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DESIGN OF HIGH SELECTIVITY LOW-LOSS LADDER FILTERS

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Abstract –Ladder resonator filters (LDRF) [1,2] provide the lowest insertion loss IL=0.6-1.2 dB as compared with other types of LSAW filters, such as longitudinally coupled resonator filters [3]. A drawback of ordinary LDRF is their limited selectivity (or minimal attenuation in the stop band) about UR=40-45 dB. In addition some problems arise when matching LDRF to balanced or differential symmetric loads.

The present paper describes basic symmetric Π-type and T-type sections as well as various structures of ladder filters that allow symmetric loads. An extra advantage of symmetric filters is their potentially higher selectivity thanks to low level of parasitic electromagnetic signal. The results of our study have been illustrated by a number of 600-1500 MHz filters exhibiting high selectivity UR=55-70 dB and small insertion loss IL=1.2-4.0 dB.

1. INTRODUCTION

Traditionally, the elementary cell of LSAW ladder resonator filters (LDRF) is a Γ-type cell [1,2]. On the basis of this cell, Π-type and T-type basic sections are created [4,5]. The schemes of both the Γ-type cell and Π- as well as T-type basic sections are asymmetric relative to the middle grounded point. As a result, the whole structure of a conventional ladder filter involving such cells and sections is also asymmetric, hindering the matching of the filter to balanced or differential symmetric loads.

The present paper describes cells and sections symmetric relative to the middle grounded point. We refer to them as the symmetric Γ-type cell and the symmetric Π-type (or T-type) section, respectively.

These cells and sections allow one to create symmetric structures of ladder filters matching various loads: single / balanced or single / differential, balanced / balanced or differential / differential.

Frequency responses of symmetric cells and sections have been investigated in a wide frequency range. It has been shown that the attenuation in the stop band increases for symmetric Π-type sections and decreases for symmetric T-type sections with increasing frequency. Combining different symmetric cells and sections in a single filter enables one to obtain fairly even attenuation more than 65-70 dB in a wide frequency range.

2. STRUCTURES OF SYMMETRIC SECTIONS AND FILTERS

A conventional Γ-type elementary cell involves one-port LSAW resonator in the series arm and another one-port LSAW resonator in the parallel arm [1, 2]. This cell possesses two types of asymmetry.

First, its input Z_{Π} and output Z_{Γ} impedances are not equal. Second, the scheme of the cell is not symmetric relative to the middle grounded point (Fig.1a). Therefore ladder filters created on the basis of such a cell are also asymmetric [6].

The design process of symmetric filters can be divided into several stages.

The first stage is the transformation of asymmetric Γ-type cells into symmetric ones. For the purpose of operation with differential loads such a transformation is realized by simply connecting two asymmetric Γ-type cells (Fig. 1b),[7]. The symmetric Γ-type cell that operates with balanced loads is obtained by integrating two resonators based on asymmetric Γ-type cells into a single resonator (Fig. 1c). In what follows we consider symmetric cells and sections operating only with balanced loads.

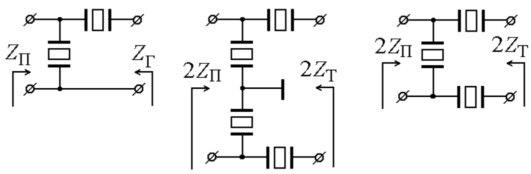

Fig.1. Elementary cells of ladder filters: a – non-symmetric Γ-type ; b – symmetric Γ-type, differential; c - symmetric Γ-type, balanced

The frequency dependence of the transfer function |S21| of this symmetric Γ-type cell is depicted in Fig. 2. One sees that the selectivity of this section is not large and equals about UR>15 dB at insertion loss IL=0.45 dB.

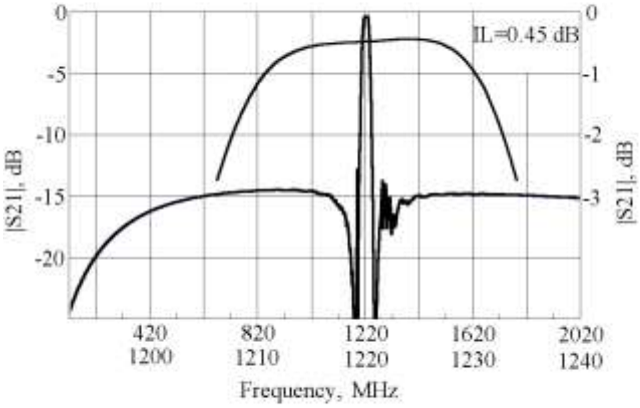

Fig.2. Simulated responses of elementary symmetric Γ -type cell (according to Fig.1c)

It should be noted that we used identical resonators on lithium tantalate 42°YX-LT with quality factors Q=200 at resonant frequency, in order that the comparison with theoretical results in Fig. 2-8 to be correct.

