Chapter 7

Biotelemetry

7.1 INTRODUCTION

It is the measurement of biological parameters over a distance. The mode of transmitting the data from the source to the point of use can take many forms. Simplest example of biotelemetry is the stethoscope. It consists of acoustic amplifier and hollow tube as transmission medium from the human body to the ear of the physician. Einthoven, who invented ECG recording, was the first person transmitted the ECG signal from a hospital to far away laboratory through telephone wires. He used the telephone wires as a conductor to transmit the ECG data from source to destination. In the modern communication system, there is no wire between the source and destination. However, the uses of telephone lines are not completely eliminated. In this chapter, how biological variables are transmitted through radio transmission (electromagnetic radiation) will be studied. This radio transmission of biological variable is called radio telemetry. Radio telemetry involves modulation of biological variables over a carrier wave. This chapter introduces the elements of the subject and to know about the example of its application. NASA used the telemetry in 1963 to record the following parameters through telemetry:

(i) Body temperature using rectal or oral thermistor
(ii) Respiration using impedance pneumograph
(iii) ECG using surface electrodes
(iv) Blood pressure using indirect method by employing microphone and cuff.

There are situations in which it is necessary to monitor physiological parameters from a distance. Some of the applications of biotelemetry are:

(i) Astronauts' physiological parameters have to be monitored through RF transmission
(ii) For exercise ECG, wireless remote data logging is simple and safe
(iii) Remote monitoring of a patient when the patient is on move in an ambulance
(iv) Collection of patients' parameters from the person at home or office
(v) Remote collection of animals' parameters from unrestrained and anaesthetized animals for research
(vi) Remote sensing of pH and pressure in the gastrointestinal tract and video endoscopy.
(vii) To protect patient from power line when susceptible to electric power
(viii) To study after treatment effects, the biotelemetry is essential one.
(ix) Remote programming of implanted pacemakers.

7.2 PHYSIOLOGICAL PARAMETERS ADAPTABLE TO BIOTELEMETRY

Physiological parameters adaptable to biotelemetry can be broadly classified in two ways:

(i) Bioelectrical parameters like ECG, EEG, and EMG
(ii) Physiological variables like blood pressure, gastrointestinal pressure, blood flow and temperatures

The first category signals are in the electrical form, but the second category signals have to be sensed and converted into electrical signal using resistive, capacitive and inductive transducers. The signals obtained from these transducers can be calibrated to represent the temperature, pressure and flow rate. The signal obtained from the transducer or electrode is amplified and converted into a form of code that can be transmitted. The transmitted signal received at the receiving end will be decoded to get back the original form. The coding, transmission and decoding processes may involve amplification also. If the data will be useful for future use then it can be stored. Let us discuss these aspects after discussing the applications for these systems.

7.2.1 Applications of Telemetry

Nowadays, biotelemetry is widely used for transmission of ECG signals. The instrumentation required to transmit ECG signal will be simple because ECG is in the electrical form. The ECG can be transmitted to the hospital from the emergency site or from the ambulance. The cardiologists at the receiving end can instruct the trained accompanying person for first aid and arrangements can be made for necessary treatment on arrival of the patient. The wireless voice communication link established between hospital and ambulance can be used to send the ECG signals. The use of telemetry for ECG is not only limited to emergency applications but also can be extended to exercise ECG. During recording of exercise ECG, the use of telemetry removes the connecting wire between the body and instruments. Hence the patients can walk and can do exercise freely without any hindrance due to connecting wires. Another application of ECG telemetry is 24 hours online monitoring of ECG for critical patients. In this arrangement, the patient's ECG can be monitored from the hospital when he is at work or at home. In sports, online monitoring of ECG of athletes will be useful to improve their performance. The ECG telemetry transmitter can be attached to the patient without obstructing his usual routine works. The ECG telemetry transmitter consists of electrodes and a cell phone like transmitter. The ECG electrodes will be affixed at appropriate place using adhesive tapes. The cell phone like transmitter can be placed either at pocket or at the waist belt. The battery powered transmitter can withstand 30 hours without recharging. The dressing sense should allow the wires running between the electrodes and transmitter. Telemetry of ECG can be used for animal research also. In that case two modifications are required. One is the needle electrode has to be used instead of plate electrodes and the other is subcutaneous miniature transmitters has to be implanted in the animal body by surgery.

One of the applications of telemetry of EEG is monitoring the mentally affected child. The EEG electrodes, a specially designed helmet, are placed at the inner side of the helmet. The behaviour and EEG of the child can be viewed remotely using EEG telemetry and video signals of child's activity.

Disease with intermittent symptoms may not be identified by physician at the time of medical examination since the symptoms may not occur at the time of medical examination. So, they have to be recorded and monitored whenever they happens in a body. The telemetry can be used for intermittent symptoms to monitor the patient during other timings than during the medical examination. Local data storage in the transmitter will be included for large and long duration data. The data storage becomes very cheap nowadays, and it enables the instrumentation system to store the long duration data and can be retrieved later for analysis. The long duration data can be replayed at faster rate to find any abnormalities. Once the abnormality is found, then that portion of data alone can be taken for analysis and the remaining data can be deleted.

