SECTION 5D: ASPECTS RELATIVE TO THE TERRESTRIAL BROADCASTING AND MOBILE SERVICES

REPORT 239-7*

PROPAGATION STATISTICS REQUIRED FOR BROADCASTING SERVICES USING THE FREQUENCY RANGE 30 TO 1000 MHz

(Question 11/5)

(1959-1963-1966-1970-1974-1978-1982-1986-1990)

1. Introduction

This Report gives details of the construction and use of the propagation curves in Recommendation 370, and includes descriptive statistics concerning depolarization phenomena. It also discusses the effects of urban areas and of vegetation on propagation. Section 5 indicates methods for computing field strength over mixed land-sea paths.

Propagation curves for broadcasting in the African Continent and neighbouring countries are given in the Final Acts of the VHF/UHF Television Broadcasting Conference, Geneva, 1989. The curves were prepared taking into account the climatic differences expected within the continent of Africa and in the neighbouring countries concerned.

The acquisition of field-strength data and the development of prediction methods – vital factors in spectrum planning – are continuing in many countries. The results of such activities complement the information given in Recommendation 370 and emphasize the importance of co-ordination, which leads to the earliest possible improvement in prediction techniques and clarification of descriptive texts. This Report outlines areas of work where such developments are taking place.

Report 1145 ———————— discusses the influence of the terrain on propagation and the theoretical basis for some of the parameters used with curves of field strength versus frequency, distance, antenna heights, and type of terrain. Report 228 discusses the measurement and descriptive analysis of field strengths for broadcast services and shows how propagation curves may be used to describe effective service areas. For prediction of long-term medians and time variability of point-to-point transmission loss, other methods of prediction are usually employed (e.g. [NBS, 1967]).

2. Construction of the propagation curves

The propagation curves in Recommendation 370 are for within-the-horizon and beyond-the-horizon distances. The two parts were produced by different methods. The curves incorporate a large amount of data made available by many administrations.

2.1 *Beyond-the-horizon distances*

The long-term data for distances beyond the horizon were separated into VHF and UHF classes, and further subdivided for land and sea paths.

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* This Report is brought to the attention of Study Groups 10 and 11.

2.1.1 *VHF*

In Figs. 1a to 4c of Recommendation 370, the portions of curves corresponding to beyond-the-horizon distances incorporate a very large amount of data over many land and sea paths. These data were obtained with transmitting and receiving antennas at various heights. The data were first normalized for a transmitting antenna height of 300 m by assuming that the field strength at a distance X km from the transmitter, for an antenna height of h_1 m, is the same as the field strength given by the curve for a transmitting antenna height of 300 m at a distance $(X + 70 - 4 \cdot 1 \sqrt{h_1})$ km. The same formula was then applied to obtain the family of curves in Recommendation 370.

The procedure is based on the assumption that the field strength is constant if the distance between horizons is constant, disregarding differences in free space attenuation and assuming a smooth spherical Earth model.

In general for oversea paths, the measurements were taken at open coastal sites directly overlooking the sea. In order that they may be applicable for the calculation of co-channel interference in coastal towns, where the field strength may be expected to be lower than at the open sites, they incorporate a correction of approximately 7 dB relative to the measured values. It should be noted that such corrections should be applied to all measured results in the VHF band at open coastal sites.

Propagation for distances exceeding 500 km at frequencies below about 90 MHz may be caused by sporadic-E reflection from the ionosphere for small percentages of time. Such effects are treated in Volume VI of the CCIR, in particular in Report 259 and Recommendation 534.

2.1.2 *UHF*

The same procedure was applied to obtain the portions of curves corresponding to beyond-the-horizon distances in Figs. 9, 10, 11, 13, 14a and 14b of Recommendation 370.

However, for oversea paths, and for small percentages of the time, the field strength is relatively independent of the height of the transmitting antenna. For this reason Figs. 16a and 16b, corresponding to 1% of the time, have no antenna height correction for beyond-the-horizon distances. The 5% curves, which are interpolations between the 1% and 10% curves, therefore contain approximately half the height-gain correction.

In the Mediterranean area, the measurements were taken at open coastal sites directly overlooking the sea. In order that they may be applicable for the calculation of co-channel interference in coastal towns, where the field strength may be expected to be lower than at the open sites, they incorporate a correction of approximately 7 dB relative to the measured values.

It should be noted that such corrections should be applied to all measured results in the UHF band at open coastal sites.

2.2 *Within-the-horizon distances*

Propagation curves for distances within the normal horizon were developed by comparing the data obtained from many mobile surveys and a number of long-term measurements at fixed locations for short path lengths, with theoretical propagation curves for a smooth earth at the appropriate frequencies and antenna heights. The variation in field strength with frequency proved to be relatively minor and the data were separated into VHF and UHF classes, as was done for the beyond-the-horizon distances.

Figures 1a and 1b of Recommendation 370 show the field strength exceeded for 50% of the time at VHF. The curves within the normal horizon distances were derived by comparison with the corresponding theoretical curves for a smooth earth. These curves were then merged smoothly into the corresponding family of curves for distances beyond the horizon, as described in the previous section. Figures 1a and 1b of Recommendation 370 thus include portions of field-strength curves within the horizon and beyond the horizon, as well as intermediate portions which are the result of merging the within-horizon and beyond-horizon curves.

Figures 2a, 2b, 2c and 4a of Recommendation 370 show field strengths exceeded for 10% and 1% of the time, respectively, at VHF. The derivation of these curves was very similar to those of Figs. 1a and 1b. The assumption was made that time fading is negligible at short distances, so that the median curves of Figs. 1a and 1b may be used as a guide at short distances and merged with the appropriate 10% and 1% curves from the other Figures.

The near-distance field strengths in Figs. 3b, 3c, 4b and 4c of Recommendation 370 which show the 5% and 1% (time) oversea VHF curves, were constructed on a corresponding assumption; namely, that the 5% and 1% field strength for propagation over land and over sea would not be materially different at a distance of 10 km from the transmitter. The sea curves were consequently merged smoothly with the land curves at this distance.

The 5% time curves for propagation over land, Fig. 3a of Recommendation 370, have been derived by linear interpolation between the 1% and 10% time curves, assuming a normal distribution, such that:

$$E(5\%) = 0.653\ E(10\%) + 0.347\ E(1\%) \qquad \text{dB}$$

A set of field-strength versus distance curves was derived for UHF in a similar fashion. These are shown as Figs. 9, 10 and 11 of Recommendation 370 for overland paths and in Figs. 13, 14a, 14b, 15a, 15b, 16a and 16b for oversea paths.

