MODELLING AND DEVELOPING OF MICROSTRIP ROTMAN LENS BASED ON ELECTRIC FIELD ANALYSIS AND DEFECTED GROUND STRUCTURE

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Sincerely dedicated to my family.

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ABSTRACT

Allocating multiple beams in desired angles is a cornerstone component in modern wireless systems. Scanning in microwave lens is independent of phase coupler and phase shifter compared to other scanning techniques. A discontinuity between the 50 Ω feeding lines and unknown lens cavity impedance has a direct impact on lens performance in terms of power loss, phase performance, and lens size. A tapered line is used conventionally in microstrip lens. However, taper line modelling required sophisticated computer specifications to optimise its dimensions besides the simulation time factor. Further, taper line length increases lens size. Therefore, two approaches have been introduced in this study to solve this problem. The first contribution is introduced a matching impedance based on determining and analysing the magnitude of the standing wave pattern of an electric field. The impedance matching is achieved effectively using the proposed approach independent of the optimisation process, which saves 3 hours of simulation time compared to the taper line approach. Further, an increase of bandwidth for beam ports two and three by 25.65% and 11.47%, respectively is notified. However, beam port one bandwidth is decreased by 7.17%. While the second work in this study is embedding a defected ground structure for microstrip lens is used for the first time to replace the full ground of the microstrip lens and examined the effect of the defected ground structure on the lens performance. A suggested defect structure is used to modify the inductance and the capacitance of the lens cavity to increase its characteristic impedance and balance the 50 Ω feeder lines. The suggested method successfully increases the impedance of the lens cavity and reduces the discontinuity between input ports and lens internal impedance to achieve an acceptable return loss at design frequency with an enhancement of 22.9% for beam port one and 103% for beam port three. Further, miniaturization of lens size by 11.21% is achieved due to the replacement of the taper line by the proposed approach. The suggested methods are applied to microstrip lens works at ISM band frequency and measurements are led to successful validation.

ABSTRAK

Menguntukkan pelbagai rasuk dalam sudut yang dikehendaki adalah komponen asas dalam sistem tanpa wayar moden. Pengimbasan dalam lensa gelombang mikro adalah bebas daripada pengganding fasa dan penganjak fasa berbanding dengan teknik pengimbasan lain. Masalah galangan antara 50 Ω garisan makan dan galangan rongga lensa yang tidak diketahui mempunyai kesan langsung ke atas prestasi lensa dari segi kehilangan kuasa, prestasi fasa, dan saiz kanta. Talian tirus digunakan secara konvensional dalam lensa mikrojalur. Walau bagaimanapun, pemodelan garis tirus memerlukan spesifikasi komputer yang canggih untuk mengoptimumkan dimensi selain faktor masa simulasi. Panjang garis tirus lagi meningkatkan saiz lensa. Oleh itu, dua pendekatan telah diperkenalkan dalam kajian ini menyelesaikan masalah ini. Sumbangan pertama diperkenalkan galangan yang sepadan berdasarkan menentukan dan menganalisis magnitud corak gelombang berdiri medan elektrik. Proses pemadanan galangan di antara talian masukan dan rongga lensa dicapai dengan berkesan menggunakan pendekatan bebas yang dicadangkan daripada proses pengoptimuman, yang telah menjimatkan masa simulasi kepada 3 jam berbanding dengan pendekatan garis tirus konvensional. Tambahan lagi, peningkatan lebar jalur untuk liang-liang rasuk dua dan tiga masing-masing sebanyak 25.65% dan 11.47% diperolehi. Walau bagaimanapun, lebar jalur liang rasuk satu menurun sebanyak 7.17%. Struktur hakisan berbentuk untuk lantai lensa mikrojalur digunakan untuk pertama kalinya dalam kajian ini untuk menggantikan reka bentuk lantai penuh lensa mikrojalur dan meneliti kesan struktur hakisan berbentuk pada prestasi lensa. Struktur hakisan berbentuk yang dicadangkan digunakan untuk mengubah kearuhan dan kemuatan rongga lensa bagi meningkatkan ciri-ciri galangan dan menyeimbangkan talian masukan 50 Ω. Kaedah yang dicadangkan berjaya meningkatkan galangan rongga lensa dan mengurangkan ketakselanjaran antara liang masukan dan galangan dalaman lensa untuk mencapai nilai kehilangan yang dapat diterima pada frekuensi yang diperlukan dengan peningkatan 22.9% untuk liang satu dan 103% untuk liang