The vital data for analysis of muscle damage,. partial paralysis and performance of a man are electromyogram (EMG). EMG can also be sent by telemetry for the above said purpose. Telemetry can also be used to send data from hospital to the patient to stimulate a particular nerve. Dropfoot is a common disability when a patient is suffered from stroke. The particular nerve of the patient can be stimulated to contract and relax according to a stimulus signal from the implanted stimulator. Appropriate signal may be sent to the implanted stimulator through telemetry system.

The telemetry system consists of three parts. The electrode or sensor to generate physiological variable acts as the first part. This part is identical to the transducers studied in Chapter 2. The second part is a transmitter to transmit the signal obtained in the first part. The same amplitude received from first part may be used in the second part for many physiological parameters. However, the amplitude of the signal to be transmitted has to be selected suitably. Third part is receiver and decoder.

Physiological parameters like blood pressure and heart rate of un-anaesthetized animals can be studied using telemetry system. A transmitter and sensor will be implanted in the body of the animal by surgery. This will reveal the physiological parameters of the animal when they are un-anaesthetized.

Blood flow and body temperature can also be transmitted through telemetry. For temperature measurement, thermistor will be employed as a sensor. Apart from body temperature, telemetry transmission of temperature of other parts of the body is also useful in the area of gynecology.

Nowadays the size of the transmitter can be miniaturized to the size of a capsule. Hence a radio transmitting sensor pill called radio pills can be swallowed to monitor stomach pressure videograph and pH value at the stomach or the digestive system.

7.3 ELEMENTS OF BIOTELEMETRY SYSTEM

The block diagram of a telemetry transmitter and receiver system is shown in Figure 7.1(a) and Figure 7.1(b). The transmitter system consists of physiological subject, physiological signal transducer, amplifier, processor, modulator and antenna. Physiological signal will be obtained either from the electrodes or from the transducer from the physiological subject. The amplifier amplifies the transducer signal. It is not possible to transmit this signal directly through telemetry system since the signal obtained from the body is at low frequency or dc signal. Hence it has to be modulated using a high frequency carrier signal. Modulation means superimposing the original signal on a high frequency carrier signal. The modulated signal then will be transmitted through an antenna as electromagnetic waves.

The receiver shown in Figure 7.1 (b) consists of a receiving antenna, demodulator with tuner and display unit and plotter. The data received at the receiving end may be stored in a data storage unit either before demodulation or after demodulation. Most of the biotelemetry systems use radio transmission. Hence it is important to understand the concepts behind the telemetry systems. A radio transmission spreads the radio frequency signal over the air space in the form of electromagnetic signal. Radio frequency signal is high-frequency sinusoidal frequency signal (above 20 kHz). The high frequency signals can be sent through thousands of kilometres with comparatively less power. To spread the electromagnetic radio frequency signals over the space an antenna is required. The height of the antenna is inversely proportional to the radio frequency and directly proportional to the distance. The distance between the transmitter and receiver is called range. The process of superimposing the physiological signal on a carrier high frequency signal is called modulation. There are various methods available to modulate the signal to be transmitted.

The electronic circuits which generate the carrier signal and modulate the given signal on a carrier is called transmitter. The electronic circuit which gets back the original signal is called demodulator.

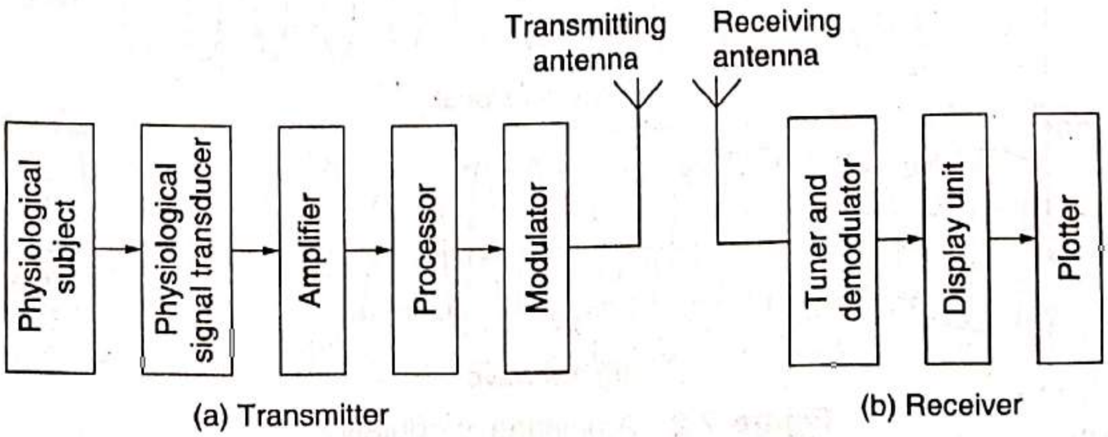


Figure 7.1 Telemetry transmitter and receiver.

The demodulator has to be tuned to select the particular frequency and has to reject the other carrier frequencies received by the antenna. This can be achieved by a tuner circuit which is the part of the demodulating circuit. The range of the telemetry system depends upon the carrier frequency, the distance between the receiving and transmitting antennas, and sensitivity of the receiver.

