Novel Multiplexer Topologies based on Coupled Resonator Structures

Talal F. Skaik and Deeb A. Tubail
Electrical Engineering Department
Islamic University of Gaza
Gaza, Palestine
talalskaik@gmail.com

***Abstract*—Novel multiplexer structures based on all-resonator topologies are presented here. The proposed multiplexers consist of only resonators without extra manifolds or circulators or power dividers. They can achieve various requirements of different filtering responses and arbitrary number of channels with miniaturized size. The proposed multiplexers are synthesized using optimization technique where coupling coefficients between coupled resonators are found. Different structures with various properties and responses are presented including symmetrical and asymmetrical channels. Reduction of the complexity of optimization processes is also presented.**

Keywords— coupled resonator;filter; multiplexer; optimization

I. INTRODUCTION

Multiplexers are used to separate signals from common port to other ports and they are conventionally constituted from channel filters combined together using manifolds or circulators or power dividers. Other multiplexer structures formed of only resonators have also been proposed in literature. Those resonator-based multiplexers can be miniaturized in comparison to conventional multiplexers since they do not contain external combining circuits. Star-junction multiplexers have been proposed in literature where the channel filters are combined using a resonating junction [1] as shown in Fig. 1 (a). However, such structures are difficult to practically implement for large number of channels as the area around the resonating junction is limited to few connections. In [2], other star-junction multiplexer structures have been proposed as depicted Fig. 1 (b) where each two channels have only one connection to the resonating junction. However this proposed topology is still limited to six channels. Other resonator-based multiplexer structures formed exclusively by coupled resonators have also been proposed as depicted in Fig. 1 (c) [3] and Fig. 1 (d) [4,5]. In [6,7], triplexers based on coupled resonator structures are designed and implemented. The previous resonator–based multiplexer structures are convenient for small number of channels and they are not generalized for large number of channels.

In [8], we proposed a generalized novel all-resonator multiplexer structure with symmetrical pairs of channels as shown in Fig. 2 and it can be noticed that this structure has even number of channels. Furthermore, we presented two examples of multiplexers with symmetrical pairs of channels, the first is a four-channel multiplexer while the second is a six-channel multiplexer. Here, we present many structures of resonator-based multiplexers with different number of resonators and with different specifications and characteristics including multiplexer with asymmetrical channels and also a multiplexer with channels that differ in bandwidth. The examples presented here also exhibit topologies with even and topologies with odd number of channels. Moreover, simplification of the optimization process for large coupled-resonator multiplexers by sub-dividing the structure into smaller blocks is presented. The proposed multiplexers can be implemented by any type of resonators such as microstrip resonators and air-filled waveguide cavities for communications satellites. However, a limitation could arise with microstrip multiplexers since undesired couplings may exist between resonators that affect the response.

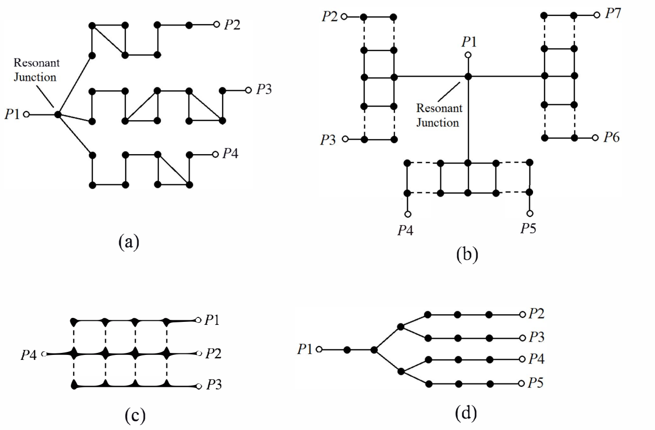


Fig. 1. Coupled Resonator multiplexer topologies in literature (a) Star-junction Multiplexer [1], (b) Novel star-junction multiplexer with more channels and fewer connections to resonant junction [2], (c) Coupled resonator multiplexer with distributed coupling [3], (d) Multiplexer based on all-resonator structures [4]. (black dots represent resonators and lines represent coupling, *Pi* stands for *Port i*)

II. SYNTHESIS OF COUPLED RESONATOR MUTIPLEXERS

The presented coupled resonator multiplexers here are synthesized using optimization technique where the coupling coefficients between resonators m_{ij} and resonators frequency offsets m_{ii} are found. The optimization is performed by

