Concept of Dual-Band Bandpass Filters with Antiparallel Configuration

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***Abstract*—This paper explores the application of band pass filters with antiparallel configurations for obtaining dual band filters of compact sizes and various characteristics. The previously developed model for filters with antiparallel configuration is enhanced by replacing the ideal inductances with transmission lines. The characteristic impedance of the transmission lines is introduced as an additional independent parameter that affects the occurrences and the position of the parasitic passband at higher frequencies. This property is implemented within a program for electrical circuit simulation to obtain a model of dual band bandpass filter with tunable characteristics and a simultaneous calculation of values for all components of an ideal circuit model. The obtained component values of the filter prototype can be scaled to an arbitrary microwave frequency.**

***Index Terms*— Band pass filter, antiparallel configuration, dual band filters, microwave filters.**

I. INTRODUCTION

The interest for the design of band pass filters with multiple pass band increased in recent years due to the appearance of advanced multiple-band wireless systems. At the beginning, dual band wireless systems operated at 900 MHz and 1.9 GHz, but later at frequencies of 2.4 GHz and 5.2 GHz. The initial version of the dual band filter was proposed in [1] and contained a parallel combination of two individual bandpass filters with a single passband. Such a solution required the matching circuits for the filter branches and suffered from a large overall size and high insertion loss. In the following years, several designs of dual band filters using various types of resonators were proposed, such as: parallel-coupled resonators [2], ring resonators [3], open-loop resonators [4], stepped-impedance resonators [5] and quarter wavelength resonators [6]. The major challenge in all these cases was to use the same resonator for obtaining the small insertion loss in both passbands as well as a sharp selectivity and good suppression at higher frequencies. Besides the electrical characteristics, equally important requirements were obtaining a small overall filter size and simple construction. This paper demonstrates that filters with antiparallel configurations, described in [7-10], that were initially used as a standard bandpass, could be used for achieving dual-band characteristics by tuning the values of four independent variables that control the electrical characteristics, without changing the overall filter configuration.

II. IDEAL FILTER WITH ANTIPARALLEL CONFIGURATION

Filters with antiparallel configurations are introduced and explained in detail in [7]. It was shown that S parameters of an antiparallel connection of two identical asymmetrical subnetworks could be significantly different from the S parameters of a parallel connection of the same subnetworks as well as from the S parameters of the original subnetwork. The antiparallel network could contain additional transmission and reflection zeros and, depending on the subnetwork structure, can have the characteristics of low-pass, high-pass or band-pass filters. The simplest configuration capable of having band-pass frequency characteristics is presented in Fig. 1.

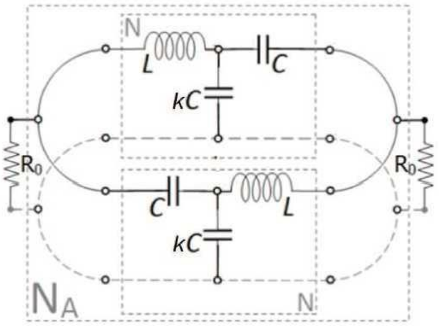

Fig. 1. The simplest configuration of an antiparallel network that could form a bandpass filter [7].

The frequency characteristics of network N_A from Fig.1 are defined by only three parameters: *C*, *L* and *k*. By requesting N_A to be a band pass filter with double S_{11} zeros at $\omega_c=1$, therefore having a normalized central angular frequency, and selecting *C* as an independent variable, the parameter *k* can be expressed with a certain approximation discussed in [8] as functions of *C*:

$$k \approx \sqrt{4C^2-1} - 2 - 0.20844 \cdot C^{-3.047732} \tag{1}$$

while parameter *L* can be calculated from *C* and *k* as:

$$L = \frac{1+k(1+C(C(k+2)+\sqrt{4C^2-(k+2)^2}))}{C(C^2k^2+(k+1)^2)} \tag{2}$$

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In that manner, a prototype family of the basic configuration of an antiparallel band pass filter with the passband centered on the unity angular frequency is defined, having selectivity and passband widths, controlled by independent variable C.

