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ELEC S211 Fundamentals Of Communications Technology (Free Courseware)

香港公開大學
THE OPEN UNIVERSITY OF HONG KONG

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Contents

Chapter 1 Introduction to electromagnetic waves and communication systems

1.1 About this module

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Welcome to this free courseware module 'Introduction to electromagnetic waves and communication systems'!

This module is taken from the OUHK course *ELEC S211 Fundamentals of Communication Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&c=C_ETPU&cid=191154028200&lang=eng)*, a ten-credit, Middle level course that is part of the Bachelor of Science (BSc) or BSc (Hons) degree programme offered by the School of Science and Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcSubWeb&l=C_ST&lid=191133000200&lang=eng)of the OUHK. This course provides you with a firm foundation for understanding communications technology.

ELECS211 is mainly presented in printed format and comprises ten study units. Each unit contains study content, activities, self-tests, assigned readings, etc for students' self-learning. This module (The materials for this module, taken from the print-based course ELECS211, have been specially adapted to make them more suitable for studying online, and multimedia elements have been added where appropriate. In addition to this topic on 'Electromagnetic waves and communication systems', which is an extract from Unit 1 of the course, the original Unit 1 also includes the topics 'Major inventions and trends in wireless communications technology', 'Overview of telecommunication services and statistical data in Hong Kong', 'Telecommunications regulations and issues in Hong Kong' and 'Technical case studies'.) retains most of these elements, so you can have a taste of what an OUHK course is like. Please note that no credits can be earned on completion of this module. If you would like to pursue it further, you are welcome to enrol in *ELEC S211 Fundamentals of Communication Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&c=C_ETPU&cid=191154028200&lang=eng)*.

This module will take you about **eight hours** to complete, including the time for completing the activities and self-tests (but not including the time for assigned readings).

Good luck, and enjoy your study!

1.2 Introduction

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In this module, you will learn several basic concepts of communications systems such as major building blocks of a communication system, properties of electromagnetic (EM) waves, and frequency allocation in communication systems.

You can quickly review the important terms used in this module in the glossary at the end of this module. As you work your way through the module, you'll encounter some words or terms that are printed in **bold**. That is an indication that the term or word is in the glossary.

1.3 What are communication systems?

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No matter whether a society is old or modern, communication plays an essential role in all sectors of that society. But what does the word *communication* really mean?

Definition of 'communication'

The New Oxford Dictionary of English (1998) (------ (1998) The New Oxford Dictionary of English, Oxford: Clarendon Press.) defines *communicate* as meaning to 'share or exchange information, news, or ideas'. The same source defines *communications* as 'the means of connection between people and places' (ibid).

In old Chinese societies (and others for that matter), pigeons were used to carry letters. The small paper message was the sharing of information and the pigeon was the means of connection. Nowadays, you can communicate with your friends by phone, email or MSN. A communication system is built to send information from one location to another.

Information sent by communication systems

Information can be speech, text, images or any form of data, which can, for example, be exchanged by sending emails or teleconferencing using satellite communication, cellular phones, pagers, and so on

The next issue concerns how to transmit the data in a fast and reliable way. These are the main objectives in designing or choosing a communication system and we'll discuss several communication systems in detail in the later units of *ELEC S211*.

1.3.1 Building blocks of communication systems

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You'll learn the design and applications of communication systems in this course. So, as you work toward your first reading, the first idea you need to understand is the building blocks of a communication system.

A communication system should consist of at least *one source*, one *sink* (destination) and a *channel*. Examples of communication systems that contain:

1. a single source and a single sink; and
2. a single source and multiple sink;

are shown in Figure 1.1.