Next stage is building of symmetric sections, which are the basis for structures of symmetric filters. To obtain the symmetric Π -type section, two series-connected resonators of Γ -type cells to be combined must be integrated into a single resonator (Fig.3a). To obtain the symmetric T -type section, it is necessary to integrate two parallel resonators of two Γ -type cells into a single resonator (Fig.3b).

Figure 4 shows the frequency responses of Π -type and T -type basic sections. The frequency dependences of impedances $|Z_{in}|$ in the pass-band are different for Π -type and T -type sections (Fig.4c). Accordingly, the pass-band edge frequencies, e.g., at a level of –1 dB, are shifted relative to each other for these sections (Fig.4a). The positions of the poles of attenuation coincide for both the sections. The frequency responses |S21| in the stop band are asymmetric relative to the mean frequency. Both the sections exhibit approximately identical selectivity UR=15-30 dB.

By changing the ratio C_{0S}/C_{0P} of the static capacitance of resonators in the series and parallel arms (Fig.5) one can change the selectivity (or minimal attenuation in the stop band) UR and the shape factor SH of |S21| of the symmetric Π - and T -type sections. However, if higher selectivity is specified, the insertion loss grows.

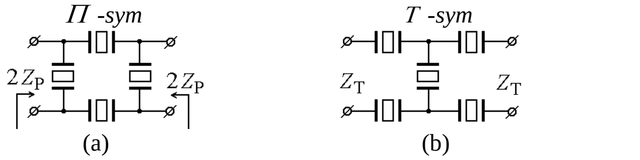

Fig.3. Basic symmetric sections of balanced ladder filters: a – Π -type ; b – T -type

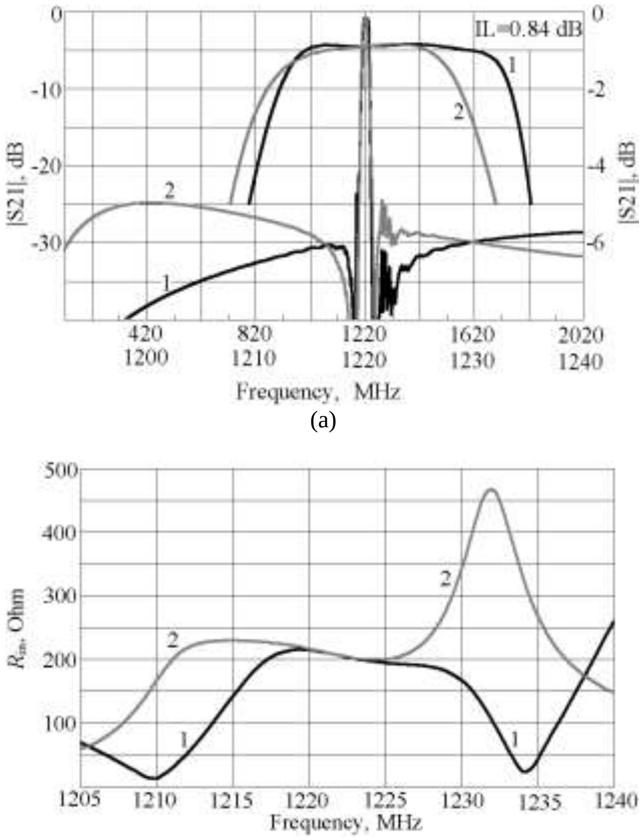

Fig.4. Simulated responses of basic symmetric Π -type (1) and T -type (2) sections (according to Fig.2a,b)

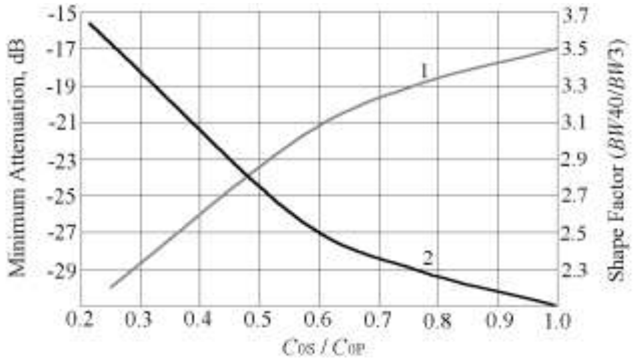

Fig.5. Dependence of minimum attenuation (1) and shape factor (2) on ratio of static capacitances C_{0S}/C_{0P} in 2 Π -type sections

Normally the selectivity UR=15-30 dB of a single section is not sufficient for the majority of applications. Therefore the next stage is to build the structure of the symmetric filter from several symmetric Γ- and T- type sections, taking into account the selectivity UR and insertion loss IL required.

