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NOVEL STAR-JUNCTION COUPLED-RESONATOR MULTIPLEXER STRUCTURES

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Abstract—Star-junction multiplexers are used when the number of channels is relatively small since the resonating junction has to be connected to many filters' outputs. In this paper, novel topologies of star-junction multiplexers with resonating junctions are proposed. The advantage of the proposed topologies is that the number of connections to the resonating junction is reduced and thus allowing multiplexers with more channels to be implemented. An optimization technique is used to synthesize the coupling matrix of the proposed multiplexers, and numerical examples are illustrated in this paper.

1. INTRODUCTION

Multiplexers are widely used in communication systems to combine or split signals of different frequencies. There are several approaches in designing and implementing multiplexers. The most common configurations are manifold-coupled, circulator-coupled, and hybrid-coupled multiplexers [1]. Diplexers/multiplexers based on coupled resonator circuits with multiple outputs have been reported in [2–6]. The complete networks of those diplexers/multiplexers are formed of many coupled resonators, similar to filters but with more output ports.

Star-junction multiplexers are implemented when the number of channels is relatively small [1]. A general approach to the synthesis of star-junction multiplexers with a resonating junction with the topology shown in Fig. 1 is illustrated in [7]. The grey circle represents a resonant junction, an extra resonator in addition to the channel filters. Diplexers and triplexers employing a resonating junction have been implemented and reported in [8, 9]. In the general topology in Fig. 1,

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the number of connections to the resonant junction is $N+1$, where N is the number of channels. In consequence, the larger the numbers of the channels, the more connections to the resonating junction are needed. In fact, it is not practical to implement multiplexers with relatively large number of channels using the topology in Fig. 1 due to the large number of connections to the resonating junction.

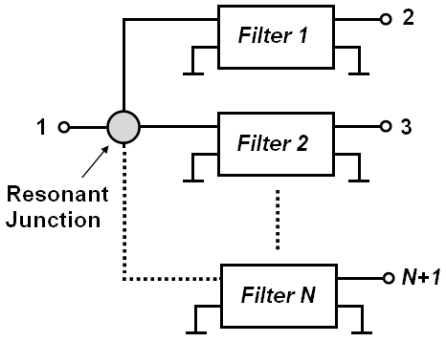

Figure 1. General topology of resonant star-junction multiplexer.

In this paper, novel topologies for star-junction multiplexers with a resonating junction are proposed. A distinct advantage of the proposed topologies is that the number of connections to the resonating junction is reduced from $N+1$ to $\lceil N/2 \rceil + 1$, thus allowing multiplexers with more channels to be implemented. Fig. 2 shows the proposed topologies for star-junction multiplexers with different number of channels, where the grey circle in each topology represents a resonating junction. Fig. 2(a) shows a general topology for a 4-channel multiplexer, with three connections to the resonating junction (including the input port), whereas Fig. 2(b) shows a 5-channel multiplexer with four connections to the resonating junction and Fig. 2(c) shows a 6-channel multiplexer with four connections to the resonating junction. The complete network of the proposed topologies consists of coupled-resonator sections of one or two channels and a resonating junction to connect these sections together. The proposed multiplexers can be implemented by using any type of resonators such as microstrip and waveguide cavity resonators. Due to the limited coupling area to the resonating junction, the proposed structures allow implementing multiplexers with up to six channels. The resonators should be properly located around the resonating junction to avoid any undesired coupling, particularly when the multiplexer is constructed using microstrip resonators.

