Novel Rectangular Coupled Line Bandpass Filter

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Abstract— This paper reports a novel band pass filter without any periodic response. The novel filter has been named Rectangular Parallel Coupled Line filter (RPCL) and derived from reforming the conventional parallel coupled line filters. The novel band-pass filter has narrowband response. RPCL filter with center frequency of 475 MHz, 1 dB pass-band of 10 MHz and 25 dB stop-band of 50 MHz has been reported here. The area which has been occupied by this RPCL filter is approximately about 52 cm^2. The RPCL can be tuned for various applications at desired center frequency and bandwidth. The occupied area by the filter reduced related to the center frequency of RPCL. High power transmission capability is another distinguished feature of the RPCL filter. Furthermore, at high frequency applications the filter can be designed due to use in high power MMIC packages. The periodic frequency responses related to approximately all types of Microstrip passive filters has been suppressed in the novel RPCL filter. The novel RPCL filter can be designed for dual band applications such as 3G/GSM in a 3 cm^2 MMIC package.

1. INTRODUCTION

Filters play an important role in the design of microwave circuits and their applications are various. So far, quite a lot of Filter structures with various types such as LPF, BPF and HPF have been proposed. Parallel coupled line filters are one of the most practical and common structures in microwave transceivers. In almost all of the parallel coupled line filter structures, quarter wavelength long transmission lines are used as the basic building section resulting in a significant circuit size. Consequently, continuous efforts were carried on to reduce the device length while increasing the original performances [1, 2].

Periodic response is another feature which is existed in almost all of the microstrip filter structures. The novel filter has suppressed the periodic response. This suppression has been estimated about −25 dB.

Some of the narrowband transceivers require narrowband band-pass filters with high rejection at near frequency offsets. One of the vital requirements of the microwave transmitters is high power elements include filters. The microstrip passive elements can transmit high power signals and because of this feature, microstrip filters [4] are indispensable components of microwave transmitters. The novel proposed filter is one of the modified and enhanced microstrip filters and has a new shape with smaller area on board. However, conventional parallel coupled line filters are quite long especially below C-Band where the quarter-wave transmission lines can be several centimeters long.

The design of proposed filter has been based on theoretical parallel coupled line relationships for a Butterworth filter. The filter employs one stub for suppressing the periodic response. To fully illustrate this approach, the characteristics and the shape of novel Rectangular Coupled Line filter together with related equations are presented and its dimensions and simulation results are compared to the conventional one. The characteristics include 1 dB bandwidth, 3 dB bandwidth, 25 dB rejection, and insertion loss. The new enhanced filter is designed at frequency of 475 MHz which is the operational frequency of a specific telecommunication system.

2. NOVEL BAND PASS FILTER DESIGN

Indeed, the novel filter is a modified version of the conventional parallel coupled line filter. Therefore, at the beginning, the conventional one should be designed at desired center frequency. This one consists of some $\lambda/4$ transmission lines which have been coupled with adjacent lines, as shown in Fig. 1.

2.1. Conventional Filter Design

It is a Butterworth filter and the amplitude-squared transfer function for Butterworth filters with insertion loss $L_{Ar} = 3.01$ dB at the cutoff frequency $\Omega_C = 1$ is given by [4]:

$$|S_{21}(j\Omega)|^2 = \frac{1}{1+\Omega^{2n}} \tag{1}$$

For this filter, the elements values of the low-pass prototype can be derived from the following equations [4]:

$$\begin{aligned} g_0 &= 1.0 \\ g_i &= 2\sin\left(\frac{(2i-1)\pi}{2n}\right) \quad \text{for} \quad i = 1 \text{ to } n \\ g_{n+1} &= 1.0 \end{aligned} \tag{2}$$

The minimum value of n can be calculated from the following equation:

$$n \geq \frac{\log(10^{0.1L_{AS}} - 1)}{2\log\Omega_s} \tag{3}$$

Equation (3) suggests that for $L_{AS} = 25\,\text{dB}$ and $\Omega_s = 3$, $n \geq 2.6$, therefore, a 3-pole ($n = 3$) Butterworth prototype has been chosen and eventually the values of the low-pass prototype elements has been calculated and shown at the following table.

