Information Technology

Mobile Computing

Module: Electromagnetic Waves

Learning Objectives

- Concepts of Electromagnetic waves
- Parameters of Electromagnetic waves
- Electro Magnetic Spectrum
- Bands of E.M. Spectrum for communication
- Frequencies used by common wireless technologies and standards
- Signal
- Analog Vs. Digital Signal

Introduction

In the previous modules we learnt that Electromagnetic waves are used for wireless communications. Electromagnetic waves are sinusoidal periodic waves travelling with speed of light. They are characterized by amplitude, frequency, wavelength and phase. In communication scenario, E.M. waves are used and discussed in frequency perspective. According to frequency, E.M. waves are divided into seven bands constituting Electromagnetic spectrum. Of these seven bands only four bands namely radio waves, micro waves, Infrared waves and Visible band are appropriate for communication. Rest all bands namely Ultra violet rays, X-rays and gamma rays are harmful to surroundings. Radio waves and micro waves collectively known as radio communication and Infrared and visible band collectively known as optical communication. This module explains in detail the concept of E.M waves and its attributes. The characteristics of each band of spectrum and its uses are explained in detail. The ITU nomenclature of each band and frequencies used by different wireless technologies have been mentioned. The concept of signal as physical representation of data and its form analog and digital is presented.

Electromagnetic wave

Electrons when propagated either in a guided media or free space follow a wave like pattern. They have both an electrical as well as a magnetic field associated with them. Hence the name electromagnetic waves. This phenomenon was first predicted to exist by James Maxwell, in 1865, and it was first produced and observed by Heinrich Hertz in 1887. All of these waves vary with time in direction and intensity. They move with speed of light in vaccum but the speed decreases after entering materials. They move through vacuum, and do not need a medium to travel. For eg. Light, radio waves all are examples of Electromagnetic wave. They are periodic waves as they repeat themselves after regular intervals of time(Figure 2)

Representation of E.M. wave

E.M. waves are represented as function of time or function of frequency as shown in Figure 1

