MILIMETER-WAVE BANDPASS FILTER FOR RADIO OVER FIBER APPLICATION

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To my beloved family and friends

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ABSTRACT

Radio over fiber (RoF) technology is a promising option to deliver high speed broadband networks as it capable of delivering high data rate transmission, has low attenuation, immune to radio frequency interference (RFI) and simple design of remote antenna unit (RAU). Milimeter-wave on the other hand is in the range 30 GHz to 300 GHz and offers higher bandwidth compared to lower RF frequency. The adoption of millimeter-wave in RoF technology will enhance its ability to deliver high speed broadband by utilizing the benefits of RoF and millimeter-wave. Millimeter-wave bandpass filter has been design in this project for frequency range of 40 GHz to 42 GHz as part of the RAU design. The designed bandpass filter will be fabricated using low temperature co-fired ceramic (LTCC) technology that will enable compact and flexible bandpass filter design.

ABSTRAK

Teknologi radio melalui fiber merupakan satu alternatif yang baik untuk penghantaran jalur lebar berkelajuan tinggi, di mana ia mampu menghantar data pada kadar transmisi yang tinggi, mempunyai pengecilan isyarat yang rendah, imun kepada gangguan isyarat frekuensi radio dan rekabentuk unit antena yang lebih ringkas (RAU). Gelombang milimeter adalah pada julat frekuensi di antara 30 GHz dan 300 GHz, dan menawarkan jalur lebar yang lebih tinggi berbanding yang ditawarkan oleh frekuensi RF. Penggunaan gelombang millimeter dalam teknologi radio melalui fiber akan meningkatkan kebolehannya untuk menghantar jalur lebar berkelajuan tinggi dengan memanfaatkan kelebihan radio melalui fiber dan gelombang millimeter. Penyaring 'bandpass' gelombang millimeter telah direka dalam projek ini pada julat frekuensi antara 40 GHz dan 42 GHz yang merupakan sebahagian daripada unit antena. Penyaring yang telah direka ini akan difabrikasi menggunakan teknologi 'low temperature co-fired ceramic (LTCC)' yang akan membolehkan rekaan penyaring 'bandpass' yang lebih kompak.

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LIST OF ABBREVIATIONS

ADS	-	Advanced Design System
BPF	-	Bandpass Filter
CS	-	Control Station
DAS	-	Distributed Antenna System
dB	-	Decibel
FBW	-	Fractional Bandwidth
FSIW	-	Folded Substrate Integrated Waveguide
GHz	-	Gigahertz
HD	-	High Definition
IF	-	Intermediate Frequency
IL	-	Insertion Loss
LTCC	-	Low Temperature Co-fired Ceramic
LTE	-	Long Term Evolution
MAN	-	Metropolitan Area Network
MIMO	-	Multiple-input-multiple-output
MMF	-	Multimode Fiber
POF	-	Polymer Optical Fiber
QAM	-	Quadrature Amplitude Modulation
RAU	-	Remote Antenna Unit
RF	-	Radio Frequency
RFI	-	Radio Frequency Interference
RL	-	Return Loss
RN	-	Remote Node
RoF	-	Radio over Fiber
SIW	-	Substrate Integrated Waveguide

SMF	-	Single Mode Fiber
TEM	-	Transverse Electromagnetic
THz	-	Terahertz
VSWR	-	Voltage Standing Wave Ratio
WDM	-	Wavelength-division Multiplexing
WiFi	-	Wireless Fidelity
WiMAX	-	Worldwide Interoperability for Microwave Access

LIST SYMBOLS

Sij	-	S parameters
b	-	Reflected waves
a	-	Incident waves
g_n	-	Element of ladder type lowpass prototype with a normalized cut off Ω_c=1
$J_{j,j+1}$	-	Characteristic admittances of J-inverters
Y	-	Characteristic admittance of microstrip line
Π	-	PI
$B_{j,j+1}$	-	Series-capacitance discontinuities of susceptance
$\Delta l_j^{e1,e2}$	-	Effective lengths of shunt capacitances on both ends of resonator j
λ_{g0}	-	Guided wavelength
ω	-	Angular frequency
l	-	Physical length of resonators
$C_g^{j,j+1}$	-	Coupling capacitances
$C_p^{j\ j+1}$	-	Shunt capacitances