3. Additional measurement data

3.1 *North Sea and Baltic Sea areas*

Measurements in Bands IV and V, for distances less than 200 km in the North Sea area, indicate that for 50% and 10% of the time, field strengths may be several decibels greater than those derived from Recommendation 370, but there is better agreement for 1% of the time.

As a result of OIRT measurements [Kühn *et al.*, 1969] conducted over a period of 3 years, there is further evidence that the values shown in Recommendation 370 for the North Sea area are applicable to the Baltic Sea area. It was noted, however, that, for small percentages of time, there was a tendency for measured field strengths to be slightly higher than those predicted.

Measurements of field strength made in Sweden over periods ranging from 7 months to 4 years on transmissions over three VHF and three UHF paths in the Baltic Sea area are, as regards the VHF paths, in good agreement with values shown in Recommendation 370 for the North Sea area. The month-to-month variation of field strength is, however, found to be large, and for the worst month the measured field strengths exceeded for 1% and 10% of the month, are greater than the predicted relevant field strengths by 30 to 40 dB.

3.2 Mediterranean Sea and Black Sea areas

It should be noted that in the Mediterranean area in particular, field strengths in the summer months [Fedi *et al.*, 1973] are considerably greater than in the winter months. VHF and UHF measurements of field strengths were carried out in Italy [CCIR, 1974-78] on two different paths in the central Mediterranean area. These measurements were made over a two-year period with various receiving antenna heights. The results obtained were compared with those calculated for 1%, 5% and 10% of the time by using the Figures of Recommendation 370, and applying the formula given in § 2.1.1, for the transmitting antenna heights, and a similar formula for the receiving antenna heights. Good agreement was obtained between calculated and measured results at UHF, but measured results were from 3 to 14 dB higher than calculated at VHF.

In addition, measurements conducted in Italy [CCIR, 1978-82a] on 29 grazing or transhorizon paths (four all-land paths, nine primarily sea paths and sixteen mixed land-sea paths) in the period between 1968 and 1977 gave valuable results which could be used for further propagation studies.

VHF and UHF measurements conducted in the Black Sea area between the USSR and Bulgaria [Troitsky et al., 1989] over a path length of 970 km gave field strength levels for 1% of the time which were about 10 dB higher for both VHF and UHF than calculated using Recommendation 370. For 10% of the time measured values were coincident with calculations using Recommendation 370 for UHF and 7 dB higher for VHF.

VHF measurements in the Black Sea area over path lengths of 309 km and 402 km also resulted in field strengths which were higher than calculated using Recommendation 370 for 1% and 10% of the time by between 6 dB and 13 dB [CCIR 1986-1990c].

For these comparisons in the Black Sea area the "Warm Sea" curves of Recommendation 370 were used, increased by 7 dB to correspond to clear receiving locations. The high signal levels at VHF and UHF may be explained by occurrence of tropospheric ducting.

3.3 *Central Europe*

An important conclusion to be drawn from measurements made by the OIRT, on five paths in Central Europe at 1100 MHz over a period of three years, was that the variation of field strength for several paths was considerably greater than indicated by Recommendation 370. These paths are such that they are particularly influenced by the overlapping effects of more than one propagation mechanism. For example, it was observed that over paths of some 200 km in length, the fading range (the difference between the field strength exceeded for 1% and 50% of the time) is of the order of 30 dB, compared with a difference of about 18 dB which would have been expected from the curves of Recommendation 370, drawn for a median frequency of about 700 MHz (middle of Bands IV and V).

Additional measurements carried out in the German Democratic Republic in cooperation with the Administrations of the Socialist Republic of Czechoslovakia and the People's Republic of Poland [CCIR, 1978-82b], over a period of several years, at 1100 MHz, on 9 transhorizon paths with typical conditions for Central Europe, up to distances of 400 km, showed that the fading range lies between the values 19 dB and 32.5 dB. These values are greater by almost 15 dB in comparison with the values which could be expected following Recommendation 370 and were observed for distances up to 250 km. This difference decreases with the distance, but is still 3 dB at a distance of 400 km. In addition, a difference of 9 dB was observed between the measured and predicted fading range at 500 MHz on paths with lengths of approximately 200 km.

3.4 *North America*

Measurements by Canada of VHF and UHF signal strengths exceeded for 50% and 10% of the time, over non line-of-sight paths between 125 and 250 km in length in the Great Lakes region of continental North America, show that significant diurnal and seasonal variations of signal strength occur [Palmer, 1980]. Signal strengths exceeded for both 50% and 10% of the time have minimum values during the afternoon and in winter and maximum values during the night and in summer. The diurnal variability of median signal strength is 5 to 9 dB in summer and 2 to 3 dB in winter. The seasonal variability ranges between 6 and 15 dB, the higher values being observed on paths, a significant fraction of which is over water. Signal strengths exceeded for 10% of the time exhibit diurnal variations of 2 to 6 dB in winter and between 10 and 26 dB in summer. The seasonal variation is 2 to 6 dB at noon and 15 to 25 dB at night. As for the median values of signal strength, the higher values of diurnal and seasonal variability are observed on paths, a significant fraction of which is over water. Similar results have been obtained with a new experiment in Canada, in which the signal strengths from five television transmitters were monitored for two years at a site near Yarmouth, Nova Scotia, on the east coast of Canada. The path lengths ranged from 92 to 384 km and the frequencies from 67 to 543 MHz [Whitteker, 1985].

Measurements made in the United States of America in the same region show slightly higher field-strength seasonal and diurnal variations [Kalagian and Tawil, 1983]. The diurnal variability of median field strength is 5 to 11 dB in the summer and 1 to 9 dB in the winter. The seasonal variability ranges between 7 and 22 dB. Field strength exceeded for 10% of the time shows a diurnal variation of 11 to 19 dB in the summer and 4 to 10 dB in the winter. The seasonal variation is 11 to 31 dB. Field-strength variations were slightly lower at VHF.

Measurements carried out in the Gulf of Mexico have shown that the field strengths, particularly in the summer, may exceed the figures given by the curves in Recommendation 370 for the North Sea by as much as 20 dB for distances exceeding some 200 km.

3.5 Asia

Field strength measurements were carried out in the lower latitude areas of Asia by seven Member Organizations of the ABU in Bangladesh, Hong Kong, India, Malaysia, Pakistan, Saudi Arabia and Thailand. These utilized VHF emissions at different seasons and times of the day. Provisional results for flat terrain are given in Figure 1 [CCIR 1986-90a]. These curves are generally in good agreement with the corresponding curves in Figure 1a of Recommendation 370. However, for distances less than about 30 km the ABU curves are lower by up to 5 dB especially for low effective transmitting antenna heights. It should be noted that if a correction is applied for surface refractivity (section 1.7 of Annex I to Recommendation 370) the predicted values are too high in the diffraction region. Measurements made in both hilly/mountainous and desert terrains also indicate generally lower values than expected from Recommendation 370.