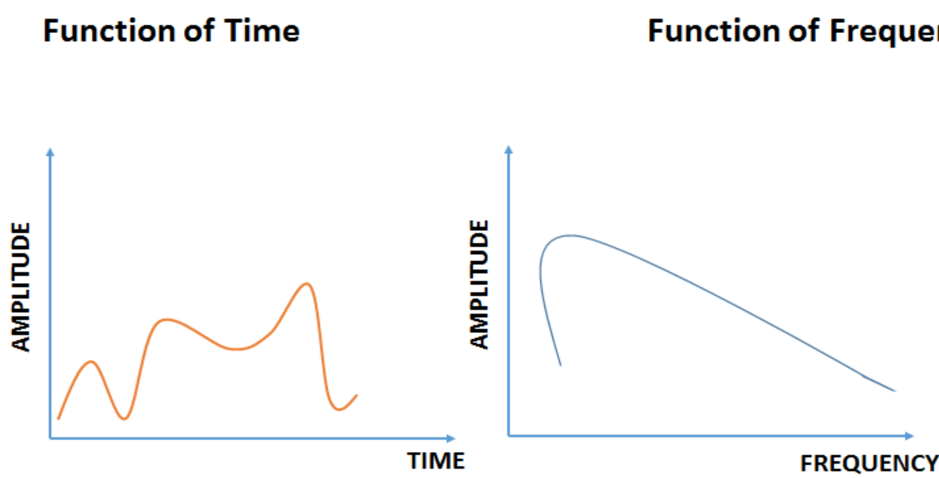


Figure 1 Representation of E.M. wave

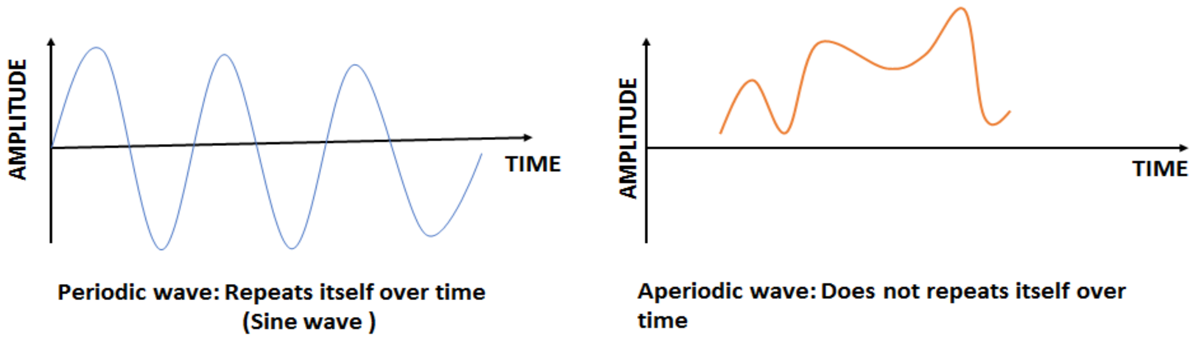


Figure 2 Periodic vs. Aperiodic waves

Parameters of E.M. wave

Amplitude

Maximum value or strength of the signal over time. Unit is volts. For light, amplitude represents brightness and for sound it represents loudness. For radio waves to be detected, they should be of significant amplitude to be discernible. Suitable signal processing operations are done to vary to make the signal suitable for transmission. In Fig. 3 waves of different amplitudes are depicted in color coded form. It is evident from the diagram that wave the wave coded in red color has maximum amplitude.

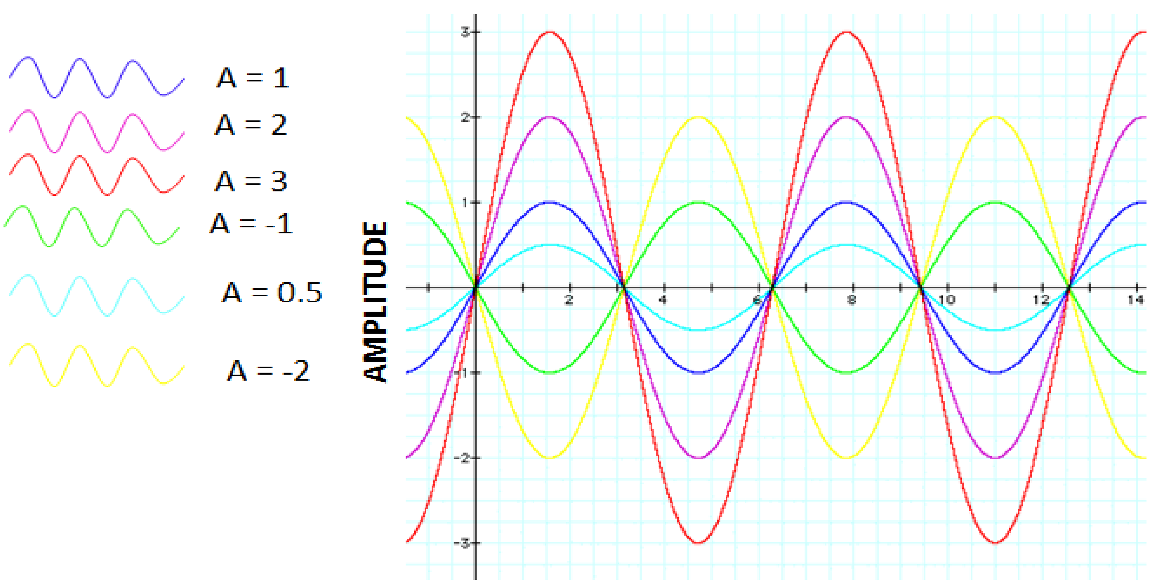


Figure 3: Waves with different amplitudes

Frequency (v)

Number of cycles per unit time. Unit is hertz. Amount of time taken to complete one cycle is known as time period. Unit is sec, ms…etc. In Fig. 4 we can see that wave color coded in blue has maximum amplitude.

