UNIVERSITI PUTRA MALAYSIA

POINT-TO-POINT MULTILAYER ANTENNA DESIGN FOR GAIN AND BANDWIDTH IMPROVEMENT FOR ISM 5.8 GHz

SAFA NASSR NAFEA

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By

SAFA NASSR NAFEA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

June 2016

DEDICATION

This thesis dedicated

to

MY BELOVED FAMILY.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

POINT-TO-POINT MULTILAYER ANTENNA DESIGN FOR GAIN AND BANDWIDTH IMPROVEMENT FOR ISM 5.8 GHz

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June 2016

Chairman : Associated Professor Alyani Ismail, PhD
Faculty : Engineering

In this research, a compact multilayer antenna was proposed to enhance the gain and operating bandwidth of a single layer patch antenna and reduce the side lobe level (SLL). The proposed multilayer antenna consists of a feeding patch and three dielectric superstrate layers located at a specific height for each layer above the ground plane to enhance the performance of the antenna over the Industrial, Scientific, and Medical ISM band (5.725 - 5.875) GHz.

Based on literature review and theoretical analysis, adding superstrate layers above the patch antenna to enhance the performance of the antenna is presented in this thesis. The objectives of this thesis include enhancing the gain of the antenna over the ISM band and reducing the SLL using multilayer antenna, which is composed of patch antenna covered by layers of dielectric material.

The feeding patch was designed based on theoretical analysis of designing a patch antenna with optimization to achieve an operating frequency of 5.8 GHz. This feeding patch is composed of an optimized rectangular patch with four circles located at corners of the patch to obtain higher gain. However, three slots etched from the surface of the patch to improve the operating bandwidth. The feeding patch was printed on Rogers RT / Duroid 5880 substrate which has dimensions of $38 \times 60 \times 0.787\, mm^3$, while the ground plane of the antenna which is under the antenna's substrate directly has the same length and width of the substrate with thickness of 17 μm which is the same thickness of the laminated patch's copper. The feeding patch resonated at 5.806 GHz with operating bandwidth of 130.15 MHz and gain of 8.23 dB with 88.98 % radiation efficiency and radiation pattern which has -4 dB SLL and 70.5^{o} Half Power Beam Width (HPBW).

For enhancing the performance of the antenna, three multilayer antenna designs (Antenna 1, Antenna 2, and Antenna 3) were presented and simulated. The performance of each antenna was studied. A comparison between the performance of

these antennas has been taken in consideration to achieve the optimum performance among these multilayer antennas.

The first multilayer antenna design (Antenna 1) utilized three FR4 layers located above the feeding patch at specific height for each layer. The FR4 superstrate layers have dielectric constant (ϵ_r) of 4.3 and loss tangent ($\tan\delta$) of 0.02, while the dimensions of each layer are$38 \times 60 \times 1.57\, mm^3$. The area of each superstrate layer used in Antenna1 is the same area of the feeding patch. Antenna 1 had resonated at 5.8 GHz. The gain and operating bandwidth were 10.78 dB and 183.29 MHz, respectively, with 48^o HPBW and low SLL radiation pattern.

The second multilayer antenna design (Antenna 2) is composed of feeding patch and three Rogers RO3010 layers located above the feeding patch at specific height for each layer. The Rogers superstrate layers have dielectric constant (ϵ_r) of 10.2 and loss tangent ($\tan\delta$) of 0.0023, while the dimensions of each layer are $38 \times 60 \times 0.64\, mm^3$. Antenna 2 resonated at 5.8 GHz and provided gain and operating bandwidth of 11.30 dB and 190.54 MHz, respectively, 46.4^o HPBW and low SLL radiation pattern

The third multilayer antenna design (Antenna 3) utilized three Rogers RO3006 as superstrate layers. These superstrate layers have dimensions of $43 \times 65 \times 1.28\, mm^3$ for each layer, which show larger area than the area of the feeding patch. Antenna 3 had resonated at 5.806 GHz and achieved gain and operating bandwidth of 11.70 dB and 189.39 MHz, respectively. Antenna 3 has a lower SLL radiation pattern than those achieved for Antenna 1, Antenna 2, where the side lobe level and HPBW for Antenna 3 found to be -14.9 dB and 43.1^o, respectively. Antenna 3 proposed gain and bandwidth improvement with SLL reduction and HPBW narrowing where 3.5 dB gain enhancement and bandwidth improvement around 60 MHz with SLL reduction around -11 dB are achieved compared to the single layer feeding patch.

