

ELECTROMAGNETIC WAVE PROGATION

(PREVIOUSLY MLR 051)

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1. INTRODUCTION.

1.1 This paper deals with aspects of electromagnetic wave propagation in the Very High Frequency (V.H.F.), Ultra High Frequency (U.H.F.) and Super High Frequency (S.H.F.) ranges. It should be studied in conjunction with Radio 2, Papers 1 and 10 which give details of radio wave propagation in the Medium Frequency (M.F.) and High Frequency (H.F.) ranges.

For additional information on the subject of electromagnetic wave propagation, reference can be made to Terman, Electronic and Radio Engineering (Fourth Edition), Chapter 22.

1.2 The Departmental radio communication services provided in these frequency ranges are listed in the paper. The majority of these are point-to-point radio communication systems, and for this reason, the principles of wave propagation are, in this paper, largely related to these systems.

2. GENERAL ASPECTS OF PROPAGATION.

2.1 There are a number of mechanisms by which radio waves may travel from a transmitting aerial to a receiving aerial. The more important of these are termed ground waves, sky waves and space or tropospheric waves. Fig. 1 shows the component part of a transmitted electromagnetic wave.

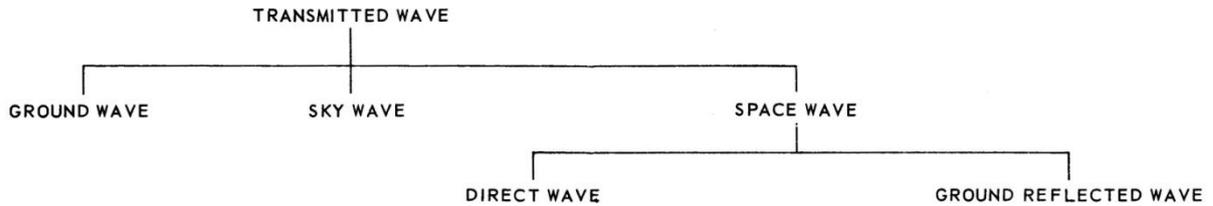


FIG. 1. COMPONENT PARTS OF ELECTROMAGNETIC WAVE.

The ground wave can exist when the transmitting and receiving aerials are close to the surface of the earth and are vertically polarised. This wave is of practical importance in the medium frequency range, and all broadcast signals received in the daytime are ground waves.

The sky wave represents the energy that reaches the receiving aerial as a result of a bending of the wave path introduced by ionization in the upper atmosphere. This ionized region is termed the ionosphere. It begins about 50 miles above the earth's surface, and accounts for practically all very long distance radio communication.

The space wave represents energy that travels from the transmitting aerial to the receiving aerial in the earth's troposphere. The troposphere is the portion of the earth's atmosphere in the first 10 miles adjacent to the earth's surface. The space wave commonly consists of two components. One of these is a ray which travels directly from transmitter to receiver, and the other is a ray which reaches the receiver as a result of reflection from the surface of the earth. Radio transmission at frequencies above 30MHz is usually by space wave propagation.

2.2 A radiated wave is modified by the presence of the earth to an extent that depends on the ground conductivity, permittivity and permeability. The effect on a propagating wave depends on frequency, and the spectrum can be divided into bands on this basis. Table 1 shows the accepted terms, and indicates the types of propagation that characterise each band.

Band	Frequency Limits	Mechanism of Propagation
L.F.	30- 300kHz	Ground wave.
M.F.	300-3,000kHz	Ground wave; after dark, ionosphere reflection of sky wave.
H.F.	3- 30MHz	Ionospheric reflection of sky wave. This mode of propagation can cause interference up to 60MHz.
V.H.F.	30- 300MHz)	Space wave.
U.H.F.	300-3,000MHz)	
S.H.F.	3- 30GHz)	

TABLE 1. FREQUENCY BANDS AND TYPES OF PROPAGATION.

2.3 Departmental Communication Services. The V.H.F., U.H.F. and S.H.F. ranges are used to provide communication services, ranging from single channel capacity to 1800 channel capacity. The radiotelephone trunk systems must be capable of fitting into the general transmission plan, and the standard of the telephone service provided should be equivalent to that provided over a properly maintained trunk line.

The services provided in the various frequency bands are:-

- V.H.F. Range. The majority of communication systems provided in this range are single channel and four channel systems. In general they provide telephone service over routes where the construction and maintenance of physical lines is difficult or costly. Typical examples are services from the mainland to off-shore islands or lighthouses, services over mountainous terrain, and services in flood prone areas where some form of communication is required in the event of disruption to the telephone circuits depending on physical lines. The majority of the single and four channel systems operate at frequencies in the vicinity of 160MHz.

A V.H.F. Mobile Subscribers' Service is established in some capital cities to provide radiotelephone services to mobile vehicles operating within the metropolitan area. The service is provided over an average radial distance of 15 miles.

Each vehicle subscribing to the service is fitted with an F.M. transmitter and receiver operating at frequencies in the vicinity of 160MHz. The base F.M. transmitter, and receiver and associated control equipment, are located at a central telephone exchange. Remote F.M. receivers are installed at some suburban telephone exchanges, and the audio outputs of these receivers are fed to the base stations over cable pairs.

At the time of writing the method of working is similar to a party line system and all calls to and from the mobile units are routed via a manual position to the central exchange. Later systems will use an automatic calling system.

- U.H.F. Range. In this range, radiotelephone systems operating at frequencies in the vicinity of 900MHz, are used as bearers for 12 and 24 channel systems which provide telephone traffic circuits between relatively large centres. In some cases these systems operate over large distances, and incorporate a number of repeater stations.

The supervisory systems associated with some broadband radiotelephone bearers use frequencies in the vicinity of 450MHz. These systems provide for a number of fault indications from each repeater to be repeated and displayed at the adjacent control stations in each direction. Protection switching to a standby circuit and an omnibus operating circuit can also be provided by the supervisory system.

- S.H.F. Range. The need to provide T.V. relays to outlying regional areas from the corresponding capital cities has given an impetus to the provision of microwave telephone bearers, because nearly all the T.V. relay routes are planned for telephony systems also. In the S.H.F. range the radiotelephone bearers can provide for medium capacity systems (12-300 channels) and broadband systems (600-1200 channels) although in many cases the maximum system capacity cannot be achieved with suitable channel performance.

At the time of writing microwave systems (systems in the S.H.F. range) operate at frequencies in the vicinity of 4GHz, 6GHz, 7GHz, 8GHz and 10GHz.