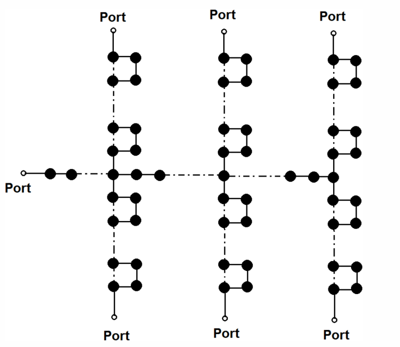


Fig. 2. Coupled resonator multiplexer structure for symmetrical channels [8]

minimization of a cost function that is related to matrix [A] given in (1). The cost function and the base methodology of the synthesis are presented and explained in [8]. The matrix [A] consists of the sum of three matrices, the external coupling coefficient matrix, the identity matrix and the coupling coefficient matrix, where P is the complex low pass frequency variable, q_{ei} is the normalized external quality factor, m_{ij} is the normalized coupling coefficient between resonators i and j, m_{ii} in the diagonal is the normalized self-coupling coefficient of resonator i representing frequency shift since resonators in each arm have different self-resonant frequencies from those in other arms, and j is the imaginary unit. The multiplexers here are normalized in lowpass prototype and they can be transformed to practical bandpass frequency domain using known transformation formula [9].

$$[A]=\begin{bmatrix} \frac{1}{q_{e1}} & \cdots & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & \frac{1}{q_{e(n-1)}} & 0 \\ 0 & \cdots & 0 & \frac{1}{q_{en}} \end{bmatrix} + P\begin{bmatrix} 1 & \cdots & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & 1 & 0 \\ 0 & \cdots & 0 & 1 \end{bmatrix} -j\begin{bmatrix} m_{11} & \cdots & m_{1(n-1)} & m_{1n} \\ \vdots & \ddots & \vdots & \vdots \\ m_{(n-1)1} & \cdots & m_{(n-1)(n-1)} & m_{(n-1)n} \\ m_{n1} & \cdots & m_{n(n-1)} & m_{nn} \end{bmatrix} \tag{1}$$

The general formulae of the S-Parameters are given as

$$S_{xx}=1-\frac{2}{q_{ex}}[A]_{xx}^{-1} \quad , \quad S_{xy}=\frac{2}{\sqrt{q_{ex}q_{ey}}}[A]_{xy}^{-1} \tag{2}$$

where S_{xx} is the return loss at port x, and S_{xy} is the insertion loss between ports x and y. The normalized external quality factors are numerically calculated as

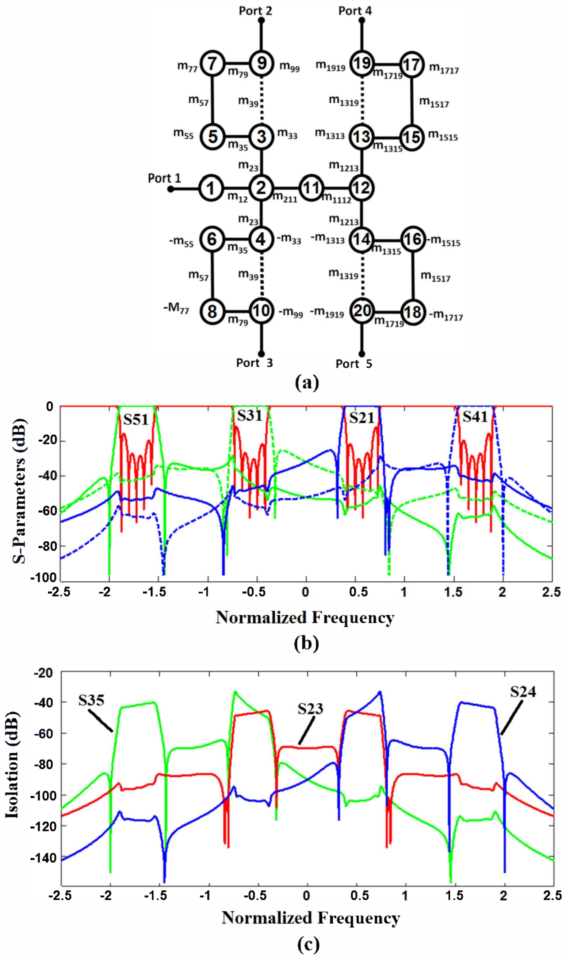
$$q_{ex_1x_2}=\frac{2}{x_2-x_1}q_{e\pm 1} \quad , \quad \frac{1}{q_{e1}}=\sum_{i=1}^{N}\frac{1}{q_{ei}} \tag{3}$$

where q_{ex1x2} is the normalized external quality factor of a filter with edges x_1 and x_2, $q_{e\pm 1}$ is that of filter with edges of ±1, which is numerically calculated from known g-values [9] and N is total number of channels.

