CHAPTER IV
HIGH FREQUENCY ACOUSTIC PROPAGATION CHARACTERISTICS

4.1 Introduction

For most of the practical applications, high frequency sound waves are employed at sea because of their directional nature. However, high frequency acoustic waves, by virtue of their short wavelength, are subjected to larger absorption and scattering, limiting the useful range of propagation. The distinction between high and low frequency propagation is primarily a matter of scale, defined by the dimensionless parameter \( k_h \), \( k \) being the horizontal component of the wave number and \( h \) the ocean depth. In practice high frequency acoustic concerns with the range \( k_h \gg 10 \) i.e., usually \( k_h > 10^2 \). In shallow waters, frequencies above around 2500Hz can be considered as high frequencies. However, these frequencies find only limited applications such as underwater communications while ultrasonic frequencies are employed for a large number of applications like identification, localisation and fish finding.

The characteristics of high frequency acoustic propagation in an oceanic area are very much influenced by the vertical sound velocity gradient. Since the vertical sound velocity distribution changes with season, the acoustic propagation characteristics also exhibit seasonal variations. In regions where the sound velocity gradient is negative, a horizontal acoustic beam will get refracted downwards forming a surface shadow zone. The sharpness of bending will depend on the magnitude of the gradient, the larger the magnitude, the sharper will be bending. In such situations, the horizontal range of
propagation will be very much limited. On the other hand, in a layer where the sound velocity gradient is positive, the beam gets refracted upward forming a bottom shadow zone (Urick, 1975). In this case, the acoustic propagation will be as in a surface duct where the propagation losses tend to be smaller (Camp, 1970). However, in cases where the gradient are very small, large horizontal ranges of propagations are possible irrespective of the sign of the gradient.

4.2 RESULTS

Monthly vertical profile of sound velocity are drawn for the sections off Quilon, Cochin and Kasargode for the years 1972 and 1973. (Fig.19 to 28) The vertical distribution diagrams of sound velocity are discussed for the individual sections grouping corresponding months of both the years with a view to bring out inter-annual variability.

4.2.1 QUILON

Fig. (19) shows the vertical profile of sound velocity off Quilon during March 1972. The vertical profile show a negative gradient up to a depth of 10m and a positive gradient up to about 30m at the third and fourth stations from the coast while at the second station this feature is limited to 20m depth. The first station shows no vertical gradient. This indicates the presence of a surface channel extending up to a depth of 20-30m. Below 30m, the gradient is again negative with small magnitudes up to 75m. Below this depth at the fourth station, the profile shows a larger negative gradient up to the bottom. The negative gradients below 30m indicate that high frequency propagation as in a bottom
duct. A horizontal acoustic beam below 30m, where the sound velocity gradient is negative, will refract downwards to form a shadow zone below the surface channel. Small gradients observed during this month indicate large horizontal ranges of propagation. It is interesting to note that the picture is strikingly different during March 1973 (fig. 19) at the three stations where the sound velocity gradients are slightly positive at the second station and nearly zero at the other stations. This indicates possibility of sound propagation as in a surface duct and formation of a bottom shadow zone.

During April 1972 (fig. 20) the profile show negligible gradient up to 10m at all stations except the fourth station, where the gradient is negligible up to 20m. Below these depths, the gradient is negative up to bottom at all stations. This sound velocity structure indicates possibility of sound propagation as in a bottom duct. During April 1973 (fig. 20) all stations show slightly negative gradients in the entire water column indicating again sound propagation as in a bottom duct.

During May 1972 (fig. 21), the vertical profiles show negative gradient at the first station. At the second and fourth stations, small positive gradients are observed in the surface layers up to 10m and 20m respectively. Below these depths, the gradients are negative. However, at the third station the gradient is small and negative in the surface layers up to 20m and comparatively large and negative below. The above distribution indicates the sound propagation as in a surface duct above 10-20m depth and as in a bottom duct below. Similar vertical distribution is observed during June 1973 also (fig. 22).
During July 1972 (fig. 23) the gradients are small and negative in the surface layers up to 20m and comparatively large and negative below that depth. The gradient of the vertical profile of sound velocity during August 1973 (fig. 24) indicate similar features in the surface layers, except at the first station where the gradient is large and negative whereas in deeper layers the gradients are smaller. The above feature indicates sound propagation as in a bottom duct.

