Chapter 1

Introductory Chapter: RF/Microwave Applications

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1. Introduction

Owing to the rapid development of microwave technology, the microwave components and devices are increasingly common and relative low price compared to 10 years ago. Nowadays, microwave devices are often used and become an indispensable necessity in our daily routines, such as microwave ovens, mobile phones, and Internet. This introductory chapter reviews the microwave applications in this era based on a detailed literature survey and author's experience in microwave researches.

Radio waves and microwaves are a form of electromagnetic radiation with operating frequencies ranging from 30 to 300 MHz and 300 MHz to 300 GHz, respectively [1]. Different microwave applications and technologies will use certain frequency band to avoid frequency interference. These frequencies are grouped into several smaller bands. The most commonly used frequency spectrum classification today is created by the Institute of Electrical and Electronics Engineers (IEEE), which is listed in **Table 1**. Microwave applications for heating and crushing normally use high microwave power which is up to megawatts. In contrast, low microwave power (less than milliwatts) is widely used for domestic wireless communication or high-frequency electronic devices. Microwave applications can be categorized into two groups, namely, communication and noncommunication. Industrial, scientific, and medical (ISM) applications are normally classified as noncommunication group. Several scopes of microwave applications are listed in **Table 2**. The first three industrial, scientific, and medical (ISM) frequency allocations (at 13.66 MHz, 27.32 MHz, and 40.98 MHz) were designated by US Federal Communications Commission (FCC) in 1945 [2]. Recently, there are two microwave frequencies allocated by the FCC for ISM usage, namely, 915 MHz and 2.45 GHz.

Currently, most of the applications are devoted to the 2.45 GHz point, since it provides a suitable compromise between power deposition and penetration depth. The ISM bands defined

Electromagnetic wave spectrum	Frequency band	Wavelength
Radio waves	**Very high frequency (VHF) (30–300 MHz)**	**10–1 m**
Microwaves	**Ultrahigh frequency (UHF) (300–3000 MHz)**	**(100–10 cm)**
	P band (230 MHz–1 GHz)	130–30 cm
	L band (1–2 GHz)	30–15 cm
	S band (2–4 GHz)	15–7.5 cm
	Super high frequency (SHF) (3–30 GHz)	**(10–1 cm)**
	S band (2–4 GHz)	15–7.5 cm
	C band (4–8 GHz)	7.5–3.75 cm
	X band (8–12.5 GHz)	3.75–2.4 cm
	Ku band (12.5–18 GHz)	2.4–1.67 cm
	K band (18–26.5 GHz)	1.67–1.13 cm
	Ka band (26.5–40 GHz)	1.13–0.75 cm
Millimeter waves	**Extremely high frequency (EHF) (30–300 GHz)**	**(10–1 mm)**
	Ka band (26.5–40 GHz)	1.13–0.75 cm
	V band (40–75 GHz)	7.5–4 mm
	W band (75–110 GHz)	4–2.73 mm
	Millimeter band (110–300 GHz)	2.73–1 mm

Table 1. Institute of Electrical and Electronics Engineers (IEEE) frequency spectrum.

by the International Telecommunication Union (ITU) are listed in **Table 3** [1]. However, during recent years, ISM bands have also been shared with license-free error-tolerant communications applications, such as wireless LANs. In addition, now is the era of the fourth industrial revolution, so-called Industry 4.0, which most operation systems in the industry are in cyber based. Hence, the combination between communication (Internet) and noncommunication (microwave things) technologies is increasingly popular in order to produce smart devices, so-called Internet of Things (IoT), in which the devices are embedded with electronics, software, sensors, actuators, and network connectivity that are capable of covering a variety of protocols, domains, and applications, which include the automotive industry, public safety, emergency services, and medical field [3].