tiga. Selanjutnya, pengecilan saiz lensa sebanyak 11.21% telah dicapai menerusi penggantian garis tirus dengan menggunakan pendekatan yang dicadangkan. Kaedah yang dicadangkan diterapkan pada lensa mikrojalur yang berfungsi pada frekuensi jalur ISM dan pengukuran membawa kepada pengesahan yang berjaya.

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LIST OF SYMBOLS AND ABBREVIATIONS

α_n	-	Attenuation constant
β	-	Off focal /on focal length
β_n	-	Phase constant
γ	-	Propagation constant
ε	-	Relative complex permittivity
ε_e	-	Effective dielectric constant
ε_r	-	Dielectric constant
λ_0	-	Wavelength in free space
λ_g	-	Wavelength in medium
μ	-	Permeability of the material
σ	-	Medium conductivity
Γ	-	Reflection coefficient
υ_p	-	Phase velocity
δ_s	-	Skin depth
ω	-	The angular radian frequency
c	-	Light speed
Z_0	-	Characteristic impedance
5G	-	Fifth-generation
BFN	-	Beamforming network
CPU	-	Central process unit
DGS	-	Defected Ground Structure
EBG	-	Electromagnetic bandgap
ECC	-	Envelope correlation coefficient
FDTD	-	Finite-difference time-domain
FE	-	Finite Element
FEM	-	Finite element method
FIT	-	Finite integration technique

ISM	-	Industrial scientific medical
LSFEM	-	Least-squares finite element technique
MIM	-	Metal-Insulator-Metal
MIMO	-	Multiple input multiple outputs
MOM	-	Method of Moment
MOR	-	Model-order reduction
MU-MIMO	-	Multiuser multiple-input multiple-output
NFF	-	Near field focus
OAM	-	Orbital angular momentum
PBG	-	Photonic bandgap
PMBA	-	Passive multibeam antennas
PML	-	Perfect matched layer
R-2R		Radius-2Radius
RAM	-	Random access memory
RF	-	Radio frequency
RFID	-	Radio-frequency identification
RGW	-	Ridge gap waveguide
SD	-	Standard deviation
SMA	-	Subminiature version A
TEM	-	Transverse electromagnetic
TLM	-	Transmission line matrix
TTD	-	True time delay
Tx/Rx	-	Transmitter/Receiver
UAV	-	Unmanned aerial vehicle
UWB	-	Ultra-wideband
VNA	-	Vector Network Analyzer

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CHAPTER 1

INTRODUCTION

1.1 Background

Generating multiple beams using an array along with having wide bandwidth and beam steering capability is of crucial importance for modern radar and communication systems. For this purpose, various multiple beamforming networks are introduced to have control over the amplitude and phase at each element of the antenna array. Phased array antennas consist of multiple stationary antenna elements, which are fed coherently and use variable phase or time-delay control at each element to scan a beam to given angles in space, as shown in Figure 1.1.

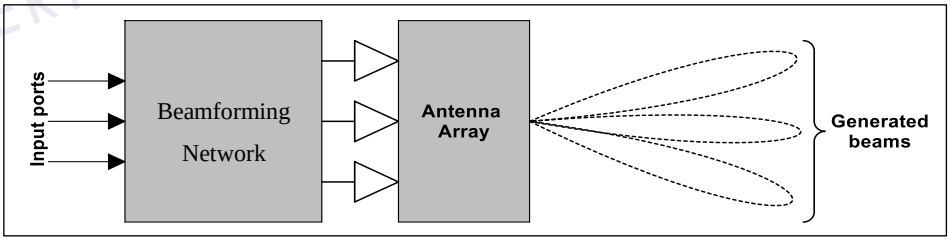

Figure 1.1: Beamforming diagram

Variable amplitude control is sometimes also provided for pattern shaping. Arrays are sometimes used in place of fixed aperture antennas (reflectors, lenses) because the multiplicity of elements allows more precise control of the radiation pattern, thus resulting in lower sidelobes or careful pattern shaping. However, the primary reason for using arrays is to produce a directive beam that can be repositioned (scanned) electronically. Passive multibeam antennas (PMBA) are a class of multi-beam