Broadband radio systems are sub-divided into "short haul" and "long haul" types. The short haul systems are designed for operation over short distances, generally one or two hops; three hops, each of about 30 miles, is a maximum. The long haul systems are designed for operation over long routes and are designed to a higher standard, particularly in regard to frequency stability and linearity, than the short haul systems.

The existing and proposed microwave radio routes in Australia are shown in Fig. 20. These routes provide telephony and/or television services throughout Australia.

3. DEFINITION OF TERMS.

3.1 The terms "reflection", "refraction" and "diffraction" are applied to electromagnetic transmission in all frequency ranges, but because of their importance in V.H.F., U.H.F. and S.H.F. transmission they are defined in this paper.

3.2 Reflection. By studying the changes in a wave front which occur as a wave advances through a medium of one density, it is possible to predict the effects that will be produced when a wave encounters a medium of a different density which either reflects, refracts, or absorbs energy.

The behaviour of a wave upon striking a reflecting surface is illustrated in Fig. 2, where an electromagnetic wave is shown being reflected from the ground somewhere between a transmitting and receiving aerial. (Fig. 2a) A close-up drawing of the wave front at the point of reflection shows the incident wave front impinging upon the surface of the ground, through which it cannot penetrate. (Fig 2b) If the earth's surface were absent, the wave would have advanced without change in direction, and, at a certain point in time, would have reached the position A'B. However, the presence of the earth's surface causes a change in the direction of the wave front as illustrated by the line AOB. The line AO represents the reflected wave front and the line OB represents the incident wave front. The angle i , which is the angle of incidence, and the angle r , which is the angle of reflection, are equal and lie in the same plane. For horizontally polarised waves a phase change of about 180° occurs at the point of reflection. For vertically polarised waves the phase change is somewhere between 0° and 180° depending on the angle of incidence and the type of reflecting surface.

In the case of wave propagation we deal with the transfer of electromagnetic energy, and it is convenient to express the energy relations of the incident and reflected waves by a ratio called the coefficient of reflection. The coefficient of reflection (p) is found by dividing the reflected energy per second leaving a reflecting surface by the energy per second incident to the same surface. If the two energies are of equal magnitude ($p = 1$), we have perfect reflection.

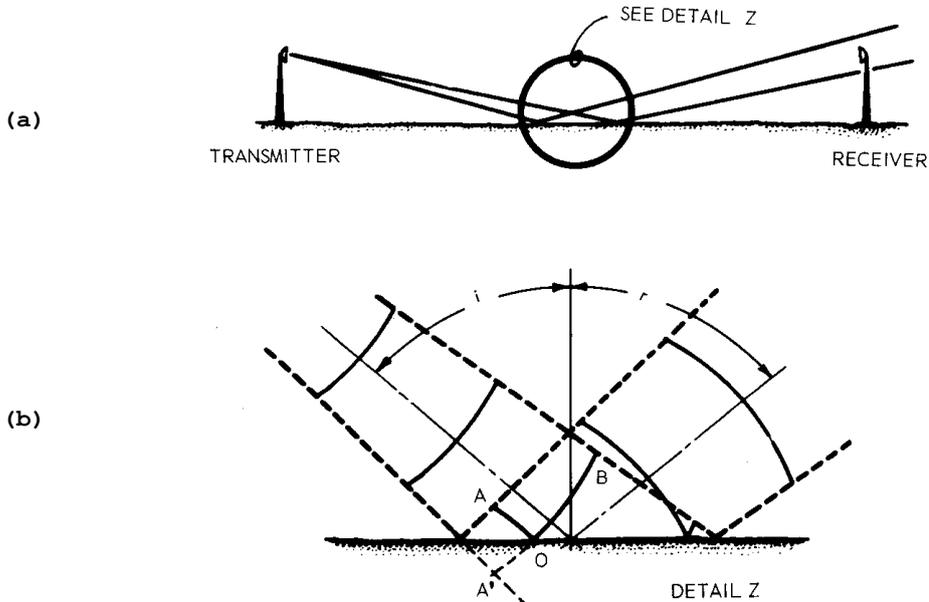


FIG. 2. REFLECTED WAVE.

3.3 Refraction. If the reflected energy is smaller than the incident energy, the difference is either dissipated at the reflecting surface, or partially dissipated at the surface and partially passed through the surface as a refracted ray. For example when an electromagnetic wave impinges upon a cloud, most of the energy is transmitted through the cloud. However, due to various particles in the cloud, a portion of the wave will be returned by reflection at the surface of the cloud and another portion will be absorbed within the cloud itself. When the wave energy is absorbed, it is converted into heat. The part of the wave that is passed through the cloud is refracted, or changed in direction, if the electromagnetic properties of the cloud differ from those of the surrounding air. In fact, when a radio wave encounters any medium whose electromagnetic properties differ from those of the previous medium, reflection and refraction take place simultaneously.

If Fig. 3 an electromagnetic wave is illustrated being refracted through a mass of air which is denser than the air surrounding it. For the sake of simplicity all the action is shown taking place at the interface between the air mass and the surrounding atmosphere. Actually the refraction occurs in gradual steps, since air masses have no sharply defined interface. Because the mass of air is denser than the surrounding air the wave is slowed down as it enters and is therefore bent. If the air mass were not present, point B on the wave from AOB would have advanced to B' at a uniform rate of velocity. However, the wave velocity is less in the air mass than in the surrounding air and the line OB represents the new direction on the wave front. The angle r which it makes with the 'normal' is called the angle of refraction. The normal is the line drawn at right angles to the interface at the point of incidence. The law of refraction states that a beam travelling from a lighter to a denser medium is refracted towards the normal, and a beam travelling from a denser to a lighter medium is refracted away from the normal.

If the density of the air mass were less than the surrounding air, the wave velocity would have increased and the wave refracted upward. Therefore, a wave is refracted toward the normal, when its velocity is reduced, and away from the normal when its velocity is increased. Consequently, the law of refraction states that an incident wave, travelling obliquely from one medium to another, undergoes a change in direction if the velocity of the wave in one medium is different from that in the other.