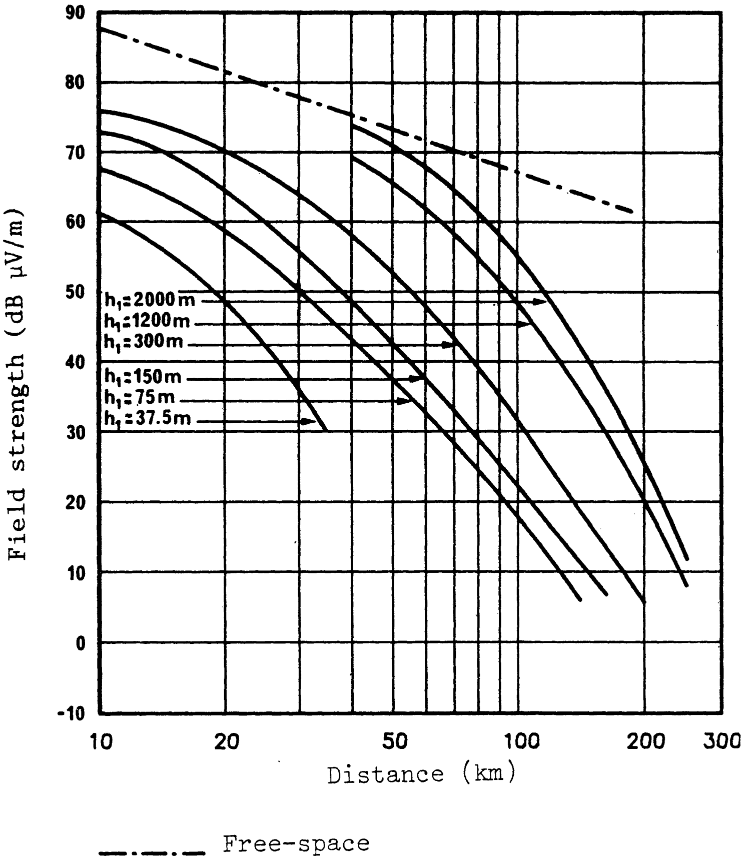

FIGURE 1

Field strength (dB(µV/m)) for 1 kW e.r.p.

Frequency: 60 - 250 MHz (Bands I, II and III) - Tropical zone - Flat terrain
50% of the time - 50% of the locations - h_2 = 10 m;
Δh = 20 m to 50 m

(see also Figure 1a of Recommendation 370)

Measurements made in India [CCIR, 1978-82d] indicated that the difference between the field strengths exceeded for 10% and 90% of the time, on VHF Band III television signals over a transhorizon path of length 216 km is 4.2 dB for the whole year and 3.5 and 5.5 dB in summer and winter respectively, showing marginal seasonal changes.

In addition, anomalous propagation of VHF Band I television signals, believed to be due to super-refraction has been observed in India during the pre-monsoon months [CCIR, 1978-82e] indicating that these signals could propagate, for a considerable period of time, over distances of the order of 1000 km.

Field-strength measurements have been made in Japan [Akeyama and Nishio, 1985] on board ship over a sea path ranging from 20 to 100 km at frequencies of 252 and 920 MHz. Although these results cannot be directly compared with the curves in Recommendation 370, in view of the instantaneous nature of the measurements, the propagation attenuation due to Earth diffraction produces measurement results in line with the values calculated according to Report 715.

3.6 *Areas affected by marked super-refraction phenomena*

Measurement campaigns have been undertaken by Gulfvision [CCIR, 1982-86a], the Islamic Republic of Iran and the State of Israel [CCIR, 1982-86b] to study VHF and UHF propagation in super-refractive climatic conditions. Measurements in the area from the Shatt-al-Arab to the Gulf of Oman [Murray, 1972; Gough, 1958] have also been given in [CCIR, 1982-86c]. The first results obtained, in the area between the Shatt-al-Arab and the Gulf of Oman on the one hand, and in the Mediterranean east of the 30° E meridian on the other, show that the 50% of the locations, 10% of the time and especially 1% of the time oversea curves differ considerably from those given in Recommendation 370 for warm sea. For oversea paths up to 500 km and at frequencies around 100 MHz, the 1% of the time curves are very similar to the free-space propagation curve.

The field strengths measured during periods of duct propagation at frequencies above 150 MHz are in general agreement with values predicted by equation (3) in Report 569 using appropriate values for the parameters A_c and γ, although this Report is primarily intended for frequencies above 500 MHz.

For overland paths remote from coastal areas, there are still not enough data available; measurement campaigns (being planned) in Africa might shortly provide useful information.

With regard to the 50% of the locations, 50% of the time curves, the differences with respect to the curves in Recommendation 370 are only slight, particularly for short distances. Results are still insufficient to define these differences since the curves are used mainly to determine coverage i.e. for short distances it is unlikely that any significant errors would result from using the curves in Recommendation 370, even for areas affected by super-refraction phenomena.

Pending fuller analysis and appraisal of the experimental data from the propagation measurement campaigns, the areas where super-refraction conditions are very likely to be frequent can be identified by comparing their climatic conditions with those of the areas in which propagation measurements have been carried out.

These areas probably include:

- the west coast of Africa between the Equator and the Tropic of Cancer;
- the Straits of Gibraltar;
- the Red Sea;
- the sea areas of Central America, the Gulf of Mexico and California;
- the Arabian Sea;
- the Bay of Bengal.

The need for clarification of this aspect of radio propagation is emphasized by reports which have emerged from the extensive research programme conducted by Gulfvision [CCIR, 1982-86d]. This opens up new questions concerning the estimation of coverage and interference. For example, contrary to previous conclusions, it suggests that in such areas use of 50% of the time curves may be inadequate because of significant differences between levels at 50% and 99% of the time for relatively long distances. With respect to interference calculations, and to the extensive reports of long-range reception at 100 MHz already mentioned above (see also [CCIR, 1982-86e]), the Gulfvision measurements reveal field strengths at long distances in Bands III, IV and V in excess of free space on oversea paths for low percentages of the time. Means of estimating the extent of this propagation have been proposed, which require information describing the topography and radiometeorology of the area concerned. The technique involves a definition of the boundaries of coastal land areas for paths crossing such areas. This requires an adjustment of the attenuation factor γ (dB/km) related to ducting, which turns out to be a function of the perpendicular distance from the coast. The boundary of the zone is determined by equating the value of γ resulting from ducting to the corresponding variable of the diffraction mechanism.