Depending on the preset amplitude ripples in the pass band one can increase the number of basic sections in the filter either by merely connecting them (Fig.6a, 7a) or integrating adjacent resonators of neighboring sections into a single resonator (Fig.6b, 7c).

With increasing frequency the attenuation in the stop band increases for Π-type section filters and decreases for T-type section filters independently of the number of basic sections (Fig.8b). As a rule, the rejection band is wider and deeper nearby high-frequency pole for T-type sections and nearby low-frequency pole for Π-type sections (Fig.4a, 8b). These properties of characteristics |S21| can be useful for designing ladder filters for duplexer modules with asymmetric characteristics |S21| of filters in transmitter T_x and receiver R_x.

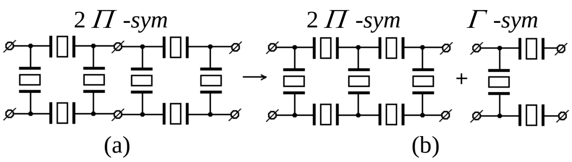

Fig.6. Connection and transformation of symmetric Π-type basic sections: a - two Π-sections (2 Π - type) ; b – integration of two resonators and connection with Γ-type sections

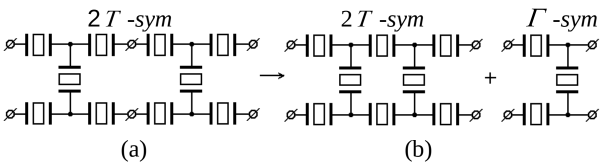

Fig.7. Connection and transformation of symmetric T-type basic sections: a – connection of two T-sections (2 T -type) ; b – integration of two resonators and connection with Γ-type sections

If fairly even attenuation in a wide frequency range is required, then additional symmetric Γ-type cells must be used at the filter input and output (Fig.8b).

In order to estimate quickly the selectivity of a complex filter in a wide frequency range, one can use a simple equivalent scheme where all LSAW resonators are replaced by capacitors whose capacitances equal the static capacitances of the corresponding resonators (Fig.8c).

