MODIFIED PARALLEL COUPLED LINE FILTER FOR WIFI APPLICATION

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

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ABSTRACT

Wireless Local Area Network (WLAN) is a network that allows different devices to communicate and connect without wire. The common application for WLAN in daily life is Wireless Fidelity (WiFi). Most devices, such as mobile phones, laptops, smartwatches, and some Internet of Things (IoT) devices support a WiFi connection. Recently, the technology WiFi 6 has been introduced which has a standard of 802.11ax. The operating frequency of WiFi 6 is 5 GHz with a bandwidth of 160 MHz. In the RF front end, a filter is very important in to filter out the unwanted signal and influence the performance of applications. A parallel coupled line (PCL) bandpass filter is one of the filters that can be used in WiFi transceiver, which has low cost and flexible layout and easy fabrication. Conventional PCL bandpass filter has large size at a higher order and slow attenuation level in stop band at a lower order. Hence, the main objective of this project is to design a PCL bandpass filter with a small size and have good attenuation performance at the stop band. This can be achieved by adding extra stub of coupled line and a quarter wavelength line for low order PCL filter to form transmission zero at upper and lower stopband. The proposed PCL bandpass filter support for WiFi 6 at 5GHz. The conventional PCL and proposed PCL bandpass filter are designed by manual calculation. Simulation and optimization are done by using CST and ADS softwares. The proposed filter is fabricated and comparison of conventional and proposed PCL bandpass filter based on size and performance are discussed. The proposed PCL bandpass filter has better performance in stopband rejection level and the area taken in planar is smaller.

ABSTRAK

Rangkaian Kawasan Setempat Tanpa Wayar (WLAN) ialah rangkaian yang membenarkan peranti berbeza berkomunikasi dan bersambung tanpa wayar. Aplikasi biasa untuk WLAN dalam kehidupan seharian ialah Wireless Fidelity (WiFi). Kebanyakan peranti, seperti telefon mudah alih, komputer riba, jam tangan pintar dan beberapa peranti IoT menyokong sambungan WiFi. Terkini, teknologi WiFi ialah WiFi 6 yang mempunyai standard 802.11ax. Frekuensi operasi WiFi 6 ialah 5 GHz dengan lebar jalur 160 MHz. Penapis sangat penting dalam komunikasi tanpa wayar untuk menapis isyarat yang tidak diingini dan mempengaruhi prestasi aplikasi. Penapis laluan jalur gandingan selari (PCL) ialah salah satu penapis yang boleh digunakan dalam transceiver WiFi, yang mempunyai kos rendah dan susun atur fleksibel serta fabrikasi yang mudah. Penapis laluan jalur PCL konvensional mempunyai saiz yang besar pada susunan yang lebih tinggi dan tahap pengecilan perlahan dalam jalur henti pada susunan yang lebih rendah. Oleh itu, objektif utama projek ini adalah untuk mereka bentuk penapis laluan jalur PCL dengan saiz yang kecil dan mempunyai prestasi pengecilan yang baik pada jalur henti. Ini boleh dicapai dengan menambah stub tambahan bagi talian berganding dan garis suku panjang gelombang untuk penapis PCL tertib rendah untuk membentuk sifar penghantaran pada jalur henti atas dan bawah. Penapis laluan jalur PCL direka untuk WiFi 6 pada 5 GHz. PCL konvensional dan penapis laluan jalur PCL yang dicadangkan direka bentuk dengan pengiraan manual. Simulasi dan pengoptimuman dilakukan dengan menggunakan perisian CST dan ADS. Fabrikasi akan dilakukan untuk penapis yang dicadangkan. Perbandingan penapis laluan jalur PCL konvensional dan cadangan berdasarkan saiz dan prestasi akan dibincangkan. Hasil yang dijangkakan untuk projek ini ialah penapis laluan jalur PCL yang dicadangkan mempunyai prestasi yang lebih baik dalam tahap penolakan jalur henti dalam graf S_{21} dan kawasan yang diambil dalam planar adalah lebih kecil.

