1

Introduction

Learning Objectives

The learning objectives of Chapter 1 are as follows:

1. Introduction to emerging wireless and guided electromagnetic technologies that have impacted our everyday life.
2. Introduction to the practical applications and significance of the advanced electromagnetics in our everyday life
3. Introduction to topics usually covered in modern textbooks on advanced electromagnetics. The basic definitions of wireless transceivers, wireless channels and uniform plane wave propagation, various transmission lines and waveguides, optical fibres, antennas and antenna arrays, and finally, electromagnetic interference (EMI) and electromagnetic compatibility (EMC).
4. The modern pedagogical practices in advanced electromagnetics at the university.
5. A design project to show the applications of the learned theories of wireless and guided electromagnetics.

Learning Outcomes

At the end of the chapter, you will be able to comprehend the following:

1. The contributions and significance of wireless and guided electromagnetics.
2. A concrete understanding of the fundamental building blocks of wireless and guided electromagnetics.
3. New pedagogical methods used in modern universities.
4. A design project that sets the foundation for the practical application of the learned theories of wireless and guided electromagnetics.

Chapter Outline

The outline of the chapter is shown Figure 1.1. First, the emerging applications of advanced electromagnetics are introduced. The chapter has introduced many interesting applications of advanced electromagnetics in modern emerging technologies that have impacted our everyday

Electromagnetic Applications for Guided and Propagating Waves, First Edition. Nemai Chandra Karmakar.

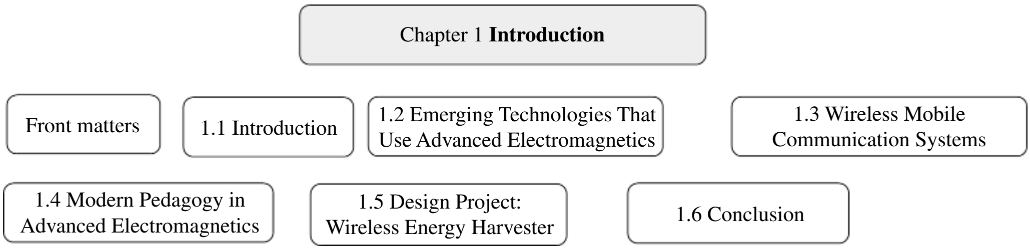


Figure 1.1 Chapter 1 outline.

life, business practices, medical treatments, social interactions and leisure. The modes of delivery of pedagogical practices have evolved from whiteboards and overhead projectors to the multi-media based interactive teaching and learning sessions with modern laboratory facilities, and cutting-edge design projects to enhance students' learning experiences. It is a non-trivial task to design a laboratory to enhance the learning experiences through experiments in advanced electromagnetics. Usually, radio frequency (RF) and microwave sources, receivers and measuring equipment are too expensive to implement, need specific sets of expertise and the teaching methods are too abstract for students to digest. A very low-cost innovative laboratory setup that was derived for the author's research laboratory is introduced for advanced electromagnetic teaching. A design project of wireless energy harvesting is also introduced so that students can apply their knowledge gained from the theories learned in each topic of the textbook. Laboratory experiments can be applied in a real world, emerging and ubiquitous design project with the aid of full-wave electromagnetic solvers such as computer simulation technologies (CST) Microwave Studio™ (MSW) and Keysight Advanced Design System (ADS™). These specialised software tools are used in industry for high-end design. Hands-on knowledge and skills gained in the design project develop the graduate skills and employment readiness of learners. Besides these, the knowledge and skills developed in calibration methods and measurement using a full two-port vector network analyser are also an added advantage for the students to develop graduate skills for industrial applications. The chapter concludes with Section 1.6 Summary of Chapter.

1.1 Introduction

Welcome to the textbook: *Electromagnetic Applications for Guided and Propagating Waves*. Advanced electromagnetics (AEM) has an abstract nature with full of mathematical derivations, and many fundamental physical laws such as the laws of Coulomb, Gauss, Biot-Savart, Ampere, and Faraday. All these laws are well presented in a set of equations, which are called Maxwell's Equations. Figure 1.2 shows a sketch of various laws of AEM in complex vector mathematical forms. These advanced and highly complex mathematical equations for the electromagnetic laws and hypotheses easily scare new learners of electrical and electronic engineering and physics. To enjoy this subject, you should look at the big picture of contemporary technologies that we are using in modern society, and then analyse with your mind how these technologies that use wireless and guided electromagnetics impact our daily lives. Then only you can appreciate the complex nature of the discipline and enjoy learning the theories that

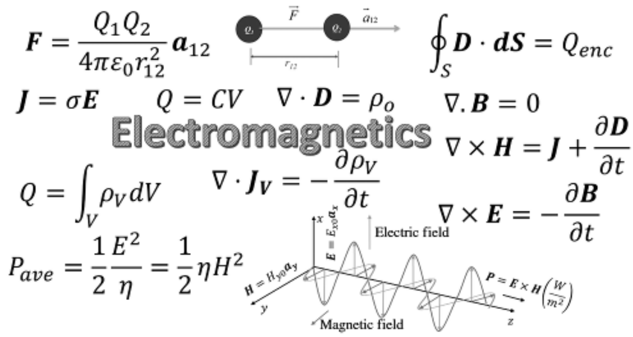


Figure 1.2 Laws of EM and complex perception of the AEM discipline by learning.

underpin the modern wireless and guided communications world in RF, microwave, millimetre wave and light wave spectra.

With the advent of fast Internet connectivity via submarine optical fibre networks, wireless fidelity (Wi-Fi), voice over internet protocol (VoIP),[1] we are so well connected, as if we are living in a small global village. The motto of the modern wireless technological development is to provide boundless flexibility and scalability without any wires. *It is interesting to observe how wireless and guided* electromagnetic *have impacted upon us through these emerging technologies in the twenty first century.* The most advancements in wireless technologies, such as global positioning satellite (GPS) system, near field communications (NFC), google navigation, 4G/5G/5G+[2] wireless communications that are packaged in a smartphone, are overwhelming. If the 1980s technologies had been used, it would require tens of truckloads of electronic equipment to match the functionality of a modern smartphone, forget about the scalability.[3]

Figure 1.3a introduces Internet of Everything (IoE), which collects data wirelessly from every tagged item, small or big. NFC devices in your smartphones use the radio frequency identification (RFID) technology to help create a cashless society. All are being done wirelessly. The smart cities and smart farming become a reality with wireless communications. The modern technology becomes multidisciplinary and requires engineers and scientists from all branches to work together. As shown in Figure 1.3b, a modern fighter jet is equipped with advanced radar systems with steerable antennas, many wired and wireless sensors for navigation, and manoeuvring in challenging situations.

The textbook addresses all of the emerging and burning issues of our society in the new millennium and shows how the new technologies utilise the theory of AEM to address and solve many of these problems. To make the complex and abstract electromagnetic theory interesting, the introductory chapter has briefly analysed the most popular technologies that have been impacting our lives in recent decades.

1 The most recently emerged VLC also called light fidelity (LiFi), will provide wireless connectivity in the order of tens of gigabits per second (Gbps) with the light as the carrier from the LEDs. For more details, refer to https://en.wikipedia.org/wiki/Visible_light_communication.

2 5G wireless communications is due in 2020 with a large data capacity and operating over 1–100 GHz to exploit all possible resources in the frequency spectrum, smart antenna technologies, embedded systems and signal processing algorithms.

3 Smartphones, Planet of the phones, The Economist, Feb 28th, 2015.


(a)


(b)

Figure 1.3 (a) IoE. (b) A fighter plane is packed with so many advanced levels RF/microwave/mm-wave equipment, such as the most advanced radar systems in the world, smart antennas and signal processing algorithms. *Source*: Senior Airman Gustavo Gonzalez/Wikimedia Commons/Public Domain.

1.2 Emerging Technologies That Use Advanced Electromagnetics

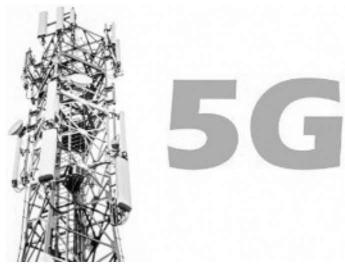
Table 1.1 summarises the most popular and advanced technologies that have emerged as the mainstream breakthroughs in the twenty-first century. AEM is all about the analyses of the electromagnetic wave phenomena inside the wireless channels and guided structures. The most beautiful aspect of the electromagnetic theory is that we can perceive the three-dimensional (3D) field distributions and wave phenomena due to the electromagnetic stimuli inside any structure. That is why electromagnetic theory penetrates every branch of electrical and electronic engineering. For example, in a semiconductor device, we can analyse the microscopic level of 3D field distributions and associated changes in current and voltage at the junction of different doped elements due to changes in the terminal biasing conditions. The current and voltage establish the electric (E) and magnetic (H) fields[4] at the junctions of the active devices, such as diodes and

4 The electric field intensity *(E)* is referred to as the electric field or in short *E*-field and has the unit (V/m). Likewise, the magnetic field intensity (H) is referred to as the magnetic field or in short *H*-field and has the unit (A/m).

transistors. Likewise, electromagnetic theories become the backbone of power system analysis for high-voltage transmission lines, power transformers, and generators.

The applied electromagnetics covers many branches of wireless communications and their emerging disciplines such as the dynamic wireless channels established by the smart antennas, and beamforming algorithms for the fourth and fifth generations of wireless communications systems,[5] active and passive RF/microwave circuits, and advanced modulation techniques of the light emitting diodes (LEDs) for emerging light fidelity (LiFi), visible light communication (VLC) technology.

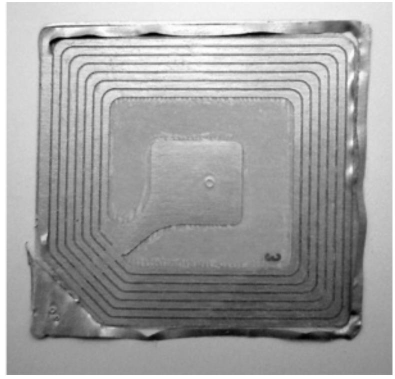
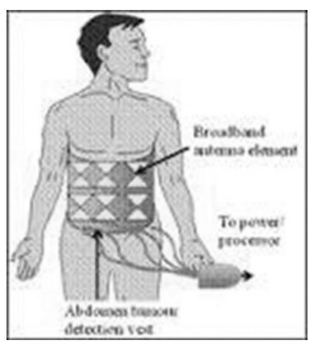
Table 1.1 Emerging technologies in the twenty-first century.