The required frequency transformation of a low-pass prototype response to a band-pass prototype response has been shown at (4); and the center angular frequency ω_0 and the fractional bandwidth FBW can be inferred from (4) [4].

$$\begin{aligned} \Omega &= \frac{\Omega_c}{\text{FBW}}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \\ \text{FBW} &= \frac{\omega_2 - \omega_1}{\omega_0} \\ \omega_0 &= \sqrt{\omega_2\omega_1} \end{aligned} \tag{4}$$

The FBW and ω_0 resulted from (4) together with the upper and lower 3 dB cutoff frequencies, have been listed in Tables 2 and 3. The characteristic admittances of J-inverters can be calculated from (5) where Y_0 is the characteristic admittance of the terminating lines. To realize the J-inverters, the even- and odd-mode characteristic impedances of the coupled microstrip line resonators has been determined by (6) and listed in Table 4 beside their related J-inverters values [3].

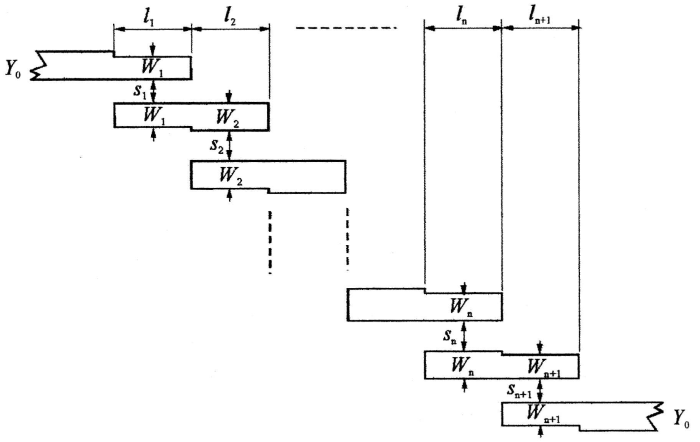

Figure 1: Conventional parallel coupled line filter.

g_0	g_1	g_2	g_3	g_4
1.0	1.0	2.0	1.0	1.0

Table 1: The values of Low pass filter prototype elements.

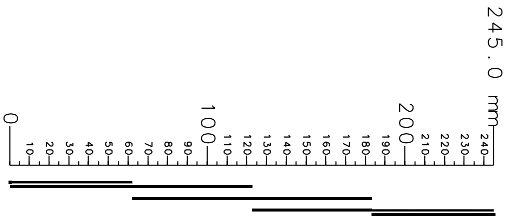

Figure 2: Conventional parallel coupled line filter layout.

Table 2: Pass and Stop frequencies of desired filter.

f_{s1}	f_1 (3 dB cutoff)	f_2 (3 dB cutoff)	f_{s2}
450 MHz	467 MHz	483 MHz	500 MHz

Table 3: Fractional bandwidth and center angular frequency.

FBW	ω_0	ω_1	ω_2
0.02	$2\pi\times 475$ MHz	$2\pi\times 470$ MHz	$2\pi\times 480$ MHz

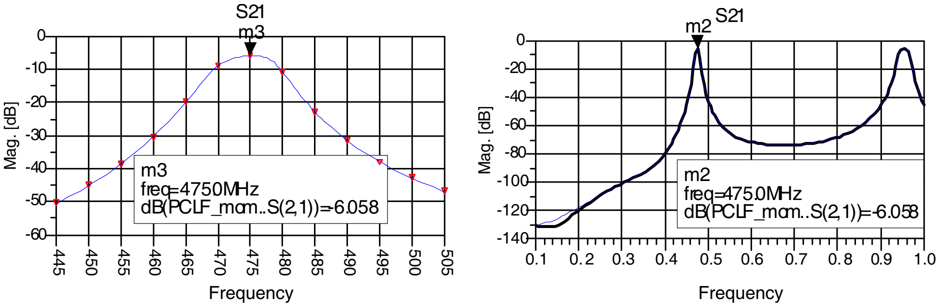

Figure 3: Conventional Parallel coupled line filter frequency response.

