PROPAGATION OF RADIO WAVES

INTRODUCTION

1. The design of a communication system depends very much on how energy is propagated from transmitter to receiver. A radio communication system is complicated by the fact that propagation occurs in different ways for different frequency ranges. We therefore find that different frequency ranges are used for different communication purposes. The frequency range used depends mainly on the range required.

(1) At VLF and LF, reliable long distance communications can be achieved. However, because the wavelength is large, practical aerials are inefficient at these frequencies and high power transmitters must be used.

(2) At HF, equipment is of manageable proportions and long ranges can be achieved. These circuits are relatively unreliable and frequent frequency changes can be necessary.

(3) Above HF, equipment is small and the size of the aerial decreases as the operating frequency increases. The ranges obtainable are slightly greater than the line of sight range.

RADIATION FROM AN AERIAL

2. The energy radiated from a transmitting aerial consists of waves of electric and magnetic fields (electromagnetic waves) travelling through space at the velocity of light (approximately 3×10^8 metres/sec). The distance between peaks of Electric (or Magnetic) field strength is the wavelength (λ) of the radiated field and is related to the frequency (f) by:

$$f \times \lambda = 3 \times 10^8 \text{ m/s}$$

3. Close to the aerial the electrical and magnetic fields are very complicated, but at distances of greater than about 5λ, the electric and magnetic fields are much simpler and are of the form shown below. These simpler fields are known as the 'radiation field' and consist of electric and magnetic fields which are at right angles to each other and to the direction of propagation. Note that electromagnetic waves are radiated in almost all directions from the aerial, with field strengths varying according to the particular aerial's radiation polar diagram.

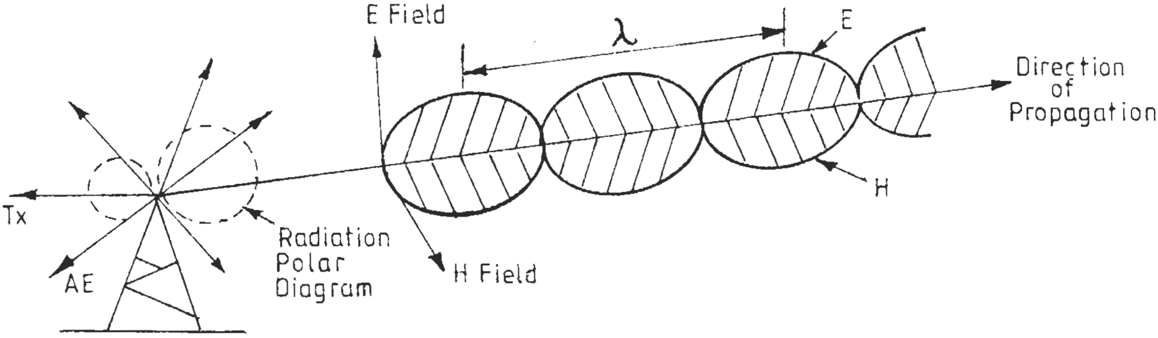

Figure 2A.1 - The Radiation Field

4. All the electromagnetic waves contain the same information and this means that it is possible for the receiver to get the same information from two or more propagation paths. As the path lengths will probably be different, the phases of the received signals will be different and fading can occur. Also the mechanism by which the propagation takes place can be different for the various electromagnetic waves being radiated from the aerial.

RF SPECTRUM

5. The internationally accepted classification of radio frequencies is shown in the diagram below:

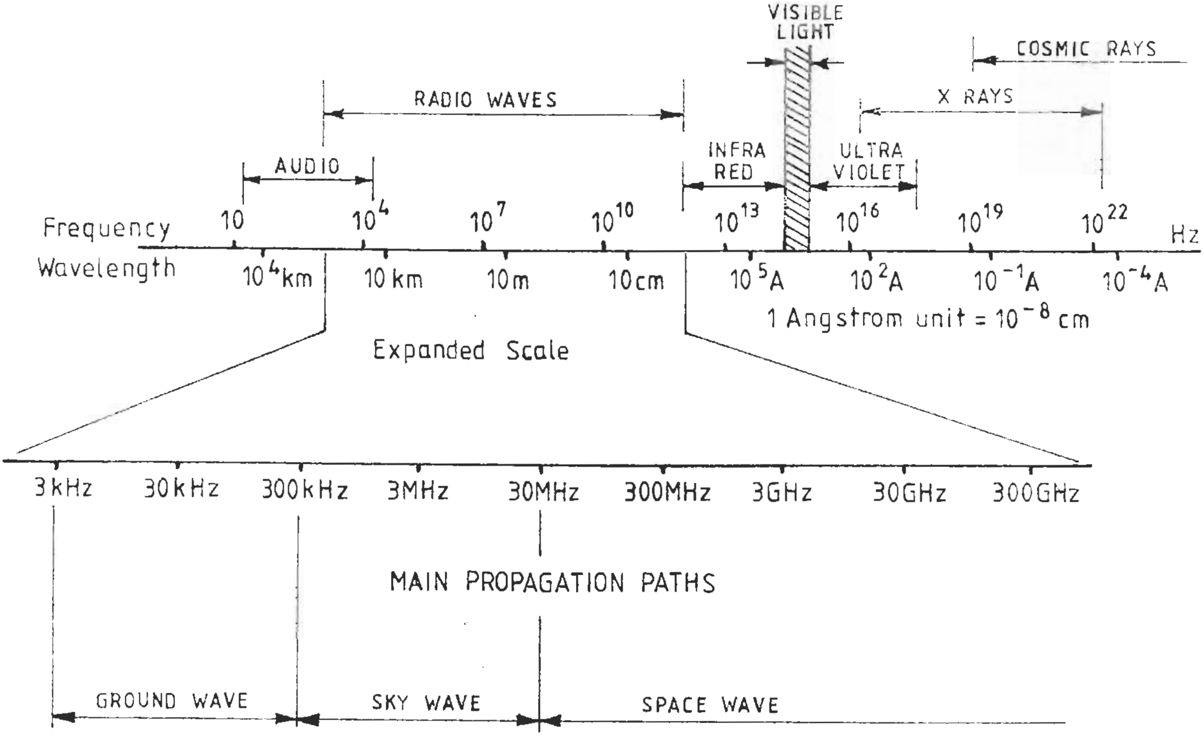

Figure 2A.2 - The RF Spectrum

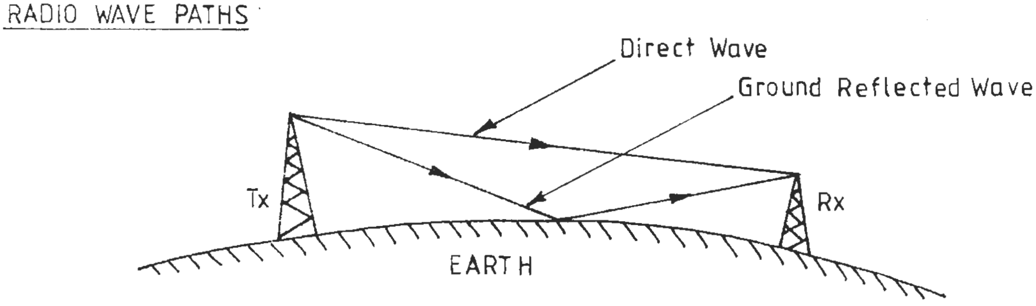

Figure 2A.3 - Propagation Paths

RADIO WAVE PATHS

6. If the transmitter and receiver can be joined by a straight line, then a radio wave can propagate directly between the transmitter and receiver. This line of sight transmission is called the DIRECT WAVE.

7. Another radio wave can be received called the GROUND REFLECTED WAVE which has been reflected from the surface of the earth.

8. The combination of these two waves is called the SPACE WAVE.

SPACE WAVE = DIRECT WAVE + GROUND REFLECTED WAVE

9. If these were the only two paths, it would be impossible to receive signals from a transmitter situated below the horizon. Reception beyond the horizon can take place by means of SURFACE WAVES and/or SKY WAVES.

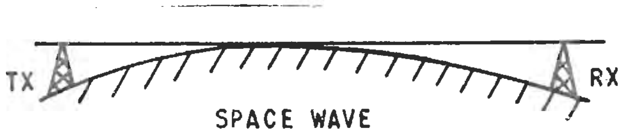

Figure 2A.4 - Space Wave

10. The SURFACE WAVE is produced by energy travelling close to the surface of the earth. The combination of DIRECT, GROUND REFLECTED and SURFACE waves is called the GROUND WAVE.

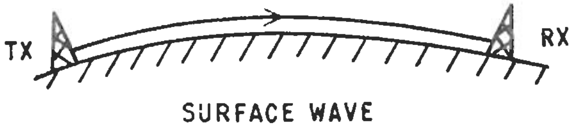

Figure 2A.5 - Surface Wave

ie: GROUND WAVE = DIRECT + GROUND REFLECTED + SURFACE WAVE

11. The SKY WAVE is a wave which passes through the upper atmosphere and is refracted back to earth by an ionised layer called the IONOSPHERE.