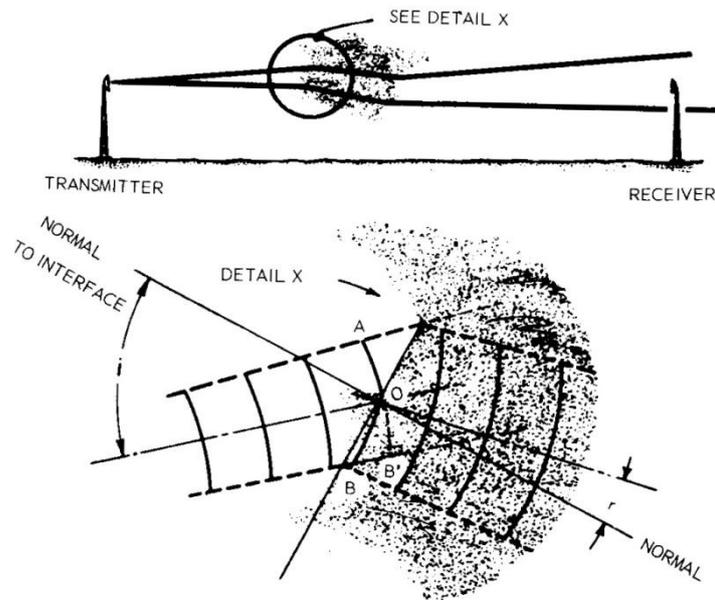


FIG. 3. REFRACTED WAVE.

3.4 Diffraction. The amount of R.F. energy in the form of electromagnetic waves that will travel from a transmitting aerial to a receiving aerial is determined by the transmission path. It was often thought that high frequency waves travelled according to geometric line of sight, or slightly beyond of atmospheric refraction existed. However, experiments have shown that, at frequencies below approximately 200MHz, waves may reach receiving aerials out of the optical and radio line of sight regions.

Waves do not originate at one point only, but from the entire surface of an obstacle which is in the path of electromagnetic waves. Wavelets re-radiate in all directions from a multitude of elementary radiation centres at the earth's horizon as they receive incident wave energy. Electromagnetic diffraction is, therefore, the re-radiating and subsequent bending of waves as they graze the earth's surface or any other intervening obstacle. Diffraction of electromagnetic waves into the geometrical shadow region behind a mountain ridge is illustrated in Fig. 4.

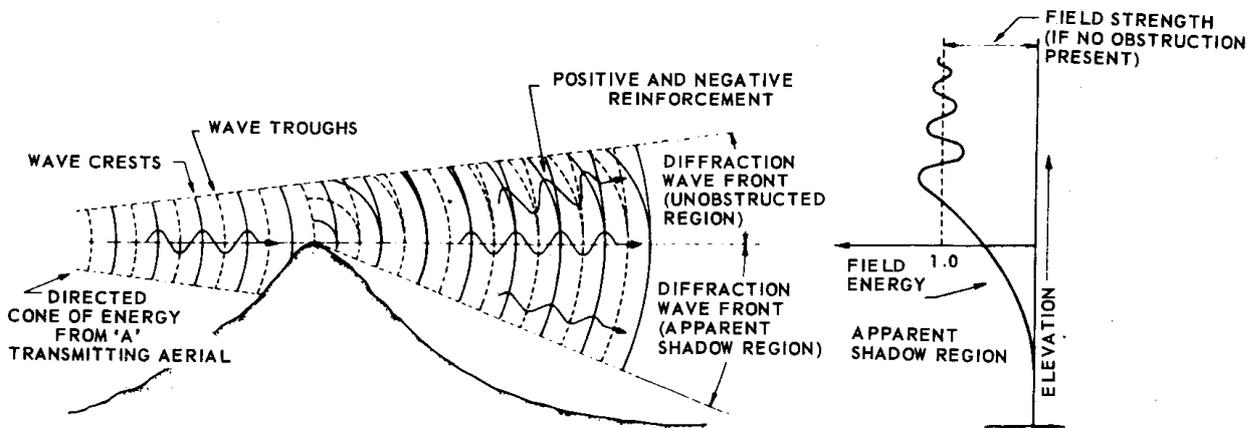


FIG. 4. DIFFRACTION.

4. PROPAGATION AT V.H.F.

4.1 Normally, signals in the V.H.F. band are not returned to earth by the ionosphere, and the ground wave is greatly attenuated. Transmission between two points therefore depends only on the space wave. The three main characteristics of V.H.F. propagation are:-

- The ground acts as a very good reflector.
- Propagation between transmitting and receiving aerials takes place over two paths; these are a direct, nearly optical path and one involving reflection from the ground.
- Where there is no direct path, signals may reach a receiving aerial by diffraction.

Fig. 5 shows the direct and indirect paths by which energy can travel from a transmitting aerial to a receiving aerial. For the sake of clarity the aerial heights are greatly exaggerated in comparison to the distance.

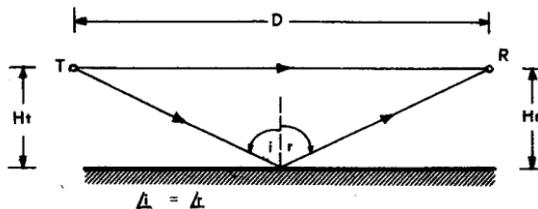


FIG. 5. DIRECT AND INDIRECT PATHS BETWEEN AERIALS.

Field strength at a receiving aerial is the vector sum of the direct and ground reflected waves. The magnitude and phase of a ground reflected wave depends on the reflection coefficient of the reflecting surface. Where the distance between transmitting and receiving aerials is large, with respect to their height above ground, the wave is reflected at a small angle to the horizontal (grazing incidence) and the reflection can be assumed to take place with no change in magnitude but with a change of phase.

The lengths of the alternative paths are unequal and the relative phase of the two signals arriving at the receiving aerial depends on distance from the transmitting aerial because phase difference is also a function of the wavelength. The resultant field strength is given by:-

$$\text{FIELD STRENGTH AT RECEIVER} = \frac{2E_0}{D} \sin \frac{2\pi H_t H_r}{\lambda D}$$

- Where E_0 = Field intensity of direct ray at a unit distance.
 D = Distance from transmitter to receiver (In wavelengths).
 λ = Wavelengths.
 H_t = Height of transmitting aerial.
 H_r = Height of receiving aerial.

4.2 Effective Aerial Height. In making calculations of received field strength the effective height of an aerial is used. This is not the physical height above its immediate surroundings but the effective ground plane is established by making the angle of reflection r equal to i , the angle of incidence, as shown in Fig. 6. Note that if either aerial is moved back from the edge of falling ground, so that ground reflection takes place at or near that edge, the effective height is reduced.

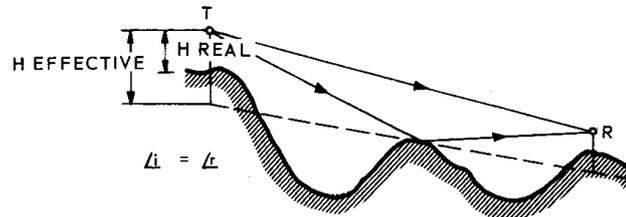


FIG. 6. CALCULATION OF EFFECTIVE HEIGHT OF AN AERIAL.