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LIST OF ABBREVIATIONS

WiFi	-	Wireless Fidelity
PCL	-	Parallel Coupled Line
TEM	-	Transverse electromagnetic (TEM) modes
EM	-	Electro Magnetic
ADS	-	Advanced Design System
CST	-	CST Studio Suite
WLAN	-	Wireless Local Area Network
FBW	-	Fractional Bandwidth

LIST OF SYMBOLS

λ	-	Wavelength
f_c	-	Centre Frequency
ε_r	-	Relative permittivity
ε_{eff}	-	Effective permittivity
$tan\ \delta$	-	Loss tangent
π	-	Pi
H	-	Hight of Substrate
T	-	Thickness of Copper

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

In the 21st century, communication technology has become an integral part of people's lives. Especially for wireless communication makes human life much more convenient due to it requiring no wire and can operate at a certain distance. WLAN (Wireless local area network) has been installed in different environments in a city such as universities, homes, hospitals, shopping malls or even on a train and airplane. 802.11 is one of the standards for WLAN, which also can be called WiFi. Compared to wireless mobile telecommunications technology, WiFi has faster speed and lower cost. Hence, people prefer to use WiFi if it is available in their area. According to the Global - 2021 Forecast Highlights - Cisco, 51.6% of total internet traffic was taken by WiFi in 2016 and it forecast the WiFi will take up 52.6% of total internet traffic in 2021[1]. The current and predict data of WiFi internet traffic illustrate that WiFi takes up most of internet traffic and keeps increasing.

WiFi networks are commonly regarded as infrastructure that is equally as important as water and electricity. WiFi 5 is enabled by 802.11ac technology. It was published in December 2013 as the fifth generation of WiFi networking standards. The standard operating frequency is 5 GHz, with bandwidth sectors of 20, 40, 80 and 160 MHz. The recent technology for WiFi is WiFi 6, which has standard 802.11 ax and can also operate at 5 GHz with 20, 40, 80 and 160 MHz bandwidth [2].

Microwave filter is an essential part of the microwave communication system. The performance of filter will affect the signal quality of the entire communication system [3]. Hence, the signal quality of WiFi devices can be influenced by filter, hence designing a good filter for WiFi is significant to have better performance. Low cost and flexible layout and easy fabrication are the properties for Micro-strip filters.

Parallel coupled line (PCL) filters are the most commonly used Micro-strip filter [4] and it can be one of the choices to design WiFi filter. A perfect filter would have infinite attenuation in the stopband [5]. With the increase order of filter, the attenuation level is higher. But the filter size will increase at the same time.

1.2 Problem Statement

WiFi is the most commonly WLAN application. The most recent technology is WiFi 6, and it operates at 5 GHz with bandwidth up to 160 MHz. To have better performance, a good filter design is needed. Conventional band-pass PCL filter has a very low attenuation level at lower order. A high attenuation level aids a filter's ability to differentiate between signals of comparable frequency and it is generally seen as a desirable characteristic. The most common way to improve the attenuation level will require higher order which results in more couple lines needed and size will be larger, and it will take certain areas, which may lead to enlarge the WiFi devices size. Hence, it needed to design a PCL filter which has less size compared to conventional filter.

1.3 Research Objectives

The objectives of the research are:

1. To design, simulate and fabricate the proposed filter which support for WiFi 6 and have good attenuation level.

2. To compare the performance of the proposed filter with the 1st and 3rd order conventional PCL filters.

1.4 Scope of Project

The scope of this project is to design a modified first-order PCL filter. This modified filter incorporated an extra coupled line with a quarter wavelength transmission lane, which produces two transmissions zero symmetry to center frequency and improves the attenuation level. In this project, the PCL filter is chosen because of easy fabrication as compared to market filter. ADS circuit simulation and CST EM simulation software is used to achieve the goal, which is to make size reduction of 3rd order conventional filter. The proposed and the conventional filter performance will be executed in this project. Circuit fabrication of the proposed PCL filter is done for verification purpose.

