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# A Diplexer with Direct Coupled Resonant Junction

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**Abstract**— Conventionally, diplexers are designed by connecting two filters of different frequencies using a transmission T-line junction which acts as a distribution network serving the individual filters. Here, a novel diplexer has been proposed and designed to utilise a directly coupled resonator as the distribution network. The directly coupled resonator is designed using two square open-loop resonators of the same resonant frequency of 1.95 GHz. Coupling of the two resonators is achieved using a  $\lambda/4$  transmission line to directly couple them. This process made the resonator pair to possess a dual-mode resonator function, resonating at 1.85 GHz and 2.05 GHz. Two bandpass filters are then designed in the corresponding modes of the resonator pair with 5% fractional bandwidth and coupled accordingly. This technique allowed the resonator pair to contribute to the resonant poles of the diplexer while functioning as the distribution network.

**Keywords**—Diplexer, resonator pair; direct coupled resonator

## I. INTRODUCTION

The dual mode resonator has contributed immensely in reducing the complexity and the size of RF components used in communication systems in comparison to utilising two single mode resonators method in circuit designs. It has found its way in contributing to major improvements in the design of filters where it contributed to generating transmission zero in a filtering response leading to improved frequency selectivity [1–4]. With the help of a slot coupling technique, it has contributed in designing a highly compact dual-band filtering antenna where the resonator and the antenna were coupled back to back [5] also in designing of duplexing antenna using slot coupling [6, 7]. In diplexers, it has been used as a frequency distributor to service two channel filters leading to improved frequency response and miniaturisation [8 – 13]. Using the dual mode resonators as a distributor in diplexer designs has been popular over the years as it also contributes to the filtering poles of the individual channels. This is contrary to the conventional counterparts where a half wavelength transmission line-based junction, such as T-junctions, hybrid couplers, manifolds or circulators [14 – 18] are used as shown in Fig. 1a.

A novel approach is proposed in designing a microstrip diplexer with a directly coupled resonant junction in this paper. The diplexer is designed to operate at 1.85 GHz and 2.05 GHz respectively with a fractional bandwidth (FBW) of 5% in each channel response. The resonant junction consists of a resonator pair made up of two resonators of the same frequency at 1.95 GHz. Two three-pole channel filters were used and separately

designed to specifications and coupled to the corresponding frequencies of the directly coupled resonant junction. The resonant junction is used to replace the first resonators of each individual filter. In this design, the resonator (1a) is used as a coupling point for the two channel filters as shown in Fig. 1a. It is interesting to mention that the resonator (1b) can also be used as a coupling point for the two channel filters as it possesses the same properties as resonator (1a). However, further research needs to be done on how these properties can be maximised. Comparison of the conventional and novel approaches are depicted in Figs. 1a and 1b, the latter is shown to consist of resonator configuration and the coupling path of the proposed diplexer design integrated as a unit.

It can be seen from the proposed configuration of Fig. 1a that this design comprises of six resonators. Hence, this made the size to be fairly big and finding itself between the conventional diplexer [19, 20] and the recent compact diplexer designs [21 - 24] where the resonant junction is a single dual mode resonator, making the diplexer to be one resonator short. The quarter-wavelength transmission line used in designing the resonant junction provides an opportunity for frequency tuning in the diplexer. This makes it unique when compared with single resonators of dual mode and provides the novelty in this design. The proposed diplexer layout is shown in Fig. 2, where the letters represent the dimensions of the diplexer size as tabulated in Table 1.

The remaining part of the paper is presented as follows. An overview of the microstrip diplexer with a resonant junction designed is covered in section II. The fabrication procedure is briefly described along with a comparison of simulated and measured numerical results of the performance analysis of the novel approach are discussed in section III. Finally, concluding remarks highlighting the capabilities and limitations of a diplexer with direct coupled resonant junction are provided in section IV.

Fig. 1. (a) A conventional diplexer configuration with a non-resonant junction; (b) The proposed diplexer configuration with a resonant dual-mode junction.