The work reported in the previous paragraph, and the relationship with results obtained using existing techniques described in Recommendation 370, require urgent study. Until such time as this work is completed propagation curves for meeting the requirements of planning in super-refractive areas have been proposed [CCIR, 1982-86f].

3.7 *Other data*

Some observations indicate that in particular conditions and for small, but not insignificant, percentages of time perceptible signals may be received from high-power transmitters at distances exceeding 4000 km in tropical regions. For example, a field strength of 0.15 μV/m for an effective radiated power of 1 kW and transmission frequency of 417 MHz was measured at a distance of 4740 km (across the Atlantic Ocean) for approximately 2% of the year [Misme, 1966].

Data from the European radio amateurs have been discussed by Flavell [1985]. They show that maximum ranges, due to anomalous tropospheric propagation, of 2500 km and 1890 km have been reported at 144 MHz and 432 MHz respectively.

4. Influence of irregularities in the terrain

Random selection of broadcast receiving locations on or near roads and in valleys, results in higher values of the median transmission loss than are seen with more carefully selected receiving sites. Terrain roughness first increases the expected (or median) field strength by breaking up the destructive phasing between direct line-of-sight propagation and radio waves reflected or diffracted by the ground. Then increasing terrain irregularity and terrain clutter will reduce signals due to shadowing, absorption (including attenuation caused by vegetation) and the scattering and divergence or defocusing of diffracted waves. Convergence or focusing and specular reflection also play a part in these multipath phenomena, as does average refraction, turbulence and stratification of the refractive-index structure of the atmosphere.

Two phenomena play a major part in determining the complex standing waves which determine antenna height gain at a fixed distance from a transmitter. With reflection or diffraction from a surface which is sufficiently smooth and sufficiently large, a linear height gain is to be expected for lower heights, and as a receiving antenna is raised above irregularities and clutter, a height gain is to be expected for the quite different reasons mentioned in the preceding paragraph.

Depolarization phenomena are discussed in Report 722 and some recent measurements are discussed below. Here again site selection is of prime importance, either to reject unwanted signals, for instance, or to take advantage of depolarization with diversity; polarization discrimination is better in open country and with high signal levels than when field strengths are low, as, for example, where a UHF receiving antenna is surrounded by obstacles.

The nature of the receiving site also has other important influences on wave polarization phenomena. For example, VHF observations in the Federal Republic of Germany have shown that, in shadow regions, whereas reflections have little effect on horizontally polarized signals, their effects on vertically polarized signals are often great enough to distort FM reception seriously. Comparative measurements of vertical and horizontal polarization for VHF television transmissions in hilly and wooded terrain in Norway have shown that there may be considerable differences in multipath effects (and hence in picture quality) between the polarizations. Despite the field strength normally being higher for vertical polarization the multipath effects were less pronounced for horizontal polarization at most of the measured sites [Danielsen et al., 1987]. Some comments on the effect of polarization on local variations of field strength are given in § 5 of Report 567.

It is useful now to discuss some aspects of the problems arising from irregular terrain, vegetation, etc., with special reference to the use of VHF and UHF propagation curves.

4.1 *The parameter* Δh

The parameter Δh is used to define the degree of terrain irregularity. For broadcasting services it is applied in the range 10 to 50 km from the transmitter (see Recommendation 310 and Fig. 6 of Recommendation 370). Computer methods for derivation of Δh are given in [Thèlot, 1981]. All of the curves for propagation over land refer to the kind of rolling irregular terrain found in many parts of Europe and North America, for which a value of Δh of 50 m is considered representative. The influence of irregularities in the terrain increases with frequency. It is therefore of more importance at UHF (Bands IV and V) than at VHF (Bands I, II and III). For this reason the parameter $\Delta h/\lambda$ is used in some cases (see § 4.3 for example).

If one could visualize an ideal experiment in which long-term recordings are made at a large number of locations, then the distribution of time median for each and every site will result in a location distribution such as Fig. 5 of Recommendation 370 for VHF over typical rolling terrain for a Δh of 50 m.

It is further assumed that the change in the range of variation, i.e., the slope, of this location distribution is approximately unaffected by the roughness of the terrain at VHF, so that the distribution of Fig. 5 of Recommendation 370 may be assumed to apply for most practical values of Δh.

At UHF, typical location distributions for various values of Δh are shown in Fig. 12 of Recommendation 370; the changes in the range of variation cannot be assumed to be negligible.

Not only does the range of variation of the location distribution increase with the terrain roughness, but also the average received field strengths are reduced as the terrain becomes rougher, i.e., Δh becomes greater. Again, this effect increases with frequency. Recent measurements in the Czechoslovak Socialist Republic and the United Kingdom confirm that the corrections given in Figs. 7 and 8 of Recommendation 370 apply for distances up to 100 km in Bands III, IV and V [EBU, 1965]. Measurements carried out by the OIRT [Kühn, 1968] have indicated the requirement for using the same correction factor in Band II as in Band III. Extensive measurements carried out in the USSR in suburban and rural areas, having values of Δh ranging from 70 to 400 m, indicate that increased correction factors may be appropriate for Δh. These measurements, made in bands I, II, III and IV, have also provided further information regarding the effects of frequency, and would facilitate the preparation of a clearer statement of the Δh parameter [CCIR, 1982-86g].

In the above, the attenuation correction factor which is given in Figs. 7 and 8 of Recommendation 370 should be subtracted from the field strength for the required value of Δh.

Recent work has shown the single parameter Δh to be inadequate to define precisely the attenuation correction factor. It has been found, for example, that any location along transmission paths broadly defined by $\Delta h \approx 50$ m, the median field strength predicted may be in error by more than 20 dB, although it is generally within 10 dB, the error in the VHF bands tending to be less than at UHF. For values of Δh other than 50 m, these errors may be even greater. The Δh correction may be of less relevance for paths greatly in excess of 50 km particularly if the type of terrain is changing. For interference calculations over great distances, the Δh correction should therefore be applied with caution in order not to underestimate interfering signal strengths.

Situations in which Δh corrections may lead to errors, include:

- propagation paths deviating substantially from the horizontal;
- propagation paths containing a deep valley;
- propagation paths containing a single dominant terrain feature, e.g. a single mountain or steep ridge;
- significant irregularity features outside of the 10-50 km range (in which Δh is evaluated), especially in the immediate vicinity of the transmitter or receiver.