Antenna 3, which shows the optimum simulated results compared to the performance of other antennas (Antenna 1 and 2), has been fabricated. The superstrate layers are located above the feeding patch at specific height for each one, according to the optimum heights which were optimized in simulation and were fixed using nylon spacers.

The measurements of the return loss and the gain of the fabricated antenna are obtained. A slight difference was observed between the simulated and measured results due to the occurrence of deficiencies and analogue losses through fabrication process, which were not considered in the simulator environment. Compared to the multilayer antennas presented in literature review in this thesis, the proposed antenna has a reduced size of 76.34% and low SLL of -14.9 dB due to optimizing the height of superstrate layers. Moreover the multilayer proposed antenna achieved lower return loss by 217%, while multilayer antenna presented in literature review overcome the proposed antenna by 9.4% for gain.

The SLL of antenna's radiation for Antenna 1, Antenna 2, and Antenna 3 were eliminated due to optimizing the height of each superstrate layer. By using the multiple superstrate layers, the gain was enhanced, the operating bandwidth was improved, and the radiation efficiency of the antenna was increased while the return loss and the SLL were decreased. The proposed point-to-point multilayer antenna in this research (Antenna 3) is a directive antenna with gain suitable for Line of Sight (LOS) links that operating at 5.8 GHz.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKA BENTUK ANTENA TITIK-KE-TITIK BERBILANG LAPISAN UNTUK PENINGKATAN GANDAAN DAN LEBAR JALUR UNTUK ISM 5.8 GHz

Oleh

SAFA NASSR NAFEA

Jun 2016

Pengerusi : Profesor Madya Alyani Ismail, PhD
Fakulti : Kejuruteraan

Dalam kajian ini, suatu antena berbilang lapisan gandaan tinggi telah dicadangkan untuk meningkatkan gandaan dan jalur lebar yang beroperasi untuk antena tampal dan mengurangkan tahap lobus tepi (SLL). Antena berbilang lapisan yang dicadangkan terdiri daripada satu tampal pengisian dan tiga lapisan superstrat dielektrik yang terletak pada ketinggian tertentu untuk setiap lapisan di atas satah bumi untuk meningkatkan prestasi antena atas jalur ISM Perindustrian, Saintifik dan Perubatan (5.725 - 5.875) GHz.

Berdasarkan kajian literatur dan analisis teori, tesis ini membentangkan penambahan lapisan superstrat ke atas antena tampal untuk meningkatkan prestasi antena tersebut. Objektif tesis ini termasuk meningkatkan gandaan antena melebihi jalur ISM dan mengurangkan SLL dengan menggunakan antena berbilang lapisan, yang terdiri daripada antena tampal yang diliputi lapisan-lapisan bahan dielektrik.

Tampal pengisian direka berdasarkan analisis teori untuk merekabentuk suatu antena tampal dengan pengoptimuman untuk mencapai frekuensi operasi sebanyak 5.8 GHz. Tampal pengisian ini terdiri daripada tampal segi empat tepat yang dioptimumkan dengan empat bulatan yang terletak di penjuru tampal tersebut untuk mendapatkan gandaan yang lebih tinggi.Walau bagaimanapun, tiga alur telah diukir dari permukaan tampalan untuk meningkatkan jalur lebar yang beroperasi. Tampal pengisian telah dicetak pada substrat Rogers RT/Duroid 5880 yang mempunyai dimensi$38 \times 60 \times 0.787\, mm^3$, manakala satah bumi antena tersebut, yang berada terus di bawah substrat antena, mempunyai panjang dan lebar yang sama dengan substrat dengan ketebalan 17 μm yang sama dengan ketebalan tampal berlapis tembaga. Pengisian antena telah bergema pada 5.806 GHz dengan jalur lebar yang beroperasi pada 130.15 MHz dan berganda sebanyale 8.23 dB dengan kecekapan sinaran 88.98 % dan corak radiasi yangmem punyai - 4 dB SLL dan 70.5^o HPBW.