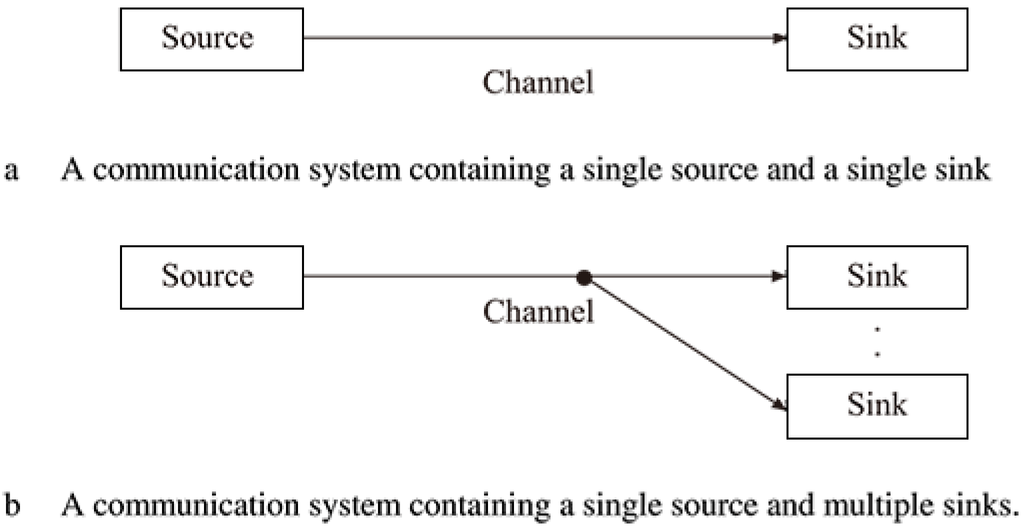

Fig. 1.1: Examples of communication systems

At one end, the information will be transmitted from the source through a medium (i.e., the **channel**) to the destination (called the sink), which is the other end point.

Let's take a chat with your friend as an example:

You (source) voice out a **message (information)** to **your friend (sink)** through the **air (channel)**.

That's to say, you are one of key components in this communication system.

Similarly, you should already be aware of other types of communication systems in daily use. All of these systems are essentially similar to the voice conversation described above — the technology used is obviously different. Let's consider a typical process in a telephone system as an example.

Other types of communication systems found in our daily life

- Telephone systems
- Commercial radio
- Television
- Satellite systems
- Mobile cellular telephone systems
- Fax
- Internet

Typical process in a telephone system

1. When the speaker speaks at the transmitting end, the telephone converts his or her voice into an electrical signal.
2. The electrical signal is transmitted over a link to a telephone network.
3. The telephone network routes the signal to the receiving end according to the phone number dialled.
4. At the receiving end, the electrical signal is converted back to voice. Therefore, the receiving party is able to listen to the speech.

This is a simple explanation of the idea of a communication system. You will learn a lot more about these basic concepts throughout this unit, which will help you to build up a complete picture of the subject.

The terms used to describe the building blocks of communication systems might be different in other reference books. Here are some equivalent terms:

Equivalent term	Schweber
Input transducer	A device that *converts* the original message to a suitable form for transmission.
Channel	The medium of the communication path, sometimes also called *link*
Output transducer	A device that *converts* the output signal at the receiver back to the *original* signal form.

1.3.2 Simplex, half-duplex and full-duplex systems

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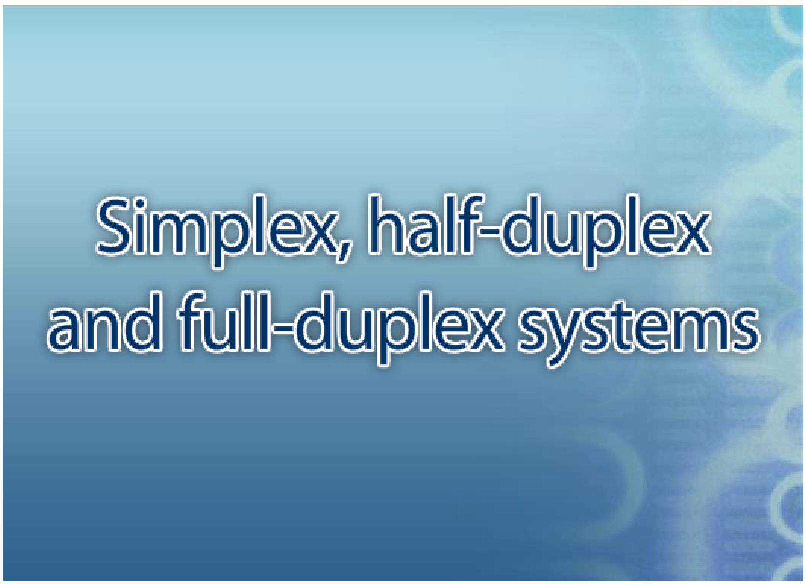
Communication systems can be classified into **simplex**, **half-duplex** and **full-duplex** systems.



