1

Electromagnetic Spectrum and Introduction to Microwave

1.0. Introduction

We have an experience, that when we strike an object, it creates its vibration. God's creation is so strange, if the frequency of vibration is below 20 Hz, then we cannot listen the wave generated by that object *i.e.,* it will not create any sensation to our body. But if we strike that object more rapidly, it will increase the frequency of vibration and if this frequency of vibration lies in between 20—20,000 Hz, then only we can listen the creation of the sound wave. Again if the wave frequency goes beyond 20,000 Hz, it will not create any sensation to our body. The frequency range lying in between 20—20 KHz is called *audible frequency range*. Human body system can receive two types of wave one is audio wave (20—20 KHz) by ear and other is visible wave ($8 \times 10^{14} - 4 \times 10^{14}$ Hz) by eye. And the remaining frequencies are not directly sensible to us.

Energy can be transferred from one place to another through the bulk motion of the matter. There is another way by which energy can be transferred

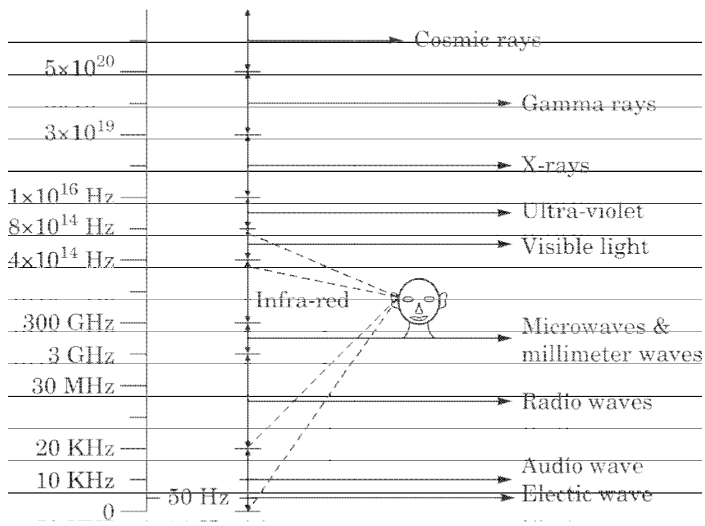

Fig. 1.1. Different waves with different frequency band.

without bulk motion of matter. This is by means of wave. Here the energy (or disturbance) moves progressively onwards in the form of alternate troughs and crests. The waves are of two types mechanical waves and electromagnetic waves.

The mechanical waves can be produced and propagate only in those material media which possesses elasticity and inertia. These wave are also known as elastic waves. Sound wave is an example of elastic wave.

But electromagnetic waves do not require any such material medium for its propagation. Electromagnetic wave is so called because it consists of electric and magnetic field.

1.1. Short History of Electromagnetic Wave

In 1864, James Clark Maxwell made theoretical prediction of electromagnetic waves from an accelerated charge. According to him, an accelerated charge sets up an magnetic field in its neighbourhood, which in turn creates an electric field in the neighbourhood, as moving magnetic field produces electric field and vice versa. These two fields are time varying, so they act as source of each other. So, an oscillating charge having non-zero acceleration, will emit electromagnetic waves and the frequency of the wave will be same as that of the oscillating charge.

After 20 years, in 1879-86, Heinrich Hertz come to conclusion by a series of experiment, that an oscillatory electric charge $q = q_0 \sin \omega t$ radiates e.m. waves and these waves carry energy. Hertz was also able to produce e.m. waves of frequency 3×10^{10} Hertz. The experimental set up is shown in Fig. 1.2. To detect e.m. wave, he also used loop S_1 slightly separated as shown in figure and it is held in position such that the electromagnetic field produced by the oscillating current is perpendicular to the plane of the dector coil.

