JOURNAL OF ENGINEERING RESEARCH AND TECHNOLOGY, VOLUME 2, ISSUE 2, JUNE 2015

Coupled Resonator Diplexer for LTE-Advanced System

H. Abukaresh [1], T. Skaik [2]

UNRWA, Gaza, bh2003azem@hotmail.com
Islamic University of Gaza , Gaza, tskaik@iugaza.edu.ps

Abstract— This paper presents the design of a microstrip hairpin diplexer. The design is based on coupled-resonator structure using U-Shaped resonators. It is designed to meet The Long Term Evolution-Advanced (LTE-A) system Band 7, operating at uplink (UL): 2.50–2.57 GHz and downlink (DL): 2.62–2.69 GHz for base transceiver station antenna. The structure has three ports with 10-coupled resonators with direct coupling to produce diplexer with chebyshev filtering response. The diplexer does not involve any external junctions for distribution of energy, so it can be miniaturized in comparison to conventional diplexers.

Index Terms— Component; Coupled-Resonator, Coupling Matrix, Diplexer, Optimization.

I INTRODUCTION

The diplexer is a device that isolates the receiver from the transmitter while permitting them to share a common antenna. It is often the microwave key component that allows two way radios to operate in a full duplex manner. An ideal diplexer provides perfect isolation with no insertion loss, to and from the antenna. Conventional diplexers consist of two channel filters connected to an energy distribution network. The channel filters pass frequencies within a specified range, and reject frequencies outside the specified boundaries, and the distribution network divides the signal going into the filters, or combines the signals coming from the filters [1].

The most commonly used distribution configurations are E- or H-plane n-furcated power dividers [2,3], circulators [4], manifold structures [5-8], Y-junction [9] and T-Junction [10].

In [11] a coupled resonator diplexer has been implemented at X-band with waveguide cavity resonators. The difference in this paper from the work in [11] is that the diplexer presented here is designed to work on a different frequency band that is used for the full duplex LTE-A system and it is implemented using microstrip technology.

The synthesis procedure of the proposed diplexer in this paper is based on elimination of the additional common junction. This approach to diplexer design can achieve reductions in the size and volume of the circuit.

The coupled-resonator based diplexer, without additional common junction is presented in [11-12]. This method for synthesizing coupled resonator diplexers is based on optimization of coupling matrix of multiple coupled resonators representing a three-port network, and it is performed in the normalized frequency domain.

II DIPLEXER SYNTHESIS

There are many possible topologies for coupled resonators that can achieve a Chebyshev response. One example is illustrated in Figure 1; it is a schematic of a diplexer with resonators. Each circle represents a resonator, and the lines between resonators are internal couplings. The arrowed lines between resonators and ports represent external couplings.

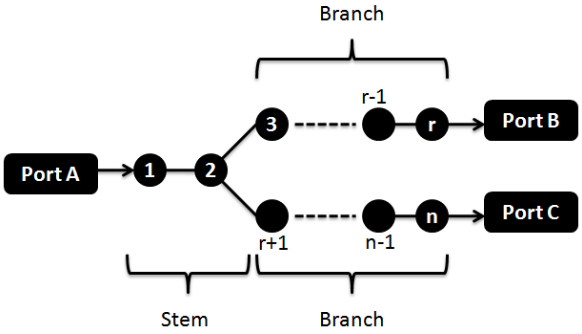

Figure 1 n -resonator based diplexer.

The coupling matrix of a multiport circuit with multiple coupled resonators has been used in the synthesis. A unified solution for the coupling matrix $[A]$ has been utilized and it is generalized for both types of magnetic and electric couplings [13,14]. Transmission (S_{21}, S_{31}) and reflection (S_{11}) scattering parameters of a three-port coupled resonator circuit that have been found in terms of the general coupling matrix may be generalized as [13]:

$$
\begin{aligned}
S_{11} &= 1 - \frac{2}{q_{e1}}\,\overline{[A]}_{11}^{-1} \\
S_{21} &= \frac{2}{\sqrt{q_{e1}q_{ex}}}\,\overline{[A]}_{x1}^{-1} \\
S_{31} &= \frac{2}{\sqrt{q_{e1}q_{ey}}}\,\overline{[A]}_{y1}^{-1}
\end{aligned}
\qquad (1)
$$

It is assumed that port 1 is connected to resonator 1, ports 2 and 3 are connected to resonators x and y respectively.