As described in [9], the basic configuration of an antiparallel band pass filter has limited practical applicability. This can be mitigated by extending the filter's configuration with one additional series capacitor and one additional series inductor in series branches of the basic subnetwork as illustrated in Fig. 2.

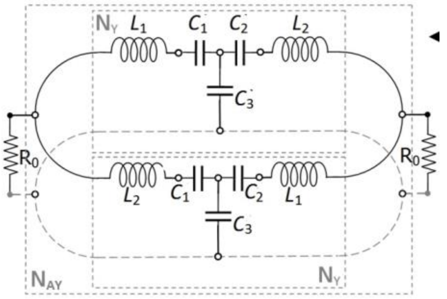


Fig. 2. Configuration of extended antiparallel filter with Y-connected capacitances [9].

As shown in [9], the components of N_Y can be defined with the same parameters (C, L, k) used for the basic filter's configuration, with two additional positive parameters (m, n):

$$L_1 = (m+1)L \tag{3}$$

$$L_2 = n/C \tag{4}$$

$$C_1 = 1/mL \tag{5}$$

$$C_2 = C/(n+1) \tag{6}$$

$$C_3 = kC \tag{7}$$

As shown in [9], parameters m and n are closely related to the angular frequency position of the transmission zero pair (ω_{EZ1}, ω_{EZ2}) which is inherent to extended antiparallel filters.

With certain approximation, parameters m and n can be expressed as a function of ω_{EZ1} and ω_{EZ2}, respectively with the following simple relations:

$$m \approx \frac{[LC(k+1)]^{-1} - \omega_{EZ1}^2}{\omega_{EZ1}^2 - 1} \tag{8}$$

$$n \approx \frac{1+k^{-1}}{\omega_{EZ2}^2 - 1} \tag{9}$$

The filter configuration from Fig. 2 can be transformed to the configuration shown in Fig. 3 by a Y to Δ transformation of the capacitors. The Δ configuration is more suitable for practical realization as explained in [10]

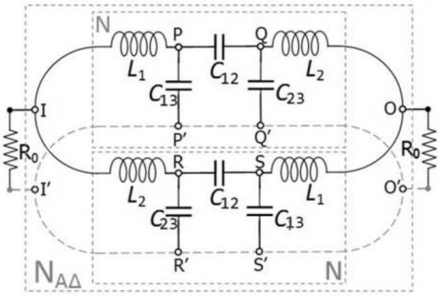


Fig. 3. Configuration of extended antiparallel filter with Δ-connected capacitances [9].

The values of capacitors of Δ configuration are also defined by the same set of parameters (C, L, k, m, n) with the following expressions:

$$C_{13} = \frac{k(n+1)C}{1+n+m(1+k(n+1))LC} \tag{10}$$

$$C_{23} = \frac{kmC^2L}{1+n+m(1+k(n+1))LC} \tag{11}$$

$$C_{12} = \frac{C}{1+n+m(1+k(n+1))LC} \tag{12}$$

Both Y and Δ filter configurations are mutually electrically compatible. By applying expressions (1), (2), (8) and (9) into expressions (3-7) and (10-12) all components of the filters can be calculated in terms of three independent parameters C, ω_{EZ1} and ω_{EZ2}. The S-parameter frequency responses of the filters can also be expressed in terms of the same three parameters as explained in [9-10]. Fig. 4 shows S-parameter frequency characteristics for several various filters for several values of three independent parameters. It demonstrates that various bandwidths and controlled positions of transmission zeros can be achieved with good accuracy. It also validates the approximate expressions (8) and (9) since the positions of the transmission zeros in Fig. 4 accurately correspond to the given values of ω_{EZ1} and ω_{EZ2}. The increase of C parameter increases the isolation in both the lower and the upper stopband and simultaneously decreases the bandwidth of the passband.