Fig. 2. The proposed diplexer layout with the design dimensions

## II. DESIGN

The proposed microstrip diplexer is designed to offer the following requirements and specifications for the intended application:

- Center frequency of the lower and upper passbands,  $f_{0,BPL}$  and  $f_{0,BPU}$ : 1.85 GHz and 2.05 GHz respectively
- Passband return loss: 20 dB
- Fractional bandwidth (FBW) of the lower passband (BWL) and upper passband (BWU), 5 %

TABLE I: Direct coupled resonant junction diplexer parameters in millimeter (mm)

### A. Topology and coupling matrix

The dual mode directly coupled resonant junction and distributor shown in Fig. 1b, is denoted as 1a and 1b, representing the two directly coupled resonators in dashed blue line. The TL represents the transmission line used in coupling the resonators 1a and 1b. The mode 1a is coupled to the resonators 2 and 3 to generate the lower channel. Also, it is coupled to the resonators 4 and 5 to generate the higher channel. The resonators 2 and 3 as well as resonators 4 and 5 are part of 3-pole channel filters which are separately designed. These filters have a passband ripple factor of 0.043 dB of Chebychev lowpass response of terminal immittances denoted with  $g$  values of  $g_0 = g_4 = 1.0000$ ,  $g_1 = g_3 = 0.8516$  and  $g_2 = 1.1032$  [25, 26]. Using equations (1) and (2), the required external quality factor  $Q_{ex}$  and coupling coefficients,  $M_{1a,2}$ ,  $M_{2,3}$ ,  $M_{1a,4}$ ,  $M_{4,5}$  used for the physical dimensioning of the microstrip resonators were derived.

$$M_{1a,2} = M_{2,3} = M_{1a,4} = M_{4,5} = \frac{FBW}{\sqrt{g_1 g_2}} = 0.031 \quad (1)$$

$$Q_{ex1a} = Q_{ex2} = Q_{ex3} = \frac{g_1 g_0}{FBW} = 28.387 \quad (2)$$

### B. Direct coupled resonator

The direct coupled resonator pair is used as the junction resonator connecting the two separately designed filters. Besides, it functions as the power distributor and contributes to the resonant poles of each channel filter in the diplexer. The two open loop resonators (1a) and (1b), resonating at 1.95 GHz is first designed and directly coupled to each other using the  $\lambda/4$  transmission line (TL). Due to the coupling introduced between the resonators (1a) and (1b), both resonant peaks are then adjusted to acquire new resonances. This technique made the directly coupled resonators to behave as a dual mode resonator, resonating at 1.85 GHz and 2.05 GHz respectively. By varying the length of the TL, the dual modes of the resonator pair can be adjusted to the desired frequencies. This is due to varying the coupling strength associated by varying the length of the TL. Fig. 3a shows the resonant frequencies of the resonator pair as a function of the TL length. When the TL is at 29.7 mm, the required resonances were achieved.

Fig. 3: (a) Two resonance frequencies of the resonator pair as a function of the TL length. The insets show the layout used in the simulation and a typical simulated  $S_{21}$  response; (b) Configuration used to extract  $Q_{ex1a}$  and the typical resonance curves; (c) Simulated resonance curves from the assembled resonator 1, 2 and 4. The inset shows the layout used in the simulation;

### C. Couplings

The external quality factor ( $Q_{ex1a}$ ) at the common port was achieved using the configuration shown in Fig. 3b. At port-1, a feeder line was tapped to the resonator pair, on the resonator 1a, whereas port-2 and port-3 were weakly coupled to the same resonator 1a. The length, the width, and the tapping point, T1 of the feed line of port-1 was adjusted. The tapping points T2 and T3 of the TL was also adjusted. The T2 and T3 represents the tapping points of the TL on the resonators 1a and 1b respectively. During adjustments, the tapping points on resonator 1b was changed by rotating the resonator 1b. Using equation (3), the  $Q_{ex}$  towards both modes of the resonator pair was obtained.

$$Q_{ex} = \frac{f_0}{\Delta f} \quad (3)$$

where  $\Delta f$  is the 3-dB bandwidth measured from the peak of the resonance curve and,  $f_0$  represents the center frequency of the peak. Fig. 3b shows the typical resonance curves between port-1 and 2 in red line and between port-1 and 3 in blue line.

