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Hybrid Combination of Tri-Band Isolation Circuits Based on Conventional and Double-Lorentz Transmission Lines for Quadruplexers

Hanseung Lee and Tatsuo Itoh

Department of Electrical Engineering, University of California, Los Angeles

420 Westwood Plaza, Los Angeles, California, USA

hlee0411@ucla.edu

itoh@ee.ucla.edu

***Abstract*—Tri-band isolation circuits based on conventional transmission lines (TLs) and double-Lorentz (DL) TLs are proposed and studied. The quadruplexer composed with two types of isolation circuits has significant advantages. Because it uses less DL TLs than the quadruplexer previously studied (shown in Fig. 1(a)), it can be designed easily and demands less lumped components. Also, the advantages of the previous quadruplexer, i.e. no modification of filters and straightforward design process, remain in the proposed quadruplexer. For verifying the concept, a quadruplexer, of which center frequencies are 942.5 MHz, 1575 MHz, 2140 MHz, and 2450 MHz, is designed and fabricated. The measured results are well matched with the simulation results.**

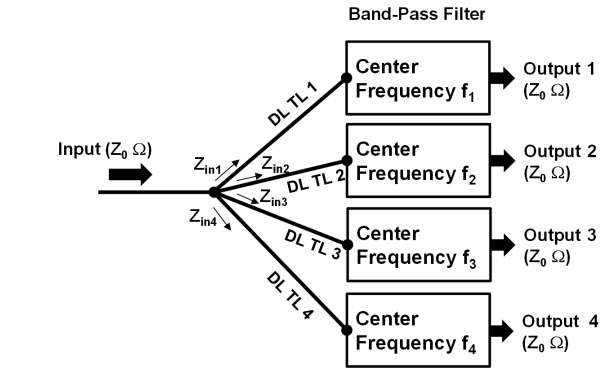
I. INTRODUCTION

A multiplexer becomes an important part in modern communication system, because many systems are required to handle multiple frequency bands. For example, a quadruplexer is necessary for a mobile phone base station which deals with two communication standards. (One standard requires two frequency bands for transmitting and receiving a signal.) Profound research for multiplexers has been carried out and many approaches have been proposed that require complex optimization process and modification of filters [1]-[7]. However, using designed filters without modification and straightforward design method could be preferable in many applications. For satisfying these demands, multiplexers based on isolation circuits have been studied [8]-[10]. An isolation circuit is composed with a transmission line and a filter, and combination of isolation circuits realizes a multiplexer.

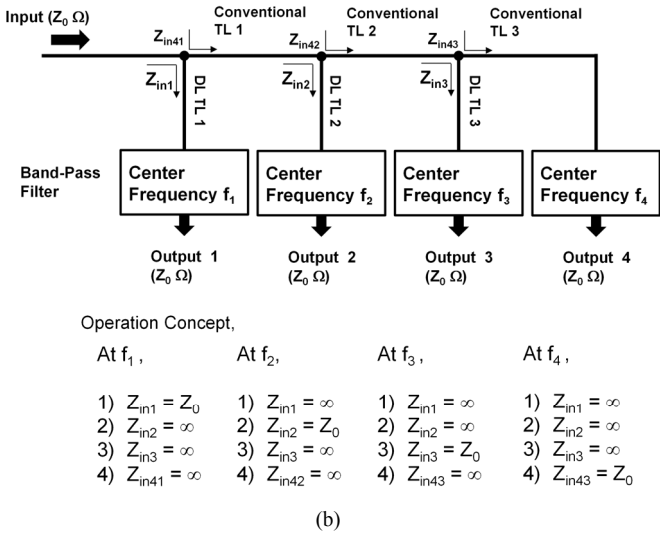
In this paper, the quadruplexer based on tri-band isolation circuits using three DL TLs and three conventional TLs is presented. First, the theory for tri-band isolation circuits and the design process are explained. Also, the simulated and measured results of the proposed quadruplexer are provided.