Untuk meningkatkan prestasi antena, tiga rekabentuk antena berbilang lapisan (Antena 1, Antena 2, dan Antena 3) telah dikemukakan dan disimulasi. Prestasi setiap antena telah dikaji. Perbandingan yang dibuat antara prestasi ketiga-tiga antena ini telah diambil kira untuk mencapai prestasi yang optimum di kalangan antena berbilang lapisan ini.

Rekabentuk pertama antena berbilang lapisan (Antenna 1) telah menggunakan tiga lapisan FR4 yang terletak di atas tampal pengisian pada ketinggian tertentu untuk setiap lapisan. Lapisan superstrat FR4 mempunyai pemalar dielektrik (ϵ_r) sebanyak 4.3 dan tangen kehilangan ($\tan\delta$) 0.02, manakala dimensi setiap lapisan adalah $38 \times 60 \times 1.57\, mm^3$. Keluasan setiap lapisan superstrat yang digunakan dalam Antena 1 adalah keluasan yang sama bagi tampal pengisian. Antena 1 bergema pada 5.8 GHz. Jalur lebar gandaan dan operasi adalah 10.78 dB dan183.29 MHz,masing, dengan 48^{o} HPBW corak sinaran SLL yang rendah.

Rekabentuk antena berbilang lapisan yang kedua (Antena 2) terdiri daripada tampal pengisian dan tiga lapisan Rogers RO3010 yang terletak di atas tampal pengisian pada ketinggian tertentu untuk setiap lapisan. Lapisan superstratRogersmempunyai pemalar dielektrik (ϵ_r) sebanyak10.2dan tangen kehilangan ($\tan\delta$) 0.0023, manakala dimensi setiap lapisan adalah$38 \times 60 \times 0.64\, mm^3$. Antena 2 bergema pada 5.8 GHz dan menyediakan jalur lebar gandaan dan operasi sebanyak 11.30 dB dan190.54 MHz,masing-masing, dengan 46.4^{o} HPBW corak sinaran SLL yang rendah.

Rekabentuk antena berbilang lapisan yang ketiga (Antena 3) menggunakan tiga Rogers RO3006 sebagai lapisan-lapisan superstrat.Lapisan-lapisan superstrat in mempunyai dimensi$43 \times 65 \times 1.28\, mm^3$untuk setiap lapisan, yang menunjukkan keluasan yang lebih daripada keluasan tampal pengisian. Antena 3bergema pada 5.806 GHz dan mencapai jalur lebar gandaan dan operasi sebanyak 11.70 dB dan 189.39 MHz,masing-masing.Antena 3 mempunyai corak sinaran SLL yang lebih rendah daripada yang dicapai bagi Antena 1 dan Antena 2, dimene cadangan gandan lebar jdur meningkat dengan pengurangan SLL sebanyale 60 MHz dengan pengurangan sebenyale - 11 dB jika dibandingkan dengan satu lapisan pengisian antena

Antena 3,yang menunjukkan hasil simulasi yang optimum berbanding dengan prestasi antena lain (Antena 1 dan 2),telah direka. Lapisan-lapisan superstrat terletak di atas tampal pengisian pada ketinggian tertentu untuk setiap lapisan, sesuai dengan ketinggian yang dioptimumkan dalam simulasi dan yang ditetapkan dengan menggunakan penjarak nilon.

Pengukuran kehilangan pulangan dan gandaan antena yang direka diperolehi.Perbezaan kecil diperhatikan antara keputusan simulasi dan yang diukur disebabkan oleh berlakunya kekurangan dan kerugian analog melalui proses fabrikasi, yang tidak diambil kira dalam persekitaran simulasi. Berbanding dengan antena-antena berbilang lapisan yang dibentangkan dalam kajian literatur tesis ini, antena yang dicadangkan mempuyai saiz yang dikurangkan, sebanyale 76.34% gandaan yang setanding dan SLL yang dikurangkan sebanyale -14.9 dB kerana pengoptimuman ketinggian lapisan-lapisan superstrat, untuk menghapuskan SLL. Walavbagiamanapun, berbangai lapis antena ini membeni pengurangan sebanyale 217%, sementara burbagi lapis antena yang tutera didalam penyelidikan sebelum ini membani kebaikan kepudu antena yang dicadangkan sebanyale 9.4% peningkatan.