1. ***Fifth Generation (5G) wireless communications*** network provides an extremely high data rate for wireless communications between devices and clouds. The 5G technology utilises a frequency band below 1 G up to 100 GHz. The pico-cells, augmented with smart antenna beamforming, are used to track the mobile users in the cell and ensure smooth handover from one cell to another as the users move. Ultra-wide bandwidth and free frequency spectra in mm wave and THz are exploited since the lower band of microwave frequency spectra is overcrowded. To develop the technology around such a wide frequency spectrum, we need the sound fundamental and design knowledge of precision transmission lines, matching networks, antennas, and antenna beamforming networks, passive and active design in those frequency bands.	 Ivan Radic on VisualHunt
2. ***Bluetooth*** is a short-distance wireless data communications technology between devices, such as computers, smartphones, and many electronic gadgets (TVs and sound systems). With the IoE, Bluetooth will play an even bigger role in our everyday lives. Bluetooth uses 2.45 GHz electromagnetic frequency spectrum.[6]	 Lukatoyboy on VisualHunt

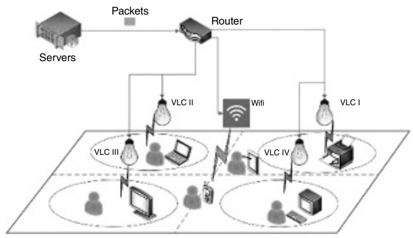
(Continued)

5 As for example, Keysight's SystemVue and Genesis software tools can analyse the whole 4G and 5G communications network augmented with smart antenna beamforming. Visit Keysight website: www.keysight.com
6 The technologies that use 2.4 GHz bands are Wi-Fi, ZigBee, car alarms, codeless phones, wireless microphones, and microwave ovens.

Table 1.1 (Continued)

3. ***RFID*** is a wireless data transmission and reception technology for identification, tracking and tracing of items, goods, and personnel. It uses RF spectrum from hundreds of kilohertz up to 100 GHz. Every pet in a modern household has an RFID bolus inserted in its neck. RFID is the backbone of the Internet of Things, coined by the MIT Auto-ID Lab, and IoE coined by Cisco.	 Melanie_hughes on VisualHunt
4. ***Driverless cars*** developed by Google will enable safe driving in the busy city streets. A GPS system (rooftop antenna) at 1.5 GHz and anti-collision radars at 24 and 60 GHz make the car a wireless powerhouse. Ten million self-driven cars are predicted to be on the road in the near future.	 Steve Jurvetson/Flickr
5. ***eHealthcare and biomedical engineering***: mHealth (mobile health), telemedicine, remote monitoring tools, and real-time locating services remove unnecessary emergency room visits and monitor grannies remotely with the wireless sensors attached to their appliances. Telemedicine brings a new revolution by removing the burden on hospitals and healthcare systems and reduces healthcare costs.	
6. ***Microwave biomedical imaging*** is a low-cost option for traditional imaging methods, such as MRI, X-rays, ultrasound, CT scans, and is less harmful to human tissues. It will revolutionise the medical diagnostics market and will be readily available in developing countries and remote areas of developed countries due to its low cost.	

7. ***Light Fidelity, or Li-Fi technology*** is a VLC system and an alternative to Wi-Fi technology. It uses the visible light spectrum emitted by an LED source. It is cheaper and much faster than Wi-Fi technology. A German physicist, Prof. Harald Hass of Edinburgh University, UK, has envisioned switching of visible light via LEDs that can transmit 10–100 Gbps of data in a room.



8. ***Smart road, smart transportation***, and car-to-car communication, wireless battery charging of electric vehicles while on the move, use wireless and guided wave electromagnetics in various forms.

JCT600 on VisualHunt

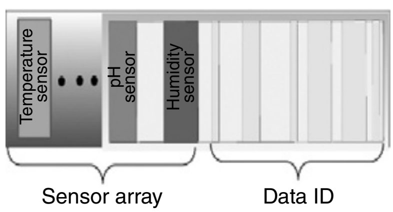
9. ***Virtual reality using mm-wave radar***. Google has patented a virtual reality called *Magic Leap*. The technology uses a silicon waveguide to create a 3D image in the retina to augment virtual reality.

   The other technology is the projector phone on your palm from your smartwatch. All are augmented with the knowledge of wireless and guided electromagnetics.

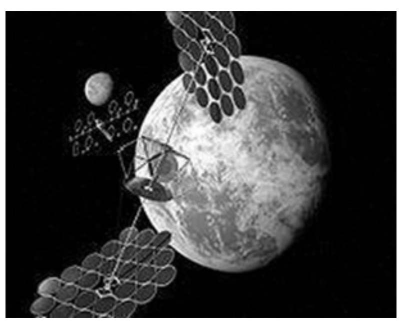
   Google has developed a hand gesture virtual reality technology using mm-wave radar. You can control many electronic gadgets just using your fingers as if you are controlling physical devices.

Eugene Capon/Pexels/Public Domain

10. ***Chipless RFID and sensor*** are a fully printable microwave passive circuit on plastic and paper. The individual frequency signature for each microwave resonator provides 1:1 data correspondence. By adding functional materials, the chipless tag is converted to a multi-parameter, single-node sensor. Due to its printability and sensing capability, it will revolutionise the IoE in the near future.



11. ***Space-based solar power***: Energy sectors are going through a huge revolution with renewable and wireless energy harvesting. Outer space energy harvesting from sunlight and beaming gigawatts of energy via wireless microwave link to the Earth will revolutionise the energy sector in both developed and developing countries. A very high-gain pencil beam antenna will direct the gigawatts of energy to the Earth base station.



NASA/Wikimedia Commons/Public Domain

Due to the environmental issues and unsustainable carbon dioxide (CO_2) footprint, the energy sector is under tremendous regulatory scrutiny. Many old-fashioned, coal-fired power stations are being closed. Therefore, the sector has been going through tremendous evolution. Traditional energy generation using fossil fuels will be replaced with renewables such as millions to billions of solar cell units and photovoltaic (PV) panels, windmills, wave energy generators, and battery storage systems. Every household will be an independent energy source based on renewables such as rooftop PV panels. The energy collected from the solar panels will be stored in batteries. As the world is running out of traditional energy resources, and becomes more concerned about environmental issues and sustainability, we must move to renewable energy sources as advocated by Mr. Elon Musk, PayPal co-founder, CEO and CTO of SpaceX, and CEO and Chief Product Architect of Tesla Motors. He has also advocated for a power network grid of 100 miles by 100 miles arrays of PV panels to meet the energy requirements of the whole of America.[7] For efficient operation of such big panel arrays, each panel requires automated and wireless monitoring of their health. Even the conventional power grid needs such wireless monitoring for efficient operation and avoidance of blackouts. These transitions of renewable energy sectors can benefit from the RF technology and RF sensors. Wireless/RF technology provides the information of the health of individual PV panels and the whole grid in real time remotely. RFID technology is already being used in the energy sector for personnel information management, inventory controls, and asset management. RFID sensors are being used for health monitoring of power equipment.[8] Therefore, RF technology can play a major role in diagnostics, planning, and operational efficiency improvement.

Wireless power transfer. The current world has an abundance of electromagnetic energy. The sources of abundant electromagnetic energies are overhead power lines at 50 Hz, the radio and TV transmission towers at low frequency, high frequency, and ultra-high frequency, the mobile base stations at 900 and 1800 MHz, and the wireless routers at homes and offices at 2.45 GHz. These are just a few examples. Can we scavenge such energy for our low-power devices so that we will not need any battery to operate our smartphones and wireless sensors? Use of fossil fuel in cars and heavy vehicles is the most polluter of our environment, and the cost of healthcare due to smoke inhalation is exorbitant. Nowadays, electric vehicles are getting popular. However, the poor efficiency of the battery packs, their weight and disposal after they wear out are the main bottlenecks preventing the technology from being sustainable. Can we scavenge power wirelessly from the overhead power lines to charge our electric vehicles when the vehicles are on the move? Can we remove kilometres of wires in modern vehicles and passenger planes for hundreds and thousands of individual sensors, and lighting systems using wireless power transfer? Yes, it is possible through efficient wireless power transfer devices that use both near and far field couplings of electromagnetic energy from the source to the devices. Sound knowledge in wireless channels, antennas, and microwave circuit design augment such development. Recently Ohio State University developed a casing for 4G and 5G smartphones that scavenges energy for the on-board power supplies wirelessly from the electromagnetic energy emitted by the Wi-Fi router at homes, offices, shopping centres, airports and stadiums.[9] Apple has just introduced a wireless iPhone charger in the market as shown in Figure 1.4.

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7 http://www.goodspeaks.org/event/Is-Solar-Energy-Inevitable%3F--Absolutely,-says-Tesla-CEO-Elon-Musk accessed 32/11/2016 title; Is Renewable Energy Inevitable? Absolutely, says Tesla CEO Elon Musk by Ellen Alderton.

8 See Author's developed PD Hawk™ commercialised by industry partner AusNet Services and EA Technologies, UK.

9 http://www.momentumenergy.com.au/habitat/technology/phone-case-that-charges-your-phone-from-thin-air/ accessed 25/11/2016.

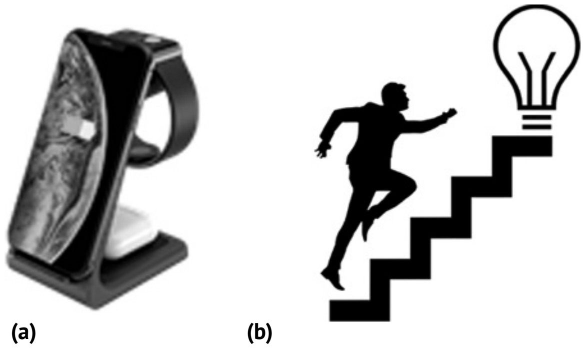

Figure 1.4 (a) Wireless charger. *Source*: iEsrcharger/Pixabay/Public Domain and (b) innovation is the key to success.

If you look at these big pictures of the applications of the wireless and guided electromagnetic and find the potentials of the learning objectives and outcomes of the subject matters, then you will enjoy the abstract nature of the electromagnetic theories. Additionally, to the learned theories and the examples of associated applications, we also introduce you with a Design Project: Wireless Energy Harvester to enhance your hands-on skills set and learning outcomes. There, you will apply all the learned theories of the subject matters in a practical design exercise. Can you turn the outcomes of your Design Projects into niche products? This project has countless applications. As for example, the author developed wireless orthopaedic needles for bone healing and bone growth using the wireless power transmission concept.[10] This is a fantastic application of wireless power transfer into biomedical engineering. A microwave imaging vest for microwave medical imaging is shown in Table 1.1. The vest has many switched-beam antenna elements that scan the torso of a patient and develop a 3D image of the abdomen. The imaging system diagnoses tumours and malignant tissues inside the abdomen. You may think of many applications of this technology and retrofit your design to suit particular emerging applications.