$$T = 1/ v$$

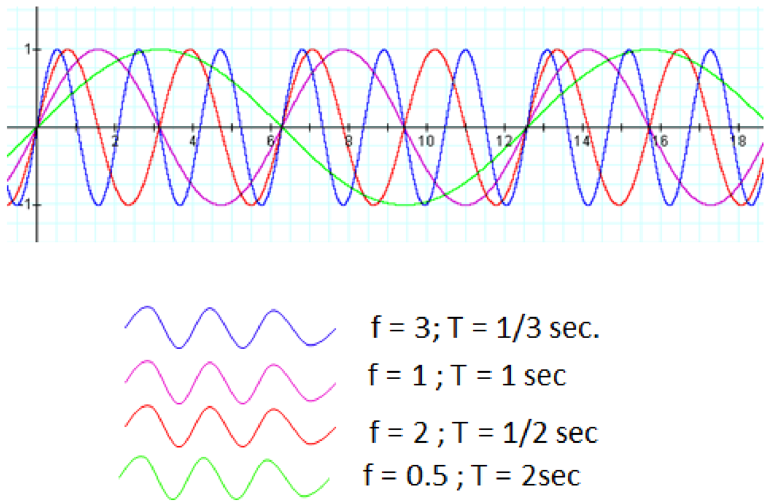


Figure 4 Waves with different frequencies and time period

Phase Shift

Phase shift represents the shift of the wave from the origin. Unit is degrees or radians .A negative phase shift indicates a movement to the right, and a positive phase shift indicates movement to the left.

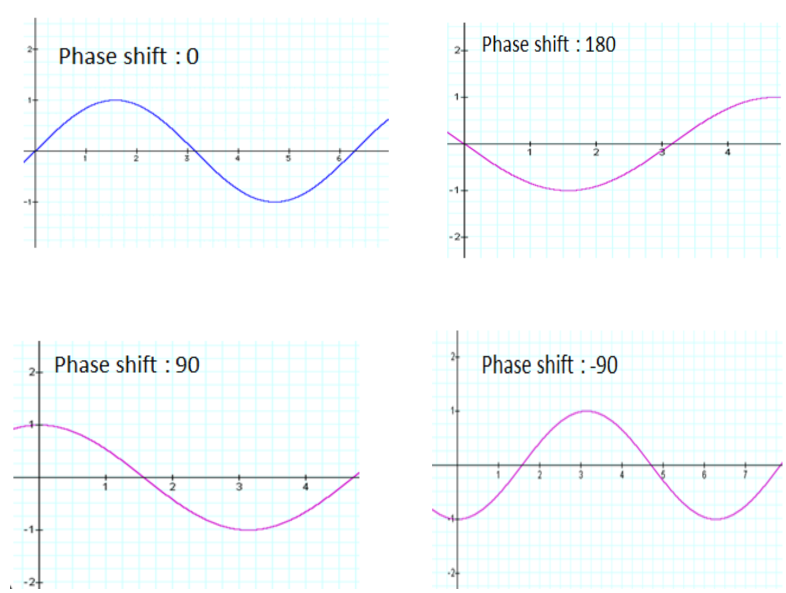


Figure 5 Phase Shift

Wave Length

Distance covered by one cycle. It can be measured as the distance between two peak values of a wave. Represented by symbol λ. Unit is unit of distance. Fig 6 represents the wavelength. It can be seen that as frequency increases wavelength decreases.
Or $\nu \propto 1/\lambda$
or $\nu \lambda = c$; where c is speed of light=$3X10^8$ m/sec.

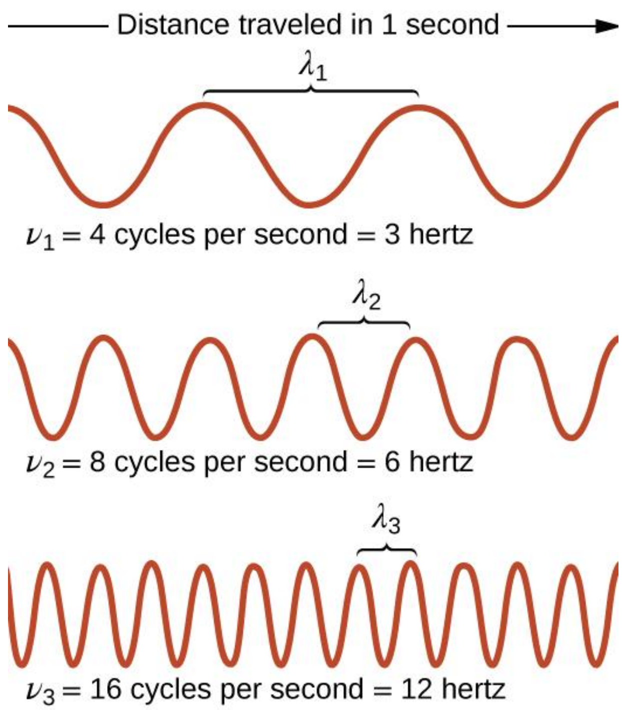


Figure 6 Frequency VS Wave Length

Spectrum and Band Width

The frequencies used for transmission is known as spectrum. Difference in maximum to minimum frequency is called bandwidth. In Figure 7, bandwidth is 2.5 Hz