Click this link to watch the video:
http://www.opentextbooks.org.hk/system/files/resource/10/10349/10355/media/Simplex%2C%20half-duplex%20and%20full-duplex%20systems.mp4

Information can be sent in a one-way or a two-way direction in communication systems. When information can only be transmitted in a one-way direction, e.g. in television and radio broadcasting, the system is a **simplex system**.

Conversely, both you and your friend can talk *simultaneously* on the telephone. When your friend speaks into the phone, a signal is transmitted from their side to your side. Similarly, when you speak into the phone, a signal is transmitted from your side to their side. Therefore, information is two-way in a telephone system. When it's possible to send information in both directions, such systems are*duplex* systems. It is also possible to classify duplex systems into **full-duplex** and **half-duplex** systems.

In a full-duplex system, signals can travel in *both* directions at the same time. A half-duplex system is midway between simplex and full-duplex systems. Information can go in either direction, but only in one direction at a time. A walkie-talkie is an example of this category. When one of the users speaks, the other user must stop speaking until the first user ends their turn and the channel is handed-over to the other user.

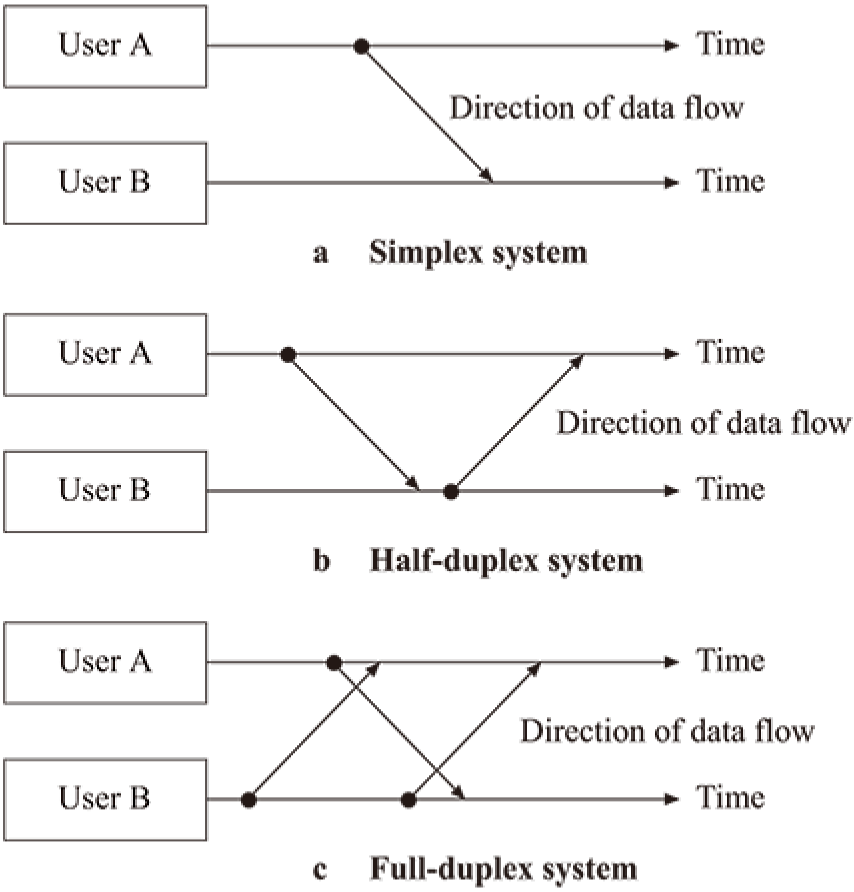


Fig. 1.2: The timing diagram of the three systems

Now, can you identify examples of simplex, full-duplex and half-duplex systems in the real world?

