BBC RD 1974/4

RESEARCH DEPARTMENT REPORT

Computer prediction of UHF broadcast service areas

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THE BRITISH BROADCASTING CORPORATION January 1974

BBC RD 1974/4
UDC 621.391.812.8
621.396.721

COMPUTER PREDICTION OF UHF BROADCAST SERVICE AREAS

J.H. Causebrook, B.Sc.

Summary

A computer program has been written to predict the service area of relay stations using data derived from maps. In this report an outline is given of the methods employed to achieve this aim. Details are given of the required input and the form of output. This report is companion to a further report on predicting co-channel interference in a service area.

Issued under the authority of

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

January 1974

(RA-125)

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1. Introduction

Current planning for UHF television requires recommendations for many relay stations to serve communities of more than 1000 people. Decisions on the location, power, aerial height etc. for these new transmitters may be determined by installing temporary equipment and measuring the fields so produced. This is a costly process, in both time and money, making it desirable to have a method for predicting the coverage of proposed transmitters by calculation. Methods for making reasonably accurate predictions inevitably involve long and awkward computations and much data handling; thus manual calculations are not practicable where many cases have to be dealt with. Consequently computer programs have been written to perform these tasks. The purpose of this report is to describe the programs written to make field-strength predictions from small relay stations up to a maximum distance of 25 kilometres. For the longer distances needed for the calculation of co-channel interference, other programs have been written.[1]

It is not the intention in this report to give a full description of all the operations performed in the computer program but simply to give an outline of the processes involved.

2. The computer

The programs are written for use on a terminal connected to a Univac 1108 computer. The programming language is Univac 1108 Fortran V but the differences from standard Fortran are not great. Therefore, with slight modifications, the program could be run on most computers.

3. The input data

The topographical data are taken from maps and recorded on punched paper tapes using a machine called a 'Terrain Coder'. An early version of this machine is described in BBC Research Department Report RA-22.[2] In addition to the topographical data the Terrain Coder supplies information about the points at which field strengths are to be calculated. This may be either a set of individual points or a range of distances over which computations are made at 0·1 kilometre intervals.

At present the Terrain Coder produces five-track paper tape in a code unsuitable for direct use by the program and a preliminary program named 'TERCOD' has been written to convert these data into an acceptable form. 'TERCOD' also checks for certain errors which may have been introduced at the terrain coding stage. A listing of the output from 'TERCOD' may be obtained for manual checking and correcting before the information is used as input to the main program.

The first line of the input data to the field strength calculation program consists of the channel number, national grid reference of transmitter, receiving aerial height above ground level (if zero the aerial is assumed to be 10 metres above ground level). An instruction 'noplot' may be written if only tabulated output is required (the form of the output will be discussed later). The second line of input data is any title required by the user and this is followed by several lines giving details of the transmitting aerial.

4. The controlling sub-program

The controlling sub-program is given the name 'CODER'; a flow diagram of its operations is given in Fig. 1. After the initial line of data has been read in, subroutines 'GRID' and 'NGRGEO' determine the difference between true and grid north because aerial data are given relative to true north and profile data relative to grid north. The next significant operation is the use of a subroutine named 'STADAT' which controls the reading of aerial data. The calculation of effective radiated power (e.r.p.) is discussed in Section 7.

'CODER' now has the task of reading the topographical data and is programmed so that if an error in format occurs the program stops. Thus the possibility of getting into an infinite loop is precluded. The subroutine 'PROFTC' turns the profile information into a series of heights spaced at regular intervals of 50 metres. Details of this process are given in Section 5.

The subroutine 'CLUTTA' converts the information about buildings and trees, (i.e. where each group begins and ends) into a fractional coverage by the obstacles in each 50 metre interval.

Details of the calculations performed by the field strength subroutine 'TCFS' are covered in Section 6. This subroutine is used by 'CODER' once for each field point on a particular profile. When all the field calculations are complete a subroutine named 'OUTPUT' is called; this is described in Section 8.

If the first line of data has 'noplot' in the position allocated, the work of the program is complete. However, the user may require a plot, as shown in Fig. 2, giving the fields calculated along each of the profile lines from a transmitter, and this is achieved using subroutines contained in an available soft-ware package. The plot is made to scale such that it may be overlayed onto a map and the service area of the proposed transmitter quickly determined.