The transmission of radio frequency energy for long distance requires legal permission since it may create interference with other radio systems. However, the systems with very low power that can transmit inside a building do not generate interference with other systems. Some frequency band is allotted for this type of applications. Systems that transmit over longer distance requires license. The licensing procedure varies from country to country.

There are two basic types of modulation: amplitude modulation (AM) and frequency modulation (FM). Let us discuss two basic methods in detail.

7.3.1 Amplitude Modulation (AM)

When the amplitude of high frequency carrier signal is modified in accordance with the intensity of the signal, the process is called amplitude modulation. In the amplitude modulation, only the amplitude of the carrier signal is modified. The frequency and phase angle of the carrier signal is kept constant. Figure 7.2 shows the physiological signal (modulating signal), carrier signal and modulated signal. Figure 7.2(a) shows the physiological signal to be transmitted. Figure 7.2(b) shows a carrier signal of constant amplitude with frequency f_c. Figure 7.2(c) is the amplitude modulated signal. Note that the amplitude of both positive and negative half cycles of carrier signal is modified according to the physiological signal. Thus, the amplitude of the modulated signal possesses the frequency of the physiological signal.

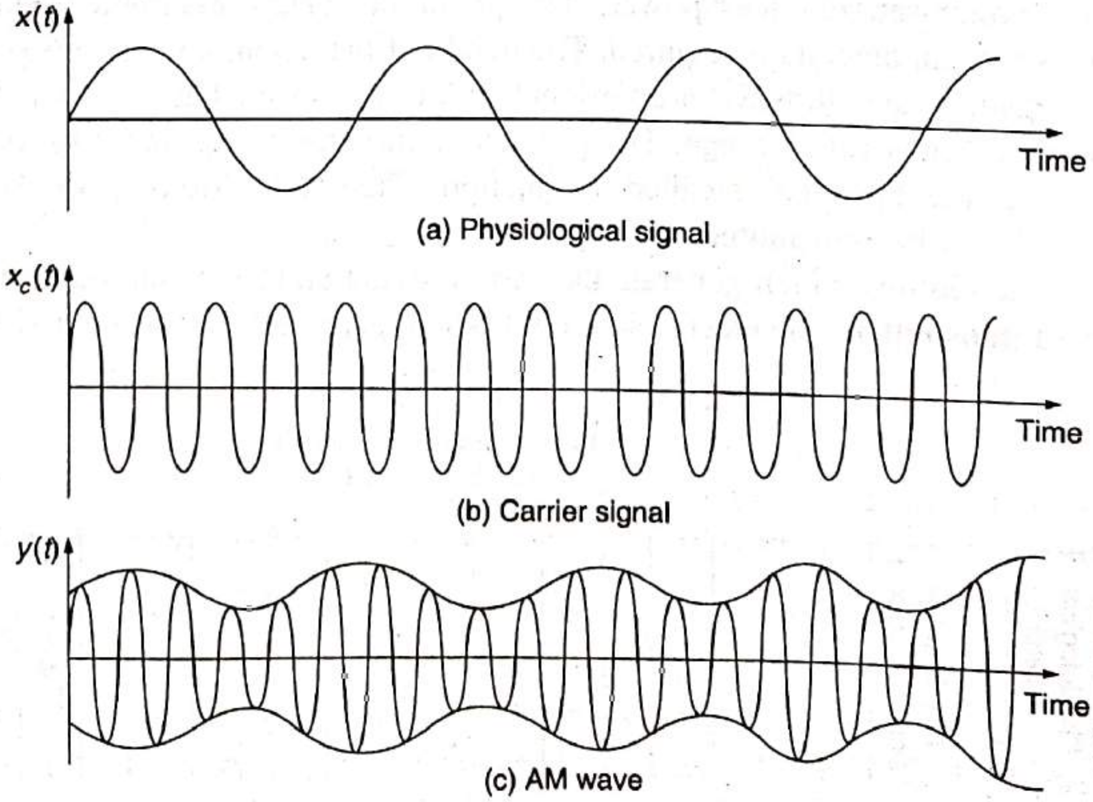


Figure 7.2 Amplitude modulation.

The advantages of amplitude modulation are:

(i) Easy transmission and reception
(ii) Lesser bandwidth requirements
(iii) Low cost

The limitations of the amplitude modulation are as follows:

Noisy reception: In an amplitude modulated signal, the amplitude of the carrier signal is varied according to the physiological signal. The physiological signal appears in the amplitude variations of the carrier signal. In practice, all the natural electronic noises and man made noises may be added to the carrier signal as electrical amplitude disturbances. The receiver circuit can not distinguish between physiological variable's amplitude variation and noise amplitude variations. Hence the amplitude modulation is susceptible to noise.

Low efficiency: The frequency spectrum of the amplitude modulated signal has sidebands. The useful power is available in the sidebands as low power. Hence the efficiency of the amplitude modulated signal is very low.

Small operating range: The amplitude modulation has low efficiency hence it can be operated for small range only. It cannot be transmitted for long distance.