4.3 Line-of-sight Criterion. The derivation of the equation for field strength is based on the assumptions that:-

- D is large compared with H_t and H_r .
- Neither H_t nor H_r is excessively small.
- Earth curvature has negligible effect.

Curvature of the earth's surface raises the ground level between the two aerials and so reduces the path length between direct and ground reflected signals. This results in a lower field strength than predicted by the equation. On the other hand, reflection at a spherical surface causes divergence of the reflected ray; the reduced strength of this signal at the receiving aerial results in a greater field-strength than predicted.

The two effects tend to cancel, and if the aerials are at a reasonable height above ground, the equation is useful up to the point where one aerial is just above the horizon when viewed from the other. This limitation has given rise to the expression line-of-sight transmission.

4.4 The troposphere. The troposphere extends upward from the earth's surface to about 10 miles; and contains almost all the atmospheric conditions and changes known as "weather". Ionised layers of air occur rarely in the upper part of the troposphere, and not at all in the lower half. For this reason, waves returned from the troposphere are almost always the result of changes in the atmospheric characteristics, rather than reflections from ionized layers. Where reflections do occur from these ionized layers, there is little effect on propagation since the reflecting ability of the layers is very low. Another source of reflected wave from the troposphere is an air mass differing considerably in its dielectric constant from the surrounding air. Electromagnetic waves reflected from such a mass are called tropospheric waves and may seriously interfere with radio propagation. Waves travelling through the lower part of the troposphere (ground waves) on the other hand are not reflected, but curved. The curvature is caused by the gradual change in the refractive index of air that accompanies an increase in elevation.

The refractive index of air depends on the temperature, atmospheric pressure and water vapour pressure of the air, and ordinarily decreases uniformly with elevation. This usually results in a downward curving of the radio wave. This curving follows the law of refraction which states that a beam passing from a lighter to a denser medium is refracted toward the normal. In Fig. 7 this is illustrated between the transmitting aerial and the midpoint. At the midpoint however, the beam commences to travel from the denser to the lighter medium. The beam continues to bend downward, since according to the law of refraction, a beam travelling from a denser to a lighter medium is refracted away from the normal. This condition is shown in the figure between the midpoint and the receiving aerial, and the whole path therefore, is curved downward.

In Fig. 7(a), both the earth's surface and the beam are curved. Any calculations based on such curves may be simplified by multiplying the earth's radius by some constant that causes the radio beam to appear as a straight line as shown in Fig. 7(b). The curvature of the earth's surface is exaggerated to illustrate this feature.

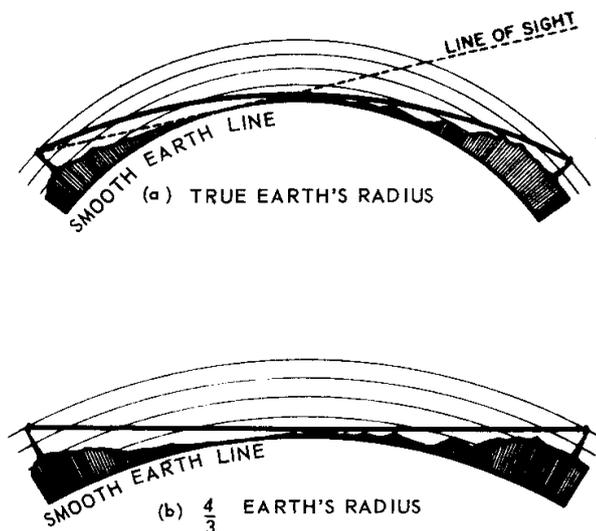


FIG. 7. REFRACTION THROUGH STANDARD ATMOSPHERE.

The multiplying constant, (k factor) is dependent upon the rate of change of the refractive index of air with altitude, which in turn is dependent upon weather conditions. A value of $\frac{4}{3}$ is generally assumed for conditions normally found to exist in the atmosphere. The k factor is subject to diurnal and seasonal variations which cause a variation over wide limits. The actual path over which the radio waves are propagated is called the radio path.

4.5 Fading. The term fading is used to define the variation of received radio field strength, caused by the transmission medium, with time.

The refractive index of air can change quite quickly due to local weather effects. This can cause large amplitude fading for varying periods of time. In addition as the weather pattern changes from hour to hour or day to day, the changes in refractive index cause continual small amplitude fading.

Some examples of types of fading are:-

- Two-Ray (Two-Path) Fading. For line-of-sight transmission paths it is common for a direct ray and a ground reflected ray to reach the receiving aerial. The received signal is their vector sum; that is, it depends on their relative amplitudes and phases. If the surface is a good reflector their amplitudes are almost equal. As the refractive index of air changes, the difference in path lengths between the two rays changes, and in turn, their phase difference increases or decreases. This results in interference fading as the refractive index of air varies.

Fig. 8 illustrates this type of fading. In Fig. 8(a) a standard refractive index of $4/3$ is assumed, and the direct ray and the reflected ray are assumed to be in phase at the receiving aerial. This in phase condition is obtained when the reflected path is one half wavelength longer than the direct path, and a phase change of 180° occurs at the reflection point.

In Fig. 8(b) a sub-standard refractive index is assumed. This has the effect of causing a downward bending of the ray and makes the earth's curvature appear greater. Under these conditions the path length of the reflected wave is decreased and its half wavelength relationship with the direct wave is lost, resulting in a decrease in signal strength.

In Fig. 8(c) a super-standard refractive index is assumed and this has the effect of making the earth's curvature appear even less. The reflected path length is now greater than in Fig. 8(a), and if for example it becomes one wavelength greater than the direct path, then almost complete cancellation of received signal occurs.

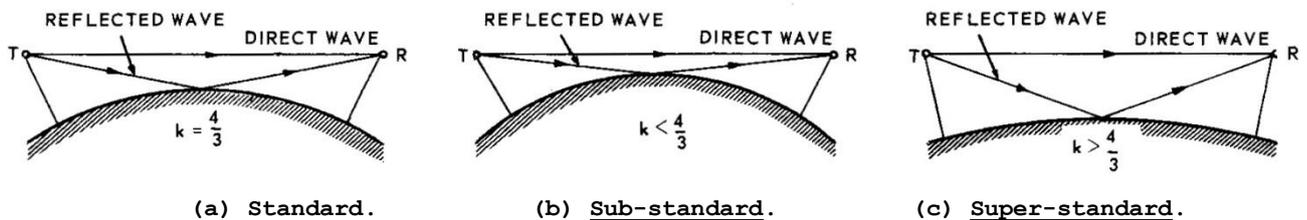


FIG. 8. TWO-RAY FADING.

