COMMUNICATION SYSTEMS

A LECTURE NOTES BY

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1 Introduction

The process of transmitting and receiving meaningful information or intelligence is termed as communication. Electronic communication involves converting speech or intelligence into electrical signals using transducers. The signals are processed and transmitted. Receiver located kilometers away from the transmitter receives these signals. The receiver processes the received signals and finally drives the transducer which converts the processed signals into speech or intelligence. Transducers are the devices which convert energy from mechanical to electrical and vice-versa. Radio commnication (Transmission and reception) is one of the effective communication system.

2 Modulation and Demodulation

The transmission of information and reception of meaningful information can be successfully achieved with the help of two processes. The two processes are

1. Modulation
2. Demodulation

Modulation : Modulation is the process of combining the low-frequency audio waves with a very-high frequency radio waves. The low-frequency wave is called Modulating Wave. The very-high frequency radio wave which carries the low frequency audio wave information is called a Carrier Wave. The resultant wave obtained is called Modulated Carrier.

Demodulation : Demodulation involves recovering the low-frequency audio wave from the Modulated Carrier Wave. This process is performed at the receiving end. It is the reverse process of modulation.

Carrier Wave : Carrier wave is a high frequency radio wave produced using radio-frequency oscillators. The radio frequency ranges from 3kHz to 300GHz. In radio transmission, Carrier waves in the radio frequency range from hundreds of kHz to few MHz are preferred.

3 Need for Modulation

Audio frequency signals are low-frequency signals.There are disadvantages in transmitting the unmodulated low frequency signals during communication. They are

1. Low frequency signals cannot propagate over long distances. They are short range signals
2. If there are many transmissions of low frequency signals directly without modulation they interfere and the information at the receiving end will not be clear.
3. The antenna length required for the transmission of audio-frequency signals is around 75 m which is practically very large.

Thus a low frequency signal cannot be transmitted effectively and efficiently without modulation. Hence radio frequency carrier waves are modulated by low frequency signals and are transmitted to reach longer distances. Even the antenna size required for the transmission of the radio frequency waves is of reasonable size.

4 Types of Modulation

The High frequency radio carrier waves are the sinusoidal waves and are represented by the equation

$$e_c = E_c Sin(\omega_c t + \phi) \tag{1}$$

$$e_c = E_c Sin(2\pi f_c t + \phi) \tag{2}$$

here E_c is the amplitude of the carrier wave, f_c is the frequency of the carrier wave and ϕ is the phase of the carrier wave.

Based on the change in characteristic property of the carrier wave when combined with the low frequency audio signals, the modulation is classified into three types.

Amplitude Modulation : In amplitude modulation the amplitude of the radio-frequency (RF) carrier wave is varied by low frequency audio signals(AF) without affecting the frequency and phase of the carrier wave.

Frequency Modulation : If the frequency of the radio frequency carrier wave is varied by low frequency audio signals then the modulation is called Frequency Modulation. In frequency modulation the amplitude and phase of the carrier wave remain unchanged.

Phase Modulation : During the phase modulation the information signal modifies the phase of the carrier without affecting the other two parameters.

The amplitude modulation and frequency modulation are graphically shown in figure 1.

5 Amplitude Modulation

The information is converted into audio frequency (AF) signal is called modulating signal. The amplitude of the RF carrier wave is varied proportionately with the instantaneous amplitude of the AF signal to obtain the modulated carrier wave. The fluctuations in the amplitude of the carrier wave depends on the amplitude of the AF signal. It is obvious that the frequency and the phase of the carrier waves remain unchanged. For the sake of understating and simplicity the modulating AF signal is chosen to be a sinusoidal wave. The Modulating wave, the Carrier wave and the Modulated waves are graphically shown in the figure 1.

Thus it could be summarized as below

- The amplitude fluctuations in the modulated carrier depends on the instantaneous amplitude of the modulating signal.
- The frequency with which these fluctuations occur depends on the frequency of the AF signal.