7.3.2 Amplitude Modulated (AM) Transmitter

Block diagram of amplitude modulated radio transmitter is shown in Figure 7.3. It consists of two sections. One is physiological signal frequency (PSF) section and the other is radio frequency (RF) section.

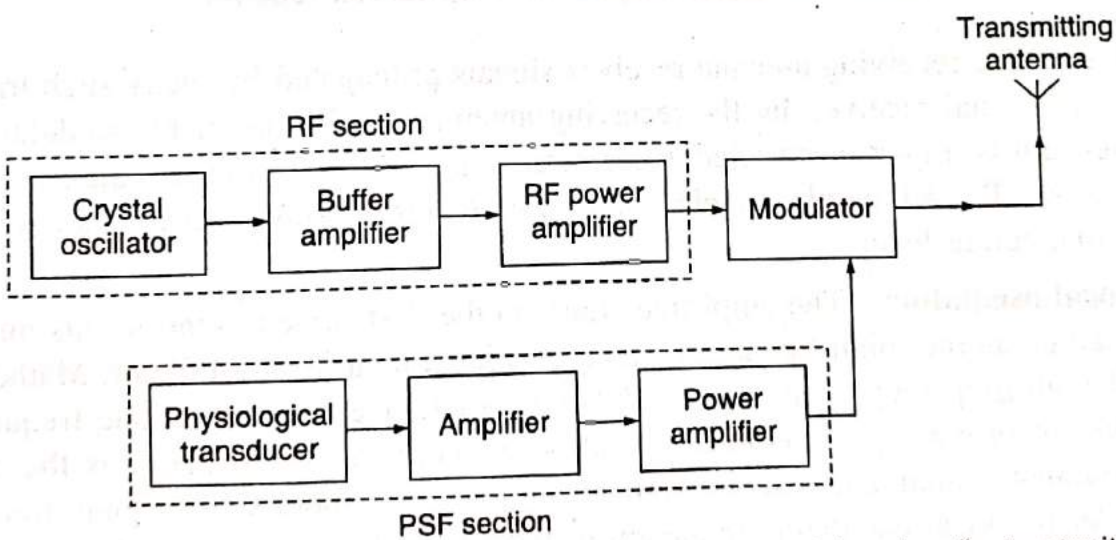


Figure 7.3 Functional block diagram of amplitude modulated radio transmitter.

PSF Section: The PSF section of the transmitter generates the modulating wave (physiological signal). The conversion of physiological signal into electrical signal is performed by either electrodes or transducers. The electrical signal available from the transducer or electrode is very low, and hence it has to be amplified in the PSF amplifier. The output from the PSF amplifier is fed to the PSF power amplifier. The power amplifier gives the required physiological signal power. The output of the PSF power amplifier is fed to the modulator. A modulator is an electronic circuit consisting of passive and active components to do the process of modulation.

RF Section: In the RF section, the high frequency carrier signal is generated by a crystal oscillator. The RF power amplifier is used to amplify the high frequency carrier signal. A buffer amplifier is included between oscillator and power amplifier to match the impedance. The modulator mixes the RF carrier signal and physiological variable to produce the amplitude modulated signal. The output of the modulator is fed to the antenna for electromagnetic propagation.

7.3.3 Superheterodyne AM Receiver

The functional block diagram of an AM receiver is shown in Figure 7.4 . It consists of a receiving antenna, RF amplifier and RF local oscillator, a mixer, intermediate frequency (IF) amplifier, detector and PSF amplifier.

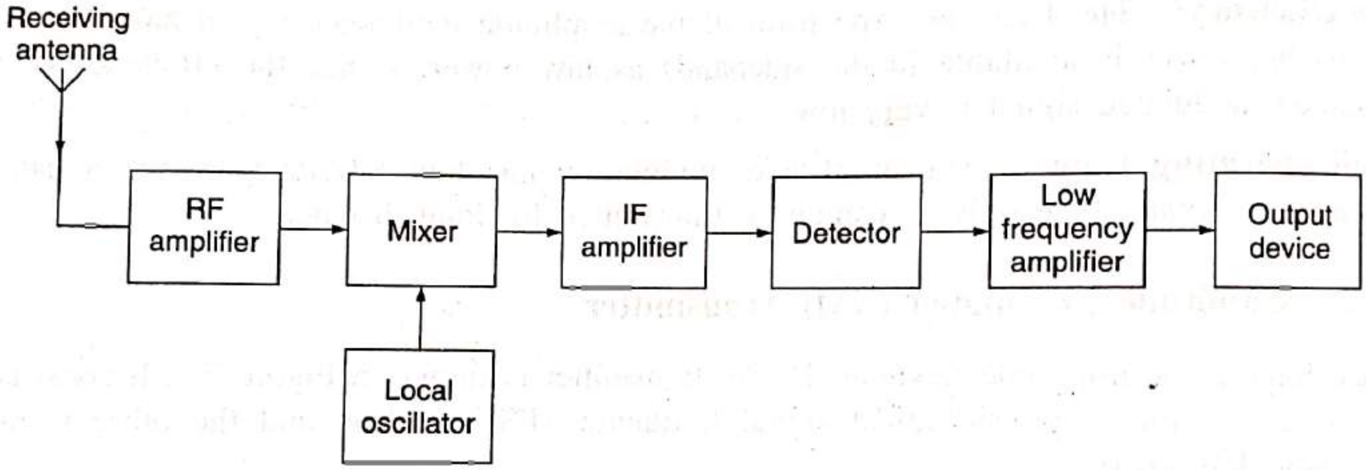


Figure 7.4 Block diagram of a typical AM receiver.