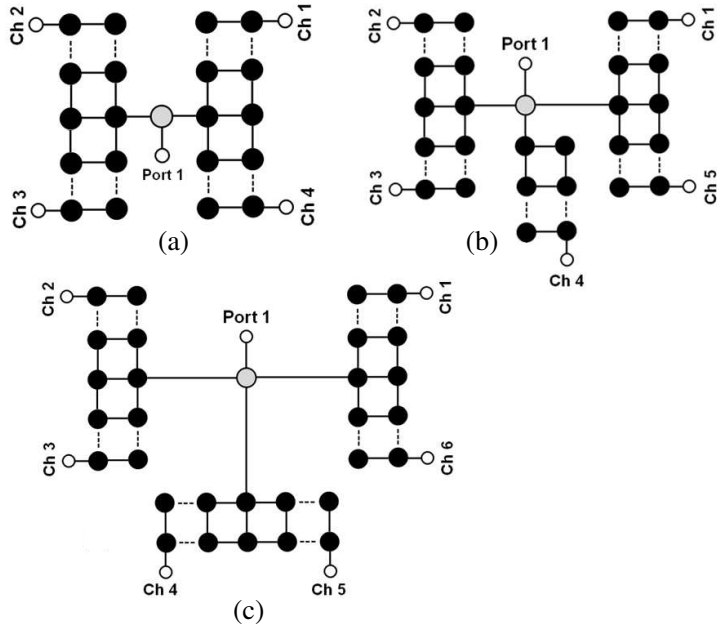

Figure 2. Novel topologies of resonant star-junction multiplexers, (a) 4-channel, (b) 5-channel, (c) 6-channel.

The proposed multiplexers are synthesized using coupling matrix optimization techniques, and numerical examples of 4-channel and 5-channel multiplexers are illustrated in this paper.

2. MULTIPLEXER SYNTHESIS

The synthesis of the proposed multiplexers is based on optimization of the coupling matrix for multiple coupled resonators with multiple outputs. The reflection and transmission scattering parameters of a multiport coupled-resonator circuit are related to a general matrix $[A]$ by [5]:

$$S_{11} = 1 - \frac{2}{q_{e1}} [A]^{-1}_{11}, \qquad S_{ij} = \frac{2}{\sqrt{q_{ea} q_{eb}}} [A]^{-1}_{ba} \tag{1}$$

where it is assumed that port 1 is at resonator 1, port i at resonator b, and port j at resonator a. The matrix $[A]$ is general matrix derived for a multiport coupled-resonator circuit in terms of the coupling coefficients

and the external quality factors and it is given by [5],

$$[A] = \begin{bmatrix} 1/q_{e1} & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \dots & 1/q_{e(n-1)} & 0 \\ 0 & \dots & 0 & 1/q_{en} \end{bmatrix} + P \begin{bmatrix} 1 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots \\ 0 & \dots & 1 & 0 \\ 0 & \dots & 0 & 1 \end{bmatrix} - j \begin{bmatrix} m_{11} & \dots & m_{1(n-1)} & m_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ m_{(n-1)1} & \dots & m_{(n-1)(n-1)} & m_{(n-1)n} \\ m_{n1} & \dots & m_{n(n-1)} & m_{nn} \end{bmatrix} \quad (2)$$

where q_{ei} is the scaled external quality factor of resonator i; P is the complex lowpass frequency variable; m_{ij} is the normalized coupling coefficient; the coefficients m_{ii} accounts for asynchronous tuning.

An optimization technique based on minimization of a cost function is utilized to synthesize the coupling matrix $[m]$. The cost function used in the current work is similar to that given in [5].

3. MULTIPLEXER EXAMPLES

3.1. 4-channel Multiplexer

A 4-channel multiplexer with a resonant junction is illustrated here. The specifications of the normalized passbands of the multiplexer channels are: channel 1: (-2.6 to -2.2), channel 2: (-1 to -0.6), channel 3: (0.6 to 1) and channel 4: (2.2 to 2.6). All the channels have 3rd order Chebyshev filtering function and a return loss of 20 dB. The topology of the multiplexer is depicted in Fig. 3 with two different arrangements of channels, where resonator 1 is the resonant junction. An unconstrained local optimization technique has been employed to synthesize the coupling matrix of the multiplexer for both arrangements of channels in Fig. 3(a) and Fig. 3(b).

The optimized normalized coupling coefficients for the topology in Fig. 3(a) are as follows: $m_{11} = m_{22} = m_{33} = m_{88} = m_{99} = 0$, $m_{12} = 1.2875$, $m_{18} = 1.0573$, $m_{23} = 2.242$, $m_{34} = m_{36} = 0.3003$, $m_{45} = m_{67} = 0.2104$, $m_{44} = -m_{66} = 2.3673$, $m_{55} = -m_{77} = 2.39$, $m_{89} = 0.748$, $m_{9,10} = m_{9,12} = 0.2795$, $m_{10,11} = m_{12,13} = 0.2128$, $m_{10,10} = -m_{12,12} = 0.7386$, $m_{11,11} = -m_{13,13} = 0.7809$, and the normalized external quality factors are $q_{e1} = 0.4$ and $q_{e5} = q_{e7} = q_{e11} = q_{e13} = 4.255$. The optimized normalized coupling coefficients for the topology in Fig. 3(b) are as follows: $m_{11} = 0$, $m_{22} = m_{88} = 0.8442$, $m_{33} = m_{99} = 0.6887$, $m_{12} = m_{18} = 1.1515$, $m_{23} = m_{89} = 1.5049$, $m_{34} = m_{36} = m_{9,10} = m_{9,12} = 0.2899$, $m_{45} = m_{67} = m_{10,11} = m_{12,13} =$