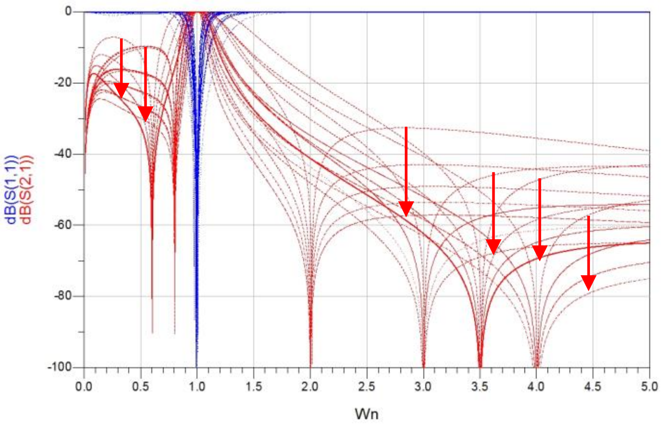


Fig. 4. S-parameter frequency characteristics of the filter model for various combinations of parameter values (C={2, 3, 4, 5}; ω_{EZ1}={0.6, 0.8}; ω_{EZ2}={2, 3, 3.5, 4} [8]. The red arrows indicate the isolation increase with increasing of C.

III. FILTER WITH ANTIPARALLEL CONFIGURATION AND TRANSMISSION LINES AS INDUCTIVE ELEMENTS

Filter realization in some of the planar techniques requires a realization of the filer's components as transmission lines. The corresponding mathematical model of the filter can be obtained by replacing the transmission matrix of the ideal components with a transmission matrix of the corresponding transmission lines. The transmission matrix of the transmission line that substitutes inductances L_1 and L_2 can be expressed with the following equations:

$$\mathbf{T}_{TL_1}=\begin{bmatrix}\cos\dfrac{(m+1)L\omega}{z_c} & i\cdot z_c\sin\dfrac{(m+1)L\omega}{z_c}\\ \dfrac{i}{z_c}\sin\dfrac{(m+1)L\omega}{z_c} & \cos\dfrac{(m+1)L\omega}{z_c}\end{bmatrix} \tag{13}$$

$$\mathbf{T}_{TL_2}=\begin{bmatrix}\cos\dfrac{n\omega}{z_cC} & i\cdot z_c\sin\dfrac{n\omega}{z_cC}\\ \dfrac{i}{z_c}\sin\dfrac{n\omega}{z_cC} & \cos\dfrac{n\omega}{z_cC}\end{bmatrix} \tag{14}$$

where z_c represents the normalized characteristic impedance ($z_c=Z_c/R_0$) of the corresponding transmission line. For practical reasons it is assumed that both transmission lines have the same characteristic impedance. For large values of the relative characteristic impedance z_c the following applies:

$$\lim_{z_c\to\infty}\mathbf{T}_{TL_1}=\begin{bmatrix}1 & i\omega(m+1)L\\ 0 & 1\end{bmatrix}=\begin{bmatrix}1 & i\omega L_1\\ 0 & 1\end{bmatrix} \tag{15}$$

$$\lim_{z_c\to\infty}\mathbf{T}_{TL_2}=\begin{bmatrix}1 & i\omega\dfrac{n}{C}\\ 0 & 1\end{bmatrix}=\begin{bmatrix}1 & i\omega L_2\\ 0 & 1\end{bmatrix} \tag{16}$$