These cases may be summarized as situations in which significant changes occur in the topographical characteristics along the propagation path, in turn, giving rise to high values of Δh, e.g. 500 m. Recommendations restricting the use of Δh may therefore be expressed in terms of an upper limit for the value of Δh, above which application may be invalid. An upper limit of 150 m is considered to represent a realistic maximum value of Δh, characteristic of an area having essentially similar topographical features.

Efforts have been made to improve accuracy by the introduction of further terrain parameters on an empirical basis. These methods are listed below and may be used in cases where the prediction accuracy required is greater than that associated with the use of parameter Δh alone:

4.1.1 A method developed in the Federal Republic of Germany in which the mean slope of the terrain plays an important role in the derivation of the factor, as does the r.m.s. value of Δh.

4.1.2 A method developed in the People's Republic of Poland and based upon a modification of the TASO method [LaGrone, 1960], in which the factor is dependent upon both Δh and the mean wavelength of terrain undulations.

4.1.3 A method developed in the United Kingdom [EBU, 1965] in which factors dependent upon Δh and the mean slope of the terrain are used. A similar method has also been developed in Japan for the prediction of field strengths [Okumura *et al.*, 1968].

4.1.4 The various prediction methods described above are all based either on modifications of the field strength derived for propagation over a smooth spherical earth or on the assumption of well-defined diffracting obstacles along the transmission path. However, in a further method, recently developed in Japan [Okumura *et al.*, 1968], the free-space field strength is taken as the initial standard of reference for propagation over any kind of terrain.

4.2 *Receiver terrain correction*

If more precision is required for predicting the field strength for reception conditions in specific areas, e.g., in a small receiving area, a correction may be made based on a "terrain clearance angle". This angle, θ, should be representative of those angles in the reception area, which are measured between the horizontal at the receiving antenna and the line which clears all obstacles within 16 km in the direction of the transmitter. The example in Fig. 2 also indicates the sign convention which is negative if the line to the obstacles is above the horizontal.

From the terrain clearance angles, appropriate correction factors are given in Fig. 3; they should be applied to the results from Recommendation 370 for 50% of the locations. Use of this correction for selected receiving sites within a defined area will give a more realistic assessment of the variation of field strength within this area than would be possible using the corrections given in Figs. 5 and 12 of Recommendation 370.

Corrections for terrain clearance angles outside the range $-5°$ to $0.5°$, are not given in Fig. 3, because of the small number of paths concerned in the study. However, they may be obtained tentatively by linear interpolation between the curves of Fig. 3 and limiting values of 30 dB for VHF and 40 dB for UHF at 1.5° and -40 dB for both VHF and UHF at $-15°$, subject to the condition that the free-space field strength is not exceeded.

EBU calculations for over 200 paths in the Federal Republic of Germany, Finland, France and the United Kingdom indicate that when applying the correction as defined above statistically a reduction of about 4 dB in the difference between the predicted value and a reference value, the latter being determined using the computer method referred to in § 6.1, may be achieved.

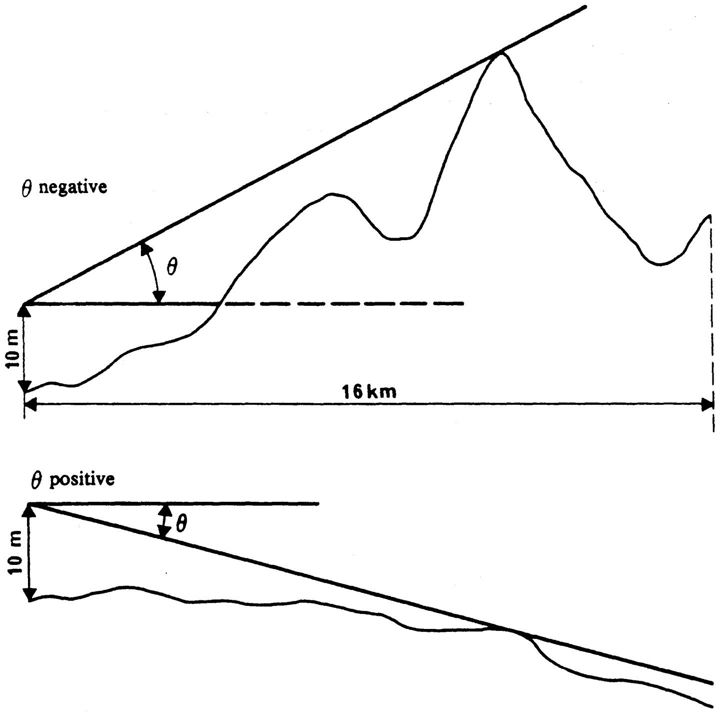

FIGURE 2 – *Terrain clearance angle*

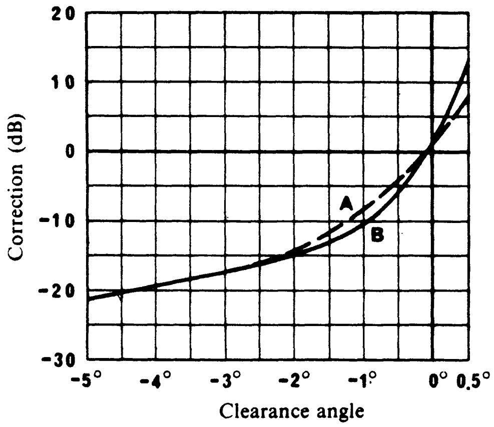

FIGURE 3 – *Receiving terrain clearance angle correction*

Curves A: VHF
B: UHF

The results of measurements made in Yugoslavia in the VHF/FM band for path lengths between 25 km and 70 km, were compared with those for 50% of the time by using the method of Recommendation 370. Three sets of calculations have been performed, each based on different correction parameters. In the **first set of calculations**, terrain irregularity Δh was the only correction parameter used, while in the second **set**, clearance angle θ was used as the single correction parameter. Finally, parallel corrections based on both clearance angle θ and terrain irregularity Δh were applied. Results measured on all 64 paths confirm that the best agreement between calculated and measured results are in the case when both clearance angle θ and terrain irregularity Δh are applied [Rašajski and Petrović, 1987; CCIR, 1986-90d]; then both the root mean square of the difference between calculated and measured results and the standard deviation of the distribution of the differences are about 12 dB.