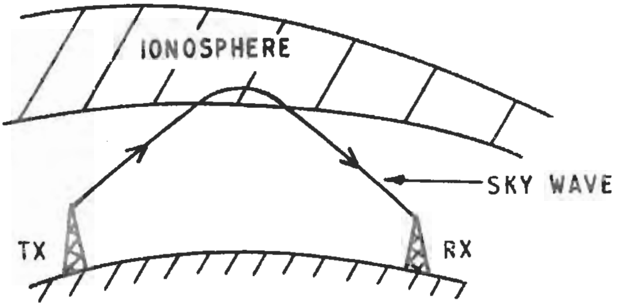

Figure 2A.6 - Sky Wave

Notes:

(1) All practical aerials radiate some energy in ALL directions so that energy is propagated along all the paths so far mentioned.

(2) The actual radio path which carries most of the energy depends to a large extent on the frequency of the transmitted signal.

(3) All waves are electromagnetic radiation, it is only their paths which determine their nomenclature.

THE GROUND WAVE

12. The ground wave consists of the three components shown below:

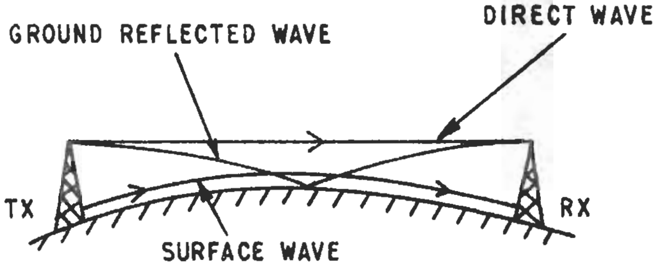

Figure 2A.7 - Ground Wave

(1) At VHF and above: the wavelength is small and the aerials are usually elevated. The surface wave is severely attenuated at these frequencies so the SPACE WAVE predominates.

(2) At low frequencies: the wavelength is so large that the aerials are close to the ground. When an aerial is not elevated, the ground reflected wave suffers a 180° phase change on reflection so that the direct and ground reflected waves cancel. Thus at these frequencies, the SURFACE WAVE is the main radio path.

The Surface Wave

13. The surface wave is produced by the electromagnetic wave travelling close to the ground and guided by it to follow the curvature of the earth. This is due to the mechanism of diffraction. Diffraction occurs for all types of wave motion and causes bending of the wave around any obstacle it passes. For the surface wave the obstacle is the earth, and the amount of diffraction is dependent upon the ratio;

$$\frac{\lambda}{\rho}$$

where λ = wavelength of EM wave
and ρ = radius of the earth

14. Another factor affecting the diffraction is the imperfect conductivity of the ground. As the wave travels it induces currents in the earth and energy is therefore continually lost from the surface wave in maintaining these currents against the finite conductivity of the earth. This causes the surface wave to be attenuated; the lower the conductivity, the smaller the surface wave range.

15. The depth of penetration of the induced current into the ground depends on the ground constants and the EM wave frequency. It can be shown that the depth of penetration δ is dependent on the ratio;

$$\frac{\sigma}{f}$$

where σ = conductivity of earth
and f = frequency of EM wave

16. The range of the surface wave depends upon a number of factors:

(1) The radiated power.

(2) The radiated frequency; the lower the frequency the greater the range.

(3) Nature of the ground; the higher the conductivity the greater the range. All other factors being constant, the range of the surface wave is therefore greater over the sea than it is over the desert.

(4) Aerial efficiency and directivity; the greater the directivity the stronger will be the surface wave and therefore the greater the range in certain directions.

(5) Polarisation of the wave; must be vertical. Horizontally polarised waves are greatly attenuated because the electric field is effectively short circuited by the earth and the magnetic field simply sets up eddy currents in the earth.

17. Typical ranges under given conditions are shown in the graph below:

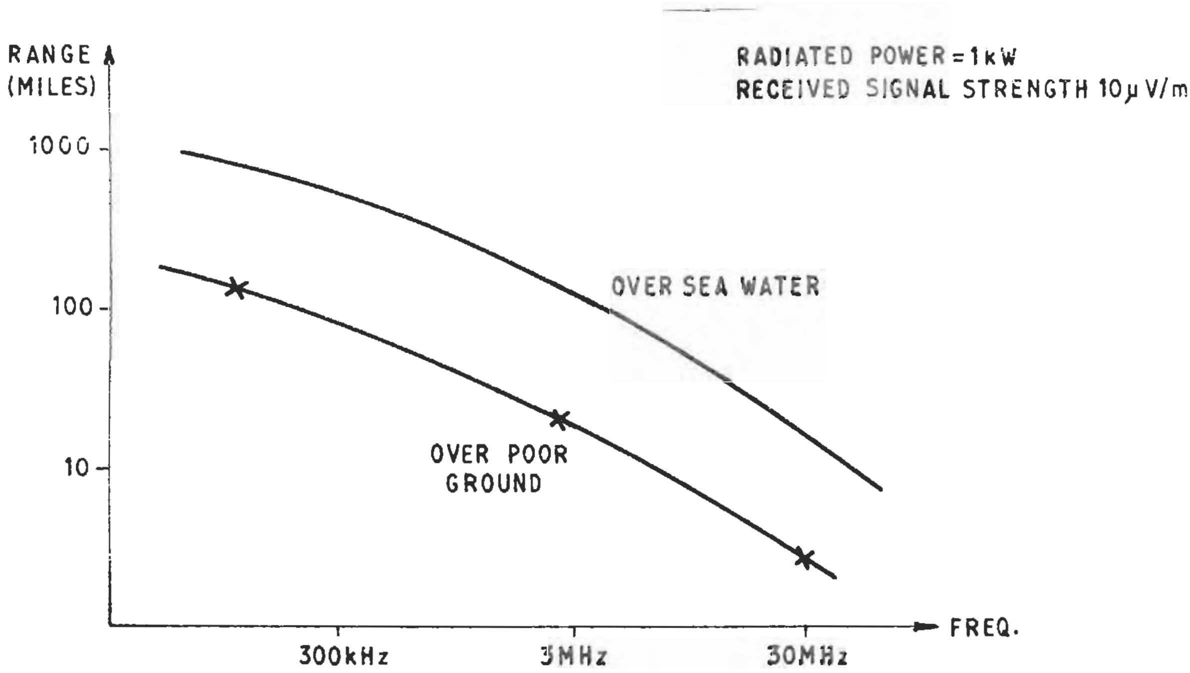

Figure 2A.8 - Typical Ranges for Ground Waves

<u>The Guided Wave</u>

18. Once the EM wave frequencies are low enough, the ionosphere acts as a reflecting boundary and the distance between the earth and the ionosphere becomes comparable with wavelength of EM wave. When this happens, the wave is trapped between the ionosphere and earth boundaries, and the EM waves are guided around the earth to give world-wide ranges. The ionosphere and earth boundaries form a "waveguide" for the VLF electromagnetic waves.

<u>Application of Surface Wave</u>

19. Surface wave propagation gives reliable communications free from ionospheric effects at frequencies below 2 MHz. Long distance communications use the LF and VLF bands. Since very large aerials and high transmitter powers are required, LF and VLF transmitters are usually shore based. Other applications include communications to submarines (at periscope depth or surfaced), navigational aids (DECCA, LORAN) and some broadcasting (Radio 2, 200 kHz etc).

THE ATMOSPHERE

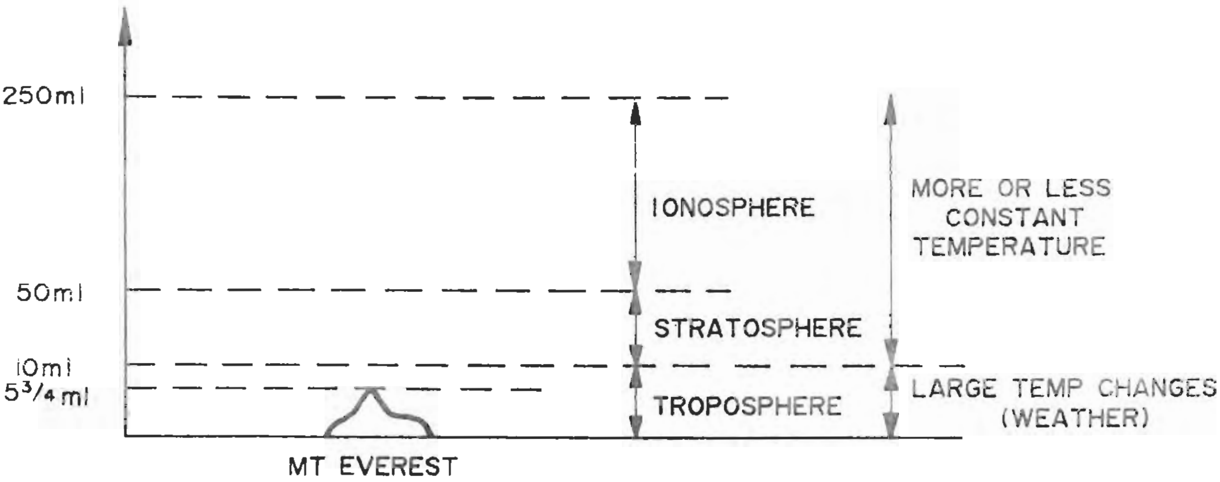

Figure 2A.9 - Atmospheric Layers

THE SKY WAVE

20. It was originally thought that radio waves only travelled in straight lines, like light waves, so that reception beyond the horizon was impossible. However, in 1901, Marconi established communications between England and Newfoundland, a distance of about 2000 miles. Heaviside and Kennelly suggested independently that the earth was surrounded by a layer of ionised gas which could bend radio waves of certain frequencies downwards so that they would be received at a distant point. This layer of gas was later termed the IONOSPHERE and found to be composed of four separate layers during the day.