antennas that achieve the desired beamforming in the RF domain without using any active components. In general, the passive multibeam antennas contain a finite number of well-isolated input ports. Each port, backed by a transceiver (Tx/Rx), controls a single narrow beam pointing at a predefined direction. Multiple beams can thus be simultaneously emitted from a shared aperture of a particular physical size for covering a prescribed angular range. The resolution is limited by the beam width, while the number of beams determines the range of coverage. Typically, the performance of a PMBA is characterized by the scanning range, polarization, gain, sidelobe level, bandwidth, port isolation, and efficiency. According to the system architecture and principle of operation, the PMBA can be divided into three categories: PMBA based on reflectors, PMBA based on lenses, and PMBA based on beamforming circuits [1]. The microwave lens is considering extensive passive networks forming a class of these multiple beamforming networks.

Microwave lens is a type of beamforming network that applies a path delay mechanism to form the desired phase front at the array input. Each of the inputs connects to a beam port that radiates the semi-circular phase front within the lens cavity. An array of receiving elements functioning as receivers then guides the energy into the output array. Because of the adequately designed beam, receiving port positions and transmission line length, correct phase, and acceptable amplitude distributions can be achieved across the aperture, as explained in the following figure.

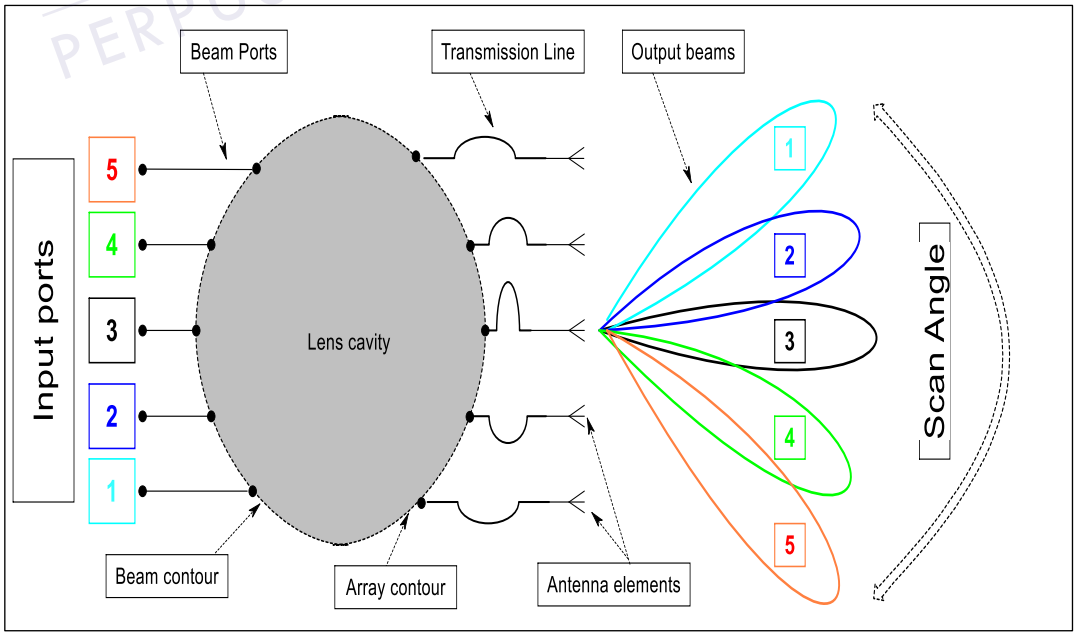

Figure 1.2: Microwave lens configuration

Figure 1.2 explains the scanning beams are resulted from the switching feeding of input ports due to the phase combination reached to the radiated elements which are results in shifting the generated beams from the radiated elements with respect to the center antenna element position. Therefore, the radiated beams shown in the above figure are the combination of the radiation from each antenna element based on phased array theory.