The next step of the filter design is finding the dimensions of coupled microstrip lines that exhibit the desired even- and odd-mode impedances. This microstrip filter has been constructed on substrate Cer10 with a relative dielectric constant of 10 and thickness of 1.27 mm. Using the design equations for coupled microstrip lines given in [5], the width and spacing for each pair of quarter-wavelength coupled sections have been derived. The conventional parallel coupled line filter layout and its simulation results have been depicted in Figs. 2 and 3, respectively.

$$\begin{aligned} \frac{J_{01}}{Y_0} &= \sqrt{\frac{\pi}{2}\frac{\text{FBW}}{g_0 g_1}} \\ \frac{J_{j,j+1}}{Y_0} &= \frac{\pi\text{FBW}}{2}\frac{1}{\sqrt{g_j g_{j+1}}} \qquad j = 1 \text{ to } n-1 \\ \frac{J_{n,n+1}}{Y_0} &= \sqrt{\frac{\pi\text{FBW}}{2 g_n g_{n+1}}} \end{aligned} \tag{5}$$

$$\begin{aligned} (Z_{0e})_{j,j+1} &= \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \qquad j = 0 \text{ to } n \\ (Z_{0o})_{j,j+1} &= \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \qquad j = 0 \text{ to } n \end{aligned} \tag{6}$$

2.2. Novel Filter Design

The proposed filter which has been named Rectangular Parallel Coupled Line filter or RPCL has been designed by deforming the conventional one in order to fit aptly in the receiver and transmitter circuits. The filter transmission lines have been curved with 90 degrees angle to shape a rectangular which has been depicted in Fig. 4. Additionally, an open ended quarter wavelength stub at frequency of 950 MHz has been used at filter configuration due to suppress the periodic response of filter at double center frequency of 475 MHz. The stub has been deformed too to fit tightly in the filter inner space.

As we see, we have been obliged to choose filter order equal to $n = 3$ in order to shape a rectangular. The filter depicted in Fig. 4 has been optimized to reach the desired responses. The length and width of Transmission lines together with the curves radiuses and spaces between transmission lines have been optimization parameters and their values after optimization has been listed in Table 5.

Table 4: The J-inverters values together with even- and odd-mode impedances.

j	$J_{j,j+1}/Y_0$	$(Z_{0e})_{j,j+1}$	$(Z_{0o})_{j,j+1}$
0	0.231	64.22	41.12
1	0.038	51.97	48.17
2	0.038	51.97	48.17
3	0.231	64.22	41.12

Table 5: Values of Lengths, widths and spaces.

j	W_j	S_j	L_j
0	1.11 mm	0.64 mm	56.9 mm
1	1.20 mm	3.04 mm	55.6 mm
2	1.20 mm	3.54 mm	58 mm
3	1.11 mm	0.81 mm	55 mm

3. RPCL FILTER ANALYSIS

The RPCL filter layout after final optimization and the conventional one layout have been simulated with momentum method by ADS software. The conventional filter simulation results have been illustrated in previous section at Fig. 3 and the simulation results of proposed RPCL filter has been illustrated in Figs. 5 and 6. Improvements in some aspects have been considered in designing the RPCL filter.

First, the conventional filter was very long which could not be appropriate for implementation in transmitters and receivers circuits. Second, the filter can be used in high power transmitters because of its transmission lines widths. This filter can pass about 500 Watt of signal power which can be applicable in the outputs of some high power amplifiers. Third, the parallel coupled line filters have periodic responses like a lot of microwave filters. In the novel RPCL filter, the second periodic response has been suppressed about −25 dB compared with the conventional one. The frequency responses of the novel RPCL filter and conventional one have been compared in Table 6 at some frequency points. The insertion loss of RPCL filter has been improved about 2 dB related to conventional filter. The bandwidth of the novel filter has been increased by optimization due to specific application which required 1 dB bandwidth of 10 MHz. Additionally, the suppression at 950 MHz is an useful enhancement to eliminate interferences.

Table 6: Comparison table for frequency responses.

	Loss at 450 MHz	Loss at 460 MHz	Loss at 467 MHz	Loss at 470 MHz	Insertion Loss	Loss at 480 MHz	Loss at 483 MHz	Loss at 490 MHz	Loss at 500 MHz	Loss at 950 MHz
RPCL	33.1 dB	18.6 dB	7.3 dB	5.3 dB	4.3 dB	5.1 dB	7.6 dB	18.1 dB	29.5 dB	< 30.3 dB
conventional	44.2 dB	29.5 dB	15.7 dB	9.0 dB	6.1 dB	11.4 dB	18 dB	31.6 dB	42.2 dB	6.6 dB

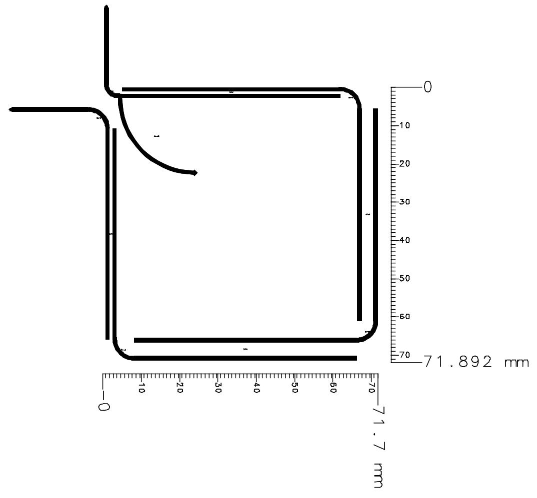

Figure 4: Novel PRCL filter layout.