- Multi-Ray (Multi-Path) Fading. When some local regions with fairly steep refractive index gradients, such as cloud masses, are present in the atmosphere, they may refract or even reflect extra rays to the receiver. The received signal depends on their vector sum. This leads to multi-ray fading which is illustrated in Fig. 9.

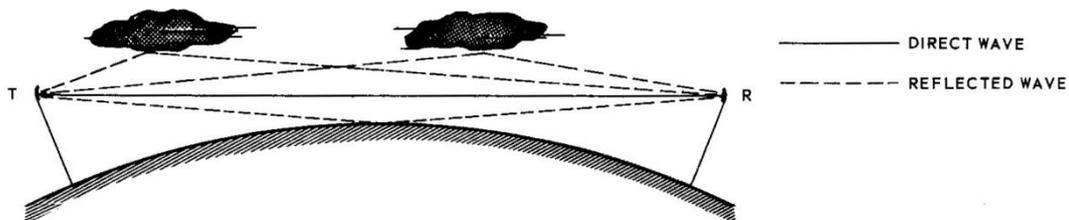


FIG. 9. MULTI-RAY FADING.

- Duct-Fading. With settled weather conditions, large air masses having different refractive indexes may lie one above the other in the troposphere. These layers form a duct which "traps" radio waves. Each layer bends the beam in opposite directions in a similar manner to a waveguide. As a result the radio signal may not be received at the receiving aerial, and in fact can be transmitted well beyond this point. This type of duct is known as an elevated duct. A similar ducting action can occur between a heavy air layer and the earth's surface. This is termed ground ducting.

The principle of ducting can be used for transmission beyond radio line-of-sight, but as no great application because of the random nature of its occurrence.

- Obstruction Fading. This occurs when the value of the refractive index becomes small and causes the beam to be obstructed. As the refractive index decreases, the effective earth's radius decreases, and the earth can be imagined as bulging between the transmitting aerial and the receiving aerial. If this earth bulge is sufficient the beam can be obstructed as shown in Fig. 10. The electromagnetic wave can travel to the receiving aerial by diffraction, but a decrease in signal strength results.

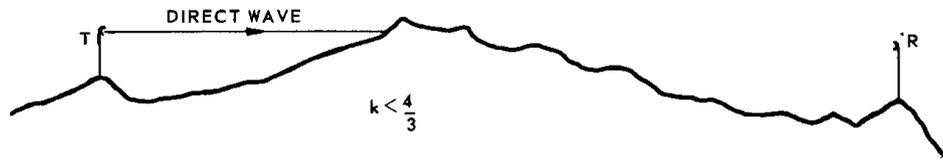


FIG. 10. OBSTRUCTION FADING.

4.6 Propagation beyond Radio Line-of-Sight. Transmission of radio waves beyond radio line-of-sight is possible, but in general, services using this facility are subject to fading. The two main mechanisms whereby such transmission takes place are:-

- Diffraction. As explained in para. 3.4 any obstruction in the path of an electromagnetic wave will reradiate energy in all directions. This causes the electromagnetic waves to bend as they graze the earth's surface, and transmission becomes possible beyond obstructions, and beyond radio line-of-sight. High powered transmitters are normally used in the frequency range below about 200MHz when propagation by this method is used.

The problem of fading arises when variations in the refractive index of the air cause apparent variations in the earth's radius. This results in the earth "bulging" more or less between the transmitting and receiving aerials. The greater the bulge, the greater is the loss in the diffraction path. This is sometimes called earth bulge fading.

- Scatter. Both the troposphere and the ionosphere are in a continual state of turbulence which gives rise to local variations in the refractive index. These small turbulent areas may be large in terms of wavelength. A wave may be scattered by these turbulent areas within a narrow cone surrounding the forward direction of propagation.

If a high-gain transmitting aerial and a high gain receiving aerial are aligned so that their beams overlap in the scattering area it is possible to transmit signals between them over great distances. Because of the random nature of the scattering process the scattered signal is subject to random variations of amplitude and phase. Tropospheric scattering is used at frequencies above about 400MHz for transmissions at ranges of about 200 to 400 miles. In the frequency range 30 to 50MHz Ionospheric scattering allows transmission of signals over a range of about 750 miles. The greater range is achieved because of the greater height of the scattering centres which are in the "E" region.

4.7 Fresnel Wave Interference. In general radio systems operating on frequencies higher than about 100MHz, use free space propagation. In some practical cases however, the received signal is the resultant of the free space wave and one or more waves reflected from the earth's surface. A simple and typical example of multiple path transmission is shown in Fig. 11. The signal received at B is the resultant of the direct wave TR and the wave reflected at the mid-point, O. With small angles of incidence, the phase change at the reflection point approaches 180°, and the co-efficient of reflection is close to unity.

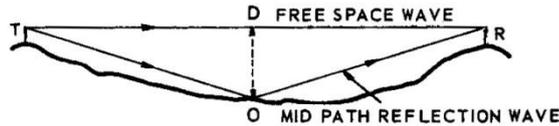


FIG. 11. PROPAGATION OF FREE SPACE AND REFLECTED WAVES-MID-PATH REFLECTION.

The distance of the point O below the line TR has an appreciable effect on the signal received at R. As this distance is increased from zero the signal strength at R increases from a low value, and after passing through a maximum, fluctuates about a value equal to the free space value. There is an optimum clearance called first Fresnel zone clearance, for which transmission is better than the free space value. Physically, this clearance is of such magnitude that the phase shift along the path of the reflected wave is one half wave length greater than the phase shift along the path of the direct wave. Assuming a 180° phase change at the reflection point, the two waves at B are in phase and their resultant is greater than the free space intensity.

4.8 A Fresnel Zone can be defined as a circular zone about the direct path at such a radius that the distance from a point on this circle to the receiving point is some multiple of a half wavelength longer than the direct path. For this reason, according to Fresnel zone theory, all the even numbered zones send wavefronts to the receiver in opposite phase to all those from odd numbered zones. Fig. 12 shows first, second and third Fresnel zones surrounding the direct wave path TDR. The energy contained in a zone is proportional to the zone area and as the width of the rings making up the zones decreases as the radius of the circles increases, only the first few zones are of practical importance.

