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Formulation for Energy Distribution in T-Junctions for Diplexer Design

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***Abstract*—A new formulation for implementing T-junction matching networks used in diplexer design is proposed in this paper. The investigation exploits the electrical length of quarter-wavelength microstrip transmission lines, and the guided-wavelength of the lines at one giga-Hertz frequency, in achieving the T-junction design formulation. This novel design would eradicate the uncertainties associated with frequent tuning and optimisation of T-junctions to achieve the desired energy distribution in diplexer designs. A prototype diplexer for separating the transmit from the receive frequencies within the front end of a wireless cellular base station is investigated and used to demonstrate the new design method. The prototype microwave diplexer with Tx and Rx centre frequencies of 2680 MHz and 3000 MHz, respectively, have been designed, implemented using microstrip, simulated, and presented. The simulation results of the circuit model and that of the microstrip layout prototype diplexer, demonstrate decent agreement with a high isolation of better than 50 dB between the transmit (Tx) and the receive (Rx) channels. The in-band lowest insertion loss is located at 1.1 dB, with a better than 20 dB in-band return loss across both the Tx and Rx bands.**

Keywords—microstrip, T-junction, diplexer, filter, resonator, hairpin, coupling

I. INTRODUCTION

T-junctions have been playing a vital role in the design of microwave diplexers for modern wireless communication systems. Diplexers are characteristically composed of two distinctly designed channel/bandpass filters, connected using a 3-port impedance matching circuit/network as shown in Fig. 1. Each of the separate bandpass filters are particularly designed to function at dissimilar frequency channels that match the frequencies of the Tx and the Rx channels of the prototype microwave diplexer. The connecting network, i.e., the three-port impedance matching circuit/network, is usually designed to yield decent transmission in one of the passbands and deliver profound impedance in the second passband [1].

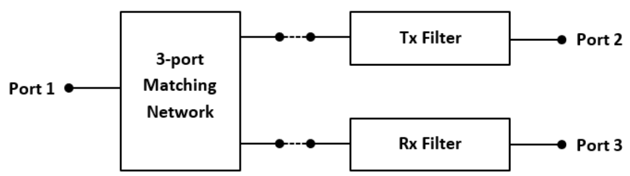


Fig. 1. Junction diplexer layout.

The careful design criteria of the three-port impedance matching circuit/network would permit the attainment of the anticipated frequency isolation. Referring to [2], it was stated that designing a circuit/matching network that can yield a decent transmission in one of the passbands and a decent attenuation in the second passband is very demanding. The frequency performance of a microwave diplexer vastly depends on the individual channel/bandpass filters [3], together with the connecting circuit/network [4]. This is because the combined loss characteristic of the microwave diplexer is because of the totality of the different losses contributed by each channel/bandpass filter and the matching circuit/network [5].

T-junction [6]–[9] is one of the popular candidates for implementing the 3-port matching circuit/network presented in Fig. 1. Some other types of combining networks that have been reported in literature include manifolds [10], circulators [11], and Y-junctions [12]. This paper investigates a new formulation to make circuit matching simple and dependable at the diplexer junction. This implies that results can be simply replicated by the research community worldwide, by merely selecting their design conditions and exploiting the proposed formulation.

II. CIRCUIT MODEL

The prototype diplexer circuit model is developed from two distinctly designed channel filters and a T-junction as shown in Fig. 2.

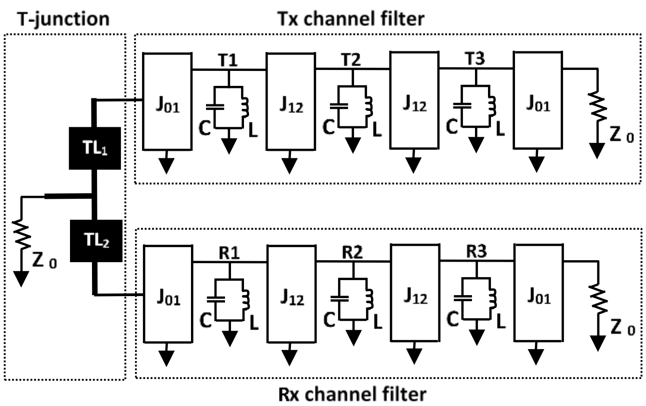


Fig. 2. T-junction diplexer lumped elements circuit model showing equal LC resonators components and J-inverters.

