

A New Microstrip Diplexer Using Coupled Stepped Impedance Resonators

A.Chinig, J. Zbitou, A. Errkik, L. Elabdellaoui, A. Tajmouati, A. Tribak, M. Latrach

Abstract—This paper presents a new structure of microstrip band pass filter (BPF) based on coupled stepped impedance resonators. Each filter consists of two coupled stepped impedance resonators connected to microstrip feed lines. The coupled junction is utilized to connect the two BPFs to the antenna. This two band pass filters are designed and simulated to operate for the digital communication system (DCS) and Industrial Scientific and Medical (ISM) bands at 1.8 GHz and 2.45 GHz respectively. The proposed circuit presents good performances with an insertion loss lower than 2.3 dB and isolation between the two channels greater than 21 dB. The prototype of the optimized diplexer have been investigated numerically by using ADS Agilent and verified with CST microwave software.

Keywords—Band Pass Filter, coupled junction, coupled stepped impedance resonators, diplexer, insertion loss, isolation.

I. INTRODUCTION

BAND-PASS filters and diplexers with compact size and light weight are very suitable to implement the wireless communications systems, Radar systems, cellular phones or satellite communications systems. Planar BPFs and diplexers fabricated using printed circuit technologies are particularly popular structures because they are suitable to operate in many applications due to their compact size, low cost and high performance.

It would seem that diplexer which can route the signal from the transmitter to the antenna and from the antenna to the receiver [1] represents a key component in many modern communication systems which require simultaneous reception and transmission. Diplexers can be designed for different frequencies to operate in multi-service and multi-band mobile communication systems. The frequencies 1.8 GHz and 2.45 GHz are used with the digital communication system (DCS) band and the Industrial, Scientific and Medical (ISM) band. So, diplexers designed for the DCS/ISM bands are in demand to meet the IEEE standards.

Recently, the fast growth of the wireless communication technologies simulates the development of various methods and technologies to design microwave diplexers. Different techniques to design a microwave diplexer have been reported in the literature, such as diplexers based on coupled folded-line resonators [2], open-circuited stubs [3], square ring resonators [4], Parallel coupled lines [5] or common

resonators sections [6]. Diplexer based on stepped impedance resonators remains the most useful because this kind of resonators offers the possibility to reduce the circuit size and to control the spurious response and the insertion losses.

Based on the studies done in [6]-[16], this paper presents a new structure of microstrip band-pass filters based on coupled stepped impedance resonators (SIRs) used to design a new structure of microstrip diplexer. This paper provides a simple method to achieve a compact microstrip diplexer with good performances. By choosing an appropriate impedance ration, length ratio and an optimal coupling spacing between the two coupled SIRs used to design each filter and the feed lines a good frequency response can be achieved. The simulations in this work were performed using ADS Agilent and CST microwave software.

II. DESIGN OF COMPACT DIPLEXER

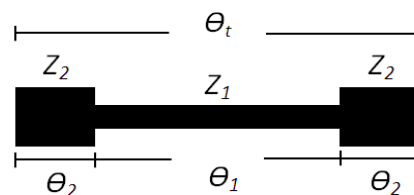


Fig. 1 Structure of the stepped impedance resonator (SIR)

Fig. 1 illustrates the structure of stepped impedance resonator with Z_1 and Z_2 being the characteristic impedances of the transmission line sections of electrical lengths θ_1 and θ_2 , respectively.

The impedance ratio K is defined as:

$$K = \frac{Z_2}{Z_1} \quad (1)$$

and the input admittance Y_{in} is given as [7]:

$$Y_{in} = jY_2 \frac{2(K \tan \theta_1 + \tan \theta_2)(K - \tan \theta_1 \tan \theta_2)}{K(1 - \tan^2 \theta_1)(1 - \tan^2 \theta_2) - 2(1 + K^2) \tan \theta_1 \tan \theta_2} \quad (2)$$

The condition required for the resonance to occur is when $Y_{in} = 0$.

The resonance conditions are given by one of the following equations:

$$\begin{aligned} \tan \theta_1 &= K \cot \theta_2 \\ -\cot \theta_1 &= K \cot \theta_2 \end{aligned} \quad (3)$$

A. Chinig, A. Errkik A. Tajmouati and L. Abdellaoui are with LITEN Laboratory, FST of Settat Hassan 1st University–Morocco. (e-mail: abdo.chinig@gmail.com, ahmed.errkik@uhp.ac.ma).

