Mathematical Analysis of Microstrip Diplexer Design for WLAN System

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Abstract

Miniature microstrip diplexer at band frequencies of (1.45/1.95GHz and 2.5/3.5GHz) in two considered channels using the coupled stepped impedance resonators (SIRs) has been presented in this study with mathematical analysis. This diplexer has dual pairs of coupled SIRs with impedance ratio $(k > 1)$ and the source-load coupling lines. As a result of the tuning of impedance ratio and length ratio (α) of SIRs, the resonant modes are possibly determined to achieve 2nd order bandpass filter (BPF) with dualband frequency responses for the investigated diplexer. The investigated microstrip diplexer has a simple outline, compact dimensions, an in effect design technique and straightforward calculations of impedance, electrical lengths, fractional bandwidth, coupling factors and other electrical specifications.

Keywords: *Microstrip diplexer, Microstrip BPF, stepped impedance resonator (SIR), source-load coupling and electrical parameters calculation.*

1. Introduction

Microstrip diplexers with compacted dimensions, high isolation, small insertion loss, and strategic operating band frequencies stand for requested features in multi-service wireless communication systems. Several reported papers about microstrip diplexers [1-3] or diplexer with multi-bands [4] have been projected. In [1], diplexer based on SIR coupled-line structure has been used to suppress the 2nd harmonic spurious bands in the diplexer frequency responses. In [2], the microstrip diplexer has been designed by directly connecting dual parallel coupled BPFs. This device can effectually incorporate manifold practical blocks amid the antenna and TX/RX amplifiers. In [3], a diplexer has been projected using five resonators with a single-band filter for each output port. The total diplexer size is a design restriction and can be improved based on new techniques in recent reported studies. In [4], a microstrip diplexer with six-channels based on parallel coupled BPFs has been implemented using an effective technique of harmonic repression for designed filters at 10 and 12 GHz. Nevertheless, using high-order coupled resonators causes an increased insertion loss and diplexer dimensions. SIRs are extensively adopted to regulate the essential and higher order resonant modes to agree with the required specifications of multi-band frequency responses. In [7], compact microstrip diplexer using simple open loop resonators. This diplexer has dual channels with two band at each channel. It has been simulated for (1.424/1.732GHz) for first channel and (2.014/2.318GHz) for second channel. This designed diplexer has simple topology, considerable miniature size and very narrow band frequency responses can be used for modern wireless systems.

In this paper, microstrip diplexer with compact size and satisfactory bands is presented. The microstrip diplexer has considerable design practicability since the outline of coupled SIRs and passbands are straightforwardly adjusted by suitably tuning the SIR dimensions with easy calculations for important electrical parameters. The investigated diplexer is designed at 1.45/1.95 GHz for load 1 (port 1) and 2.5/3.5GHz for load 2(port 2) in accordance with the coupled SIRs with impedance ratio and the quarter wavelength source-load coupling lines. The huge isolation level amid the channels is necessary to avert the channel 1 (1.45/1.95 GHz) from being degraded by the leakage from the channel 2 (2.5/3.5GHz) and to sustain a worthy signal to noise ratio (SNR). This paper gives an uncomplicated and in effect mathematical approach to model a dual channel diplexer without complicated design, matching networks and manufacture procedure. The investigated microstrip diplexer can be used in many uses in multi-service and multi-band wireless communication systems.

2. Dual-Channel Diplexer

SIRs are widely used to regulate the resonant modes with high order to verify the specification of the passbands at the same time. The coupled-line of SIR is utilized to repress the 2nd harmonic pseudo response in the diplexer passband.

In this paper, a simple design of compacted dual-channel diplexer has been designed by using a pair of SIRs and source load coupling-lines. The conventional structure four-load/four-channel multiplexer block diagram is shown in Figure (1a). To organize a four-channel multiplexer, four-bandpass filters would be designed individually. Therefore, the parameters are very complex, and the big size of the circuit to be applied for multiband wireless applications. The dual-channel structure is the block diagram that shows in Figure (1 b). This design uses two pairs of coupled SIRs, therefore, it shows a dual-passband response for every load channel and small circuit size. The source-load coupling lines have

been used as design input, so there is no need to use four port matching network [8].

3. Dual-Channel Circuit Design

A close dual-passband has been generated by using dual pairs of the SIRs. They are designed at (1.45 and 1.95GHz) for load1and at (2.5 and 3.5GHz) for load 2. The source-load coupled lines for load1 are designed under conditions of full reflection for load 2 at (2.5 GHz) and no reflection for load 1 at (1.45 GHz). Therefore, the transmission lines are designed at (1.45 and 1.95 GHz) and (2.5 and 3.5 GHz) to be the source-load coupled lines to realize these conditions that could be good option. The SIR structure with (k >1) is shown in Figure (2), where K is the impedance ratio $(k = Z_2/Z_1)$ while (Z_1) stands for low-impedance section. The long length $(2\theta_1)$ connected with (Z_2) represents high-impedance sections and acting by two short lengths (θ_2) in both sides.