Within the past 40 years, microwave technology using frequency operation exceeding 300 GHz to 3 THz also existed, so-called Terahertz technology. In fact, operating frequency of 300 GHz to 3 THz occupies a middle ground between microwaves and infrared light waves. The corresponding range of the wavelength for the Terahertz frequencies is 0.1–1 mm; thus, it is a denominated submillimeter wave [27]. The Terahertz technology is widely utilized in the field of astronomy, medical, and security, such as space-based remote

Communication [3–8]	Noncommunication [9–26]
1 Communication network systems, such as high-speed home and business networking devices (modem and router), device-to-device communication (D2D) system, massive MIMO technology, cloud technologies, and small cell access points	1 Sensors for industrial, agricultural/food, and medical processing, such as moisture measurement, ripeness/storage period determination, fruit sweetness detection, control of milk of lime, monitoring of nitrogen/phosphorus content in fertilizer, medical diagnostic, moisture soil testing, metal crack detector, and storage tank measurement devices
2 Communication devices and test instruments, such as spectrum analyzer, RF power meter, frequency counter, signal generator, and vector network analyzer	2 Heating/drying or freeze-drying process (sterilization / pasteurization) in food industry to control pathogenic and spoilage microorganisms in packaged foods
3 Navigation systems such as maritime navigation, Global Positioning System (GPS), air traffic control, airborne radars, and satellite communication	3 Industrial heating applications, such as casting waxes, sintering ceramics/metal powders, melting of glass/rubber, metal coating, brazing, and paper/wood drying
4 Wireless remote control for security and healthcare systems such as automatic gate/door, automatic barrier systems, burglar alarms, and industrial automation systems (Industry 4.0)	4 Medical applications, such as hyperthermia treatments, bio-impedance instrumentation, and medical diagnostic imaging (to detect a location or movement of objects within a human body or animal body)
5 Vehicular radar systems to detect the location and movement of objects near a vehicle, enabling features such as near collision avoidance, improved airbag activation, and suspension systems that better respond to road conditions	5 Material characterization fixtures (materials including graphene, metamaterials, carbon nanotube, conductive polymer, high-temperature superconductor, aerogel, ceramics, semiconductor, polymer insulation, fibers, gases, and chemical liquids)
6 Entertainment and information communication devices/systems such as television broadcast, FM broadcast, radio beacons, maritime radio, walkie-talkie, coast guard communication, satellite communication, and weather radars	6 Image scan systems to detect the images of buried objects, location of objects contained within a wall, location or movement of persons or objects which are located on the other side of a wall, as well as the intrusion of persons
7 Domestic communication devices, such as 4G/5G smart phone, computer, Bluetooth, Wi-Fi devices, wireless webcam, and wireless microphones	7 Civil engineering applications (rock crushing, tar road comminuting)
	8 Radiation for agricultural pest control

Table 2. Microwave applications for communication and noncommunication technologies.

sensing and medical diagnostic imaging [28–31], due to the submillimeter waves that are nonionizing, and it can penetrate a wide variety of nonconducting materials. Recently, high operating frequency requirements for microwave test instruments are increasing, such as recent commercial vector network analyzer which is capable of achieving 1.1 THz. Hence, in future, these microwave components and devices are expected to be very small and sensitive.

Frequency range (f)		Bandwidth (Δf)	Center frequency (f_o)
MHz	*6.765–6.795 MHz	*30 kHz	*6.780 MHz
	13.553–13.567 MHz	14 kHz	13.560 MHz
	26.957–27.283 MHz	326 kHz	27.120 MHz
	40.660–40.700 MHz	40 kHz	40.680 MHz
	**433.050–434.790 MHz	*1.74 MHz	*433.920 MHz
	***902.000–928.000 MHz	*26 MHz	*915.000 MHz
GHz	2.400–2.500 GHz	100 MHz	2.450 GHz
	5.725–5.875 GHz	150 MHz	5.800 GHz
	24.000–24.250 GHz	250 MHz	24.125 GHz
	*26.975–27.283 GHz	*308 MHz	*27.129 GHz
	*61.000–61.500 GHz	*500 MHz	*61.250 GHz
	*122.000–123.000 GHz	*1 GHz	*122.500 GHz
	*244.000–246.000 GHz	*2 GHz	*245.000 GHz

*Subject to local acceptance

**Only Europe, Africa, the Middle East/Middle West of the Persian Gulf, the former Soviet Union, and Mongolia

***Only Americas, Greenland, and some of the eastern Pacific Islands

Table 3. Industrial, scientific, and medical (ISM) operating frequency band defined by the International Telecommunication Union (ITU).

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