CHAPTER 2
BASIC THEORY

This chapter will examine the theories that support this thesis, including the introduction to visible light communication, advantages and disadvantages, devices or component that needed to design the system.

2.1. Free Space Optic

Free Space Optic (FSO) is a communication which uses an optical carrier wave to data transmission. Advantages of this technology are great bit rate, non-licence operating, relatively easy installation, relatively low cost. FSO is easily usable in spaces where other communication technologies. Generally, optical communications have a great potential and they will replace several radio links in future. The greatest source of problems in FSO communication is itself transmission media, the atmosphere. Plenty of scientific articles and books have been written which deal with different kinds of losses which effect on FSO link (Vitasek, 2014). Because of that, free space optical communication systems network have been proposed in this project research. The relation between power transmitted and power received against distance is given by the equation below (Soni and Banga, 2013) :

$$P_R = P_T\left(\frac{A_{RX}}{(\theta L)^2}\right) . e^{-\alpha L}$$

where :

P_R : power at the Receiver (dBm)

P_T : power at the transmitter (dBm)

A_{RX} : receiver aperture area (m^2)

θ : divergence angle (mrad)

α : atmospheric attenuation (dB)

L : distance between transmitter and receiver (m)

Furthermore, the FSO performance can be analysed with founding its optical power loss or attenuation. A standard and convenient method for measuring optical power loss through a FSO link is to reference the receiver power to the transmitter power. Thus for convenience one can designate signal attenuation or amplification in term of a logaritmic power ratio measured in desibels (dB). The dB unit is defined by :

$$\text{Power ratio in dB} = 10 \log \frac{P_2}{P_1}$$

Where P_1 is transmitter power and P_2 is receiver power. Log in this equation is the base-10 algoritm. The logarithmic nature of the decibel allows a large ratio to be expressed in a fairly simple maner (Keiser, 2015).

2.2. Introduction to Visible Light Communication

One of the free space optic communication technology that have many advantages is Visible Light Communication (VLC). It use visible light wavelength ranging from 400 nm ~ 700 nm (428 THz ~ 750 THz) if converted to frequency (Pohlmann, 2010). There are various areas of VLC applications: communication between traffic light, location determination technology that inform indoor location information, broadcasting communication that delivers information through display or digital multi signboard, and LED lighting or communication that utilizes display infra.

Using visible light communication for data transmission entails many advantages and eliminates most drawbacks of transmission via electromagnetic waves outside the visible spectrum. For instance, few known visible light-induced health problems exist today, exposure within moderation is assumed to be safe on the human body. Moreover, since no interference with electromagnetic radiation occurs, visible light can be used in hospitals and other institutions without hesitation (Pohlmann, 2010).

Furthermore, visible light is free. No company owns property rights for visible light and thus no royality fees have to be paid no do expensive patent licence have to be purchased in order to use visible light for communication purposes (Pohlmann, 2010). Visible light can serve as an entirely free infrastructure base on a complex communication network. VLC is mostly used indoors and transmitted light consequently does not leave the room when the doors are closed and the curtains drawn, because light cannot penetrate solid objects such as walls or furniture. Therefore, it is hard to eaves drop on a visible light based conversation, which makes VLC a safe technology if the sender intends to transmit confidential data.

The most important requirement that a light source has to meet in order to serve communication purposes, is the ability to be switched on and off again invery short intervals, because this is how data is later modulated. This rules out many conventional light sources, such as incandescent lamps.

2.3. Visible Light Communication System

Visible light communication have two main component which are transmitter and receiver as shown in Figure 2.1. The system deployed an LED (Light Emiting Diode) as the transmitter and photodetector at the receiver. To transmit the information, visible light communication used LED that will be transmitted to receiver to transmit the information via the air. At the receiver, the light will be captured by the photodetector at the receiver. The signal are demodulated to get back the original information.

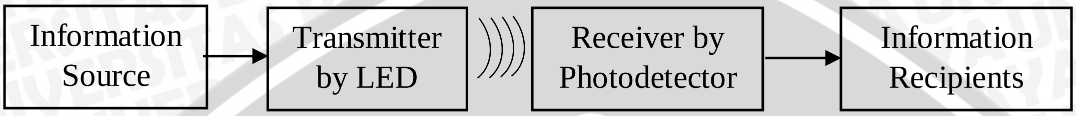

Figure 2.1 Visible light communication system

2.4. Light Emiting Diode (LED) as Transmitter

Light-emitting diodes are semiconductor devices that are directly modulated by varying input current. They are usually made of aluminum gallium arsenide (AlGaAs). These devices can emit light in both the visible and infrared regions of the spectrum. Unlike a semiconductor laser (a laser pointer for example), a light emitting diode spews light in all directions and has low irradiance. Power from LEDs generally is in the microwatt range up to maybe a few milliwatts. LEDs are small in size, low temperature, rugged, and inexpensive devices. They operate with *pn* junctions (see Figures 2.2 a and 2.2 b).

