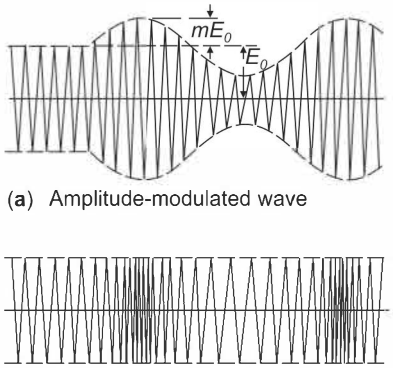

(a) Amplitude-modulated wave

(b) Same information transmitted by frequency-modulated wave

Fig. 1.3: (a) Amplitude-modulated wave (b) Frequency-modulated wave

Fig. 1.3 (a), the amplitude of RF oscillation is given by $V = V_c + mV_c \sin 2\pi f_s t$. V_c represents the amplitude of the carrier wave, f_s is the signal or message frequency and m is the *degree of modulation* or *modulation index*. Hence, the amplitude-modulated wave can be mathematically represented by

$$v = V_c(1 + m \sin 2\pi f_s t) \sin 2\pi f_c t \qquad (1.2)$$

where f_c is the carrier frequency. Eq. (1.2) may be written as

$$v = V_c \sin 2\pi f_c t + m \sin 2\pi f_s t \sin 2\pi f_c t \qquad (1.3)$$

By expanding the last term in Eq. (1.2), we get

$$v = V_c \sin 2\pi f_c t + (mV_c/2) \cos 2\pi (f_c - f_s)t - (mV_c/2) \cos 2\pi (f_c + f_s)t \qquad (1.4)$$

Thus, the amplitude-modulated (AM) wave consists of *three separate waves*. One of them is the carrier wave. Its amplitude is independent of the presence or absence of modulation. The magnitude of the other two components are the same but their frequencies differ, one of them is less than the carrier frequency by the signal or message or *modulating* frequency and the other one is more than the carrier frequency by the signal or message or *modulation* frequency. These two frequencies are called *sideband frequencies*. The lower frequency band is called *lower sideband* and the higher frequency band is called *upper sideband* frequencies. Both the sidebands carry the message or intelligence that is being transmitted. The frequency of the sideband components relative to the carrier frequency is determined by the modulation frequency. The relative amplitudes of the sideband components is determined by the amplitude of the modulation signal, or in other words, on the modulation index.

When the modulation signal is more complex than a simple sine wave, it results in the occurrence of additional sideband frequencies. Thus, if the modulation signal has a frequency band of 300 Hz to 3,500 Hz and the carrier frequency is 1000 kHz, then the modulated wave will contain two sidebands, the lower sideband will be from 996.5 kHz to 999.7 kHz, and the upper sideband will be from 1000.3 kHz to 1003.5 kHz.

The analysis of the frequency-modulated (FM) wave is more complex. However, the result is analogous to amplitude modulation. The principal difference is that the frequency-modulated wave contains not only the same sideband frequencies as that of amplitude-modulated wave but also contains higher order sidebands. For example, if the modulation signal has a frequency of 1000 Hz and the carrier frequency is 1000 kHz, then the modulated wave will not only contain two sidebands of 999 kHz and 1001 kHz but also contain 998 kHz and 1002 kHz sidebands and possibly 997 kHz to 1003 kHz sidebands. The amplitudes of the various sidebands will depend on the extent and the rate of frequency variation.

1.7 SIGNIFICANCE OF SIDEBANDS

The carrier and sideband frequencies are present in the modulated wave and can be separated from each other by suitable filters. The sideband frequencies are generated as a result of modulation. Their magnitude and field". He developed four basic equations known as Maxwell's equations and demonstrated that the electromagnetic fields travel at the speed of light.

1888: Heinrich Hertz generated 30 MHz signal and validated the Maxwell's theory. Established the relationship $f\,\lambda_0 = c$, where λ_0 is the free space wavelength and c is the velocity of light (3×10^8 m/s.).

1893: Heinrich Hertz demonstrated that parabolic reflectors concentrate the EM energy, thus improving the efficiency of transmission. Parabolic reflectors are used even today as efficient MW antennas.

1895: Guglielmo Marconi transmitted radio signals over 1 mile; thus demonstrating the first practical application of EM waves in the field of communication. The transmission distance was increased to 4 miles by using parabolic reflectors with an operating frequency of 1.2 GHz.

1897: Lord Rayleigh theoretically proved that EM waves could propagate through hollow metal tubes (waveguides).

1897: Oliver Lodge demonstrated EM wave propagation in waveguides at 1.5 and 4 GHz.

1901: Guglielmo Marconi transmitted successfully the first transatlantic wireless message from England to Newfoundland at a distance of 3,000 miles.

1919: Barkhausen and Kurz developed positive grid MW oscillators.

1921: Hull developed smooth bore Magnetron for MW signal generation.

1921 to 1930: Remarkable progress in wireless transmission was achieved. Frequencies from hundreds of kHz to hundreds of MHz were used to transmit messages over thousands of miles through space.