1.3 Wireless Mobile Communication Systems

Figure 1.5 shows a modern wireless cellular communications system. Our goal is to augment the understanding of how the wireless and guided electromagnetic theories are applied in the modern mobile communications system. As shown in Figure 1.5, the mobile communication system is comprised: (i) radio/microwave transceiver, (ii) wireless propagation channel, (iii) transmission lines, (iv) antennas, (v) antenna arrays, and finally (vi) electromagnetic compatibility issues due to electromagnetic interferences.

Let's begin with a brief introduction to each element and then we shall dive into details in each section sequentially with brief theory, design examples, numerical and qualitative problems and solutions.

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10 P. Zakavi and N.C. Karmakar, Wireless Orthopaedic Pin for Bone Healing and Growth: Antenna Development, IEEE Transactions on Antennas & Propagation, vol. 58, no. 12, December 2010, pp. 4069–4074.

P. Zakavi and N. C. Karmakar, Wireless Orthopaedic Pin for Bone Healing and Growth: Antenna Development, Proc. EPSM-ABECC 2009, Canberra, Australia, 8–12 November 2009.

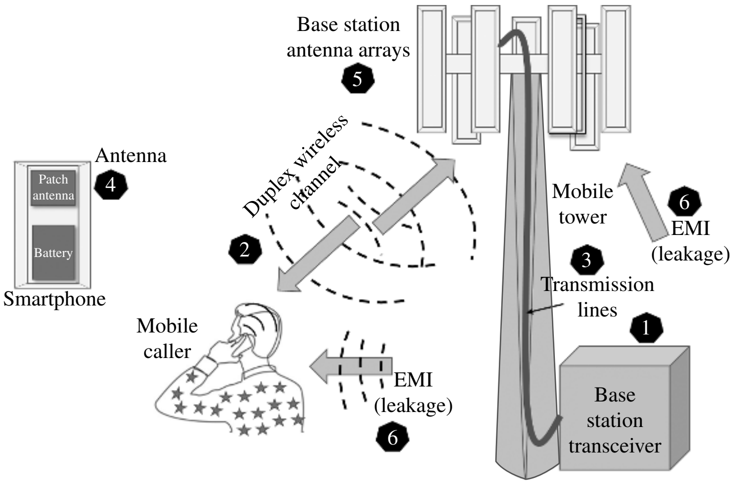


Figure 1.5 A modern cellular system.

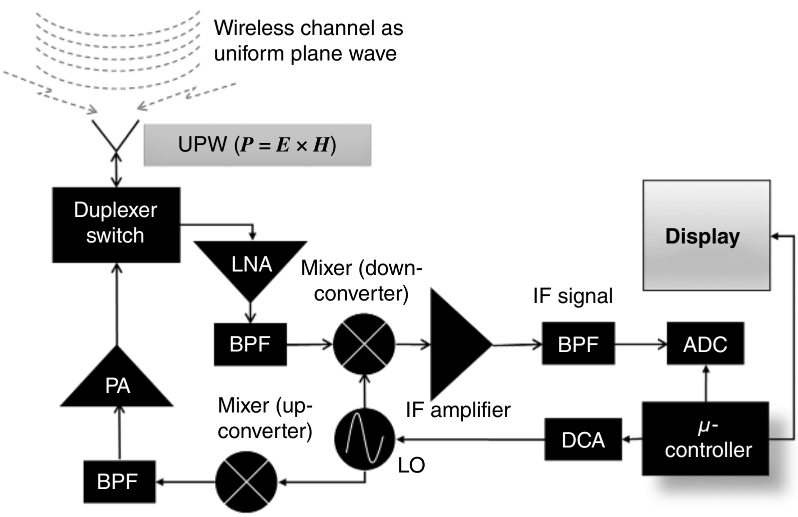


Figure 1.6 A modern transceiver with transmitter, receiver, and digital control section.

1.3.1 Wireless Transceiver

This section presents a brief overview of a microwave transceiver system. Fujitsu has introduced a wireless mesh network with multiple of such transceiver systems to cover a city. Each tower has its own transceiver to make a cellular network.

A radio transceiver is an electronics system that comprises both a transmitter and a receiver electronics in a single package (Figure 1.6). It is the heart of the wireless communications system. The transceiver is connected to the antenna via a transmission line so that signal can be transmitted and received simultaneously to complete a task.

A radio/microwave transceiver block is a subsystem within the total wireless network system. It is comprised of four main functional blocks: a radio transmitter, a radio receiver, a digital control section and an antenna. A duplexer switch with 100 dB isolation is used to switch between transmission and reception when a single antenna is used.

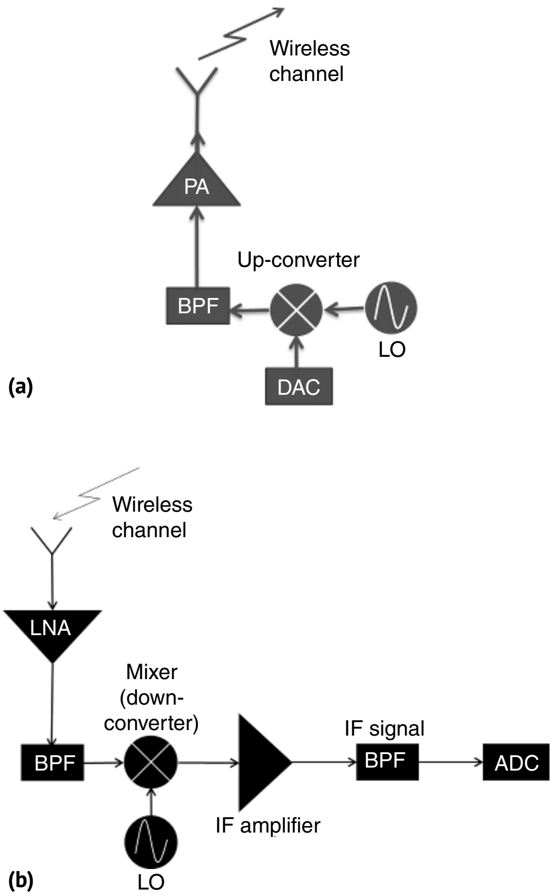


Figure 1.7 (a) Modern microwave transmitter and (b) receiver block diagram.

As shown in Figure 1.7a, a modern-day transmitter comprises a signal generator, a local oscillator (LO), a digital-to-analogue converter (DAC), an up-converter mixer, a band pass filter (BPF), a power amplifier (PA), and finally, a transmitting antenna. Since a high-frequency generator is expensive, a DAC's and a LO's signals are up-converted by the mixer, then a BPF filters out harmonics generated by the mixer, an amplifier amplifies the signal, and then, the amplified signal is sent to the wireless channel via the antenna. Thus, a transmitter converts a guided signal to a free-space or unguided signal.

A 10 GHz receiver is shown in Figure 1.7b. A microwave receiver receives very weak signals from the wireless channel and converts the signal to guided wave signals. It comprises a receiving antenna, a low noise amplifier (LNA), and a BPF to remove harmonics. The signal is down-converted to an intermediate signal intermediate frequency (IF) signal by a mixer and a LO. An IF amplifier and a BPF process the IF signal and send it to the digital section for further processing.

Frequency designation is very important to know. Table 1.2 shows industrial frequency designations from 1 to 40 GHz and their applications. Your design projects will be at 2.45 GHz (S-band). Signal behaves differently in different frequencies. Design becomes complicated with increasing frequencies.

Table 1.2 IEEE frequency band designation.

Radar bands	Frequency range (GHz)	Commercial applications
L	1–2	Mobile satellite communications, Inmarsat, GPS, personal communications
S	2–4	Mobile personal communications, Wi-Fi-Bluetooth, Satellite communications
C	4–8	Satellite communications
X	8–12.5	Radar systems, navigations
Ku	12.5–18	Soil moisture radiometer, radar point-to-point microwave links
Ka-band	26.5–40	Soil moisture radiometer, weather radar, military radars, point-to-point communications

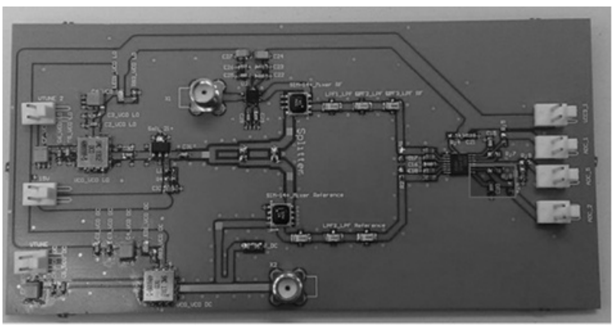


Figure 1.8 A chipless RFID tag reader at 4–8 GHz developed at the Monash Microwave, Antenna, RFID and Sensor (MMARS) research group.

Now, let us have a look at how our electromagnetic theory is useful in designing a modern microwave transmitter. Figure 1.8 illustrates the photograph of a C-band handheld transceiver with is an ultra-wide bandwidth reader for a chipless RFID system. Transmission line theory is used to connect and match different functional blocks. Passive devices such as power dividers/combiners, filters of various sorts and couplers are designed using T-line and matching theories. The Smith chart is used for matching circuit design. The microwave network theory is used to understand the signal flow between different blocks. Figure 1.9 shows the photo of the Rodhe & Schwarz vector network analyser (VNA) to measure network parameters of a microwave circuit. A VNA is basically an advanced transceiver system with many varieties of configurations to measure the vector microwave signal in a wide frequency band.

Now let us have a look at how electromagnetic theory is in action in the reception of unguided electromagnetic signal as shown in Figure 1.10. Uniform plane waves (UPWs) carry both time-varying electric $\boldsymbol{E}(t)$ and magnetic $\boldsymbol{H}(t)$ fields. The magnetic field is also defined with the magnetic flux density $\boldsymbol{B}(t) = \mu\boldsymbol{H}(t)$, where μ is the permeability of the propagation medium – in this case, air. According to Faraday's law, when a time-varying magnetic field cuts a conductor (here, the receiving antenna), it induces a voltage V_{emf} at the antenna terminals as shown in Figure 1.10a. This signal is processed for useful information by the receiver as shown in Figure 1.10b.