REFERENCES

[1] Cisco and/or its affiliates. (2016). Global - 2021 Forecast Highlights - Cisco.

[2] Jain, R., Tiwari, N., & Yadav, M. (2020). A COMPARISON STUDY OF WIFI 6 AND WIFI 5. choice, 5, 6.

[3] LI, M., Peng, Y., Zhang, Y., Han, X., Chen, R., Wang, B., & Zhu, X. (2017). A high-selectivity Microstrip Band-pass Filter. Proceedings of the 2017 2nd International Conference on Control, Automation and Artificial Intelligence (CAAI 2017). doi:10.2991/caai-17.2017.42

[4] Velidi, Vamsi & Sanyal, Subrata. (2010). Sharp-rejection microstrip bandpass filters with multiple transmission zeros. Aeu-international Journal of Electronics and Communications - AEU-INT J ELECTRON COMMUN. 64. 1173-1177. 10.1016/j.aeue.2010.01.015.

[5] David M. Pozar, Microwave Engineering, John Wiley Son

[6] V. Van and V. Van, *Analog filter Design*. Holt Rinehart and winston, 1982.

[7] Jan Zehentner, Jan Mrkvica, Jan Machac, "Spectral Domain Analysis of Open Planar Transmission Lines," Europe, 2009.

[8] R S, Beere & Khan, Am & Reddy, Manjunatha. (2015). Global Journal of Trends in Engineering Simulation Study on Insertion and Return Loss of Planar Transmission Lines for Different Dielectric Substrates. Global Journals of Trends in Engineering. 2.

[9] Awan, F. and N. A. Sheikh. "DESIGN AND IMPLEMENTATION OF AN OPTIMIZED J-BAND MICRO- STRIP SYMMETRIC COUPLED LINE BAND PASS FILTEr." (2015).

[10] M. Abdulhamid and A. Mugambi, "Design of 2.4 GHz Microwave Bandpass Filter," *Journal of Siberian Federal University. Engineering & Technologies*, pp. 773–779, 2019.

[11] Srinath, Mr. (2016). Design of 3rd Order Coupled Line Bandpass Filter for Wireless Application using Agilent ADS. 10.15680/IJIRSET.2016.0507034.

[12] Seghier, Salima & Benahmed, Nasreddine & Benabdallah, Nadia. (2012). Parallel Coupled Microstrip Bandpass Filter for G.S.M Band Applications. 2. 119-122.

[13] Temes, Gabor C.; LaPatra, Jack W. (1977). Circuit Synthesis and Design. McGraw-Hill. ISBN 0-07-063489-0.

[14] C. Chen, "A Coupled-Line Coupling Structure for the Design of Quasi-Elliptic Bandpass Filters," *in IEEE Transactions on Microwave Theory and Techniques*, vol. 66, no. 4, pp. 1921-1925, April 2018, doi: 10.1109/TMTT.2017.2783378.

[15] Li, D, Wang, J-A, Liu, Y, Chen, Z, Yang, L. Compact quasi-elliptic bandpass filter with high selectivity using short-circuited coupled line. *Microw Opt Technol Lett.* 2019; 61: 2873–2878.

[16] çakir, G. & Cimen, Sibel & Sevgi, Levent. (2006). A Matlab-based Filter Design Tool Using the Analogy between Wave and Circuit Theories. 10.1007/3-540-30636-6_15.

[17] Sheikh, Tasher & Borah, Janmoni & Roy, Sahadev. (2014). Bandwidth Improvement in BPF using Microstrip Couple lines. 10.13140/2.1.3254.6881.

[18] Yousaf, Jawad & Mehmood, Z. & Nah, Wansoo. (2017). Comparison of microstrip coupler simulation in different electromagnetic solvers and circuit simulator. International Journal of Microwave and Optical Technology. 12. 294-301.