RF Amplifier: The receiving antenna receives signals propagated by many such transmitting antennas. So the signal received by the receiving antenna consists of many modulated signals and noise. Hence it is important to select the desired signal alone. Moreover, the selected signal will be very weak. The RF amplifier selects the desired signal using a tuner and amplifies it to the required magnitude level.

Mixer and local oscillator: The amplified signal in the first stage is send to this mixer stage. Here it is mixed to another high frequency signal generated by a local oscillator. Mathematically the mixing of high frequency signal and modulated signal gave an intermediate frequency with the information of original physiological signal. The intermediate frequency is the difference between modulated signal and carrier signal. Suppose the modulated signal frequency is 600 kHz and let the local oscillator frequency is 1055 kHz then the intermediate frequency is 455 kHz. The reduction of frequency helped to achieve the operation of demodulator with maximum stability, good selectivity and good sensitivity.

IF Amplifier: The weak IF signal will be amplified by the IF amplifier. Normally this amplifier will be designed for a narrow band of operation. In this instance it will be designed for 455 kHz narrow band.

Detector: The output of the IF amplifier is fed to the detector. The function of the detector is to get back the original physiological variable from the IF signal. In general, a half-wave rectifier made up of a diode with shunt capacitor filter will be used as decoder.

PSF Amplifier: The extracted original signal will be of low frequency. An amplifier with suitable bandwidth will be used to amplify the signal to display or to print in a plotter.

7.3.4 Frequency Modulation (FM)

In frequency modulation, the frequency of carrier signal is modified according to the magnitude of the physiological signal. In this modulation, the amplitude of the carrier signal is kept constant. The frequency variation of the carrier signal depends upon the instantaneous amplitude of the physiological signal as shown in Figure 7.5. The potential of the physiological variable is zero whenever it crosses the time axis. Note that the frequency of the carrier signal does not change at and near these points. Note also that the frequency of modulated signal is at maximum when the physiological signal has positive maximum. Similarly, the frequency of modulated signal is at minimum when the physiological signal is at minimum (negative maximum). The frequency of an FM transmitter without modulation (in the absence of modulating signal) is called resting frequency or centre frequency f_0 and this is the allotted frequency of the transmitter. Whenever the instantaneous value of physiological signal is zero

