UNIT 8 MULTIPLEXING

Structure

8.1 INTRODUCTION

The communication field is expanding at a great pace with more and more subscribers using the telephones and the Internet. To cater for all these users, it is not possible to provide individual dedicated media or channels. To avoid this problem, initially idea of exchanges came forward. But, in any exchange, there are limited number of channels to carry signals from one exchange to another. Hence it is necessary to use these channels in an efficient way. Any subscriber does not use the line continuously. For example, when one person is talking on phone, the user at the other end listens. Keeping this in mind, there is no necessity of keeping continuously two lines, viz. transmitting and receiving busy. Since, any line is idle for a long time and the idea came forward to use the same line for transmitting and receiving signals from many users. This is achieved by *multiplexing* process.

Multiplexing is done in different ways. The main three domains used in multiplexing of communication signals are (i) space; (ii) time; and (iii) frequency. In optical communication, wavelength of signal is multiplexed. Further derivatives of these multiplexing methods are spread spectrum and code division multiplexing. The last one, commonly called Code Division Multiple Access (CDMA) is the most popular technology used in recent cellular mobile telephony.

In this unit you will learn about the basic principles of commonly used multiplexing methods, their implementation and applications. In Sec. 8.2 we shall discuss the basic concept of multiplexing and multiple access, with reference to modern communication technology. In the last unit, we mentioned about the space division multiplexing (SDM). In Sec. 8.3 we shall discuss details of SDM. The time division multiplexing (TDM) allows us to use the same channel for different users, at different time intervals. In Sec. 8.4 we shall discuss TDM in details. The frequency division multiplexing (FDM) allocates different frequency bands to different users. The signals of different frequencies are sent over the same communication channel and appropriate filtering is used to separate the signals at the receiver end. In Sec. 8.5 you will learn about the FDM technique in details. Use of different optical wavelengths to carry different signals through single optical fibre is called wavelength division multiplexing (WDM). You will learn about WDM in Sec. 8.6. In Sec. 8.7 we shall discuss about the CDMA technology, which is gaining importance at present due to its application in the cellular telephones.

Objectives

After learning this unit, you should be able to:

- state the necessity of multiplexing;
- explain the implementation of SDM;
- state the principle of TDM and explain its implementation;
- explain the technique of FDM;
- construct the different FDM modulation plans as per ITU standards;
- explain the implementation of WDM;
- describe the concept of spectrum spreading;
- explain CDMA technique; and
- state the applications of various multiplexing techniques in electronic communication.

8.2 MULTIPLEXING AND MULTIPLE ACCESS

When more than one base band signals are sent using a single channel, this process is called *multiplexing*. Multiplexing facilitates an efficient use of the channel. This could be in the form of:

(i) providing connection between sender and receiver by establishing a physical contact through a switch. This is called a **Space Division Multiplexing** (SDM);

(ii) sending different signals on the same channel at different points of time. This is **Time Division Multiplexing** (TDM); and

(iii) sending different base band signals riding on different frequency bands and all these frequency bands are sent over a single channel. This is **Frequency Division Multiplexing** (FDM).

A variant of frequency division multiplexing can also be seen in case of radio transmission, where the same base band signal (20 kHz, audio signal) is transmitted by different radio stations by modulating it on different frequency carrier waves. This allows us to distinguish between different radio stations, depending on the carrier frequencies assigned to them. By changing the tuning frequency of local oscillator, we can catch different frequencies, and listen to different stations.

Nowadays, optical fibre is widely used as a communication medium. Here, the base band signal is converted (or modulated) into an optical (visible or IR) wave and then transmitted through the optical fibre. In this case, one special type of multiplexing technique is used. It is called **Wavelength Division Multiplexing** (WDM). Here, the signals from different users are modulated on optical signals of different wavelengths. These signals can travel through a single optical fibre simultaneously, without interfering with each other. At the receiver end, optical filters are used to separate the different wavelength signals and then demodulated to obtain original base band signals.

You must have noticed that the wavelength and frequency are complimentary to each other and could be treated as the same multiplexing technique. However, as you learnt in Unit 1, the optical signals are commonly referred in terms of wavelengths while the electrical or radiation type signals with wavelengths higher than far infrared are referred in terms of their frequencies. The techniques used for implementing WDM and FDM are quite different, from the point of view of circuitry, sources and detectors. Hence, these are treated as two separate multiplexing methods.

All these multiplexing techniques are used for utilising the communication channels more efficiently. The commercial use of communication system is dependent on its efficiency. When more subscribers are accommodated on single communication channel, it is economically beneficial and hence a lot of research is going on in developing more and more efficient multiplexing techniques.

When these multiplexing techniques are used for giving access to more than one user, these are called **multiple access systems**. We have three main categories of multiple access system, viz:

i) Time Division Multiple Access (TDMA);

ii) Frequency Division Multiple Access (FDMA); and

iii) Code Division Multiple Access (CDMA).

We will be discussing about these different multiplexing and multiple access systems in the following sections. In the next section you will learn about the *space division multiplexing*.

8.3 SPACE DIVISION MULTIPLEXING (SDM)

In the cross bar exchanges, the telephone lines from the subscribers are connected in form of a matrix of number of rows and columns. Any row can be connected with any column by activating a switch between them. This is a scheme of connection, where a physical path for carrying a signal is created in space. This type of multiplexing was widely used in the earlier telephone exchanges. Since each subscriber has to be allotted a separate channel, this method is not efficient and instead of just space division multiplexing, a combination of time and space division multiplexing called *S-T* (space-time) switching is used. Here, multiple-space switches are connected to single time channel, i.e. on a single channel, different SDM signals are sent in different time slots.

Another wide application of SDM is found in radio and satellite communication. The radio stations situated in different towns are separated from each other by several kilometres. Now, the signals transmitted by a station undergo attenuation as they travel away from the station, and are very weak beyond the range of the transmitter. Hence, beyond this range, it is possible to use the same carrier frequency for another station, which has a transmitter range outside the range of first station. This is shown in Fig. 8.1. Here, the physical separation of the transmitters in space-domain is used for employing the same carrier frequency signals. This region specific transmission is a form of space division multiplexing. You will recall that the similar strategy is used in *frequency re-use* in cellular mobile telephony.