Formation of the Ionosphere

21. The ionosphere is a region of the atmosphere between 30 and 150 miles above the earth. It consists of electrically charged particles, positive ions and electrons, which affect the propagation of radio waves through this part of the atmosphere. The effect which the ionosphere has upon the radio waves, depends upon the frequency of the wave. It will produce refraction and absorption of all waves by different amounts.

22. The energy required to change the atmosphere into a varying concentration of charged particles, comes from the sun as X-rays, extreme ultra violet, and ultra violet radiation. This dependence upon the energy of the sun, means that the ionospheric density will alter with changes in the time of day, season of the year, and position of the earth's surface (latitude).

23. The atmosphere consists of several different gases which require different ultra violet radiation wavelengths to produce ionisation. The number of gas atoms which are ionised therefore depends upon the gas density in a particular region and the intensity of the appropriate ultra violet radiation. An additional factor which will finally govern the resultant free electron density is the process of recombination. In the lower atmosphere the number of gas atoms is so large that recombination takes place almost immediately. However in the upper atmosphere where the number of atoms is considerably smaller, the chance of a meeting between ion and electron is very much less and hence recombination takes place at a much slower rate. An equilibrium is reached where number of electrons being formed per second by radiation equals the number recombining per second. Diagrams illustrating the formation of the ionosphere are shown below:

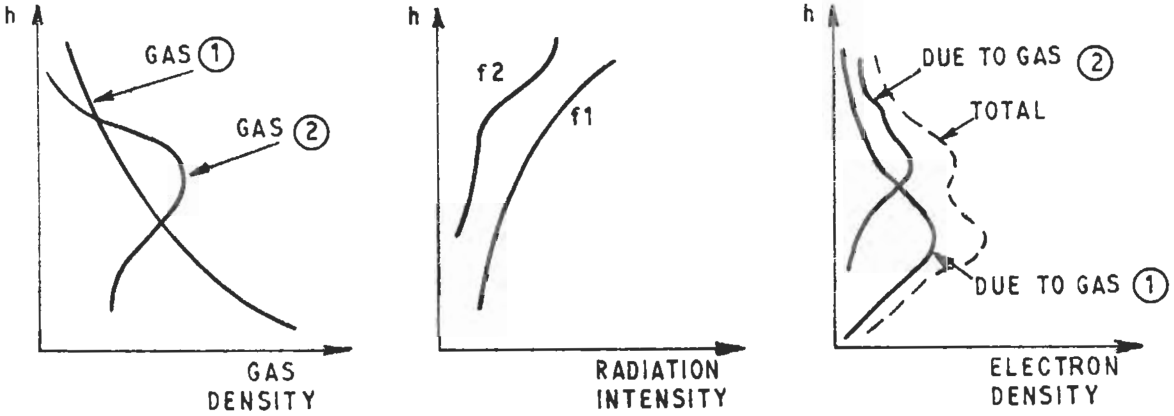

Figure 2A.10 - Ionospheric Formation

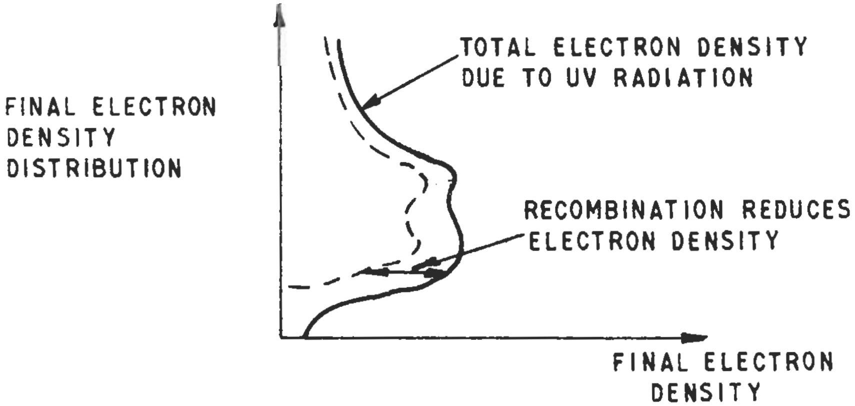

Figure 2A.11 - Electron Density Distribution

24. It can be seen that the formation process produces a number of irregularities in the distribution of electrons in the atmosphere. The resulting peaks in the distribution are referred to as the D, E, F1 and F2 layers. An example of a practical distribution is shown below:

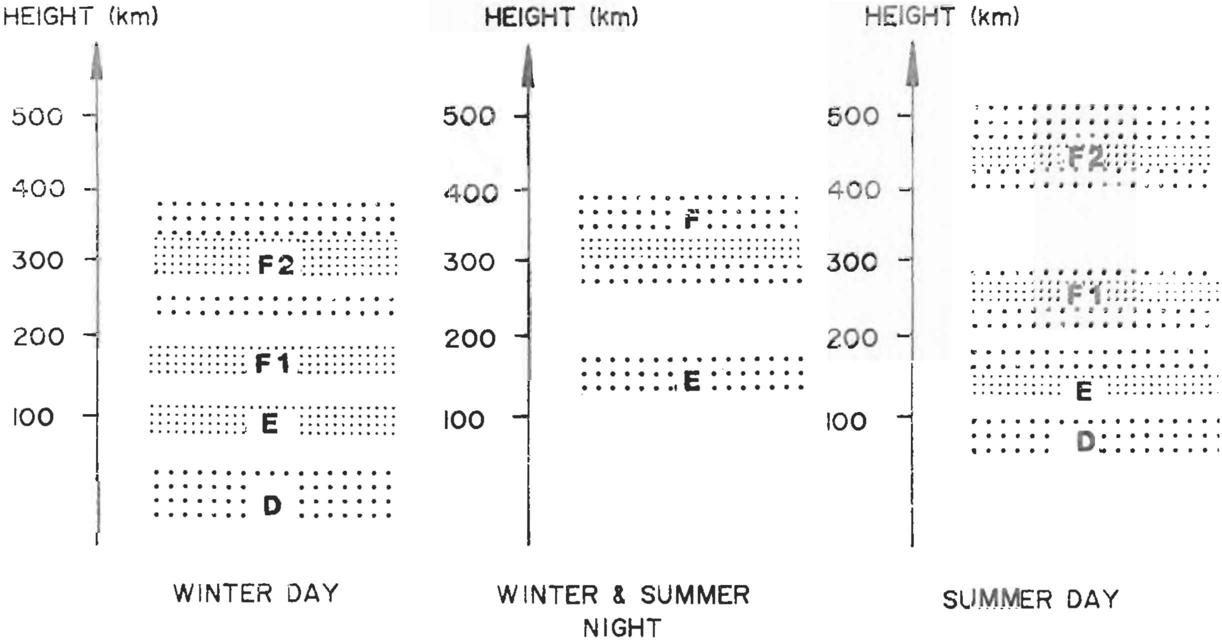

Figure 2A.12 - Ionospheric Layers

Properties of the Ionised Layers

25. D Layer. Occurs only during the daylight hours and behaves as REFLECTOR only to VLF and LF radio waves, when ranges in excess of several thousand miles are easily obtained.

It is weakly ionised layer of high GAS DENSITY which attenuates all waves passing through it.

NB: This excludes the VLF and LF bands since these frequencies are reflected instead of being refracted.

E Layer. During daylight hours, the height of the E layer remains practically constant. It remains weakly ionised during the night, but this is insufficient to affect the propagation of radio waves with frequencies above LF.

F Layer. This is the most important layer as far as HF propagation is concerned. During the day it is divided into two layers F1 and F2 but at night the layers combine to form a single layer, referred to as the F layer.

Refraction of E-M Waves

26. As an electromagnetic wave crosses the boundary between two regions having a different 'refractive index', the wave is bent as shown below:

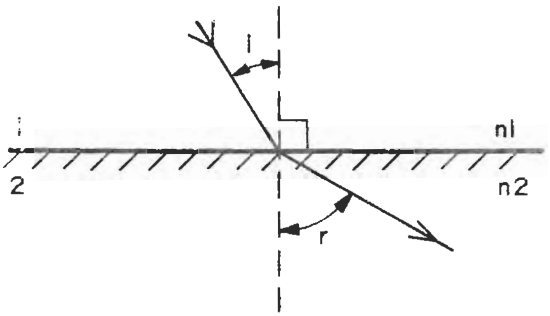

Figure 2A.13 - Refraction of EM Waves

where n1 = refractive index of region 1
and n2 = refractive index of region 2

27. The direction in which the wave bends (either towards or away from the normal to the boundary surface) depends upon the relative sizes of the two regions refractive indices. This bending is defined by Snell's Law and is given by:

$$\frac{\sin i}{\sin r} = \frac{n2}{n1}$$

where i = angle of incidence
and r = angle of refraction

Thus if n2 is greater than n1:

$\sin i > \sin r$

$\therefore$ $i > r$

$\therefore$ wave is refracted towards the surface normal.

But if n2 is less than n1:

$\sin i < \sin r$

$\therefore$ $i < r$

$\therefore$ wave is refracted away from the surface normal.