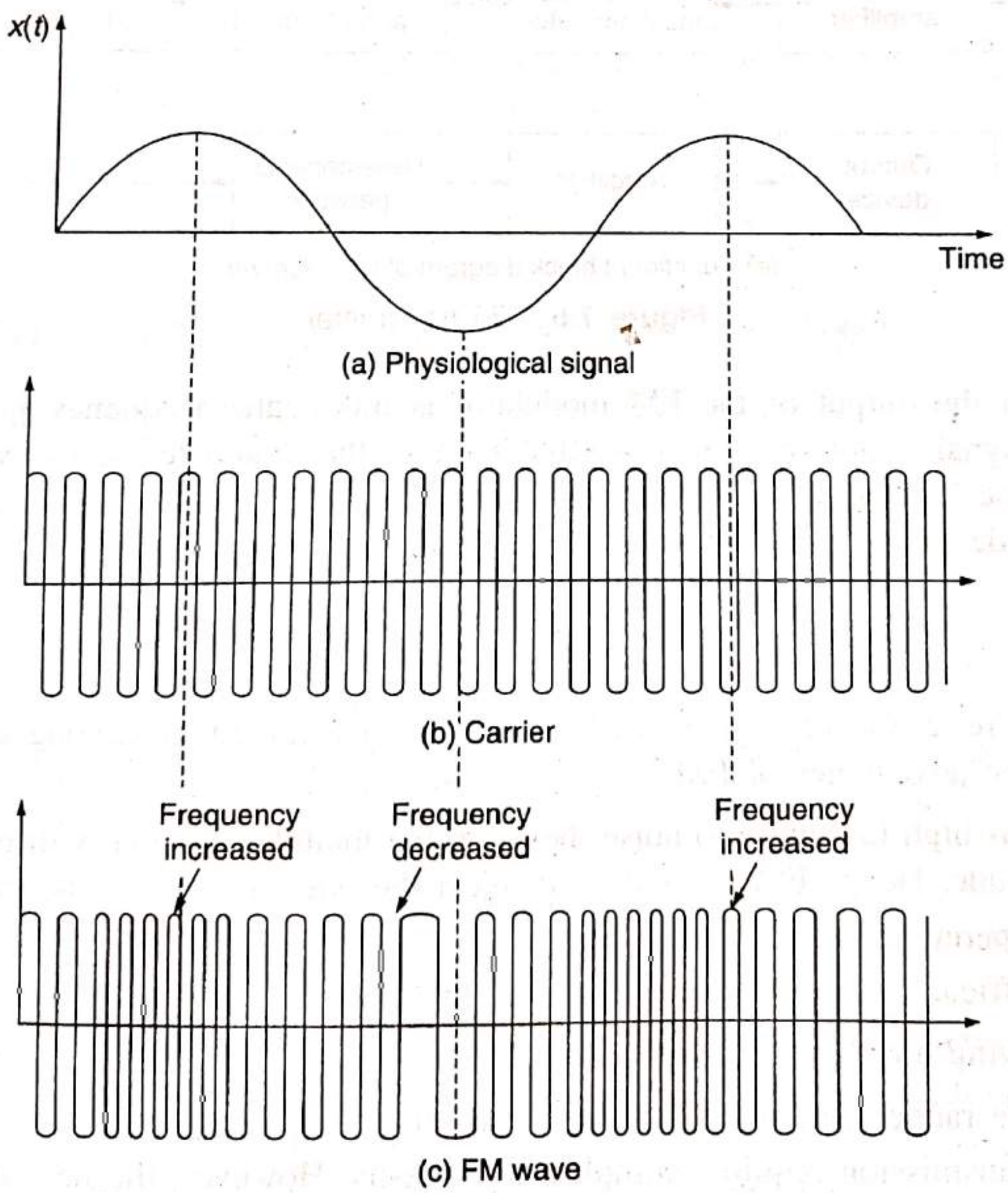
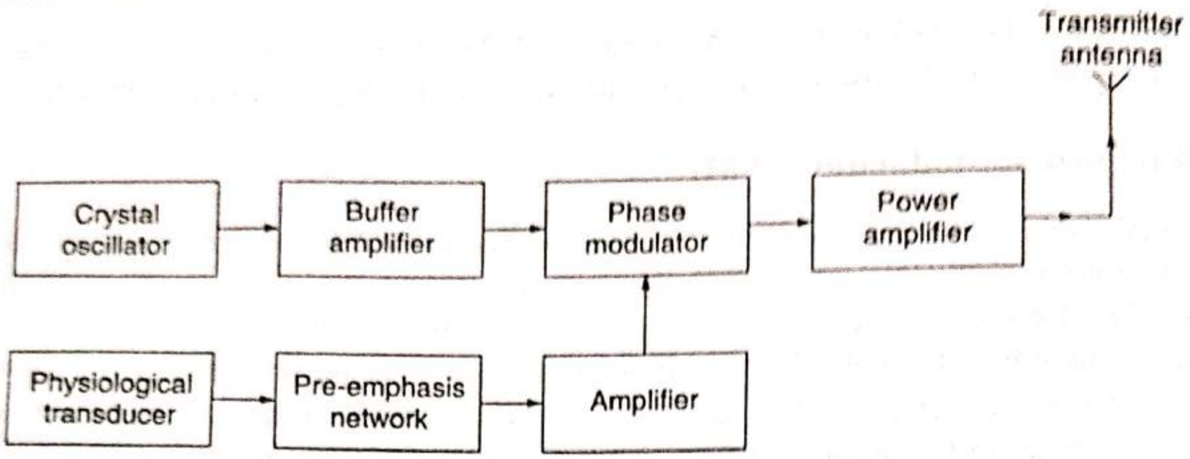
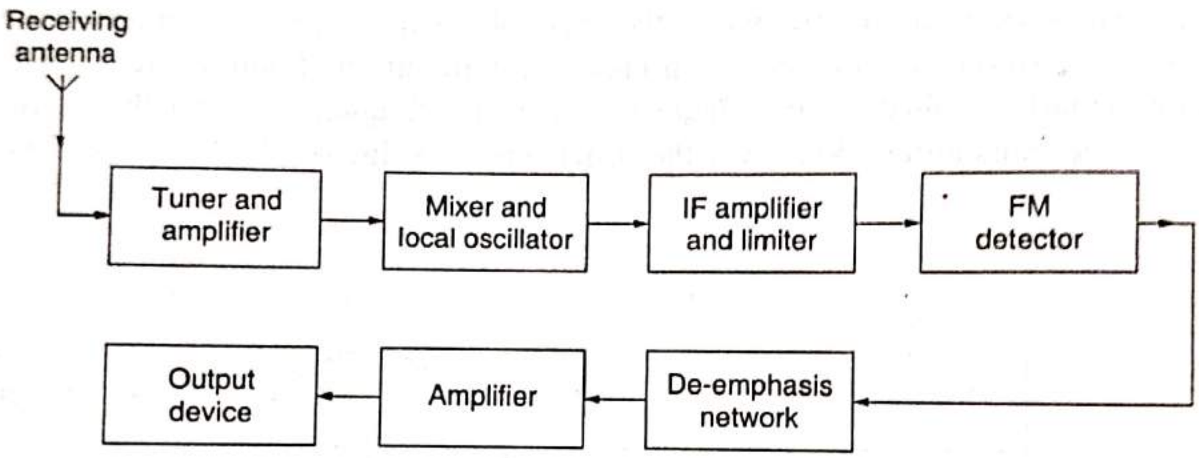


Figure 7.5 (Contd.)