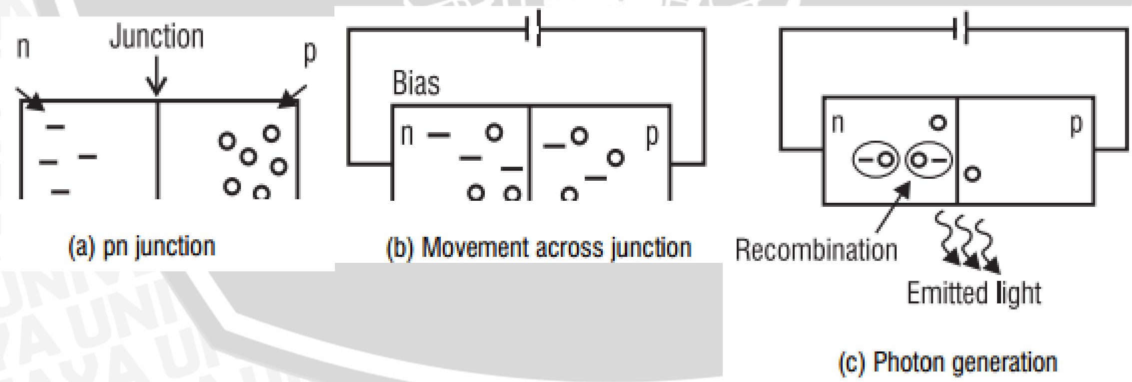

Figure 2.2 Simplified theory of LED operation
(Source: Roychoudhuri, 2008)

In a *pn* junction, two slabs are put together with the *n* material having an excess of electrons and the *p* material having a deficiency of electrons or an excess of holes. Each time an electron falls into a hole (recombination), a photon of light is emitted (see Figure 2.2c) (Roychoudhuri, 2008). The emitted photons produce an incoherent beam of light. When current flows across a *pn* junction, free electrons from the n-type material are forced to combine with holes in the *p* type material and release energy.

The wavelength of light emitted by the LED is inversely proportional to the bandgap energy. The higher the energy the shorter the wavelength. The formula relating electron energy to wavelength is given below :

$$\lambda = \frac{h\,c}{\varepsilon_{ph}} = \frac{1.24}{\varepsilon_{ph}(Ev)}$$

where: λ = wavelength in microns

h = Plancks constant = 6.63 x 10^{-34} = 4.14 x 10^{-15} *eV.s*

c = speed of light = 3 x 10^{8} *metres.sec*

ε_{ph} = photon energy in eV

This means that the materials of which the LED is made determine the wavelength of light emitted. The following table 2.1 shows energies and wavelengths for commonly used materials in semiconductor LEDs and lasers (Senior, 1951).

Table 2.1 Bandgap energy and possible wavelength ranges in various materials

Material	Formula	Wavelenghth Range λ (µm)	Bandgap Energy $W_{g\,(eV)}$
Indium Phosphide	Inp	0.92	1.35
Indium Arsenide	InAs	3.6	0.34
Gallium Phosphide	GaP	0.55	2.24
Gallium Arsenide	GaAs	0.87	1.42
Aluminium Arsenide	AIAs	0.59	2.09
Gallium Indium Phosphide	GaInp	0.64-0.68	1.82-1.94
Aluminium Gallium Arsenide	AIGaAs	0.8-0.9	1.4-1.55
Indium Gallium Arsenide	InGaAs	1.0-1.3	0.95-1.24
Indium Gallium Arsenide Phosphide	InGaAsP	0.9-1.7	0.73-1.35

(Source: Dutton, 1998)

2.5. Photodiode as Receiver

A photodiode is a semiconductor device that converts light into current. In photovoltaic effect, for which no bias voltage is required. It is also possible to use a pn junction to detect light if one does apply a bias voltage in the reverse direction. The reverse direction is the direction of low current flow, that is, with the positive voltage applied to the n-type material. A pn junction detector with bias voltage is termed a photodiode.