Total Internal Reflection

28. When a wave travels from a region of high refractive index into a region of low refractive index the wave is refracted away from the normal. As the angle of incidence is increased, eventually the angle of refraction will approach 90° when the wave would be expected to travel along the boundary. The wave does not, in fact, travel along the boundary. Instead it is totally reflected at the boundary and never enters region 2 as shown in Fig 2A.14. The critical angle at which total internal reflection occurs is also shown in Fig 2A.14. For all angles greater than i_{cr} the wave is refracted normally.

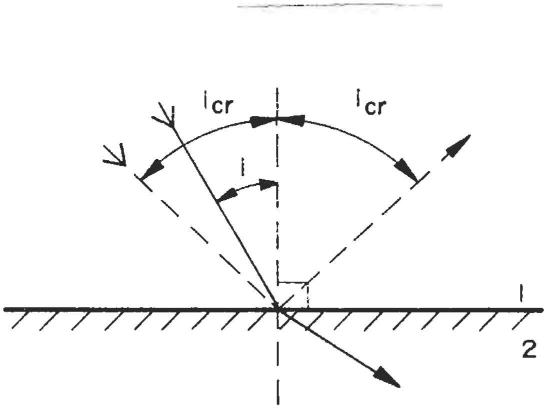

Figure 2A.14 - Total Internal Reflection

Path of Sky Wave through the Ionosphere

29. As discussed previously, the ionosphere consists of a region containing free electrons, the density of which varies with height. It can be shown that because of the free electrons, this region has a refractive index less than that of air (n for air = 1). Further the refractive index is inversely proportional to the electron density and therefore varies with height through the ionosphere. To trace out the path of a wave through the ionosphere we divide up the ionosphere into a number of very small layers where we assume the refractive index (and therefore the electron density) is constant.

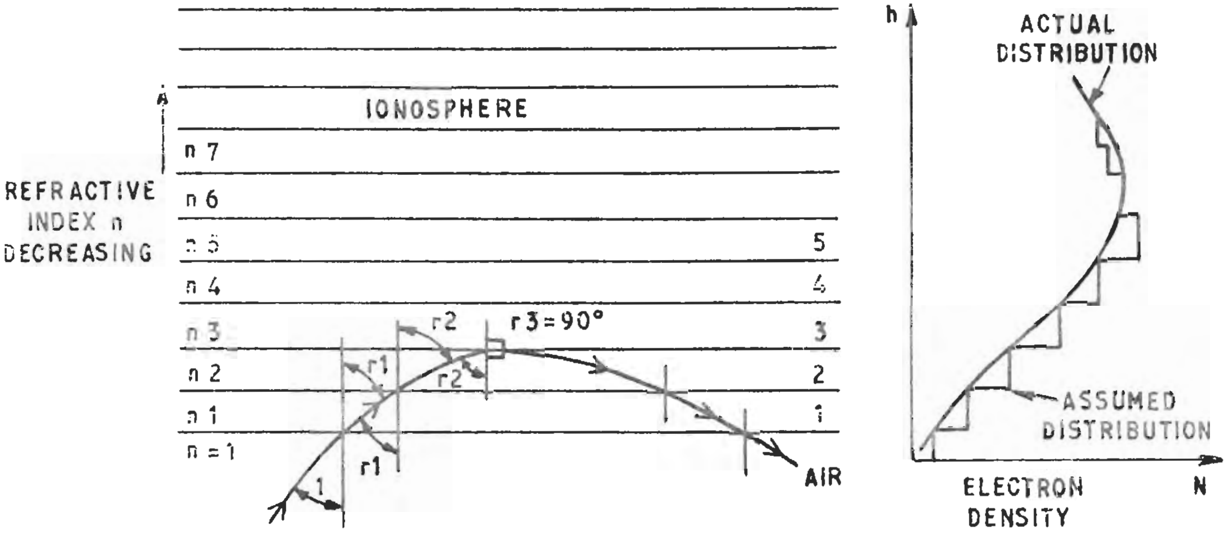

Figure 2A.15 - Wave Path Through Inosphere

30. In Fig 2A.15 above the wave is being refracted at the first and second boundaries. At the third boundary the wave is totally internally reflected. On entry into the ionosphere refraction occurs away from the normal as the wave moves from a region of high refractive index into a region of lower refractive index. On exit from the ionosphere, the reverse occurs. For total internal reflection to occur and therefore for the wave to return to earth, a critical value of refractive index must be found somewhere within the ionosphere. If this critical refractive index is not found, the wave will not return to earth. This critical refractive index is related directly to the initial incidence of the wave as is shown below.

Refractive Index of Ionosphere

31. The refractive index of the ionosphere depends upon two main factors:

(1) Electron density (N). Hence as N varies with the height of the ionosphere, so also will the refractive index.

(2) The frequency of the electromagnetic wave (f).

It can be shown that:

(3) As N increases, n decreases (assuming f = constant), ie enhanced refraction.

(4) As f increases, n increases (assuming N = constant), ie reduced refraction.

Path Variation with Frequency

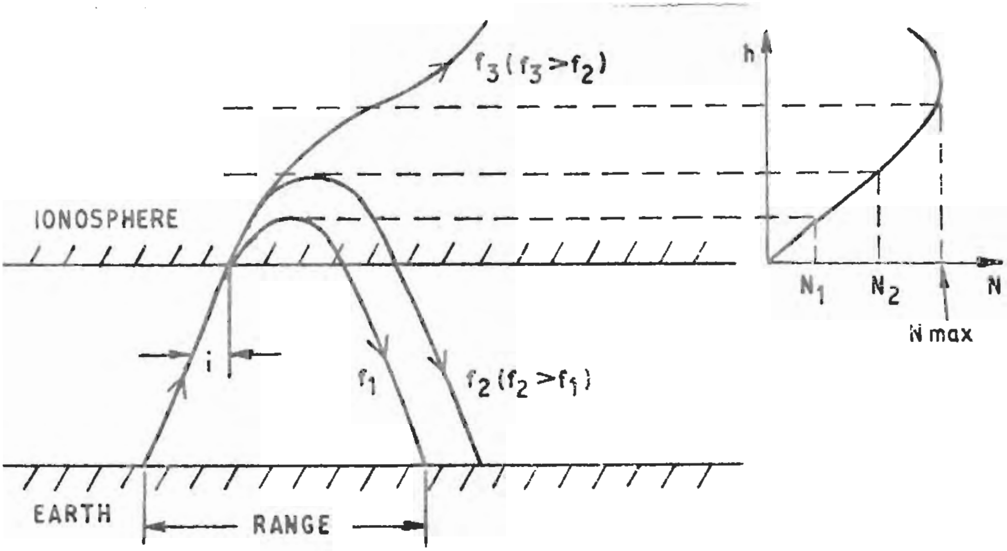

Figure 2A.16 - Path Variation with Frequency

32. For the wave to be returned to earth, a critical refractive index must be found. Because refraction is reduced as frequency is increased, waves of higher frequency must penetrate more deeply into the ionosphere to encounter a critical refractive index. Increased ionospheric penetration results in increased range, as shown above (f_1 and f_2). As frequency is increased still further, however, a point is reached where total internal reflection has not occurred when the wave has penetrated to the point of N_{max} (f_3). Such a wave will not therefore be totally internally reflected at all, but continue through the ionosphere and into space.

Path Variation with the Angle of Incidence

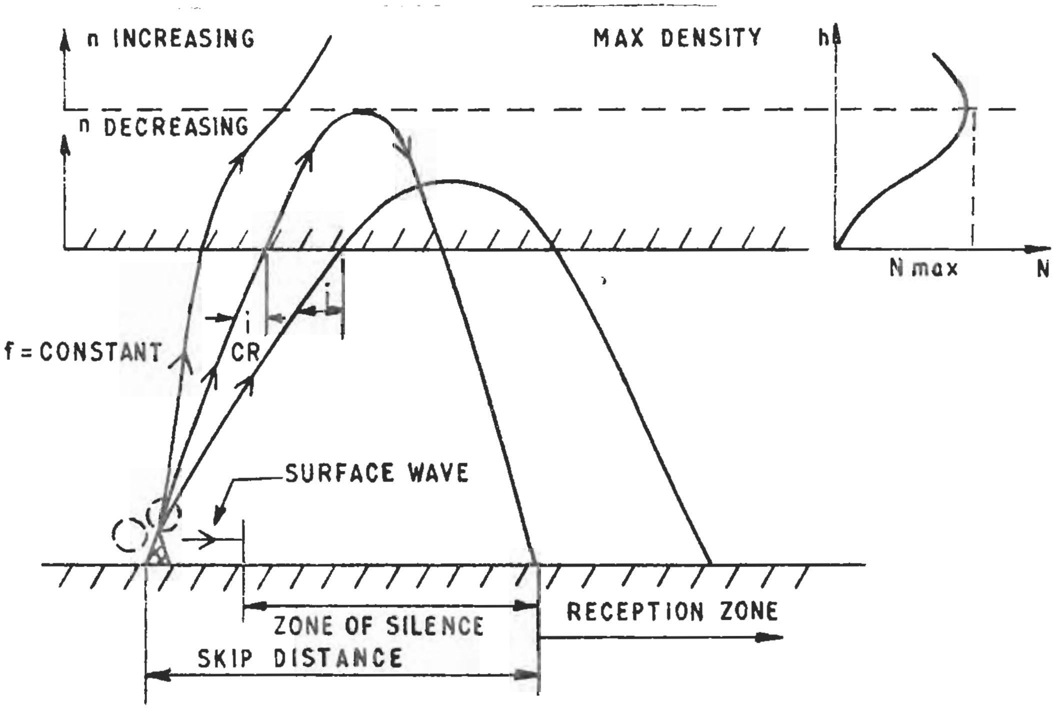

Figure 2A.17 - Path Variation with Angle of Incidence

33. It may be deduced from Fig 2A.17 that decreasing the angle of incidence (i) will require deeper penetration to occur before total internal reflection will take place. A limitating case will occur, therefore, where the wave penetrates to the point of N_{max} without TIR taking place and this wave also will pass through the ionosphere as shown in Fig 2A.17.