II. BASIC THEORY

Fig. 1(a) and (b) show the diagrams of quadruplexers based on tri-band isolation circuits. The quadruplexer shown in Fig. 1(a) comprises with four DL TLs and four filters, and each DL TL and corresponding filter make a tri-band isolation circuit [9]. On the other hand, the proposed quadruplexer shown in Fig. 1(b) is made by combining three isolation circuits using DL TLs and one isolation circuit using conventional TLs. The



(a)



Operation Concept,

At f_1,	At f_2,	At f_3,	At f_4,
1) $Z_{in1} = Z_0$	1) $Z_{in1} = \infty$	1) $Z_{in1} = \infty$	1) $Z_{in1} = \infty$
2) $Z_{in2} = \infty$	2) $Z_{in2} = Z_0$	2) $Z_{in2} = \infty$	2) $Z_{in2} = \infty$
3) $Z_{in3} = \infty$	3) $Z_{in3} = \infty$	3) $Z_{in3} = Z_0$	3) $Z_{in3} = \infty$
4) $Z_{in41} = \infty$	4) $Z_{in42} = \infty$	4) $Z_{in43} = \infty$	4) $Z_{in43} = Z_0$

(b)

Fig. 1. Diagrams of quadruplexers based on tri-band isolation circuits. (a) Previous quadruplexer using only DL TLs. (b) Proposed quadruplexer using both DL TLs and conventional TLs.

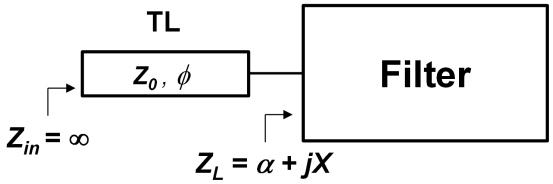


Fig. 2. An isolation circuit diagram.

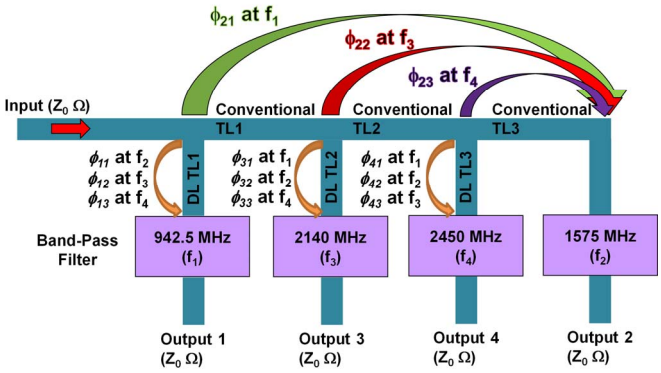


Fig. 3. The quadruplexer diagram with phase responses of TLs.

isolation circuit consisting of a DL TL and a filter can be isolated at three specified frequencies, because a DL TL can have appropriate phase shifts at the frequencies. However, the isolation circuit using three conventional TLs and a filter has its own tri-band characteristic by adjusting phase responses of three conventional TLs. Because the proposed quadruplexer requires one less DL TL than the quadruplexer shown in Fig. 1(a), it is easier to design and requires less lumped components, which are used for a DL TL.

A. Required Phase response of an Isolation Circuit

The main function of an isolation circuit is having infinite input impedance at the target frequencies. Hence this circuit can be isolated from an input port and does not disturb signal flow. Fig. 2 shows a schematic of an isolation circuit. Because a filter has an imaginary input impedance except at the pass band of a filter, a proper phase response of a TL makes a circuit have infinite input impedance or open condition. For solving an appropriate phase response ϕ, the transmission line impedance equation can be used [11].

$$\phi = n\pi - \arctan(Z_0 / X) + \psi \qquad (1)$$

where n is an integer and Z_0 is the characteristic impedance of the transmission line. X presents the imaginary part of the input impedance of the filter and ψ is adjusting constant [9]. By the way, this equation can be used in the condition of small α (real part of an input impedance of the filter). If the value of α is considerable, a more rigorous equation is necessary and presented as,