III. NUMERICAL EXAMPLES

A. Example1: Multiplexer with Quasi-Elliptic Channels

Example 1 illustrates a coupled resonator symmetrical multiplexer with Quasi-Elliptic filtering response and equal bandwidth four channels. Fig. 3 (a) presents the topology where there are four cross couplings (dotted lines) to generate the transmission zeros. Fig. 3 (b) presents the response of the multiplexer while Fig. 3 (c) shows the isolation between multiplexer channels. The calculated normalized external quality factors are q_{e2} = q_{e3} = q_{e4} = q_{e5} = 5.5509 and q_{e1} = 1.3877. The optimized normalized coupling coefficients and frequency offsets are m_{12} =1.3489, m_{23}= m_{24} = 0.4391, m_{33} = - m_{44} = 0.5429, m_{35}= m_{46} = 0.1031, m_{39}= m_{410} = -0.0371, m_{55} = - m_{66} = 0.5602, m_{57}= m_{68} = 0.1219, m_{77} = - m_{88} = 0.5627, m_{79} = m_{810} = 0.1329, m_{99} = - m_{1010} = 0.5588, m_{211} = 0.8746, m_{1112} = 0.9734, m_{1213}= m_{1214} = 0.5078, m_{1313} = - m_{1414} = 1.5098, m_{1315} = m_{1416} = 0.1097, m_{1319} = m_{1420} = -0.0271, m_{1515} = - m_{1616} =1.7157, m_{1517}= m_{1618} = 0.1177, m_{1717} = - m_{1818} = 1.7213, m_{1719}= m_{1820} = 0.1371, m_{1919} = - m_{2020} =1.7189.



(a)

(b)

(c)

Fig. 3. Example 1 (a) The structure (b) Reflection and insertion losses (c) The isolation between adjacent channels.

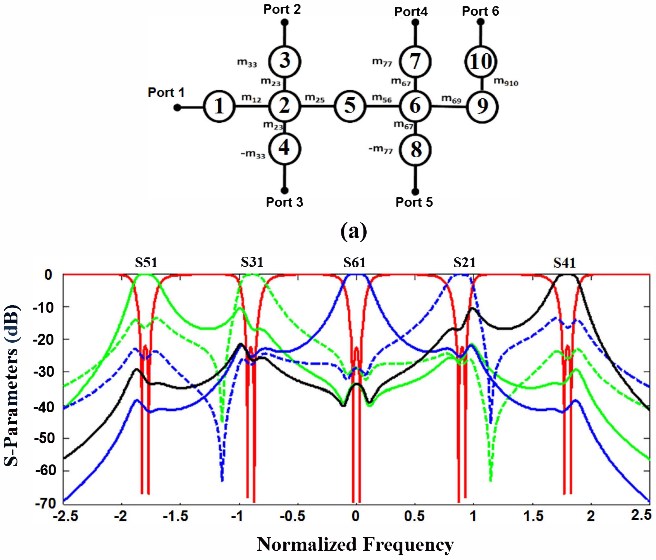
B. *Example2: Multiplexer with Five Chebyshev Channels*

Example 2 is a five channel multiplexer (odd number of channels) with ten resonators. Fig. 4 (a) shows multiplexer topology and Fig. 4 (b) illustrates multiplexer response. The normalized external quality factors are numerically calculated as $q_{e2} = q_{e3} = q_{e4} = q_{e5} = q_{e6} = 13.2960$ and $q_{e1} = 2.6592$. The optimized normalized coupling coefficients and frequency offsets are $m_{12} = 1.2806$, $m_{23} = m_{24} = 0.2339$, $m_{25} = 1.0270$, $m_{33} = - m_{44} = 0.8925$, $m_{56} = 0.9376$, $m_{67} = m_{68} = 0.2380$, $m_{77} = - m_{88} = 1.7530$, $m_{69} = 0.7147$, $m_{910} = 0.1111$.