5.1 Modulation Index (MI) and Percent Modulation (m)

The extent to which the AF wave modulates the RF carrier is expressed in terms of MI. The degree to which the AF wave modulates carrier is called Modulation Index (MI). It is defined as the ratio of amplitude of the AF wave to the amplitude of the RF wave. The percentage modulation (m) is MI expressed in percentage.

$$MI = \frac{E_m}{E_c} \tag{3}$$

$$m = MI \times 100\% \tag{4}$$

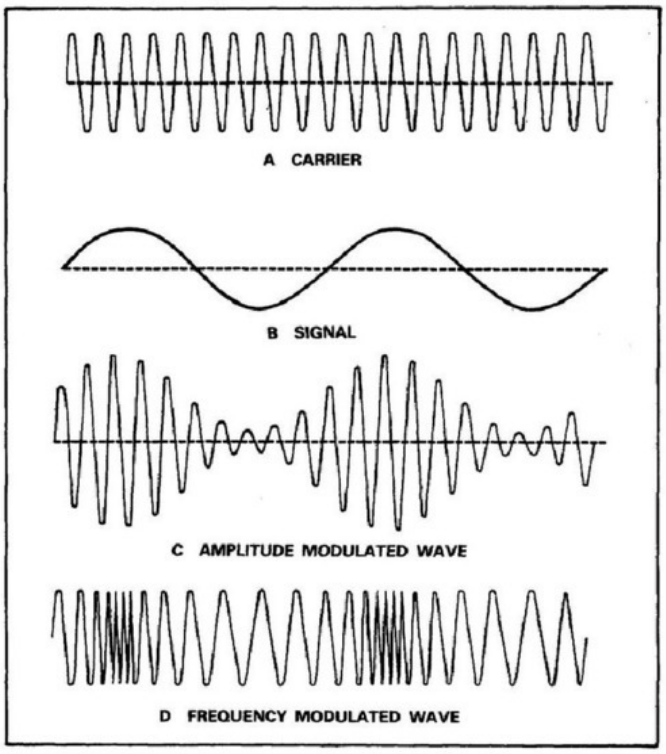

Figure 1: Amplitude and Frequency Modulation

Modulation Index (MI) could be expressed in terms of the maximum and minimum amplitudes of the modulated RF carrier wave. If E_{cmax} and E_{cmin} are the maximum and minimum amplitudes of the modulated carrier wave then the MI is given by

$$MI = \frac{E_{cmax} - E_{cmin}}{E_{cmax} + E_{cmin}} \tag{5}$$

5.2 Mathematical Analysis of Amplitude Modulation

The information in the form of AF signal is assumed to be sinusoidal and of single frequency, for the sake of study and simplicity. It is represented by the equation

$$e_m = E_m Sin(\omega_m t) \tag{6}$$

$$e_m = E_m Sin(2\pi f_m t) \tag{7}$$

here E_m is the amplitude of the AF wave and f_m is frequency of the AF wave. From equation 1 the equation for the RF carrier is given by

$$e_c = E_c Sin(\omega_c t) \tag{8}$$

here E_c is the amplitude of the carrier wave and f_c is the frequency of the carrier wave As per the definition of the amplitude modulation the amplitude of the RF carrier wave is changed as per the instantaneous amplitude of the modulating AF wave. Hence the amplitude of the modulated carrier wave is given by

$$e_{mc} = E_c + E_m Sin(\omega_m t) \tag{9}$$

Thus the equation for the Amplitude Modulated Carrier Wave could be written as

$$e = (E_c + E_m Sin(\omega_m t)) Sin(\omega_c t) \tag{10}$$

$$e = (E_c Sin(\omega_c t) + E_m Sin(\omega_c t) Sin(\omega_m t)) \tag{11}$$

From Trigonometry, We know that $SinA.SinB = \frac{1}{2}[Cos(A - B) + Cos(A + B)]$

Hence equation 11 becomes

$$e = E_c Sin(\omega_c t) + \frac{E_m}{2}[Cos(\omega_c - \omega_m)t - Cos(\omega_c + \omega_m)t] \tag{12}$$

$$e = E_c Sin 2\pi f_c t + \frac{E_m}{2}[Cos 2\pi(f_c - f_m)t - Cos 2\pi(f_c + f_m)t] \tag{13}$$

$$e = E_c Sin(\omega_c t) + \frac{E_m}{2} Cos 2\pi(f_c - f_m)t - \frac{E_m}{2} Cos 2\pi(f_c + f_m)t \tag{14}$$

5.3 Frequency Spectrum - Single frequency AF wave Modulating the RF carrier

The resulting equation 14 represents the amplitude modulated carrier wave obtained after modulation of carrier wave in the equation 1 which is modulated by a single frequency AF signal. The amplitude modulated RF carrier wave consists of three frequency components. They are given by

Carrier Frequency Component : Indicated by the first term of equation (14) which is of frequency f_c and amplitude equal to E_c.