Sinaran antena SLLuntuk Antena 1, Antena 2, dan Antena 3 telah dihapuskan disebabkan oleh pengoptimuman ketinggian setiap lapisan superstrat. Dengan menggunakan pelbagai lapisan superstrat, gandaan telah dipertingkatkan, jalur lebar yang beroperasi telah bertambah baik, dan kecekapan sinaran antena tersebut telah ditingkatkan sementara kehilangan kepulangan dan SLL telah dikurangkan. Titile ke titile berbayai lapisan antena yang dicadangkan dalam penyelidikan ini (Antena 3) adalah antena mengarah dengan peningkatan bersesuaian dengan laluan LOS yang beroperasi puda 5.8 GHz.

ACKNOWLEDGEMENTS

Firstly. I would like to thank chairman of supervisory committee, Assoc. Prof. Dr. Alyani Ismail for her support, encouragement, patience and dedication during the duration of my study. This work would not have been possible without her guidance and input.

I would like also to thank committee member of supervisory committee Assoc. Prof. Dr. Raja S. A. Raja Abdullah1to help any difficulty. Finally, I would like to thank anybody helped me to solve technical problems.

I certify that a Thesis Examination Committee has met on 15 June 2016 to conduct the final examination of Safa Nassr Nafea on her thesis entitled "Point-to-Point Multilayer Antenna Design for Gain and Bandwidth Improvement for ISM 5.8 GHz" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

SLL	Side Lobe Level
ISM Band	Industrial, Scientific, Medical Band
PRS	Partially Reflecting Surface
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
RFID	Radio Frequency Identifier
RF	Radio Frequency
VSWR	Voltage Standing Wave Ratio
HPBW	Half Power Beam Width
(F/B) Ratio	Front-to-Back Ratio
DGS	Defective Ground Structure
EBG	Electromagnetic Band - Gap
LHM	Left Handed Materials
LHCP	Left Hand Circular Polarization
RHCP	Right Hand Circular Polarization
GPS	Global Position Services
MIMO	Multi-Input Multi-Output
AMC	Artificial Magnetic Conductors
SL-AMC	Stub Loaded - Artificial Magnetic Conductor
FSS	Frequency Selecting Surfaces
PEC	Perfect Electric Conductor
HIS	High Impedance Surfaces
PP	Parasitic Patch
SIW	Substrate - Integrated Waveguide
IF	Iteration Factor
FP	Feeding Patch

CHAPTER 1

INTRODUCTION

1.1 Background

The microstrip patch antenna is considered to be an interesting area of research for many researchers in the field of microwave engineering because of the features provided by this type of antenna. Disadvantages of the microstrip patch antenna are low gain, narrow operating bandwidth, low efficiency, and high side lobe level (SLL) radiation pattern. The researchers had conducted researches to enhance the performance of the patch antenna through enhancing the gain, improving the operating bandwidth, increasing the radiation efficiency of the antenna and eliminating the SLL of the antenna's radiation pattern.

The interest in point-to-point wireless communications was the motivation of designing a microstrip patch antenna operating at 5.8 GHz and cover the industrial, scientific, and commercial ISM Band (5.725 - 5.875) GHz. To design a microstrip patch antenna for point-to-point communications, enhancing the gain, eliminating the SLL, and radiation efficiency of the conventional patch antenna have to be taken in consideration in order to satisfy point-to-point link specifications and improving its operating bandwidth to cover the ISM Band (5.725 - 5.875) GHz.

The microstrip antenna can be presented as a single layer patch antenna or as a multilayer antenna to satisfy the specifications of point-to-point links for wireless communications applications such as Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) and other applications which require a high gain point-to-point antenna.

1.2 Problem Statement

The microstrip patch antenna is providing many advantages such as being low weight, low cost, and low profile antenna (Jothi Chitra & Nagarajan, 2013)(Balanis, 2008). Patch antenna shows many disadvantages such as offering low gain, narrow operating bandwidth, low radiation efficiency, and high side lobe level radiation pattern (Balanis, 2008) (Kim et al., 2013). This research is aiming to solve problems such as low gain, narrow operating bandwidth, low radiation efficiency, and high SLL of patch antenna which are considered as milestone facing the use of patch antenna for point-to-point communications.

A number of techniques will be presented in Chapter Two to enhance gain of microstrip patch antenna to be compatible with the point-to-point link specifications which require gain higher than provided by the conventional microstrip patch antenna (Vaidya, Gupta, & Mishra, 2014). This research had proposed an antenna composed of a feeding patch which covered by three layers of dielectric material to enhance the gain of microstrip patch antenna.