By employing (13) and (14), the S-parameters matrix of the entire filter can be expressed as:

$$\mathbf{S}_{ETL}=\begin{bmatrix}\dfrac{SN_{TL1}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)}{SD_{TL}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)} & i\dfrac{SN_{TL2}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)}{SD_{TL}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)}\\ i\dfrac{SN_{TL2}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)}{SD_{TL}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)} & \dfrac{SN_{TL1}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)}{SD_{TL}(C,\omega_{EZ1},\omega_{EZ2},z_c,\omega)}\end{bmatrix} \tag{17}$$

which means that besides C, ω_{EZ1} and ω_{EZ2}, the filter characteristics depend on additional independent parameter z_c. Fig. 5, which is obtained by implementing (17) into [11], shows the dependence of frequency characteristics of the antiparallel filter with inductances replaced with transmission lines due to different values of relative characteristic impedance z_c and for the fixed values of the remaining three independent parameters. It can be seen that the frequency characteristics of the filter with transmission lines having the higher values of z_c are very close to the characteristics of a filter composed of ideal components having $\omega_c=1$ and the transmission zeros at exact values set by the input parameters ω_{EZ1} and ω_{EZ2}. The lower values of z_c cause the reduction of the isolation in the upper stopband region and appearance of parasitic passbands at higher frequencies. Lower z_c also causes the shift of the positions of transmission zeros and ω_c toward frequencies lower than ω_{EZ1}, ω_{EZ2} and 1, respectively, due to the influence of the parasitic capacitance of the inductive transmission lines. The exact new frequency positions of the transmission zeros and the central frequency of the passband can be calculated numerically by solving transcendental equations derived from (17) for specified C, ω_{EZ1}, ω_{EZ2} and z_c. The lowest and the highest achievable value of z_c depends on the substrate characteristics and transmission lines type. For microstrip lines it ranges typically from 0.4 to 3.

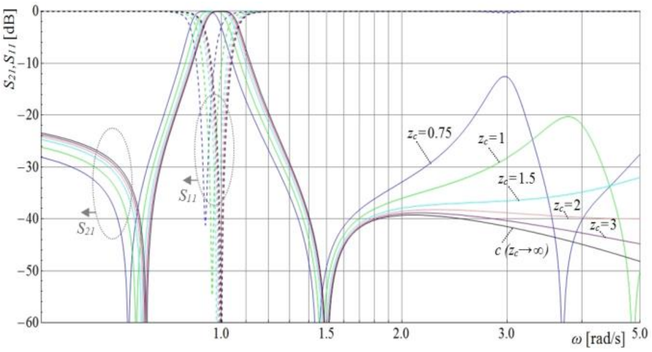


Fig. 5. Frequency characteristics of the filter with transmission lines of various z_c for $C = 4$, $\omega_{EZ1} = 0.75$ and $\omega_{EZ2} = 1.5$.

IV. FILTER WITH TRANSMISSION LINES AS DUAL BAND BANDPASS FILTERS

The feature of the filter with antiparallel configuration with transmission lines that is described in the previous section can be employed for the designing of filters with dual passbands by tuning the input parameters to obtain an additional passband with a small insertion loss and good matching.