The coupling coefficient of  $M_{1a,2}$  were extracted by varying the spacing,  $S_1$ , shown in Fig. 2. between the resonator 1a of the direct coupled resonator and resonator 2 of the low passband channel. Also, the coupling coefficient of  $M_{1a,4}$ , is extracted by varying the spacing  $S_2$  between the resonator 1a of the direct coupled resonator and resonator 4 of the high passband channel. Equation (4) was used to calculate the coupling coefficients using the two pairs of resonance peaks. The layout configuration and the graphical response of the eigenmode achieved during the extraction is shown in Fig. 3c.

$$M_{1a,2} = M_{2,3} = M_{1a,4} = M_{4,5} = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \quad (4)$$

### D. Diplexers

After extracting the coupling coefficients and the external quality factor  $Q_{ex}$ , the layout of the diplexer was arranged as shown in Fig. 2, followed by optimisation to requirement. Fig. 5 shows the simulated response using dashed lines. Figs. 4a and 4b show the current distributions at 1.85 GHz and 2.05 GHz respectively during operation. It also shows that the direct coupled resonator is excited in orthogonal directions.

## III. FABRICATION AND MEASUREMENTS

This microstrip diplexer with a directly coupled resonant junction design is fabricated on Rogers RO 4003C substrate with the following parameters; substrate thickness of 1.52 mm, a relative permittivity of 3.55, and a loss tangent of 0.0029. The LPKF ProtoMat S63 micro milling machine was used during the fabrication process and the prototype is depicted in Fig. 5 as an inset. The Agilent Network Analyzer N5230A was used to measure and evaluate the performance of the fabricated prototyped diplexer with direct coupled resonant junction. Comparison of the simulated and measured numerical results is

shown in Fig. 5 with respect to the S-parameters at passband and this demonstrated a similar pattern with good agreement. The measured return loss at the low passband is approximately 23 dB and 22 dB respectively at higher passband. The measured bandwidth of the low passband and high passband matches the simulated response. However, the measured high passband has a frequency shift of about 2 MHz towards the low passband. The differences observed between the simulated and measured responses are due to the machining tolerance and the imperfection of post fabrication tuning. The insertion loss ( $S_{21}$ ) of the high passband is noticed to be bulging towards the low passband. This is also due to unwanted coupling between resonator 2 and the feedline of port 1.

(a) (b)

Fig. 4. (a) Current distribution at 1.85 GHz and (b) current distribution at 2.05 GHz

Fig. 5 Measured responses in comparison with full-wave simulations with the photograph of the fabricated diplexer with a direct coupled resonant junction.

#### IV. CONCLUSION

In this work, we demonstrated a unique way of designing diplexers using directly coupled resonators. Here, this resonator functions as a distributor and contributes to the resonant poles of the filtering channels. By having a dual mode response, it is used in joining two three-poles bandpass filters in corresponding modes. This also replaced the two resonators configuration, one from each channel filter. The technique of using the novel approach resulted in a gradual reduction of the diplexer structure in comparison with the conventional configuration methods. The passband filter responses of the measured and simulated have shown good agreement. This design approach has extended and confirmed the feasibility of implementing the direct coupled resonator as a resonant junction in the diplexer implementation.

