Novel Analysis and Design of Size-Reduction Microwave Devices with Periodic Structures Using Equivalent Transmission-Line Models and Meta-Smith Charts

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***Abstract*— Quarter-wave transformers (QWTs) have been widely employed in microwave and antenna applications. In this paper, the graphical and theoretical analysis and design show that properly designed conjugately characteristic-impedance transmission lines (CCITLs), called quarter-wave-like transformers (QWLTs), can provide the impedance matching capability like standard QWTs but with significantly shorter electrical length. Design procedures of QWLTs using the Meta-Smith charts (MSCs) are illustrated. A design example is discussed to illustrate an application of QWLTs.**

***Index Terms*— conjugately characteristic-impedance transmission line; quarter-wave transformer; quarter-wave-like transformer; miniaturization; Meta-Smith charts.**

I. Introduction

A quarter-wave transformer (QWT) is a simple and useful circuit component employed to match a real load impedance to a lossless transmission line (TL), and is implemented in several useful microwave devices. Due to their physical requirement of having a fixed electrical length at an operating frequency, standard QWTs used in designing microwave devices are relatively large, especially at lower frequencies.

In recent years, several concepts involving periodic structures have been proposed to miniaturize QWTs; e.g., slow-wave periodic structures. Note that periodic TL structures can be efficiently modeled using an equivalent TL, called a conjugately characteristic-impedance TL (CCITL), which has been studied in detail in [1]. In this paper, it is shown, analytically and graphically, that properly designed CCITLs, called quarter-wave-like transformers (QWLTs), can match an arbitrary real load to an arbitrary lossless TL using shorter electrical length than that of standard QWTs. These QWLTs can potentially replace standard QWTs, and can be employed to significantly miniaturize microwave and antenna components.

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II. Theoretical Design of QWLTs

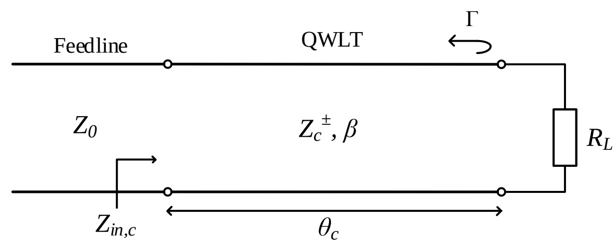


Fig.1 A QWLT matching circuit.

Consider the QWLT matching circuit in Fig. 1. A load resistance R_L and a feedline of characteristic impedance Z_0 are given and connected through a QWLT implemented using a properly designed reciprocal CCITL of unknown characteristic impedances $Z_c^{\pm} = |Z_c^{\pm}| e^{\mp j\phi}$, ($|Z_c^{\pm}|$ and ϕ denote their magnitude and phase, respectively) and of unknown electrical length θ_c. Using the matching condition at the input of the QWLT, it can be rigorously shown that the unknown magnitude $|Z_c^{\pm}|$ for a given ϕ can be found as [2]

$$|Z_c^{\pm}| = \sqrt{Z_0 R_L}, \quad (1)$$

which is surprisingly the well-known formula of the QWT case. In addition, the unknown θ_c is given as

$$\theta_c = \tan^{-1}\left(-\frac{R_L - Z_0}{R_L + Z_0}\cot\phi\right), \quad (2)$$

when $R_L > Z_0$ if a given ϕ is negative or vice versa, whereas

$$\theta_c = \tan^{-1}\left(-\frac{R_L - Z_0}{R_L + Z_0}\cot\phi\right) + \pi, \quad (3)$$

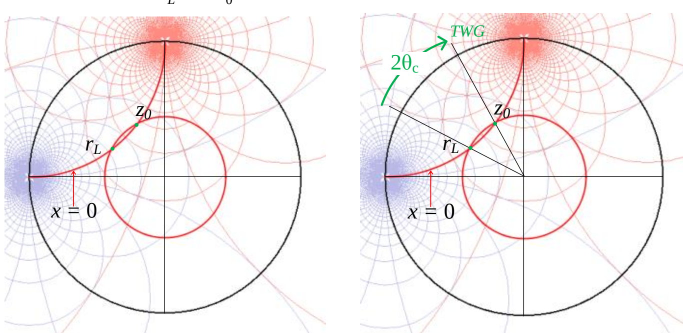
when $R_L < Z_0$ if a given ϕ is negative or vice versa. For given Z_0, R_L, and ϕ, QWLTs can be readily designed by solving for two unknowns $|Z_c^{\pm}|$ and θ_c using (1) to (3).

