All-resonator-based waveguide diplexer with cross-couplings

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All-Resonator Based Waveguide Diplexer With Cross-Couplings

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This paper reports on an investigation into new diplexer topologies, based on all-resonator structures with cross-couplings between common resonators (shared by both channels) and branch resonators. This all-resonator structure eliminates the need for separate frequency distribution networks and uses resonators to achieve this functionality. For diplexers based on such all-resonator structures, cross-couplings can be added between the common resonators and branch resonators to achieve some desired specification (e.g. improved isolation). Two diplexer topologies with such cross-couplings are presented. The first topology is implemented at X-band using waveguide technology. Excellent measurement results verified the proposed topology as well as the design procedure.

Introduction: Diplexers are critical components to a communication system, where there is a need to separate or combine two RF channels. Many design and implementation techniques for diplexer circuits have been developed. Among these techniques, the most common approaches are to design each channel filter separately and then combine them with a frequency distribution network such as a manifold [1], a resonant junction [2], a circulator [3] or a hybrid coupler [4]. Recently, diplexers based on all-coupled resonators have been proposed [5-7]. In this approach, a resonator can not only be used to provide a reflection zero, but also as a signal distribution element. This effectively reduces the size of the diplexers by removal of the conventional distribution network. In addition, as the diplexer is formed of only resonators, a single coupling matrix can be used to fully characterise its response, and therefore the coupling between different channel filters can be accurately determined during the synthesis. In [7], such a diplexer, based on all-resonators, with a cross-coupling between common resonators (i.e. resonators in the main stem) has been reported. Its topology is shown in Fig.1*a*.

Here, we extend the study into utilising cross-couplings between common resonators and branch resonators. This increases the possible frequency responses significantly, and facilitates the designs with some challenging and difficult specifications, such as a high isolation and a sharp rejection. Two diplexer topologies, with such cross-couplings, as shown in Fig. 1, are investigated and presented here. The first diplexer (Fig. 1*b*) is demonstrated at X-band using waveguide technology. Excellent agreement between simulation results and experiment results are achieved. To the best of authors' knowledge, this is the first-ever reported diplexer with cross-coupling between common resonators and branch resonators.

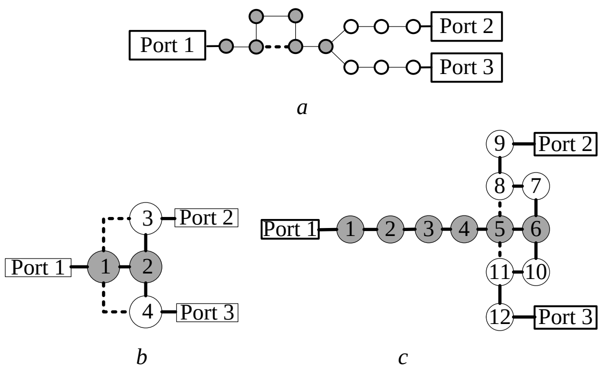

Fig. 1. *Novel diplexer topologies with cross-couplings (denoted using dotted lines) between common resonators (grey colour filled) and branch resonators (white background).*

a 12th order diplexer with a cross-coupling between common resonators [7]

b Topology 1: 4th order diplexer. Two cross-couplings (i.e. $m_{1,3}$ and $m_{1,4}$) are introduced to improve the port isolation performance.

c Topology 2: 12th order diplexer. $m_{5,8}$ and $m_{5,11}$ are employed to generate transmission zeros which are capable of increasing the out-of-band attenuation.

Coupling matrix design: The coupling matrices for both topologies are obtained using a gradient-based optimization technique [7]. Fig. 2 shows *S*-parameter responses of Topology 1 with the cross-coupling ($m_{1,3}$= 0.375) and for comparison purposes without the cross-coupling ($m_{1,3}$= 0). For both cases, the return loss is designed to be -20 dB and the two bands are located at a normalised frequency of [-1, -0.4] and [0.4, 1]. Their corresponding coupling coefficients and external quality factors are:

With cross-coupling: $m_{1,3}$=-$m_{1,4}$=0.375, 2q_{e1}=q_{e3}=q_{e4}=2.280, $m_{1,2}$= 0.815, $m_{2,3}$=$m_{2,4}$=0.295, $m_{3,3}$=-$m_{4,4}$=0.725. No cross-coupling: $m_{1,3}$=-$m_{1,4}$ =0, 2q_{e1}=q_{e3}=q_{e4}= 2.250, $m_{1,2}$=0.525, $m_{2,3}$=$m_{2,4}$=0.525, $m_{3,3}$=-$m_{4,4}$=0.586.