J. Zbitou is with LITEN Laboratory, FST/FPK Hassan 1st University-Settat Morocco. (e-mail: jazbitou@gmail.com).

A. Tribak is with Microwave group, INPT, Rabat Morocco.

M. Latrach is with Microwave group, ESEO, Angers France.

where the two equations correspond to the odd and even mode resonances respectively.

The length ratio of the SIR is defined as:

$$\alpha = \frac{\theta_2}{\theta_1 + \theta_2} = \frac{2\theta_1}{\theta_1} \tag{4}$$

Substituting (4) into (2) and (3), any desired frequency ratio of harmonic (f_{si}) to fundamental (f_0) resonances depends on the choice of a suitable combination of the impedance and the length ratios of the SIR.

$$\frac{f_{s1}}{f_0} = \frac{\pi}{2 \tan^{-1} \sqrt{K}} \tag{5}$$

$$\frac{f_{s2}}{f_0} = 2 \frac{f_{s1}}{f_0} - 1 \tag{6}$$

$$\frac{f_{s3}}{f_0} = 2 \frac{f_{s1}}{f_0} \tag{7}$$

Let the upper filter with the center frequency 1.8 GHz and the lower filter with the center frequency 2.45 GHz be the Tx and the Rx filter respectively. The traditional approach to design a microwave diplexer is to design the Rx and the Tx filters individually then to combine the two Band pass filters to form the diplexer. Fig. 2 shows the configuration of the proposed filter. Each filter consists of two coupled stepped impedance Resonators (SIRs) and two feed lines coupled to the input/output ports. Using this type of resonators a wide stop band can be obtained furthermore the size of each filter can be easily reduced and the configuration of the whole circuit can be miniaturized by adopting the coupled junction and a good arrangement of the feed lines.

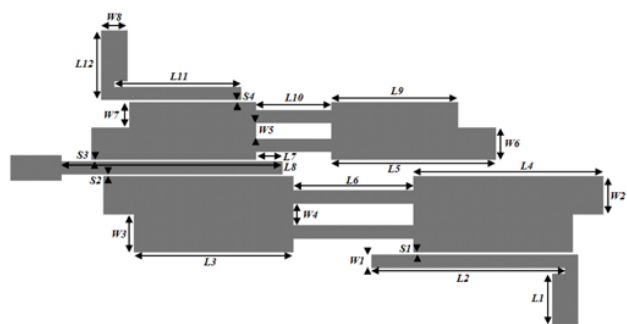


Fig. 2 Layout of the proposed microstrip diplexer in ADS Agilent

In order to obtain a high isolation between the Rx and the Tx filter, the main challenge is to design two band pass filters with highest rejection level with a minimum number of resonators and small size. Thus, good stop band suppression for the Rx filter is required at 1.8 GHz. In parallel, high stop band suppression for the Tx filter is required at 2.45 GHz.

The first step in our design procedure begins by the design of the Tx and Rx filters. The theoretical analysis of each filter is based on the filter synthesis technique outlined in [6]. The structure of the proposed Rx band pass filter is constructed by

coupling two stepped impedance resonators with different impedance ratio K. The same procedure is utilized to design the Tx filter, since the operating frequency can be found by changing the length of the resonators based on the calculation method and a careful optimization of the dimensions. Besides, the structure gap between the SIRs and the coupled transmission feed lines allows to adjust the operations frequency of each filter, this can reduce the dimensions of the device and can make a significant variation in the filter performances especially in the insertion loss value.

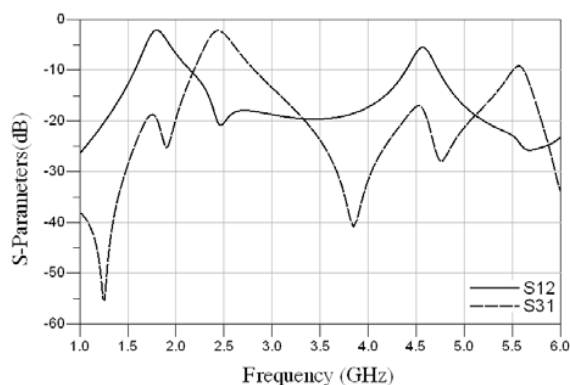


Fig. 3 Simulated results of the fundamental and the first spurious frequencies of the designed diplexer.

