# WIDEBAND BAND-NOTCHED ANTENNA USING ELECTROMAGNETIC BAND-GAP STRUCTURE WITH DUAL 5G BANDS

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To my father Nasidi Abdullahi, my mother Nafisa Bello, my siblings and my sponsors – the Kano state government of Nigeria.

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# ABSTRACT

A wideband band-notched antenna using electromagnetic band-gap (EBG) structure with dual 5G bands is proposed and demonstrated. The single element antenna consists of a spade-shape radiating element, partial ground plane and two EBG structure fed by a microstrip line. The two EBG structures have an edge-located via. The wideband is realized by the combine resonance of the radiator and partial ground plane. The band notch was realized using two similar mush-rooms like EBG structures integrated into the feedline of the wideband antenna. The antenna has operating frequency of 6-12GHz with a band-notch between 8.2-10.7GHz. The EBG provide the band notch by degrading the antenna matching and changing current distribution. Moreover, the performance of the antenna has been studied and it has been found that the radiation patterns of the antenna without EBG and that with EBG are exactly the same. This indicates that the EBG has no effect on the radiation characteristics of the antenna. The simulations were done on using CST microwave studio. The fabrication of the antennas was carried out on FR4 substrate with dielectric constant $\varepsilon_r$ of 4.6 and thickness 1.6mm. The measured and simulated results are compared and analysed. With two 5G bands, the antenna can be considered for future (5G) wireless mobile communication applications.

# ABSTRAK

Wideband band-notched antenna menggunakan struktur electromagnetic band-gap (EBG) dengan dua band 5G telah diusulkan dan didemontrasikan. Elemen tunggal antenna dibuat daripada spade-shape radiating element, partial ground plane dan dua struktur EBG disambung pada garisan mikrostrip. Kedua-dua struktur EBG tersebut mempunyai edge-located via. Wideband didapati dengan gabungan resonans pada radiator dan partial ground plane. Band notch didapati dengan menggunakan dua persamaan mush-rooms iaitu seperti struktur EBG yang diintegrasikan kepada feedline wideband antenna. Antenna tersebut mempunyai operasi frekuensi 6-12 GHz dengan band notch di antara 8.2-10.7 GHz. EBG tersebut menghasilkan band notch dengan mengurangkan persamaan antara antenna dan perubahan pada tenaga elektrik. Tambahan pula, prestasi antenna telah dikaji dan didapati bahawa corak radiasi pada antenna samada tanpa EBG dan mengunakan EBG adalah sama. Ini menunjukkan bahawa EBG tidak mengubah karakteristik radiasi pada antenna. Semua simulasi dijalankan dengan menggunakan CST microwave studio. Fabrikasi antenna dijalankan atas FR4 substrate dengan tetapan dielektrik, $\varepsilon_r$ =4.6 dengan ketebalan 1.6mm. Hasil daripada pengukuran and simulasi telah dibandingkan dan dianalisa. Dengan dua band 5G, antenna tersebut boleh dipertimbangkan untuk aplikasi (5G) komunikasi tanpa wayar pada masa depan.

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| | | |
|---|---|---|
| EBG | - | Electromagnetic band gap |
| UWB | - | Ultra wideband |
| CST | - | Computer simulation technology |
| VSWR | - | Voltage standing wave ratio |
| FR4 | - | Flame retardant 4 |
| WLAN | - | Wireless local area network |
| Q-factor | - | Quality factor |
| dB | - | Decibel |
| GHz | - | Giga hertz |
| mm | - | Millimeter |
| 5G | - | Fifth generation |
| E-plane | - | Electric plane |
| H-plane | - | Magnetic plane |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| $f_0$, $f_c$, $f_r$ | - | Resonant frequency |
| $\varepsilon_r$ | - | Dielectric constant of substrate |
| $h$ | - | Substrate thickness |
| $\delta$ | - | Dielectric tangent loss |
| Ω | - | Ohm |
| $Z_0$ | - | Characteristic impedance |
| $\lambda$ | - | Wavelength |
| $c$ | - | Speed of light |
| $\pi$ | - | Pi |
| $\eta$ | - | Efficiency |
| $S11$ | - | Return loss |
| $W_s$ | - | Substrate width |
| $L_s$ | - | Substrate length |
| $W$ | - | Patch width |
| $L$ | - | Patch length |
| $W_f$ | - | Feedline width |
| $W_e$ | - | EBG width |
| $L_{gs}$ | - | Ground plane length |
| $g$ | - | Gap between feedline and EBG |
| $r$ | - | Via radius |
| $\varepsilon_{eff}$ | - | Effective dielectric constant |

| | | |
|---|---|---|
| $L_{eff}$ | - | Effective patch length |
| $\Delta L$ | - | Extended patch length |
| $C$ | - | Capacitance |
| $L$ | - | Inductance |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