The channel filters are designed using the procedure reported in [13], [14] with center frequencies that match to those of the Tx and the Rx channels of the proposed prototype microwave diplexer. The channel filters are designed to have a fractional bandwidth (FBW) of 0.03; a channel return loss of 20 dB; and a characteristics impedance of 50 Ohms. The additional design parameters of the transmit and the receive channel/bandpass filters are given in Table I. As shown in Fig. 2, T1, T2, T3 are the resonators of the transmit filter, and R1, R2, R3 are the resonators of the receive filter. The TL_1 and TL_2 shown in Fig. 2 are the quarter-wavelength microstrip transmission lines for implementing the T-junction. The electrical lengths of TL_1 and TL_2 are 63 and 67 degrees, respectively as shown Fig. 3. The lumped elements circuit model of Fig. 2 was simulated on the commercially available Keysight electromagnetic (EM) circuit simulator, Advanced Design System (ADS), with the J-inverters modelled as capacitors-only networks as reported in [15], [16] and shown Fig. 3. An alternative way to conduct the circuit simulation on ADS would be by the modelling of the J-inverters as inductors-only networks is reported in [3].

TABLE I. CHANNEL FILTER LUMPED ELEMENTS CIRCUIT MODEL DESIGN PARAMETERS.

Filter	f_0 (MHz)	L (nH)	C (pF)	J_{01}	J_{02}
Tx	2600	0.1078	34.7529	0.02	0.0176
Rx	3000	0.0934	30.1192	0.02	0.0176