III. Graphical Design of QWLTs

The analytical approach in Section II does not provide intuitive solutions. In order to assist in the analysis and design of QWLTs, the Meta-Smith charts (MSCs) are used as a graphical tool providing an additional physical insight. The design procedure of QWLTs using the MSCs can be systematically divided into two steps as follows:

1. Select an appropriate value of ϕ for $\theta_c < 90^\circ$ and locate the normalized Z_0 and R_L (z_0 and r_L, respectively) using (1) on an MSC as shown in Fig. 2(a).
2. Draw a circle passing through both z_0 and r_L, and read θ_c from the MSC in the toward-generator (TWG) direction as shown in Fig. 2(b).

In order to make $\theta_c < \theta_{QWT}$, where θ_{QWT} is the electrical length of QWT and is equal to 90° at the operating frequency, an appropriate value of ϕ is required; i.e., a negative ϕ is chosen when $R_L > Z_0$, or vice versa.

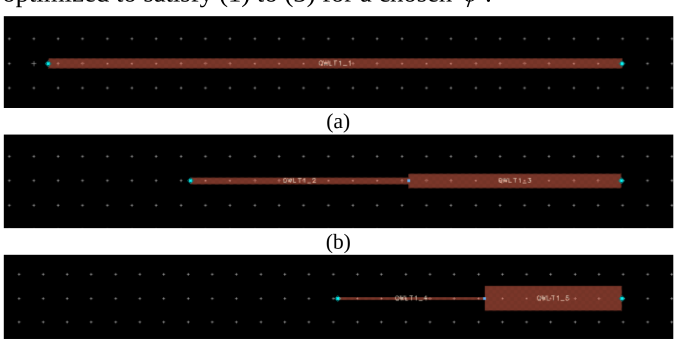


(a) (b)

Fig. 2. The two-step design procedure of QWLTs using the MSC.

IV. Design Example

In this section, QWLTs are synthesized using two-section TLs. Each QWLT is initially designed using the stepped-impedance low-pass filters [3], and then numerically optimized to satisfy (1) to (3) for a chosen ϕ.



(a)

(b)

(c)

Fig. 3. Microstrip layout of (a) QWT. (b) QWLT with length-reduction of 25%. (c) QWLT with length-reduction of 50%.

For matching a 50 Ω feedline to a 100 Ω load, Figure 3(a) to (c) illustrates the microstrip layouts using the RT/duroid® 5880 of a QWT and two QWLTs with the length reduction of 25% and 50%, respectively. Their bandwidth performance compared with that of the QWT is illustrated in Fig. 4. It is found that the bandwidth of QWLTs are close to that of QWT with slight decrease for more length reduction. Thus, QWLTs can be used to replace QWTs in some applications.

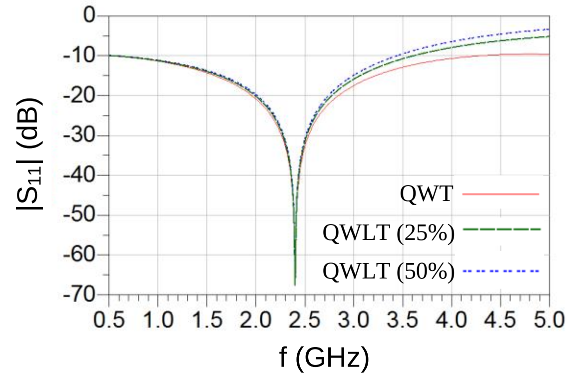


Fig. 4. Bandwidth performance of the two QWLTs compared to that of QWT.

In the future, QWLTs will be applied to design multisection matching transformers for a broader bandwidth application. In addition, they can be used in the design of size-reduction microwave devices such as power dividers, directional couplers, microwave filters and phase reversal antennas.

V. MTT-S Scholarship Experience and Future Plans

The MTT-S Scholarship has been a great motivation for me as a student. It allowed me to join the 2016 Thai-Japan MicroWave Conference (TJMW 2016) for which I received a best presentation award [4] and met many Thai and Japanese professors, industry professionals and other students. In addition, I will present my accepted paper in the 2016 International Conference on Electrical Engineering/ Electronics, Computer, Telecommunications and Information Technology (ECTI-CON 2016) [5].

Upon graduation, I will join industry by working as a design and development engineer at Celestica (Thailand) Ltd. During my employment there, I will conduct a self-study in other advanced microwave courses to prepare myself for my graduate study abroad in the area of microwave and RF. After I finish studying my Ph.D., I plan to become a successful researcher and an educator performing useful and productive microwave research to benefit both Thailand and the international community.

References

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