Rotman lens model is a component that provides an efficacious ability to form a multi radiation beam at the desired angles based on the linear phase-shifting generated from the physical input ports location related to the radiated elements [2]. The feature of true-time delay for the lens, derived from the geometric optic theory, introduced the capability to steer the generated beams independently of frequency. Many interests were traced in the implementation and development of a phased array system, which is an integrated lens as a beam switching technique due to advances in the technology of printed circuits. Furthermore, compactness, easy for implementation in the microstrip model with low cost, is the primary property for the Rotman lens compared to the other beamforming approaches such as the Blass matrix [3], Nolen matrix [4], and Butler matrix [5]. However, this type of beamforming network is hard to construct. The Nolen matrix is a modified design of Blass and Butler matrices but is seldom used owing to the high parts count and difficulties connected with the networks [6].

Recently, new applications based on the microwave lens on the various platform have been suggested, such as fifth-generation (5G) applications [7][8], MIMO system [9], ultra-wideband radiators [10], satellite communication [11], [12], RFID identification [13], remote sensing and near field focus communications [14], transmit array lens [15], and collision avoidance for automotive framework [16].

1.2 Problem statement

Wide scan angle with fast-tracking ability without physically antenna elements movement is considered valued requirements in a wide application such as radar system and remotely piloted platform. In general, the Rotman lens is an electronically steerable microwave structure that generates multiple output beams in the space based on the position of the feeding ports and the path length of these feeding ports regarding

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APPENDIX A

LIST OF PUBLICATIONS

Publication(s):

[1] Al-Obaidi, Mohammed K., Ezri Mohd, Noorsaliza Abdullah, Samsul Haimi Dahlan, and Jawad Ali. "Design and implementation of microstrip rotman lens for ISM band applications." *Bulletin of Electrical Engineering and Informatics* 8, no. 1 (2019): 90-98.

[2] Al-Obaidi, Mohammed K., Ezri Mohd, Noorsaliza Abdullah, and Samsul Haimi Dahlan. "Design of wideband Rotman lens for wireless applications." *Telkomnika* 17, no. 5 (2019): 2235-2243.

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[5] Al-Obaidi, Mohammed K., Noorsaliza Abdullah, Samsul H. Dahlan, and Ezri Mohd. " Microstrip Lens Formulation and Analysis: A Parametric Study"

In *Proceedings of the 12th National Technical Seminar on Unmanned System Technology 2020*, pp. 15-23. Springer, Singapore, 2021.

Conference(s):

[1] Al-Obaidi, Mohammed K., Ezri Mohd, Noorsaliza Abdullah, Samsul Haimi Dahlan, and Jawad Ali. "Design and implementation of microstrip rotman lens for ISM band applications., in The 4th International Conference On Electronic Design (ICED), Melaka, Malaysia, Aug. 9-10, 2018- Presented

[2] Al-Obaidi, Mohammed K., Ezri Mohd, Noorsaliza Abdullah, and Samsul Haimi Dahlan. "A new approach for impedance matching rotman lens using defected ground structure", in International Conference on Electrical and Electronic Engineering (IC3E), Johor, Malaysia, Apr. 15-19, 2019-Presented.

[3] Al-Obaidi, Mohammed K., Noorsaliza Abdullah, Samsul H. Dahlan, and Ezri Mohd. " Microstrip Lens Formulation and Analysis: A Parametric Study, in the 12th national technical seminar on unmanned system technology 2020 (NUSYS'20), Malaysia, Nov. 24-25, 2020-Presented.

APPENDIX B

VITA

The author was born in Iraq. He went to Al-khadraa higher secondary school in Baghdad. He received the Bachelor of Science Engineering (B.Sc) in Electrical and Electronic Engineering from the University of Baghdad, Iraq, in 2009. He received his Master degree (M.S.) in Electrical Engineering from Eastern Mediterranean University (EMU), Cyprus, which specialised in the communication system in 2014. He joined the Radio Communications and Antenna Design (RACAD) laboratory, Faculty of Electrical and Electronic Engineering (FKEE) at Universiti Tun Hussein Onn Malaysia (UTHM), Johor, Malaysia, in 2017. He worked towards his PhD degree in Electrical Engineering. He also published well-reputed international refereed journals and attended conferences. He is an active researcher interested in dielectric-based material study, microstrip antenna designing, beamforming network, electromagnetics, and phased array antenna.