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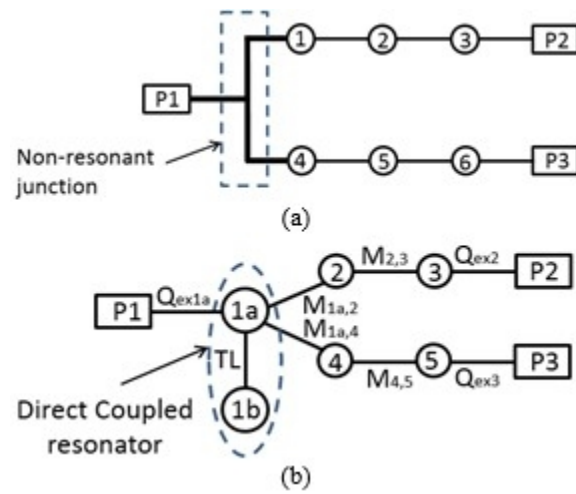


Fig. 1. (a) A conventional diplexer topology with a non-resonant junction; (b) The proposed diplexer topology with a resonant dual-mode junction.

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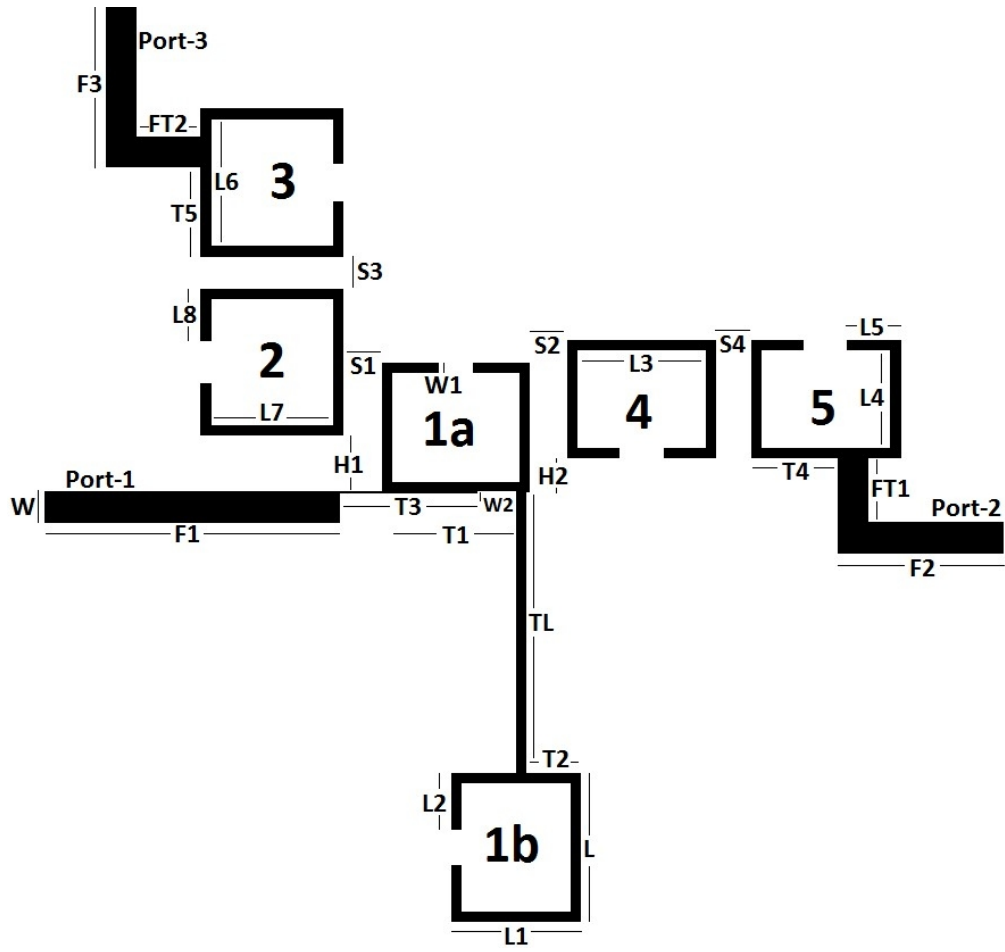