The resonant frequency of a SIR can be found by choosing a suitable combination of the impedance Ratio K and the length ratio (α). In this work, when sitting $Z_1=91 \Omega$, $Z_2= 66 \Omega$, $\theta_1=127^\circ$, $\theta_2=219^\circ$ and $Z_1=91 \Omega$, $Z_2= 59 \Omega$, $\theta_1=127^\circ$, $\theta_2=288^\circ$ for the SIR1 and SIR 2 respectively, the first band pass filter can be designed for the 2.45 GHz and the first spurious frequency is placed at 5.65 GHz. Similarly, when sitting $Z_1=91 \Omega$, $Z_2= 53 \Omega$, $\theta_1=202^\circ$, $\theta_2=336^\circ$ and $Z_1=91 \Omega$, $Z_2= 53 \Omega$, $\theta_1=202^\circ$, $\theta_2=282^\circ$ for the SIR1 and SIR 2 respectively, the second band pass filter can be designed for the 1.8 GHz and the first spurious frequency is placed at 4.57 GHz. Fig. 3 shows the simulated results of the fundamental and the first higher order frequencies of each band pass filter.

The following step is to choose the coupling spacing S1 and S2 between the resonators and the feed lines in the Tx filter. Several simulations were realized, to attain good insertion loss and return loss in the first and the second pass bands. Fig. 4 depicts the simulated results of the Tx filter under different coupling spacing S1 and S2 between the stepped impedance resonators and the feed lines. As we can clearly observe the return loss $|S11|$ increases while the insertion loss $|S21|$ decrease when S1 decreases from 0.6 to 0.2 mm (without changing the other dimensions of the circuit). The same performances are obtained when S2 decreases from 0.6 to 0.2 mm. Therefore S1=0.2 mm and S2=0.2 mm are chosen to be the optimal coupling spacing to get good attainments.

The structure of the proposed diplexer is shown in Fig. 2, whose design parameters were determined as follows:

$W1=1, W2=3, W3=3, W4=1.81, W5=1.3, W6=2.5, W7=2, W8=2, L1=4, L2=15.3, L3=12.6, L4=15, L5=13, L6=9.5, L7=2.1, L8=17.5, L9=10, L10=6, L11=10, L12=5.5, S1=0.2, S2=0.2, S3=0.2, S4=0.2$, all in (mm).

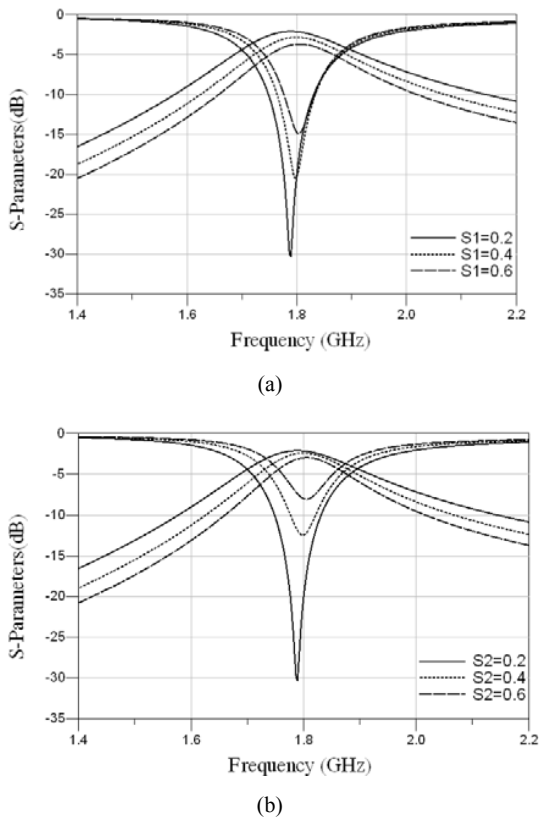


Fig. 4 Simulated frequency response of the Tx filter for different values of (a) S1 (b) S2

III. RESULTS

The design procedure of the two band pass filter has been described in the previous section. This section is dedicated to discuss the electrical performances of the designed diplexer. The main challenge after the design of the Rx and the Tx filters is to combine them together to form the microstrip diplexer which can seriously deteriorate the predicted simulations results of each filter.

Fig. 2 illustrates the configuration of the designed diplexer. The substrate used is the FR4 with a thickness of 1.58 mm, a relative electric constant of 4.4, a loss tangent of 0.025 and a conductor thickness of 35 μm . The size of the proposed diplexer is nearly (47 mm \times 24 mm). The diplexer performances were investigated by simulation. The circuit was initially, simulated using an EM simulator ADS Agilent to evaluate its frequency response and Fig. 5 shows the simulated results. As shown in the figure the insertion loss is about 2.24 dB for the Rx filter and 2.16 dB for the Tx filter. The return loss is about 29 dB for the upper and lower filter respectively while the isolation between the two channels is more than 21 dB at the center frequency of 1.8 GHz. The -3 dB pass band

width is about 6.27% and 5.44 % for the Rx and the Tx filters respectively. In addition, the BPFs have several transmission zeros located at 1.3 GHz, 1.9 GHz, 2.47 GHz and 3.8 GHz with attenuation of 55 dB, 25 dB, 21 dB and 47 dB respectively. The presence of these transmissions zeros at the pass band edges improves the isolation between the two band pass filters.