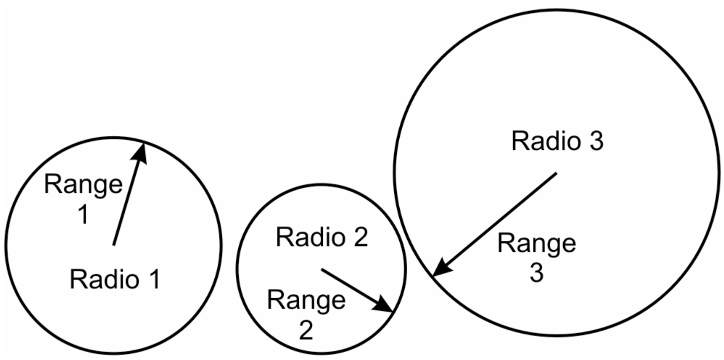

Fig. 8.1: SDM in radio transmission

The same is true for the satellite communication. Two satellites having different *footprint* regions can use same frequency without interfering each other's signals. *Footprint* of the satellite is the region on the earth surface, where the signal from the satellite can be captured. This is shown in Fig. 8.2.

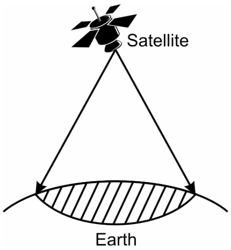

Fig. 8.2: Footprint of a satellite

After learning about the space division multiplexing, let us now discuss another important multiplexing method viz. *Time Division Multiplexing* (TDM).

8.4 TIME DIVISION MULTIPLEXING (TDM)

The time division multiplexing uses the principle of sampling. In Fig.8.3 SW_1 and SW_2 are the rotary switches having contact points 1,2,3….etc. Switch SW_1 is on the

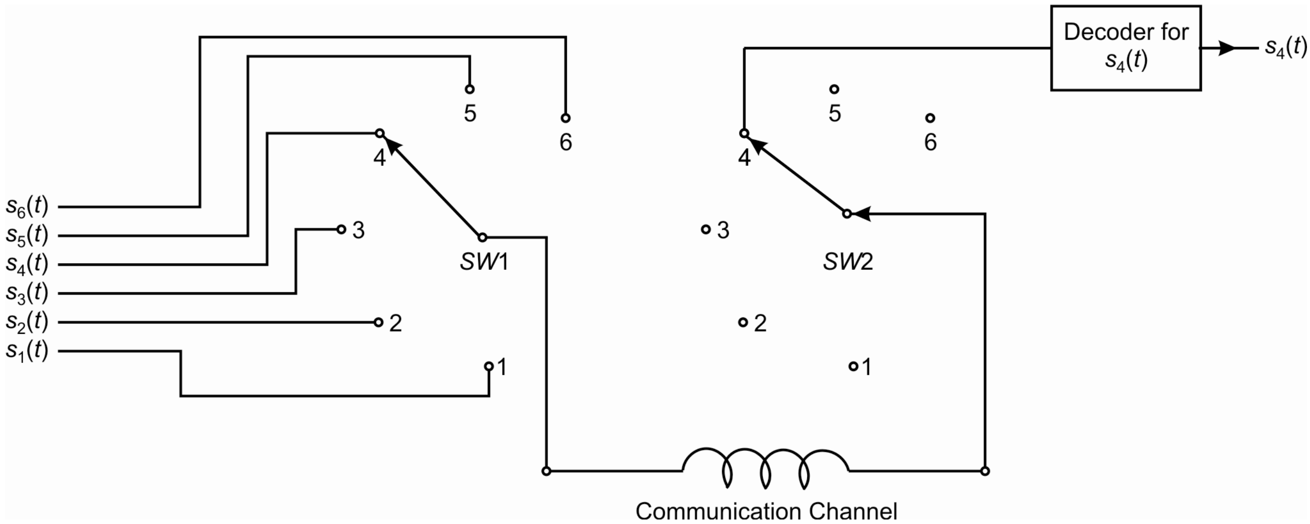

Fig. 8.3: Use of sampling in TDM

transmitter side and SW_2 is on the receiver side. Both the switches operate in synchronisation; i.e. they make contact simultaneously at identically numbered contact points. The signals from different sources are connected to the contact points of a rotary switch. As the rotary arm of the switch SW_1 swings around, it samples each signal one by one. Say SW_1 is on contact point-4 sampling $s_4(t)$ signal. Since SW_2 moves in synchronism with SW_1, the sampled signal on point-4 is available on the contact point-4 on SW_2 simultaneously. With each revolution of the switch, one sample is taken from each input signal and is presented to the corresponding numbered contact of the receiving end switch. The train of samples, at each terminal in the receiver passes through the low pass filter. The output of the low pass filter is the original signal. If ω_M is the highest frequency component present in any input signal, to satisfy the sampling theorem, the switches must make at least $2\omega_M$ revolutions per second. When the switching speed required is outside the range of mechanical switches, electronic switching is used. Fig. 8.4 shows interlacing of samples from different channels. This interlacing allows multiplexing of signals. For simplicity multiplexing of two signals $s_1(t)$ and $s_2(t)$ is shown. Both the signals are sampled at the intervals of T_s but the samples are taken at different times separated by t_1. You must have noticed the empty time space between the first sample of $s_2(t)$ and the second of $s_1(t)$. This time interval $(T_s - t_1)$ can be used for accommodating many more signals. This is a multiplexing done on time scale and is called **time division multiplexing**.

