Osaka University Knowledge Archive

Title	Study on Electro-Optic Modulators Using Planar Antennas for Wireless Microwave-Lightwave Signal Conversion
Author(s)	Wijayanto, Yusuf Nur
Citation	
Issue Date	
Text Version	ETD
URL	https://doi.org/10.18910/26210
DOI	10.18910/26210
rights	
Note	

Osaka University Knowledge Archive : OUKA

https://ir.library.osaka-u.ac.jp/repo/ouka/all/

Osaka University

Form 3

Synopsis of Thesis

Title:

Study on Electro-Optic Modulators Using Planar Antennas
for Wireless Microwave-Lightwave Signal Conversion

(マイクロ波無線信号―光信号変換のための平面アンテナを用いた電気光学変調器の研究)

Name of Applicant <u>YUSUF NUR WIJAYANTO</u>

The demand for high quality services in wireless communication increases every year. Currently, wireless communication with a hundred Mbps data rate is developed. In order to anticipate bottleneck in the future, large capacity for the data traffics is required. The capacity can be enhanced by use of high frequency operation as a wireless carrier. The high frequency carrier has large transmission loss in the air. Based on that, wireless communication with large capacity and short coverage area can be achieved with a Gbps data rate. The coverage area can be expanded by connecting each small wireless communication using optical fibers with low propagation loss. Therefore, broadband wireless communication can be realized using the radio-over-fiber (ROF) technology.

Since the radio (microwave) and optical (lightwave) signal are used simultaneously in the ROF technology, converters between microwave and lightwave signals are required. Converters from lightwave to wireless signals are composed of a high speed photo-detector and antenna. These devices have mature/ advanced technology for high frequency operation. In contrary, converters from wireless microwave to lightwave signals can be composed of an antenna and optical modulator. These devices have been developed for microwave bands. They have drawbacks for millimeter-wave/ sub-millimeter-wave bands such as losses, substrate resonant mode, rather difficult tuning, and so on.

In order to overcome the remaining issues, I study on electro-optic (EO) modulators using planar antennas for wireless microwave-lightwave signal conversion. EO modulators have advantages such as high speed operation, large bandwidth, and good linearity. In this dissertation, various EO modulators using planar structures are proposed with new fusion and integrated structures. The efforts to improve device performances and functions are also presented with array and suspended structures.

Firstly, I propose a new invention of a fusion EO modulator using a patch antenna embedded with a single narrow gap. A patch antenna embedded with a narrow gap is fabricated on an EO crystal substrate. By utilizing a displacement current and electric field across the gap, optical modulation can be obtained. The basic operations of the proposed device for wireless microwave-lightwave signal conversion were verified experimentally. The new invented EO modulator is operated with low microwave losses and no external power supply. It has simple compact structures and no precise tuning requirement.

Secondly, fusion EO modulators using a patch antenna embedded with double narrow gaps are proposed for device function improvement. In here, I present an EO modulator using a patch antenna embedded with two parallel gaps for Mach-Zehnder optical interferometry. I also propose an EO modulator using a patch antenna embedded with two orthogonal gaps for receiving wireless microwave signals with orthogonal linear polarization and identifying the microwave polarization. In the experiment, the operations of the proposed device were measured successfully.

Thirdly, I propose a new integrated EO modulator using a planar yagi antenna coupled to a resonant electrode. Since the yagi antenna has higher gain and the resonant electrode has longer length compared to the devices with a patch antenna, larger modulation efficiency can be achieved. However, the precise tuning is required and rather difficult since the planar yagi antenna, resonant electrode, and connection line are used. Microwave losses might be also induced in the integrated EO modulator.

Fifthly, the efforts to improve modulation efficiency and device functions are done by EO modulators using an array of planar antennas. Modulation efficiency is proportional to the antenna number in an array structure, since optical modulation is induced effectively at each antenna. I propose an EO modulator using a quasi-phase-matching (QPM) array of patch antennas embedded with a narrow gap for further modulation efficiency enhancement. More compact device can be obtained with double number of antennas. Therefore, modulation efficiency of the device with QPM array structures becomes doubles than the device with conventional array structures. A ROF link using the proposed device was also demonstrated experimentally. Additionally, I also propose an EO modulator using a 2-D array of patch antennas embedded with orthogonal narrow gaps for wireless irradiation angle (beam forming) control. By using meandering gaps to compensate for the EO modulation degradation, 1-D and 2-D beam forming of wireless microwave signals can be obtained optically.