C. *Example 3: Multiplexer with Unsymmetrical Channels*

Fig. 5 (a) presents unsymmetrical structure of multiplexer where the number of resonators per channel is not the same. Fig. 5 (b) shows the response of the multiplexer and it can be noticed that the channels differ in number of reflection zeros and also in bandwidth. Moreover, it can be noticed that two channels have Chebyshev responses and the others have Quasi-Elliptic responses. This multiplexer is considered more general and complex than previous ones because of unsymmetrical structure and different specifications and characteristics for the channels.

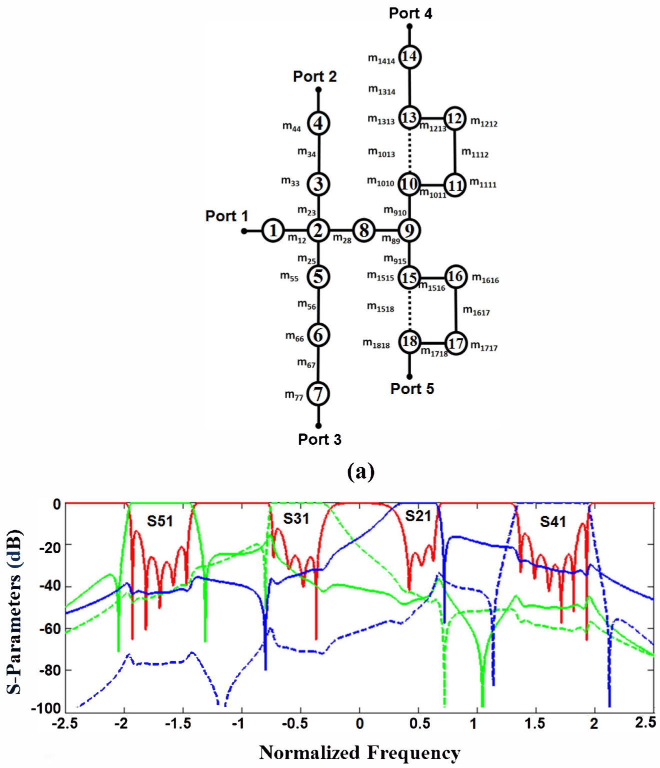
The normalized external quality factors are numerically calculated as $q_{e1} = 1.0629$, $q_{e2} = 3.8856$, $q_{e3} = 4.2580$, $q_{e4} = 6.8128$ and $q_{e5} = 3.3133$. The optimized normalized coupling coefficients and frequency offsets are: $m_{12} = 1.4304$, $m_{23} = 0.4585$, $m_{33} = 0.4847$, $m_{34} = 0.1422$, $m_{44} = 0.4893$, $m_{25} = 0.5452$, $m_{55} = -0.5056$, $m_{56} = 0.1570$, $m_{66} = -0.5081$, $m_{67} = 0.1837$, $m_{77} = -0.5079$, $m_{28} = 0.7554$, $m_{89} = 1.1210$, $m_{910} = 0.6703$, $m_{1010} = 1.1484$, $m_{1011} = 0.2281$, $m_{1111} = 1.6091$, $m_{1112} = 0.1926$, $m_{1212} = 1.6475$, $m_{1213} = 0.1661$, $m_{1313} = 1.6360$, $m_{1314} = 0.2322$, $m_{1414} = 1.6353$, $m_{1013} = 0.0354$, $m_{915} = 0.6360$, $m_{1515} = -1.2528$, $m_{1516} = 0.1877$, $m_{1616} = -1.6637$, $m_{1617} = 0.1836$, $m_{1717} = -1.6953$, $m_{1718} = 0.1943$, $m_{1818} = -1.6814$, $m_{1518} = 0.0656$.



(a)

(b)

Fig. 4. Example 2 (a) The structure (b) Reflection and insertion losses



(a)

(b)

Fig. 5. Example 3 (a) The structure (b) Reflection and insertion losses

IV. SIMPLIFICATION OF OPTIMIZATION PROCESS

Designing a multiplexer with a large number of resonators especially with unsymmetrical channels produces a large number of parameters that enter into the optimization process. Here we present a method to reduce the complexity of the optimization process.

The optimization process in the previous examples has been performed in one step where all the coupling coefficients are entered into optimization process. In this case the optimization algorithm can converge rapidly for small structures but may fail to find a solution for relatively large topologies as the number of parameters increases. To simplify the optimization process large multiplexer structures can be sub-divided into smaller blocks (diplexers) and optimization is done for each individual diplexer. Then, the results are taken as the initial values in the optimization process for the whole multiplexer. Thus reducing the complexity for large structures and starting with good initial values.