During September 1972 (fig. 25), the vertical gradients are negative and large in the entire water column indicating possibility of formation of strong shadow zone just below the surface. The larger velocity gradients indicate lower ranges of propagation. Identical situation is presented in fig. 26, for October 1973 except that the gradients are considerably lower indicating larger ranges of propagation.

Fig. 27 illustrates the profile of sound velocity off Quilon during November 1972. The gradient is slightly negative up to the bottom at the first and third stations and up to 20m at the second station. At this station, below 20m, the gradient shows larger negative values. The possibility of propagation as in a bottom duct with larger horizontal range and formation of a surface shadow zone is indicated during November.

January 1973 (fig. 28) presents a different picture with nearly zero gradient at the first station and slightly positive gradients at the second and third stations from the surface to the bottom. This indicate that the sound propagations is as in a surface duct with very large range of propagation and possibility of formation of a bottom shadow zone.
4.2.2 Cochin

Fig. (19) illustrates the vertical profiles of sound velocity off Cochin during March 1972. The vertical profiles show small positive gradients at the first and third stations where as it is slightly negative at the second station. The fourth station from the coast, however, shows small negative gradient up to a depth of 10m, slightly positive gradient up to 50m and again negative gradient up to the bottom. This sound velocity structure indicates the possibility of high frequency propagations as in a surface duct and the formation of a bottom shadow zone. The small positive gradients generally observed during the months indicate large horizontal ranges of propagation. The picture is slightly different in March 1973, (fig. 19) where the sound velocity gradients are slightly negative up to the bottom except at the first station where it is slightly positive. This indicates the possibility of high frequency propagation as in a bottom duct, and the formation of a surface shadow zone. The small gradients indicate comparatively larger ranges of propagation.

During April 1972 (fig. 20), the profile show a small negative gradient at the first station and nearly zero gradient at the second station. At the third station, the gradient is small and positive up to a depth of 20m below which the gradient is negative. At the fourth station, however the gradient is slightly negative up to 10m, slightly positive up to 20m, and again negative below. This sound velocity structure indicates the formation of a surface duct above 20m depth and a bottom duct below that depth.
During May 1972 (fig. 21) the profiles show slightly positive gradient at the first station. At the second station the gradient is negative and is of small value up to a depth of 10m below which it is larger. At the third station, however, the gradients is comparatively larger and negative up to the bottom. The fourth station shows a small positive gradient up to 10m below which the gradient is negative and small up to 50m. Below this depth the negative gradient is comparatively larger. This velocity structure indicates the high frequency propagation as is a bottom duct and formation of a surface shadow zone. During 1973 May (fig. 21), the profile show negative gradient at the first station. The second station shows nearly zero gradient up to the bottom. At the third and fourth stations, the gradients are negative and small up to a depth of 10m and 30m respectively, below which the gradients are larger. The above feature indicates a propagation characteristic similar to May 1972.

During July 1972. (fig.23) the profiles show large negative gradient at the first station. The sound velocity gradients are positive at the second and third stations up to a depth of 10m whereas it is positive up to 20m at the fourth station. The gradients are negative and large below 10m depth at second and third stations. At the fourth station, however, it is negative and large up to a depth of 50m, below which the negative gradient is comparatively smaller. The above structure indicates the propagation as in a surface duct above 10 to 20m depth and as in a bottom duct below with the formation of a shadow zone just under the surface duct. It is interesting to not that during
July 1973 (fig 23) also the sound velocity structure is more or less similar except at the third station where the gradient is slightly negative up to 10m.