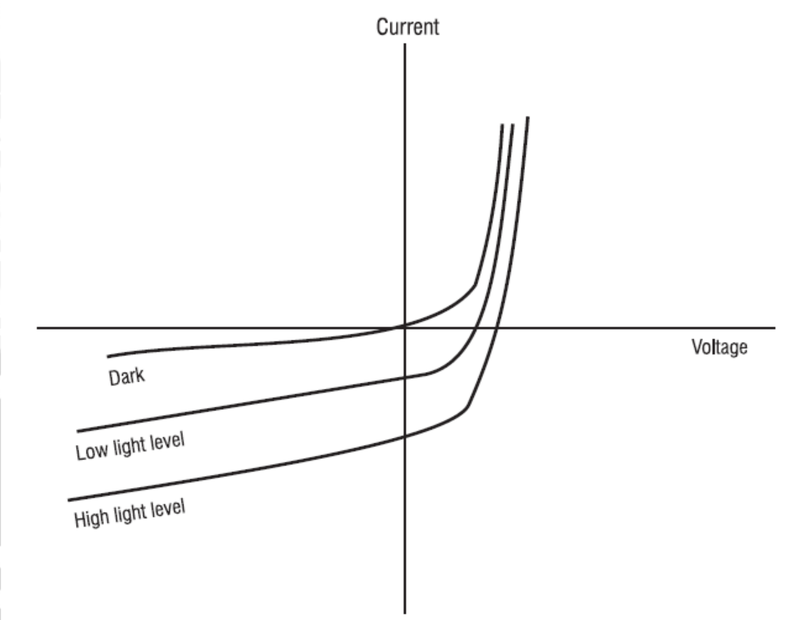

Figure 2.3 Current-voltage characteristic for a photodiode
(Source: Roychoudhuri, 2008)

Figure 2.3 shows the current-voltage characteristics of a photodiode. The curve marked dark shows the current-voltage relation in the absence of light. It shows the familiar rectification characteristics of a pn semiconductor diode. The other curves represent the current-voltage characteristics when the device is illuminated at different light levels. A photovoltaic detector, with zero applied voltage, is represented by the intersections of the different curves with the vertical axis. Figure 2.3 is intended to show qualitatively how a photodiode operates. No quantitative values are shown for the axes in this figure; these values will vary from one material to another. A photodiode detector is operated in the lower left quadrant of this figure, where the current that may be drawn through an external load resistor increases with increasing light level. In practice, one measures the voltage drop appearing across the load resistor.

A variety of photodiode structures are available. No single photodiode structure can best meet all requirements. Perhaps the two most common structures are the planar diffused photodiode, shown in Figure 2.4 (a), and the Schottky photodiode, shown in Figure 2.4 (b). The planar diffused photodiode is fabricated by growing a layer of oxide over a slice of high-resistivity silicon, etching a hole in the oxide and diffusing boron into the silicon through the hole. This structure leads to devices with high breakdown voltage and low leakage current. The circuitry for operation of the photodiode is also indicated, including the load resistor.