A symmetrical four-channel multiplexer is investigated here where two of the channels are quasi-elliptic with same bandwidth and different from the other two that have smaller bandwidth and Chebyshev response. The structure is subdivided into two-diplexers and each diplexer is optimized individually as shown in Fig. 6 (a).

The first diplexer is optimized to get some coupling coefficients (in vertical arm) to be used as initial values in the optimization of the whole structure as follows: $m_{33} = 0.4963$, $m_{35} = 0.1293$, $m_{55} = 0.5180$. Similarly, the second diplexer is optimized to get some coupling coefficients in the vertical arm as follows: m_{99} = 1.6751, m_{911} = 0.1438, m_{915} = -0.0736, m_{1111} = 1.6986, m_{1113} = 0.2039, m_{1313} = 1.7015, m_{1315} = 0.2032, m_{1515} = 1.7007.

The optimized normalized coupling coefficients and frequency offsets of the whole multiplexer after using results of individual diplexers as initial values are m_{12} = 1.4543, m_{23} = 0.4798, m_{27} = 0.7550, m_{33} = 0.4951, m_{35} = 0.1409, m_{55} = 0.4942, m_{78} = 1.1151, m_{89} = 0.7059, m_{99} = 1.1479, m_{911} = 0.2044, m_{1111} = 1.6564, m_{1113} = 0.2029, m_{1313} = 1.7056, m_{1315} = 0.2048, m_{1515} = 1.6787, m_{915} = -0.0905. The normalized external quality factors are q_{e2} = q_{e3} = 6.8128, q_{e4} = q_{e5} = 3.8856 and q_{e1} = 1.2372. It can be noticed from the results that the initial values resulted from optimization of diplexers are quite close to final values obtained after optimization process is performed for the whole structure. The final response of the whole multiplexer is depicted in Fig. 6 (b).

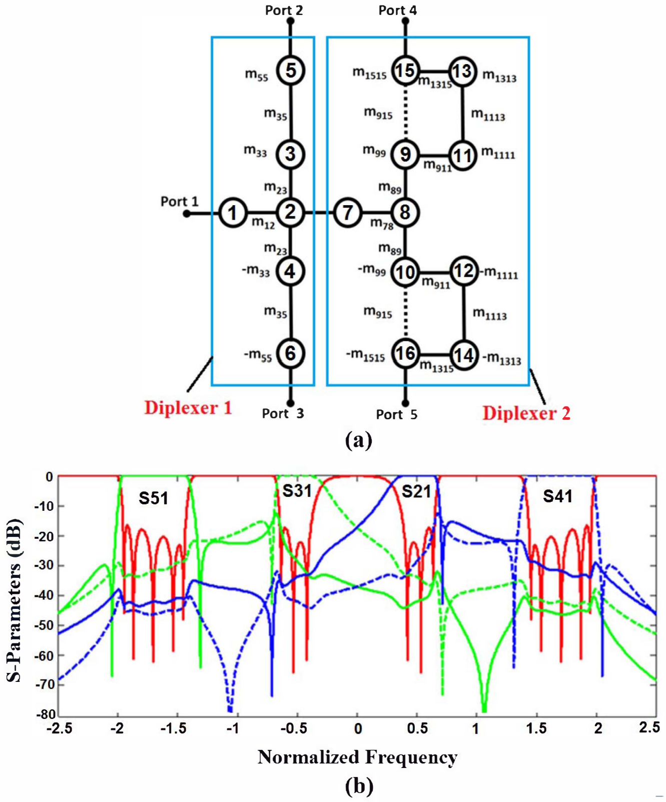


Fig. 6. Multiplexer subdivided into two diplexers (a) The structure (b) Reflection and insertion losses.

V. CONCLUSION

In this paper novel multiplexer topologies based on coupled resonator structures are presented. The proposed topologies consist of only resonators and hence they can be miniaturized in comparison to conventional multiplexers. The examples presented here include symmetrical and asymmetrical structures with different filtering responses as well as different channels bandwidths. The synthesis of the presented multiplexer is done using an optimization technique whereby coupling coefficients and frequency offsets are found. A remarkable advantage of this novel structure is the ability of dividing the multiplexer into smaller blocks (diplexers) and optimizing each diplexer individually. This decreases the complexity of optimization process and saves the time consumed in optimization.

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