Chapter 5
Electromagnetic Wave Propagation

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ABSTRACT

Electromagnetic wave propagation is an invisible phenomenon that cannot be detected by the human senses. To understand wave propagation, one must first learn what wave propagation is and the basic principles that affect wave propagation. This chapter introduces the atmospheric windows which allow electromagnetic radiation from bands to penetrate Earth. Helmholtz equations, i.e. the equations which govern wave propagation, and the properties of waves (such as propagation constant and characteristic impedance) are then briefly explained. When waves encounter different media during its propagation, they may be reflected, refracted, or diffracted. These phenomena are also covered. The last part of this chapter concisely explains the terminologies commonly used to describe electromagnetic radiation.

THE ATMOSPHERIC WINDOWS

The composition of the Earth's atmosphere is such that it allows certain wavelengths of electromagnetic (EM) waves to pass through and absorb some in certain wavelengths. The areas of the EM spectrum that are absorbed by the atmospheric gasses, such as water vapor, carbon dioxide and ozone, are known as the absorption bands. In contrast to the absorption bands, there are areas of the EM spectrum where the atmosphere is transparent to specific wavelengths. These wavelength bands are known as the *atmospheric windows* (see Figure 1).

The atmosphere absorbs most of the wavelengths shorter than ultraviolet, most of the wavelengths between infrared and microwaves, and most of the longest radio waves. Only the visible light, some ultraviolet, infrared and short wavelength radio waves are able to penetrate the atmosphere, and bring information about the universe to our instruments here on the ground. The main frequency ranges allowed to pass through the atmosphere are called the *radio window* and the *optical window*. The radio

DOI: 10.4018/978-1-7998-2381-0.ch005

window is the range of frequencies from about 5 MHz to 300 GHz (wavelengths of 100 m to 1 mm). The low frequency end of the window is limited by signal absorption in the ionosphere. The upper limit is determined by signal attenuation caused by water vapor, carbon dioxide and ozone in the atmosphere. In order to observe the universe in all the EM spectrum, some of the observation equipment are put in space.

The optical window (thus optical astronomy) can be severely limited by atmospheric conditions, such as an overcast sky, air pollution, and light pollution from cities or populated area, and blinding interference from the bright sun light. Radio astronomy is not hampered by most of the conditions mentioned here. Observation can be carried out using a radio telescope in broad daylight, which cannot be done with optical telescope. However, at the higher frequencies in the atmospheric radio window, clouds and rain can cause signal attenuation. For this reason, sub-millimetre wavelengths radio telescopes are built on the highest mountains, where the atmosphere has the least chance for attenuation, due to the low humidity level at higher altitude. One good example of such telescope is the Atacama Large Millimetre/submillimetre Array (ALMA) (Yeap & Tham, 2018), where the array of telescopes was built on the Andes in Chile.

ABSORPTION AND EMISSION LINES

When the radiation from an object passes through a gas cloud, some of the electrons in the atoms and molecules of the gas absorb some of the energy of the EM radiation. The EM radiation emerging from the gas cloud will be missing those wavelengths that are absorbed. The spectrum will show dark absorption lines. The atoms or molecules in the gas will re-emit EM radiation at those same wavelengths. If we then observe this re-emitted EM radiation from the clouds of gas in the space between the stars, we will see bright emission lines at the exact frequencies of the absorption lines. These phenomena are known as *Kirchhoff's laws of spectral analysis* (see Figure 2).

Figure 1. The atmospheric windows