# Chapter 9
# The Design of Virtual Laboratories in Microwave Engineering Education

**Man Seng Sim**
https://orcid.org/0000-0001-7776-2239
*Universiti Teknologi Malaysia, Malaysia*

**Kok Yeow You**
https://orcid.org/0000-0001-5214-7571
*Universiti Teknologi Malaysia, Malaysia*

**Fahmiruddin Esa**
*Universiti Tun Hussein Onn Malaysia, Malaysia*

## ABSTRACT

*The transformation of physical laboratory to virtual laboratory is necessary for distance learning, especially during the pandemic. The educators face challenges when designing and developing virtual laboratories. Therefore, this chapter aimed to present the implementation of virtual laboratories in microwave engineering education, which can be a reference for the educators. The first section introduces microwave, microwave engineering course, and laboratory experiments in the course. The following section reviews and presents the technological tools for the design and development of virtual laboratories. Furthermore, three examples of virtual experiments are discussed based on their design, pedagogical approach, virtual tools, and laboratory manual. The last part discusses the benefits, challenges, and future direction of virtual laboratories in microwave engineering education.*

DOI: 10.4018/978-1-7998-6963-4.ch009

## INTRODUCTION

Microwave is the region of electromagnetic wave spectrum with frequency ranging from 3 MHz to 300 GHz (Pozar, 2011). The microwave spectrum is designated to different frequency band (Bruder, 2013). Table 1 shows the band letter designations which have been used as a short notation for describing the frequency band of microwave (Radar Systems Electronic Systems Society, 2019). There are different applications for each frequency range. Some specific applications are also allocated for specific frequency. For example, 2.45 GHz is assigned for Industrial, Scientific and Medical (ISM) uses such as microwave ovens, Wi-Fi, and Bluetooth. Microwave technology has become increasingly important in recent years along with the evolving of fifth generation (5G) networks, internet of things (IoT) technology, and modern wireless and sensors technology.

*Table 1. Microwave frequency band and applications*

| Frequency Band | | Applications |
|---|---|---|
| **Letter Designation** | **Frequency Range** | |
| HF | 3 MHz to 30 MHz | Amateur radio |
| VHF | 30 MHz to 300 MHz | Amateur radio |
| UHF | 300 MHz to 1000 MHz | Television broadcasting |
| L | 1 GHz to 2 GHz | Global Positioning System (GPS), Mobile phones |
| S | 2 GHz to 4 GHz | Microwave ovens, Wireless LAN, Bluetooth |
| C | 4 GHz to 8 GHz | Long distance radio communications |
| X | 8 GHz to 12 GHz | Satellite communications |
| Ku | 12 GHz to 18 GHz | Satellite communications |
| K | 18 GHz to 27 GHz | Satellite communications |
| Ka | 27 GHz to 40 GHz | Satellite communications |
| V | 40 GHz to 75 GHz | Millimeter wave radar research |
| W | 75 GHz to 110 GHz | Radar, Remote Sensing |
| mm | 110 GHz to 300 GHz | Radar, Remote Sensing |

Source: (Radar Systems Electronic Systems Society, 2019)

### Microwave Engineering

Microwave engineering (also known as electromagnetic engineering or applied electromagnetic) involves the design of microwave circuits and components (*e.g.* power divider, couplers, circulators, filters), and devices (*e.g.* antennas, waveguides, resonators) (Pozar, 2011). Microwave engineering is different from conventional electronics engineering because it operates at higher frequency (shorter wavelength). Therefore, standard circuit theory based on Kirchhoff's laws and Ohm's law cannot be used to describe the microwave circuit's behaviour. This leads to the difference of circuit analysis techniques and design compared to those circuits at lower frequencies. For microwave circuit or component, analysis on electric and magnetic fields at every point in space based on Maxwell's equations and their solutions are