SUMMARY OF IONOSPHERIC PATH VARIATIONS

34. For a given frequency there is a minimum angle of incidence at which total internal reflection will occur (and hence a minimum range).

35. For a given angle of incidence (and hence minimum range) there is a maximum frequency at which total internal reflection will occur.

Notes:

(1) At frequencies above the HF range, sky wave propagation may be considered not to take place at all.

(2) There is a minimum distance or range when the wave can be refracted and returned to earth. This range is called the skip distance. This distance is defined by the wave which strikes the ionosphere at i_{cr} and which turns over at the point of maximum electron density in the ionosphere. The actual skip distance is therefore very dependent on the electron density distribution in the ionosphere which in turn depends upon time of day, season of year, geographical location etc.

(3) If the frequency used is increased, then so is the skip distance as a larger i_{cr} must be found at this higher frequency for the wave to turn over at the maximum electron density point. Hence for a GIVEN transmitter/receiver range there will be a maximum frequency which can be used when the receiver is effectively on the border between the reception and silence zones. This frequency is called the MUF (Maximum Usable Frequency).

(4) As the border between reception and silence zones (skip distance from transmitter) can vary due to ionospheric variations (see Note 2), the MUF is never used over a given link. Instead a more reliable frequency called the frequency of optimum traffic (FOT) is used. The FOT is taken as 85% of MUF frequency. Normally we try to operate a given link as close as possible to the FOT, as the higher the frequency, the less the ionospheric absorption of the wave energy and therefore the higher the signal strength at the receiver.

(5) When planning the frequencies to use on a given link, a third frequency is used. This frequency is known as the lowest usable frequency (LUF). The frequency is predicted for a given link from considerations of absorption in the ionosphere (lower the frequency, the greater the absorption), transmitter characteristics (eg power output, aerial gain and directivity) and receiver characteristics (aerial gain, sensitivity). The ultimate limit being determined by the S/N ratio at the output of the receiver.

A typical planning chart is shown below:

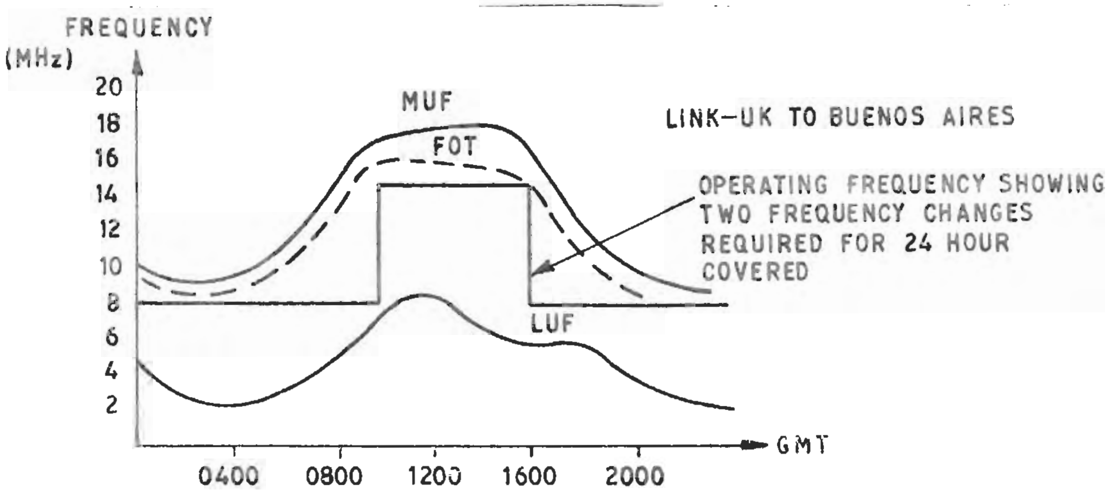

Figure 2A.18 - Typical Frequency Planning Chart

Multi-hop Propagation

36. This is a method by which greater ranges can be achieved by sky wave propagation. Initially the sky wave leaves the aerial and is refracted by the ionosphere back to earth, where it is reflected from the earth's surface and re-enters the ionosphere. It again returns to earth where it is reflected, etc.

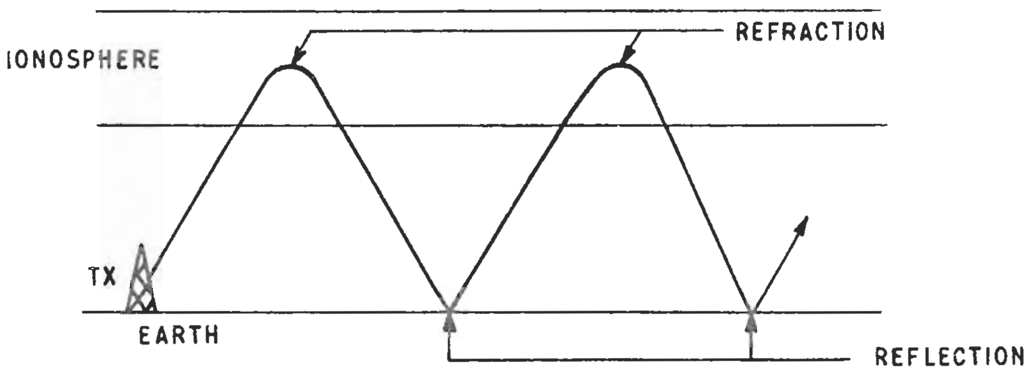

Figure 2A.19 - Multihop Propagation

Within power limitations, the range is increased by more hops.

Note that power is lost at every reflection and ionospheric refraction.

Example. The INSKIP - MAURITIUS link was either a 2 or 3-hop transmission which is refracted in the F2 layer. The range was 6000 miles and the maximum F2 hop was approximately 3000 miles.

Variations in the Ionosphere

37. Regular Variations

(1) Diurmal Changes. The height and density of the layers vary with the time of day, being greatest at 1200 Local.

(2) Seasonal Changes. The effect of the sun as the source of ionising radiation is greater during summer than winter.

(3) Sunspot Cycle. Solar activity follows 11.1 year sunspot cycle - the height and density of the layers being greatest at the maximum point of the cycle.

38. Abnormal Variations

(1) Sporadic 'E'. This is the occasional appearance in the E layer of drifting electron clouds, in which the ionisation is much greater than normal - sometimes caused by meteors.

Radio waves can be refracted from this layer, especially during summer nights, but its occurrence is too unpredictable to allow its regular use.

(2) Dellinger Fade Outs. Caused by intense uv radiation given out by the sun during solar flares.

This results in a sudden increase in the density of the D LAYER which results in complete absorption below 1 MHz, which can last for 1-2 hours.

(3) Magnetic Storms. Due to the emission from the sun of particles from a sunspot, or from the solar flare which caused a Dellinger fade out (up to 36 hours previously).

The effect usually lasts for several days and causes low signal strength and rapid fading.

Range Prediction and Frequency Selection

39. Information on suitable frequencies of probable ranges can be found in the following publications:

(1) NAVMUF.

(2) STIFS (Short Term Ionospheric Forecasts) - daily signal.

(3) BR 222 - Communication Management and Equipment Manual.

(4) JSP 321 - Manual of System Engineering (Telecommunications).

Low Probability of Intercept Techniques (Limited Range of Intercept)

40. The philosophy of Low Probability of Intercept (LPI) is to achieve tactical HF communication using ground wave propagation but to minimise the risk of such transmissions being intercepted by any receiver outside the ground wave coverage zone. LPI is achieved by:

(1) Day-time - use of frequencies in the 2-4 MHz range, which suffer greatest attenuation by the D layer and hence are least likely to be refracted back to earth.

(2) Night-time - use of frequencies above the prevailing MUF (from NAVMUF), typically in the range 20-30 MHz.

Notes:

(1) LPI is not foolproof; Sporadic E, for example, may give rise to unpredictable sky wave propagation.

(2) Ranges achievable by ground wave at HF are variable and depend upon frequency, transmitted power and sea state (cf Nature of Terrain, Paragraphs 16-17) but may be up to 300 miles at the lower end of the HF band.

THE SPACE WAVE

41. At frequencies in the VHF band and above, the main propagation path is the SPACE WAVE consisting of a direct wave and one or more ground reflected waves. The wavelength is small enough at these frequencies to allow the transmitting and receiving aerials to be elevated above the surface of the earth. The range of the space wave depends on the elevation of both aerials.