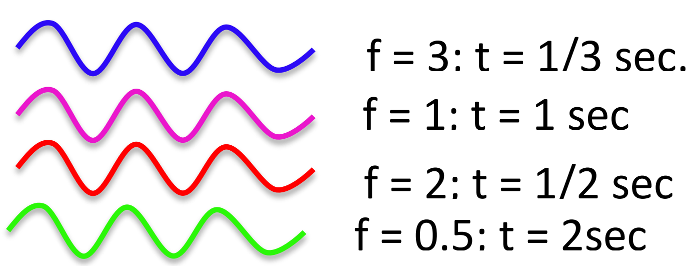


Figure 7 : Spectrum and Band Width

Electro Magnetic Spectrum

Electromagnetic radiation is transmitted in waves or particles at different wavelengths and frequencies. This broad range of wavelengths is known as the electromagnetic (EM) spectrum(Figure 8). The electromagnetic spectrum is the range of all possible frequencies of electromagnetic radiation. The spectrum is generally divided into seven regions in order of decreasing wavelength and increasing energy and frequency. The common designations are radio waves, microwaves, infrared (IR), visible light, ultraviolet (UV), X-rays and gamma-rays. It can be seen that Gamma rays has maximum frequency with minimum wavelength and radio waves have minimum frequency with maximum wavelength. The different bands blend with each other and there are no clear cut boundaries between two bands. The representative frequencies and wavelengths of different bands have been shown in Table 1.

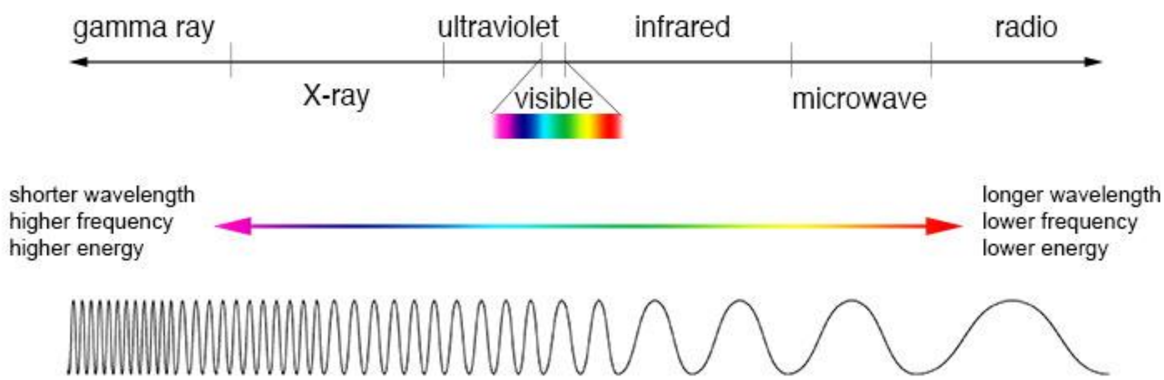


Figure 8: Electro Magnetic Spectrum

Table 1 Frequencies and wavelengths of bands of E.M. Spectrum

Name	**Wavelength**	**Frequency (Hz)**	**Photon Energy (eV)**
Gamma ray	Less than 0.01 nm	More than 10 EHz	100 kev – 300+ GeV
X – ray	0.01 – 10 nm	30 EHz – 30 PHz	120 eV – 120 keV
Ultraviolet	10 nm – 400 nm	30 PHz -790 THz	3 eV – 124 eV
Visible	390 nm – 750 nm	790 THz – 405 THz	1.7 eV – 3.3 eV
Infrared	750 nm – 1 mm	405 THz – 300 GHz	1.24 meV – 1.7 eV
Microwave	1 mm -1 meter	300 GHz – 300 MHz	1.24 µ eV – 1.24 meV
Radio	1 mm - km	300 GHz – 3 Hz	12.4 feV – 1.24 meV

Bands suitable for communication

Not all bands of E.M. Spectrum are suitable for communication. **Radio waves and Microwaves** commonly designated as radio communication and **Infrared and visible band** designated as Optical Communication are suitable for communication (Fig. 9). Other bands are harmful for human beings.