In Fig. 12 the points A, B, C, D, E, F and G are considered as points of obstruction for the purpose of this explanation. The total path length from T to R via any of these points is some multiple of a wavelength longer than the direct path TDR. Therefore, the distance CR is a half wavelength longer than DR, and the distance is a half wavelength longer than CR.

The field contributed by any zone at point R is determined by the reflected path length with respect to the direct path length, and by the phase change at the reflection point. Assuming a 180° phase change at the reflection point, the signal from the odd numbered Fresnel zones reinforces the direct wave, and the signal from the even numbered Fresnel zones has a cancelling effect.

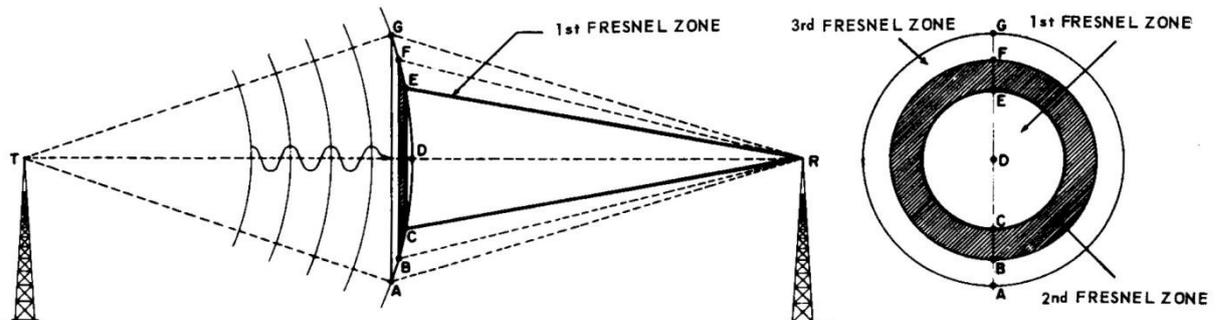


FIG. 12. FRESNEL ZONES.

An important factor in point-to-point transmission is that reflection may not occur at the mid-point of the path as shown in Fig. 11, because in many instances, a hill or sloping ground in the vicinity of one of the aerial systems, may be favourably located to cause a reflection which may have an important bearing on the propagation conditions, as shown in Fig. 13.

In analysing a propagation path, it is usual to take precautions, by the choice of a site and the selection of aerial heights, to ensure that the 'first Fresnel zone' clearance is obtained over the full section. As already stated, for lower clearances the received signal decreases rapidly whilst for greater clearances, the variation in signal strength is relatively small. The conditions necessary for this clearance can be determined by plotting on the profile diagram, a curve showing the limits of the clearance necessary to place the receiving aerial in the first Fresnel zone. This curve is an ellipse. The efficiency of reflection decreases as the frequency of transmission is raised. Further, the increased directivity of the aerial used at higher frequencies tends to reject locally reflected signals. Nevertheless, it is usual to apply the above analysis to all paths, and by the selection of sites and the provision of towers of appropriate height, to endeavour to secure the free space value of field intensity at the receiving aerial. It is usual to plan the path with a clearance slightly less than first Fresnel zone clearance.

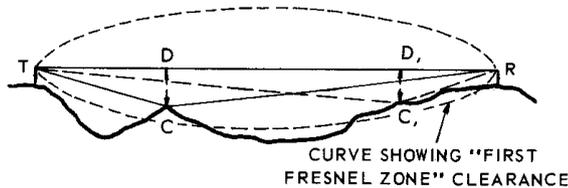
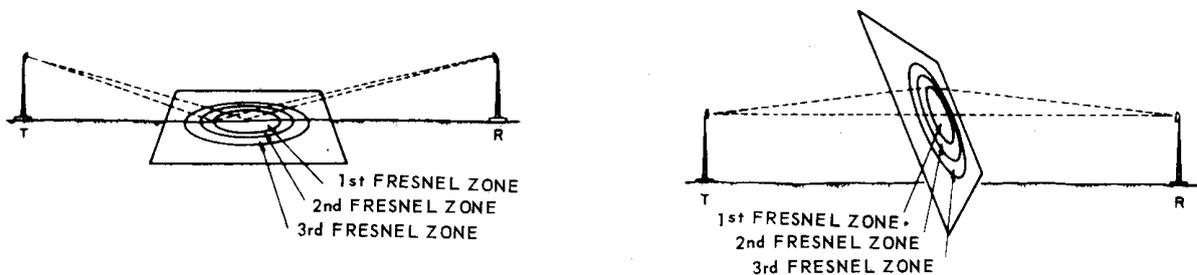


FIG. 13. PROPAGATION OF FREE SPACE AND REFLECTED WAVES-REFLECTIONS OTHER THAN MID PATH.

4.9 Earth Reflection Zones. When a radio wave is incident upon the earth's surface it is not actually reflected from a point on the surface, but from a sizeable area. This reflection area may be large enough to include several Fresnel zones, or it may be in the form of a ridge or peak including only a part of the first Fresnel zone. For the case where the wave is incident upon a plane surface, the resulting Fresnel zones formed on the reflecting surface take the form of ellipses.

The projected image of these earth reflected zones, from a plane surface, gives a Fresnel zone pattern similar to that shown in Fig. 12. Because of the difficulty in obstructing the unwanted Fresnel zones under these conditions, transmission paths over flat country or large expanses of water is avoided whenever possible.

Fig. 14(a) shows the ellipses formed by Fresnel zones on a plane surface and Fig. 14(b) shows these zones projected on an oblique plane to the receiving aerial.



(a) Fresnel zones on a Reflecting surface. (b) Fresnel zones projected on an oblique plane.

FIG. 14. EARTH REFLECTED FRESNEL ZONES.

5.4 Space Diversity. In a space diversity system one signal is transmitted to at least two vertically spaced receiving aerials. One common transmitter and two receivers are used. The receivers are connected to a diversity combiner which produces a usable output.

The effectiveness of space diversity relies on path length differences. That is, the components (direct and reflected) of the same signal travelling different paths will not have the same phase relationships at their receiving aerials. When cancellation occurs at one aerial, no cancellation should occur at the other.

Fig. 16 shows the principle of a space diversity system. A common transmitting aerial (T) at the transmitting station radiates electromagnetic waves to two separate receiving aerials (R1 and R2) mounted one above the other. The direct and reflected paths between T and R1 are shown in full lines and the paths between T and R2 are shown in dotted lines. The transmitted signals (same wavelength for both systems) travel paths of different lengths. In practice the vertical spacing between aerials can range from a few feet to over 80 feet.