4.3 *Path-to-path variability*

A recent survey of land mobile and broadcast system data (20 MHz to 10 GHz) in the USA [Longley, 1976] has shown the expected large variability of data from one path to another of the same length. This variability increases with radio frequency and terrain irregularity and is strongly influenced by the presence of buildings and trees near the path terminals. However, by normalizing the terrain irregularity parameter Δh with respect to wavelength (λ), the standard deviation σ_L of the path-to-path variability, for paths of approximately equal length, may be estimated for $(\Delta h/\lambda) < 3000$ by

$$\sigma_L = 6 + 0.69\,(\Delta h/\lambda)^{1/2} - 0.0063\,(\Delta h/\lambda) \qquad \text{dB} \qquad (1)^*$$

or for $(\Delta h/\lambda) \geqslant 3000$ by

$$\sigma_L = 25\ \text{dB} \qquad (2)$$

Except for data obtained above 300 MHz in a rugged mountainous area, 90% of all observed standard deviations fell within 2 dB of the values calculated by equations (1) and (2).

A comparison of equations (1) and (2) was made with a body of independent measurements at 172 and 410 MHz over 130 paths (in a flat, forested area of Florida, a hilly, forested area of California and in the rugged, arid mountains of Arizona) with antenna heights of 1 m or less. The differences between equations (1) or (2) and the observed standard deviations were within 1.5 dB for values of $\Delta h/\lambda$ from 15 to 175.

4.4 *Effect of change in the height of the receiving antenna*

4.4.1 *Variation in field strength with height*

Work by various administrations has indicated the field strength reduction which may be expected in changing the receiving antenna height from 10 m to 3 m above ground level. The values which may be used are given in Recommendation 370 although more recent work in the United Kingdom [CCIR, 1978-82f] suggests that the effect of changing receiving antenna height on received signal levels in Band II does not depend on distance; however, further measurements are needed. At any specific location in an area, the actual field-strength variation may differ by many decibels from the median value.

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[*] The coefficients in equation (1) differ from those [Longley, 1976] where Δh is defined as a function of distance rather than for a fixed range of 10 to 50 km

An extensive programme of receiving antenna height gain measurements has been carried out in the USSR. Several hundred measurements on Bands I, III, IV and V were made in suburban and rural environments at receiving antenna heights of 3 and 10 m above ground level, at distances from 10 to 100 km from the transmitting sites. The Δh values in the selected areas varied from 30 to 350 m, and the results confirmed that the height gain factor decreased as Δh increased, in agreement with the trend noted in Fig. 17 of Recommendation 370. However, the measured values are higher than the curves shown in that graph, and they also reveal that the results do not depend on distance within the range studied.

A study of measurements made in the United States in the frequency range 55 to 800 MHz, at distances from 8 to 90 km [TASO, 1959], indicates that the difference in field strength for receiving antenna heights of 9.1 m and 3.0 m in the presence of clutter such as buildings and vegetation in the vicinity of the receiving antenna is greater than that for open and low vegetation areas. The median field strength difference was found to be 9 dB for sites with buildings, 7 dB for sites with high densities of trees and vegetation, and 5 dB for open areas and sites with low densities of trees and vegetation. These results were found to be generally independent of frequency. However, the data are being further studied concerning the effect of frequency on the median height gains and their standard deviations.

Measurements made in the United Kingdom further indicate that, whereas horizontally-polarized and vertically-polarized signal components of transmissions both exhibit linear field-strength variation over the range 10 m to 3 m above ground level, there is little change in the received vertical component at heights below 3 m.

Measurements were conducted in Yugoslavia [CCIR, 1986-1990e] with receiving antenna heights of 3 m and 10 m, using different combinations of receiving and transmitting antenna polarization. The measurements were carried out at a frequency of 96.9 MHz at open sites in a suburban area over a propagation path of about 25 km. The results show average gains due to increasing the antenna height ranging from 8.1 to 8.8 dB for the various combinations of transmitting and receiving polarization, the lowest value being obtained for horizontal polarization in transmission and vertical polarization in reception.

Measurements were carried out in India [CCIR 1986-1990a] to study the effect of changing the receiving antenna height from 3 m to 10 m on the received field strength. The variation with distance in flat terrain for different VHF bands is shown in Figure 4. No clear trend of variation in field strength with receiving antenna height could be established in hilly/mountainous terrain.

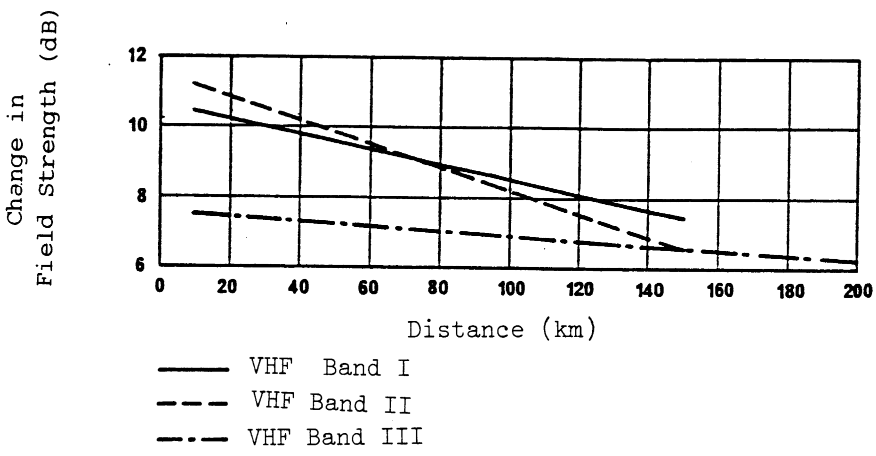

FIGURE 4

Variation of field strength difference between 3 m and 10 m receiving antenna heights with respect to distance for flat terrain in VHF bands

4.4.2 *Ratio between field strengths in town and in surrounding areas*

Presently available evidence suggests that, provided receiving antenna heights are sufficiently above the local roof level, the received field strength will be substantially that given by the curves in Recommendation 370.

Experience has shown that in Bands I and II no great difference exists between field strengths measured at a height of 10 m in rural and urban areas. In Band III, work done in the People's Republic of Poland has shown that field strengths at a height of 10 m in suburban areas are much the same as in equivalent rural areas, and the maximum attenuation in the centre of an urban area is as follows: in an urban area of 400 000 people, 16 dB at 10 m and 6 dB at 16 m (the average roof level) and in an urban area of 80 000 population [TASO, 1959], 12 dB at 10 m. In heavily built-up areas, the received field strength may be reduced by 6 to 16 dB, dependent upon the character of the buildings in the area. Studies carried out in Band III in India [CCIR 1986-1990a] to compare field strengths at 10 m above ground in urban and surrounding rural areas in flat terrain for a town having a population of about one million (mostly three storey buildings with some up to eight storeys) and another with a population of about 0.1 million (one or two storey buildings) indicate median reductions of 14.5 dB and 8 dB respectively.