Lower Side Frequency : Indicated by the Second term of the equation (14) which is of frequency $f_c - f_m$ having amplitude $\frac{E_m}{2}$.

Upper Side Frequency : Indicated by the Second term of the equation (14) which is of frequency $f_c + f_m$ having amplitude $\frac{E_m}{2}$

The frequency spectrum is as shown in the figure 2.

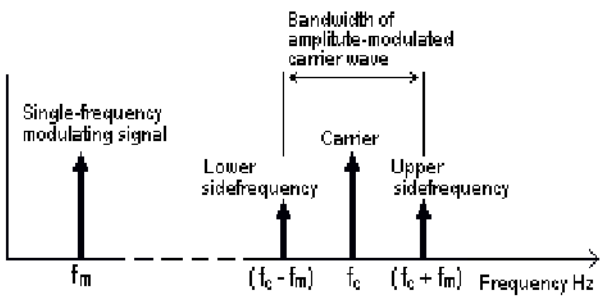

Figure 2: Frequency Spectrum

5.4 Frequency Spectrum - Upper and Lower Side Bands

If the RF carrier described by the equation 1 is modulated by a modulating AF signal having the range of frequencies from f_{mmin} to f_{mmax}, then the frequency spectrum of the amplitude modulated carrier consists of the following components.

Carrier Frequency Component : Indicated by the first term of equation (14) which is of frequency f_c and amplitude equal to E_c.

Lower Side Band : Consisting of frequencies in the range $f_c - f_{mmin}$ to $f_c - f_{mmax}$ having amplitude $\frac{E_m}{2}$.

Upper Side Band : Consisting of frequencies in the range $f_c + f_{mmin}$ to $f_c + f_{mmax}$ having amplitude $\frac{E_m}{2}$.

The frequency Spectrum of modulated carrier wave is as shown in the figure 3.

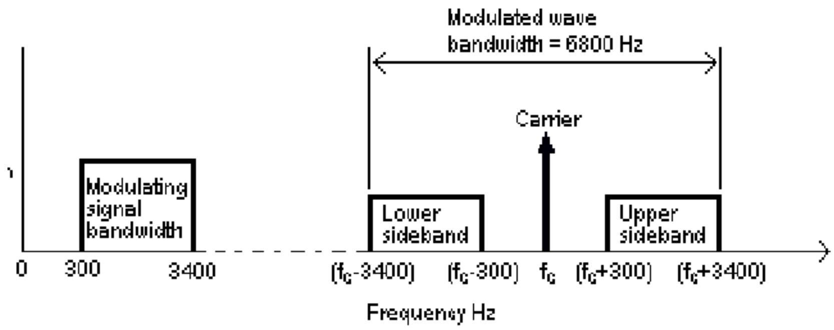

Figure 3: Frequency Band Spectrum

5.5 Power Relations in Amplitude Modulation

The power of a wave radiated out through an antenna is proportional to the amplitude of the wave. The three components of the modulated RF carrier wave in the equation 14 have the amplitudes as shown below

1. Amplitude of the original carrier E_c
2. Amplitude of the Lower side band $\frac{E_m}{2}$ or $\frac{mE_c}{2}$
3. Amplitude of the Upper side band $\frac{E_m}{2}$ or $\frac{mE_c}{2}$

The total transmitted power is given by

$$P_T = P_C + P_{SB} \tag{15}$$

$$P_T = P_C + P_{LSB} + P_{USB} \tag{16}$$

Here

$$P_{SB} = P_{LSB} + P_{USB} \tag{17}$$

The Carrier Power is given by

$$P_C \propto {E_c}^2 = K{E_c}^2 \tag{18}$$

Similarly the power of the sidebands are given by

$$P_{LSB} = K\frac{{E_m}^2}{4} \tag{19}$$

and

$$P_{USB} = K\frac{{E_m}^2}{4} \tag{20}$$

Hence the total power associated with the side bands is given by

$$P_{SB} = 2 \times K\frac{{E_m}^2}{4} = K\frac{{E_m}^2}{2} = K\frac{[mE_c]^2}{2} = \frac{m^2}{2}P_C \tag{21}$$