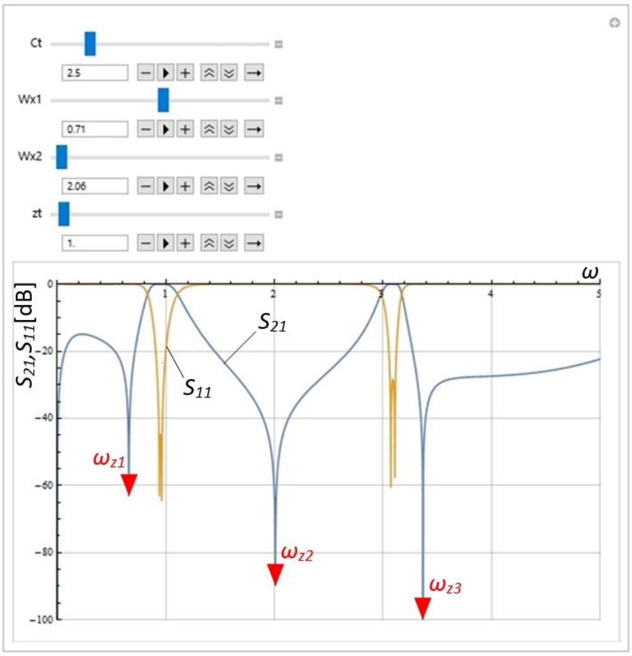
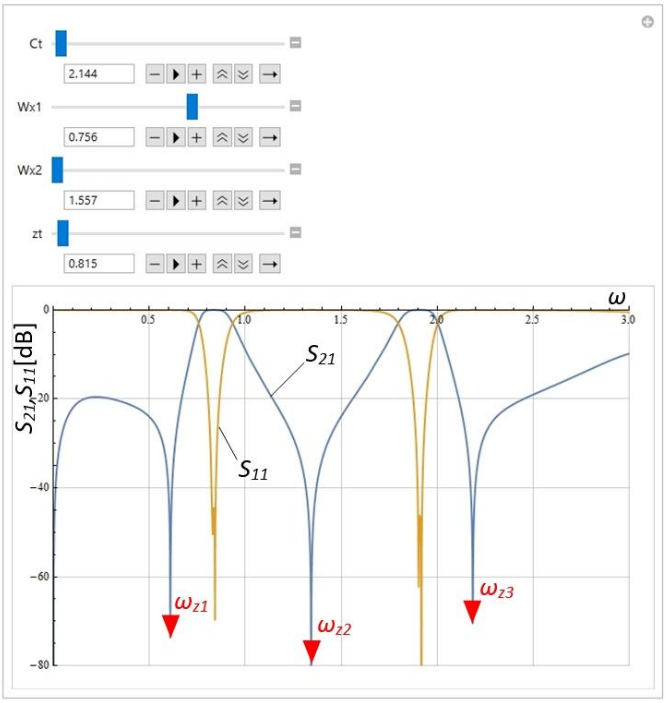

Ct 2.5
Wx1 0.71
Wx2 2.06
zt 1.

Fig. 6. Frequency characteristics of the filter with antiparallel configuration with corresponding values of independent variables Ct (C), Wx1 (ω_{EZ1}), Wx2 (ω_{EZ2}), and zt (z_c) example 1

Fig. 6 and Fig. 7 show two examples of dual band frequency characteristics obtained by [11] for two different sets of independent variables C, ω_{EZ1}, ω_{EZ2} and z_c.

These examples demonstrate that dual band filters with a different frequency distance between the first and second passband and with various bandwidths can be obtained. Since the major objective is to achieve low insertion loss and good matching in both passbands, the position of the transmission zeros cannot be independently adjusted as in the case of the extended antiparallel filters from Section II. As explained in Section III, the transmission zeros positions (marked as ω_{Z1} and ω_{Z2} in Figs. 6 and 7) deviate from the values set by parameters ω_{EZ1} and ω_{EZ2}. This deviation increases as the characteristic impedance of the inductive transmission lines decreases. Dual band filters also acquire additional transmission zeros above the upper passbands, marked as ω_{Z3} in Figs. 6 and 7. The value of ω_{Z3} can also be calculated numerically by solving transcendental equations derived from (17) for specified C, ω_{EZ1}, ω_{EZ2} and z_c.



Ct 2.144

Wx1 0.756

Wx2 1.557

zt 0.815

Fig. 7. Frequency characteristics of the filter with antiparallel configuration with corresponding values of independent variables Ct (C), Wx1 (ω_{EZ1}), Wx2 (ω_{EZ2}), and zt (z_c) example 2

From examples shown in Fig. 6 and Fig. 7 it can be seen that dual band filter characteristics may require the lower values of parameter C, which as shown in the examples from Fig. 4 decreases the isolation in all stopbands.

V. CONCLUSION

This paper demonstrated that band pass filters with antiparallel configurations could be employed for obtaining dual band filters of various characteristics. Practical implementation of the proposed method is in progress.

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