A general normalized coupling matrix $[A]$ in terms of coupling coefficients and external quality factors is as follows [13]:

$$[A] = [q] + p[U] - j[m] \tag{2}$$

$$[A] = \begin{bmatrix} \frac{1}{q_{e1}} & \cdots & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & \cdots & \frac{1}{q_{ex}} & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & \cdots & \frac{1}{q_{ey}} \end{bmatrix} + p \begin{bmatrix} 1 & \cdots & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & 1 & 0 \\ 0 & \cdots & 0 & 1 \end{bmatrix} - j \begin{bmatrix} m_{11} & \cdots & m_{1(n-1)} & m_{1n} \\ \vdots & \ddots & \vdots & \vdots \\ m_{(n-1)1} & \cdots & m_{(n-1)(n-1)} & m_{(n-1)n} \\ m_{n1} & \cdots & m_{n(n-1)} & m_{nn} \end{bmatrix} \tag{3}$$

where q_{ei} is the scaled external quality factor $(q_{ei} = Q_{ei}.FBW)$ of resonator *i*, *FBW* is the fractional bandwidth given by $FBW = (\omega_2 - \omega_1) / \omega_0$, $[U]$ is the $[n \times n]$ identity matrix, *n* is the number of the resonators, *p* is the complex lowpass frequency variable, $[m]$ is the coupling matrix and entry m_{ij} is the normalized coupling coefficient between resonators i and j, $(m_{ij} = M_{ij} / FBW)$, and the diagonal entries m_{ij} account for asynchronous tuning, so that resonators can have different self-resonant frequencies [13].

The optimization of the coupling matrix $[m]$ is based on minimization of a cost function that is evaluated at the frequency locations of the reflection and transmission zeros. The cost function used here is given as [13,15],

$$\begin{aligned} \Omega = & \sum_{i=1}^{T_1} \left| \frac{2.cof_{1a}([A(s_{ti})])}{\sqrt{q_{e1} q_{ea}}} \right|^2 \\ & + \sum_{k=1}^{T_2} \left| \frac{2.cof_{1b}([A(s_{tk})])}{\sqrt{q_{e1} q_{eb}}} \right|^2 \\ & + \sum_{j=1}^{R} \left| \Delta_A(s_{rj}) - \frac{2.cof_{11}([A(s_{rj})])}{q_{e1}}) \right|^2 \\ & + \sum_{v=1}^{R-2} \left| \left| 1 - \frac{2.cof_{11}([A(s_{pv})])}{q_{e1}.\Delta_A(s_{pv})} \right| - 10^{\frac{L_R}{20}} \right|^2 \end{aligned} \tag{4}$$

where q_{e1}, q_{ea}, and q_{eb} are the external quality factors at ports 1, 2 and 3 respectively, $\Delta_A(s=x)$ is the determinant of the matrix $[A]$ evaluated at the frequency variable x, and $cof_{mn}([A(s=y)])$ is the cofactor of matrix $[A]$ evaluated by removing the m^{th} row and the n^{th} column of $[A]$ and finding the determinant of the resulting matrix at the frequency variable $s=y$. S_{ti}, S_{tk} are the frequency locations of transmission zeros of S_{21}, S_{31} respectively, T_1, T_2 are the numbers of the transmission zeros of S_{21}, S_{31} respectively, R is the total number of reflection zeros, L_R is the specified return loss in dB $(L_R < 0)$, s_{rj} and s_{pv} are the frequency locations of the reflection zeros and the peaks frequency values of $|S_{11}|$ in the passband. The last term in the cost function is used to set the peaks of $|S_{11}|$ to the required return loss level. It is assumed here that both channels of the diplexer have the same return loss level.