During September, 1972 (fig. 25), the profiles show large negative gradients at the first station. At the second stations the gradients are large and negative up to a depth of 30m and 50m respectively below which the gradient is smaller. At the third station however, the gradient is negative and comparatively smaller up to a depth of 10m. Below this depth, the gradient is very large up to a depth of 20m. The magnitude of the gradient decreases below 20m. The above features indicate the high frequency propagation as in a bottom duct. The large negative gradients suggest shorter ranges of propagation.

Fig (26) illustrates the sound velocity profiles during October 1972. At the first station, the sound velocity gradient is negative and smaller than during the previous month. At the second and third stations the sound velocity gradients are negative and small up to a depth of 10m below which the values are comparatively larger. However, at the third station, below 30m, comparatively smaller values are encountered. At the fourth section, the gradient is negative and small up to a depth of 30m and slightly positive below up to a depth 50m. Below this depth, the gradient is again slightly negative up to 75m depth. Below 75m the gradient is large and negative. The above features indicate the propagation characteristics similar to September, 1972. The sound velocity profiles during October 1973 (fig 26) show a different picture. The sound velocity gradient at the first station is nearly zero. The gradient at the second station is positive and small up to a depth of 10m below which it
is slightly negative. At the third station, the gradient has extremely small negative values up to 20m below which it is slightly larger. However, at the fourth station the sound velocity gradient is small and negative up to 10m and slightly positive up to 20m. Below this depth, the gradient is comparatively larger and negative. The conditions as above indicates the propagation as in a surface duct above 10m to 20m and as in a bottom duct below with a shadow zone just below the surface duct.

The sound velocity profiles during November 1972 (fig. 27) show that the sound velocity gradient at the first station is nearly zero. At the second station, the gradient is negative up to 10m and nearly zero below this depth. The gradients are negative up to 10m and slightly positive below up to 30m at the third station and up to 50m at the fourth station. The sound velocity gradients are again negative below these depths. The above sound velocity structure indicates the propagation as is a surface channel above 20 to 30m and as in a bottom duct below this depth, with a shadow zone just below the surface channel. November 1973 (fig. 27), however shows negative gradients at the first station and slightly positive gradients at the second station. At the third and fourth stations, the sound velocity gradients are slightly negative up to 10m and slightly positive up to 30m below which the values are again slightly negative. In this case also the propagation characteristics will be more or less similar to that during November 1972.

During January 1973 (fig. 28) the profiles show negative gradient at the first station. At the other stations the gradients are
negative in the surface layers and positive below except at the fourth station where it is again negative below 75m. The gradient is negative up to 10m at the second station, 30m at the third station and 50m at the fourth station. The above conditions indicate the high frequency propagation as in a surface channel.

4.2.3 KASARGODE.

Fig. 19 shows the vertical profiles of sound velocity during March 1972. The sound velocity gradients are seen to be negative and small up to the bottom at all the stations. This indicates that the high frequency propagation in this region is as in a bottom duct. Small gradients values indicate large ranges of propagation. Similar propagation characteristics are observed during March 1973 (fig. 19) also when the sound velocity gradients are again negative and small.

During April 1972 (fig. 20), the gradients are positive and small at the first station. At the second station, the gradient is positive up to 10m and negative below, the magnitudes being small in both the cases. At the third station, however, the gradient is slightly negative up to 10m, slightly positive up to 20m and again negative is the entire water column. This velocity structure indicates the propagation as in a surface duct above 10 to 20m depth and as in a bottom duct below. The propagation characteristics during May 1973 (fig. 21), June 1972 and June 1973 (fig. 22) are also observed to be similar. During May 1973 small positive gradients are observed in the surface layers at the third and fourth stations, up to 10m and 20m respectively with negative gradients below these depths. During June 1972 and June
1973 positive gradients are observed at these stations up to 30 m. At the first station the gradient is negative during these three months. At the second station it is nearly zero up to 10 m during May 1973, it is positive up to 30 m during June 1972 (fig. 22). Below these depths, the gradients are negative. During June 1973, the second station shows negative gradients in the surface layers also. The magnitudes of the negative gradients below the surface layers during June 1973 are considerably larger than those during the other two months.