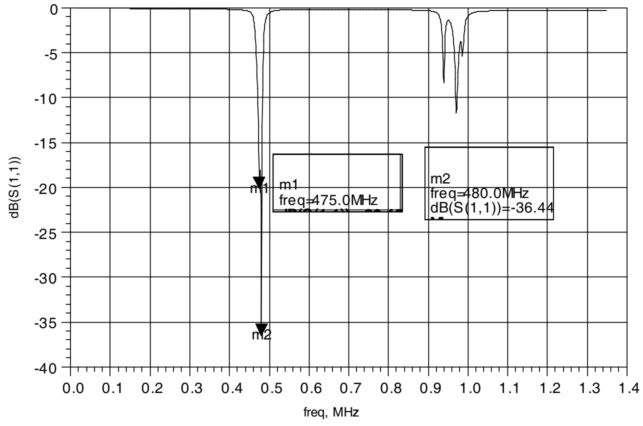

Figure 5: Return loss of novel RPCL filter.

4. DIMENSIONS COMPARISON

The filter shape has been one of the most important motivations in the forming of RPCL. The dimensions of two types of filters have been compared in Table 7. The central area of filter has been left empty. If this filter was designed for GSM systems at 900 MHz together with UMTS systems at 2140 MHz, higher frequency filter could be fitted in central empty area of lower frequency one. On the other hand, it is a good idea to implement some parts of transceiver circuits in this area.

5. APPLICATION OF NOVEL RPCL FILTER

The RPCL filter which has been reported in this paper, has been designed to use in a particular high power transmitter which transmitted the signal at 475 MHz with 1 dB bandwidth of 10 MHz. However, the novel RPCL filter is a general method in band-pass filter designing at desired center frequency with proper bandwidth for so many applications.

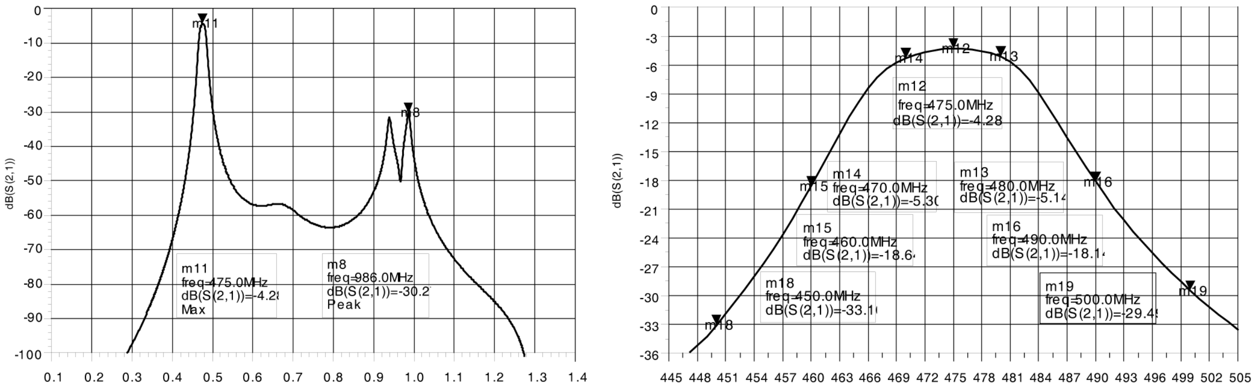

Figure 6: Frequency response of novel RPCL filter.

Table 7: Filters dimensions comparison table.

	RPCL	Conventional
Length	72 mm	245 mm
Width	72 mm	18 mm

6. CONCLUSION

A novel Rectangular Parallel Coupled Line filter has been developed and reported. A shape deforming, insertion loss reducing and periodic response suppression has been achieved. Also the novel filter has extra narrowband response and the area which has been occupied by this RPCL filter is arguably decreased.

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