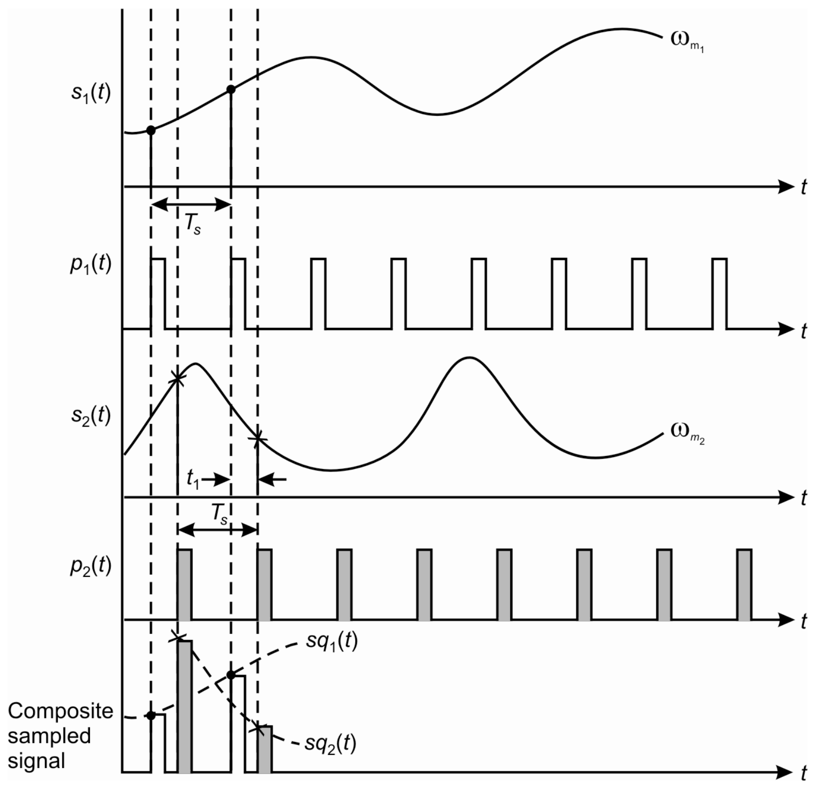

Fig. 8.4: Interlacing of samples from different channels

You may now like to attempt the following SAQ.

SAQ 1

Spend 3 Min.

If pulses of 2 ms duration are used for sampling each signal and 2 ms spacing is left between two consecutive signals, how many signal channels can be handled by a TDM system with 10 Hz sampling rate?

Use of Pulse Amplitude Modulation in TDM

You have learnt about Pulse Amplitude Modulation (PAM) in Unit 6. The main purpose of PAM is to conserve power dissipation in low frequency amplifiers. To explain this, if we consider the duty cycle of pulse in PAM to be 10%, then the amplifier works only for 10% of time and for the rest 90% of the time the amplifier of the system remains idle. During this idle time, the system could be used to process signals from other channels using time division multiplexing.

Fig. 8.5 shows TDM of four PAM signals. This means that the system will permit four PAM signals to be transported over a single pair of wires without interference

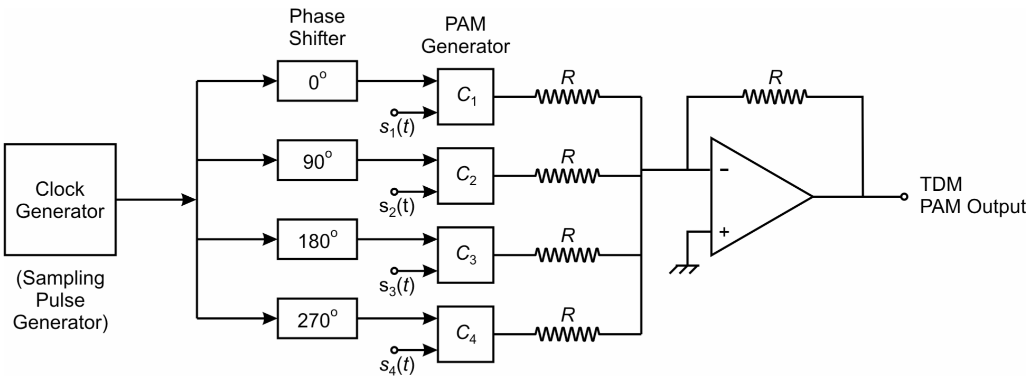

Fig. 8.5: TDM of 4 PAM signal

and without increasing base band frequency response. This system consists of four pulse amplitude modulators C_1, C_2, C_3, and C_4. Each of the messages contains frequencies between 300 Hz to 4 kHz (voice channel range). The clock pulse generator output is a square wave at 8 kHz with 20% duty cycle. This is used to control the circuit C_1, which is similar to the one shown in Fig. 6.7. The same gating pulse is delayed by 90° and used to make C_2 *ON*. It is delayed by another 90° (total 180°) and turns C_3 *ON*. It is further delayed by 90° (total 270°) and fed to C_4.

Each amplifier is *ON* for 20% of time. There is 5% time space (quiet time) between the turn *OFF* of one amplifier and turn *ON* of next amplifier. This avoids the two amplifiers being simultaneously *ON* at the same instant. Outputs of C_1, C_2, C_3 and C_4 are PAM signals. The output of each is shifted by 90° from each other and therefore only one at a time will be given at the output. These outputs are added using a summing amplifier, which results into a train of pulses, the consecutive pulse representing different signals. The wave shapes at different stages of the TDM system handling 4 PAM channels is shown in Fig. 8.6.

The output contains any and all frequencies between 300 Hz to 4 kHz plus the gating signal frequency of 8 kHz.

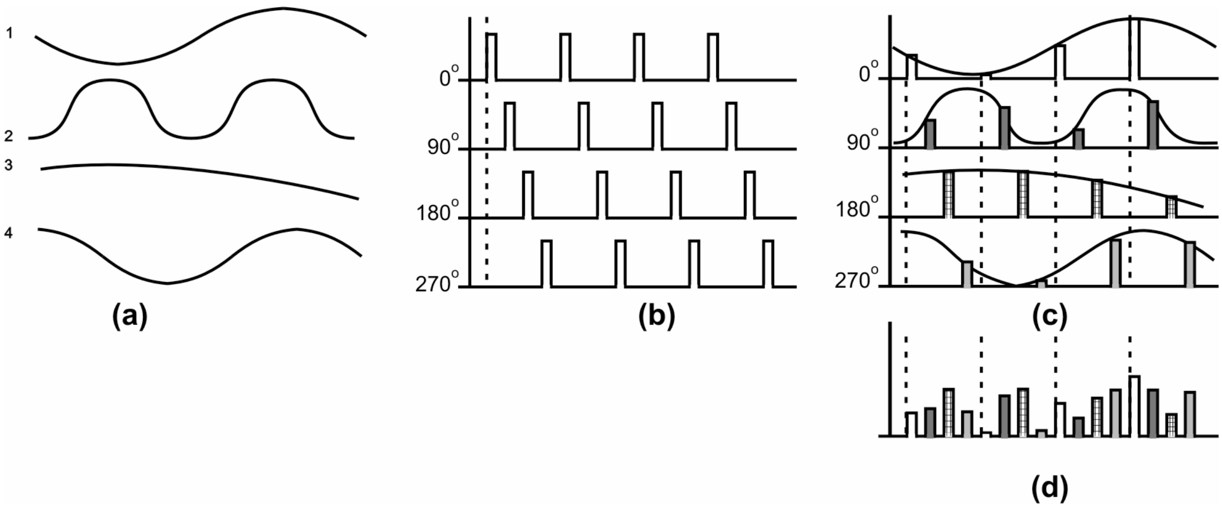

Fig. 8.6: The waveshapes for TDM system with 4 PAM channels: a) message inputs; b) clock pulses; c) modulated pulses; and d) sum of four sampled signals