III DIPLEXER DESIGN

An LTE-Advanced band 7 diplexer operating at uplink (UL): 2.50–2.57 GHz and downlink (DL): 2.62–2.69 GHz with symmetrical channels has been designed using microstrip hairpin resonators. The diplexer has a Chebyshev response with passband centre frequency of 2.535 GHz for channel 1 and 2.655 GHz for channel 2, minimum isolation of 60 dB, and a desired return loss at the passband of each channel is 20 dB. The diplexer topology is shown in Figure 2.

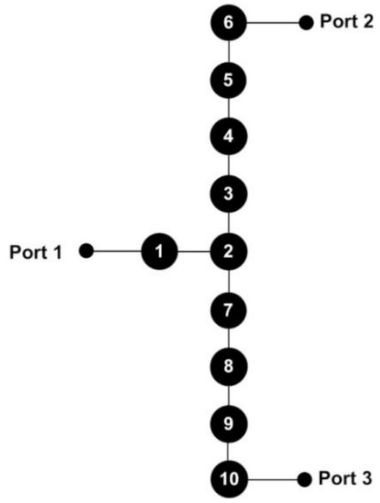

Figure 2 Topology of Diplexer with 10 resonators.

The total number of resonators is n=10, the fractional bandwidth is FBW = 0.073267. A formula in [13] has been used to calculate the normalized external quality factors of diplexers with symmetrical channels and their values are found as $q_{e6} = q_{e10} = 2.636$ and $q_{e1} = 1.318$.

The normalized coupling coefficients between any adjacent resonators are initially set to 0.5 in the initial coupling matrix, and the same for self-coupling coefficients $m_{3,3}$, $m_{4,4}$, $m_{5,5}$, $m_{6,6}$, $-m_{7,7}$, $-m_{8,8}$, $-m_{9,9}$ and $-m_{10,10}$. The coefficients m_{11}, m_{22} and the couplings that do not exist between resonators are set to zero.

A gradient based optimization technique has been utilized to synthesize the coupling coefficients, and the cost function in equation (4) has been used. The optimization has been carried out using MATLAB.

The optimized normalized coupling matrix is shown in Table 1, and the response of the diplexer is shown in Figure 3.

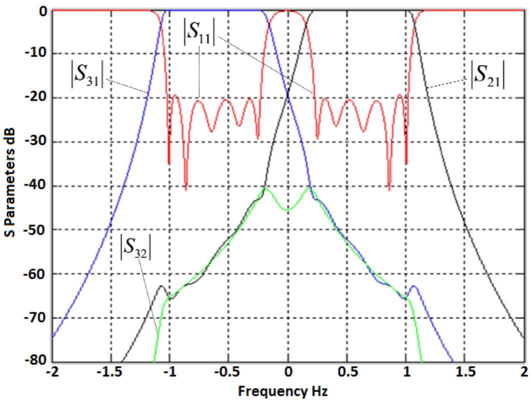

Figure 3 Diplexer prototype response with 10 resonators from optimization process.

LTE-Advanced 10-resonator diplexer has been designed using hairpin microstrip coupled resonators. Electromagnetic Computer Simulation TechElectromagnetic Computer Simulation technology (EM CST) simulator has been used to extract the desired design dimensions according to a prescribed general coupling matrix and external quality factors.

The EM simulated performance of the diplexer is shown in Figure 4. It can be shown from the simulation results that the return loss is better than 12 dB in the transmit and receive band, the insertion loss is only about 0.3 dB in transmit and receive band and isolation greater than 60 dB in the uplink channel and greater than 35 dB in the downlink channel.

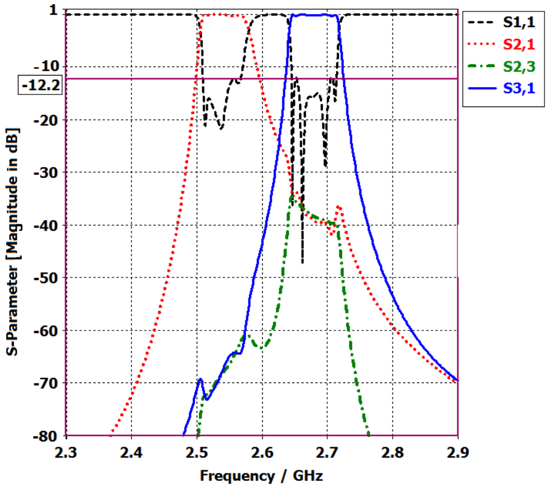

Figure 4 The EM simulated performance of the diplexer.