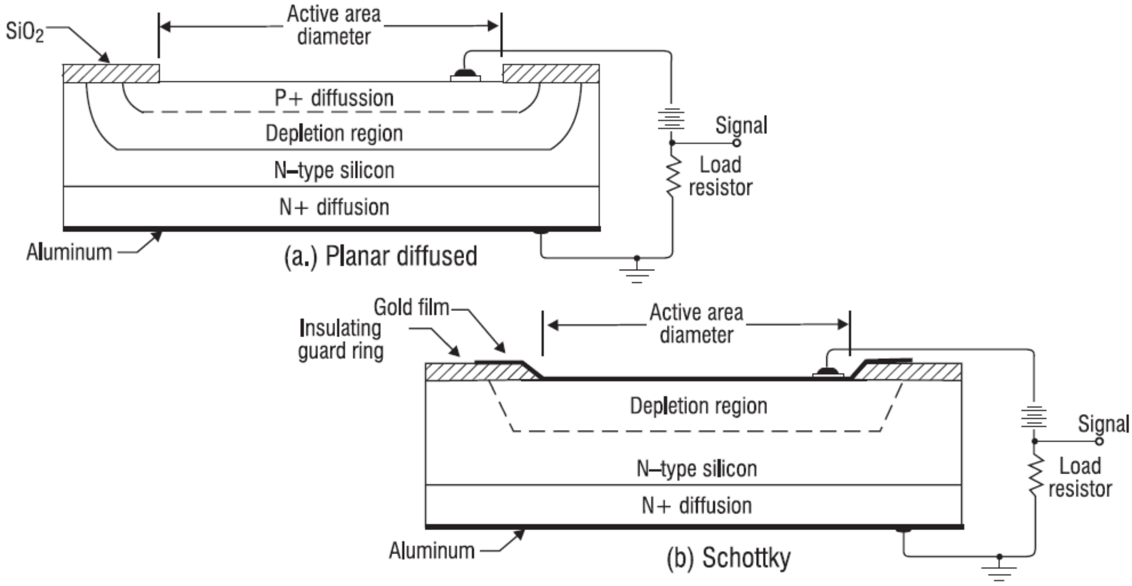

Figure 2.4 Photodiode structures: (a) Planar diffused photodiode; (b) Schottky photodiode (Source: Roychoudhuri, 2008)

The Schottky barrier photodiode is formed at a junction between a metallic layer and a semiconductor. If the metal and the semiconductor have work functions related in the proper way, this can be a rectifying barrier. The junction is fabricated by oxidation of the silicon surface, then etching of a hole in the oxide, followed by the evaporation of a thin transparent and conducting gold layer. The insulation guard rings serve to reduce the leakage current through the device. A number of different semiconductor materials are in common use as photodiodes. They include silicon for use in the visible, near ultraviolet, and near infrared; germanium and indium gallium arsenide in the near infrared; and indium antimonide, indium arsenide, mercury cadmium telluride, and germanium doped with elements like copper and gold in the longer-wavelength infrared (Roychoudhuri, 2008).

The most frequently encountered type of photodiode is silicon. Silicon photodiodes are widely used as the detector elements in optical disks and as the receiver elements in optical fiber telecommunication systems operating at wavelengths around 800 nm. Silicon photodiodes respond over the approximate spectral range of 400–1100 nm, covering the visible and part of the near infrared regions. The spectral responsivity (in A/watt) of typical commercial silicon photodiodes is shown in Figure 2.5. The responsivity reaches a peak value around 0.7 amp/watt near 900 nm, decreasing at longer and shorter wavelengths. Optional models provide somewhat extended coverage in the infrared or ultraviolet regions. Silicon photodiodes are useful for detection of many of the most common laser wavelengths, including argon, HeNe, AlGaAs, and Nd:YAG.

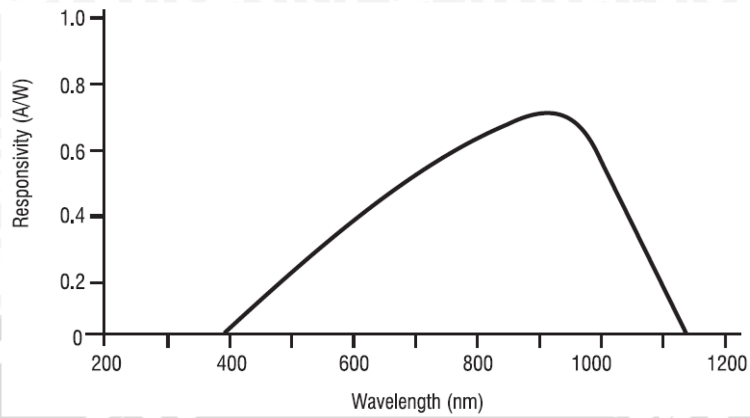

Figure 2.5 Responsivity as a function of wavelength for typical silicon photodiodes
(Source: Roychoudhuri, 2008)

In practice, silicon photodiodes have become the detector of choice for many photonics applications within their spectral range. They use well-developed technology and are widely available. They represent the most widely used type of detector for lasers operating in the visible and near infrared portions of the spectrum (Roychoudhuri, 2008).

2.6. PIN Photodiode

The most common photodetector is the semiconductor PIN photodiode. The device structure consists of *p* and *n* semiconductor regions separated by a very lightly η doped intrinsic region. In normal operation a reverse-bias voltage is applied across the device so that no free electrons or holes exist in the intrinsic region.