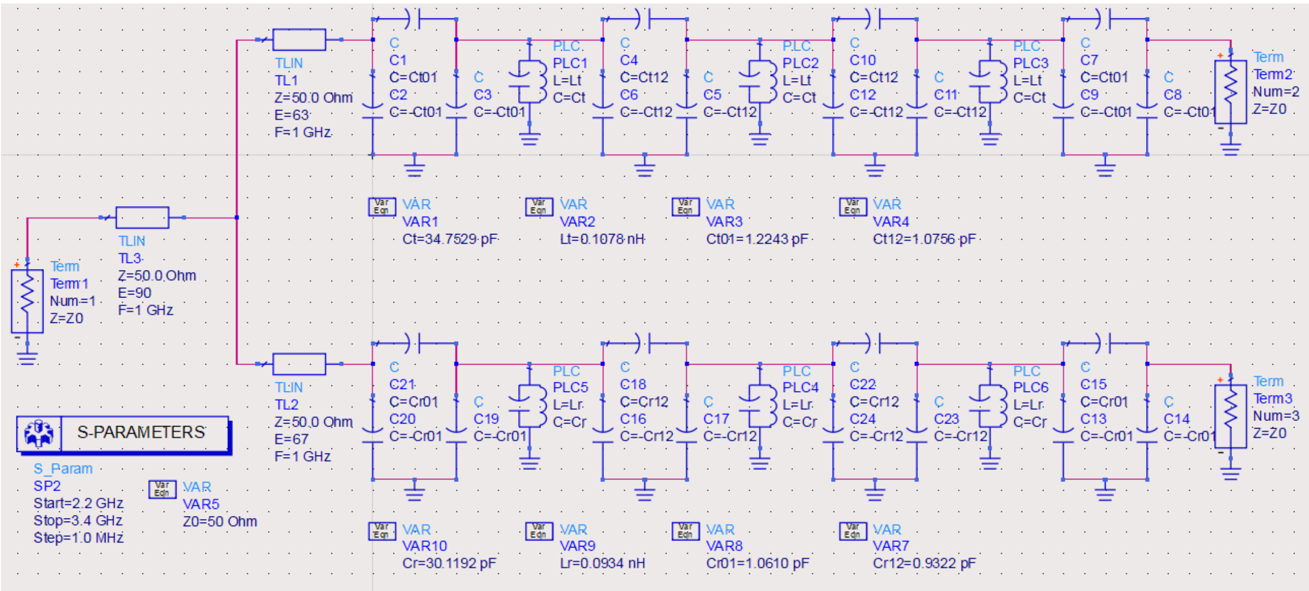


Fig. 3. T-junction diplexer circuit with J-inverters modelled as capacitor-only network.

III. MICROSTRIP LAYOUT

The microstrip layout implementation for the prototype microwave diplexer is captured in Fig. 4. The originality in the microwave diplexer layout design is traced to the formulation used to design the T-junction matching network. The formulation is specified in Equation (1), where *EL* denotes the electrical length for the microstrip quarter-wavelength microstrip line (ML), λg is the guided-wavelength for the ML at one giga-Hertz frequency. The 90° in the numerator of Equation (1) indicates the phase shift that occurs in the quarter-wavelength microstrip line. The diplexer layout operation is based on the Rogers RT/Duroid 6010LM substrate of relative dielectric constant, $\varepsilon_r = 10.7$; thickness, h = 1.27 mm; and loss tangent, $\tan\delta = 0.0023$. The simulated dimensions of the diplexer were determined using the ADS Momentum full-wave electromagnetic simulator.

$$TL(mm) = \frac{(EL+90^o)}{360^o}\lambda_g \quad (1)$$

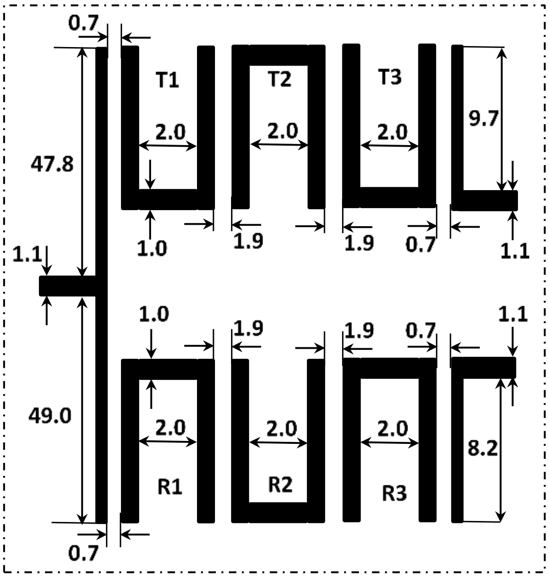
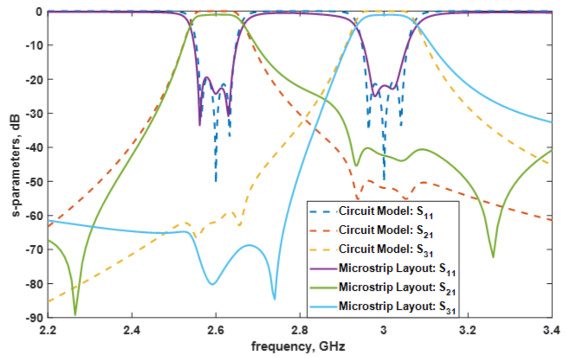


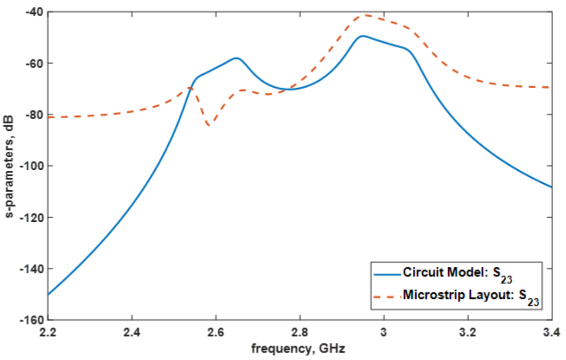
Fig. 4. Microstrip layout of the T-junction diplexer circuit with all dimensions in mm.