The top view of diplexer structure is shown in Figure 5.

IV CONCLUSIONS

An LTE-Advanced band 7 coupled resonator diplexer has been presented, and its synthesis is based on coupling matrix optimization. The diplexer structure consists of resonators coupled together, and it does not involve any external junctions for distribution of energy. This enables miniaturization in comparison to the conventional diplexers. The diplexer has been designed with microstrip hairpin resonators, and the simulation results showed acceptable return loss and isolation.

TABLE 1

Normalized Coupling matrix of diplexer with 10 resonators from optimization process.

	1	2	3	4	5	6	7	8	9	10
1	0	0.794	0	0	0	0	0	0	0	0
2	0.794	0	0.379	0	0	0	0.379	0	0	0
3	0	0.379	0.543	0.258	0	0	0	0	0	0
4	0	0	0.258	0.606	0.242	0	0	0	0	0
5	0	0	0	0.242	0.626	0.331	0	0	0	0
6	0	0	0	0	0.331	0.613	0	0	0	0
7	0	0.379	0	0	0	0	-0.543	0.258	0	0
8	0	0	0	0	0	0	0.258	-0.606	0.242	0
9	0	0	0	0	0	0	0	0.242	-0.626	0.331
10	0	0	0	0	0	0	0	0	0.331	-0.613

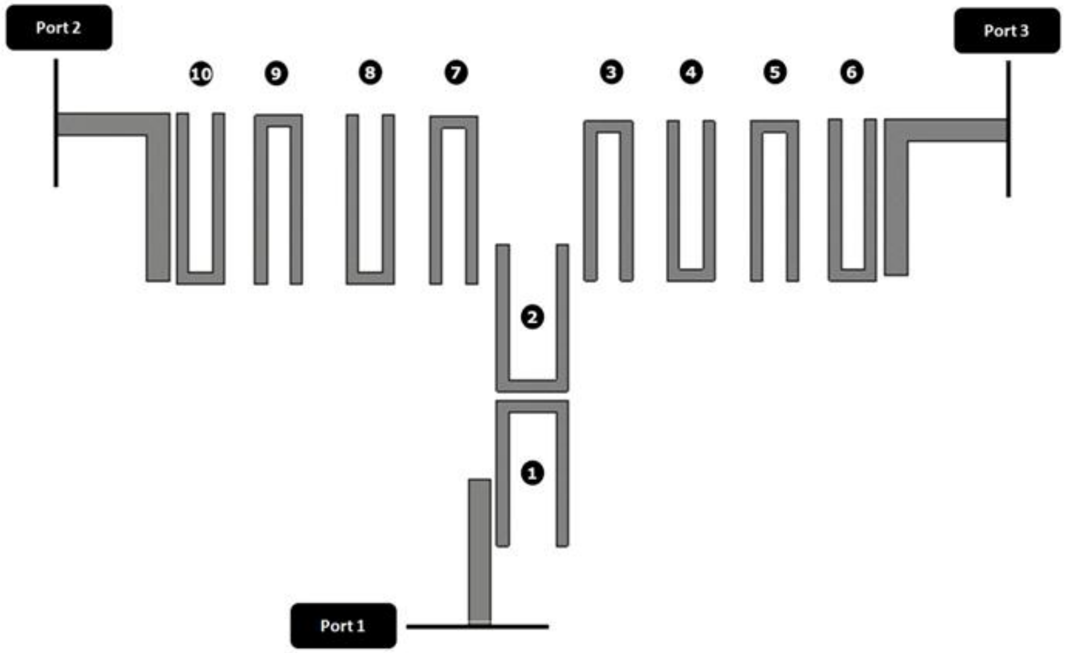

Figure 5 The layout of the LTE-A 10-resonator diplexer design

REFERENCES

[1] I. Carpintero, M. Padilla-Cruz, A. Garcia-Lamperez, and M. Salazar- Palma,"Generalized multiplexing network," U.S. Patent 0114082 A1, Jun. 1, 2006.