After understanding the principle and working of time division multiplexing you will now learn about the frequency division multiplexing (FDM).

8.5 FREQUENCY DIVISION MULTIPLEXING (FDM)

For any transmission, some specific frequency bands are reserved. Width of those bands is usually much higher than the base band frequency of the signal to be transmitted (20 kHz for audio, 4.2 MHz for video, etc.). Hence to make optimum use of the bandwidth allotted, many signals are properly modulated and sent using the same band. In case of frequency division multiplexing the entire band allowed for transmission is divided into small slots (or channels), which have bandwidth just enough to handle one signal. Each of these channels have one particular carrier frequency. The signal assigned to a particular channel is modulated on the carrier frequency associated with that channel and transmitted. At the receiver end, the signal is recovered by subtracting this carrier frequency.

In telephony, the base band voice signal is in the range of 0.3 kHz to 3.4 kHz. The simplest system used in telephony is 3-channel system. In this system a 7 kHz to

17 kHz band is used for transmitting signals from three voice channels. In this case channel 1 is modulated with 7 kHz carrier, channel 2 is modulated with 10.5 kHz and channel 3 is modulated with 14.0 kHz.

After modulation, there will be lower side band (LSB) carriers and higher or upper side band (USB) carriers. But in a well designed modulator circuit, carrier will be suppressed. Since both the side band will contain the signal information, for economic reason we can use any one side band.

So, in the first channel, a voice band 0.3 to 3.4 is modulated with 7 kHz carriers and the output of the modulator will be 7 kHz ± (0.3 to 3.4 kHz) i.e. from 6.7 to 3.6 kHz and from 7.3 to 10.4 kHz. When the second channel is modulated with 10.5 kHz, its lower and upper side bands are respectively 10.2 to 7.1 kHz and 10.8 to 13.9 kHz. The third channel is modulated with 14 kHz. Hence the lower and upper side bands are 13.7 to 10.6 kHz and 14.3 to 17.4 kHz respectively.

Since the upper sidebands are used, for transmission,
Channel 1 is put in the frequency slot of 7.3 to 10.4 kHz,
Channel 2 is put in the frequency slot of 10.8 to 13.9 kHz, and
Channel 3 is put in the frequency slot of 14.3 to 17.4 kHz.
These channels are shown in Fig. 8.7a. In Fig. 8.7b the combined side bands of 3-channel system are shown.

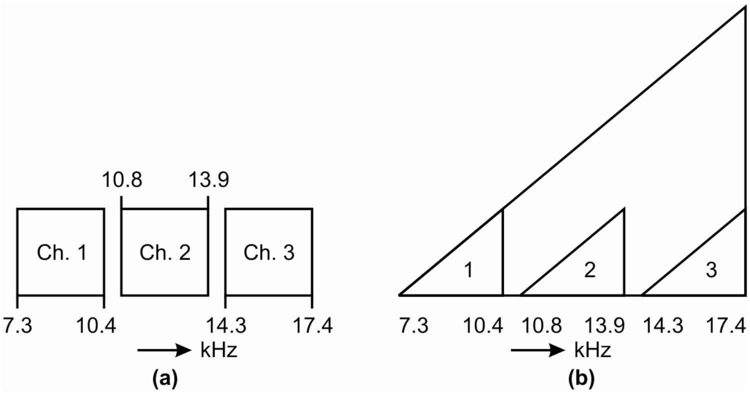

Fig. 8.7: a) 3- channel carrier telephone system; and b) the combined side bands of 3-channel system

Hence, the channel modulation (carrier) frequencies (7 kHz, 10.5 kHz and 14 kHz in case of 3-channel system) allow us to form a band of frequencies which are ready for transmission on the line or any other transmission medium. Such band is called the **line frequency**.

ITU was earlier known as CCITT (International consultative Committee on Telephone and Telegraph).

In order to bring in compatibility in the transmitted signals nationally and internationally, the International Telecommunication Union (ITU), in Geneva, Switzerland has standardised the modulation plans for multichannel telephone system. These modulations are carried out to form *Groups*, *Supergroups*, *Mastergroups* and *Supermaster groups* of channels.

As per these standards, the voice signal is limited from 0.3kHz to 3.4 kHz and the necessary control signal is sent at 3.825 kHz frequency. Fig. 8.8 shows the frequencies in typical voice channel signal which is allotted 4 kHz bandwidth.

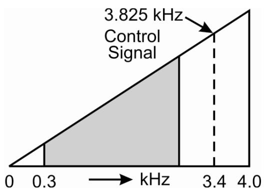

Fig. 8.8: Basic voice signal

The **Group** is defined as 12 voice channels modulated in the frequency band of 60 kHz to 108 kHz. Each voice channel is of 4 kHz bandwidth. Similar to the 3-channel telephony, in a group, 12 frequencies in the range of 60 kHz to 108 kHz are used for modulating 12 voice signals of 4 kHz frequency band each. Fig. 8.9 shows the constitution of a typical ITU group. In this case, the lower side bands are used