Hence

$$P_T = P_C + P_{SB} = K{E_c}^2 + K\frac{[mE_c]^2}{2} = P_C[1 + \frac{m^2}{2}] \tag{22}$$

Power of carrier and sidebands in terms of total power are give by the equations

$$P_C = [\frac{2}{2+m^2}]P_T \tag{23}$$

and

$$P_{SB} = \frac{m^2}{2}P_C \tag{24}$$

$$P_{SB} = \frac{m^2}{2}[\frac{2}{2+m^2}]P_T \tag{25}$$

$$P_{SB} = [\frac{m^2}{2+m^2}]P_T \tag{26}$$

Thus the power expressions for the side bands in terms of the total power is given by

$$P_{LSB} = P_{LSB} = \frac{1}{2}[\frac{m^2}{2+m^2}]P_T \tag{27}$$

6 Frequency Modulation

Process of Frequency Modulation : Unlike amplitude modulation, in frequency modulation the frequency of the carrier wave is varied in accordance with the input AF signal. The frequency modulation is as shown in the figure 1. The process of frequency modulation could be summarized as

1. The amount of change in frequency is determined by the amplitude of modulating AF signal.
2. The rate at which the deviation or change in frequency occurs depends on the frequency of the modulating AF signal.

Thus the information is carried as variation in the frequency of the carrier.

With reference to the figure 1 it can be observed that frequency of the modulated carrier increases as signal amplitude increases and the frequency of the modulated carrier decreases as the AF signal amplitude decreases. The frequency of the modulated carrier is highest when the amplitude of the modulating AF signal is positive maximum and the frequency of the modulated carrier is lowest when the amplitude of the AF signal is negative maximum. Thus the maximum and minimum frequency variation occurs in accordance with the modulating AF signal and hence the rate of this change is determined by the frequency of the modulating AF signal.

Frequency Deviation,Carrier Swing & Modulation Index : The frequency of the unmodulated carrier used in frequency modulation is called Resting frequency or Center frequency and is denoted by f_0. When the AF signal is combined with the RF carrier wave, the frequency of the carrier changes between maximum and minimum from its resting frequency. The shift in the frequency in the higher or lower side is called frequency deviation and is denoted by Δf. The carrier swing is defined in-terms of frequency deviation as below

$$CarrierSwing = 2 \times \Delta f \tag{28}$$

The modulation index in case of frequency modulation is defined as the ratio of frequency deviation to modulating frequency.

$$m_f = \frac{\Delta f}{f_m} \tag{29}$$

7 Radio Communication Systems

A typical radio communication system from a broadcasting station consists of a transmitter. The broadcasting station is allocated with a unique RF carrier wave along with a well defined channel width. The transmitter transmits the modulated carrier into space through an antenna. These wave propagate through space. Else where in a remote location there exists a receiver which receives the modulated carrier through the receiving antenna with the help of a tuning circuit. The receiver demodulates the modulated carrier and converts it into speech or intelligence. A block diagram of a typical radio system consisting a transmitter and receiver is as shown in the figure 4.

Transmission : The radio transmitter consists of a transducer which converts speech or intelligence into audio frequency electrical signals. These amplified AF signals modulate the radio frequency carrier. The modulator performs the task of modulation. The modulated RF carrier is then amplified and transmitted through an antenna.

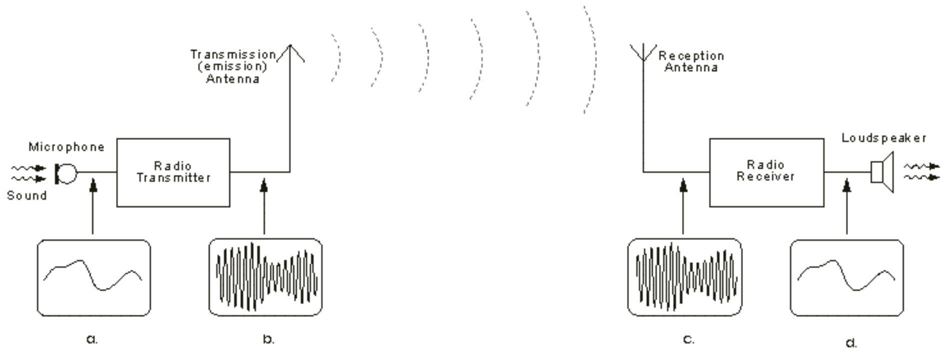

Figure 4: Radio Communication System - Transmission and Reception

Reception :

The radio receiver consists of an antenna connected to a tuning circuit. The received modulated RF carrier is amplified and then passed through the demodulator to extract the AF signals. The AF signal is then amplified and fed to transducer which converts it into speech or intelligence.