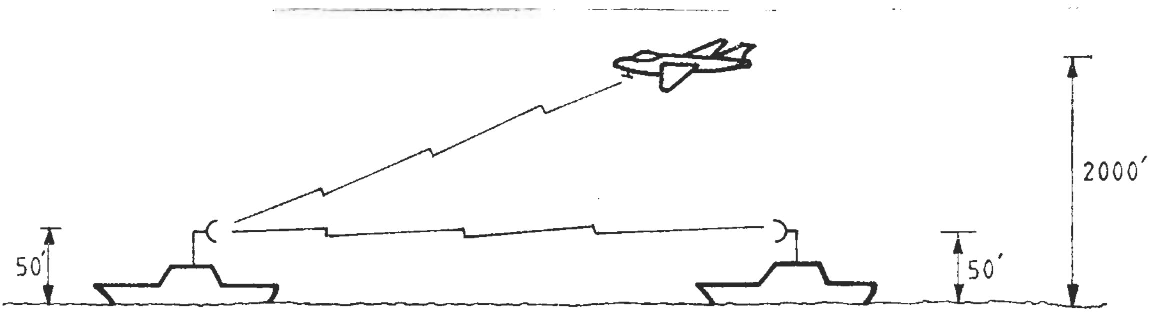

Figure 2A.20 - Ranges of Space Wave Propagation

	TRANSMITTER AERIAL HEIGHT (FT)	RECEIVER AERIAL HEIGHT (FT)	RANGE (MILES)
SHIP TO SHIP	50	50	20
SHIP TO AIR	50	2000	75
AIR TO AIR	2000	2000	125

in general:

Space wave range (miles) =

$$\sqrt{2 \times \text{Tx aerial height (ft)}} + \sqrt{2 \times \text{Rx aerial height (ft)}}$$

42. This type of propagation is called <u>TROPOSPHERIC PROPAGATION</u> since the E/M waves propagate through the TROPOSPHERE which is the region of the atmosphere between the surface of the earth and a height of about 10 miles. Since the refractive index of the atmosphere decreases slightly with height, a wave travelling through the troposphere is slightly refracted.

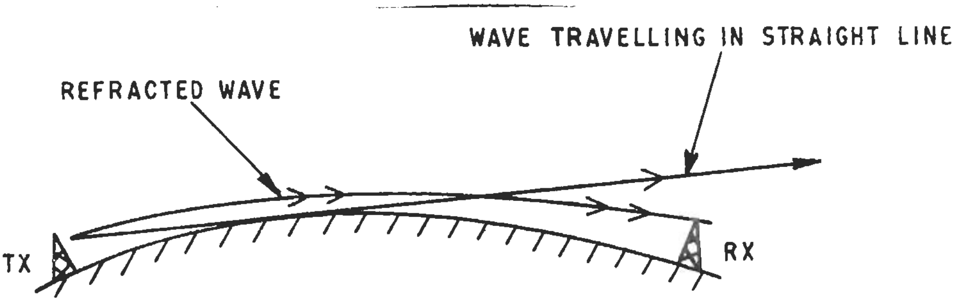

Figure 2A.21 - Tropospheric

This slight amount of refraction increases the space wave range to about $^4/_3$ × line of sight range.

<u>Note</u>: The figures given in the above Table (Fig 2A.20) have been corrected for the effects of refraction.

43. Space wave propagation is complicated by the interference of the direct wave with ground reflected waves which have been reflected from various objects.

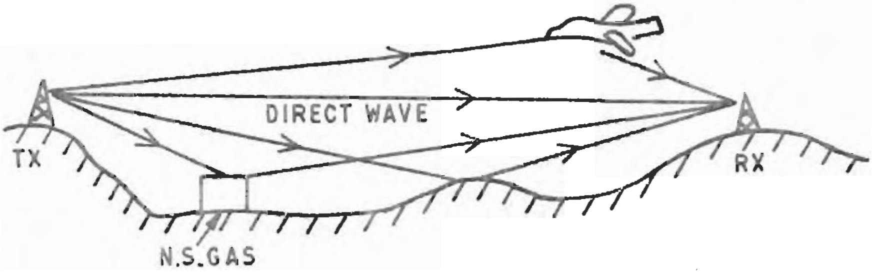

Figure 2A.22 - Interference of Ground Reflected and Direct Waves

44. In general, the reflected waves travel by paths which have different lengths so that several signal components are received with different phases. This causes the received signal to fade (signal strength fluctuates) especially if a wave has been reflected from a moving object. This effect can be reduced by using highly directive aerial arrays which can be fairly easily constructed because of the small wavelength. In practice, VHF space wave propagation can give good reliability over ranges slightly greater than the optical horizon. The space wave range can be greatly increased by the following phenomena:

Super Refraction

45. The refractive index of the atmosphere does not always decrease uniformly with height. Conditions can arise, particularly in summer, where the refractive index of the lower 50 m decreases with height much more rapidly than is usual. This forms an ATMOSPHERIC DUCT, in which the VHF/UHF wave is trapped, giving extended ranges.

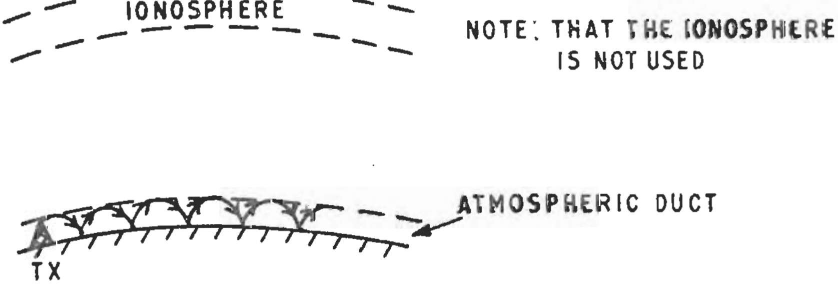

Figure 2A.23 - Super Refraction

46. If the wavelength of the energy being propagated is small compared to the height of the duct then the waves are trapped as shown below. This is called SUPER REFRACTION and is the cause of irregular reception of London TV signals in South Africa.

VHF signals from French broadcasting stations can be received very often in Southern England during summer.

Note: This type of propagation does NOT make use of the ionosphere.

Tropospheric and Ionospheric Scatter

47. Ionospheric Scatter. The E layer is in a continuous state of turbulence which gives rise to localised clouds of heavy ionisation (Sporadic E). If the wavelength of the radiation is comparable to the size of the clouds then while most of the energy will penetrate the ionised layer, some will be SCATTERED towards the earth. A scattered signal can be received beyond the horizon if a high transmitter power is used (up to 50 kW usually) and highly directional aerials are employed.

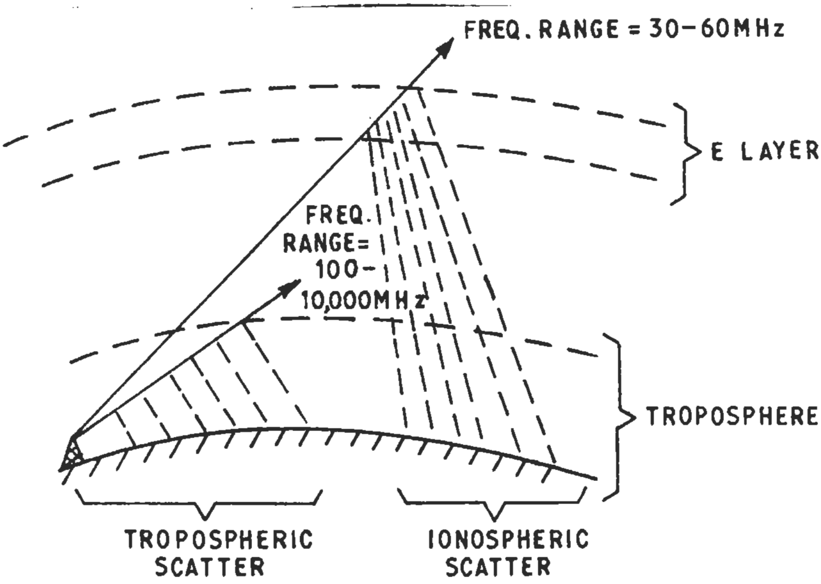

Figure 2A.24 - Tropospheric of Ionospheric Scatter

48. Frequencies in the range 30-60 MHz can be used, giving ranges of between 600 and 1500 miles. Ionospheric scatter propagation is particularly useful when ionospheric conditions prevent the use of HF, since the scattering is frequently enhanced when the ionosphere becomes highly ionised.

49. Tropospheric Scatter. Unsettled weather, resulting in a well-mixed atmosphere, eg Heavy Cloud cover, produces the best conditions for tropospheric scatter since there are localised variations of the refractive index.

50. Tropospheric scatter can be used with frequencies in the band 100-10,000 MHz giving ranges of 75-400 miles with a transmitter power of about 10 kW. Whilst scatter propagation installations have a high initial cost compared with HF systems, their main advantage lies in the reliable communications they provide which are unaffected by disturbances in the ionosphere.

SATELLITE COMMUNICATIONS

51. Space wave propagation can be used for round-the-world communications by the use of satellites and ground repeater stations.