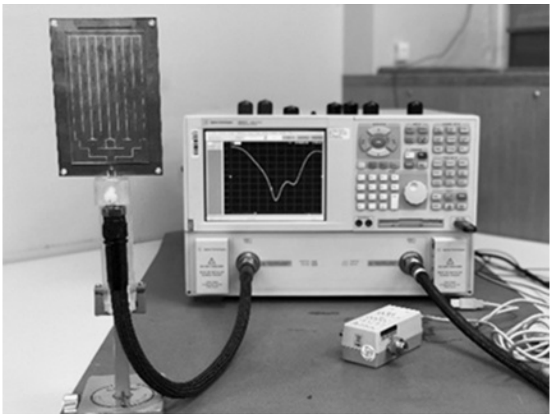
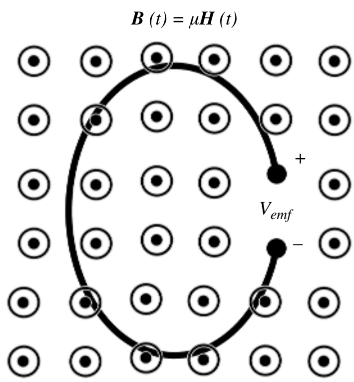
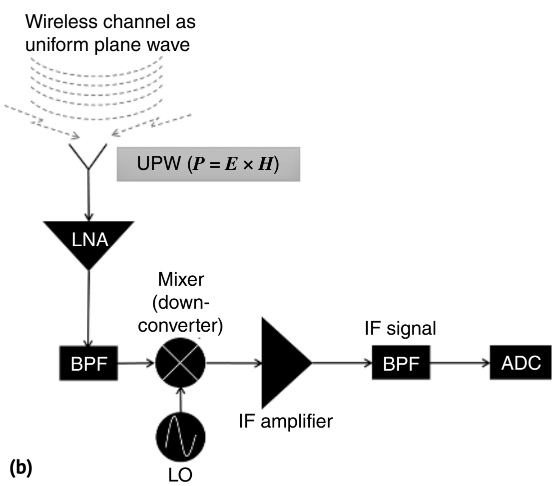


Figure 1.9 A VNA at MMARS laboratory with a test setup for array antenna return loss vs frequency measurement.



(a)



(b)

Figure 1.10 (a) Time-varying magnetic fields induce a V_{emf} across loop terminals. (b) Block diagrams show how a UPW is converted to analogue signals in the receiver.

Review Question 1.1: Applications of advanced electromagnetics

Q1. What are the main functional blocks of a modern microwave transceiver?
Q2. How Faraday's law is in action in a receiver? Explain.
Q3. A mixer down-converts a 10 GHz UPW signal to 150 MHz IF signal. What is the LO frequency?

Answer: $f_{LO} = (10 \pm 0.15)$ GHz = 10.15 or 9.85 GHz.

1.3.2 Wireless Channel via UPW

A wireless communications channel is an invisible, unguided electromagnetic energy path in which the wireless data traffic moves from the transmitter to the receiver. In a duplex system, this communication happens in both ways. The wireless channel is established via the UPW propagation from the transmitting antenna to the receiving antenna.

This section presents the wireless channel and plane wave propagation. The GPS system, satellite to ground station network and mobile devices as well as desktops, are all connected via the wireless channel. GPS is a massive network with 24 low-earth orbiting satellites. GPS has become an indispensable technology with numerous applications. The most important example is the car navigation system. GPS becomes an integral part of the smartphone for navigation. Figure 1.11 shows the handheld GPS receiver. In the modern world wireless channels are indispensable part of our daily life. Therefore, modern wireless communications engineers require to gain knowledge of the theory of UPW for efficient design of wireless devices and systems.

Figure 1.11 Handheld GPS receiver. *Source*: Avlxyz on VisualHunt.

Now we discuss the second item – wireless channel augmented with the electromagnetic theory of UPW propagation. Figure 1.12 shows a CSTs, microwave animated plane wave propagation from a horn antenna in 3D movies. Initially, the phase front of the wave is spherical, and after a certain distance, the phase front becomes planar. This wave with a planar phase front is called the UPW, or UPW in short.

Figure 1.13 illustrates the UPW in the rectangular coordinates. A UPW is composed of two orthogonal electric and magnetic fields. As shown in the figure, the x-directed electric (E for short) field, which is vectorially denoted as $\boldsymbol{E} = E_{x0}a_x\left(\frac{\text{V}}{\text{m}}\right)$. Here, E_{x0} is the amplitude of the electric field and $\boldsymbol{a}_x$ is the x-directed unit vector. The magnetic (H in short) field is denoted as $\boldsymbol{H} = H_{y0}a_y\left(\frac{\text{A}}{\text{m}}\right)$. Here, H_{y0} is the amplitude of the magnetic field and a_y is the y-directed unit vector. Both electromagnetic fields are propagating in the z-direction with the power flow density vector $\boldsymbol{P} = \boldsymbol{E} \times \boldsymbol{H}$. Note that all are vector entities. Therefore, $\boldsymbol{E}$, $\boldsymbol{H}$ and $\boldsymbol{P}$ are orthogonal to each other. The medium of propagation has an intrinsic impedance, η (Greek alphabet eta), which is equal to

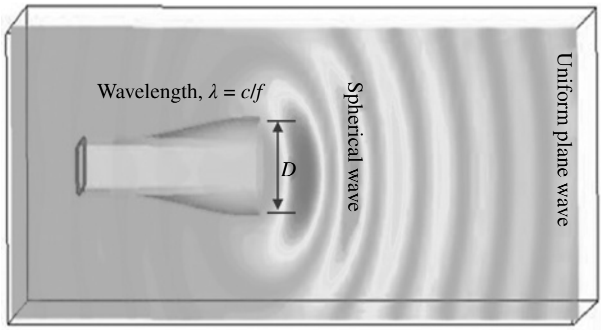


Figure 1.12 CST animated radiation propagation of electromagnetic wave showing how the spherical wave becomes UPW radiated from a horn antenna.

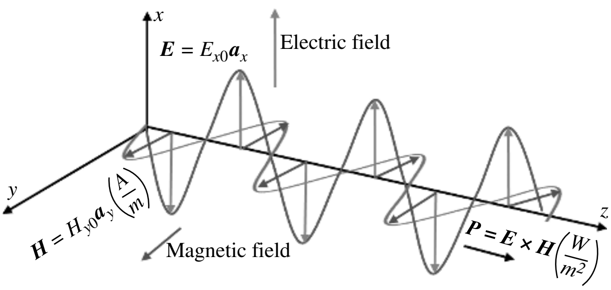


Figure 1.13 UPW in rectangular coordinate.

$\eta = 120\pi(\Omega) \approx 377(\Omega)$. The magnetic field intensity H is defined via the electric field and the wave impedance $H_0 = E_0/\eta$. Where E_0 is the amplitude of the E-field. The average power intensity is defined as $P_{ave} = \frac{1}{2}Re\,(E \times H^*) = \frac{|E_0|^2}{2\eta}$. This is the basic property of UPW propagation or wireless channel.

Review Questions 1.2: The theory of uniform plane wave
Q1. Define a UPW? **Q2.** In a UPW, what are the relative orientations of E, H, and P?

Example 1.1 The theory of uniform plane wave

A wireless transmission system operates at 100 MHz. A technician brings a power metre and an antenna and measures the average power density of 75.4 $\left(\frac{\text{mW}}{\text{m}^2}\right)$. Assume the UPW is propagating along the z-direction. Calculate the associated electric and magnetic field intensities. Ignore losses in the metre and the antenna.

$$P_{ave} = \frac{|E_0|^2}{2\eta} = 75.4\left(\frac{\text{w}}{\text{m}^2}\right),\ E_0 = 7.54\left(\frac{\text{v}}{\text{m}}\right),\ H_0 = \frac{|E_0|}{120\pi} = 20\left(\frac{\text{mA}}{\text{m}}\right)$$

The electromagnetic field theory of the UPW will be covered comprehensively in subsequent chapters. The reader may find the following YouTube videos very interesting. The first one is a video on battling rope fitness. It shows how the sine wave is created with a rope. The next two videos are fundamentals of UPW. The last one is very interesting. Someone harvests energy from a TV antenna. The reader may find many similar interesting videos on the Internet to enhance their learning experience in the UPW theory. Understanding uniform plane wave theory is at the heart of advanced applications of microwave engineering, antennas and optical communication.

i. https://www.youtube.com/watch?v=zw0OMi00X5g (accessed 05 July 2025) (battling rope video)
ii. http://study.com/academy/lesson/diffraction-relation-to-sound-light-and-effects-on-wave length.html (wave propagation)
iii. https://www.youtube.com/watch?v=xkG86pwaOH0 (wave propagation)
iv. Free energy from old antenna: https://www.youtube.com/watch?v=DvBPcQpq19A

1.3.3 Transmission Lines and Waveguides

A transmission line, T-line in short, is an electromagnetic conduit that guides electromagnetic signal propagation from one point to another point in a system. A transmission line conveys electromagnetic energy from the transmitter to the antenna, and for the reception, from the antenna to the receiver. Transmission lines are designed for various specific applications so that they efficiently transmit electromagnetic energy from one device to another in a system is possible. Figure 1.14 illustrates various forms of transmission lines for different applications. Figure 1.14a is a coaxial cable with the circular inner conductor and an outer jacket which are uniformly spaced with a dielectric medium. Coaxial cables are highly immune to interferences and have low loss at RF and microwave frequencies. Coaxial cables are commonplace in many applications such as computer networks, microwave systems, radars and antennas. Figure 1.14b illustrates a two-wire system separated by an insulating spacer. This type of transmission line is used for antenna feed for a television receiver. Figure 1.14c is a twisted pair line, which is used in a telephone. Figures (1.14d–f) are the metallic waveguide, optical fibres and power lines, respectively. The transmission lines are analysed with advanced electromagnetic theories. Note that a two-wire transmission line supports UPW, whereas the waveguides support either transverse electric or transverse magnetic waves. The various modes of wave propagation in transmission lines and waveguides are analysed using advanced electromagnetic field theory.

Figure 1.15 illustrates the Smith Chart. It is a bilinear transformation chart between the reflection coefficient and the impedance of a terminated transmission line; hence, it becomes an integral part of T-line and impedance matching theory. The chart is named after the inventor Philip Smith of Bell Labs. The Smith chart depicts the impedance variation over a terminated transmission lines. Therefore, it is very handy to know the impedance at every point on a terminated T-line. It is a very powerful tool for impedance matching design. Impedance matching is a significant aspect of electromagnetic theory in action in any type of transmission lines.

Finally, electromagnetic theory knowledge helps you to design higher level passive circuits such as power divider/combiners and filters just to name a few.