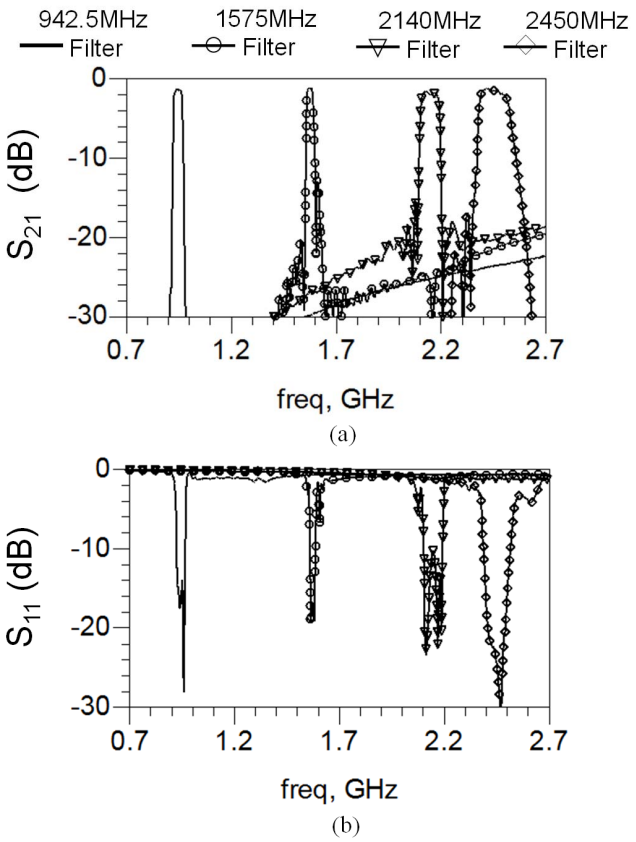


Fig. 4. Performances of filters used on the quadruplexer. (a) S_{21}. (b) S_{11}.

$$\phi = n\pi - \frac{\arg\left\{(\alpha^2 + X^2 - Z_0^2) + j2Z_0X\right\}}{2} + \psi. \qquad (2)$$

B. Tri-Band Isolation Circuit Based on DL TL

A double-Lorentz TL is one kind of multi-band metamaterial TL. In the balanced condition, it can be divided into a dual-CRLH (D-CRLH) TL and a conventional TL. Because a D-CRLH TL can have dual-band characteristic and a conventional TL gives one more freedom to choose a phase response, a DL TL has tri-band characteristic. So, an isolation circuit consisting of a DL TL and a filter can have open condition at operating frequencies of other three channels. Fig. 3 shows detailed diagram of proposed quadruplexer with necessary phase responses of TLs. In Fig. 3, the filters, having center frequencies of 942.5 MHz, 2140 MHz, and 2450 MHz, are used for tri-band isolation circuits based on DL TLs. The required phase responses of 942.5 MHz tri-band isolation circuit are ϕ_{11} at 1575 MHz, ϕ_{12} at 2140 MHz and ϕ_{13} at 2450 MHz. Such three pairs of frequency and phase response can be satisfied by a DL TL and the process of extracting circuit parameters of a DL TL with three frequency-phase pairs was introduced [9]. Similarly, DL TLs for 2140 MHz and 2450 MHz tri-band isolation circuits can be designed.