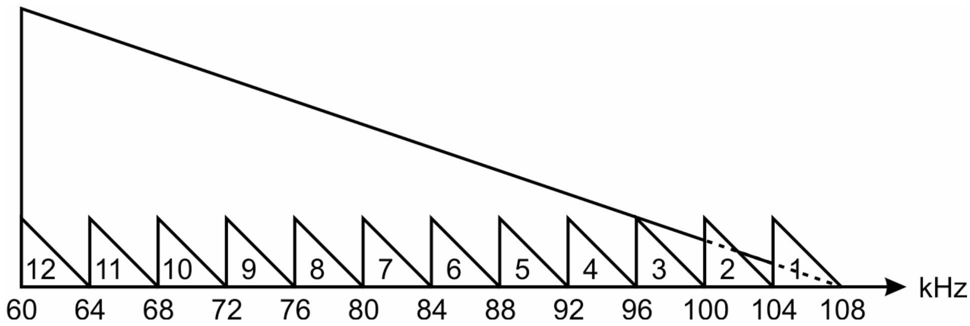

Fig. 8.9: ITU Group consisting of 12 channels

and hence the carrier frequencies are 64 kHz, 68 kHz, 72 kHz,… 108 kHz. The highest frequency channel (104-108 kHz) is numbered as the first channel, while the lowest frequency channel (60-64 kHz) is the twelfth channel. Here, each group bandwidth is 48 kHz.

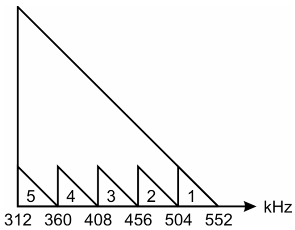

Fig. 8.10: Structure of ITU Supergroup

Five such 12 channel groups are modulated over higher frequency to form a **Supergroup**. These groups are modulated in the range 312-552 kHz and lower side bands are used for transmission. Hence a supergroup can handle 60 voice channels. This modulation plan is shown in Fig. 8.10.

Combining 5 supergroups in the modulation frequency range of 812-2044 kHz a **Mastergroup** is formed. It can handle 300 voice channels. In this case, between each supergroup channel 8 kHz band is left free to avoid any interference between adjoining supergroups. Hence the bandwidth of a Mastergroup is 1232 kHz corresponding to (5×240 kHz + 4×8 kHz).

Spend 5 Min.

SAQ 2

Draw the modulation plan for forming a mastergroup by combining 5 supergroups.

By combing 3 mastergroups in the frequency band of 8516-12388 kHz a **Supermaster group** is formed. Hence a supermaster group can handle 900 voice channels. In this case, between each mastergroup 88 kHz frequency band is left free as shown in Fig. 8.11.

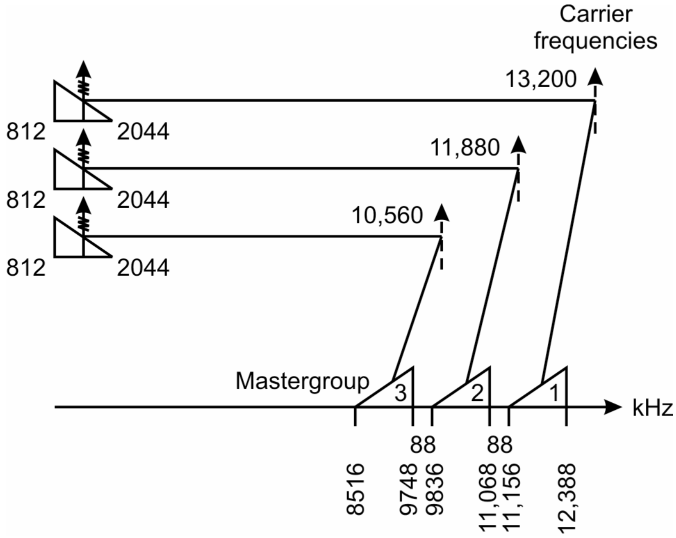

Fig. 8.11: Supermaster group carrying 900 voice channels

Thus, many telephone signals are handled by a single transmission medium by a frequency multiplexing technique. You must have noticed that in this frequency division multiplexing scheme, we have gradually increased the carrier frequency from group to supergroup to mastergroup to supermaster group. This is done due to practical considerations in electronic implementation of the scheme. It is very difficult to achieve a circuit which would be able to directly modulate a narrow band voice signal (4 kHz) on the 13 MHz carrier wave (supermaster group carrier frequency), which is almost 3000 times higher in frequency. This is because we are having a low frequency signal, which is almost 0.01% of the carrier frequency and hence the precision of the devices in the modulating circuit will have to be extremely good. This is not very practical and cost effective. Instead, when the modulation is done step-by-step, gradually increasing the carrier frequency, practically available components can be used for circuit implementation.

Let us now discuss a variant of this technique as applied to the optical fibre communication.

8.6 WAVELENGTH DIVISION MULTIPLEXING (WDM)

In the previous section we discussed about the multiplexing in the form of different frequencies travelling on the single electrical path. The same scheme can be used for sending optical signals through an optical fibre. The driving force motivating the use of multichannel optical systems is the enormous bandwidth available in optical fibre. Typical optical fibre can handle a bandwidth up to 25000 GHz (25THz) around 1.55 μm wavelengths, before transmission losses of the optical fibre limit transmission. Obviously, this bit rate is impossible for present-day optical devices to achieve, given that the lasers, external modulators, switches or detectors have bandwidths < 100 GHz. As such, a single high-speed channel utilises an extremely small portion of the available fibre bandwidth.

To exploit more of the fibre's terahertz bandwidth we seek a solution in which several base-band-modulated channels are transmitted along a single fibre but with each channel located at a different wavelength as shown in Fig.8.12. Each of *N* different wavelength lasers operate at the slower switching speeds (Gigabytes per second), but the aggregate system transmits at *N* times of the individual laser speed, providing a significant capacity enhancement. The WDM channels are separated in wavelength to avoid cross-talk between neighbouring channels. WDM allows us to use much of the fibre bandwidth, although various device, system, and network issues limit the utilisation of the full fibre bandwidth.

