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Convert Microwave Circuits Into Useful L-C Circuits

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The conversion of microwave circuits into useful L-C circuits is achieved using pi- or tee-network equivalents of transmission lines. This facilitates miniaturization, cost reduction, and sometimes provides supplementary filtering. This note is a combination of tutorial and historical information.

The classic microwave three half wavelength hybrid ring was converted into an L-C version almost 40 years ago [1]. Subsequently, this design technique was applied to other microwave circuits such as quadrature hybrids, quarter-wave coupled band-reject filters, Wilkinson dividers, and multi-quarter-wave transformers. The advantage of supplementary filtering was recognized many years after the original paper.

Hybrid Ring

In 1962 [1], a lumped-circuit equivalent of the microwave three half wavelength hybrid ring was designed, fabricated and tested. The design center frequency was 6 MHz and the impedance level was 50 ohms. Center frequency isolation greater than 45 dB was obtained. This is consistent with inductor unloaded Qs slightly less than 100. Inductor quality places limits on the achievable hybrid ring performance.

In 1965 [2], a lumped-circuit equivalent of the microwave hybrid ring was designed, fabricated, and tested. This hybrid was used in a VHF transistor power amplifier. The design center frequency was 131.25 MHz and the impedance level was 50 ohms. The hybrid had to handle 10 watts of power and the air core inductors used heavy buss wire. The actual hybrid was a modified unit where the two grounded parallel resonators were omitted.

In 1989 [3], a lumped-circuit equivalent of the three half wavelength hybrid ring was designed for MMIC applications at 7.95 GHz. Some measurements were made and the unloaded Q limitations of printed circuit spiral inductors were cited. With the advent of MMICs and digital data processing at microwave frequencies, important and useful technical information was presented.

Band-Reject Filter

In 1989 [4], the quarter-wave coupled microwave band-reject filter was designed as an L-C circuit using pi-section equivalents of the quarter-wave connecting line. A three resonator top-C coupled band-reject filter was designed, constructed and tested. The filter had a center frequency of 60 MHz, three dB bandwidth of 3 MHz, and source/load impedances of 50 ohms. Supplementary low pass filtering was achieved between 99 and 240 MHz.

Quadrature Hybrid

In 2001 [5], a quadrature hybrid (also called branch line coupler) was designed as an L-C circuit using pi-section equivalents of quarter-wave lines. The hybrid was designed for a center frequency of 60 MHz and an impedance level of 50 ohms. Simulated hybrid performance prediction showed appreciable supplementary low pass filtering above 90 MHz. This quadrature hybrid used only two branch lines and is inherently narrow band. Broader bandwidths can be obtained by using more than two branch lines.

Wilkinson Power Divider

In 2002 [6], various Wilkinson power dividers were designed, constructed and tested at frequencies near 1 GHz, with 50 ohms impedance levels. Quarter-wave lines were replaced by their L-C pi equivalents. Microstrip construction was employed using FR-4 substrates with dielectric constant of 4.3 and thickness of 1 millimeter. Supplementary low pass filtering has been cited.

Multi-Quarter-Wave Transformer

In 2003, an L-C transformer was designed at 10 MHz [7] using the pi equivalents of a known transmission line transformer double-quarter-wave transformer [8]. L-C transformers obtained directly via network synthesis [9, 10] are viable alternative designs. The distributed low pass filter prototype [11] could also be a useful starting point for L-C transformer design.

Summary

L-C equivalents of microwave circuits can be achieved readily using the pi and tee equivalents of transmission lines. This usually achieves significant miniaturization at relatively low operating frequencies that would require a physically large microstrip layout. By employing modern automated manufacturing using surface mount components, appreciable cost savings also can be realized. The subject technique can be helpful in ultimate integration of complex systems and subsystems on a single semiconductor chip.

The L-C equivalents of TEM microwave circuits have replaced the relatively non-dispersive microwave circuits with L-C circuits that are inherently dispersive. This results in L-C circuits that can provide useful supplementary filtering. The computer-aided simulation of some of these circuits uses the classic method of analysis [12] which employed even and odd modes to characterize symmetrical four port circuits.

References

1. R. M. Kurzrok, "Design Technique for Lumped-Circuit Hybrid Ring," *Electronics,* May 18, 1962.

2. R. M. Kurzrok, S. J. Mehlman, and A. Newton, "Hybrid-Coupled VHF Transistor Amplifier," *Solid State Design,* pp. 2-6, August 1965.

3. S. J. Parisi, "A Lumped Element Rat Race Coupler," *Applied Microwave,* pp. 130-135, August/September 1989.

4. R. M. Kurzrok, "Band-Reject Filter Provides Supplementary Low Pass Filtering," *RF Design,* pp. 54, 56, October 1999 plus errata p. 16, November 1999.

5. R. M. Kurzrok, "Lumped Element Quadrature Hybrid Provides Supplementary Low Pass Filtering," *Applied Microwave & Wireless,* pp. 88, 90, May 2001.

6. F. Noriega and P. J. Gonzalez, "Designing LC Wilkerson Power Splitters," *RF Design,* pp. 18, 20, 22, 24, August 2002.

7. R. M. Kurzrok, "L-C Transformer Cuts Cost and Size, Adds Low-Pass Filtering," *Electronic Design,* pp. 57-58, July 21, 2003.

8. G. L. Matthaei, L. Young, and E. M. T. Jones, "Microwave Filters, Impedance Matching Networks, and Coupling Structures," McGraw-Hill, Chapter 6, 1964.

9. G. L. Matthaei, "Tables of Tchebychev Impedance Transforming Networks of Low-Pass Filter Form," *Proc. IEEE,* Vol. 52, pp. 939-963, August 1964.

10. E. C. Cristal, "Tables of Maximally Flat Impedance Trans-forming Networks of Low-Pass Filter Form," *IEEE Trans. MTT,* Vol. MTT-13, pp. 693-695, Sept. 1965.

11. R. Levy, "Tables of Element Values for the Distributed Low-Pass Prototype Filter," *IEEE Trans MTT,* Vol. MTT-13, pp. 514-536, Sept. 1965.

12. J. Reed and G. J. Wheeler, "A Method of Analysis of Symmetrical Four-Port Networks," *IRE Trans. MTT,* Vol. MTT-4, pp. 246-252, October 1956.

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It is acknowledged that this microwave-to-lumped element design technique is quite simple and has been certainly been used by others whose work has not been referenced herein.

About the Author

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