Fig. 2. Layout of the proposed diplexer (unit: mm)

232x219mm (96 x 96 DPI)

<b>F1</b>	32	<b>S1</b>	0.4	<b>T3</b>	14.6	<b>L2</b>	4.9
<b>F2=F3</b>	15	<b>S2</b>	1.6	<b>T4</b>	9.1	<b>L3</b>	13.6
<b>FT1</b>	10	<b>S3</b>	2	<b>T5</b>	9.5	<b>L4</b>	12.4
<b>FT2</b>	10	<b>S4</b>	2	<b>H1</b>	6	<b>L5</b>	4.6
<b>W</b>	1	<b>TL</b>	29.7	<b>H2</b>	3.6	<b>L6</b>	13.5
<b>W1</b>	4.9	<b>T1</b>	14.1	<b>L</b>	15.6	<b>L7</b>	15
<b>W2</b>	13.5	<b>T2</b>	5.8	<b>L1</b>	13.6	<b>L8</b>	4.5

75x25mm (96 x 96 DPI)



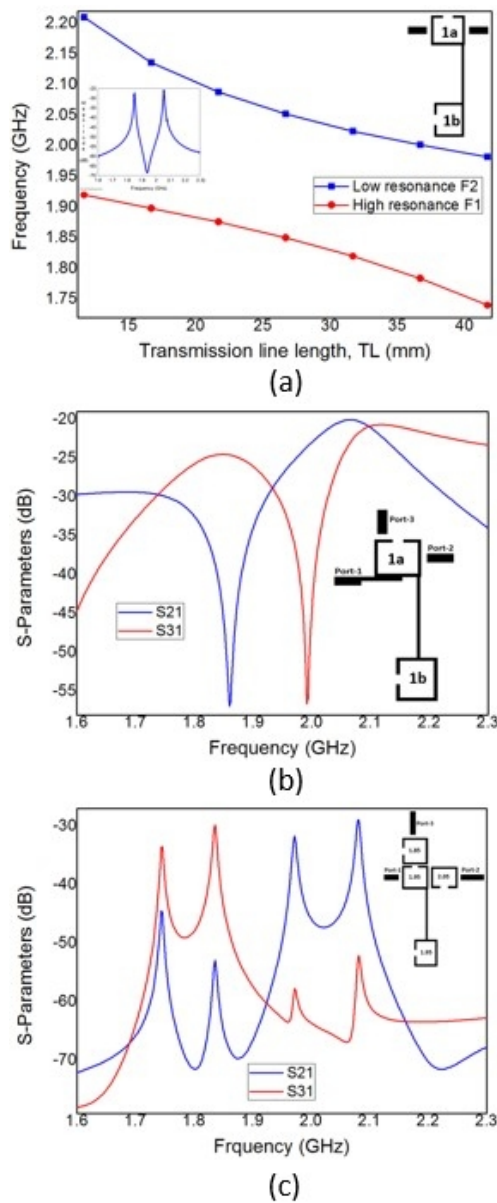


Fig. 3: (a) Two resonance frequencies of the resonator pair as a function of the TL length. The insets show the layout used in the simulation and a typical simulated S21 response; (b) Configuration used to extract Qex1a and the typical resonance curves ; (c) Simulated resonance curves from the assembled resonator 1, 2 and 4. The inset shows the layout used in the simulation

76x184mm (96 x 96 DPI)