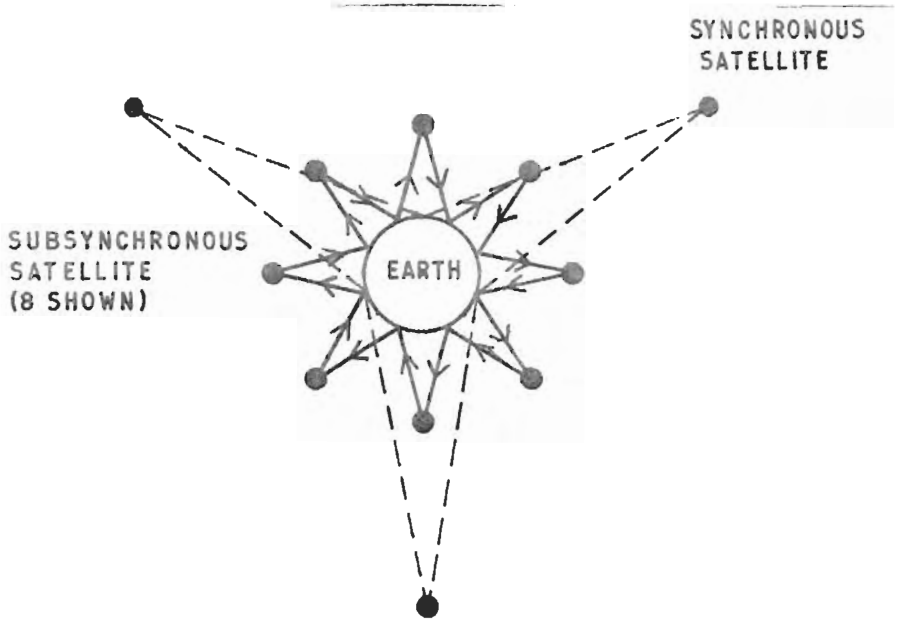

Figure 2A.25 - Satellite Communication

SUMMARY OF PROPAGATION

Propagation at VLF (3 kHz to 30 kHz)

52. The propagation mechanism is by guided waves using the earth and the ionosphere as waveguide boundaries. Communication at these frequencies is very reliable with world-wide range. Its only RN application is a submarine broadcast using a GPO transmitting station at Rugby.

Propagation at LF (30 kHz to 300 kHz: Surface Wave Predominates)

53. At these frequencies:

(1) The D layer no longer forms a good reflecting boundary and the dimensions of the earth to ionosphere and the wavelengths involved no longer allow guided wave propagation to occur.

(2) The direct and ground reflected components of the space wave effectively cancel due to the long wavelengths involved. (In terms of wavelengths, the aerials are very close to the ground and therefore the path difference in wavelengths between direct and ground reflected waves is negligible. As 180° phase shift occurs on reflection with the ground, the two space wave components will arrive virtually 180° out of phase at the receiver and cancel.)

(3) Sky waves at these frequencies are absorbed by the ionosphere and propagation by this mechanism is therefore negligible.

(4) The principle propagation mechanism is therefore the surface wave which provides reliable communications over ranges up to about 2000 miles.

54. The principle RN applications are submarine broadcasts, reliable long range communication between shore stations and ship/shore links with the main surface ships.

Propagation at MF (300 kHz to 3 MHz: Surface Wave - day-time;
Sky Wave - night-time)

55. At these frequencies:

(1) No guided wave propagation can occur for the same reason as LF.

(2) Again significant cancellation of ground reflected and direct waves occurs and space wave propagation is negligible.

(3) Ionospheric absorption is great enough during the day-time to prevent any sky wave propagation. The absorption occurs because as the wave passes through the ionosphere, the alternating electric field sets the free electrons in motion and energy is continuously exchanged between the wave and these electrons. This energy is lost, however, whenever one of these electrons collides with a gas molecule. The absorption of the wave energy is therefore greatest in the region of greatest molecular density, and this is in the D region. (It can also be shown that the absorption is inversely proportional to the square of the frequency.) Thus at night when the D layer disappears, sky wave propagation can occur at the higher MF frequencies.

Propagation at HF (3 kHz to 30 MHz: Sky Wave)

56. At these frequencies:

(1) For ranges of 50 miles or so, the surface wave still predominates.

(2) For long range communications, the sky wave predominates and ranges of 5000 miles or so. Multi-hop propagation is required.

Propagation at VHF/UHF (30 MHz: Space Wave)

57. At these frequencies:

(1) Guided waves are impossible as the ionosphere has negligible effect on waves at these frequencies (see Note 2 below).

(2) The refractive index of the ionosphere at these frequencies is nearly that of un-ionised air. Thus very little bending of waves takes place and no sky way propagation occurs.

(3) Attenuation of the surface wave is now very large (see Paragraphs 14-17) and therefore this propagation mechanism is negligible.

(4) The principal propagation mechanism is therefore the space wave which gives reliable communications for ranges dependent on transmitter and receiver aerial heights. In the region below the ionosphere the refractive index does decrease slightly with height and causes a small amount of bending of the electromagnetic wave. The range achieved is therefore slightly greater than line of sight and is given by:

Space Wave Range (miles) =

$$\sqrt{2 \times \text{Tx aerial height (ft)}} + \sqrt{2 \times \text{Rx aerial height (ft)}}$$

Used for line of sight tactical communications ship/ship, ship/air, FM and TV broadcasting.

Longer ranges are achieved by ionospheric and tropospheric scatter, the latter is particularly useful for "filling in" in the zone of silence in an HF transmission.

Frequencies of the order of 200-300 MHz are used for satellite telemetry (control signals).

Propagation at SHF > 300 MHz

58. Point to point microwave links, satellite communications and tropospheric scatter.

Comparative Ranges

59.

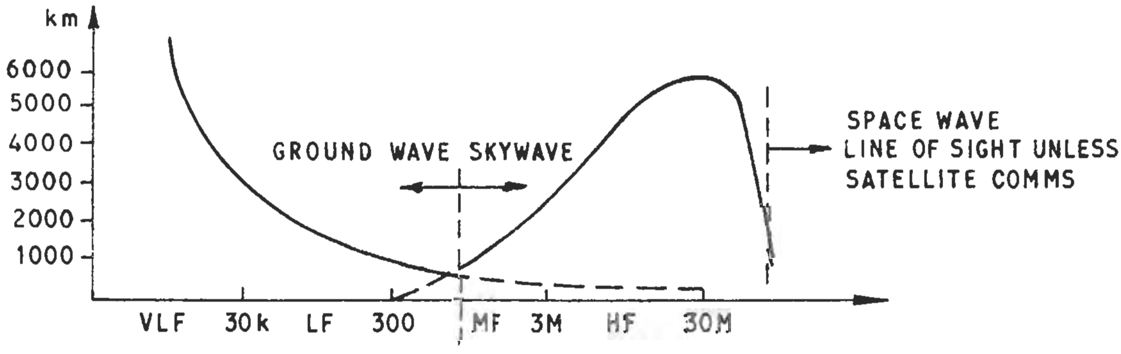

Figure 2A.26 - Comparative Ranges

Notes:

(1) Ground Wave:

a. Very much dependent on transmitter power and terrain.

b. Less power required at HF than at LF for the same range.

(2) Sky Wave:

a. Maximum Distance for F layer reflection 3000 miles) for one only
) reflected
b. Maximum Distance for E layer reflection 1400 miles) wave.

That means INSKIP to MAURITIUS was a 2 or 3-hop transmission.

FADING

60. Fading necessitates the transmission of much more power than would be required in stable conditions. Some forms of fading cause distortion as well as causing the amplitude of the signal to fluctuate.

Slow Flat Fading

61. The average received intensity of a SKY WAVE depends mainly on the radio path and the number of ground reflections.

There are however, daily variations (and other variations related to the season and degree of solar activity etc) due to the absorption of radio waves by the D layer.

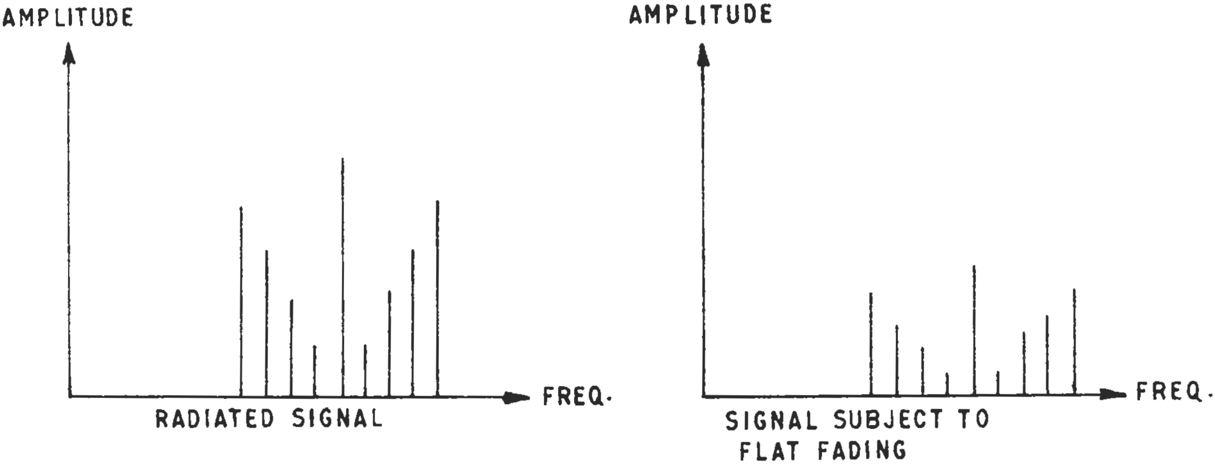

Figure 2A.27 - Slow Rate Fading

All frequency components of the signal are equally affected by this type of fading.