The narrow operating bandwidth provided by the conventional microstrip patch antenna may not cover the ISM band (5.725 - 5.875) GHz. The proposed design in this thesis will improve the operating bandwidth of patch antenna through adding three dielectric layers to cover the ISM Band (5.725 - 5875) GHz (Yang et al., 2013).

High side lobe level of microstrip patch antenna's radiation pattern is considered to be one of the problems which patch antenna is suffering from. Because of the high SLL the conventional patch antenna is considered to be not applicable for point-to-point applications. One of the effective techniques to reduce SLL of patch antenna's radiation pattern is using a multilayer antenna structure which composed of patch antenna covered by layers of dielectric material (Vaidya, Gupta, & Mishra, 2014).

The size of the antenna is considered as an important factor which must be taken in consideration in case of choosing an antenna for a specific application. As mentioned in the previous sections the multilayer antenna structure will be used to enhance the antenna's gain, improve its operating bandwidth, and to reduce the SLL of the antenna's radiation pattern. The multilayer antennas operating over the ISM band (5.725 - 5.875) GHz presented in previous works can be considered to applicable for outdoor applications only due to the size of these antennas.

Because of the disadvantages that patch antenna is suffering from such as low gain, narrow operating bandwidth, and high side lobe level, patch antenna will not be compatible for point-to-point communications over ISM band (5.725 - 5.875) GHz. In general this research work has the aim on presenting compact patch antenna operating for point-to-point links over ISM band (5.725 - 5.875) GHz with directive radiation pattern.

1.3 Objectives

This section explains the objectives of this research. The main objective of this research is designing a point-to-point microstrip patch antenna operating at 5.8 GHz and covering the ISM Band (5.725 - 5.875) GHz.

1. To design and develop a directive patch antenna with gain suitable for point-to-point applications.
2. To improve the operating bandwidth of the patch antenna to cover Industrial, Scientific, and Medical band (5.725 - 5.875) GHz.
3. To reduce side lobe level of the designed antenna to be compatible with point-to-point communications requirements.
4. To produce compact size of the point-to-point antenna.

1.4 Thesis Scope

There are many techniques can be used for enhancing gain of microstrip patch antenna and improving its operating bandwidth. The technique of multilayer antenna structure was used for enhancing gain and improving the operating bandwidth of microstrip patch antenna. In this research a multilayer antenna was proposed to achieve the objectives of the research. Three 1.28 mm Rogers RO3006 superstrate layers which have a dielectric constant (ϵ_r), and loss tangent ($\tan\delta$) of 6.15 and 0.002, respectively, were located above the feeding patch at a specific height for each superstrate layer. Unlike the multilayer antennas presented in the literature review of this research, the superstrate layers used by the proposed design do not contain partially reflecting surfaces (PRS) printed on the superstrate layers to reduce the SLL of the antenna radiation pattern.

Partially reflecting surfaces were used in multilayer antenna designs presented in the literature review, to eliminate SLL of patch antenna radiation pattern, as well as enhancing the gain. The superstrate layers were used to enhance the gain of patch antenna. The proposed multilayer antenna in this research had used three superstrate layers which were located above the feeding patch to enhance the gain and improve the operating bandwidth of the antenna, while the SLL were eliminated due to optimizing the height of each superstrate layer from the ground plane. In general this research is aiming to present directive antenna operating for point-to-point applications at 5.8 GHz with suitable gain over the ISM band (5.725 - 5.875) GHz.

1.5 Thesis Structure

The proposed thesis of this research is composed of five chapters. Chapter one "Introduction" shows background, problem statement, research objectives, thesis scope, and thesis structure. Chapter two "Literature Review" proposes a literature review about basic concepts, parameters of patch antenna, enhancing its gain, improving and operating bandwidth, and reducing side lobe level (SLL) of the radiation pattern. Chapter three "Research Methodology" which shows the design geometry for the proposed multilayer antenna which is composed of feeding patch and multiple superstrate layers which were used to enhance the performance of the patch antenna. Chapter four "Results and Discussion" which provides a parametric study, simulated, and, measured results for the proposed antenna. Chapter five "General Conclusions" which shows the conclusion of the thesis work and future works which could be based on the results of this thesis.

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