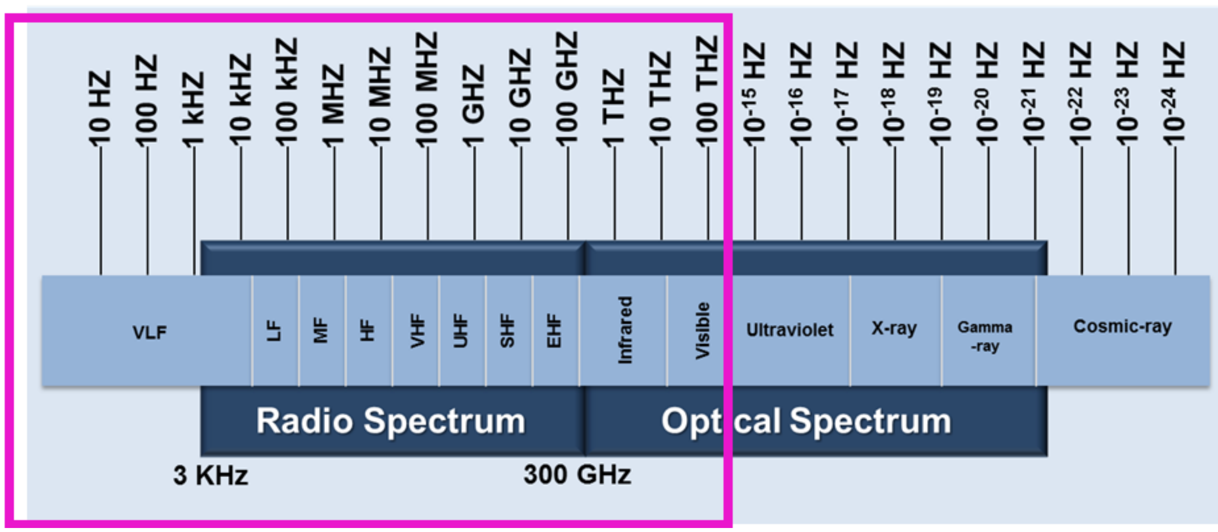


Figure 9 Bands suitable for communication

Features of Radio Waves

The lowest frequency portion of the electromagnetic spectrum is designated as "radio," generally considered to have wavelengths within 1 millimeter to 100 kilometers or frequencies within 300 GHz to 3 kHz. They can travel long distances carrying message. These waves can travel along Earth's surface as ground Wave propagation. At higher wavelengths, they can travel under water, as required in submarine communication. They have different penetration through the walls of the buildings or houses based on the frequency making it appropriate for radio and television transmission and for cellular mobile phone service. They are able to bounce off the ionosphere and travel around the world. They are easy to generate. Antenna size for radio wave is in the range of millimetres to metres, which is feasible to make. They have same velocity in vacuum. They are omni-directional hence can be used for broadcasting in all directions. Radio waves are used for multi-casting, in which there is one sender but many receivers such as AM and FM radio, television, maritime radio, cordless phones and paging. Radio waves have adverse effects on surroundings.Uncontrolled radiation of RF affects pre-adolescent children, pregnant women, elderly humans, patients with pace makers, small birds, flora and fauna, small insects etc. The areas near RF cellular towers have been observed with more lightening compare to other areas. It also affects some of the fruits grown near the RF tower areas. As RF waves are available both in LOS and non LOS regions of transmitter, it can be easily intruded by the hackers and crucial personal/official data can be decoded for malicious motives.

Features of Micro Waves

Microwaves are at high frequency than radio waves. Large amount of information can be transmitted therefore cost efficient. Meticulous circuitry is required at the receiving end. Antenna size small hence massive towers not needed. They can travel faster; more reliable less maintenance is required. Microwaves can travel through short distances due to higher frequency. They can travel through atmospheric layers making them suitable for satellite communication. Use directional antennas hence applicable in hilly remote areas where directionality is required. At high frequencies, they follow line-of-sight transmission; signal has to be transmitted several times in different directions for propagating signal. Due to high frequency, are obstructed easily. Microwave radio communication can also be degraded by heavy moisture in the atmosphere, snow, rain and fog, a phenomenon known as rain fade.