Sixthly, in order to enhance modulation efficiency in further and operate in high frequency operation, millimeter-wave optical modulators using thin EO waveguides suspended to planar antennas on a low-*k* dielectric substrate are proposed. Since effective dielectric constant of the proposed devices is low, large antenna aperture and long interaction length can be realized. The substrate resonant modes can be eliminated since a thin EO crystal is used. Therefore, large modulation efficiency can be achieved using the proposed device.

The various EO modulators using planar antennas were proposed and discussed. Basic operations of the proposed device for wireless microwave-lightwave signal conversion were verified. Modulation efficiency can be enhanced in further by considering internal and external device characteristics. By increasing modulation efficiency furthermore, the broadband wireless communication can be realized using the proposed devices. Additionally, several attractive applications can be also constructed using them, such as low induction electromagnetic compatibility measurement, high resolution surveillance radar, long distance remote antenna, and so on.

様式7

論文審査の結果の要旨及び担当者

氏　名　（　YUSUF NUR WIJAYANTO　）			
論文審査担当者		(職)	氏　名
	主 査	教　授	岡村　康行
	副 査	教　授	占部　伸二
	副 査	教　授	永妻　忠夫
	副 査	准教授	村田　博司

論文審査の結果の要旨

電界により媒質の誘電率を変化させる電気光学効果は、ミリ波やテラヘルツ波までの高い周波数の電気信号に応答し、電波を光波へ重畳させることが可能である。この効果を用いて構成した光変調器は光通信システムにおける重要なデバイスであり、通信分野のみならず光情報処理や計測分野への応用も期待されている。一方、インターネットの爆発的な普及に伴い、大容量情報通信システムの開発が要求され、そのため無線通信システムの高周波化が必須とされている。本論文は、無線通信システムの高周波化とサービスエリアの拡大を目指した電波光波融合デバイス、特に、電気信号を光波へ載せるための光変調器に着目し、信号受信用アンテナと光変調電極とを兼ね備えた新しい構造を有する光変調器の提案と動作確認、さらにその応用に関する研究の成果をまとめたものである。

本論文では、まず移動体無線通信システムの現状を概観し、高周波化とサービスエリアの拡大化の必要性を指摘し、その解決方法として、超高速光変調器とROF(Radio over Fiber)による構成の有効性を述べている。そのため、平面アンテナと変調用電極とを同一基板上の配置した新しいアンテナ電極光変調器を提案し、強誘電体基板材料の検討を含め様々な構成法を示し、その可能性を追求している。強誘電体基板上に配置した平面パッチアンテナを中央で分割しミクロンメートルオーダのギャップを基板表面下に形成した光導波路と並行に設け、変調電極と共用するアンテナ変調電極一体構造について、詳細にデザインを含めて検討し、$LiTaO_3$および$LiNbO_3$ 基板を用いたデバイス作製、マイクロ波・ミリ波帯での動作確認実験により、その有効性を示している。従来の光変調器と異なり変調のための外部電源が不要であり、単純な構造であるにも関わらず、マイクロ波・ミリ波信号を光波に載せることが可能となる。次いで、変調効率改善のための構成法について論じ、アンテナ電極のアレイ化および複層化、アンテナ構造の詳細な検討を行っている。二種類のアレイ化を検討し、QPM（Quasi-Phase Matching：擬似位相整合）構造を併用することにより単一構造に比べ１０倍の効率の向上をえている。さらに、アレイ構造とQPMの特徴を利用し、受信指向特性を制御できることを実験的に示し、空間多重システムへの適用可能性を示唆している。複層構造の複雑化と作製技術の高度化が要求されるにも関わらず、デバイス作製に果敢に挑戦し、基板貼り合わせ技術を確立し、変調用基板と低誘電率基板との複層化に成功し、変調効率の向上を実現させた。

以上のように、本論文は、電気信号受信用アンテナと光変調電極を共用した一体構造の次世代の新奇光変調器を提案し、実験によりその基本動作および有効性を確認しており、移動体無線通信のみならず光通信システム・計測システムの発展に大きく寄与するものであり、博士（工学）の学位論文として十分価値あるものと認める。