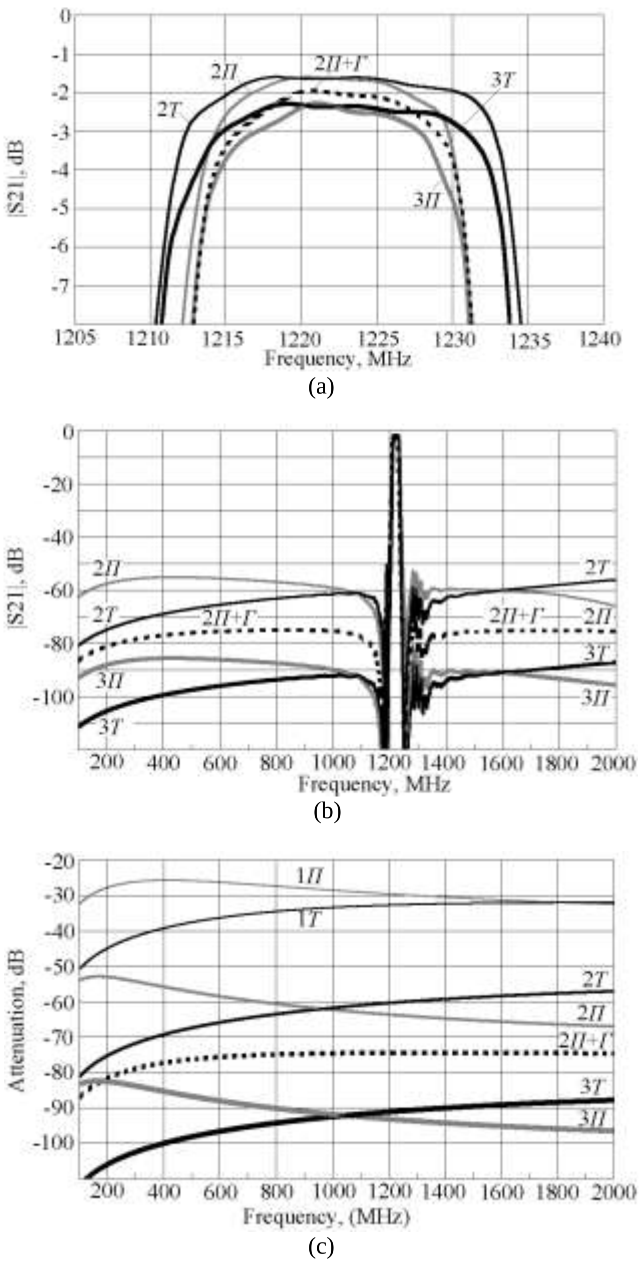

Fig.8. Simulated responses of symmetric sections (a,b) and attenuation in stop band as their equivalent capacitors combination (c)

3. EXPERIMENTAL RESULTS

For the sake of comparison, the experimental characteristics of two 620 MHz filters for balanced loads are given in Fig. 9. One of the filters involves two symmetric Π-type sections and the other two symmetric T-type sections. The behavior of |S21| in a wide frequency range is different for these two types of filters. The selectivity is about UR=52 dB and agrees well with theoretical estimations.

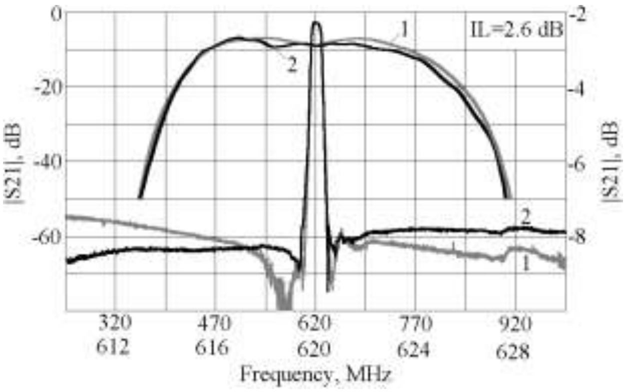

Fig.9. Comparison of measured responses for 620 MHz filters with 2 Π -type (1) and 2 T -type (2) sections each

The measured attenuation in the stop band for the 603 MHz filter involving three symmetric Π-type sections (Fig.10) and for the 610 MHz filter with three symmetric T-type sections (Fig.11) equals UR=65-70 dB which is worse than theoretical values by 12-15 dB.

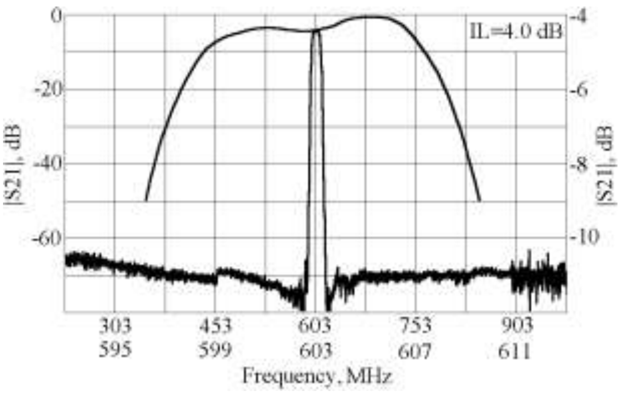

Fig.10. Measured responses of 603 MHz filter with 3 Π -type symmetric sections

Such a discrepancy can be ascribed to electromagnetic cross-talks in the filter package and parasitic capacitance between contacted pads and grounded base of the package. These effects break the symmetry of the filter, impairing its selectivity.

The higher the required attenuation in the stop band and the filter frequency are, the stronger the influence of these effects is. (Fig.12).

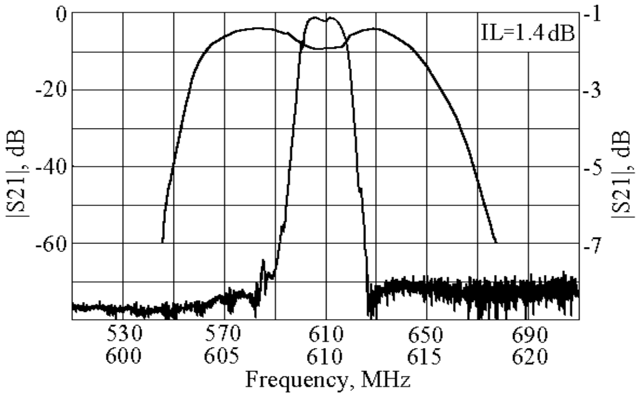

Fig.11. Measured responses of 610 MHz filter with 3 T -type sections for 50 Ohm single ended loads

Comparing experimental |S21| in Fig. 12 and 13 reveals that insertion loss in filters with identical structure can be lowered at the expense of a decrease of selectivity.