0.2122, $m_{44} = -m_{12,12} = 2.361$, $m_{55} = -m_{13,13} = 2.3862$, $m_{10,10} = -m_{66} = 0.7624$, $m_{11,11} = -m_{77} = 0.7894$, and the normalized external quality factors are $q_{e1} = 0.4$ and $q_{e5} = q_{e7} = q_{e11} = q_{e13} = 4.255$.

The prototype response of the multiplexer in Fig. 3(a) is shown in Fig. 4(a), and the response of the multiplexer in Fig. 3(b) is shown in Fig. 4(b). The isolation performance is different when the responses of both channel arrangements are compared. It is noticed that the isolation between the adjacent channels for the multiplexer with channel arrangement in Fig. 3(b) is better than that of Fig. 3(a). This is due to existence of more resonators between the ports of adjacent channels. For example, there are nine resonators between any pair of ports of adjacent channels in Fig. 3(b), whereas there are

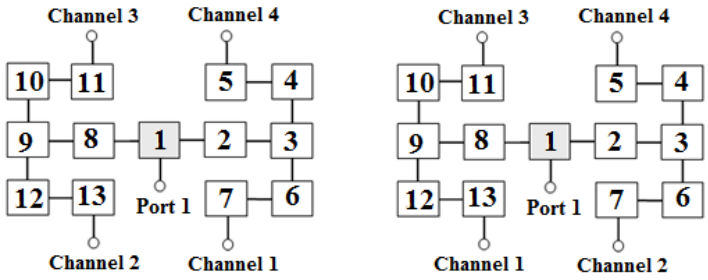

Figure 3. Topology of 4-channel star-junction multiplexer with two channel arrangements.

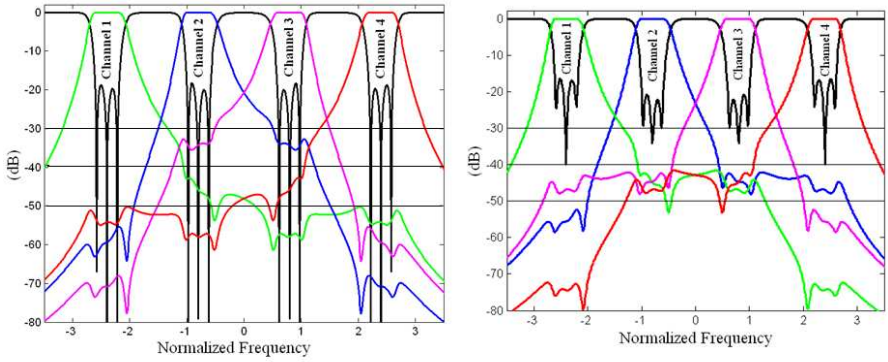

Figure 4. Response of the 4-channel multiplexer (a) for Fig. 3(a), (b) for Fig. 3(b).

only five resonators between the ports of the adjacent channels 2 and 3 in Fig. 3(a). Generally, the more resonators between the ports of channels, the better isolation is.

3.2. 5-channel Multiplexer

The second example illustrated here is a 5-channel multiplexer with a resonant junction. The specifications of the normalized passbands of the multiplexer channels are:

Channel 1:

Passband: (−1.5 to −1.1)
Order: 5th order.
Transmission zeros: −1.625, −0.971

Channel 2:

Passband: (−0.9 to −0.6)

Order: 4th order Chebyshev.

Channel 3:

Passband: (−0.4 to 0.4)

Order: 6th order.

Transmission zeros: −0.539, 0.539

Channel 4:

Passband: (0.6 to 0.9)

Order: 4th order Chebyshev

Channel 5:

Passband: (1.1 to 1.5)

Order: 5th order.

