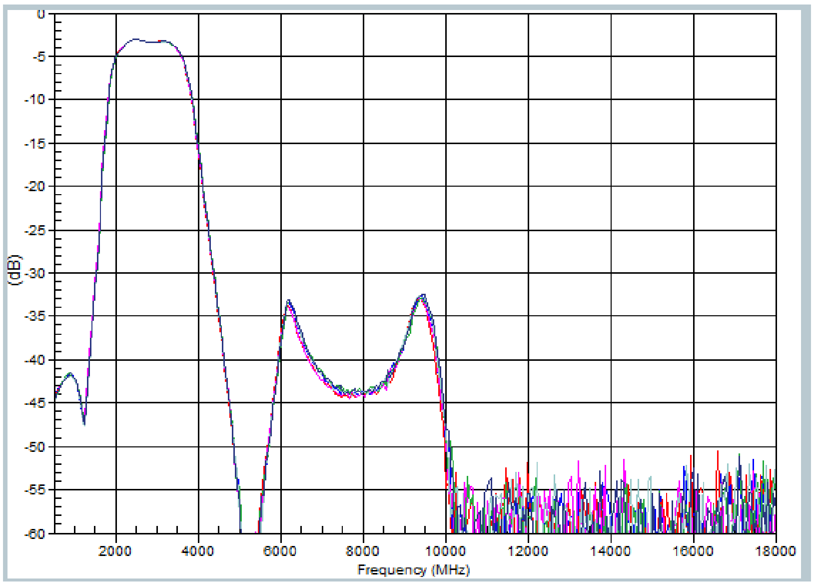

Fig. 10. S21 measurement results

Alternatively, without welding the experimental samples, a Cascade Microtech EP6RF probe station can be used. GSG-type probes (two outer contacts are "ground", the central one is signal) are connected via coaxial wires to a Rohde Schwarz ZVA40 vector network analyzer. In the case of the topologies shown in Fig. 5 and 6, the probes are connected once. For the topologies in Fig. 7 and 8, the samples are connected one by one in the order from the top to the bottom. The connection is checked visually. The S-parameters (transmission and reflection coefficients, phase characteristics) are measured in the two-port mode of the vector analyzer. The results are recorded both on the device display and saved in the s2p file format for further processing in CAD. The measurements are performed in two modes: in a wide frequency range to evaluate the frequency characteristics as a whole and in an enlarged scale in the filter passband. Since the filters are passive and non-tunable, no power supply or control signals are required. After receiving the s2p files, all secondary characteristics (e.g., VSWR) can be obtained in CAD by converting the measured S-parameters.

A microphotograph for a test sample for 2.5 GHz frequency is shown in Fig. 9. All samples show good correlation between CAD topology simulation results and production.

The results of measurement of six microwave filter samples with a central frequency of 2.5 GHz according to the described measurement procedure are shown in Fig. 10–12. Fig. 10 shows the modulus of the parameter S21, Fig. 11 – the reflection coefficient at the input S11, Fig. 12 – the reflection coefficient at the output S22.