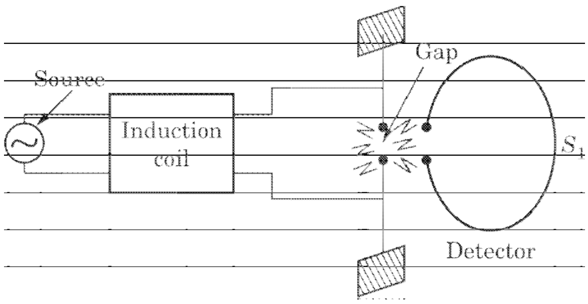

Fig. 1.2. Hertz experiment.

In 1895-97, Jagdish Bose succeeded to generate electromagnetic wave of very short wavelength (≈ 25 mm). After one year, 1896, Marcony in Italy, discovered that if one of the spark gap terminal is connected to an antenna with other terminal earthed, then in this condition the e.m. wave can go upto several kilometres. This experiment opened a new era in the field of communication.

1.2. Electromagnetic Spectrum

All electromagnetic waves travel with same velocity ($c = 3 \times 10^8$ m/sec.) in free space. But their frequencies are different. The arrangement of electromagnetic radiations according to wavelength (or frequency) is called electromagnetic spectrum. The electromagnetic spectrum has no definite upper or lower limit and various regions of e.m. spectrum do not have sharply defined boundaries. The e.m. spectrum and their applications are given in Table 1.1.

Table 1.1: Electromagnetic Spectrum and it's Applications

Name of e.m. wave	*Frequency range (Hz)*	*Wavelength range(m)*	*Source*	*Applications*
(1)	(2)	(3)	(4)	(5)
Electric waves	60 – 50	5×10^6 – 6×10^6	Weak radiation from A.C. circuits	Lighting.
Radio waves	3×10^9 – 3×10^4	1×10^{-1} – 10^4	Oscillating circuits	Radio comm., Television.
Micro waves	3×10^{14} – 3×10^8	1×10^{-3} – 2	Oscillating currents in special vacuum tubes, Gunn, IMPATT, Tunnel diodes	Radar, television satellite communication, remote sensing.
Infra-red	4×10^{14} – 1×10^{13}	7.5×10^{-7} – 3×10^{-5}	Excitation of atoms and molecules	Gives information on the structure of molecules and of external atomic electron sheel. Remote sensing.
Visible light	8×10^{14} – 4×10^{14}	3.75×10^{-7} – 7.5×10^{-7}	Excitation of atoms and vacuum spark	
Ultra violet	1×10^{16} – 8×10^{14}	3×10^{-8} – 3.75×10^{-7}	Excitation of atoms and vaccum spark	
X-rays	3×10^{19} – 1×10^{16}	1×10^{-10} – 3×10^{-8}	Bombardment of high atomic number target by electrons.	X-rays therapy, industrial radiography, Medical radiography crystallography.
Gamma rays	5×10^{20} – 3×10^{19}	6×10^{-15} – 1×10^{-10}	Emitted by radioactive sub-stances	Gives information about the structure of atomic nuclei.
Cosmic rays	$>10^{20}$	$< 10^{-11}$	Stars from other glaxies.	

Table 1.2: Radio Spectrum

Name of the band	*Frequency range*	*Wavelength range*	*Typical uses*
Very low frequency (VLF)	10 – 30 KHz	30,000 – 10,000 m	Long range distance point to point communication.
Low frequency (LF)	30 – 300 KHz	10,000 – 1,000 m	Long distance point to point to communication, marine and navigational aids.
Medium frequency (MF)	300 – 3,000 KHz	1000 – 100 m	Broad casting, marine communication, navigation, haber telephone.

Very high frequency (VHF)	30 – 300 MHz	10 – 1 cm	Radar, relay systems, television transmission, airplane navigation.
Ultra high frequency	300 – 3,000 MHz	100 – 10 cm	Short distance communication, radar, relay, TV transmission.
Super high frequency (SHF)	3,000 – 30,000 MHz	10 – 1 cm	Radar, radio relay, satellite communication.

In the communication field the radio waves and microwaves have a great importance. Here we are interested about the microwave frequency spectrum. In Table 1.2 and Table 1.3 the difference bands of radio and microwaves are given.