Transmission zeros: 0.971, 1.625.

All the channels have a return loss of 20 dB and the multiplexer topology is shown in Fig. 5, where resonator 1 is the resonant junction. A local optimization technique has been used to synthesize the multiplexer, and the optimized normalized coupling coefficients are as follows: $m_{12} = 1.1194$, $m_{1,12} = 0.9892$, $m_{1,18} = 0.9248$, $m_{23} = 1.3529$, $m_{34} = m_{38} = 0.2161$, $m_{45} = m_{89} = 0.1234$, $m_{56} = m_{9,10} = 0.138$, $m_{67} = m_{10,11} = 0.1729$, $m_{47} = m_{8,11} = -0.018$, $m_{44} = -m_{88} = 1.2918$, $m_{55} = -m_{99} = 1.2997$, $m_{66} = -m_{10,10} = 1.2995$, $m_{77} = -m_{11} = 1.2997$, $m_{12,13} = 0.2747$, $m_{13,14} = 0.2381$, $m_{14,15} = 0.2085$, $m_{15,16} = 0.3253$, $m_{16,17} = 0.3190$, $m_{14,17} = -0.118$, $m_{18,19} = 0.7679$, $m_{19,20} = m_{19,23} = 0.1625$, $m_{20,21} = m_{23,24} = 0.1035$, $m_{21,22} = m_{24,25} = 0.136$, $m_{20,20} = -m_{23,23} = 0.738$, $m_{21,21} = -m_{24,24} = 0.7491$,

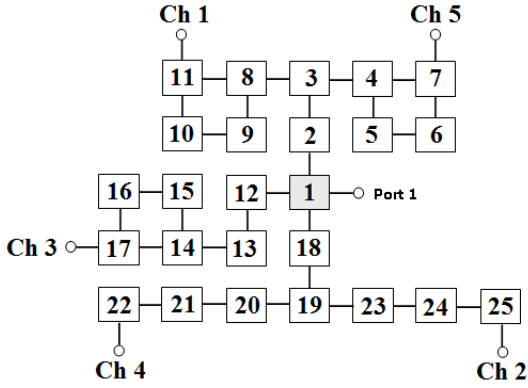

Figure 5. Topology of 5-channel star-junction multiplexer.

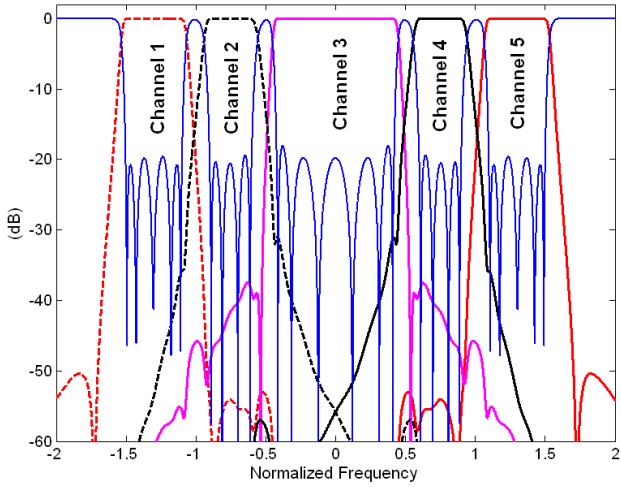

Figure 6. Response of the 5-channel multiplexer.

$m_{22,22} = -m_{25,25} = 0.7504$, and the normalized external quality factors are $q_{e1} = 0.286$, $q_{e7} = q_{e11} = 4.857$, $q_{e17} = 2.481$, and $q_{e22} = q_{e25} = 6.21$. The prototype response of the multiplexer is given in Fig. 6.

4. CONCLUSION

Novel topologies for star-junction multiplexers with a resonating junction have been proposed. The complete network of the proposed structures consists of coupled-resonator sections of one/two channels

and a resonating junction connecting the sections together. The number of connections to the resonating junction is $\lceil N/2 \rceil + 1$, where N is the total number of channels. Optimization techniques are used to synthesize the coupling matrix of the coupled resonator multiplexer. Numerical examples of 4-channel and 5-channel star-junction multiplexers have been illustrated.

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