Limitations of radio communication

- Increasingly limited availability of conventional bandwidths for electronic equipment
- Licensing of bands
- Radio communications interference with sensitive electrical equipment
- Data security
- Negative health consequences on environment

Optical Communication

Infra red waves

The wavelength of infrared radiation varies from about 750 nanometres (the near infrared) to 1 millimeter (the far infrared). Frequencies range from about 300 GHz to 400 THz. An infrared transmitting device, either a light-emitting diode (LED) or a laser diode, converts an electrical signal to an optical signal. The transmitted signal's intensity or power is proportional to the modulating signal. Photodetector at the receiver produces an output current proportional to the received optical signal intensity; Contemporary application is TV remote control. LEDs have a naturally wide transmission path and are suitable for short-range applications. They are also much safer than laser diodes for indoor use. Laser diodes have narrow transmit beams and a relatively narrow spectral width, making them more suitable for point-to-point long-range applications.

Infrared Data Association (IrDA), was set up in 1993 to develop standards for infrared communication hardware software and communications protocol standards for short-range data communications in applications such as personal area networks (PANs). Infrared laser systems can also be used for long-range communication up to about 2.4 kilometers with a maximum projected data rate of 16 Mbps. But they are sensitive to fog and other atmospheric conditions. For e.g. Building to building transmission link (Fig. 10)

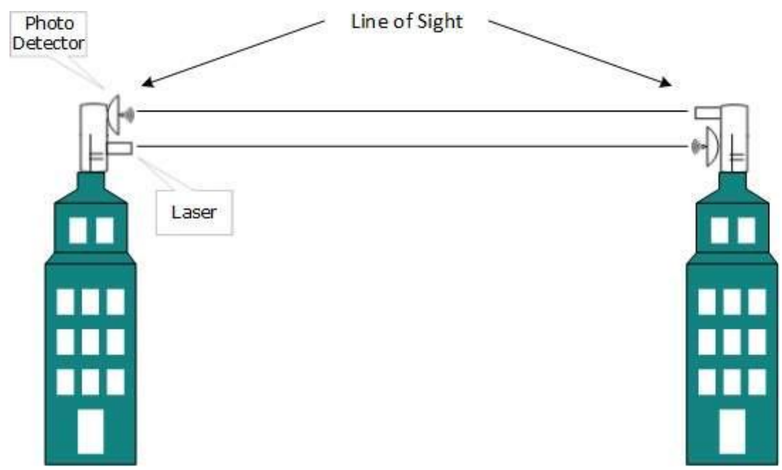


Figure 10 Point-to-point communication

Diffuse (or non-line-of-sight) systems may be used for wireless LAN connectivity, in which the link between transmitter and receiver is maintained by "bouncing" the transmitted signals off reflecting surfaces such as walls and ceilings. The specifications for infrared wireless LANs are covered in the IEEE 802.11 standard. Infrared transmitters are usually relatively directional, cheap, lightweight, reliable and easy to manufacture. An infrared system in one room of a building will not interfere with similar systems in nearby rooms. Possibility of eavesdropping is far lower than with radio-based systems. Infrared communication is more reliable alternative for indoor wireless LANs. But the limitations are that they are easily obstructed and harmful at high power levels. They cannot be used outside in day because of interference with sunlight

Visible light communication

Communicating information via light is a concept that has been around since ancient times when signal fires would relate important news across long distances. Visible light communication (VLC) is a less widely used form of communication which requires that the communication frequencies lie in the visible light spectrum. VLC methods are less pervasive because the transmitted signals are visible by people which can adversely impact their environment. A common phrase for VLC is Li-Fi (lightfidelity) after the popular Wi-Fi (wireless fidelity) communication method. Communicating information via light is an old concept using signal fires. Visible light communication (VLC) is a form of communication which requires that the communication frequencies lie in the visible light spectrum. VLC methods are less pervasive because the transmitted signals are visible by people which can adversely impact their environment. A common phrase for VLC is Li-Fi (lightfidelity) after the popular Wi-Fi (wireless fidelity) communication method. VLC refers to communication using an illumination source which provides illumination as well as communication. It can send information using light-signals The signals are sent by modulating them in ON OFF patterns to transmit 0 and 1. A photoreceptor at other end demodulates into data. In 2011, Harald Haas from University of Edinburgh, UK, demonstrated VLC through LED evolving a technology called Li-Fi which abbreviates to "LIGHT FEDILITY". The sources of light used in VLC can be florescent bulbs, incandescent bulbs, lasers, or LEDs. Incandescent lights cannot sustain quick switching in ON and OFF pattern to modulate 0 & 1. In contrast, LED can be fluctuated with high frequency as it is made up of semi-conductor material. LED is also known as green lightning resource because it is energy efficient and doesn't contain hazardous material like mercury emitted by florescent lamps. Hence LED has an edge over other sources for VLC