[2] J. Ruiz-Cruz, J. Montejo-Garai, J. M. Rebollar, and S. Sobrino, "Compact full ku-band triplexer with improved E-plane power divider," Progress In Electromagnetics Research, Vol. 86, 2008, pp. 39-51.

[3] J. Dittloff, J. Bornemann, and F. Arndt, "Computer aided design of optimum E- or Hplane N-furcated waveguide power dividers," in Proc. European Microwave Conference, Sept. 1987, pp. 181-186.

[4] R. Mansour, et al., "Design considerations of superconductive input multiplexers for satellite applications," IEEE Transactions on Microwave Theory and Techniques, Vol. 44, no. 7, pt. 2, 1996, pp. 1213-1229.

[5] J. Rhodes and R. Levy, "Design of general manifold multiplexers," IEEE Transactions on Microwave Theory and Techniques, Vol. 27, no. 2, 1979, pp. 111-123.

[6] D. Rosowsky and D. Wolk, "A 450-W Output Multiplexer for Direct Broadcasting Satellites," IEEE Transactions on Microwave Theory and Techniques, Vol. 30, no. 9, Sept. 1982, pp. 1317-1323.

[7] M. Uhm, J. Lee, J. Park, and J. Kim,"An Efficient Optimization Design of a Manifold Multiplexer Using an Accurate Equivalent Circuit Model of Coupling Irises of Channel Filters," in proc. IEEE MTT-S Int. Microwave Symp., Long Beach, CA, 2005, pp. 1263-1266.

[8] R. Cameron and M. Yu, "Design of manifold coupled multiplexers," IEEE Microwave Mag., Vol. 8, no. 5, Oct. 2007, pp. 46–59.

[9] T. King, A. Ying Ying, S. Tiong, "A Microstrip Diplexer Using Folded Hairpins," Proceeding of the IEEE International RF and Microwave Conference (RFM), Seremban, Malaysia, 12th-14th Dec. 2011, pp. 226-229.

[10] H. Zhang and G. James, "A Broadband T-junction Di-plexer with Integrated Iris Filters," Microwave and Opti-cal Technology letters, Vol. 17, No. 1, 1998, pp. 69-72.

[11] T. Skaik, Michael Lancaster, "Coupled Resonator Diplexer without External Junctions" Journal of Electromagnetic Analysis

and Applications, Vol. 3, 2011, 238-241.

[12] T. Skaik, "A Synthesis of Coupled Resonator Circuits with Multiple Outputs using Coupling Matrix Optimisation", PhD Thesis, March 2011, School of Electronic, Electrical and Computer Engineering, the University of Birmingham.

[13] T. Skaik, M. Lancaster, and F. Huang, "Synthesis of Multiple Output Coupled Resonator Microwave Circuits Using Coupling Matrix Optimization," IET Journal of Microwaves, Antenna & Propagation, Vol.5, no.9, June 2011, pp. 1081-1088.

[14] J. Hong, Microstrip filters for RF/Microwave applications. New York, NY: John Wiley, 2011.

[15] A. Jayyousi and M. Lancaster, "A gradient-based optimization technique employing determinants for the synthesis of microwave coupled filters," IEEE MTT-S International Microwave Symposium, USA, 2004, pp. 1369-1372.

H. Abukaresh received the B.Sc. degree in 2007 from the Islamic University of Gaza and M.Sc. degree in Communications Engineering in 2013 from the Islamic University of Gaza. He is currently IT & Information assistant at United Nations Relief & Works Agency for Palestine Refugees in the Near East, Gaza Field office.

T. Skaik received the B.Sc. degree in 2004 from the Islamic University of Gaza, where he worked as a teaching assistant until 2006. He was awarded Hani Qaddumi scholarship and received M.Sc. degree in Communications Engineering with distinction in 2007 from the University of Birmingham, UK. He was awarded the ORSAS scholarship for doctoral study at the University of Birmingham, UK and received PhD degree in Microwave Engineering in 2011. Throughout his PhD study, he worked as a teaching assistant, and also as a research associate on micromachined microwave circuits. He is currently an assistant professor at the Islamic University of Gaza.