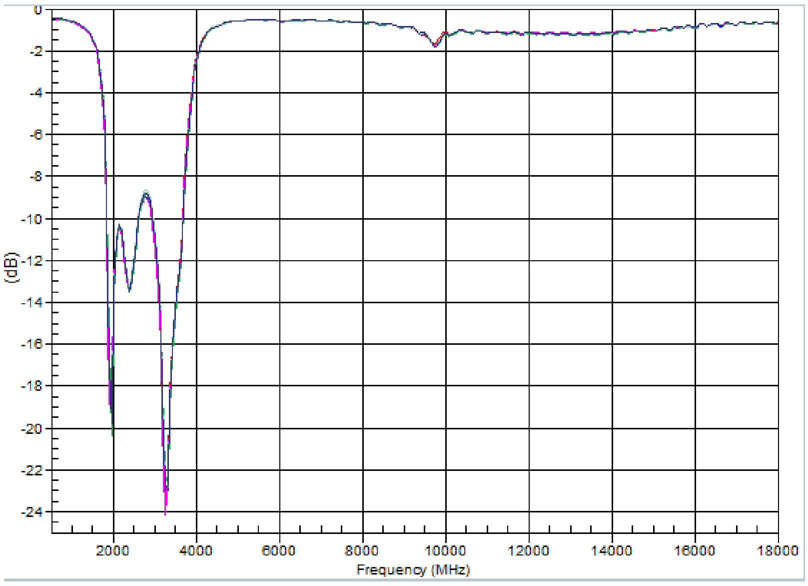

Fig. 11. S11 measurement results

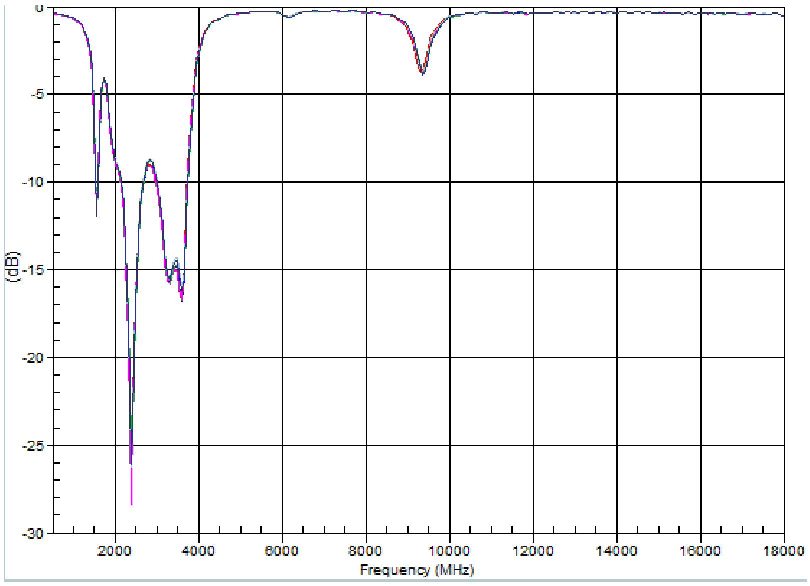

Fig. 12. S22 measurement results

The microwave filter with a central frequency of 2.5 GHz has a working frequency band of 2.2–3.4 GHz instead of the calculated one from 2 to 3 GHz, which indicates a slight shift of the central frequency by 12% due to technological deviations in the parameters of the integrated circuit elements. But at the same time, the nature of the transfer characteristic of the filter is preserved. Suppression of more than 30 dB is ensured for frequencies of 4.4 GHz and higher. Insertion losses increased by less than 2 dB compared to circuit simulation. It should be noted, that for all six samples (as for future measurements for other samples) difference in measurement results is smaller than vector analyzer sensitivity, which proves repeatability and stability of achieved result.

In Fig. 13–15 comparison of measurement versus simulation for filters with center frequencies 2.5, 3 and 5 GHz, respectively, is presented. Difference between simulation and measurement results is about

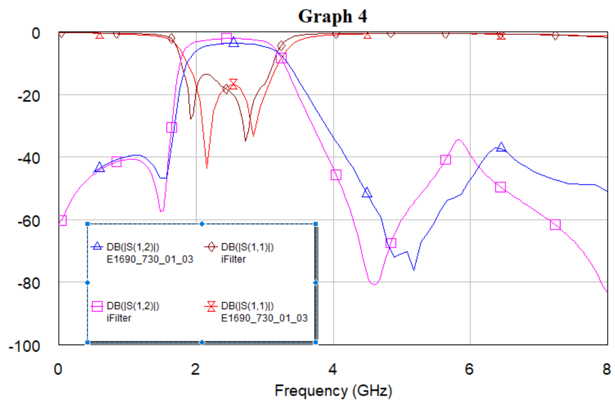

Fig. 13. Comparison of simulation (square, rhomb)
and measurement (rectangle, "clock") for 2.5 GHz center frequency

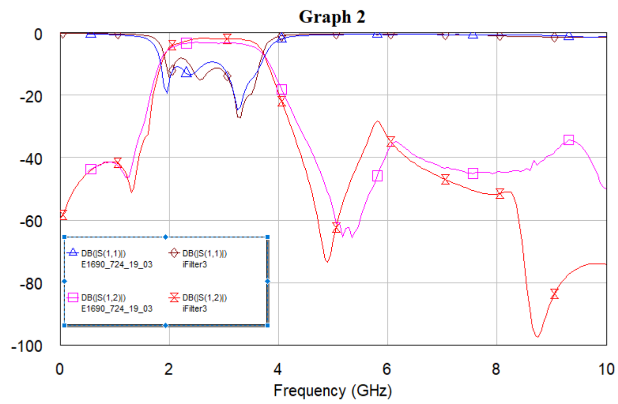

Fig. 14. Comparison of simulation (rhomb, "clock")
and measurement (rectangle, square) for 3 GHz center frequency

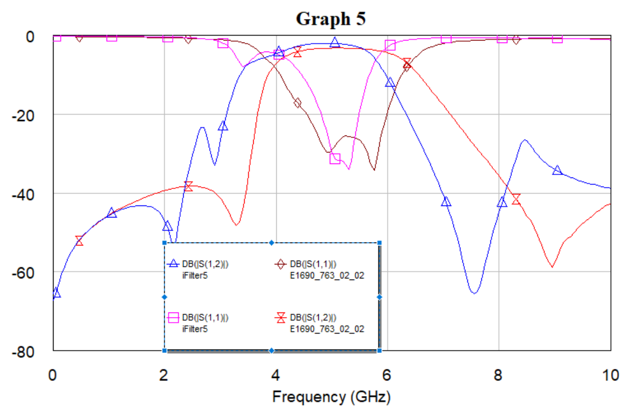

Fig. 15. Comparison of simulation (rectangle, square)
and measurement (rhomb, "clock") for 5 GHz center frequency

10% for frequencies, and in fact is closer to initial desired parameters of table 1. For 5 GHz center frequency upper stopband is 7.65 GHz from measurement with 7.5 GHz desired value. Insertion loss increases no more than by 2 dB.