1.3.3.1 Waveguides

Waveguides are a special form of transmission lines that offer low loss in microwave and mm-wave frequencies. Waveguides are hollow conducting tubes of rectangular, circular, and elliptical cross sections. In waveguides, various field modes propagate like harmonics. Likewise, an optical fibre is

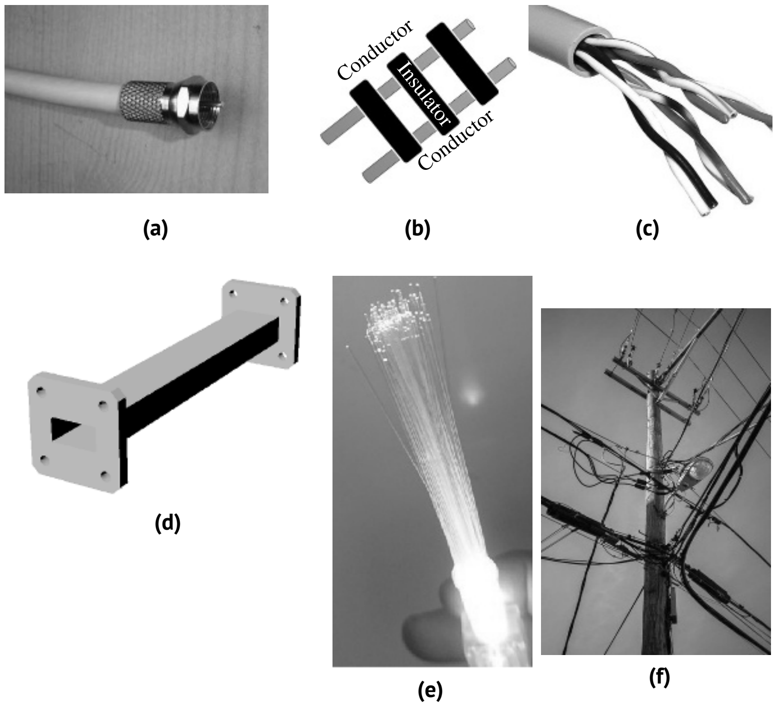


Figure 1.14 Different types of transmission lines. (a) Coaxial cables. (b) two-wire system. (c) Twisted pair lines. (d) Short length of rectangular waveguide. (e) Optical fibres. (f) power lines. *Source*: Avlxyz on VisualHunt.

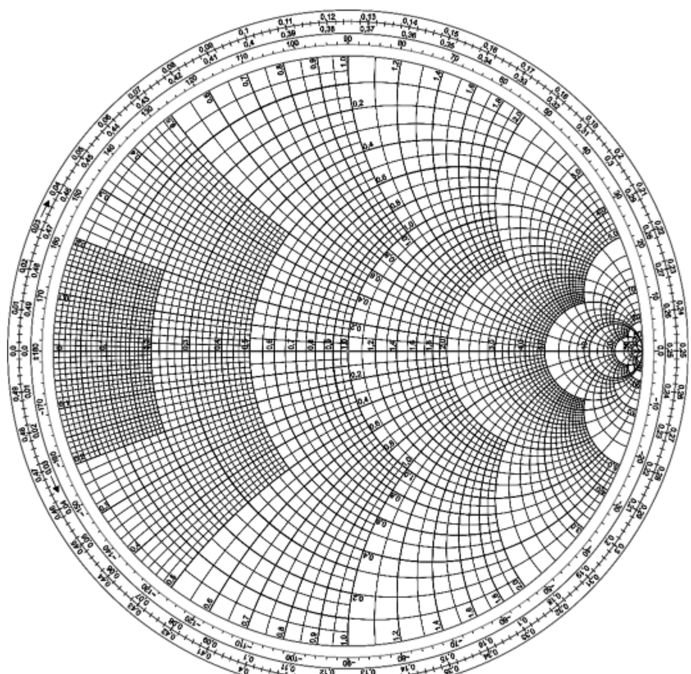


Figure 1.15 An example of the Smith Chart.

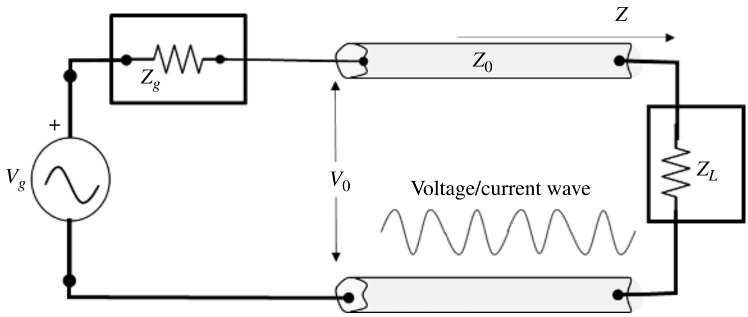


Figure 1.16 A terminated transmission line.

a dielectric tube surrounded by another cylindrical tube of different refractive index, so that total internal reflection of light wave occurs and light propagates along the fibre. The field theories of waveguides are developed based on Maxwell's equations, which help to design waveguides and optical fibres for specific modes of propagation.

1.3.3.2 Terminated Transmission Line

As shown in Figure 1.16, a terminated transmission line connects a source to a load. Any wireless communications system can be represented as a terminated T-line. The voltage and current waveforms travel along the line like waves. Any mismatch causes reflection, meaning reflecting the incident power from the source. Impedance matching between the source, T-line and load is essential for maximum power transfer.

1.3.4 Antenna

Figure 1.17 illustrates the CST-simulated 3D radiation pattern of a mobile phone antenna with a user. A designer's task is to design such antennas that minimise radiation towards the head. Therefore, the electromagnetic theory of the antenna is important for the efficient design of an antenna for a specific application, such as a mobile phone antenna in this case.

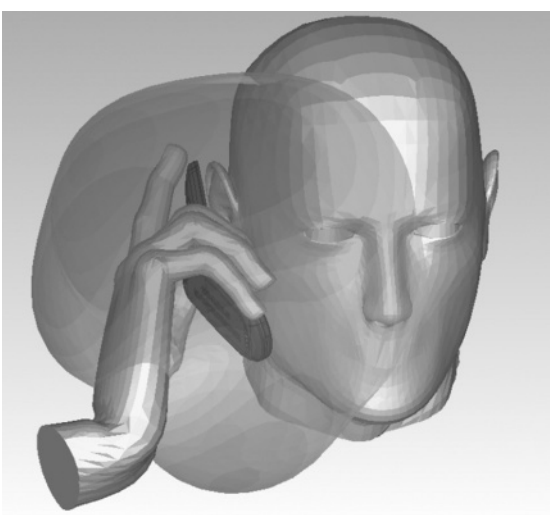


Figure 1.17 Mobile phone simulations with human head and hand models.

The antenna is the most visible part of an outdoor system. We see a TV antenna on the roof of every household and a dipole antenna on a wi-fi router inside homes. Our smartphones have concealed antennas under the cover. The scientific definition of an antenna is based on the functions of the antenna in the perspectives of electromagnetic wave propagation. Since an antenna performs various functions in space and acts as the buffer device between the free-space and guide wave propagation, the definitions of an antenna are multiple.

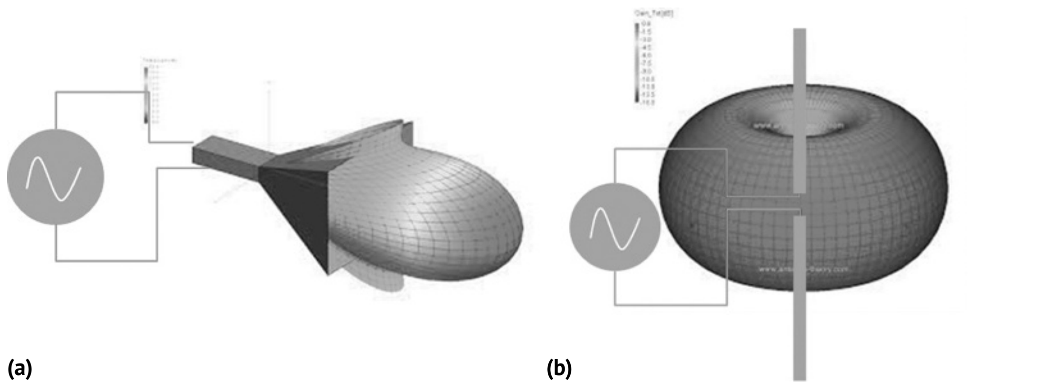


Figure 1.18 (a) 3D Simulation of a directional antenna beam. (b) 3D Simulation of an omni-directional beam.

An antenna is called a *spatial filter* as it directs radiated energy in ***E***- and ***H***-fields in prescribed directions (as in directional antennas, e.g. horns) as shown in Figure 1.18a. Omni-directional antennas like dipoles and monopoles create a figure of eight radiation pattern with a null in the vertical axis as shown in Figure 1.18b. Antennas are also called *transducers*. They convert guided electromagnetic signals into free-space signals as radiated waves in transmission and convert free-space signals into guided signals in reception. Antennas are reciprocal devices as they behave similarly in both transmission and reception. It means the radiation patterns are the same in both modes of operation. Antennas radiate power in radially outward direction in the spherical coordinate.

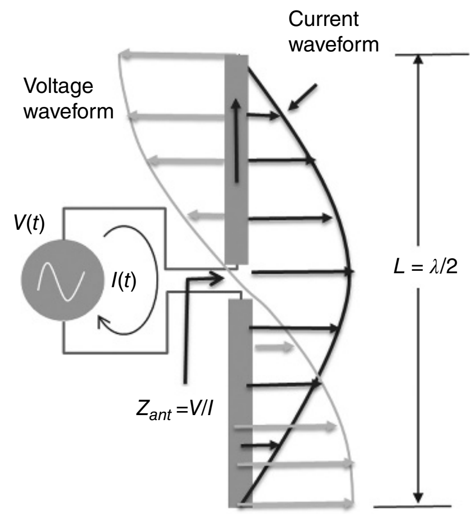


Figure 1.19 Voltage and current on a half-wavelength dipole antenna.

Let's have a look at how electromagnetic theory is used in designing antennas. In a wireless communications system, the handheld mobile phone antenna is a dipole antenna. The dipole antenna is the simplest antenna of all. Figure 1.19 illustrates the distributions of the voltage and current waveforms on a half-wavelength dipole antenna. Due to the open ends, the voltage is maximum at the ends, and the current is maximum at the centre of the dipole. It is the resonant structure and the length is a function of the operating frequency. As shown in the figure, the length is a half wavelength ($\lambda/2$) of the operating frequency. The antenna works the most efficiently if the operating frequency matches the design frequency, at which the length is exactly half a wavelength.

1.3.5 Antenna Array

This section presents a planar antenna array. Figure 1.20 shows the simulated 3D radiation pattern of a 22 × 22-element patch array antenna with main lobes and side lobes.

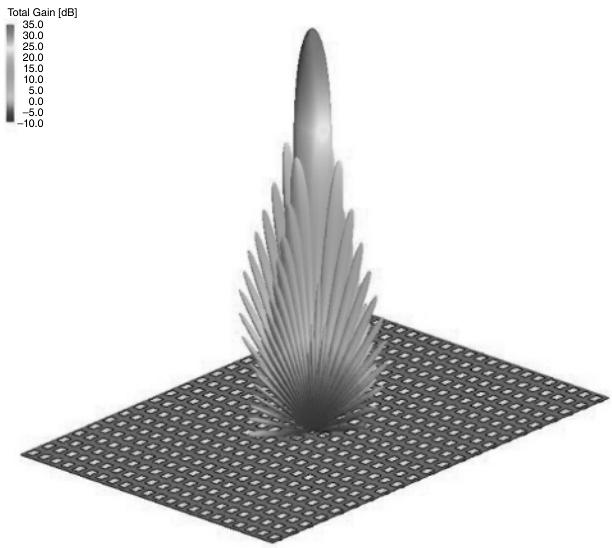


Figure 1.20 Radiation pattern of a 22 × 22-element patch antenna array (Altair Feko simulations by C.J. Reddy).