Table 1.3

Microwave frequency band	*Frequency range*	*Typical applications*
L	1 – 1.5 GHz	Short distance communication.
S	1.5 – 3.9 GHz	Radar, radio relay.
C	3.9 – 8 GHz	Satellite communication, remote sensing.
X	8.2 – 12.5 GHz	Satellite communication radar.
KU	12.5 – 18 GHz	Radar, relay systems.
K	18 – 26 GHz	Radar, radio relay, satellite communication.

There is also another band '*J*', whose frequency band lies between 5.58 – 8.2 GHz. For Laboratory purposes, *X* (wavelength range = 3.65 – 2.4 cm) and *J* band (wavelength range = 5.12 – 3.65 cm) are most commonly used. As in this frequency range the size of the wave guide and other associated equipments are convenient in size. Whereas in lower band this size increases.

1.3. Microwave and Its Importance

As the name implies microwaves are very short waves and in electromagnetic spectrum the microwave frequency lies in between 300 MHz—30 GHz (that means wavelength lies in centimetric region). The different bands of microwave and its typical use has been pointed out in Table 1.3.

The microwave communication is becoming more and more important in Satellite Communication, Navigation, Radar, Remote Sensing and also many other fields due to the following reasons.

1.3.1. Higher frequency and larger bandwidth. In order to meet the increasing demand in the area of communication the lower frequency bands (upto 1 GHz) have already been crowded by lots of Radio, T.V., Telephone (300 – 3.3 KHz), Telegraph (120 Hz) channels. We can not reuse these frequencies as that will create interference. So the only way is to use higher frequency. Hence keeping in view all these things we have to go microwave frequency band. As the microwave frequency band is very wide, so many channels can be accommodated in it.

1.3.2. Improved performance of antennas. To receive an electromagnetic wave the size of an antenna should be at least of the order of the wavelength of the electromagnetic wave (that has been discussed in chapter 10). Now at low frequency, as the wavelength $\lambda = c/f$) is large. So, the size of the antenna required will be large, but if we use microwave frequency, the antenna size will be short and easily mountable. At this frequency band the size of the antenna dipole is very small. So, arranging number of dipoles as an array, a high directivity antenna can be formed, that is called *phased array antenna*.

1.3.3. Fading. Short wave communication suffer a severe problem of fading due to reflection of the wave from the different layers of the ionosphere (discussed in chapter 12). Hence the signal at the receiver will not be of uniform strength. But as the microwave propagation is line of sight propagation so, there is no question of reflection from ionosphere. And the fading is less. The foggy weather does not effect the propagation of microwave frequency very much.

1.3.4. Energy requirement. As the gain of antenna is inversely proportional to the square of wavelength. So, at microwave frequency gain of an transmitting antenna becomes high. The power requirements at the transmitting and receiving station at microwave frequency is less compared to the short wave frequency.

1.3.5. Heating effect. Microwave can also generate heat energy. This is useful in biomedical engineering for the treatment of brain cancer and microwave diathermy machine produce heat inside the muscle without overheating the outside surface. Presently microwave oven is a miracle, where microwave is used to heat the food very quickly. Microwave is also used in drying machine and soldering purpose.

Microwave is best suited in remote sensing for studing the earth surface and terrian. Because microwave can penetrate into the earth surface and can give a brief detail about the nature of the earth surface after reflection from it.

Problem 1.1. *Electromagnetic wave of frequency 3×10^9 Hz are passed through a liquid. The wavelength of the waves in liquid measured to be 3×10^{-5} m. Calculate (i) the wavelength of e.m. waves in vacuum (ii) the refractive index of the liquid (iii) velocity of e.m. wave in the liquid. The velocity of e.m. waves in vacuum is 3×10^8 m/sec.*

Sol. (*i*) Wavelength of the e.m. wave in vacuum is $\lambda = V/f$.

$$= \frac{3 \times 10^8}{3 \times 10^9} = 0.1 \text{ m} = 10 \text{ cm}.$$

(*ii*) The refractive index (μ)

$$= \frac{\text{Velocity of the wave in vacuum}}{\text{Velocity of the wave in that liquid}}$$

Velocity of the wave in that liquid will be $v = f\lambda$

$$= 3 \times 10^9 \times 3 \times 10^{-2} = 9 \times 10^7 \text{ m/sec.}$$

So, $$\mu = \frac{3 \times 10^8}{9 \times 10^7} = \frac{10}{3} = 3.33.$$

(*iii*) Velocity of the e.m. wave in that liquid will be = 9×10^7 m/sec.