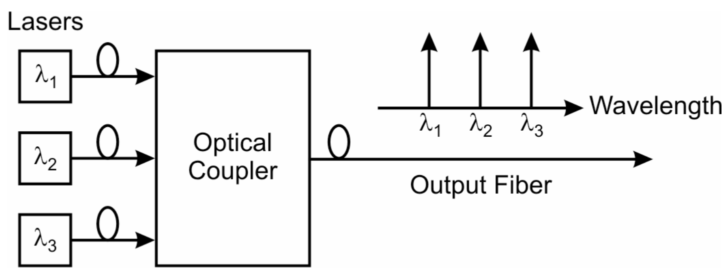

Fig. 8.12: Many WDM channels propagating in a single optical fibre

Another method conceptually related to WDM is **sub-carrier multiplexing** (SCM). Instead of directly modulating a ~terahertz (10^{12} Hz) optical carrier wave with ~ 10 Mbps (10^7) base band data, the base band data are first modulated on a ~ gigahertz (10^9) sub-carrier wave that is subsequently further modulated on the THz optical carrier. Fig. 8.13 illustrates the situation in which each channel is located at a different sub-carrier frequency, thereby occupying a different portion of the spectrum surrounding the optical carrier. For the multiplexing and demultiplexing of the SCM channels electronic circuits can be used and it is not necessary to use dedicated optical components for every channel. The obvious advantage is that several channels can share the same expensive optical components. The electrical components are typically less expensive than optical ones. The SCM is limited in maximum sub-carrier frequency and data rates by the available bandwidth of the electrical and optical components. Hence, it must be used in conjunction with WDM if we want to utilise the significant fraction of the fibre bandwidth.

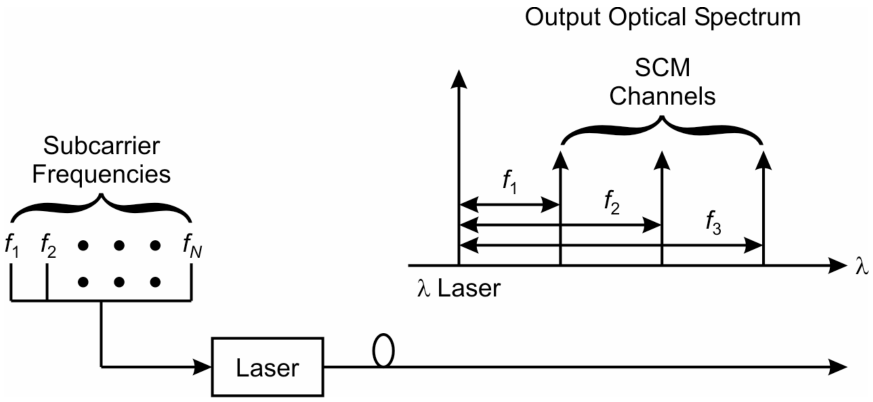

Fig. 8.13: Frequency spectrum of several SCM channels transmitted from a single laser

You have learnt about the multiplexing in the space, time, frequency and wavelength domains. Now, let us discuss about another scheme of multiple access, which is recently becoming a very widely used technology in the mobile telephony.

8.7 CODE DIVISION MULTIPLE ACCESS (CDMA)

Nowadays the mobile telephones are becoming very popular. The two main communication modes used by these mobile telephones are **Code Division Multiple Access (CDMA)** and **Global Systems Mobile (GSM)**. GSM is a digital mobile telephone system that is widely used in Europe and other parts of the world. It uses a variation of TDMA and is the most widely used technology. GSM digitises and compresses data, then sends it down the channel with two other streams of user data, each in its own time slot. It operates at either 900 MHz or 1800 MHz frequency band. This technology supports the features like short messaging services (SMS). In the present unit we will not go into the details of GSM technology but will discuss the CDMA technology now.

Code Division Multiple Access (CDMA) is a technique that spreads the information contained in a particular signal over a much greater bandwidth than that of the original signal, i.e. CDMA is a *spread spectrum technology*. The spreading process involves applying digital code to the data bits of a signal that are going to be transmitted along the channel. At the receiving end, the code is removed and the desired signal is recovered.

Please do not confuse the term *chip* with integrated circuit (IC) chips.

A CDMA spread spectrum signal is created by modulating the radio frequency with a spreading sequence. It is a code consisting of a series of binary pulses known as a **Pseudo-Noise code** (*PN*-code). A *PN*-code is essentially a sequence of high data rate bits called *chips* ranging from –1 to 1 (polar) or 0 to 1 (non-polar). The *PN*-code runs at a much higher rate than the RF signal and determines the actual transmission bandwidth. The direct result of multiplying the *PN*-code with the original modulated signal is to divide the signal into smaller bits. The process is shown in Fig. 8.14. The greater the number of chips used, the wider the resulting bandwidth. That is, the bandwidth is proportional to the number of chips.

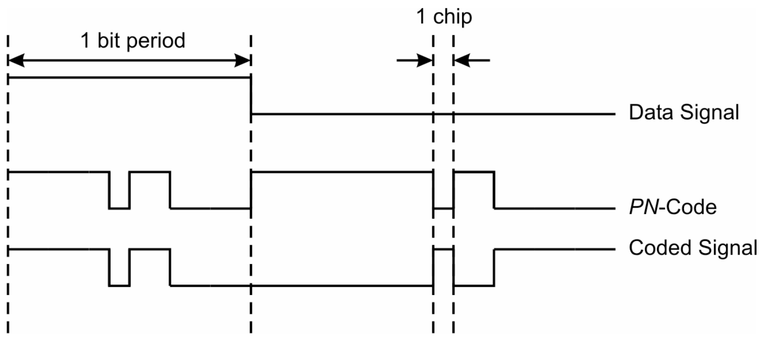

Fig. 8.14: Chip Period of a *PN*-code

In CDMA, the users share a common frequency channel. All the users work on the same frequency but each pair of user is assigned a special code that reduces interference as well as improves security. This is something like many people in a room speaking at the same time but in different languages, such that only the person listening to you understands your language.

The schematic of CDMA system is shown in Fig.8.15. The first step of CDMA signal generation is **analog to digital** (A/D) **conversion** where voice signal is converted into digital form. This digital signal is then encoded using **encoders** and **interleavers**. This process helps in introducing redundancy in the transmitted signal and allows recovery of data even if some error occurs during the transmission.