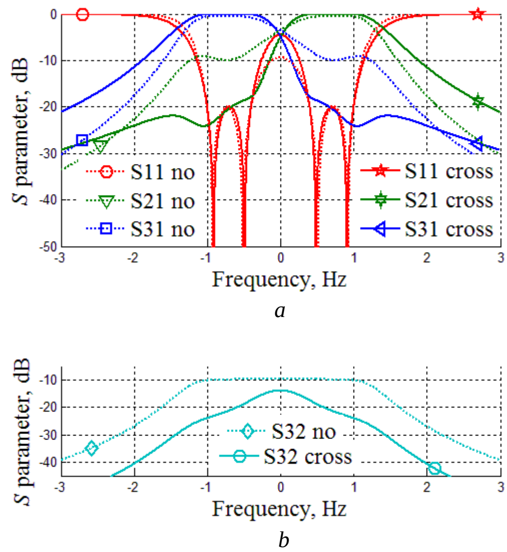

Fig. 2. *S parameter responses with and without cross-coupling $m_{1,3}$, $m_{1,4}$= -$m_{1,3}$.*

a S11, S21 and S31 responses.

b Isolation responses.

As can be observed in Fig.2*b*, by introducing cross-coupling, the isolation is improved (around -10 dB better in the middle of the passband) and the rejection is much better at the near-band frequencies. Whereas, such cross-coupling leads to a penalty of decreased far-out stopband attenuation.

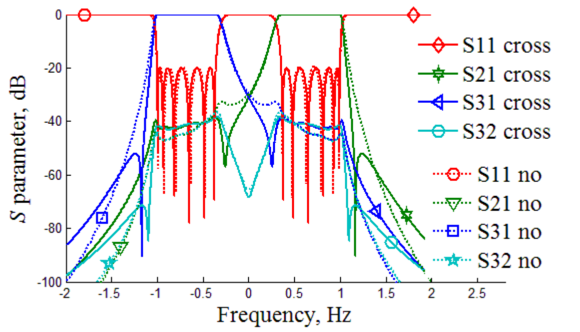

Fig. 3. *Theoretical S parameter responses of 12th order diplexer (Topology 2) with cross-coupling (in solid lines) and without cross-couplings (in doted lines).*

Using the same synthesis technique, the coupling matrix of Topology 2 has been obtained and its corresponding normalized responses are shown in Fig.3. The return loss for both bands is designed to be -20 dB and two bands are located at frequencies of [-1, -0.358] and [0.358, 1]. The coupling coefficients are: 2×q_{e1}=q_{e9}=q_{e12}=3.096, $m_{1,2}$=0.792, $m_{2,3}$= 0.477, $m_{3,4}$=0.635, $m_{4,5}$=0.404, $m_{5,6}$=0.635, $m_{6,7}$= $m_{6,10}$=0.282, $m_{5,8}$= $m_{5,11}$=-0.08, $m_{7,8}$= $m_{10,11}$=0.184, $m_{8,9}$= $m_{11,12}$=0.271, $m_{7,7}$= -$m_{10,10}$=0.733, $m_{8,8}$= -$m_{11,11}$= 0.668, $m_{9,9}$= -$m_{12,12}$= 0.671.

As shown in Fig. 3, each channel has two transmission zeros, the presence of which are due to cross-couplings $m_{5,8}$ and $m_{5,11}$. These transmission zeros result in a sharp roll-off at the near-out-band region while at the same time maintaining sound isolation between two ports.

4th order diplexer (Topology 1) implementation: Topology 1 has been implemented using X-band waveguide technology. It is designed by following an approach in [8]. For this approach, the diplexer is constructed by successively adding one resonator at a time in an electromagnetic (EM) simulator. This eliminates the need of a global optimization on all the mechanical dimensions and thereby reduces the design time. Fig. 4 shows the diplexer structure as well as the final dimensions.