Q. 1. Which component of the electromagnetic wave is responsible for all observed effect in light ?

Ans. It is the electric field component.

Q. 2. A range of frequencies more easily passed by the atmosphere than others, what it is called ?

Ans. Window.

Q. 3. Which band of frequency is called millimeter wave?

Ans. 30—40 GHz frequency band.

```
/*PROGRAM FOR THE EASY COMPUTATION–THE VELOCITY OF E.M.WAVE IN FREE
SPACE IS 3*10e10 cm/sec.,CALCULATE THE WAVELENGTH OF A MICROWAVE SIGNAL,
WHOSE FREQUENCY IS 3GHz.*/
/* PROGRAM–*/
#include <stdio.h>
#include <math.h>
#define C 3*10e+10
main()
{
float fre,wav;
fre=3*10e+9;
wav=C/fre;
printf(''The wavelength of the Microwave signal is= %f cm'',wav);
}
```

/* Program Explanation-

include <stdio.h> this statement includes the standard input and output library. Each program that uses a standard input/output function must contain the statement.

The file name stdio.h is an abbrevation for standard input-output header file. The instruction #include <stdio.h> tells the compiler to search for a file named stdio.h and place its contents at this point in the program. The contant of the header file become part of the source code when it is compiled.

include <math.h> similarly this statement include the math.library function.

It is to be remember that there will be no blank space between number sign # and include.

#define C 3*e+10 this defines that the velocity of the E.M. wave is 3*e+10. When a numeric constant is used in a computation, it can be defined initially like this. It helps for clear under-standing.

The proper way of defining is-

#define symbolic-name value of constant.

Points to be remembered-

1. '#'must be the first character in the line.
2. No blank space between # and define but a blank space is required between #define and symbolic name.
3. All c statements ends with a semicolon but this define statements must not end with semicolon.
4. After defining, the symbolic name should not be assigned any other value within the program by using assignment statement.
5. There will be no '=' sign between symbolic name and the value of the constant.

The main () is a special function used by c system to tell the computer where the program starts. Every program must have one main function. The empty parantheses indicates that the function main has no arguments.

{ this bracket tells that program starts here.

Three variable are used in the program vel for velocity, fre for frequency and wav for wave length. These variables are defined as type float as they are floating variable. Similarly for integer and double the keyward is int and double.

Now from velocity, wavelength and frequency relation we know velocity =frequency * wavelength. So wavelength=vel/fre.

The printf statement prints on the screen the contanets written inside " " and it will also print the value of the wayelength.

The program ends with '}' bracket.

The output of the program will be-

The Wavelength of the Microwave signal will be = 10,000 cm.

```
/*write a progrm to tabulate Wavelength and Frequency; strating
from 1 GHz to 300 GHz with a step of 10GHz.*/
#include<stdio.h>
#include<math.h>
#define MIN 1e9
#define MAX 3e11
#define C 3e10
main ()
{
float wave, fre,vel, step ;
printf(''Wavelength(cm)Frequency(Hz)\n'');
step = 1e+10;
for (fre=MIN; fre<=MAX; fre=fre+step)
{
wave=c/fre;
printf(''%f%f/n'',wave ,fre) ;
}
}
```

/* In the above program the 'for' loop is used to get the frequency vs. Wavelength chart. Here the step size is used 20 GHz. There is an entry controlled loop that provides a more concise loop control structure. The general form of the loop is- for (initialization; test condition; increment) { } it should be remembered that there will be no semicolon at the end of the '( )' of the for loop.*/