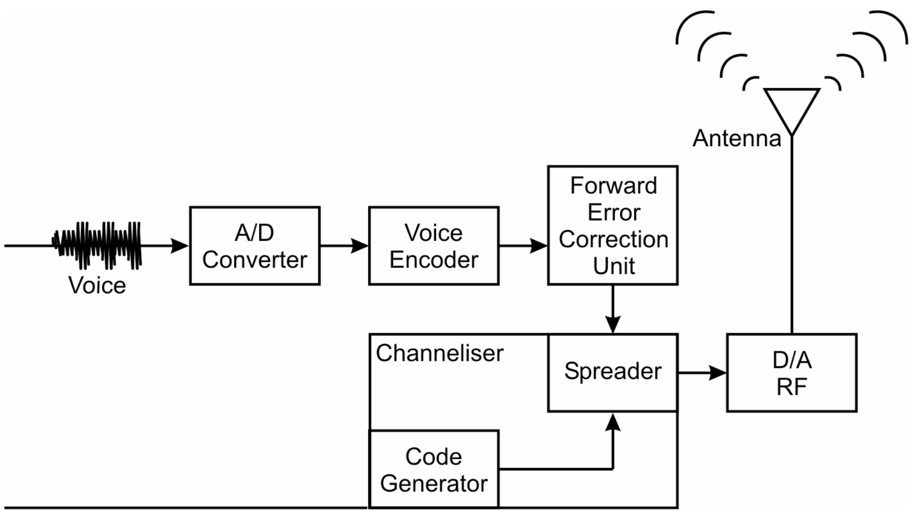

Fig. 8.15: Schematic of CDMA generator

These encoded and interleaved signals are then coded by using individual codes for each separate message. This is done in the *channeliser* block in Fig. 8.15. This block includes a **code generator**, which generates codes as per the message from different (voice) sources. The **spreader** block applies this code to the message. Fig. 8.16 shows a typical code spreading system where a data 10 (Fig. 8.16a) is coded by a signature 1001011010 (Fig. 8.16b). Each bit of this code is a **chip**. The chip duration is very small as compared to the bit period of the signal. Hence, the low bandwidth signal is spread over a larger bandwidth determined by the chip-rate. The resultant is shown in Fig. 8.16c, which can be BPSK-modulated as shown in Fig. 8.16d.

Now, at the receiver end the same code is used for decoding this message. The signals originating from different users are coded using different codes, and also selectively decoded by the corresponding receiving user. Hence, even though many signals flow over a same communication channel, there is no interference or disturbance amongst these signals.

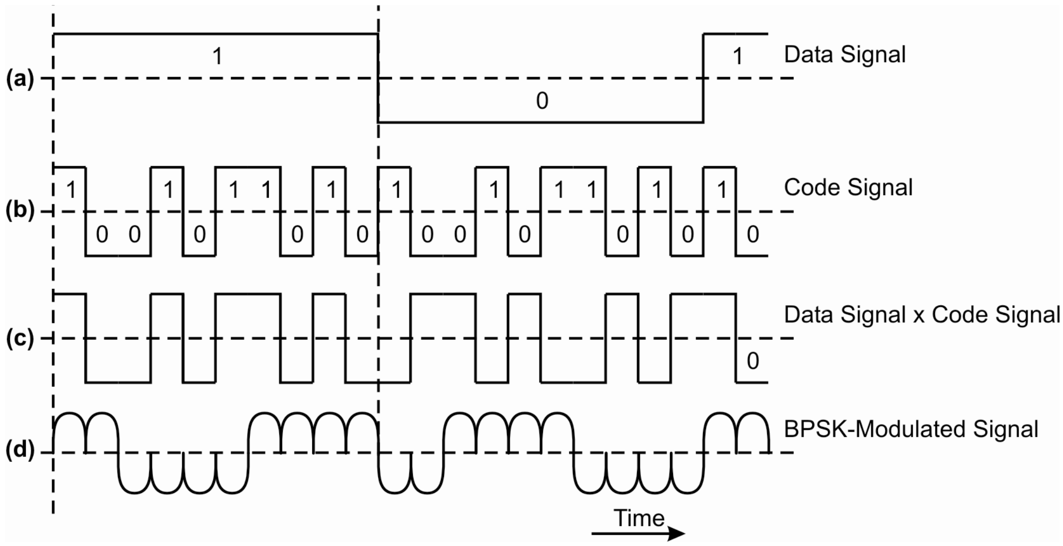

Fig. 8.16: CDMA generation a) original signal; b) code in chip form; c) CDMA signal; and d) BPSK of modulated CDMA signal

The coded spread spectrum signal is modulated over an RF carrier, which is then transmitted over free space channel and is received by the receiver. At the receiver end, first the RF carrier is removed from the received RF modulated signal. Then the message is despread with the relevant coding signal. At the receiver end, to be able to perform despreading operation, it is not enough just to know the code sequence used for spreading the signal, but the codes of received signals and the locally generated codes must also be synchronised in time. This synchronisation is initialised at the beginning of reception and is maintained until the whole signal is received.

Encoding and Decoding

The simplest encoding method used is convolutional encoding where each data is sent in triplicate. Fig. 8.17 shows one example of convolution where four messages M_1, M_2, M_3 and M_4 are sent by repeating 3 times each. At the receiver end, the decoder recognises the message using a majority logic rule i.e. if any message comes twice, it is recognised.

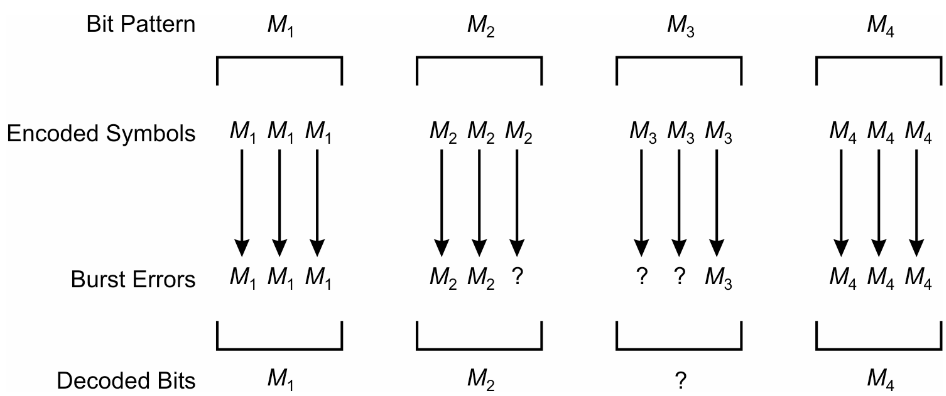

Fig. 8.17: Convolutional encoding

During transmission there can be a *burst error*, which occurs in adjacent messages. This type of error is caused by mainly fading or interference effects. In Fig. 8.17, there is burst error in message M_2 and M_3 as shown. Here the receiver fails to recognise M_3 signal since only one M_3 message is received.