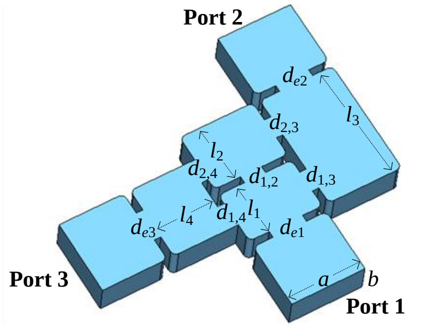

Fig. 4. *Configuration of X-band diplexer structure and its dimensions. a=22.86, b=10.16, l_1=16.15, l_2=18.27, l_3=36.11, l_4=18.09, de1=10.41, de2=10.39, de3=9.47, d_{12}=6.56, d_{13}=6.64, d_{14}=7.41, d_{23}=6.35, d_{24}=7.03, all corners have the same radius of 1.6. Unit: mm*

For this diplexer, the coupling between the 1st and 4th resonators is negative and all the other inter-resonator couplings are positive. A TE_{102} cavity is specially chosen as the 3rd resonator to provide for this coupling [9]. This is different to the other three resonators which are operating at TE_{101} mode. In order to facilitate the CNC milling, all inductive irises are employed for the couplings. To eliminate the need of any tuning, the round inner corners with a radius of 1.6 mm, which are introduced by the milling tools, are considered during the design.

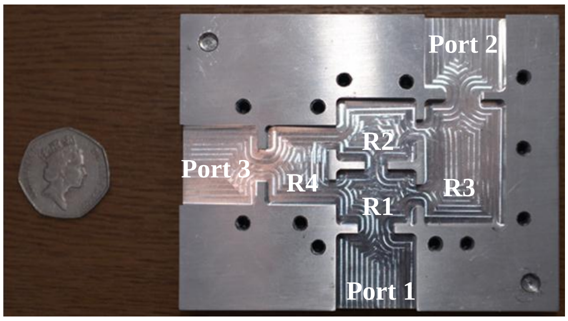

Fig. 5. *Photograph of fabricated X-band diplexer (top cover removed). Four resonators are denoted as R1-R4. Resonator 3 is operating at TE_{102} mode and the other three resonators are TE_{101} cavities. All resonators are coupled through inductive irises.*

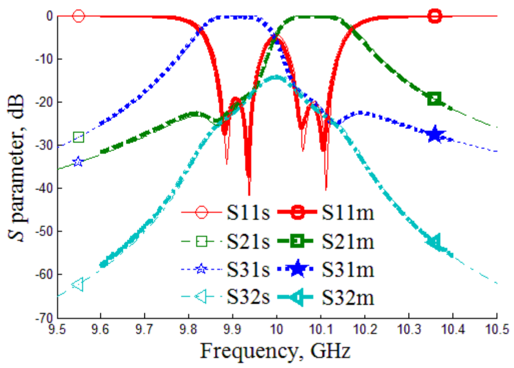

Fig. 6. *Measurement (no tuning) and simulation results of diplexer.*

Experimental verification: The diplexer is machined from aluminium and is shown in Fig.5. The measurement results agree very well with the simulated responses, as shown in Fig. 6. The insertion loss in the middle of the passband is measured to be around -0.4 dB. The expected value is -0.25 dB obtained from CST simulations using the conductivity of aluminium. The additional insertion loss is mainly originated from the construction of the diplexer which is split along the H-plane into two pieces. The loss occurs when current flows across the imperfect contact between the two pieces [10]. The measured return loss is below -20 dB in both passbands. Tuning screws have not been utilised for this diplexer.

Conclusion: In this paper, we have presented novel diplexer topologies with cross-couplings between common resonators and branch resonators. Such cross-couplings facilitate the selection of topologies and improve the isolation performance. Two cross-coupled diplexers have been synthesised and are given here as examples. The first diplexer has been demonstrated at X-band using waveguide cavities operating at TE_{101} and TE_{102} modes. The measurement results agree well with simulations.

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