Further detailed measurements made in Band IV in the People's Republic of Poland [Ogulewicz, 1971] have attempted to relate the attenuation in built-up areas with a building density factor. This work was carried out at the limit of the service area, with low angles of arrival of the received signal, and showed that the attenuation could range from 3 dB to 28 dB, for low and high values of building density factors, respectively. However, it is recognized that, in areas of high density of buildings, the excess height gain (with reference to a 10 m standard) must be taken into account; the main value being equal to approximately 12 dB for large cities where the height of the receiving antenna is doubled. For the UHF bands, recent work in the United Kingdom has shown a median loss of 9 dB for urban areas in south-east England.

Experiments made in Italy, at VHF and UHF, in heavily built-up areas have shown that the additional loss factor depends principally on the density and height of the buildings, on the angle of arrival of the wave at the receiving antenna and on the orientation of the street with respect to the direction of the transmitter from the receiving site.

It is desirable to obtain larger statistical samples for each type of urban situation.

4.4.3 *Rooftop versus indoor antennas*

The performance of existing rooftop and indoor antennas in New York City has been related to both signal strength measurements and subjective determination of television picture quality. Point-to-point transmission loss distributions were log-normal with standard deviations of 16 and 14 dB, respectively, for rooftop and indoor measurements. Median values for these distributions differed by amounts ranging from 16 to 35 dB depending on the frequency, the type of building, and the type of path. This difference was about 7 dB greater at 570 MHz than at 55 MHz, 10 dB greater for reinforced concrete buildings than for wooden buildings, and 5 dB greater for locations on Manhattan Island than for locations outside Manhattan Island.

In the United Kingdom, measurements made at UHF (600 MHz) inside two-storey suburban houses, on the ground floor and in the lofts, show a mean attenuation of 19 dB and 10 dB respectively, compared with measurements at 10 m in the street outside the house [Sofaer and Bell, 1966].

Results of studies carried out in India [CCIR 1986-1990a] on the attenuation of horizontally polarized VHF signals when received indoors, as compared to outdoors at 10 m above ground, are given below in Table I.

TABLE I

Location of indoor antenna (Height above ground level)	Band	Reduction in field strength		Type of building
		Median (dB)	Standard Deviation (dB)	
Ground floor (2.5 m)	I	24.5	5.6	Reinforced cement concrete (RCC)
Ground floor (2.5 m)	II	25	4.7	RCC
Ground floor (2.5 m)	III	23	5.4	Brick/stone
First floor (5 m)	I & II	16	4	RCC
First floor (5 m)	III	15.75	3.65	Brick
Inside hut (1.5 m)	II	20	3	Brick walls with thatched roof

4.5 *Depolarization phenomena*

The depolarization factor is considered here to be the ratio of the amplitude of the orthogonally polarized component, produced by some propagation mechanism, to the amplitude of the original plane polarized wave.

Where the transmitter itself is at a clear site, the polarization discrimination achieved at rooftop level in built-up areas by the use of orthogonal polarization, may have a median value of 18 dB; with corresponding values exceeded at 90% and 10% of receiving sites, 9 dB and 29 dB respectively (see Report 122). Measurements carried out in the United Kingdom show close agreement with the above median value for receiving antenna heights between 2.5 m and 10 m. The discrimination is better in open country and worse at cluttered receiving sites, or where reception is poor; also the United Kingdom measurements show that the discrimination is poor for low receiving antenna heights.

Measurements made in the Federal Republic of Germany, at 520 and 700 MHz have indicated 1 to 2 dB more depolarization for vertically, as compared with horizontally, polarized waves. Also, studies in the United Kingdom at 570 MHz have shown that the discrimination obtained with a vertically polarized antenna directed 180° away from an incident horizontally polarized wave, exceeds the front-to-back ratio (16 dB) of the antenna by 6 dB.

Studies have been made in the Czechoslovak Socialist Republic [Králík *et al.*, 1961 and 1962] and by other administrations on the effect of the type of terrain in the vicinity of the receiving site. Measurements have been made at a frequency of 570 MHz within the service area, and show that depolarization increases in a similar manner to diffraction loss, with an increase in the roughness of the terrain at the receiving site. Results are summarized in Table II.

The last item in Table II shows that a wooded environment causes much greater depolarization than that found in other areas having a similar path loss.

Measurements made in the the Federal Republic of Germany, at 520 and 700 MHz near Heidelberg, indicated the effects of frequency and building density to be negligible. The effect of variation in the parameter Δh is shown in Table III.

TABLE II

Type of terrain	Median path loss relative to free space (dB)	Polarization discrimination exceeded at 90 % of sites (dB)
Suburban, optical to transmitter	7	18
Suburban, in slight diffraction zone	26	13
Suburban, in moderate diffraction zone	31	10
Suburban, in deep diffraction zone	40	4
Thickly wooded area (in leaf) with no obstruction due to terrain	27	2

TABLE III

Type of terrain	Δh (m)	Polarization discrimination exceeded at 90 % of sites (dB)	Polarization discrimination exceeded at 50 % of sites (dB)
Flat	10	20	30
Hilly	50	14	27
Mountainous	200	0	16

4.6 *Attenuation due to vegetation*

Attenuation through woodland and vegetation varies with frequency. In practice it has been observed, however, that attenuation due to vegetation does not exceed values of the order of 30 dB for frequencies below about 500 MHz [Ogulewicz, 1972].

Measurements [Sofaer and Bell, 1966] made behind deciduous woods in summer and winter indicate that, although the attenuation due to foliage is not negligible at UHF, it is significantly less than that due to bare trees.

Median values of attenuation of horizontally polarized signals in Band III due to trees in the Tropical Region [CCIR 1986-1990a] have been found to vary from 6 dB to 13 dB (with standard deviations of 6.4 dB and 9.6 dB respectively) depending on the density of the trees.

Comparative measurements for horizontally and vertically polarized waves have been recorded, and, although the difference is not always marked, there appears to be a tendency for the attenuation to be slightly greater with vertical polarization.

Propagation through forested terrain is treated in greater detail in Report 1145.

4.7 *Attenuation due to buildings*

Attenuation due to buildings also varies with frequency. Work in Japan [Kinase, 1969] gives values of attenuation behind buildings as a function of the frequency, the height of buildings, their extent in the transmitter direction and the angle of arrival. A parameter is introduced, which represents the effects of environmental clutter in the vicinity of the receiving site. This is in addition to the correction for terrain irregularities. Results show good agreement with measurements at 100, 200 and 700 MHz.