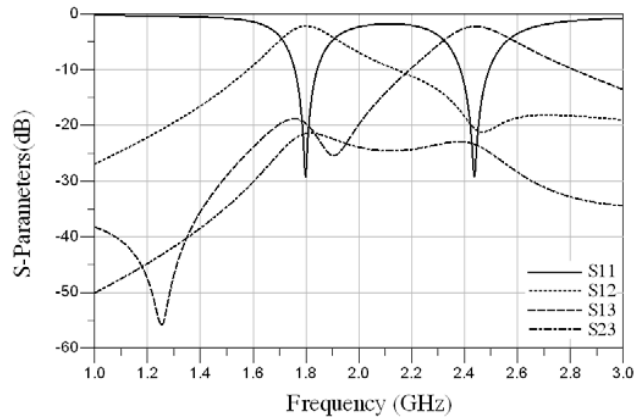


Fig. 5 Simulated frequency response of the proposed diplexer with ADS Agilent

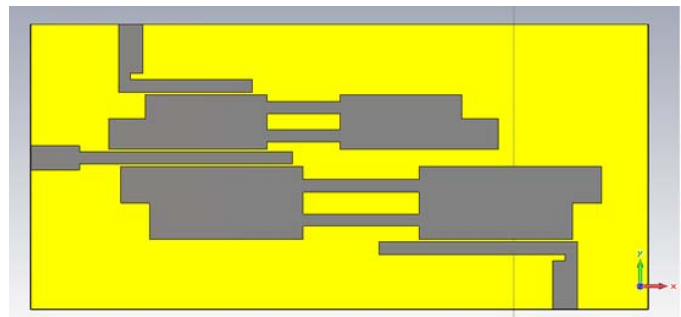


Fig. 6 Layout of the designed microstrip diplexer in CST-MW

Another step was essential in order to verify the theoretical prediction of designed diplexer, the simulation software CST Microwave Studio were used to design and to simulate the circuit. Fig. 6 depicts the layout of the proposed microstrip diplexer with CST microwave software.

The frequency response of the circuit with CST software is displayed in Fig. 7. We can observe that the band pass insertion loss remains lower than 0.27 dB and 0.23 dB for the download and the upload band respectively. The return loss are around 26 dB for transmission channel and 18 dB for the receive one. Moreover the simulated isolation between the two channels is better than 19 db. The electrical performances of the diplexer with CST software are in good agreement with its frequency response with ADS Agilent. The slight difference between the two simulated results can be explained by the use of low meshing density in the CST software. Besides, the designed diplexer shows several transmission zeros located near the pass band edges which improves the selectivity of the

BPFs. So a better isolation between the two BPFs and a wide stop band is also obtained.

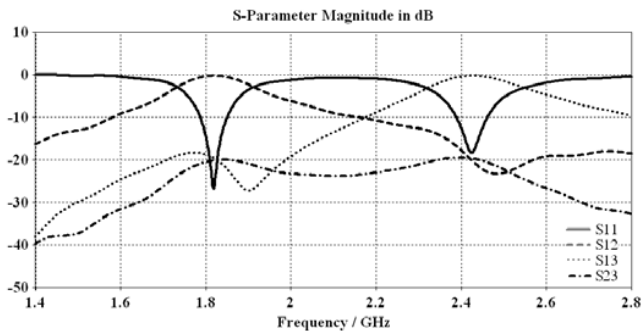


Fig. 7 Simulated frequency response of the proposed diplexer with ADS Agilent

IV. CONCLUSION

In this paper a new microstrip diplexer by using coupled stepped impedance resonators and coupled junction has been proposed and validated for the DCS and ISM applications. Two band pass filters using coupled SIRs are designed and simulated to operate for 1.8 GHz and 2.45 GHz bands then used to form the proposed diplexer. By choosing an appropriate impedance ration, length ratio and an optimal coupling spacing between the resonators and the feed lines, high performances can be achieved. The insertion losses are 2.16 dB and 2.24 dB at the center frequencies of 1.8 GHz and 2.45 GHz, respectively. The return losses are better than 29 dB at the lower and the higher channel respectively. Finally, the size of proposed diplexer is very compact and the isolation between the two BPFs is better than 21 dB. Therefore, the proposed diplexer is suitable to operate in modern wireless communication systems.