1.4 Electromagnetic waves in communication systems

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Signals can be transmitted in the form of voltage or current through wires, radio emissions through the air or as light through optical fibres. Transmitted signals can be regarded as electromagnetic waves in communication systems.

In this section, we will introduce some basic characteristics of the electromagnetic waves in communication systems, such as wavelength and frequency. After that, we will discuss the standard frequency allocation of electromagnetic spectrum for communication systems.

1.4.1 Wavelength and frequency of electromagnetic waves

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We'll cover several characteristics of electromagnetic waves in this course, such as the relationship between **wavelength** and **frequency**, radiation pattern, the direction and different ways of propagation, and so forth.

In fact, you have probably already encountered some basic properties of electromagnetic waves. If you are familiar with them already, this section will be very easy for you. It provides a quick overview of the simplest and most important properties — wavelength and frequency. The other properties will be discussed in *Unit 7* of *ELEC S211*.

Let's consider a continuous sinusoidal waveform as shown in Figure 1.3. The term period refers to the time difference between two adjacent peaks, or between the same points on any adjacent wave cycles.

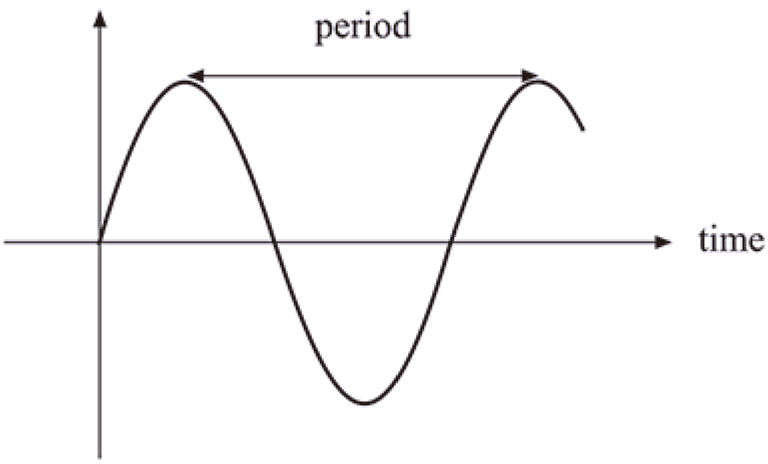

Fig. 1.3: The timing diagram of a sinusoidal waveform

For a repetitive (or periodic) signal, the term frequency refers to the number of cycles per second. The unit of frequency is Hertz (Hz).

$$\text{Frequency} = \frac{1}{\text{period}}$$

Recall the basic laws of physics: the relationship between frequency and wavelength is given by:

$$\text{wavelength}\,(\lambda) = \frac{\text{velocity}}{\text{frequency}}$$

Electromagnetic waves travel at the speed of light in a vacuum — that is, 3×10^8m/s — and the speed of light is denoted by the symbol c. In other media, the velocity will be slowed down by the characteristics of the material that makes up the medium.

Let's take a look at Example 1 (Page 8), in which we calculate the wavelength for a signal with given frequency and velocity.

You should now be ready to undertake the Self-test 1 (Page 8) in this module. While Suggested answers to Self-test 1 (Page 8) are provided below, you should always try to answer the questions on your own first. If you can't answer a particular question, this shows that you most likely need to review some of the material that you've worked through so far.

1.4.1.1 Example 1

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What is the wavelength for a signal that travels at 3 x 10^8m/s and has a frequency of 300 MHz (1 MHz equals 106 Hz)?