Fig. 16 provides overall measurement results from different samples. It should be noted that results from stand-alone designs as in Fig. 5 and 6 correspond with the results from combined topology as in Fig. 8, which additionally proves repeatability and stability of achieved result.

In Tables 3–5, comparison of results versus target values is provided. For 5 GHz filter, best optimization result has inaccuracy in frequency response which was compensated in real sample. In Table 6, a comparison with known results is held. [14, 15] are products of Svetlana-Rost JSC (pHEMT05D), and results of this work are quite close, taking into account different fractional bandwidth (40% in this work, 23% in [14] and 24% in [15]). In [16], a bandpass filter from well-known Marki Microwave has a better insertion loss, but for 95% fractional bandwidth.

Table 3

Parameters comparison for 2.5 GHz filter

	Target	Simulation	Measurements
Center frequency, GHz	2.5	2.41	2.55
Passband, GHz	1	0.99	0.9
Stopband, GHz	2.5	2.1	2.2
Insertion Loss, dB	2	2.1	3.7
Stopband attenuation, dB	30	30	30

Table 4

Parameters comparison for 3 GHz filter

	Target	Simulation	Measurements
Center frequency, GHz	3	2.73	2.81
Passband, GHz	1.2	1.3	1.3
Stopband, GHz	3	2.87	2.92
Insertion Loss, dB	2	1.9	3.4
Stopband attenuation, dB	30	30	30

Table 5

Parameters comparison for 5 GHz filter

	Target	Simulation	Measurements
Center frequency, GHz	5	4.8	5.1
Passband, GHz	2	1.77*	2.1
Stopband, GHz	5	6.2*	5.1
Insertion Loss, dB	2	2	3.2
Stopband attenuation, dB	30	30	30

* Inaccuracy of the frequency response could not be compensated with optimization

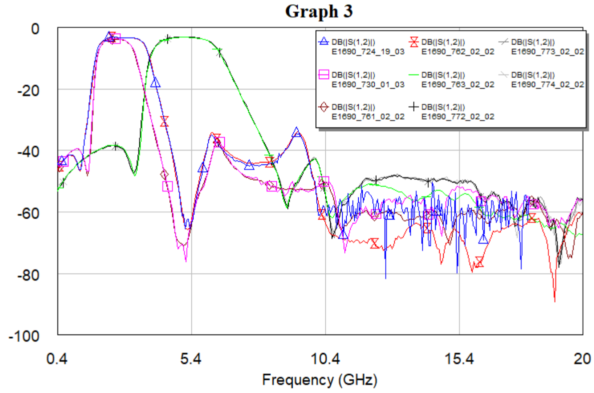

Fig. 16. Measurement results of S21 for all types of samples

Table 6

Comparison with known solutions

	Center frequency, GHz	Passband, GHz	Stopband, GHz	Insertion Loss, dB	Stopband attenuation, dB
This article	2.55	0.9	2.2	3.7	30
This article	2.81	1.3	2.92	3.4	
This article	5.1	2.1	5.1	3.2	
[14]	6.6	1.5	5.5	4.3	40
[15]	2.05	0.5	2.5	4.3	60
[16]	3.5	3.3	5.23	1.63	30

Conclusion

In this paper, design of monolithic microwave integrated circuit bandpass filters for S- and C-bands was presented for pHEMT05D technology. Three filters for 2.5, 3 and 5 GHz center frequency with 40% fractional bandwidth and 30 dB stopband attenuation were considered. Lumped elements realization for Type 1 generalized Chebyshev approximation was used.

Measurement setup was described using Rohde Schwarz ZVA40 vector network analyzer and Cascade Microtech EP6RF probe station. For first six samples, frequency shift of 12% for center frequency was found, as well as increase of insertion loss by 2 dB. It should be noted that difference between samples is smaller than vector analyzer sensitivity, which proves repeatability and stability of achieved result.

For other center frequencies, difference between model and simulation is about 10% for frequencies, and in fact is closer to initial desired parameters of Fig. 1. For 5 GHz center frequency upper stopband is 7.65 GHz from measurement with 7.5 GHz desired value. Stopband attenuation of –30 dB is achieved for all samples. Insertion loss increases no more than by 2 dB in comparison with simulation. Difference between samples is also under vector analyzer sensitivity, which proves quality of the achieved result.

Achieved results are comparable to that of Svetlana-Rost JSC products and are close to results of Marki Microwave.

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