The physical length and impedance ratio of SIRs are different to adapt fundamental resonant frequency (f_0) and second resonant frequency (f_s) over wide range [8].

The electrical parameters and characteristic impedance selected from several solution:

When $Z_1 = 20$, $Z_2 = 100$, $\theta_1 = 20°$

If $R_z = \tan\theta_1 \tan\theta_2$ when

$$k = R_z \qquad\qquad ... \quad (1)$$

Then $\theta_2 = \tan^{-1}\left(\frac{R_z}{\tan\theta_1}\right)$, $\theta_2 = 83°$ in the first pair of the SIR and the same thing in the second pair of SIR, assume $\theta_1 = 30°$, therefore $\theta_2 = 75°$.

The width of microstrip corresponding to a known Z_0 is obtained for

$W/h \leq 2$ [9].

$$\frac{W}{h} = \frac{8exp(A)}{exp(2A)-2} \qquad\qquad ...(2)$$

Where

$$A = \frac{Z_0}{60}\left[\frac{\varepsilon_r+1}{2}\right]^{0.5} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left[0.23 + \frac{0.11}{\varepsilon_r}\right] \qquad ... \quad (3)$$

And for $W/h \geq 2$

$$\frac{W}{h} = \frac{2}{\pi}\left[(B-1) - \ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right] \qquad (4)$$

Where

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \qquad\qquad (5)$$

The effective dielectric constant ε_{re} are used to describe the transmission impedance of microstrips [10].

$$\varepsilon_{re} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12\frac{h}{W}\right)^{-0.5} \qquad ... \quad (6)$$

When the effective dielectric constant (ε_{re}) of a microstrip is calculated, the guided wavelength and its can be determined directly in millimeters is given by:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{re}}} \qquad\qquad ...(7)$$

Where λ_0 represents the free space wavelength.

The phase velocity v_p and associated propagation constant β are computed by

$$\beta = \frac{2\pi}{\lambda_g} \qquad\qquad ... \quad (8)$$

From a certain physical length (*l*), the electrical length of the microstrip is calculated by:

$$\theta = \beta l \qquad\qquad .. \quad .(9)$$

Table (1) shows the calculation of the parameters to these resonators.

Table 1: The calculation of parameters

Resonator	(Z_1, Z_2) (Ω)	(θ_1, θ_2) Degree	λ_g (mm)	β (Rad/mm)
1, 2	20, 100	20°, 83°	156.65	2.3
3, 4	40, 100	30°, 75°	71.93	5

The resonance modes are determined by the equations as follows [8]:

$$K.\cot\theta_2 = \tan\theta_1 \qquad\qquad \text{for odd-mode} \qquad ... \quad (10)$$

$$K.\cot\theta_2 = \cot\theta_1 \qquad\qquad \text{for even-mode} \qquad ... \quad (11)$$

θ_2 is commensurate to physical length of the SIR, so the length ratio (α) is determined as:

$$\alpha = 2\theta_2/\theta_t \qquad\qquad ... \quad (12)$$

$$\theta_t = 2(\theta_1 + \theta_2) \qquad\qquad ... \quad (13)$$

For above mentioned equations, then

$$K.\cot\left(\frac{\alpha\theta_t}{2}\right) = \tan\left(\frac{(1-\alpha)\theta_t}{2}\right) \qquad\qquad ...(14)$$

$$K.\cot\left(\frac{\alpha\theta_t}{2}\right) = -\cot\left(\frac{(1-\alpha)\theta_t}{2}\right) \qquad\qquad ... \quad (15)$$

Table (2) illustrates the calculation results using equations from (10) to (15).

Table 2: The result value for resonator mode

	Resonator 1,2	Resonator 3,4
α	0.805	0.714
odd-mode	K = 2.942	K = 2.1526
even-mode	K = -22.003 (Neglected)	K = -6.443 (Neglected)

The values of k >1 are considered in this design and the negative values would be neglected.