[19] Chin, Kuo-Sheng & Ma, Ming-Chuan & Chen, Yi-Ping & Chiang, Yi-Chyun. (2008). Closed-Form Equations of Conventional Microstrip Couplers Applied to Design Couplers and Filters Constructed With Floating-Plate Overlay.

[20] Microwave Theory and Techniques, IEEE Transactions on. 56. 1172 - 1179. 10.1109/TMTT.2008.921672. B. Easter, and K. A. Merza, “Parallel-coupled-line filters for invertedmicrostrip and suspended-substrate MIC’s,” 11th Eur. Microwave Conf. Dig., pp. 164–167, 1981.

[21] Riddle, “High performance parallel coupled microstrip filters,” IEEE MTT-S Int. Symp. Dig., pp. 427–430, 1988.

[22] S. L. March, “Phase velocity compensation in parallel-coupled microstrip,” IEEE MTT-S Int. Symp. Dig., pp. 410–412, 1982.

[23] I. J. Bahl, “Capacitively compensated high performance parallel coupled microstrip filters,” IEEE MTT-S Int. Symp. Dig., pp. 679–682, 1989.

[24] Yang, F.; Rahmat-Samii, Y. (2008), "Electromagnetic band gap structures in antenna engineering", Cambridge University Press, ISBN: 9780511754531, doi:10.1017/CBO9780511754531

[25] Tiwary, Anjini & Gupta, Nisha. (2011). Design of Compact Coupled Microstrip Line Band Pass Filter with Improved Stopband Characteristics. Progress In Electromagnetics Research C. 24. 145-155. 10.2528/PIERC11081201.

[26] F. Karshenas, A. R. Mallahzadeh and J. Rashed-Mohassel, "Size reduction and harmonic suppression of parallel coupled-line bandpass filters using defected ground structure," 2009 13th International Symposium on Antenna Technology and Applied Electromagnetics and the Canadian Radio Science Meeting, 2009, pp. 1-6, doi: 10.1109/ANTEMURSI.2009.4805078.

[27] B. Pal and S. Dwari, "A compact parallel coupled wideband bandpass filter with DGS and spurline," 2015 International Conference on Microwave and Photonics (ICMAP), 2015, pp. 1-2, doi: 10.1109/ICMAP.2015.7408705.

[28] Piscarreta, D. and Ting, S.-W. (2008), Microstrip parallel coupled-line bandpass filter with selectivity improvement using U-shaped defected ground structure. Microw. Opt. Technol. Lett., 50: 911-915.

[29] Breed, Gary. (2008). An Introduction to Defected Ground Structures in Microstrip Circuits. High Freq Electron. 7.

[30] Cai, P., Guan, X., Yang, X., Zhang, Y., Chen, B., Huang, J., & Wu, Y. (2009). Wideband bandpass filter using parallel-coupled line and step-impedance open stubs. 2009 3rd IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, 1047-1049.

[31] Z. I. Khan, M. K. Mohd Salleh, Gaetan Prigent., “Achievable bandwidth of a quarter wavelength side-coupling ring resonator,” IEEE Symposium on Ind. Electronics and Application (ISIEA 2009), pp. 358-361, Oct 2009.

[32] Hung, Cheng-Yuan & Weng, Min-Hang & Yang, Ru-Yuan & Su, Yan-Kuin. (2007). Design of the Compact Parallel Coupled Wideband Bandpass Filter With Very High Selectivity and Wide Stopband. Microwave and Wireless Components Letters, IEEE. 15. 510 - 512. 10.1109/LMWC.2007.899312.

[33] Parthasarathy Ramanujam, Chandrasekar Arumugam, Ramesh Venkatesan P G & Manimaran Ponnusamy (2020) Design of Compact UWB Filter Using Parallel-coupled Line and Circular Open-circuited Stubs, IETE Journal of Research, DOI: 10.1080/03772063.2020.1803772

[34] Xu, K.D., & Zhang, F. (2019). High Selectivity Bandpass Filter Using Three Pairs of Coupled Lines Loaded with Shorted Stubs.