1937: Varian Brothers developed Klystron that continues to be an excellent source of MW power.

1938: Hansen invented cavity resonator.

1939: Randall and Boot developed cavity magnetrons to produce 400 W of power at 3 GHz.

1944: R Kompfner developed helix-type traveling wave tube.

1957: L Esaki developed tunnel diode.

1958: WT Reed developed IMPATT-type oscillators.

1963: JB Gunn developed Gunn-effect diodes.

1965: MW transistors were developed.

1966: Mead proposed **metal semiconductor FET**

1969: Middlebrook realized MESFET (metal-oxide semiconductor field effect transistor).

With the development of MW repeater stations and satellite communication, microwave technology has been recognized as a major field for commercial and military purposes.

1.18 MICROWAVE APPLICATIONS

Two of the earliest MW uses are for point-to-point communication and radars. Some of the most important uses of MW are discussed below:

(i) **Point-to-point communication:** For point-to-point communication, it is important that the transmitted signal is sharply focused and aimed at the receiving antenna. Since these abilities can easily be achieved at MW frequencies, they are ideally suited for point-to-point communication. The function of the radio and TV broadcasting is to *broadcast* the radio signals over as *broad* an area as possible. Therefore, AM, FM and TV broadcast frequencies are much lower than those in the MW range.

A series of repeater stations spaced along the line of sight (LOS) paths can provide a communication link between cities far away. The combination of MW transmitters and satellites enable to communicate between continents. The satellite receives the signal, amplifies and retransmits it to a large area. Since atmospheric noise is low in the fre-

- Microwaves are electromagnetic (EM) waves with wavelengths ranging from 30 cm to 3 mm. The microwave (MW) frequency range is from 1 GHz (10^9 Hz) to 100 GHz (10^{11} Hz).
- An antenna radiates electrical energy and also absorbs energy from the passing radio waves.

FURTHER READINGS

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REVIEW QUESTIONS

1.1 Why does an electrical transmission line not radiate considerable amount of energy?

1.2 At higher frequencies, considerable energy is radiated. Explain.

1.3 What is meant by directional characteristic?

1.4 What are the components of radio waves? What is their velocity of propagation?

1.5 Mention the important properties of a radio wave.

1.6 Write down the relationship between wave length and the frequency.

1.7 In what units the strength of a radio wave is measured.

1.8 What is a wave front?

1.9 What is meant by polarization?

1.10 Define modulation.

1.11 Mention the two common types of modulation.

1.12 Define amplitude modulation.

1.13 Define modulation index.

1.14 Define frequency modulation.

1.15 How many sidebands are present in amplitude modulation?

1.16 How many sidebands are present in frequency modulation?

1.17 Name the circuits used for detection.

1.18 What are microwaves?

1.19 Mention the MW bands with their frequency range.

1.20 Mention the different classification of frequency spectrum.

1.21 What is the important property of MW used in communication?

1.22 What is the important property of MW used in radar systems?

1.23 What is the important property of MW used in MW oven?

1.24 Mention four uses of MW in domestic and industrial applications.

DESCRIPTIVE QUESTIONS

1.1 Explain briefly the propagation of radio waves.

1.2 Describe the process of modulation.

1.3 Describe the process of detection.

1.4 Explain the nature of the modulated wave and the significance of sidebands.

1.5 Draw the electromagnetic frequency spectrum and indicate the relevant details.

1.6 Explain the classification of radio waves with their frequency range, wavelength range, characteristics and uses.

1.7 Give the classification of microwaves and their most important properties.

1.8 Explain the applications of microwaves in (i) point-to-point communication, (ii) radar systems and (iii) commercial applications.

PRACTICE PROBLEMS

1.1 Find the range of wavelength for very high frequency range 30 MHz to 300 MHz.
(**Ans:** 1 m to 10 m)

1.2 Find the range of wavelength for ultra-high frequency range 300 MHz to 3 GHz.
(**Ans:** 10 cm to 1 m)

1.3 Find the range of wavelength for super-high frequency range 3 GHz to 30 GHz.
(**Ans:** 1 cm to 10 cm)

1.4 Find the range of wavelength for extra-high frequency range 30 GHz to 300 GHz.
(**Ans:** 1 cm to 1 mm)

1.5 The carrier frequency in amplitude modulation is 1 MHz and the modulation frequency is 1 kHz. Find the sideband frequencies.
(**Ans:** 999 and 1001 kHz)

2.4.3 Z from Load End

At the receiving or load end, $z = l$ and the line impedance at the receiving end in terms of Z_s and Z_0 is given by

$$Z = Z_0 \frac{(Z_s + Z_0)e^{-\gamma l} + (Z_s - Z_0)e^{\gamma l}}{(Z_s + Z_0)e^{-\gamma l} - (Z_s + Z_0)e^{\gamma l}} \quad (2.29)$$