ACKNOWLEDGMENT

We thank Mr. Mohamed Latrach Professor in ESEO, engineering institute in Angers, France, and Pr. Angel Mediavilla from DICOM CANTABRIA university, for allowing us to use all the equipment available in there laboratories.

REFERENCES

- [1] D. M. Pozar, *Microwave Engineering*, John Wiley & Sons 1998.
- [2] E. Goron, J.P. Coupez, C. Person, Y. Toutain, H. Lattard, and F. Perrot, "Accessing to UMTS filtering specifications using new microstrip miniaturized loop-filters," *IEEE MTT-S Int Microwave Symp Dig Philadelphia, PA* (2003), 1599–1602.
- [3] Strassner, B. and K. Chang, "Wide-band low-loss high isolation microstrip periodic-stub diplexer for multiple-frequency applications," *IEEE Trans. Microw. Theory Tech.*, Vol. 49, 1818-1820, 2001.
- [4] Ye, C. S., Y. K. Su, M. H. Weng, and C. Y. Hung, "A microstrip ring-like diplexer for bluetooth and ultra wide band (UWB) application," *Microwave & Opt. Tech. Lett.*, Vol. 51, 1518-1520, 2009.
- [5] Weng, M. H., C. Y. Hung, and Y. K. Su, "A hairpin line diplexer for direct sequence ultra-wideband wireless communications," *IEEE Microw. Wireless Compon. Lett.*, Vol. 17, 519-521, 2007.
- [6] Chen, C. F., T. Y. Huang, C. P. Chou, and R. B. Wu, "Microstrip diplexers design with common resonator sections for compact size, but

high isolation," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, 1945-1952, 2006.

- [7] F. Sheta, J. P. Coupez, G. Tanné, S. Toutain, and J. P. Bolt, "Miniature microstrip stepped impedance resonator band pass filters and diplexers for mobile communications," 1996 *IEEE MTT-S Digest, WE2C-2*, pp. 607-610.
- [8] W. W. Choi, and K. W. Tam, "A microstrip SIR dual-mode bandpass filter with simultaneous size reduction and spurious responses suppression," *IEEE MTT-S International Microwave Workshop Series on Art of Miniaturizing RF and Microwave Passive Components, Chengdu, China*, 2008.
- [9] Tang, C. W. and H. H. Liang, "Parallel-coupled stacked SIRs bandpass filters with open-loop resonators for suppression of spurious responses," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, 802-804, 2005.
- [10] Makimoto, M. and S. Yamashita, "Bandpass filters using parallel-coupled stripline stepped-impedance resonators," *IEEE Trans. Microw. Theory Tech.*, Vol. 28, 1413-1417, 1980.
- [11] C. Quendo, E. Rius, C. Person, "Narrow bandpass filters using dual behavior resonators (DBRs) based on stepped impedance stubs and different-length stubs," *IEEE Trans. Microwave Theory & Tech.*, vol. 52, n°3, March 2004.
- [12] Sugchai, Tantivivat "A Design of Wide-Stopband Microstrip Diplexers with Multiorder Spurious-Mode Suppression Using Stepped-Impedance Resonators," presented in *IEEE Engineering and Technology (S-CET), 2012 Spring Congress*, 27-30 May 2012.
- [13] Puttadilok, Duangporn, "A microstrip diplexer filter using stepped-impedance resonators," presented in *IEEE SICE Annual Conference*, 20-22 Aug 2008.
- [14] S.-C. Lin, P.-H. Deng, Y.-S. Lin, C.-H. Wang and C. H. Chen, "Wide-stopband microstrip bandpass filters using dissimilar quarter-wavelength stepped-impedance resonators," *IEEE Trans. Microwave Theory Tech.*, Vol. 54, pp. 1011-1018, Mar. 2006.
- [15] C.-W. Tang and H.-H. Liang, "Parallel-coupled stacked SIRs bandpass filters with open-loop resonators for suppression of spurious responses," *IEEE Microwave Wireless Comp. Lett.*, Vol. 15, pp. 802-804, Nov. 2005.
- [16] H. Wang and L. Zhu, "Microstrip bandpass filters with ultra-broad rejection band using stepped impedance resonator and high-impedance transformer," in *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 683-686, Long Beach, USA, June 2005.