8 Hetrodyning

Necessity of heterodyning : Superheterodyne AM receiver works on the principle of heterodyning action. The necessity of heterodyning action is due to the following reasons.

1. It is difficult to design a RF amplifier with high gain and high band width.
2. It is relatively easier to design a high gain IF amplifier having uniform gain over a narrow band of comparatively lower intermediate frequencies (IF).
3. Hence it is necessary to convert the Radio frequencies to Intermediate Frequencies for efficient processing.

Heterodyning Action : Heterodyning action is a process of combining two ac signals of different frequencies in-order to obtain signals of new frequencies. A circuit called mixer or converter is used for heterodyning two signals. If f_1 and f_2 are the two frequencies combined, then heterodyning results in two components

1. The sum component with frequency $f_1 + f_2$ which is filtered out using a bandpass filter.
2. The difference component with frequency $f_1 \sim f_2$ is retained and processed.

In case of superheterodyne receiver the RF carrier f_c is heterodyned with a higher RF local signal f_s (From Local Oscillator or BFO) so that the output difference component ($f_s - f_c$) is always of frequency 455kHz.

9 Superheterodyne AM Receiver :

The block diagram of the superheterodyne receiver is as shown in the figure 5.

RF Tuning and Amplification : The modulated RF waves travel through space and reach the antenna of the superheterodyne receiver in situated in a remote location. The receiver is attached to a tuning amplifier circuit which receives and amplifies the modulated RF carrier.

Heterodyning using Mixer : The output of the tuning circuit is fed to the mixer which combines modulated RF with a high frequency RF signals generated by a local oscillator (BFO - Beat Frequency Oscillator) to produce modulated IF signals. To maintain the constant frequency of IF signals output by the mixer at 455kHz, principle of ganged tuning is used. The ganged tuning is a process in which the tuning circuit and the local oscillator are connected to ganged capacitor circuit. The change in the capacitance of the ganged capacitor will keep the tuned frequency and the local oscillator frequency such that the output of the mixer is of frequency 455kHz.

IF amplification : The output of the mixer is fed to the IF amplifier which amplifies the modulated IF signal and increases its amplitude without modifying its waveform.

Demodulation : The amplified IF signal from the IF amplifier is input to the demodulator (Detector). The demodulator consists of a diode circuit which will eliminate the negative portion of the signal. Thus only positive portion of the modulated IF signal is output and fed to the next stage of AF amplification. Thus the demodulator converts the modulated IF into AF signal.

AF amplification : The output of the demodulator is fed to AF amplification stage. In this stage the AF signal is amplified.

Transduction : The amplified AF signal is input to the transducer which is a speaker. Speaker converts the AF signal into speech or intelligence. The process of conversion is called transduction.

Waveforms : The output waveform at the each stage of the superheterodyne receiver is as shown in the figure 6. Thus the reception of modulated RF carrier by superheterodyne receiver and converting the same into speech or intelligence is explained.

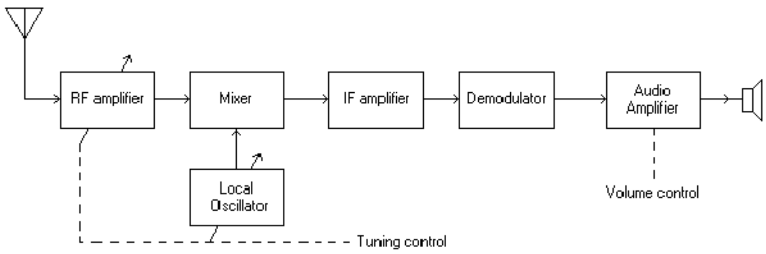

Figure 5: Super-Heterodyne Receiver

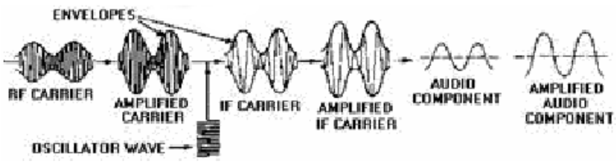

Figure 6: Super-Heterodyne Receiver Waveforms