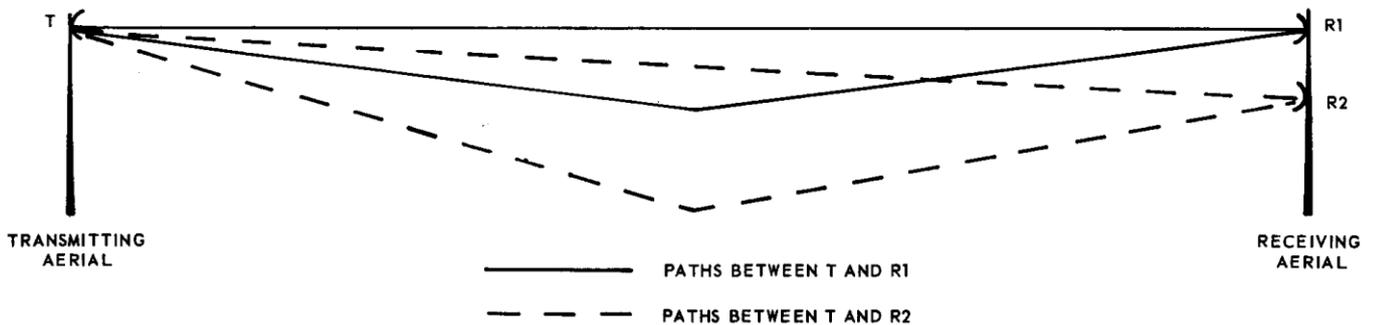


FIG. 16. SPACE DIVERSITY (TWO RECEIVING AERIALS).

5.5 Diversity Combining. In any type of diversity system some form of combining is used at the receiving point to gauge the received signals and to ensure a usable output signal. Three forms of combining can be used. These are:-

- Variable gain.
- Equal gain.
- Optimal switching.

In variable gain combining (Fig. 17) the signals from the diversity receivers are amplified then added together to form a combined output. The amount of amplification each signal receives depends on the signal to noise ratio. Both signals are monitored and the one with the better signal to noise ratio receives the larger amplification.

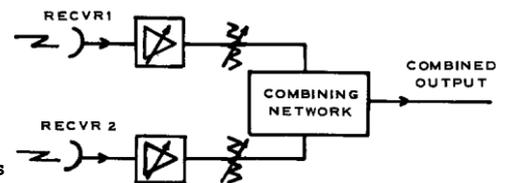


FIG. 17. VARIABLE GAIN COMBINING.

The two signals from the diversity receivers are added directly in an equal gain combiner (Fig. 18) The output signal is the sum of the two input signals. This type of combiner cannot overcome the problem of high noise incoming from one receiver during a deep fade.



FIG. 18. EQUAL GAIN COMBINING.

Optimal switching (Fig. 19) is not really a combining technique but is generally classified as such. In this system an automatic switching device monitors pilots and noise levels from both receivers and determines which signal is the better. This signal is selected and the poorer signal is disconnected.

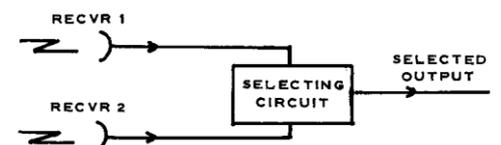


FIG. 19. OPTIMAL SWITCHING.

■ 6. U.H.F. and S.H.F. PROPAGATION.

6.1 For all practical purposes it is convenient to classify radio waves into bands of frequencies within which propagation effects are similar. However, any such classification must be of a general nature since changes in propagation characteristic with frequency are not sharply defined. For this reason, when an upper or lower limit of frequency is designated for a certain propagation effect, it does not mean that such an effect stops at those limits, but rather that it becomes negligible beyond such limits.

The main features of V.H.F. propagation are dealt with in Section 4, and in general these propagation characteristics also apply in the U.H.F. and S.H.F. range. A summary of the main features of U.H.F. and S.H.F. propagation are given in the following two paragraphs.

6.2 300MHz to 3,000MHz. Almost all the energy transmitted at these frequencies is propagated through the earth's atmosphere along a curved path. The refracted path may again be assumed as a straight-line path over a section of the earth's surface with a radius of $\frac{4}{3}$ the true radius.

Ground reflections are still present at these frequencies and can cause multipath fading due to destructive interference, although such reflections become of less importance at the higher end of the band. However, a second type of multipath fading can occur when parts of the wave are refracted through other higher layers of the atmosphere, and become bent sufficiently to return and combine with the wave received over a lower and more direct path.

At frequencies above 1,000MHz, attenuation of the transmitted signal by trees or other vegetation can range anywhere from 12 to 46dB per mile, although if the aerials are located to give first Fresnel zone clearance above the trees, such attenuation becomes negligible.

Atmospheric noise in this frequency band is extremely low. Man-made noise, with the exception of ignition pulses which can become serious at times, is also extremely low. Receiver noise is somewhat greater at these frequencies and increases with increasing frequency, thus calling for special receiving tubes and circuit design.

6.3 3,000MHz to 30,000MHz. At these frequencies, transmission is strictly limited to line of sight distances based on $\frac{4}{3}$ true earth's radius. Very little wave reflection will radiate from the earth at these frequencies. Instead, the earth acts as if it were made up of an infinite number of small mirrors, each reflecting the incident wave in a different direction. This is sometimes called diffuse reflection. In addition, incident radiation is also absorbed by the earth's vegetation. Consequently, the amount of reflected energy from the earth's surface is small, and very little wave interference occurs from this source. However, multipath fading caused by tropospheric reflections or the multiple refraction of several propagation paths through the atmosphere is important throughout the entire band. There is also a tendency for buildings and other man-made objects to cast sharp shadow at these frequencies, and if the surface of such objects is smooth, to reflect the waves in a new direction.

Rain scattering and absorption can cause a serious loss of radiated power at the higher end of this frequency range. If the drop size is comparable to the wavelength of the propagated wave, a very substantial portion of the transmitted energy is reradiated from the raindrop in a wide range of directions. This phenomenon, known as scattering, has an attenuating effect on radio waves somewhat like that of diffuse earth reflections. However, not all the energy incident upon a raindrop is reradiated, but is virtually trapped or absorbed, and converted into heat. If the drop size is comparatively small in relation to the wavelength, such losses are dependent only upon the volume of water in suspension, and therefore are generally negligible.

The use of sharply beamed waves to overcome the losses due to atmospheric attenuation in this band, conserves enough power to enable a few watts of directed power to be as effective at a distant receiver, as many kilowatts of undirected power.