TABLE I
PARAMETERS OF TRI-BAND ISOLATION CIRCUITS

	Impedance of Filter (Ω)			Required Phase Delay/Advance (deg.)			Circuit Parameter of DL TL (L : nH, C : pF)					
							L_R	C_R	L_L	C_L	L_p	C_p
942.5 MHz Isolation Circuit	1575 MHz 2.65 -j(27.75)	2140 MHz 2.20 -j(13.75)	2450MHz 1.95 -j(8.10)	ϕ_{11} 60.90	ϕ_{12} -90.41	ϕ_{13} -114.19	1.80	0.72	16.18	6.47	7.50	3.00
2140 MHz Isolation Circuit	942.5 MHz 2.15 -j(90.60)	1575 MHz 2.10 -j(45.15)	2450 MHz 4.35 -j(27.15)	ϕ_{31} -151.12	ϕ_{32} 47.89	ϕ_{33} -118.66	6.23	2.49	6.01	2.4	9.17	3.67
2450 MHz Isolation Circuit	942.5 MHz 0.5 +j(18.30)	1575 MHz 1.95 +j(44.70)	2140 MHz 471.05 +j(332.65)	ϕ_{41} -69.89	ϕ_{42} 131.84	ϕ_{43} -2.88	3.92	1.57	8.24	3.29	3.12	1.25
1575 MHz Isolation Circuit	942.5 MHz 0.85 -j(54.25)	2140 MHz 4.00 -j(16.95)	2450 MHz 2.00 -j(11.30)	ϕ_{21} -137.30	ϕ_{22} -108.80	ϕ_{23} -102.80						

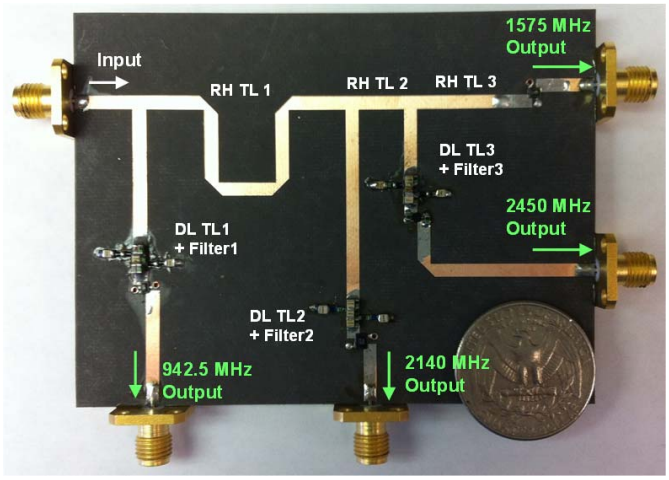


Fig. 5. Fabricated quadruplexer.

C. Tri-Band Isolation Circuit Based on Conventional TLs

Combination of three conventional TLs could be used for 1575 MHz tri-band isolation circuit. At 942.5 MHz, two isolations circuits (having 2140 MHz and 2450 MHz filters) are isolated from the quadruplexer. So, appropriate phase sum of conventional TL 1, TL 2, and TL 3 (ϕ_{21}) can make 1575 MHz isolation circuit have infinite input impedance at 942.5 MHz. Similarly, the isolation circuit has open condition at 2140 MHz, because of required phase sum of conventional TL 2 and TL 3 (ϕ_{22}) and open condition of 942.5 MHz and 2450 MHz isolation circuits. If the phase response of the conventional TL3, ϕ_{23}, is appropriate, the isolation circuit also has an open condition at 2450 MHz. With these processes, 1575 MHz isolation circuit has tri-band isolation characteristic at 942.5 MHz, 2140 MHz, and 2450 MHz.

D. Design Process of Proposed Quadruplexer

The design procedure of the quadruplexer is presented.

1. Find the input impedance of each filter at three target frequencies.
2. Find proper phase responses ϕ_{X1}, ϕ_{X2}, and ϕ_{X3} (where X = 1, 2, 3, or 4) for each filter using equation (1) or (2) in order to obtain open condition at the three frequencies (center frequencies of the other filters).
3. Obtain circuit parameters of a DL TL with three frequency-phase pairs (for isolation circuits using a DL TL) [9].
4. Obtain physical lengths of three conventional TLs using required phase responses from the procedure 2 [11].
5. Combine three isolation circuits using DL TLs to the isolation circuit consisting of three conventional TLs.

III. PROPOSED QUADRUPLEXER

For verifying the design concept, the quadruplexer using four commercial SAW filters is designed and fabricated. Fig. 4 shows the performances of the filters and their center frequencies are 942.5 MHz, 1575 MHz, 2140 MHz, and 2450 MHz. Two filters (having 942.5 MHz and 1575 MHz center frequencies) are from Panasonic and the other filters, with 2140 MHz and 2450 MHz center frequencies, are made by EPCOS and Murata, respectively. With the theory presented in Section II, DL TLs and conventional TLs for tri-band isolation circuits are designed. The design summary shown in Table 1 presents the required phases for each isolation circuit and extracted circuit parameters of DL TLs.