The coupling coefficient and external quality factor have been calculated by using equations [10]:

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}}, \qquad for\ i = 1, ..., N-1 \qquad ... \quad (16)$$

$$q_{e1} = \frac{g_0 g_1}{FBW}, \qquad q_{eN} = \frac{g_N g_{N+1}}{FBW} \qquad ... \quad (17)$$

the results from these equations are:

$M_{12} = M_{21} = 0.053$ at (1.45 GHz)

$M_{12} = M_{21} = 0.044$ at (1.95 GHz)

$M_{34} = M_{43} = 0.071$ at (2.5 GHz)

$M_{34} = M_{43} = 0.018$ at (3.5 GHz)

$$q_1 = 15.8, \quad q_2 = 20$$
$$q_3 = 11.8, \quad q_4 = 48$$

The Fractional bandwidth (FBW) has been calculated by using equation [11]:

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0}$$

$$\dots \tag{18}$$

The results from this equation are:

FBW1=0.06, FBW2=0.05   at (1.45/1.95 GHz)
FBW3=0.08, FBW4=0.02   at (2.5/ 3.5 GHz)

4. Em–Simulation Of Dual-Channel Diplexer

For dual channel diplexer, all dimensions have been calculated using equations (2) to (9) and the same for the values of electrical length (θ_1, θ_2). Table (3) illustrates the dimension values.

The design of dual-channel diplexer is constructed by using the coupled SIRs. So, there are no any extra matching networks. Therefore, it has compacted and strong design feasibility. It is designed on a substrate of Roger RT Duriod 5880 with thickness 0.78 mm. Figure (3) and Figure (4) shows the simulated design of dual channel diplexer by using ADS simulator.

Table 3: The dimensions for each resonator

Dimension (mm)	Resonator 1,2 (at Load 1)	Resonator 3,4 (at Load 2)

Length	$L_1 = 37, L_4 = 39$ $L_{12} = 35, L_{22} = 17$	$L_2 = 23, L_3 = 15$ $L_{21} = 19, L_{23} = 12$
Width	$W_1 = 8, W_2 = 0.5$	$W_1 = 3.34, W_2 = 0.5$
Space	$S_1 = 0.3$	$S_2 = 1.25$
Distance	$d_1 = 0.7, d_2 = 0.2$	$d_3 = 0.7, d_4 = 0.2$

The dual-channel diplexer has been simulated with center frequencies at (1.45 and 1.95 GHz) for load 1 and at (2.5 and 3.5 GHz) for load 2. The simulated results have insertion loss (0.5 and 1 dB) at load 1, and (2 and 2.9 dB) at load 2. The selectivity of the diplexer has been improved by appearance transmission zeros. Therefore, the isolation levels between channels are around 35 dB as it is clear from Figure (5).

The completely tuning of the source-load coupling lines and coupled SIRs generate transmission zeros nearby passband edges. This design helps to create multi-path signal diffusion by this adopted compact microstrip diplexer.

The developed dual channel diplexer has been designed to achieve lower insertion loss, compact circuit size, and good passband selectivity for each channel. The isolation is around 35dB. The band frequencies of proposed diplexer can be optimized more by trial and error method of its structure dimensions or by ADS simulator optimizer itself. However, the mathematical analysis and calculations for diplexer parameters are the central objectives of this study.

Table (4) shows the comparison results between this design and other reported designs in the literature.

Table 4: Comparison between this design and other reported designs

Reference	Passband (GHz)	Insertion losses (dB)	Isolation (dB)	Substrate Type (ε_r)	Thickness of substrate (mm)	Size
[13]	1.75 / 2.35	1.34 / 1.44	> 25	Roger 5880 (ε_r=2.2)	0.508	$0.12\lambda_g \times 0.23\lambda_g$
[12]	2.3 / 3.7 / 5 / 6.1	2.2/ 2.5/ 1.8/2.1	> 40	RT/Duroid (ε_r=10.2)	0.635	$0.39\lambda_g \times 0.4\lambda_g$
[8]	1.5/ 2/ 2.4/ 3.5	0.8/ 1/ 0.7/ 1.5	> 30	RT/Duroid (ε_r=2.2)	0.787	$0.19\lambda_g \times 0.4\lambda_g$
This work	1.45/ 1.95/ 2.5 / 3.5	0.5/ 1/ 2/ 2.9	35	RT/Duroid (ε_r=2.2)	0.78	$0.16\lambda_g \times 0.3\lambda_g$

Accordingly, the modified dual channel diplexer in this study is better than the reported designs in [8, 12, 13] as shown in Table (4) because of the high isolation between channels and compact size.

5. Conclusion

The miniature dual-channel diplexer has been investigated using the coupled SIRs and mathematical approach for its electrical specification [11]. Through the SIRs and source-load coupling lines, passbands with considerable isolation (35 dB) can be suitably implemented. Simulation frequency responses reveal that microstrip diplexer has a small size, low insertion loss and adequate passband selectivity at each channel. This diplexer can be integrated within multi-service wireless communication applications.

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