Rapid Fading

62. The direct and ground reflected waves travel by different paths and so take different times to reach the receiver, as is shown in Fig 2A.22. The signal arriving a the receiver aerial is made up of a large number of waves, each of which ha travelled by a different path. Slight changes in the troposphere or reflections fro moving objects (aeroplanes etc) cause the lengths of the paths to change slightly This causes the phase of the waves arriving at the aerial to vary in a random manner so that the amplitude of the resultant varies continuously

63 Because of the irregular and unstable nature of the ionosphere, HF signal propagated through the ionosphere tend to separate along a number of paths an arrive at the receiver aerial as a number of frequency components with rando phase. This causes the amplitude of the resultant signal to vary rapidly by up to 3 dB or more. Fading tends to be more rapid the higher the frequency, because given amount of movement of the irregularities in the ionosphere produces a greate phase shift the shorter the wavelength.

64. Considering waves which reach the receiver by only two paths, it can be seen that at a certain frequency the path difference will be an odd number of half wavelengths so that the resultant signal will be the vector difference of the two components. However, at a different frequency the wavelength will be such that the path difference is an even number of half wavelengths so that the two components add together at the receiver. Thus it is possible for certain radio frequencies to fade whilst others, perhaps only 100 Hz different, are unaffected. This is called SELECTIVE FADING and can result in the distortion of a modulated signal since some of the sideband frequencies will fade much more than others.

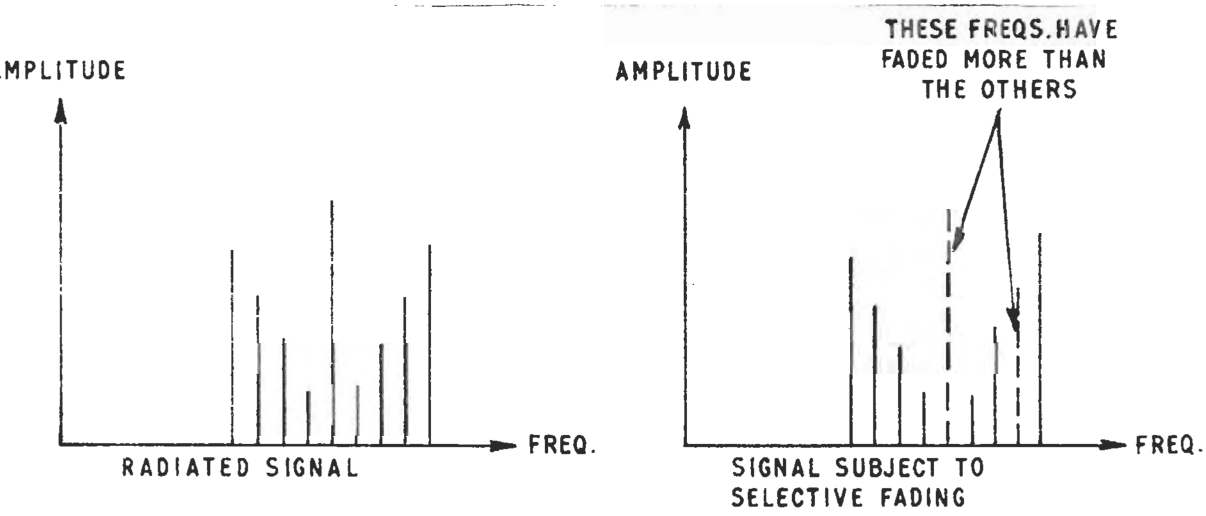

Figure 2A.28 - Frequency Selective Fading

Distortion due to Selective Fading

65. Distortion of the radiated signal occurs since only particular frequencies are affected by SELECTIVE FADING - unlike FLAT FADING which causes the amplitude of all the frequencies to change.

66. Selective fading causes the most distortion in an AMDSB signal when the carrier frequency fades more than the sidebands. This gives a waveform at the receiver which is indistinguishable from a transmission which was overmodulated by the transmitter. If the phase of the carrier changes during propagation then it is possible for the AM signal to become phase modulated so that the baseband signal cannot be recovered by an AM receiver.

67. Since an AMSSB signal does not contain a carrier, the above forms of distortion cannot occur and since it is likely that only a few frequencies will fade in a speech signal, selective fading rarely causes enough distortion to make the signal unintelligible.

Methods used to Combat Fading

A G

68. Slow flat fading can be reduced to a certain extent by the ue of automatic gain control. Unfortunately, if the signal becomes very weak there is an increase in the noise at the output of the receiver.

Space Diversity

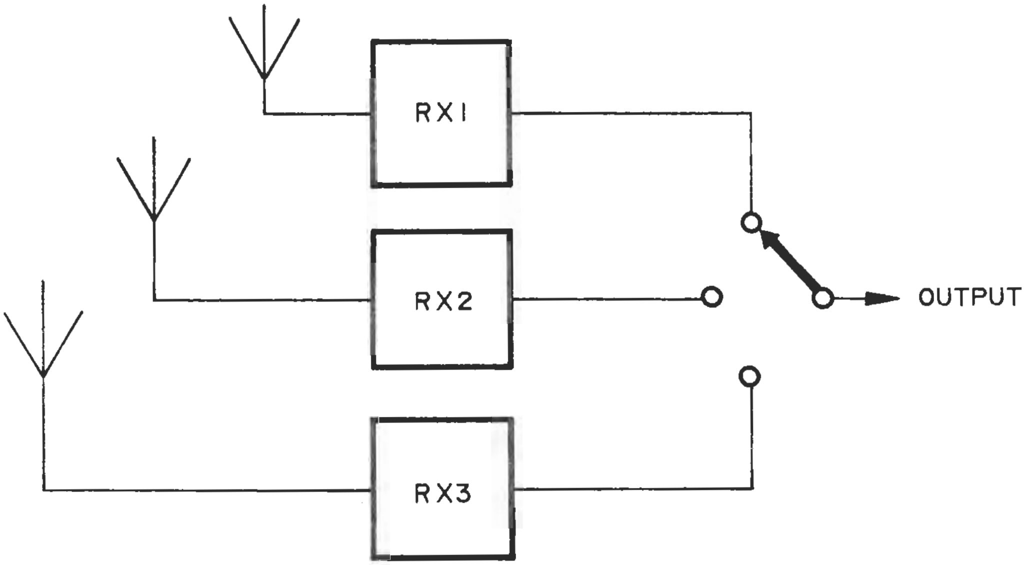

Figure 2A.29 - Space Diversity Reception

69. If a radio signal fades at a particular place on earth then there is a high probability that it will not fade at three different places at the same instant. Three aerials are spaced usually 3.10 wavelengths apart in the HF band and are connected to three receivers. The output signal is taken from the receiver which is receiving the strongest signal. In practice, the receivers have a common output and a common AGC system, the AGC voltage being derived from the sum of the signal strengths in the three receivers. This causes the receiver of the strongest signal to dominate the situation - the other receivers contributing either very little noise or very little signal.

Frequency Diversity

70. Important signals can be radiated on two or more frequencies since it is unlikely that both frequencies will fade at exactly the same instant. This can also prevent loss of signal in a zone of silence for one frequency, since another frequency will have a different coverage area.

Polarisation Diversity

71 A vertically polarised radio wave can become horizontally polarised durin propagation through the ionosphere. The signal received by the normal, verticall polarised aerial would be very weak. Polarisation changes can be reduced b transmitting the signal from two separate aerials, one vertically polarised and the other horizontally polarised. Two similar aerials are used at the receiver so that the stronger signal can be selected.

CHOICE OF FDM SEPARATION FREQUENCIES

72. Assume that, due to multipath, a transmitted frequency f follows two paths to the receiver and arrives with a time spread of x ms. The signals will be in phase if x = an exact number of periods.

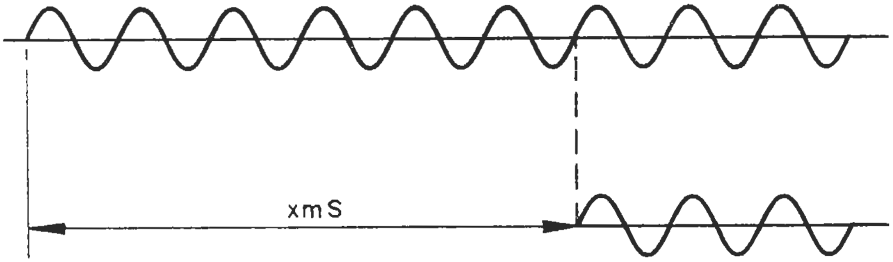

Figure 2A.30 - Choice of Separation Frequencies

FOR EXAMPLE: x = 11 periods.

If f is increased, the two signals will again be in phase when x = 12 period (frequency f')

$$f = \frac{1000}{\text{period}} = \frac{1000}{x/11} = \frac{1000 \times 11}{x}$$

$$f' = \frac{1000}{x/12} = \frac{1000 \times 12}{x} = \frac{1000 \times 11}{x} + \frac{1000}{x}$$

$$= f + \frac{1000}{x}$$

Therefore, for a given time delay x ms, the signals will be in phase at f and $f + \frac{1000}{x}$.

The signals will be in antiphase at $f + \frac{1}{2} . \frac{1000}{x}$.

In the FDM signal, all information is carried on one tone. Ideally when one tone fades the other should be a maximum. Hence, the frequency separation of Z and A tones should be:

$$\frac{1}{2} . \frac{1000}{x}$$

Time delay is typically 1.5 ms, so:

$$\text{SEPARATION} = \frac{1}{2} . \frac{1000}{1.5} = \frac{1000}{3} = \text{333 Hz approx}$$