(d) Functional block diagram of FM transmitter



(e) Functional block diagram of FM receiver

Figure 7.5 FM transmitter.

amplitude, then the output of the FM modulator is this centre frequency f_0. Whenever the physiological signal is not zero, then the frequency of the modulated signal varies around f_0. The change either above or below the resting frequency is known as frequency deviation Δf. The maximum deviation in the modulated signal is called carrier swing.

$$\text{Carrier swing} = 2 \times \text{Frequency deviation}$$

$$= 2 \times \Delta f$$

The Δf is restricted to 75 kHz as per international agreement among the nations. The following are the advantages of FM:

(i) FM has high immunity to noise. Noise in the modulated signal will be in the form of amplitude. Hence FM receiver will reject the noise signals in the modulated signal.
(ii) The operating range is very large.
(iii) The efficiency of transmission is very high.

The following are the disadvantages of FM:

(i) A wide range is required for each channel.
(ii) FM transmission requires complex equipments. However, the new inventions in the electronics field will make this simple.

7.3.5 Frequency Modulation (FM) Transmitter

The functional block diagram of a frequency modulation is shown in Figure 7.5. Frequency modulation is operated at a frequency above 40 MHz. This modulation is widely used for television sound, FM radio, mobile radio etc. The block diagram consists of physiological variable sensor, pre-emphasis network, PSF amplifier, an oscillator, buffer amplifier, frequency modulator and power amplifier.

The crystal oscillator produces a carrier signal and this carrier signal is fed to the frequency modulator through buffer amplifier. The buffer amplifier acts as an impedance matching device. The physiological variable obtained either from electrode or from the transducer is passed through pre-emphasis block to improve the power. Hence the signal is amplified by an amplifier and then passed on to the frequency modulation block. The output of the frequency modulator block is sent to the power amplifier for antenna transmission.

7.3.6 FM Superheterodyne Receiver

The functional block diagram of a FM receiver is shown in Fig. 7.6. It is identical to AM receiver. The RF section selects a particular incoming frequency among the received signals by the antenna. The mixer and local oscillator section converts the received signal in to an intermediate frequency signal. For an FM receiver the intermediate signal is 10.7 MHz. IF amplifier is used to amplify the IF signal. A demodulator is used and the demodulated signal is passed through de-emphasis network to get back the original instantaneous power. A final amplifier amplifies the signal to plot in a plotter or display device.

7.4 REQUIREMENTS FOR A BIOTELEMETRY SYSTEM

The following are the specification requirements of a biotelemetry system:

(i) The telemetry system should have maximum fidelity and simplicity in transmitting signals.

(ii) It should not have any constraint on the living system for installation of the telemetry system.

(iii) There should not be any reaction or interference with the living system.

(iv) The percentage of the weight of the telemetry system should be 1% of the living system in the case of long-term use. In the case of short-term use it may be extended to 5%.

(v) It should have stability and reliability.

(vi) Power consumption must be very small in the case of implanted units to extend life of energy source.

(vii) The transmission noise should be at minimum and input impedance must be very high.

(viii) Miniaturization of radio telemetry system may reduce noise level. Hence it is advisable to miniaturize the system.

7.7 SINGLE CHANNEL RADIO TELEMETRY SYSTEM

Figure 7.8 shows a typical block diagram of a radio telemetry single channel system. The RF is in the range of few hundred kilo hertz to 300 MHz. Any further increase in frequency will increase the attenuation by the physiological subject body. Frequency modulation or sub-carrier may be adopted to avoid variation of signal amplitude due to relative motion between receiver and transmitter. The other blocks include transducers, signal conditioner, modulator and transmitter. Similarly, in the receiver side, the blocks are receiver, demodulator, signal conditioner and display unit.

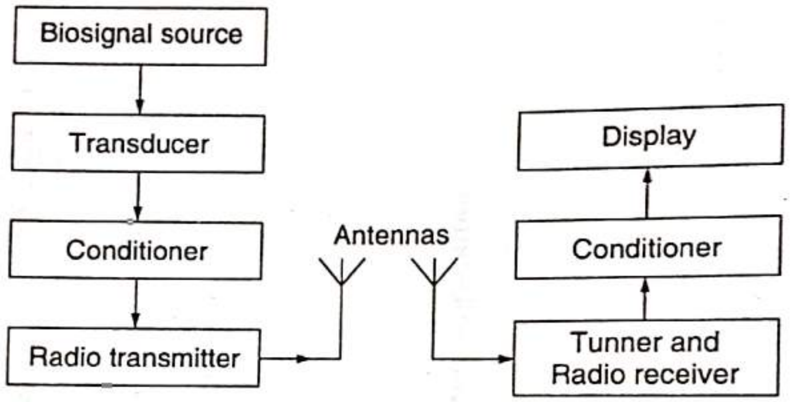


Figure 7.8 Single channel radio telemetry system.