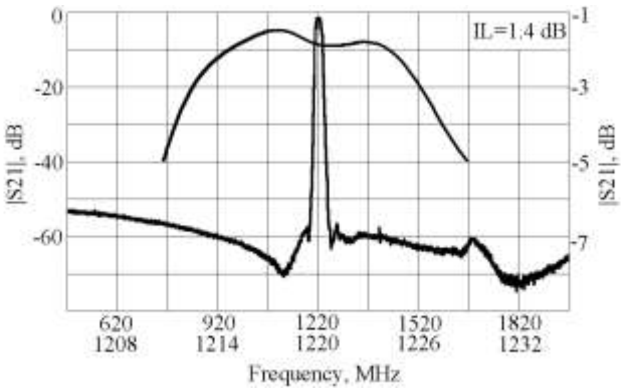

Fig.12. Measured responses of 1220 MHz filter with 2 Π -type symmetric sections

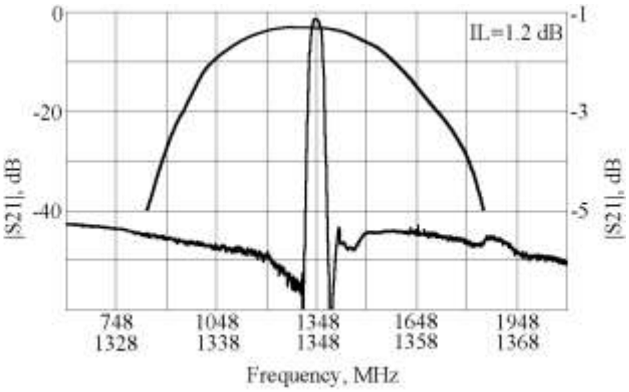

Fig.13. Measured responses of 1348 MHz filter with 2 Π -type symmetric sections

Figure 14 shows that extra Γ-type cells at the filter input and output, e.g., two 1220 MHz T-type sections, allow one to obtain even attenuation 60-65 dB in the wide frequency range of 500-2000 MHz.

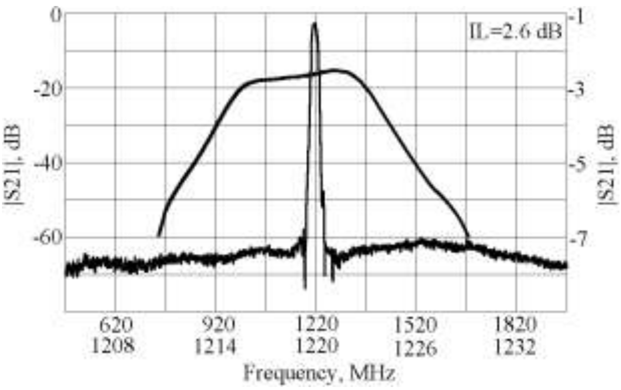

Fig.14. Measured responses of 1220 MHz filter with structure ($\Gamma + 2T + \Gamma$) -type symmetric sections

All filters described use 42°YX-LT substrates. The 600MHz filters have been mounted in 5.0x5.0 mm SMD packages while 1220 MHz and 1348 MHz ones in 3.8x3.8 mm SMD packages. All filters, excluding the one in Fig. 11, have been designed to operate between balanced 200/200 Ohm loads.

4. CONCLUSION

An elementary symmetric Γ-type cell is built from two asymmetric cells by integrating two parallel resonators into a single one. In turn, symmetric sections are constructed from two symmetric Γ-type cells by integrating series resonators (for Π-type sections) or parallel resonators (for Γ-type sections).

The selectivity of symmetric sections can be adjusted by changing the ratio of the static capacitance of series resonators to the static capacitance of parallel resonators. In so doing, increasing the selectivity increases insertion loss and vice versa.

With increasing frequency the attenuation in the stop band increases for Π-type section filters and decreases for T-type section filters .To obtain even attenuation in a wide frequency range, one can use elementary Γ-type cells at the filter input and output.

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