Figure 2.6 Simplified principle of photodiode

Figure 2.6 shows the photodetector senses the light signal falling on it and converts the variation of the optical power to a correspondingly varying electric current. Since the optical signal generally is weakened and distorted when it emerges from the end of the fiber, the photodetector must meet strict performance requirements as following :

i. high sensitivity to the emission wavelength range of the received light signal;
ii. minimum addition of noise to the signal; and

iii. fast response speed to handle the desired data rate

Furthermore, the photodetector needs to:

i. insensitive to temperature variations;
ii. compatible with the physical dimensions of the fiber;
iii. reasonable cost compared to that of other system components; and
iv. long operating lifetime

The photodiode also has some material characteristics that will affect the wavelength that can be used, as shown in the Table 2.2 (Keiser, 2003).

Table 2.2 Operating wavelength ranges for several different photodetector materials

Material	Energy gap (eV)	Λ_{cutoff} (nm)	Wavelength range (nm)
Silicon	1.17	1060	400-1060
Germanium	0.775	1600	600-1600
GaAs	1.424	870	650-870
InGaAs	0.73	1700	900-1700
InGaAsP	0.75-1.35	920-1650	800-1650

(Source: Keiser, 2003)

2.7. On Off Keying Modulation

One of the simplest techniques for sending binary data is Amplitude Shift Keying (ASK) or On Off Keying (OOK), where the voltage level is switched between two values, which are usually on or off. The signal wave will become zero voltage level space when a binary 0 occurs, and it will become one voltage level space when a binary 1 occurs as shown in Figure 2.7 (Keiser, 2003).

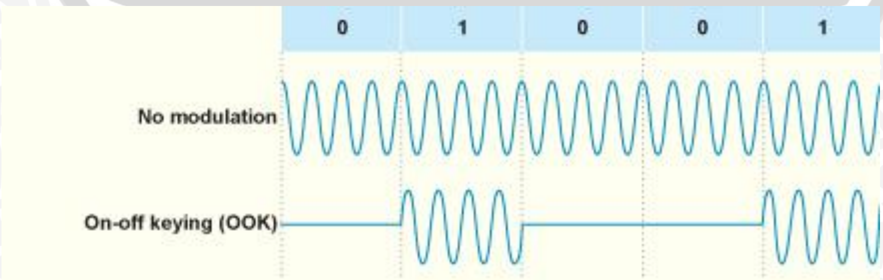

Figure 2.7 an On Off Keying signal
(Source: Zhou, 2013)

2.8. Previous Study

Some research has been conducted by other researchers in the application of visible light communication system. Based on the literature review, the new research will be conducted to prototype design and performance analysis of visible light communication for audio communication.

2.8.1. A Fully Integrated Audio, Video, and Data VLC Transceiver System for Smartphones and Tablets

The paper with title 'A Fully Integrated Audio, Video, and Data VLC Transceiver System for Smartphones and Tablets' was written by Lih Chieh Png.

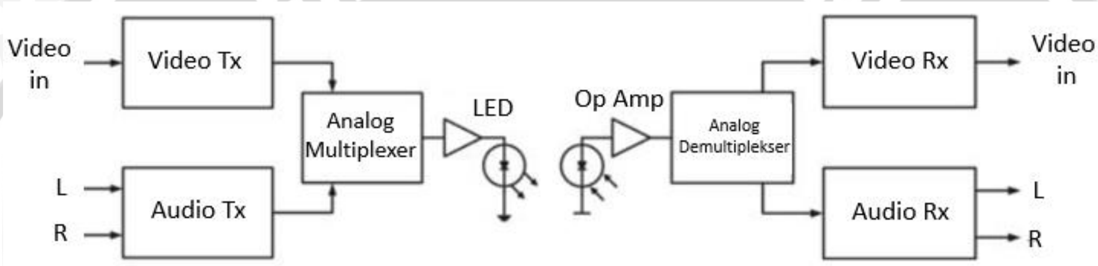

Figure 2.8 Block diagram of integration between the video and audio modules [13]. (Source: Chieh, 2013)

This paper showed a prototype design of visible light communication for audio, video, and data transmission. The system also integrated the audio and video to the multimedia communication system. Figure 2.8 shows the block diagram of the transmitter and the receiver for their project. The VLC audio circuit, are bulid VLC video circuit, and serial data transceiver has been integrated with android. VLC video, audio, and data prototype has been presented. The advantages of this project are the system include real time interacting and the availability to hear the sound and see the video simultaneously (Chieh, 2013).