Interleaving of the encoded messages can help in recovering the lost information. Interleaving is a process in which the encoded signals are regrouped before sending as shown in Fig. 8.18. In this case, the messages M_1, M_2, M_3, M_4 are sent consecutively and the whole sequence is repeated thrice.

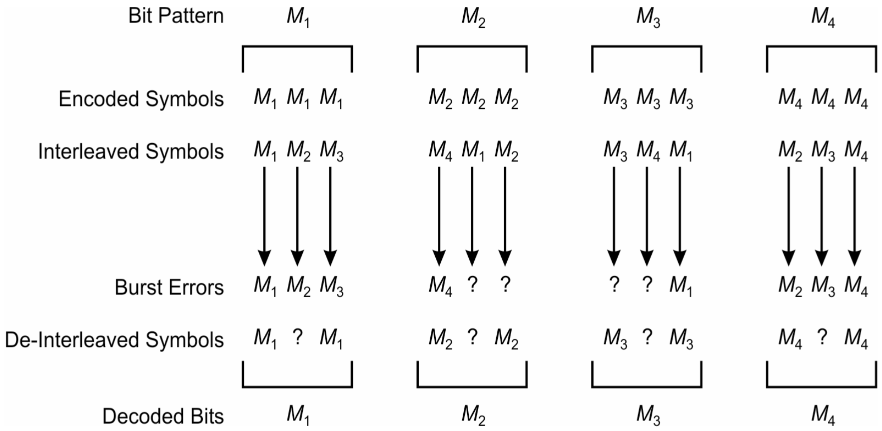

Fig. 8.18: Interleaving and de-interleaving of messages

At the receiver end, the interleaved messages are de-interleaved to get original messages sent in consecutive three repeats (M_1, M_1, M_1, etc). In this process if the burst error occurs, it affects the part of interleaved signals and gets distributed amongst all messages after de-interleaving. As is clear from the figure, all the messages are received at least twice and hence by a majority logic, all the messages are recovered.

The process of CDMA we discussed here is called a **Direct Signal Spread Spectrum** (DS-SS) **CDMA**.

If multiple users transmit a spread-spectrum signal at the same time, the receiver will still be able to distinguish between the users, provided each user has a unique code that has a sufficiently low cross-correlation with the other codes. The transmitted signal can only be despread and the data recovered if the code is known to the receiver. Hence this transmission has good privacy and security.

Let us now summarise the points you learnt in this unit.

8.8 SUMMARY

- Multiplexing allows use of single channel for carrying multiple signals.
- When multiple users can access the single channel, the system is called multiple access system.
- Multiplexing increases the efficient use of a transmission channel and makes the transmission process cost effective.
- Main domains used for multiplexing are space, time and frequency.
- In optical fibres, wavelength division multiplexing is done.
- Space division multiplexing needs dedicated physical channel for each user and hence is not preferred in isolation.
- Radio and satellite communication use SDM.
- Time division multiplexing sends different signals on same channel at different time instants.
- Frequency division multiplexing uses simultaneous transmission of many signals over the same channel, but each signal is modulated on a different carrier frequency.
- ITU standards for telephony define groups, supergroups, mastergroups and supermaster groups for telephone signal transmission.

- A group handles 12 voice channels, a supergroup contains 5 groups, a mastergroup contains 5 supergroups and a supermaster group contains 3 supergroups.
- Wavelength division multiplexing allows utilisation of full bandwidth of an optical fibre, which is much larger than the frequency response of the opto-electronic components used in the optical communication systems.
- CDMA spreads the signal bandwidth by using pseudo noise (*PN*) code in the form of chips. The bit rate of chips is very large as compared to base signal bandwidth. In CDMA each user uses a separate code to characterise the signal and it is known only to the intended receiving user. Hence CDMA transmission is a secure communication.

8.9 TERMINAL QUESTIONS *Spend* 10 *Minutes*

1. What duty cycle pulse signal should be used for an eight-message TDM system? What will be quiet time between the pulses for 8 kHz gating signal frequencies?

2. What is the total bandwidth and various carrier frequencies in case of ITU standard supergroup?

8.10 SOLUTIONS AND ANSWERS

Self Assessment Questions

1. For 10 Hz signal the period is 100 ms. Each sample requires 4 ms. Hence 25 samples can be accommodated.

2. Please refer Fig. 8.19

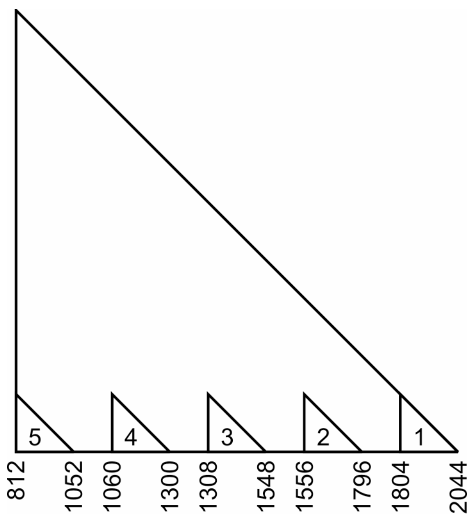

Fig. 8.19: Modulation plan of Mastergroup

Terminal Questions

1. The gating frequency in this case should be 8 kHz i.e. the period is 125 µs. In this time if eight channels are to be accommodated, each channel can get about 15 µs slot. Hence a 10% duty cycle pulse (12.5µs duration) would be appropriate. The quiet time in this case will be about 2.5 µs (15µs – 12.5µs).

2. The supergroup spans between 312 kHz and 552 kHz. Hence the bandwidth associated is 240 kHz. Since the lower side bands are considered, the carrier frequencies of supergroup are 360 kHz, 408 kHz, 456 kHz, 504 kHz and 552 kHz.

Reference Material:

1. *Telecommunication Systems Engineering* by Freeman, Roger; (III Edition) (Wiley-Interscience Publication)
2. www.itu.int