7.8 MULTIPLE CHANNEL TELEMETRY SYSTEMS

In biomedical instrumentation, it is desirable to have simultaneous recording of multiple signals for correlation study. In fact, each channel requires a telemetry channel. The cost involved in having separate telemetry channel for each variable is very high. Adopting multichannel telemetry system reduces the cost and number of equipment. Multichannel telemetry systems are:

(i) Frequency division multiplexing system
(ii) Time division multiplexing system
(iii) Pulse width modulation (PWM) multiple channel system.

7.8.1 Frequency Division Multiplex System

A typical three-channel frequency division multiplex system is shown in Figure 7.9. Each channel is frequency modulated on a sub-carrier frequency. These sub-carriers are added and they modulate the main RF carrier signal. At the receiver end, after demodulating the RF carrier signal the sub-carrier signals will be passed through proper band pass filters. The individual signals are obtained by individually demodulating the sub-carriers. In this method, the frequency of the sub-carrier has to be selected with care to avoid interference. At the final stage, a low pass filter may be incorporated as shown in Figure 7.9 to avoid noise.

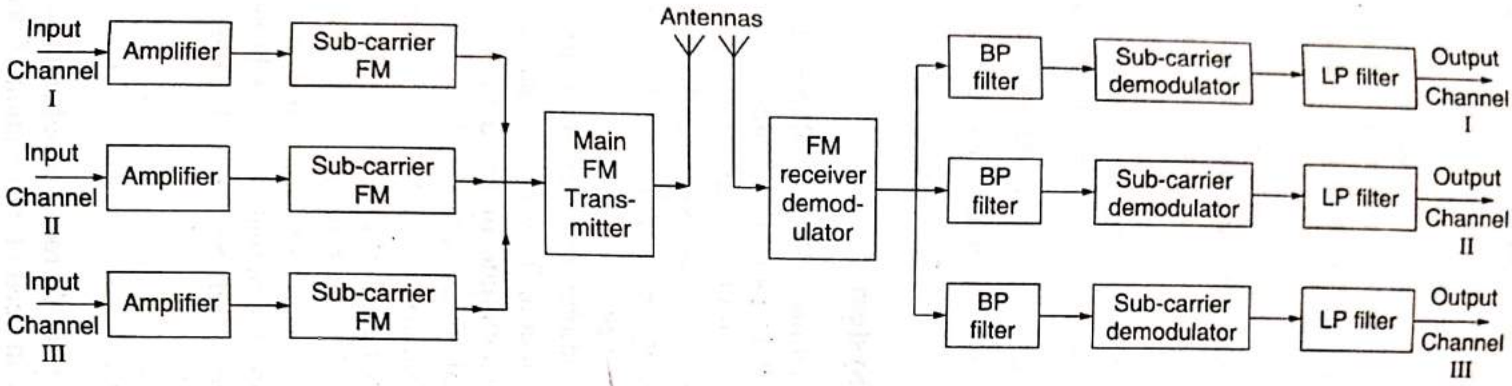


Figure 7.9 Frequency division multiplex system.

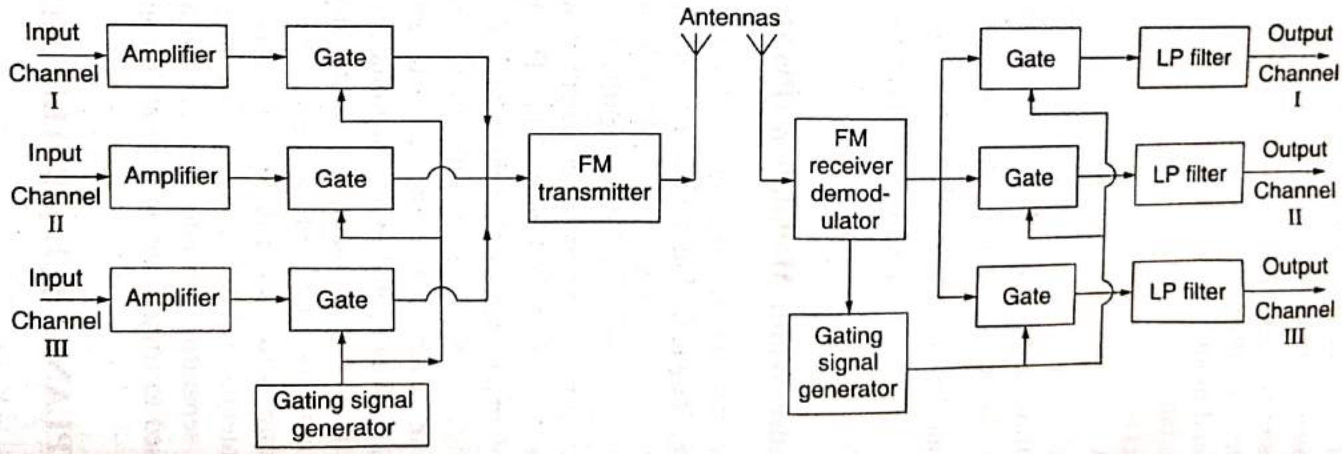


Figure 7.10 Time division multiplex system.