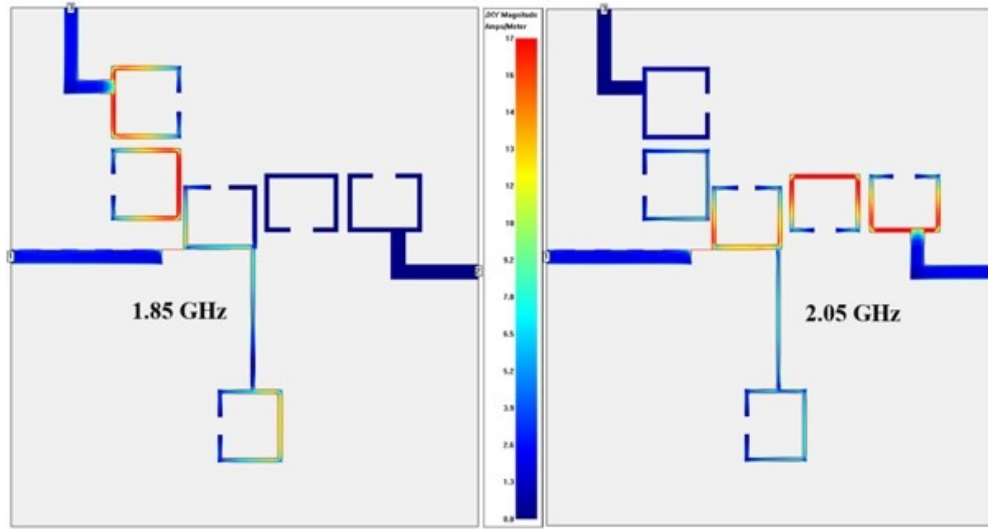


Fig. 4. (a) Current distribution at 1.85 GHz (b) current distribution at 2.05 GHz

160x86mm (96 x 96 DPI)

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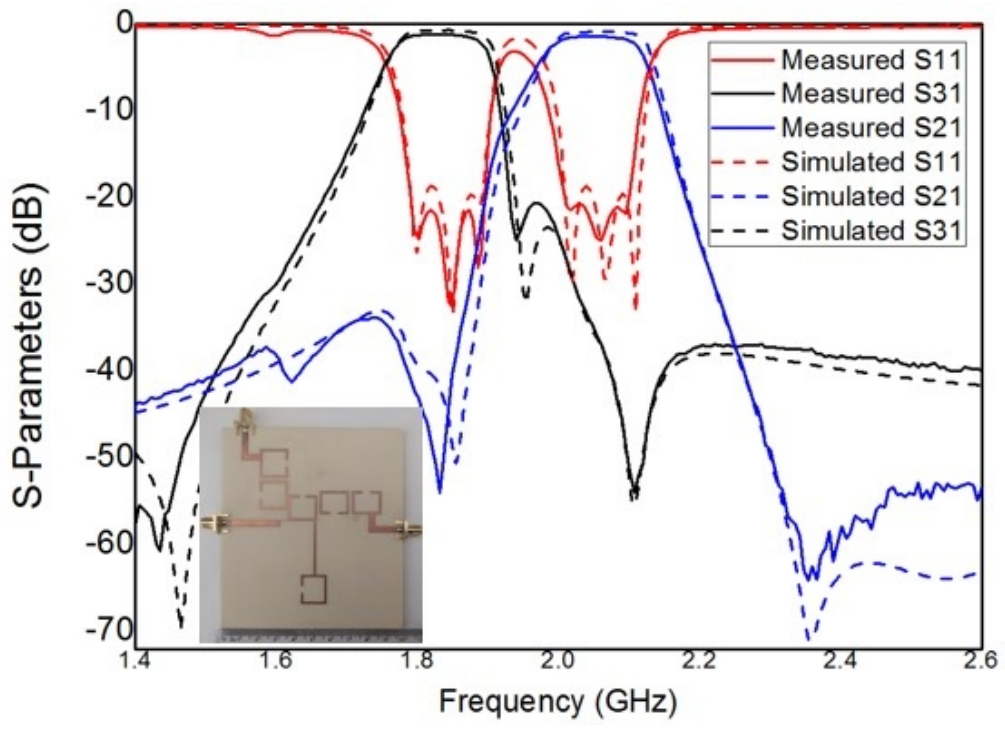


Fig. 5 Measured responses in comparison with full-wave simulations with the photograph of the fabricated duplexer with a direct coupled resonant junction.

145x105mm (96 x 96 DPI)