IV. Results and Discussion

The prototype microwave diplexer lumped elements circuit model, together with the microstrip diplexer layout operation frequency responses are co-presented in Fig. 5 for clear comparison.



(a)



(b)

Fig. 5. T-junction diplexer results comparison. (a) Insertion and return losses. (b) Isolation between Tx and Rx.

The simulated frequency responses of the T-junction prototype microwave diplexer lumped elements circuit model in Fig. 5 show that the transmit (Tx) and the receive (Rx) bands are centered at 2600 MHz and 3000 MHz, respectively, as required. The frequency bands isolation between the two filter channels is improved to around 50 dB; the in-band frequency return loss (RL) for both channels is better than 20 dB; and the insertion loss is zero (which is an ideal circuit condition).

The microstrip implementation responses of the T-junction prototype microwave diplexer are also captured in Fig. 5 and show that the results closely match the circuit model results. However, the frequency isolation between the filter bands achieved here is about 42 dB. This has a variation of just 8 dB when compared to the 50 dB isolation attained in the circuit model results. An insertion loss of about 1.1 dB is achieved from the microstrip layout. The variation in isolation and insertion loss are because the microstrip diplexer layout implementation includes both the conductor and the dielectric losses parameters. This is unlike the ideal circuit model. The loss tangent parameter of the dielectric materials considered and maintained at 0.0023. The copper conductivity, on the other hand, was maintained at 5.8×10^7 S/m. The thickness of the copper conductor was maintained at 35 microns for the microstrip transmission line.

V. Conclusion

A T-junction designed purely based on a new formulation has been utilized in the implementation of a sixth-order diplexer. The prototype T-junction diplexer has been proposed, investigated, designed, and realized using the microstrip line method. The lumped elements diplexer circuit model and prototype microstrip diplexer layout frequency responses demonstrate decent agreement; with centre frequencies of 2.6 GHz (2600 MHz) at the Tx band and 3.0 GHz (3000 MHz) at the Rx band. A performance comparison with some recently published works [17]–[20] is presented in Table II.

TABLE II. Comparison of the Friquency Responses of the Proposed Prototype Diplexer with Some Related Recently Published Works.

Ref.	f1/f_2 (GHz)	Iso.[a] (nH)	RL[b] (pF)	Selectivity
[17]	1.8/2.4	>18.2	-	Low
[18]	2.45/2.98	>27.2	>15.3	Medium
[19]	1.0/1.15	-	>20.0	Low
[20]	1.73/2.25	>35.9	>15.0	Medium
This work	2.6/3.0	>41.6	>20.0	High

a. Isolation, b. return loss

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References

[1] Z.L. Wu, Wu, C.H. Lee and H.H. Chen, "Balun diplexer design in hybrid structure of microstrip line and slot-line", *Proc. Asia-Pacific Microwave Conf.*, Nanjing, China, pp. 1–3, Dec. 2015.

[2] X. Guan, F. Yang, H. Liu, and L. Zhu, "Compact and high-isolation diplexer using dual-mode stub-loaded resonators", *IEEE Microwave and Wireless Components Letters*, Vol. 24, No. 6, pp. 385–387, Jun. 2014.

[3] A.O Nwajana, "Circuit modelling of bandpass/channel filter with microstrip implementation", *Indonesian Journal of Electrical Engineering and Informatics*, Vol. 8, No. 4, pp. 696–705, Dec. 2020.

[4] A.O. Nwajana and K.S.K. Yeo, "Multi-coupled resonator microwave diplexer with high isolation", *Proc. 46th European Microwave Conf.*, London, U.K., pp. 1167–1170, Oct. 2016.