Planar antennas are fully printed antennas on printed circuit boards (PCBs), and they are called ‘microstrip patch antennas’. Now we look very briefly at the configuration of a rectangular microstrip patch antenna. We shall study a more detailed theory of the patch antenna. A microstrip patch antenna has a resonant metallic patch on top of a ground dielectric substrate. The length of the patch antenna is lambda over two. Here, lambda is the guided wavelength. Because the patch is printed on a dielectric substrate (e.g. flame retardant 4 [FR4]). As shown in Figure 1.21a, the patch is supported by a dielectric substrate of height ‘h’, dielectric constant ε_r and loss tangent tan δ. You will learn all these parameters in UPW theory. The substrate has a ground plane on the bottom to support the electromagnetic field between the patch and the ground plane to create a resonant structure.

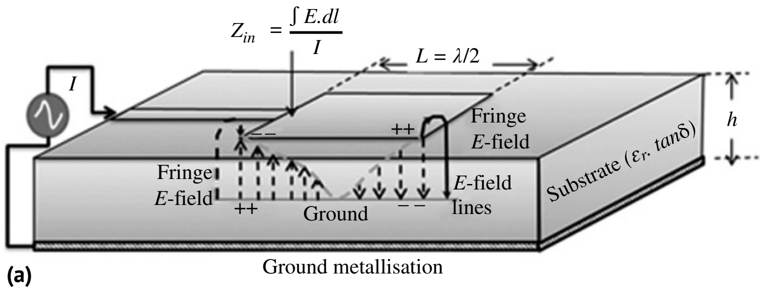
Let’s look at the field distribution under the patch antennas showing Figure 1.21a. The field distribution under the patch resonator is a half sine wave. The fringe fields leak in the air on both sides of the patch and cause radiation Figure 1.21b illustrates the 3D radiation pattern of the patch antenna.

An antenna array is a combination of many single antennas in a prescribed pattern as shown in Figure 1.22. Therefore, an antenna array is a system of antenna elements designed to produce a certain desired radiation pattern.

The first benefit that antenna arrays offer is higher gain. This means we only need to transmit less power. We can control radiation patterns so that we can steer multiple beams to serve multiple users simultaneously in a signal frequency. We can also steer nulls towards interferences to mitigate signal drops.

Now, let us examine all patterns. The element pattern has a much wider beamwidth, which means low gain. The array pattern has a much narrower beamwidth, which means higher gain. It has two some side lobes due to the array factor. The sidelobes also radiate power in other directions but with very low intensity.

What is the role of the array factor? The array factor is the main deciding factor of beam shaping, beam steering and sidelobe reduction. Therefore, the array factor is the most significant term in array design. As shown in Figure 1.22, an aggregated array pattern is a combination of element pattern and array factor.



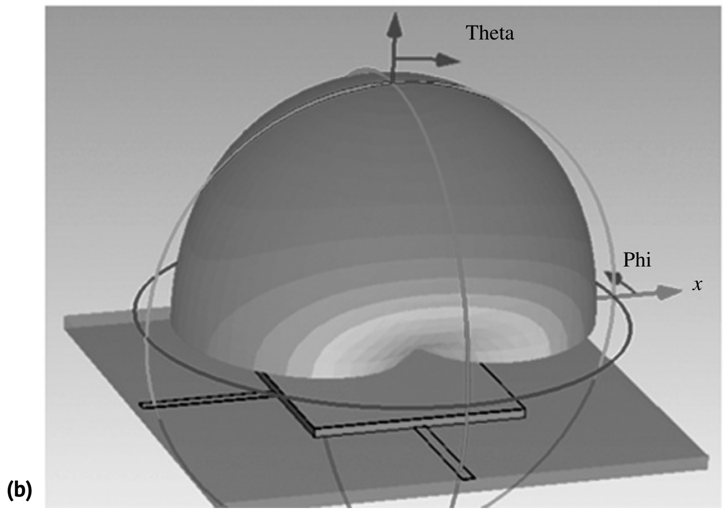


Figure 1.21 (a) Rectangular patch antenna with field distribution, impedance and currents, and (b) full-wave simulated radiation pattern of the patch antenna.

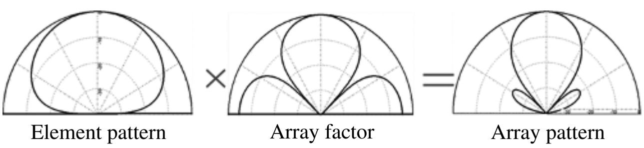


Figure 1.22 Array pattern is a combination of element pattern and array factor.

The 'array factor' depends on the number of elements, inter-element spacing, array configuration, and current excitation of elements.

Current is a vector quantity and has amplitude and phase. The relative phases of element excitation are used for beam steering.

Review Questions 1.3: Antenna and array antenna

Q1. What is an antenna?
Q2. What is the meaning of an omnidirectional antenna? Give an example of an omnidirectional antenna.
Q3. What is the total field of an antenna array? What is an array factor?

Example 1.2: Antenna and array antenna

Q1. A mobile phone operates at 800 MHz. Calculate the length of the mobile phone antenna if it is a half wavelength dipole antenna

Answer: The operating wavelength is: $\lambda = \frac{c}{f} = \frac{3 \times 10^8 \left(\frac{\mathrm{m}}{\mathrm{s}}\right)}{800 \times 10^6 (\mathrm{Hz})} = 37.5\ (\mathrm{cm})$

Therefore, the length of the half-wavelength dipole antenna is: $l = \frac{\lambda}{2} = 18.75\ (\mathrm{cm})$.

Q2. Design a rectangular microstrip patch antenna on FR4 with $\varepsilon_r = 4$ for a GPS receiver at 1.55 GHz.

Answer: The length of the patch antenna on the dielectric is determined based on the guided wavelength of the substrate, which is in this case FR4. Therefore, the length of the patch antenna is:

$$l = \frac{\lambda_g}{2} = \frac{c/\sqrt{\varepsilon_r}}{2f} = \frac{3 \times 10^8 (\mathrm{m/s})/\sqrt{4}}{2 \times 1.5 \times 10^9 \mathrm{Hz}} = 50\ (\mathrm{mm})$$

The width could be of similar size or smaller than the length. The feed inset could be 1/3 of the patch length to yield 50 Ω matching. Figure 1.23 illustrates the layout of the designed patch antenna.[11]

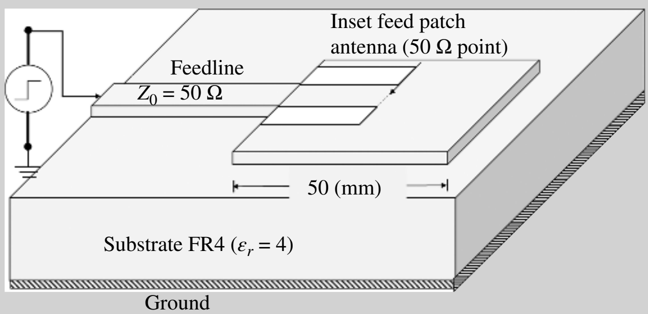


Figure 1.23 An inset direct feed rectangular patch antenna design on FR4 substrate.

Q3. What is the total field of an antenna array? What is an array factor?

Answer: The total field of an array antenna is the product of the individual element pattern and the array factor.

Array factor depends on the number of antenna elements, inter-element spacing, array configuration and current excitation of antenna elements.

1.3.6 EMI/EMC

When the above blocks, such as a transceiver system, transmission lines, and the antenna are put into a system, they can interfere due to signal leakage in unwanted directions. These

11 The patch antenna design needs complex electromagnetic software tools such as CST MWS. CST MWS is a full-wave electromagnetic solver that takes care of mutual coupling between the fields inside the substrate and the fringing fields along the edges of the patch that are responsible for radiation. We shall see these issues more closely in the design projects and laboratory.

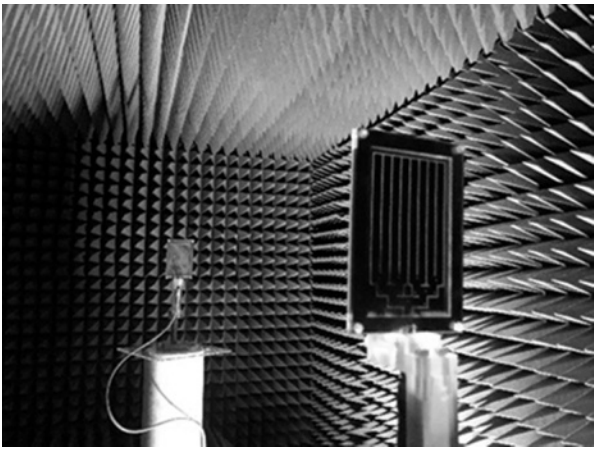


Figure 1.24 MMARS Laboratory's chipless RFID reader system team in anechoic chamber.

electromagnetic interferences are harmful for components and disrupt services [1]. This unwanted signal leakage is called EMI in short. To overcome this situation, we need to ensure that proper protection in the form of grounding, shielding and filtering is ensured so that the device can function properly and also does not cause any disturbance to the neighbouring devices. This condition is called EMC. There are different standards to ensure the EMC of a device. Most prevalent is the Federal Communications Commission in the USA, CE in European Union and military standard MIL-STD-461.

Figure 1.24 illustrates the photograph of a chipless RFID reader system in MMARS laboratory at Monash University, which is going under rigorous EMI and EMC tests. Even a $2 electronic toy may need to go through such EMI/EMC test before they are put into the market. You may find thousands of interesting case studies of EMI/EMC on websites. Equipment failed due to invisible reasons. Then, the possible causes were detected, rectified, and finally, brought the system into proper operation. Therefore, for engineers of any discipline, especially for communications and electronics manufacturing engineering, it is important to know what EMI is and how we can make electromagnetic compatible devices and systems. EMI and EMC measures are handled with the electromagnetic analysis. Efficient design for shielding, grounding, and filtering needs fundamental knowledge of the UPW and transmission line.

Case Study: EMI/EMC

The case study is for a flight take-off and landing system of a passenger plane. In-flight crews announce to turn off all electronics or put in flight mode so that any electromagnetic emission cannot cause any disturbance to the radio receiver of the plane. This is a bit of annoyance for passengers, as they have to discontinue important activities and entertainment gadgets. Explain why we need to turn off all our electronic gadgets.