Advantage over radio communication

- Ultra-high-speed
- High security
- Biologically friendly communications
- All time availability

Capacity: Light has 10000 times wider bandwidth than radio waves [2]. Also, light sources are already installed. So, Li-Fi has got better capacity and also the equipments are already available. b) Efficiency: Data transmission using Li-Fi is very cheap. LED lights consume less energy and are highly efficient. c) Availability: Availability is not an issue as light sources are present everywhere. There are billions of light bulbs worldwide; they just need to be replaced with LEDs for proper transmission of data. d) Security: Light waves do not penetrate through walls. So, they can't be intercepted and misused.

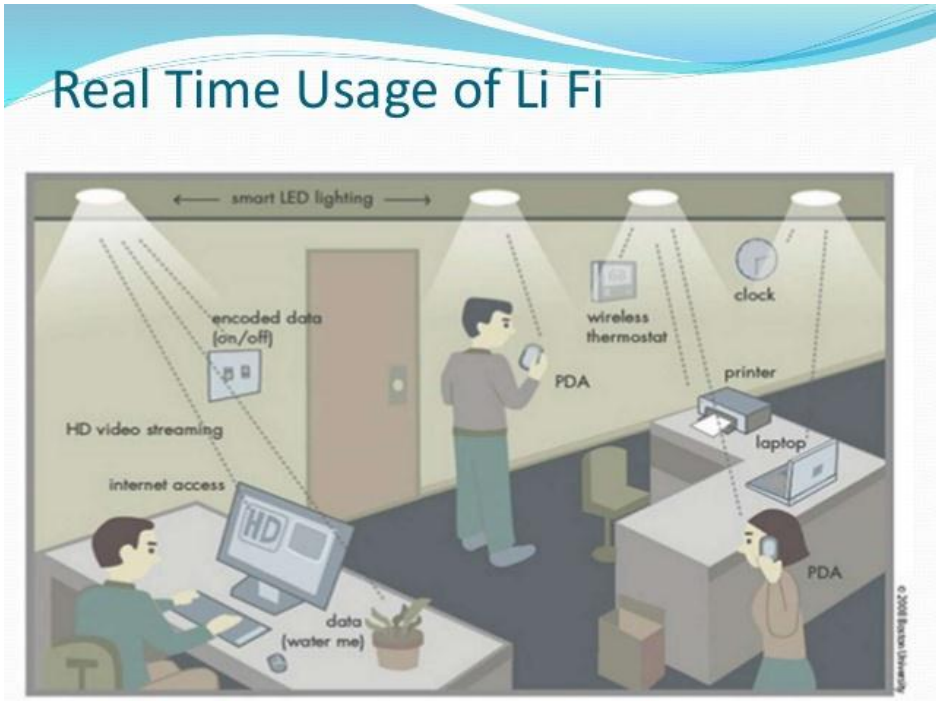


Figure 11

Although the electromagnetic spectrum represents an enormous range of frequencies, not all the frequencies are suitable to purposes of human communications. At the very low end of the spectrum are signals that would be traveling at 30Hz (that is, at 30 cycles per second). One of the benefits of a very low frequency is that it can travel much farther than a high frequency before it loses power (that is, attenuates). So a 30Hz signal provides the benefit of being able to travel halfway around the world before it requires some form of amplification. For example, one defense agency uses 30Hz to communicate with its submarines by using telemetry (for example, a message that says "We're still here. We're still here" is sent, How is data put on radio waves? There are two common ways to put information in a radio wave, and you've likely run into them yourself. They are called A.M. and F.M. just like the two choices you've always known are on a radio. To understand these two ways of sending information it is important to know that radio waves, by themselves, have very regular patterns. Generally they keep the same amplitude or frequency all the time. (Amplitude is the "height" of the radio wave, frequency is how close the waves are to each other.)A.M. stands for amplitude modulation. In this method, the information is put into a radio wave by varying the amplitude. For example, if all we wanted to do was send 1's and 0's, we could have just two different levels of amplitude that correspond to these numbers--1 being high, 0 being low.F.M. stands for frequency modulation. This time the amplitude is kept constant, it is the frequency that is varied.