Receiver noise at these frequencies has a great effect on the practical range of a receiving system. Special techniques, such as the use of crystal mixers, have been developed to minimise this noise by converting the received signal to a lower frequency before amplification. Such noise depends both upon the operating temperature and the receiver bandwidth, and increases directly with both.

■ 7. PRACTICAL APPLICATIONS.

7.1 The majority of radio communication services in the V.H.F., U.H.F. and S.H.F. ranges are provided by point-to-point radio systems.

Neglecting traffic requirements, and the economic aspects of site location, the main consideration in the selection of point-to-point radio routes are:-

- Path Lengths. Path lengths of 35 miles represent a reasonable compromise between providing a minimum number of repeaters, but still maintaining a reasonable service. In practice the majority of path lengths are between 30-40 miles, although path lengths up to about 44 miles and down to about 12 miles are used.
- Reflection Areas. Paths over water or flat open country are avoided as far as possible, as these generally produce strongly reflected signals which cause interference with the direct signal. This produces "fading" of the radio signal, and consequent degradation of the signal to noise ratio in the trunk channels. This effect can be reduced by the use of "diversity" operation.
- Path Overshoot. The number of operating frequencies available for use on any route is limited, and a repetition of similar groups is necessary. For example, the radio frequencies employed over a path A-B are a different group from B-C, but often are the same as for C-D. The receiving equipments at B and D are therefore tuned to common frequencies, and "overshoot" occurs if the signal from A is permitted to reach D. The risk of overshoot interference requires close investigation when any group of three adjoining radio paths has a configuration such that the line joining A.D. has insufficient angular separation. (less than 5 degrees), from the line of shoot from both A to B and C to D, and there is limited natural shielding by the intervening terrain.
- Path Clearance. The two important factors involved in path clearance are "Effective Earth Clearance" and "Free Space Clearance".

Refraction of transmitted radio waves affect the effective earth clearance. The bending of the radio waves gives the same result as reducing the curvature of the earth. This effective reduction in earth curvature, or increase in earth radius, is expressed by the equivalent earth radius factor "k" which is about 1.3 for the higher radio frequencies in a standard atmosphere. However, atmospheric refraction is subject to diurnal and seasonal variations, which cause a variation of the "k" factor over wide limits, e.g. from 0.6 to near infinity. Extreme variations from the standard "k" condition only occur for small percentages of the time. When assessing path clearance, it is convenient to assume that the radio beam travels in a straight line and that only the earth curvature (k factor) varies, the clearance varying as "k" increases or decreases.

Propagation between ground based stations does not achieve classical free space clearance conditions, due to the presence of the intermediate country. However, little ground influence on a radio beam is experienced when the path traverses irregular or broken terrain, provided that the clearance approaches that determined by the first Fresnel zone.

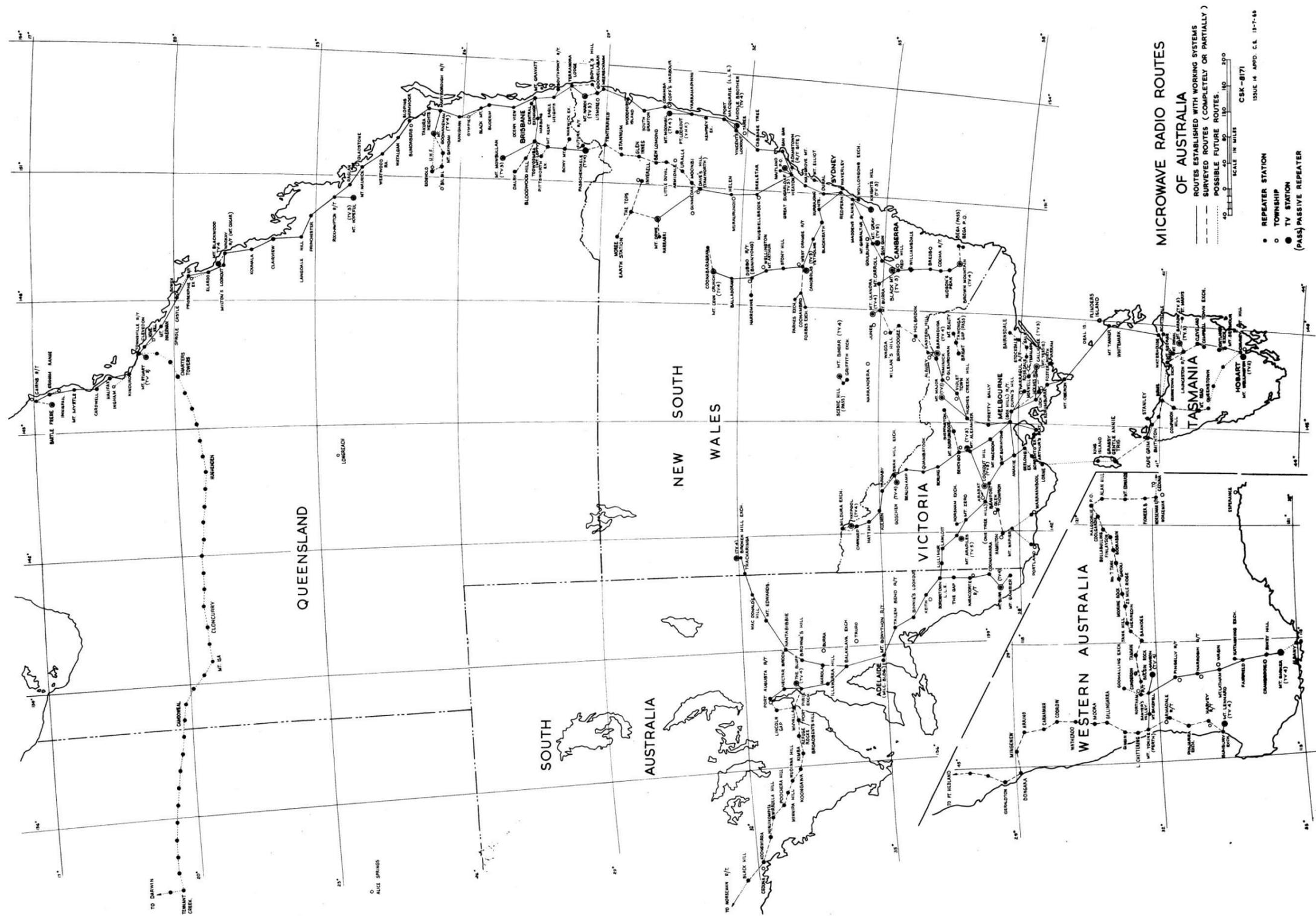


FIG. 20. MICROWAVE RADIO ROUTES OF AUSTRALIA.

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