In wireless mobile communication were size, weight and ease of integration in circuits is an issue, microstrip antenna is employed. Microstrip patch antenna exhibits several advantages which include; low profile (small thickness), light weight (etched on a thin substrate), low cost (inexpensive substrate), easy fabrication and versatility (in terms of resonant frequency, impedance and mode of operation). There are some drawbacks, however, principally in characteristics of the antenna which are narrow bandwidth and low gain[1].

As interest in microstrip antenna grows, research has been directed towards operating at high frequency. The sole reason has been increase in spectrum congestion at low frequency and advantages offered by high frequency such as increased gain and bandwidth. Frequency spectrum above 6GHz is been considered for future wireless communication (5G). Although the features for 5G are yet to be agreed upon worldwide, stakeholders (like ofcom – a UK based communication company) have identified some key features such as; very high data rate, large number of connected devices, ultra-low latency and high reliability applications [2].

To enhance the bandwidth of microstrip antenna, many techniques have been proposed which are categorized into three; (i) by lowering the Q-value: this involves selecting radiator shape, increasing substrate thickness or lowering dielectric constant. (ii) Improving impedance matching; this involves inserting a matching network such as inset feed, quarter-wave transformer, tapered feed or bevels. (iii) Introducing multiple resonances; this involves the use of parasitic element or slots [3].

To realise a band notch in an already designed antenna, an additional resonant element is added to the antenna structure. Methods to achieve this characteristic include etching slits or slot on the antenna patch, attaching parasitic elements close to the antenna patch or integrating filters [4]. However, the disadvantage of using slot for band rejection is the limitation in notch bandwidth control. To overcome the shortcoming posed by slots, EBG structure is often use for band rejection [5].

Apart from the band rejection capability, the EBG structure has been used in microstrip antenna for surface wave suppression [6], gain enhancement [7] and mutual coupling reduction in array antenna [8].

In this thesis, a wideband antenna covering frequency range from 6GHz-12GHz was initially designed, and then an electromagnetic band-gap (EBG) structure was integrated into the designed antenna so that all undesired frequencies are filtered thereby leaving dual 5G bands of interest.

## 1.2 Problem Statement

For future wireless mobile communication, high data rate transmission is the target. To provide high data rate communication system, a wide bandwidth antenna is required. However, based on the wideband spectrum under consideration, which is 6GHz-12GHz, there exists some other wireless communication system operating within the spectrum. As such international regulation prohibits all radiation in the band 10.68GHz-10.7GHz because it has been allocated for satellite communication [9]. This is due to the possibility of interference. Thus, a method to suppress or prevent the usage of this band has to be exploited.

## 1.3 Objectives

The objectives of this work are:

1. To design a wideband antenna to operate from 6-12GHz.

2. To design a band-stop filter to suppress the band 8.2-10.7GHz, thereby leaving two 5G bands.

## 1.4 Scope of Study

The scopes of this project are outline below:

- Design a wideband microstrip patch antenna and then integrate the wideband antenna with an EBG for band rejection.
- Simulate and fabricate the designed antennas.

- Study the performance of the antennas in relation to return loss, radiation pattern, VSWR and gain.

## 1.5 Thesis outline

This thesis has been outlined in five chapters. Each chapter contents are unique and different from the other as it contains a different aspect of the work.

Chapter 1 contains the introduction, problem statement, objectives and scope of the work.

Chapter 2 is the project background chapter. It contains an overview on microstrip antenna, basic characteristics of microstrip antenna, and antenna basics. It concludes with a literature review on previous related work carried out on this aspect of research

Chapter 3 describe the methodology followed for the design. It contains the antenna design equations and specifications. Simulation tools, fabrication process and measurement process are all described.

Chapter 4 focuses on result and analysis. Parameter study, current distribution, simulation and measurement results are all covered. Comparison between the measured and simulated result was done.

And finally Chapter 5 presents the conclusions and a suggestion on future work.

## 1.6 Summary

This chapter contain the introduction which mainly focuses on microstrip antenna, its features and future mobile communication (5G). Problem statements and objectives which describe the 'why' and 'how' of the project are also contain in the chapter.

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