Radio Frequency Allocation

Table 2 Radio Frequency Allocation: Radio Waves

f	**λ**	**Band**	**Description**
30 – 300 Hz	104 – 104 km	ELF	Extremely low frequency
300 – 3000 Hz	103 – 102 km	VF	Voice frequency
3 – 30 kHz	100 – 10 km	VLF	Very low frequency
30 – 300kHz	10 -1 km	LF	Low frequency
0.3 – 3 MHz	1 – 0.1 km	MF	Medium frequency
3 – 30 MHz	100 – 10 m	HF	High frequency
30 – 300 MHz	10 – 1 m	VHF	Very high frequency
300 – 3000 MHz	100 – 10 cm	UHF	Ultra – high frequency
3 – 30 GHz	10 -1 cm	SHF	Superhigh frequency
30 – 300 GHz	10 – 1 mm	EHF	Extremely high frequency

Table 3 Radio Frequency Allocation: Radio Waves

f (GHz)	**Letter Band Designation**
1 – 2	L band
2 – 4	S band
4 – 8	C band
8 – 12.4	X band
12.4 – 18	Ku band
18 – 26.5	K band
26.5 – 40	Ka band

Table 4

f	**Allocations**
148.5 KHz,283.5 KHz	Radio stations, submarine communication
520 KHz -1605.5 KHz	Radio A.M.
5.9 MHz-26.1 MHz	Radio SW, Amateur Radio
87.5 MHz -108 MHz	Radio FM
174-230 MHz and 470-790 MHz	Analog T.V.
223-230 MHz and 1452-1472 MHz	Digital Audio Broadcasting
450-465 MHz	Analog Phones

890-1880 MHz	Digital GSM
1880-1900 MHz	Cordless phones
1900-1980 MHz ,2020-2025 MHz, 2110-2190 MHz	UMTS 3G cellular systems
2.4 GHz	License free band used for WLAN,WPAN ...Bluetooth,Wi-fi..etc
1.227 -1.575 GHz	GPS
12-18 GHz	Satellite Communication
2-6 GHz	Wimax

Communication entities: Data, Signals, Transmission and Channel

Data is the entity that is to be exchanged between different computers (voice, number, image..) Signals electrical or electromagnetic representation of data. Data transmission is communication of data by the transmission or propagation of electromagnetic signals through either wired/wireless media (channel)

Table 5 Analog and Digital signal

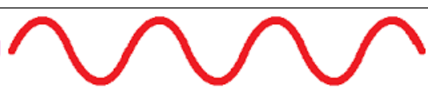
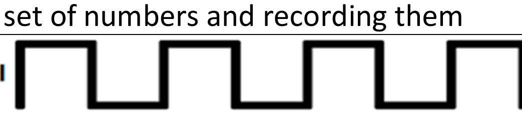
Analog signal is a continuous signal and uses continuous range of values to represent information	Digital signals are discrete time signals and uses discrete or discontinuous values to represent information via series of zeroes and ones Produced by sampling analog waveforms into a limited set of numbers and recording them
Analog 	Digital 

Table 6 Difference between Analog and Digital Signal

Property	Analog	Digital

Bandwidth	Low bandwidth (4KHz), which means low data transmission rates (up to 33.6Kbps) because of limited channel bandwidth	High bandwidth that can support high-speed data and emerging applications that involve video and multimedia
Network capacity	Low; one conversation per telephone channel	High; multiplexers enable multiple conversations to share a communications channel and hence to achieve greater transmission efficiencies
Power requirement	High because the signal contains a wide range of frequencies and amplitudes	Low because only two discrete signals—the one and the zero—need to be transmitted
Transmission	Subjected to deterioration by noise during transmission and write/read cycle.	Can be noise-immune without deterioration during transmission and write/read cycle.
Flexibility	Hardware is not flexible	Flexible hardware
Power	Analog instrument draws large power	Digital instrument draws only negligible power
Cost	Low cost and portable	Cost is high and not easily portable
Impedance	Low	High order of 100 megaohm
Errors	Analog instruments usually have a scale which gives observational errors.	Digital instruments are free from observational errors