



## Chapter 9

# The Design of Virtual Laboratories in Microwave Engineering Education

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### 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.*

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## 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

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