This equation in hyperbolic function is given by

$$Z = Z_0 \frac{Z_s \cosh \gamma l - Z_0 \sinh \gamma l}{Z_0 \cosh \gamma l - Z_s \sinh \gamma l} \quad (2.30)$$

2.4.4 Z in terms of Z_l and Z_0

Sometimes, it is necessary to express the line impedance in terms of $\boldsymbol{Z_l}$ and $\boldsymbol{Z_0}$. At the load end, $z = l$. Hence, the voltage at the load end is $\boldsymbol{V_l} = \boldsymbol{I_l Z_l}$. Then,

$$I_l Z_l = V_s e^{-\gamma l} + V_r e^{\gamma l} \quad (2.31a)$$

$$I_l Z_0 = V_s e^{-\gamma l} - V_r e^{\gamma l} \quad (2.31b)$$

From these equations we get

$$V_s = \left(\frac{I_l}{2}\right)(Z_l + Z_0)e^{\gamma l} \quad (2.32a)$$

$$V_r = \left(\frac{I_l}{2}\right)(Z_l - Z_0)e^{-\gamma l} \quad (2.32b)$$

Substituting Eqs (2.32a) and (2.32b) in Eqs (2.22a) and (2.22b) and letting $z = l - d$, we get

$$V = \left(\frac{I_l}{2}\right)\left[(Z_l + Z_0)e^{\gamma d} + (Z_l - Z_0)e^{-\gamma d}\right] \quad (2.33a)$$

$$I = \left(\frac{I_l}{2Z_0}\right)\left[(Z_l + Z_o)e^{\gamma d} - (Z_l - Z_0)e^{-\gamma d}\right] \quad (2.33b)$$

At any point from the receiving or load end, the impedance $\boldsymbol{Z}$ in terms of $\boldsymbol{Z_l}$ and $\boldsymbol{Z_0}$ is given by

$$Z = Z_0 \frac{(Z_l + Z_0)e^{\gamma d} + (Z_l - Z_0)e^{-\gamma d}}{(Z_l + Z_0)e^{\gamma d} - (Z_l - Z_0)e^{-\gamma d}} \quad (2.34)$$

Using the relation $e^{\pm\gamma d} = \cosh(\gamma d) \pm \sinh(\gamma d)$, the Eq. (2.34) can be expressed as

$$Z = Z_0 \frac{Z_l \cosh \gamma d + Z_0 \sinh \gamma d}{Z_0 \cosh \gamma d + Z_l \sinh \gamma d} \quad (2.35)$$

From Eq. (2.35), the line impedance at the sending or generator end can be found by substituting $d = l$. Thus

$$Z_s = Z_0 \frac{(Z_l + Z_0)e^{\gamma l} + (Z_l + Z_0)e^{-\gamma l}}{(Z_l + Z_0)e^{\gamma l} - (Z_l + Z_0)e^{-\gamma l}} \quad (2.36)$$

Equation (2.36) in hyperbolic functions is given by

$$Z = Z_0 \frac{Z_l \cosh \gamma l + Z_0 \sinh \gamma l}{Z_o \cosh \gamma l + Z_l \sinh \gamma l} \quad (2.37)$$

Example 2.2: An air-insulated coaxial cable of length 15 cm, $\boldsymbol{Z_0}$ = 75 ohms and α = 0.4 dB/m is terminated with a short circuit. Compute the input impedance at 1.5 GHz and 2 GHz.

Solution: Given: l = 15 cm, $\boldsymbol{Z_0}$ = 75 ohms. α = 0.4 dB/m and f = 1.5 and 2 GHz.

For an air-insulated coaxial cable $\lambda = \lambda_o$.

(a) At 1.5 GHz:

$$\lambda_o = 300 \times \frac{10^8}{1.5 \times 10^9} = 20 \text{ cm}$$

$$\beta l = \left(\frac{2\pi}{\lambda}\right) l = \left(\frac{2\pi}{20}\right) \times 15 = \frac{3\pi}{2} \text{ rad}$$

$$\alpha l = 0.4 \times 15 = 0.06 \text{ dB or } \frac{0.06}{0.8686}$$

$$= 0.007 \text{ Np/m}$$

Since $\boldsymbol{Z_l} = 0$, Eq.(2.37) reduces to

$$Z_{in} = Z_0 \left(\frac{Z_0 \sinh \gamma l}{Z_0 \cosh \gamma l}\right)$$

$$= Z_0 \tanh \gamma l$$

$$= Z_0 \tanh(\alpha l + j\beta l)$$

Since $\tanh(\alpha l + j\beta l) = \frac{(\tanh \alpha l + j \tan \beta l)}{(1 + j \tanh \alpha l \tan \beta l)}$, we get

$$Z_{in} = Z_0 \frac{(\tanh \alpha l + j \tan \beta l)}{(1 + j \tanh \alpha l \tan \beta l)}$$

Since αl is small, $\tanh \alpha l = \alpha l$. Therefore,

$$Z_{in} = \frac{75\left[(0.007) + j \tan(3\pi/2)\right]}{\left[1 + j\, 00.7 \tan(3\pi/2)\right]}$$