2.8.2. Designs of VLC Transceiver Circuits for Reading Light Transmission of High-Quality Audio Signals on Commercial Airliners

The paper with title 'Designs of VLC Transceiver Circuits for Reading Light Transmission of High-Quality Audio Signals on Commercial Airliners' was written by Lih Chieh Png, Sharon Xueqi Lim, A Rajamohan, Boone-Wy Chan, and Faiz Azhar Hazman.

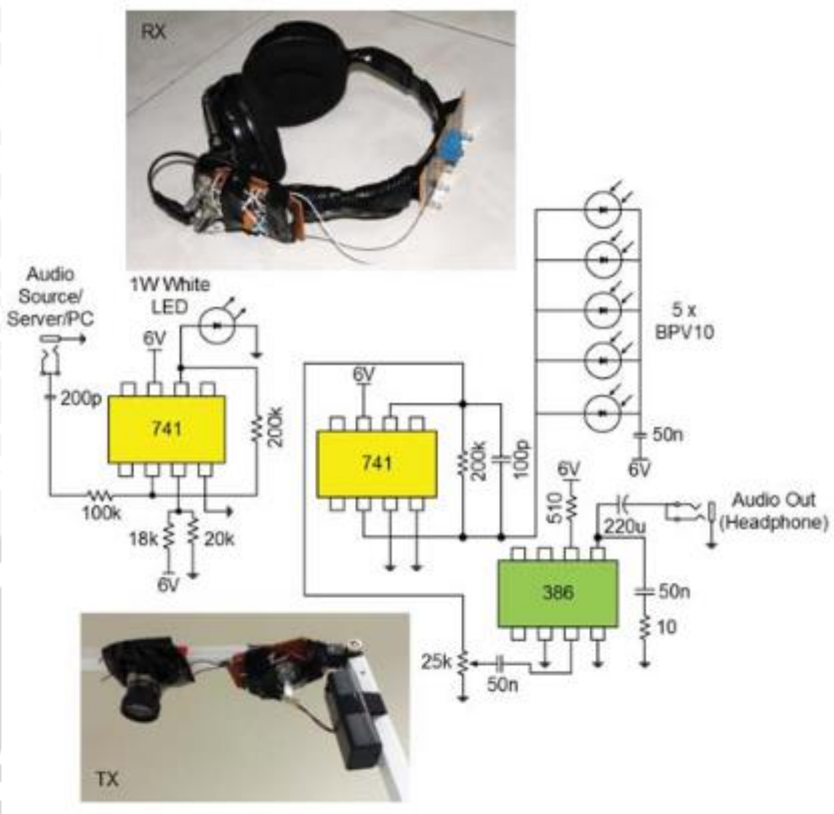

Figure 2.9 Basic circuit and constructed prototype for airline entertainment VLC audio transmission system
(Source: Chieh, 2014)

In this paper they showed three designs of audio transmitters and receivers have been built and tested successfully. Figure 2.9 shows the basic circuit of their project. The simplicity of these circuits and the very few components that are used enable them to be mass manufactured for use on passenger aircrafts. The receiver circuits can be implemented on headphones. The transmitter circuits can be integrated with LED reading lights above passengers' seats. The circuits presented here have different performance characteristics and sound qualities, depending on the type of audio ICs that are used. The conclusion of their project is the LME49860 circuit gives the best sound quality among all (Chieh, 2014).

2.8.3. The Analysis of Variable Length Code-Coded Efficiency Based on MPEG-I Layer III Audio

The paper with title 'The Analysis of Variable Length Codes-Coded Efficiency Based on MPEG-I Layer III Audio' was written by Jiaqiang Tan and Rangding Wang.

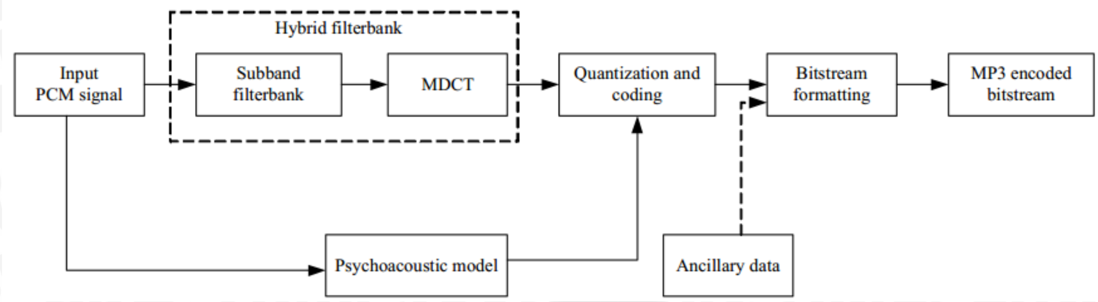

Figure 2.10 Sketch of MP3 audio encoding
(Source: Tan, 2008)