Answer: Assume that you are in a crowded and noisy environment. You get tremendous difficulty hearing what you want to hear. Likewise, electrical noises make it difficult for the plane's radio receiver to receive the communications and navigation signals from the control tower's transmitters. This unwanted disturbance is called EMI. EMI is an invisible challenge for engineers to fix and make the system function properly.

We must detect the sources of EMI so that our devices and systems will not be the victims of EMI. Therefore, we need to take corrective measures to rectify these EMIs. Figure 1.25a illustrates the block diagram of EMI. There is a coupling path between the source and the victim of EMI. Usually, EMI occurs in two ways, as shown in Figure 1.25b: Conduction interference caused by wires between the transmitter and receiver and the common power source. The second one is the radiation interferences between antennas. Conduction interferences can be managed by proper grounding, filtering, and shielding. Radiation interference is hard to manage. Directional antennas are used so that they can avoid incoming interfering radiation.

As shown in Figure 1.26, there are an enormous number of interfering sources. It can easily be comprehended that it is really an invisible battlefield, and it is very hard to detect the source of interference sometimes. As for example the electric disturbance caused by thunderstorms. A thunderstorm is a huge source of electromagnetic discharges hence huge radiation. We usually see in the old television sets that during thunderstorms TVs received hazy signals. This is EMI radiation.

As stated before, for EMI preventive measures, filtering, grounding, and shielding are used. These approaches also need proper knowledge of electromagnetic theory. Figure 1.27a depicts

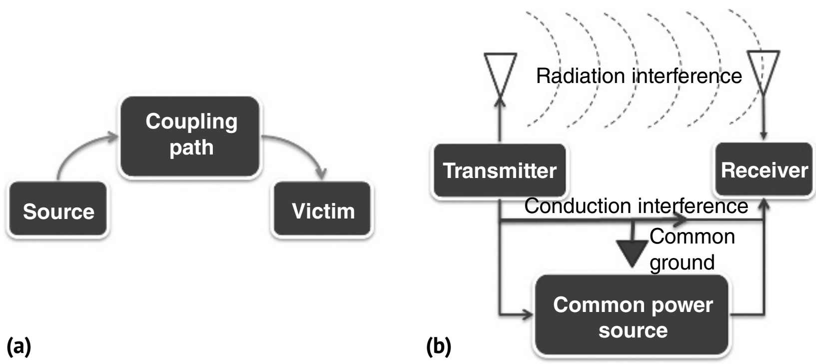


Figure 1.25 (a) Schematic of EMI and (b) types of EMI.

Figure 1.26 Various sources of EMI.

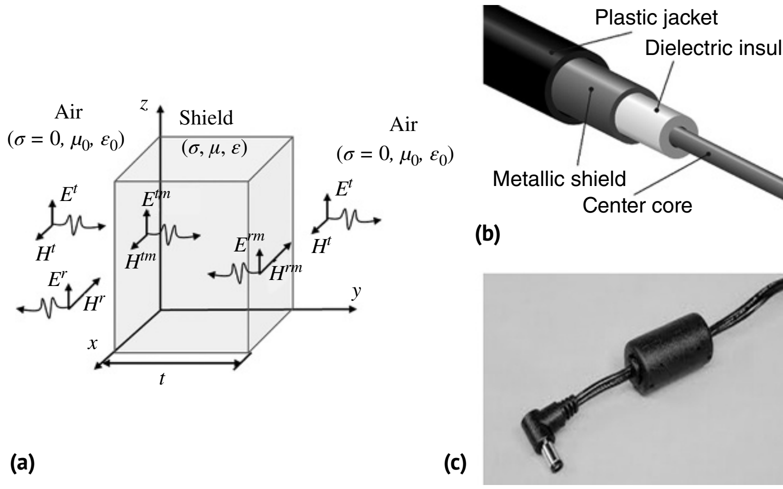


Figure 1.27 (a) Electromagnetic theory in shielding in action and (b) configuration of coaxial cable {Coaxial cable cutaway (not to scale) by Tkgd2007 is licensed under CC BY 3.0}, (c) EMI ferrite core in universal power adapters.

Figure 1.28 Simple passive electronic components are used to filter out the interference.

how UPW reflection and transmission theory is used in shielding. This problem can also be analysed with an equivalent transmission line model of the intrinsic impedances of these media. Figure 1.27b illustrates inherent shielding as part of a coaxial cable. For filtering out the noises generated from main power supplies and rectifying circuits in universal power adapters, EMI ferrite cores are used, as shown in Figure 1.27c.

Passive elements such as resistors, inductors, and capacitors of various forms are integral parts of electronic circuits. Figure 1.28 illustrates those elements. At high frequencies in RF, microwave and mm-wave bands, the parasitic effects make these elements non-ideal, and they are treated with the electromagnetic theory. For example, a capacitor has lead inductance and internal resistance that makes a resonant structure. Therefore, the passive elements are frequency-limited devices at those frequencies. Usually, the thumb rule is that the passive elements should be used below half their resonant frequency.

Review Questions 1.4: EMI/EMC

Q1. What is EMI?
Q2. How do noises transmit from sources to victims and create EMI?
Q3. What are the symptoms of EMI?
Q4. What is EMC?
Q5. Explain the methods of preventing EMI and making electromagnetic compatible devices.
Q6. Explain why passive components do not behave ideally at high frequencies.
Q7. How does electromagnetic theory help understand these non-ideal behaviours of lumped components?

1.4 Modern Pedagogy in Advanced Electromagnetics

Pedagogy of advanced electromagnetics in modern universities is not a trivial task. It needs huge planning and extraordinary resources. Usually, RF and microwave equipment and sources are too expensive. Moreover, the concepts of advanced electromagnetics are too complex to set up in experiments and providing visualisation of the abstract laws is a daunting task.

Figure 1.29 shows the different modes of delivery for advanced electromagnetics in modern universities.[12] The main active mode of delivery are theories covered in lectures following a set textbook, online lecture materials, relevant resources and references, tutorials and practicums with supervised individual and group interactive problem-solving sessions, laboratory sessions with supervised hands-on laboratories and dedicated equipment and software tools. And finally, the design projects require applications of learned theories, practical design using software, development of prototypes, and evaluation the prototypes. The students are asked to write a

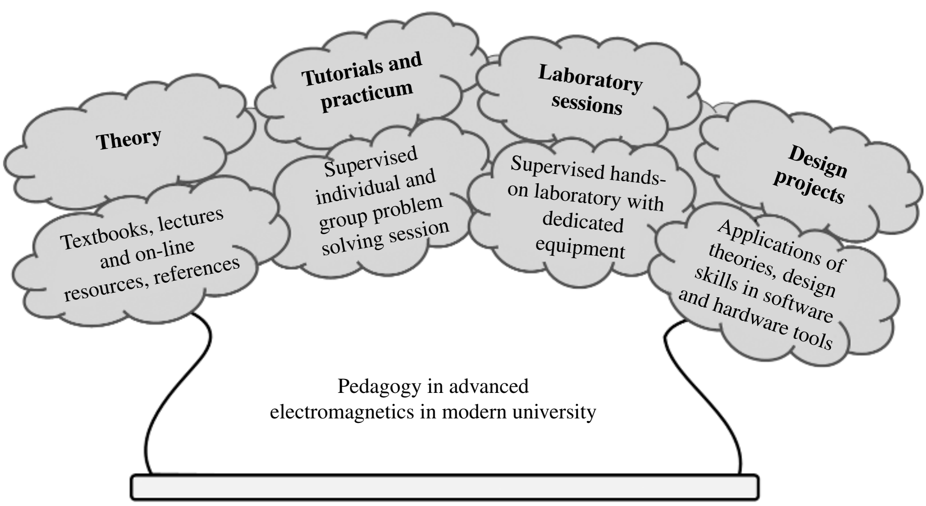


Figure 1.29 Modes of delivery and augmented resources for pedagogy in advanced electromagnetics in modern university.

12 This section is equally useful for new instructors and students to develop a teaching laboratory and deliver the contents of the advanced electromagnetics.

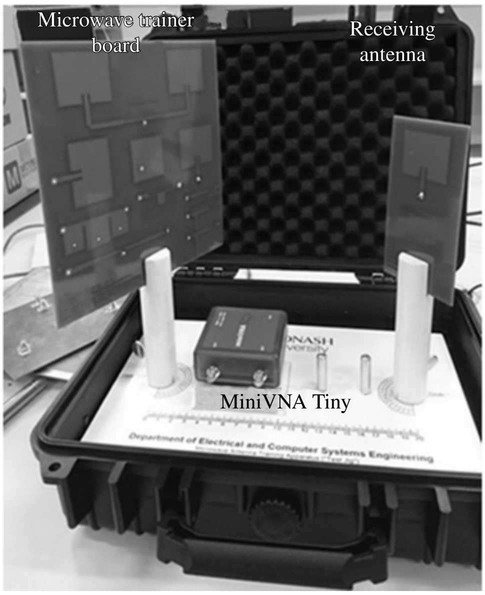


Figure 1.30 An advanced electromagnetic laboratory to teach the concept of UPW propagation, transmission and reflection, transmission line, impedance matching, antenna parameters and array analysis at Monash University.

formal report of the design project. In order to develop their graduate skills, the students are also asked to investigate innovation marketing of the developed prototypes. Usually, they are asked to develop a balanced scorecard [2] of their innovation marketing exercise and add a page or two with additional materials at the end of their design project report. All the conjoined activities should follow and be time synchronised with the topics delivered in the lectures.

Figure 1.30 illustrates the laboratory developed in author's research laboratory to underpin the learned theory in practice. The heart of the laboratory is a mini VNA called miniVNATiny from WiMO, Germany. This equipment can measure two-port circuits with a nice graphical interface with plots of return loss in dB, voltage standing wave ratio, impedance on the Smith chart, and the insertion loss in dB from a few kHz up to 3 GHz. A microwave trainer board with many passive designs at 2.45 GHz, and a receiving patch antenna, are used to enhance the learned abstract theories of uniform plan wave, polarisations, transmission and reflection, shielding effectiveness, antenna parameters and efficiency measurement and array analysis. As the very low-cost development is evolving, even cheaper and more versatile VNA that the current one can be obtained from the market.

1.5 Design Project: Wireless Energy Harvester

The main aim of the design project, titled Wireless Energy Harvester, is to apply all knowledge gained in the above topics in cutting-edge applications. There are so many emerging applications of wireless power transfer in recent years. Energy harvesting is utilised for in-body wireless drug delivery, wireless charging of vehicles, mobile phone chargers, wireless orthopaedic needles for bone healing and growth, wireless clocks, wireless fans, and wireless sleep monitoring devices.