During August 1972 (fig. 24), the first and second stations show large negative gradients throughout the water column. At the third and fourth stations, small negative gradients are observed in the surface layers up to a depth of 10 m. Below this depth the gradients are large up to 30 m at the third station and up to 50 m at the fourth station, below which the gradient is again small and negative. The vertical distribution as above indicates the propagation as in a bottom duct and formation of a surface shadow zone. Larger negative gradients indicate lesser ranges of propagation. The vertical sound velocity distributions during August 1973, September 1972 and September 1973 (figs. 25 and 26) are also similar with slight differences. During August 1973 gradients are smaller at the first and second stations and positive up to 20 m at the fourth station. During September 1972, the sound velocity gradient is negative and large in the surface layers at the fourth station. During September 1973, the negative gradients are generally small. These small differences will not however materially affect the nature of propagation in the region which will be similar to that during August 1972.
During November 1973 (fig. 27) the vertical sound velocity distribution shows negative gradient at the first station. At the second and third stations, the gradients are slightly positive up to 10m and comparatively large and negative between 10 and 30m. Below this depth, the gradient is again slightly negative. At the fourth station, small negative gradient is observed in the surface layers up to 30m. Between 30 and 50m the gradient is comparatively large and negative. Below 50m, the gradient has small negative value. The distribution as above indicates propagation as in a surface duct above 10m and as in a bottom duct below 10m.

The vertical profile during December 1972 are shown in fig. 28. The sound velocity gradient is nearly zero at the first section. At the second station, the gradient is slightly negative up to 10m and positive below. At the third station, the gradient is positive up to 30m and negative below. At the fourth station, however, the sound velocity gradient is negative up to 20m, positive up to 50m and negative below. The above distribution indicates sound propagation as in a surface channel above 30m depth and as in a bottom duct below.

During February 1973 (Fig. 28) the gradient is nearly zero at the first station and slightly positive at the second station. At the third and fourth stations small negative gradients are observed in the surface layers up to 10m below which the gradients are slightly positive in the entire water column. The above indicates the propagation as in a surface duct and formation of a bottom shadow zone.
Fig. 19 Vertical distribution of sound velocity (values in M/s-1500) during March 1972 & 1973.
Fig. 20  Vertical distribution of sound velocity (values in M/s-1500) during April 1972 & 1973.
Fig. 21 Vertical distribution of sound velocity (values in m/s-1500) during May 1972 & 1973.
Fig. 22 Vertical distribution of sound velocity (values in m/s-1500) during June 1972 & 1973.
Fig. 23 Vertical distribution of sound velocity (values in m/s-1500) during July 1972 & 1973.
Fig. 24 Vertical distribution of sound velocity (values in m/s-1500) during August 1972 & 1973.
Fig. 25  Vertical distribution of sound velocity (values in M/s-1500) during September 1972 & 1973.
Fig. 26 Vertical distribution of sound velocity (values in m/s-1500) during October 1972 & 1973.
Fig. 27 Vertical distribution of sound velocity (values in m/s-1500) during November 1972 & 1973.
Fig. 28 Vertical distribution of sound velocity (values in M/s-1500) during December 1972, January 1973 and February 1973.
4.3 DISCUSSION.

An attempt to summarize the above results to arrive and the overall features of the high frequency acoustic propagation characteristics in the region is made in the following paragraphs. From the beginning of the year up to the end of April, the sound velocity gradients in the three sections are found to be generally very small in magnitude. This is to be expected because during this time of the year, generally, a well mixed layer is present in the region. The gradients can be either positive or negative. In the section off Quilon, during March 1972, the gradient is first negative, then positive and again negative with increase in depth. During April, the gradient is negative in the entire water column. In 1973 it is positive from the beginning of the year to the end of March and negative in April. In the section off Cochin, in the year 1972, the sound velocity gradient is positive during March and positive in the surface layer and negative below during April. In 1973 off Cochin, it is positive during January and negative in March. In the section off Kasargode it is negative during March 72 and positive in the surface layers and negative below during April 72. In 1973, it is positive during February and negative during March.