In this paper they had shown the multimedia bit stream is comprised of variable length codes to a large extent. If data hiding is carried out in multimedia compressed domain, variable length codes are usually chosen as the hidden object. Figure 2.10 shows the sketch of MP3 audio encoding which have been used in their project. The variable length codes-coded efficiency is a key factor which can directly affect the method of data hiding. MPEG-I Layer III (MP3) audio is chosen as analytical object in this paper. The variable length codes -coded rule is obtained by analyzing the variable length codes-coded efficiency of the MP3 audios. The process of variable length coding in MP3 audio can be understood further passing through the variable length codes -coded rule. At the same time, it also provides a favorable theoretical base for seeking for effective data hiding methods in MP3 audio compressed domain (Tan, 2008).

2.8.4. Summary of Previous Study

On this subsection will shows the summary of previous study which have been used as reference to support this project :

First previous study with title “A Fully Integrated Audio, Video, and Data VLC Transceiver System for Smartphones and Tablets”. The problem is how to make a VLC transceiver system that can integrate the audio, video, and data for smartphones and tablets. The scope of problem contained with in the stereo audio prototype, the transmitter mainly consists of stereo encoder, band-pass filter (BPF), and PPM modulator. The receiver consists of preamplifier, PPM demodulator, low-pass filter (LPF), and stereo decoder. The method of research that has been used is build the system prototypes. It consist of VLC audio circuit, VLC video circuit, and VLC serial data transceiver for android. To solve the problem, in this research audio/video (A/V) transceiver and a data transceiver will connected to android. The real time video and pulse position modulated stereo audio signals are transmitted by a white LED over free space. The result of this research is VLC video, audio, and data prototypes have been presented. This work opens up greater possiblilties of integrating VLC with portable communication devices. The advantages of the VLC A/V system include real-time interaction and simultaneous availability of sight and sound.

Second previous study with title "Designs of VLC Transceiver Circuits for Reading Light Transmission of High Quality Audio Signals on Commercial Airliners". The problem is how to designs the VLC transceiver circuits for reading light transmission of high quality audio signals on commercial airliners. The scope of problem contained with there are three design of audio transmitter and receiver that will be implemented. The simplicity of these circuits and the very few components that are used enable them to be mass manufactured for use on passenger aircrafts. The receiver circuits can be implemented on headphones. The transmitter circuits can be integrated with LED reading lights above passengers seats. In this research, the method that have been used is building the three designs of audio transmitters and receivers that have been tested successfully. To solve the problem, in this project is started by reviewing the cross section of the *Airbus A380* passenger plane cabin to find out the distance between the reading lights and the passenger's head that able to estimate that this distance is between 570 mm and 740 mm. The reading lights are high brightness, bulbless, warm-white LEDs that have about 150 degrees of movement in the X and Y axes. The result of this research is audio circuits should be the first step into the development of wireless airline entertainment systems. Wireless optical communication using visible light has the largest potential because they can be integrated easily into existing devices on the plane and do not interfere with the aircraft's control systems.

Third previous study with title "The Analysis of Variable Length Code-Coded Efficiency Based on MPEG-I Layer III Audio". The problem is how to analyze the Variable Length Code-Coded Efficiency Based on MPEG-I Layer III Audio. The scope of problem contained with MPEG-I Layer III (MP3) audio is chosen as analytical object. The VLC-coded rule is obtained by analyzing the VLC-coded efficiency of the MP3 audios. In this research, the method that has been used is designing the data multimedia encoding. After that, the analysis of VLC-coded efficiency on MP3 audio based on Huffman coding theory. To solve the problem, in this research the process of variable length coding in MP3 audio can be understood further passing through the VLC-coded rule. At the same time, it also provides a favorable theoretical base for seeking for effective data hiding methods in MP3 audio compressed domain. The result of this research is the VLC-coded rules in MP3 audio are obtained passing through related experiments. And the rules could help us further understanding variable length coding in MP3 audio. Although VLC-coded efficiency is analyzed for only MP3 audio, other multimedia can make use of the same method to analyze their VLC-coded efficiency.