CHAPTER 1

INTRODUCTION

1.1 Project Overview

Internet has been extensively used nowadays, in line with the growth of mobile devices and applications which were facilitate by wired and wireless high speed broadband networks. As the subscribers increased, the bandwidth will be on demand and it would be not enough to cater subscribers' data usage at one time. High speed broadband networks are deployed either using wired or wireless medium. The wireless high speed broadband networks include the Enhanced Data Rates for GSM Evolution (EDGE), third generation (3G), High Speed Packet Access (HSPA), Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE) protocol. These wireless networks use the spectrum as its communication medium, which is subject to regulatory guidelines. Fiber to the x (FTTX) also has been widely deployed as a wired high speed broadband network. In FTTX, optical fiber has been used to provide all or part of the local loop for last mile telecommunications. The last mile could be to the home, desktop, node, cabinet, premises, building or telecom enclosure. Both wired and wireless has its' own benefits and also challenges.

The benefits of wireless network are the installation process is simple and fast compared to wired networks and it provides mobility to users. However, as the usage increase, the spectrum has become more congested, and the users are also exposed to radio frequency interference (RFI).

Optical fiber networks carry high bandwidth data at equal upstream and downstream specification, without much limitation on distances due to its low characteristics. However, the challenging part is the installation work because fiber optics are usually installed underneath streets or ground which took long period to complete and involve high cost budget.

Radio over fiber (RoF) is a technology whereby light is modulated by radio signal and transmitted over an optical fiber link to facilitate wireless access. The transmitted signal over the fiber link could be in the form of various protocols such as 3G and WiFi and it can be simultaneously received by the same antenna. These signals were sent to a central station (CS) where the light signals will be converted to radio signals by remote antenna unit (RAU), amplified and retransmitted through wireless medium by an antenna. Hence, frequency conversion is not required at base stations, resulting simpler remote antenna unit design.

RAU is connected to CS. RAU consist of photodiode, laser diode, bandpass filter (BPF), amplifier and antenna. Main function of RAU is to convert optical signal to wireless, done by photodiode or vice versa, which is done by laser diode. The BPF function is to pass frequencies within a certain range and attenuates frequencies outside the range. Various studies had been conducted on the BPF design for the millimeter-wave applications. The design includes the end-coupled, hairpin, substrate integrated waveguide (SIW) and stripline parallel coupled filter topologies.

The limited availability of radio frequency (RF) bands requires utilization of other frequency region and millimeter-wave is a good option because of the wide bandwidths available to support high speed transmission. The millimeter-wave spectrum is at 30GHz-300GHz frequency range.

This project is to study the millimeter-wave BPF design for radio over fiber (RoF) remote antenna unit (RAU) application. The design will then be fabricated using low temperature co-fired ceramic (LTCC) technology. Hence, as part of the millimeter-wave adoption in RoF technology, this project has been narrowed down to design the BPF.

1.2 Problem Statement

Internet access is very limited in rural areas due to its geographical factor. It is not economical to connect end-user premises using fiber optic link due to the cost of installing the fiber optic cable and cost of the fiber optic itself. RoF has been seen as a suitable option to replace fiber optic link to reduce the cost of providing internet access to rural areas.

To meet the high bandwidth transmission provided by fiber optic, the usage of millimeter-wave will provide capacity close to what has been offered by conventional fiber optic link. RoF operating in millimeter wave frequency has been proposed to ensure high capacity data can be provided to end-user.

RoF system provides a simpler RAU, whereby the modulation of millimeter-wave is done at CS. RAU consist of a photodetector, bandpass filter, amplifier and antenna. This project scope has been narrowed down to propose a millimeter wave BPF design for RoF system using LTCC technology. LTCC enables compact circuit implementation that shall reduce the BPF size and this will produce a simpler and compact RAU.

1.3 Objective

The objective of this project is to design, simulate and fabricate a downlink millimeter-wave BPF for RoF technology using LTCC technology.

1.4 Scope of Work

The following scope of work will be the guideline during the process of the proposed BPF development work:

i. The BPF topology that will be use is the end-coupled half wavelength resonator bandpass filter.
ii. The BPF will use Chebyshev response to get the sharpest frequency cut-off.
iii. The proposed filter will be design for downlink in frequency range of 40 GHz to 42 GHz.
iv. Simulation will be done using Advanced Design System (ADS) software.
v. Fabrication technology is LTCC.

1.5 Thesis Outline

This thesis is a document for master project in Electrical Engineering – Electronic and Telecommunication. The report is organized in the following manner.

Chapter 1 describes the project introduction covering project overview, problem statement, objective and scope of work during project development.

Chapter 2 summarized the literature review which consists of studies in the radio over fiber (RoF) technology, millimeter-wave properties and applications, microwave bandpass filter design method and low temperature co-fired ceramic (LTCC) technology.