Solution:

$$\lambda = \frac{3\times10^8}{300\times10^6} = 1\,\mathrm{m}$$

1.4.1.2 Self-test 1

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1. A 10.7 MHz signal travels through space. What is its wavelength?
2. A 10.7 MHz wave is sent through a channel with a propagation velocity of 0.78 c (where c is the speed of light = 3 X 10^8m/s). What is the wavelength in this case?

1.4.1.3 Suggested answers to Self-test 1

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1. wavelength = 3 x 10^8 / 10.7 x 10^6 = 28.04 m
2. wavelength = 0.78 x 3 x 10^8 / 10.7 x 10^6 = 21.87 m

1.4.2 Standard frequency allocation of electromagnetic spectrum for communication systems

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Let's go one step deeper into the subject of signals and talk about the electromagnetic **spectrum** and **bandwidth**. As you know from your experience in listening to a radio, RTHK (Radio Television Hong Kong) and other radio stations broadcast on different frequency ranges. In addition, some stations send out Amplitude Modulation (AM) (http://en.wikipedia.org/wiki/Amplitude_modulation) radio broadcasts and others send out Frequency Modulation (FM) (http://en.wikipedia.org/wiki/

Frequency_modulation) radio broadcasts. The details of both AM and FM schemes will be covered in Unit 4 of ELEC S211. Here, we've just used them as examples to demonstrate the idea of different frequency allocations.

The total span of frequencies used in communication systems is called the electromagnetic **spectrum**, or simply the spectrum. This total spectrum is allocated into different bands.

bands

For example, most mobile cellular systems transmit signals in the 900 MHz (1 MHz = 10^6 Hz) or 1.8 GHz (1 GHz = 10^9 Hz) band, and FM radio broadcasts use the 88 MHz to 108 MHz band.

Since many users, services and countries share the electromagnetic spectrum, some rules (Such rules prevent one user, service or country from interfering with another.) are necessary to govern its use. The International Telecommunications Union (**ITU**) is the international organization that performs this regulatory role. Individual countries also have local organizations that do similar jobs. In Hong Kong, the Office of the Telecommunications Authority (http://www.ofta.gov.hk/en/index.html) (**OFTA**) is responsible for the assignment, licensing and monitoring of the electromagnetic spectrum. The OFTA is an organization of the Hong Kong Government that was established in 1993.

You may readily understand the purposes of frequency allocation. But the question is, even if allocation rules are in place, how can we ensure that every signal remains precisely within the frequency boundary that has been assigned to it? The answer to this is bandwidth.

Bandwidth

Bandwidth is the span of frequencies within the spectrum that is occupied by a given signal.

For example, let's say a signal transmitted at 300 kHz (1kHz = 1 × 10^3 Hz) has a bandwidth of 20 kHz. The frequency range it occupies, therefore, is from 290 kHz to 310 kHz, as shown in Figure 4 below. So, in this case, frequencies below 290 kHz and above 310 kHz are clear for allocation to other signals.