[5] A. Nwajana, "Analysis and design of a substrate integrated waveguide multi-coupled resonator diplexer", PhD Thesis, University of East London, London, U.K., Jul. 2017.

[6] P. Zhao and K.-L. Wu, "Adaptive computer-aided tuning of coupled - resonator diplexers with wire T-junction", *IEEE Trans. Microwave Theory Tech.*, Vol. 65, No. 10, pp. 3856–3865, Jun. 2017.

[7] T. Yang and G.M. Rebeiz, "Three-pole 1.3-2.4-GHz diplexer and 1.1-2.45-GHz dual-band filter with common resonator topology and flexible tuning capabilities", *IEEE Trans. Microwave Theory and Tech.*, Vol. 61, No. 10, pp. 3613–3624, Oct. 2013.

[8] T.F. Skaik, M.J. Lancaster and F. Huang, "Synthesis of multiple output coupled resonator circuits using coupling matrix optimization",

IET Microwaves, Antenna & Propagation, Vol. 5, No. 9, pp. 1081–1088, Jun. 2011.

[9] A.O. Nwajana, P.U. Okafor and S.N. Arinze, "T-junction diplexer for RF front end of a cellular base station", International Journal of Microwave and Optical Technology, Vol. 15, No. 6, pp. 53–59, Nov. 2020.

[10] Y. Heng, X. Guo, B. Cao, B. Wei, X. Zhang, G. Zhang and X. Song, "A narrowband superconducting quadruplexer with high isolation", *IEEE Trans. Applied Superconductivity*, Vol. 24, No. 2, pp. 21–26, Apr. 2014.

[11] T. Kodera and C. Caloz, "Integrated leaky-wave antenna-duplexer/diplexer using CRLH uniform ferrite-loaded open waveguide", *IEEE Trans. Microwave Antennas Propagation*, Vol. 58, No. 8, pp. 2508–2514, Aug. 2010.

[12] K.L. Wu and W. Meng, "A direct synthesis approach for microwave filters with a complex load and its application to direct diplexer design", *IEEE Trans. Microwave Theory and Tech.*, Vol. 55, No. 5, pp. 1010–1017, May 2007.

[13] A.O. Nwajana, K.S.K. Yeo and A. Dainkeh, "Low cost SIW Chebyshev bandpass filter with new input/output connection", Proc. 16th Mediterranean Microwave Symposium, Abu Dhabi, U.A.E., pp. 1–4, Nov. 2016.

[14] A.O. Nwajana, Dual-band microwave filter for WiMax application, 1st ed., Lambert Academic Publishing, Riga, Latvia, 2020.

[15] J.-S. Hong, *Microstrip filters for RF/microwave applications*, 2nd ed., Wiley, New York, 2011.

[16] A.O. Nwajana, G.K. Ijemaru, K.L.-M. Ang, J.K.P. Seng and K.S.K. Yeo, "Unbalanced two-way filtering power splitter for wireless communication systems", *Electronics MDPI*, Vol. 10, No. 617, pp. 1–9, Mar. 2021.

[17] P. Deng, W. Lo, B. Chen, and C. Lin, "Designs of diplexing power dividers", *IEEE Access*, Vol. 6, pp. 3872–3881, Jan. 2018.

[18] G. Zhang, Z. Qian, and J. Yang, "Design of a compact microstrip power-divider diplexer with simple layout", *Electronics Letters*, Nol. 54, No. 16, pp. 1007–1009, Aug. 2018.

[19] C. Chen, K. Zhou, R. Chen, Z. Wang, and Y. He, "Design of a microstrip diplexer-integrated filtering power divider", *IEEE Access*, Vol. 7, pp. 106514–106520, Aug. 2019.

[20] C. Zhu, and J. Zhang, "Design of diplexer-integrated filtering power divider with high isolation", *Microwave and Optical Technology Letters*, Vol. 61, No. 11, pp. 2607–2613, Mar. 2019.