A horizontal acoustic beam in a water layer where the sound velocity gradient is negative will get refracted and bent downwards forming a surface shadow zone. On the other hand, in a layer where the sound velocity gradient is positive, the beam will be refracted upwards forming a bottom shadow zone (Urick, 1975). In the first case, the acoustic propagation will be as in a bottom duct and the propagation losses tend to be larger
because of the possible bottom losses. In the second case, the propagation will be as in a surface duct and the propagation losses tend to be smaller (Camp, 1970). The conditions existed during March 1972 off Quilon and April 1972 off Cochin and Kasargode are, however, different. During March 1972, off Quilon, the acoustic propagation will be as in a surface channel in the surface layers and as in a bottom duct in the bottom layers with a shadow zone forming just below the surface layers. At Cochin and Kasargode, during April 1972, the acoustic propagation in the surface layers will be as in a surface duct whereas below the surface it is as in a bottom duct. However, since the magnitudes of the gradients are very small during the period large horizontal ranges of propagation may be possible irrespective of the sign of the gradients.

From the period from May to October, in both the years, in the three sections sound velocity gradients are seen to be positive in the surface layers and negative below during May 1972 and June 1973 off Quilon, during July 72 and July and October 73 off Cochin and during June 72 and May and June 73 off Kasargode. During the other months, sound velocity gradients are negative in all the three sections. The magnitudes of the negative gradients in all the sections are generally large and the sharpest gradients are observed in the bottom layers until the beginning of July. After that period, in the sections off Cochin and Kasargode the magnitude of the gradients in the surface layers is larger than that in the bottom layers until the end of September. In the section off Quilon, however, larger gradients in the surface layers, during July to September, are observed only in 1972. In 1973, larger gradients are observed in the bottom
layers throughout the period. During the month of October 1973, in the section off Quilon, the sound velocity gradient is seen to have reduced from its value during the monsoon season and is nearly uniform throughout the water column. In the sections off Cochin and Kasargode, during September -October, sharpest gradients are observed below 10m from the surface with smaller values of gradient both in the surface and bottom layers. This sound velocity structure is almost completely broken up by the end of October in the section off Cochin, but off Kasargode it persists until the beginning of November.

Hence irrespective of the depth of the horizontal acoustic beam, in the three sections a surface shadow zone will generally be formed during this period in both the years under study except in the month when the sound velocity gradient is positive in the surface layers. A positive gradient in the surface layer and sharp negative gradient below causes a horizontal acoustic beam in the surface layer to be refracted upwards and form a surface duct with negligible penetration downwards. A horizontal beam in the bottom layer, however, will be refracted sharply downwards. Under this condition a shadow zone is formed below the depth of the surface layer.

In the section off Cochin during the months of August to October, and Kasargode during the months of July to October, in both the years, and in the section off Quilon during July to September in the year 1972, a horizontal acoustic beam in the surface layers, where a sharp negative sound velocity gradient is observed, is refracted and bent sharply downwards so that a surface shadow zone is formed and the useful horizontal range of propagation
will be limited. But in the bottom layer the acoustic beam can have a greater range of horizontal propagation. In this case the acoustic beam is prevented from reaching the surface with the result that in the bottom layer the horizontal propagation is as in a bottom duct.

The conditions in the period from November to the end of the year show that in the section off Cochin in both the years and in the section off Kasargode during 1972 the sound velocity gradients are negative in the surface layers, positive and then negative as depth increases. At Kasargode, during 1973, however, the surface layers show positive gradients below which the gradients are negative. In the section off Quilon, however, the gradients are observed to be negative. In the first two cases the acoustic propagation in the surface layers will be as in a surface channel and surface duct respectively whereas below the surface layers the propagation will be as in a bottom duct. In these cases the shadow zone will be found below the surface layers. A horizontal beam in the third case will be refracted downwards forming a surface shadow zone. Since the magnitudes of the gradients are small, horizontal propagation ranges larger than during the monsoon season are indicated.