Measurements in the United Kingdom [Sofaer and Bell, 1966] give values of attenuation behind various types of buildings at UHF (600 MHz) of as much as 30 dB.

Measurements made in the Federal Republic of Germany have shown that, at 190 MHz, the field strength over line-of-sight paths is 3 dB lower with vertical as compared with horizontal polarization, and for shadowed regions, the difference increases to 4.5 dB. Other measurements in shadowed regions at 97 MHz have shown this difference to be 5 dB with a deviation of ± 5.2 dB. At 500 MHz, the propagation differences between polarizations are much less marked and the corresponding values are 0 dB and 1.5 dB. The subjective quality of television pictures was found to correlate with these measurements.

5. **Mixed land/sea paths**

When the transmission path is over a mixture of land and sea, an estimate must be made of the effect of the mixed path on the received signal. For general planning purposes a suitable interpolation between curves for all land and all sea propagation in Recommendation 370 may be made (Method A).

When the average value of the horizon angles from receiving antennas in the reception area can be estimated, a method developed in Sweden [Rue, 1976] may be employed (Method B).

In specific cases the character of the land/sea profile between the transmitter and the point of reception may be incorporated in a prediction calculation, using a computer, [Causebrook and King, 1974] giving an individual estimate for the mixed path (see § 6.1).

Other computer methods can also be used [Longley and Rice, 1968; Causebrook and Lee, 1972; Causebrook *et al.*, 1969] for making estimates of received field strengths over mixed paths.

5.1 *Method A*

The following method can be used for interpolation between the land and sea curves of Recommendation 370; all field strengths are in dB(μV/m):

$E_{L,t}$: field strength for land path equal in length to the mixed path for t% of the time for $\Delta h = 50$ m,

$E_{S,t}$: field strength for sea path equal in length to the mixed path for t% of the time,

$E_{M,t}$: field strength for mixed path, for t% of the time,

d_S: length of sea path,

d_T: length of total path.

The median field strength for mixed-path ($E_{M,t}$) for all values of t in the VHF band, and for t equal to 10% and 50% in the UHF band can be determined by using the following formula:

$$E_{M,t} = E_{L,t} + \frac{d_S}{d_T}\left[E_{S,t} - E_{L,t}\right] \qquad (3)$$

In the case of t equal to 1% and 5% in the UHF band the median field strength can be determined from the formula:

$$E_{M,t} = E_{L,t} + A\left[E_{S,t} - E_{L,t}\right] \qquad (4)$$

where A is an interpolation factor given in Fig. 5.

A Δh correction factor may be applied for $E_{L,t}$ using the appropriate value from Figs. 7 and 8 in Recommendation 370.

This method cannot be applied for distances well beyond horizon range.

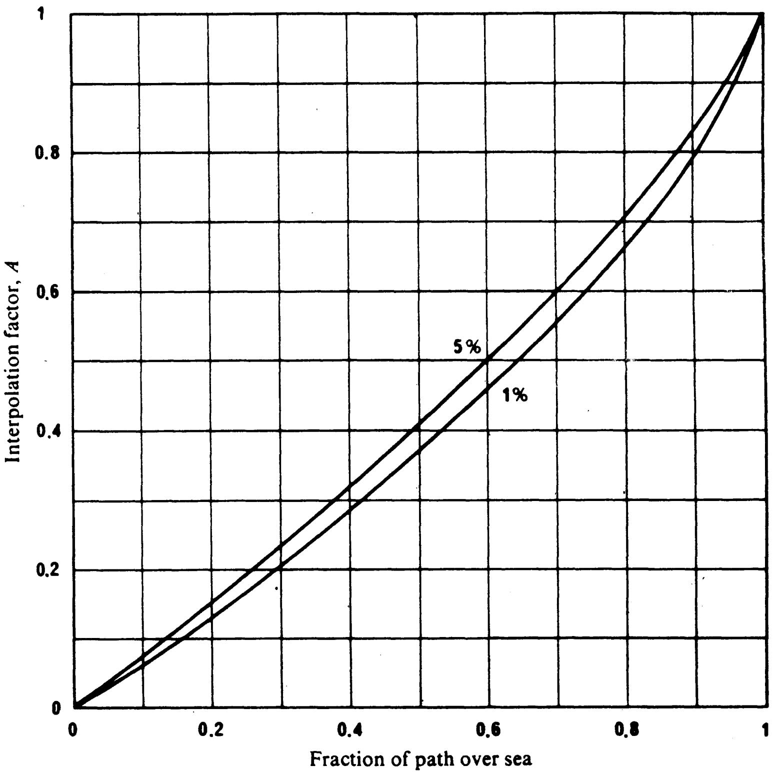

FIGURE 5 – *Interpolation for mixed land/sea paths*

5.2 *Method B*

Like Method A, Method B [Rue, 1976] may also be used in conjunction with the propagation curves of Recommendation 370, for all land and all sea paths in order to estimate field strengths over a mixed path when an estimate can be made of the average value of the horizon angle from receiving antennas in the reception area.

6. **Computer methods for field-strength calculation**

For field-strength calculation over individual paths where a great degree of accuracy is required, computer-oriented methods may be used.

6.1 A full scale computer method has been developed in the United Kingdom [Causebrook and King, 1974] for individual path profiles of any type. Features of this method, which is based on diffraction theory and the statistical analysis of measurements, include a variable effective Earth-curvature factor which is made dependent on the appropriate time percentage, and an allowance for ducting phenomena at UHF for small time percentages.

6.2 The above method will generally provide the most accurate predictions but simple computer methods from the USA [Longley and Rice, 1968] and the UK (Causebrook and Lee, 1972; Causebrook *et al.*, 1969] are also available and may be satisfactory in many applications.

Modifications of the UK method have been made in the People's Republic of Poland [CCIR, 178-82g] to take more fully into account the influence of mountainous terrain and the tropospheric parameters appropriate to the specific regions. Good agreement was obtained between calculated and measured results.

In Italy the United Kingdom method has been adapted for the VHF and UHF bands to the tropospheric situation typical of the Mediterranean region and to the orography of Italy. Good agreement was obtained between calculated and measured results. Other methods are being studied for evaluating the possibility of improving the accuracy of predictions [CCIR, 1986-1990b, Isola and Riccardi, 1988].

A simple, small-computer oriented method has been developed in the Socialist Federal Republic of Yugoslavia [CCIR, 1978-82h] for coordination and planning purposes in the VHF and UHF bands, also giving prediction results in good agreement with the measured data.

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