# Efficient Methods for Novel Passive Structures in Waveguide and Shielded Transmission Line Technology

by

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*To my dearest father and mother,*
*with all my love.*

# Contents

# Abstract

With the rapid development of microwave and millimetre-wave systems, the performance requirements for passive band-pass filters and diplexers, as essential parts in these systems, are steadily increasing. Both rectangular waveguide and substrate-integrated waveguide technologies help to satisfy various high-performance requirements. Rectangular waveguides offer the advantages of low loss and high power handling capabilities, while substrate-integrated waveguides have the advantages of low cost and easy integration into planar circuit technology. Besides, the miniaturisation of electronic devices is of great importance, especially for microwave or millimetre-wave systems whose volume is limited by system considerations. Hence, the two main aims of this thesis are firstly to develop efficient methods which can improve the design reliability and reduce the design cycle of such passive devices, and secondly to present novel structures of band-pass filters and diplexers whose dimensions are reduced.

In the first part of the thesis, a method based on the mode-matching technique is developed to rigorously and efficiently analyse the negative influence introduced by micromachining errors on the performance of band-pass H-plane iris filter. This analysis includes the effect on the centre frequency and 3 dB bandwidth caused by the round angles between waveguide walls and H-plane irises, or by the bevel angles on the H-plane irises. To remove these undesired influences, three approaches are proposed and verified with simulations performed with the finite-element method.

In the next part, efficient approximation approaches are investigated in the framework of the mode-matching method to analyse the characteristics of cylindrical posts placed in the cross-section of a rectangular waveguide or substrate-integrated waveguide. Compared with the H-plane irises in rectangular waveguides, cylindrical posts are more promising for realising band-pass rectangular waveguide filters, because the geometries are easier to manufacture and less prone to machining errors. Thus, a general design procedure for band-pass post filters in rectangular waveguides and substrate-integrated waveguides is developed and verified with finite-element simulations and measurements on prototypes. The tolerance analysis for the band-pass filters is also explored quickly and accurately with the developed method, while the influence of realistic material losses on the insertion loss of various structures, is also quantitatively

analysed with a full-wave simulation solver.

Next, the characteristics of a shielded microstrip line for single-mode operation is investigated rigorously based on the mode-matching method. The research focuses on the influence of the metal enclosure dimensions on the fundamental mode, and the relationships between the cutoff frequency of the $2^{nd}$-order mode and the geometrical variables of the cross-section of the shielded transmission line. A similar method is then applied to an E-type folded substrate-integrated waveguide. The analysis demonstrates that the propagation characteristics for the first twenty modes in the E-type folded substrate-integrated waveguide and its corresponding equivalent rectangular waveguide are almost identical if the width of the middle metal vane in the E-type folded substrate-integrated waveguide is chosen reasonably. Exploiting this similarity property, a novel concept of band-pass post filter in E-type folded substrate-integrated waveguide technology is developed to reduce the band-pass filter dimension further, together with an efficient specific design procedure. The validity of the approach is verified via finite-element simulations and measurements on a fabricated prototype.

Finally, to reduce the sizes of common diplexers, four types of novel three-port junctions are proposed, including two improved Y-junctions in substrate-integrated waveguide technology, a double-layer junction in substrate-integrated waveguide technology, a Y-junction in T-type folded substrate-integrated waveguide technology, and a junction with stairs in T-type and E-type folded substrate-integrated waveguide technology. Exploiting the flexibility of the in-house developed mode-matching code or a commercial finite-element simulation solver, the characteristics for all presented junctions are shown to satisfy the constraints for optimum performance of diplexers when adjusting the relevant variables in the corresponding structures. Three types of these junctions are then utilised in realising diplexers whose performance is verified over the required operation bands with either numerical simulations or measurements on fabricated prototypes.

In summary, this thesis has introduced novel concepts and realisations of compact band-pass filters and diplexers in unfolded or folded substrate-integrated waveguide technology, as well as related structures. One of the crucial aspects emphasised throughout the research is the need for efficient and accurate modelling methods specifically tailored to support such developments. This has been demonstrated throughout the thesis with the combined use of powerful numerical methods and equivalent models based on symmetries or unfolded geometries.

# Statement of Originality

I certify that this work contains no material, which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Signed Date

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Cheng Zhao,
March 2016,
Adelaide

# Thesis Conventions

The following conventions have been adopted in this Thesis:

## Typesetting

This document was compiled using LaTeX2e. Texmaker and TeXstudio were used as text editor interfaced to LaTeX2e. Inkscape and Xcircuit were used to produce schematic diagrams and other drawings.

## Referencing

The Harvard style has been adopted for referencing.

## System of units

The units comply with the international system of units recommended in an Australian Standard: AS ISO 1000–1998 (Standards Australia Committee ME/71, Quantities, Units and Conversions 1998).

## Spelling

Australian English spelling conventions have been used, as defined in the Macquarie English Dictionary (A. Delbridge (Ed.), Macquarie Library, North Ryde, NSW, Australia, 2001).

# Publications

## Journal Articles

ZHAO-C., FUMEAUX-C., AND LIM-C. C. (2016b). Substrate-Integrated Waveguide (SIW) Diplexers with Improved Y-junctions, *Microwave and Optical Technology Letters*, **58**(6), pp. 1384–1388.

## Conference Articles

**ZHAO-C.**, FUMEAUX-C., AND LIM-C. C. (2016a). Folded Y-junction in Substrate-Integrated Waveguide Technology, *The 2nd Australian Microwave Symposium*.

**ZHAO-C.**, FUMEAUX-C., KAUFMANN-T., ZHU-Y., AND LIM-C. C. (2015b). Mode Matching Analysis of Dimension for Single-Mode Operation of Shielded Microstrip Lines, *2015 Asia-Pacific Microwave Conference (APMC)*, Vol. 2, pp. 1–3.

**ZHAO-C.**, FUMEAUX-C., AND LIM-C. C. (2015a). Losses in Substrate Integrated Waveguide Band-Pass Post Filters, *2015 Asia-Pacific Microwave Conference (APMC)*, Vol. 2, pp. 1–3.

**ZHAO-C.**, FUMEAUX-C., KAUFMANN-T., ZHU-Y., HORESTANI-A. K., AND LIM-C.-C. (2015c). General Design Method for Band-pass Post Filters in Rectangular Waveguide and Substrate Integrated Waveguide, *International Symposium on Antennas and Propagation (ISAP2015)*, pp. 946–949.

**ZHAO-C.**, KAUFMANN-T., ZHU-Y., AND LIM-C. C. (2014a). Approximation Methods for Cylindrical Posts in Rectangular Waveguides with Mode Matching Technique, *2014 IEEE Asia-Pacific Conference on Applied Electromagnetics (APACE)*, pp. 179–182.

**ZHAO-C.**, KAUFMANN-T., ZHU-Y., AND LIM-C. C. (2014b). Efficient Approaches to Eliminate Influence Caused by Micro-Machining in Fabricating H-Plane Iris Band-Pass Filters, *2014 Asia-Pacific Microwave Conference (APMC)*, pp. 1306–1308.

## Article in Review

ZHAO-C., FUMEAUX-C., AND LIM-C. C. (n.d.). Folded Substrate-Integrated Waveguide Band-pass Post Filter, *IEEE Microwave and Wireless Components Letters*. Accepted on 1 July 2016, Subject to revision.

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