Chapter 3 covers on the project methodology whereby detailed of the project development processes will be further spell out to realize the objective of this project.

Chapter 4 covers on the simulation results and discussions. Simulation configuration is also included in this chapter.

Chapter 5 concludes the simulation findings and proposed future works to improve the filter design.

REFERENCES

[1] A. F. Molisch, Wireless Communications. Chichester, UK: John Wiley & Sons, 1996, ch. 1.

[2] A. Ng'oma and M. Sauer, "Radio-over-Fiber Technologies FOR High Data Rate Wireless Applications" Sarnoff Symposium, April 2009.

[3] M. Sauer, A.Kobyakov and J. George, "Radio over fiber in picocellular network architectures",JLT, vol. 25,no. 11,pp. 3301-3320, November 2007.

[4] A.M.Zin, M.S.Bongsu, S.M.Idrus and N.Zulkifli, " An Overview of Radio-over-Fiber Network Technology," IEEE Conference On Photonics, March 26, 2010.

[5] R. Herschel, C.G Schaffer, "Radio-over-Fiber Systems for Next Generation Wireless Access," 2011 International Students and Young Scientists Workshop, Photonics and Microsystems, July, 2011.

[6] D. Opatic, "Radio over Fiber Technology for Wireless Access", Ericsson Nikola Tesla.

[7] J. Guillory, E. Tanguy, A. Pizzinat, B. Charbonnier, S. Meyer, C. Algani and H. Li, "A 60 GHz Wireless Home Area Network With Radio Over Fiber Repeaters" Lightwave Technology Journal, Vol.29, Issue 16, pp. 2482-2488, August 2011.

[8] Sabit Farizma Iftekhar and Shanjida Hannan Popy, "Radio Over Fiber Transmission by Sub Carrier Multiplexing", BRAC University, 2009.

[9] A.M.J. Koonen and M. Garcia Larrode, "Radio-over-Fiber Techniques-Part II: Microwave to Milimeter-wave Systmes", Journal of Lightwave Technology, vol.26, No 15, August 1, 2008.

[10] Y. Yang, F. Li, C. Lim and A. Nirmalathas, “Radio-Over-MMF Technologies for Future Mobile Backhaul Supporting Cooperative Base Stations” Microwave Symposium (IMS) 2013 IEEE MTT-S International, June 2013.

[11] A. Kanno, “20-Gbaud QPSK Optical and Radio Transmission Using High-Gain Antennas for Resilient Access Network” 2012 IEEE Summer Topical Meeting, pp. 145-146.

[12] A. M. J. Koonen, and M. Garcia Larrode, “Radio-Over-MMF Techniques-Part II: Microwave To Milimeter-Wave Systems” Lightwave Technology Journal, Vol.16, Issue 15, pp. 2396-2408, August 2008.

[13] S.R. Abdollahi, H.S Al-Raweshidy, A. Ahmadinia, and R. Nilavalan, “ An All-Photonic Digital Radio Over Fiber Architecture,” IEEE Swedish Communication Technologies Workshop, March 26, 2010.

[14] David M. Pozar, Microwave Engineering, Fourth Edition, New York: John Wiley & Sons, 2011

[15] Jia-Sheng Hing and M.J Lancaster, Microstrip Filters for RF/Microwave Applications, New York: John Wiley & Sons, 2001

[16] G.Mattaei, L.Young, and E. M. T. Joes, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, Artech Gouse, Norwood, MA, 1980.

[17] Y.H.Cho, Y.C.Lee, J.W.Lee*,M.S.Song*,and C.S.Park, “A Fully Embedded LTCC Stripline Parallel Coupled BPF for 40GHz BMWS Application,” Radio and Wireless Conference IEEE, pp. 75-78, Sept.2004

[18] L. Shaolan, Y.Bao and Z. Runqi, "A Ka-Band FSIW Band-Pass Filter with LTCC Technology" Microwave Technology and Computational Electromagnetics (ICMTCE), pp.196-199, May 2011

[19] Z. Shan, and M. Fujise, "60GHz Narrow Bandpass Filter Based on Circle Patch and LTCC" 6th International Conference on ITS Telecommunications Proceedings, pp. 1173-1174, 2006

[20] B. Yuan, J. Mou, W. Yu and X. Lv, "Five-pole LTCC Cavity Filter for Wireless Applications at 34GHz" Microwave Technology and Computational Electromagnetics (ICMTCE), pp. 193-195, May 2011.