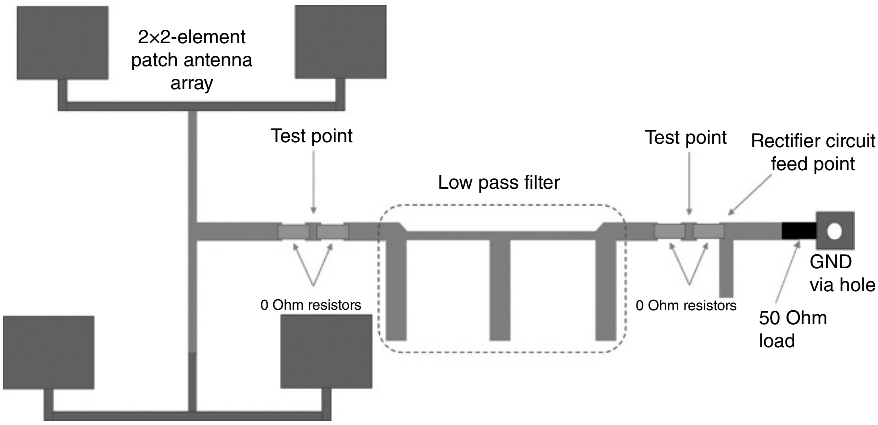


Figure 1.31 A wireless energy harvester is called a rectenna, comprised of a microstrip patch antenna, a matching circuit, a lowpass filter, a rectifying circuit, and a load like a 50 Ohm chip resistor.

Figure 1.31 illustrates the layout of a wireless energy harvester, which is also called a rectifying antenna or rectenna. As shown in the figure, a rectenna is comprised of a microstrip patch antenna array, a matching circuit, a lowpass filter, a rectifying circuit, and a load like a chip resistor.

One of the main objectives of modern pedagogy is to solve a real-world wireless and guided electromagnetic problem via an intuitive design project. A sound design project has the following components: (i) highlighting the significance of the design project with many illustrative examples, (ii) providing the concept with a block diagram, requirement analysis of the design project and expected outcomes, and finally, (iii) entrepreneurship development to market the outcome.

What is wireless energy harvesting? As stated before, we are living in a highly electromagnetic polluted world. This means we have free, abundant energy surrounding us. We can harvest and utilise this free energy wirelessly for our low power mobile devices. Even scientists are envisioning the wireless charging of cars and heavy vehicles with the power line. We are always concerned to charge our smartphones on a regular basis. Batteries are the main bottleneck for smooth operations of our mobile gadgets such as laptops, mobile phones, and cameras. We need regular battery maintenance for smooth operation. Wireless energy harvesting can mitigate this problem. If we can develop a tiny wireless energy harvester and replace the battery, then we can achieve seamless operation of many low powered mobile gadgets that we are using continuously. Wireless energy harvesting is also a green technology. This is the main motivation of the project.

Two examples of wireless energy harvesters. A passive RFID tag and wireless 50 W bulb. A car immobiliser and keyless access to a car, are two good examples of utilisation of RFID. As shown in Figure 1.32a, a passive RFID tag harvests energy from a reader antenna to process data in a microcontroller and transmits back the ID data to the reader. The reader sends the RF energy to the tag. The tag antenna (in this case a coil antenna for near field coupling) receives the energy with the hand-shaking protocol. The tag's microcontroller, also called application specific integrated circuit process the data and sends back the encoded data via the coil antenna. The reader receives the data and processes the identification code for dedicated applications. The operation is shown in sequence in the figure.

Wireless energy harvesting can also be used for a higher-power application than RFID. As shown in Figure 1.32b, a 50 W wireless bulb can glow behind a brick wall with the energy harvesting primary and secondary coil.

This design project is a wireless energy harvester also called a rectenna. A rectenna is a device that combines an antenna with a rectifying circuit, followed by a low pass filter and the load. The load can be your mobile phone. The total system includes a transmitter and a rectenna. You only will design the rectenna or wireless energy harvester. You will design individual components as follows:

- A microstrip patch antenna and array.
- A matching circuit.
- A rectifying circuit.
- A lowpass filter.
- A feed network to combine individual harvested energy from single elements, and, finally,
- Integration of all individual modules into a single PCB. The project will be fabricated, assembled and finally tested with a digital clock as a load.

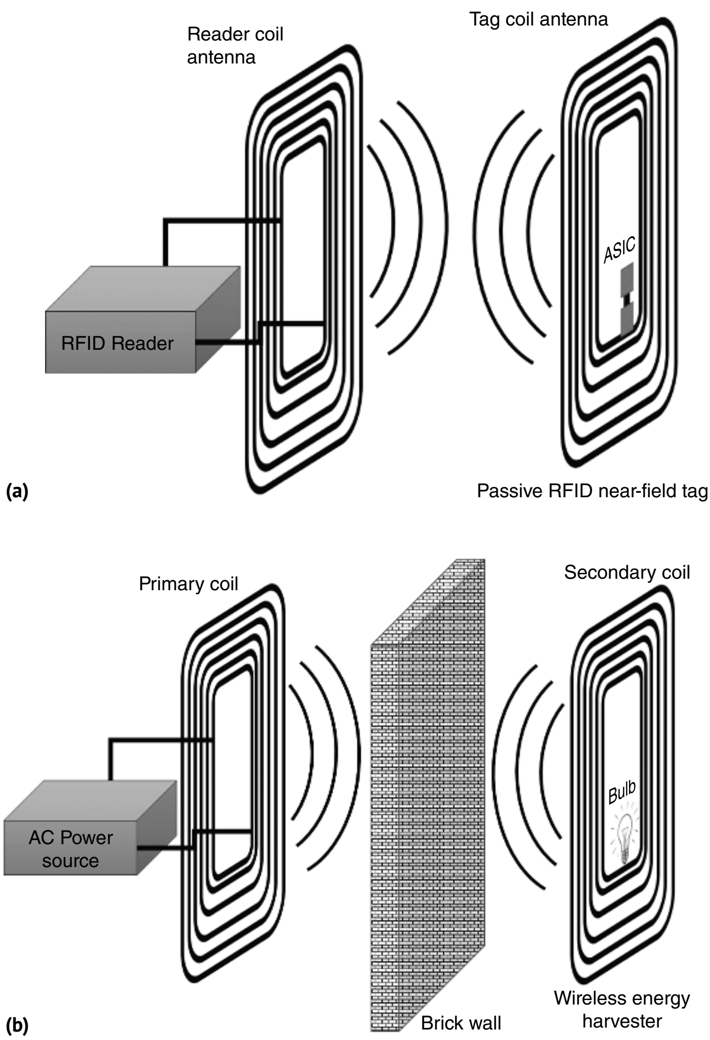


Figure 1.32 (a) A passive RFID system wireless near field coupling through reader and tag coil antennas, (b) wireless energy harvesting to light a bulb through a brick wall.

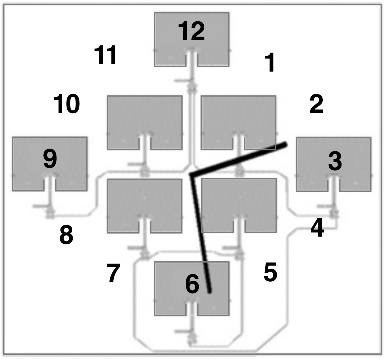


Figure 1.33 A wireless clock designed with an array of rectifying patch antennas. The dots at the end of each patch are a Schottky diode [2].

Figure 1.33 illustrates a sample wireless clock that was designed before.

This is the end of the introduction to advanced electromagnetic. In the next chapter, we shall study the fundamentals of electromagnetic theories and associated vector analyses.

1.6 Conclusion

In this era of the information age, communication – anytime, anywhere – is a must, which has led to everything wireless everywhere. The UPW constitutes the wireless channels between different communication devices. Examples include the wireless communications via the wireless channel between a base station and a mobile phone, as shown in Figure 1.3, the big picture of the modern wireless communications system.

This chapter has presented the significance of advanced electromagnetics and its impact on modern society. The most impactful technologies that have impacted our modern society have been through the electromagnetic signals. Not only the wireless communications, but also many biomedical applications in diagnostics and treatment apparatuses heavily use electromagnetic signals. To develop an interest in the subject matters, these technologies are introduced to the readers. Then a big picture – a modern mobile wireless communications system – that augments the various topics of the textbook has been introduced. They are radio/microwave transceivers, wireless propagation channel as the plane wave propagation, transmission lines of various types, such as two-wire transmission lines, coaxial cables, waveguides and optical fibres, antennas and antenna arrays, and finally, EMI and compatibility. These topics are explained in minute detail with practical examples, questions, and answers so that a reader can comprehend the overall coverage and the sequence of the topics covered in the textbook. Finally, a design project of wireless energy harvesting has been introduced so that a learner can get practical experience of the application of advanced electromagnetics.

1.7 Questions

Q1 Explain why advanced electromagnetics is so significant in the modern world.

Q2 State the different functional blocks of a wireless communication system.

Q3 What is the radar frequency designation? Find some modern applications in different radar frequency bands. You may use the most exciting technologies to find their frequencies of operations.

Q4 Explain the functional locks of a transmitter system. How do the individual blocks work in a system?

Q5 Explain the functional locks of a receiver system. How do the individual blocks work in a system?

Q6 Explain the difference between a transmitter and receiver. What are the common items in them?

Q7 What is a UPW? How does the propagation occur in a medium?

Q8 Write the expressions for the electric and the magnetic fields and the power flow density vectors. What is their relationship in terms of phase difference?

Q9 What is a transmission line? Name different transmission lines and their applications.

Q10 How is the wave nature of the voltage and current on a transmission analysed?

Q11 What is the Smith chart? How do engineers use it for their design?

Q12 What is terminated transmission line? Draw the equivalent circuit schematic of a terminated transmission line with its source and load.

Q13 What is a waveguide? How does it work?

Q14 What is an optical fibre? How does the wave propagate through an optical fibre?

Q15 Define antennas in terms of their specific characteristics. Explain why antenna is called a spatial filter?

Q16 How does an antenna radiate? Explain.

Q17 Define array antennas. Explain the advantages of an array antenna over a single element antenna.

Q18 What is the resultant radiation pattern of an antenna? Define array factor.

Q19 What is EMI? Explain the sources of EMI.

Q20 What is EMC? Explain different mechanisms of EMC.

Q21 What are the parasitic effects of passive elements at high frequencies?

Q22 How is the noise reduced in a power supply cable?

Q23 What is wireless energy harvesting? Explain some useful applications of wireless energy harvesting.

References

1 Wentworth, S. M. (2005). *Fundamentals of Electromagnetics with Engineering Applications*, NY: Wiley and Sons.

2 Cataldo, S. and Karmakar, N. C. (2008). Efficient Rectenna Design for Emerging Applications, in *Proc. 2008 Asia-Pacific Microwave Conference*, Hong Kong and Macau.