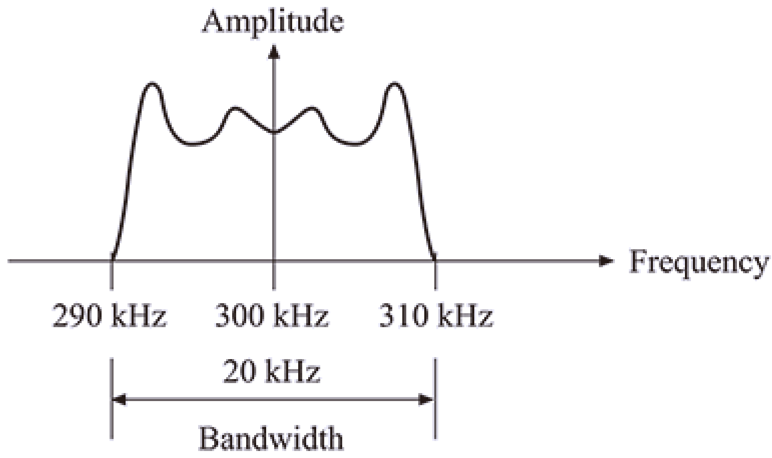

Fig. 1.4: The frequency spectrum of a signal

The next question is how much bandwidth is required to convey a given signal. This depends on the information being transmitted. For example, the human voice has significant amplitude in the frequency range of 300 Hz to 3.4 kHz. So the bandwidth required for analogue voice signals is 3.1 kHz (3.4 kHz – 300 Hz = 3.1 kHz).

Let's take a look at Example 2 (Page 10), in which we calculate the bandwidth of a signal with a given frequency range.

Now complete Self-test 2 (Page 11), and remember to attempt both questions yourself before checking the Suggested answers to Self-test 2 (Page 11). You will learn much more this way!

1.4.2.1 Example 2

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What is the bandwidth of a signal whose frequency ranges from 0 Hz to 3.4 kHz?

Solution:

Bandwidth = 3400 Hz – 0 Hz = 3.4 kHz.

1.4.2.2 Self-test 2

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1. If the High Frequency (HF) band (3 MHz to 30 MHz) were allocated to 150 identical users at the same time, what bandwidth would be allocated to each user? Assume there is no frequency gap between adjacent channels, and one channel can only be occupied by one user.
2. Suppose the bandwidth of each user is 2 kHz and there is 100 Hz frequency gap located between consecutive users. What is the maximum number of users that can be allocated within a frequency band of 200 kHz?

1.4.2.3 Suggested answers to Self-test 2

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1. Bandwidth of HF = (30 – 3) MHz = 27 MHz; Frequency band for each user = 27 MHz / 150 users = 0.18 MHz each
2. Let n be the number of users and there would be n – 1 frequency gaps in between. Then, $2000\,n + 100\,(n - 1) \leq 200 \times 10^3 \rightarrow n \leq 95.29$. The maximum number of users is 95.

1.5 References

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Below are the resources referred to or cited by the developer(s) of the original unit:

------ (1998) *The New Oxford Dictionary of English*, Oxford: Clarendon Press.

1.6 Conclusion

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In this module, you have learned the following concepts relevant to the telecommunication industries:

- You have learned the basic building blocks of communication systems.
- You should be able to define wavelength, frequency and bandwidth of electromagnetic waves, and be able to perform simple relevant calculations.

Taking the above items as a checklist, you can try to evaluate yourself to see whether you have completed all of these. In addition, you should make sure that you have understood all the reading materials that you have encountered in this module.

If you would like to learn more on this subject, you are welcome to enrol in *ELEC S211 Fundamentals of Communication Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&c=C_ETPU&cid=191154028200&lang=eng)*

offered by the School of Science and Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcSubWeb&l=C_ST&lid=191133000200&lang=eng) of the OUHK.

1.7 Glossary

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1k — 1×10^3

1M — 1×10^6

1G — 1×10^9

Bandwidth — The span of frequencies within the spectrum that is occupied by a given signal.

Channel — It is a medium of communication paths, sometimes also called link. For example, wires, optical fibres, wave guides, air, ... etc.

Frequency — The number of cycles (Hertz) per second of a periodic signal.

Full-duplex system — Information can be sent by both parties simultaneously.

Half-duplex system — Information can be sent by either one of the parties to another, but only in one direction at a time.

ITU — The International Telecommunications Union. It is a union to specify the technical communication standards among different countries.

OFTA — The Office of the Telecommunications Authority. It maintains and regulates the technical standards and issues of the telecommunication industries in Hong Kong.

Simplex system — Communication can only be conducted in one direction.

Spectrum — The span of frequencies used in communication systems.

Wavelength — The distance between two adjacent peaks, or between the same points on any adjacent cycles. It is defined mathematically as:

$$wavelength = \frac{velocity}{frequency}$$