Fig. 5 shows the fabricated quadruplexer. The used substrate is RT/Duroid 5870 model (ε_r = 2.33, Height = 0.787 mm). The simulated and measured results of the quadruplexer

are shown in Fig. 6. Measured results are well matched with simulation results.

IV. Conclusion

The quadruplexer based on hybrid combination of tri-band isolation circuits has been discussed. No necessity of modifying filters and simple design process can be preferable to system designers. Also, it uses one less DL TL comparing with a quadruplexer of which isolation circuits use only DL TLs. So, the proposed quadruplexer can be designed easily and demand less lumped components.

Acknowledgment

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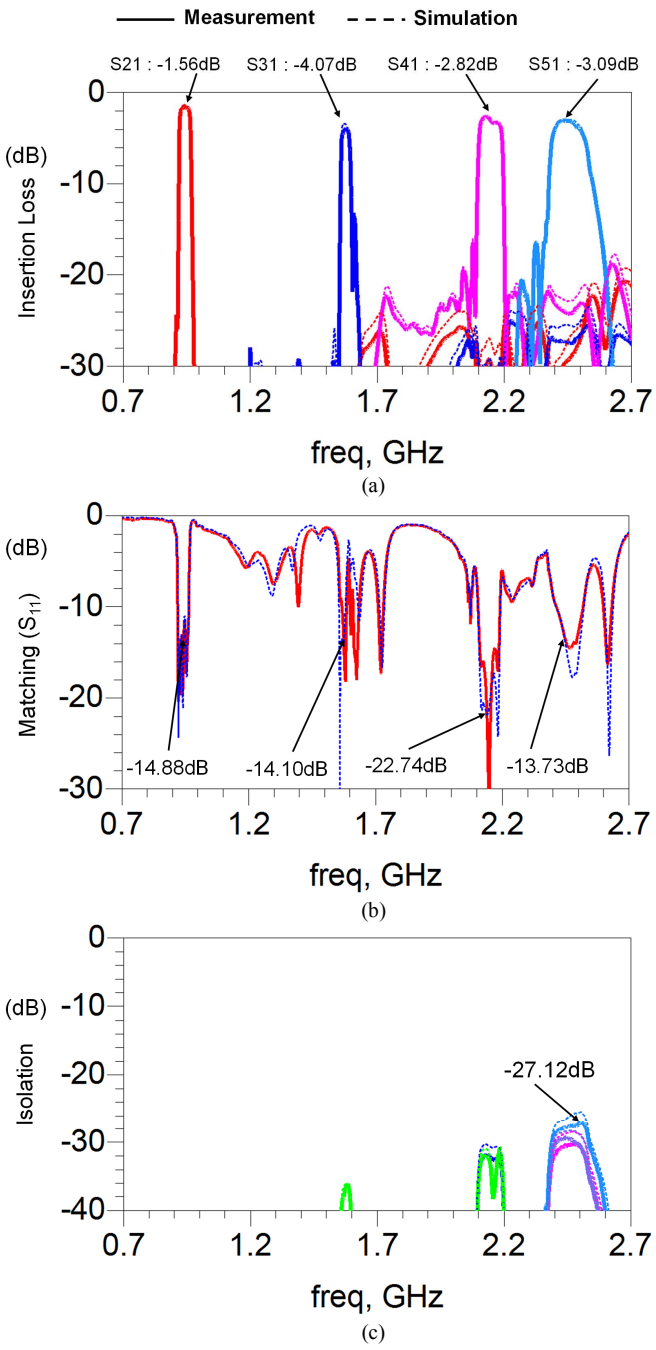

Fig. 6. Measured results of the quadruplexer. (a) Insertion loss. (b) Matching at port 1. (c) Isolation.