5. Obtaining a good profile

The data from the terrain coder contains contour heights and distances along a chosen profile line, together

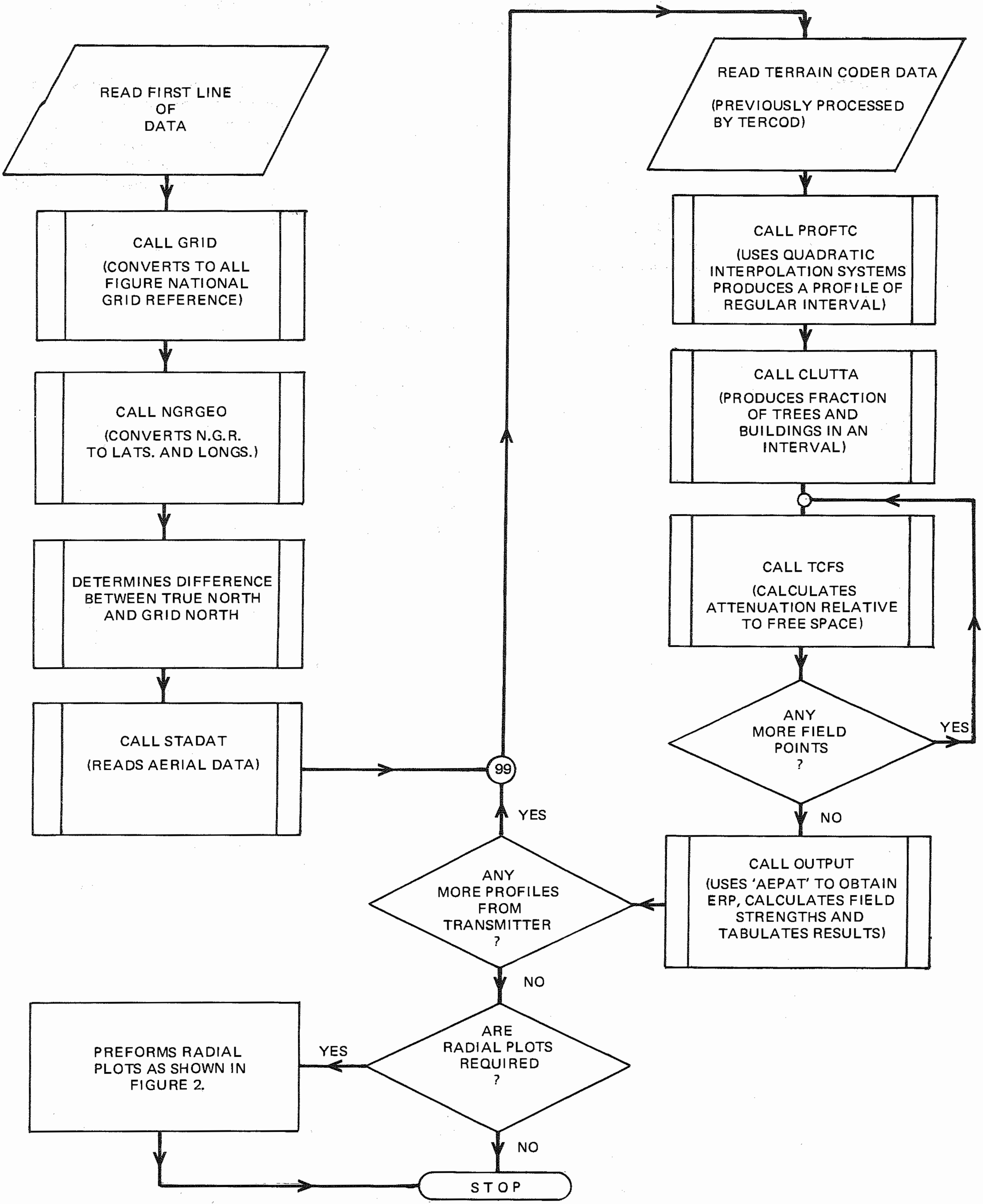

Fig. 1 - Simplified flow chart for 'CODER'

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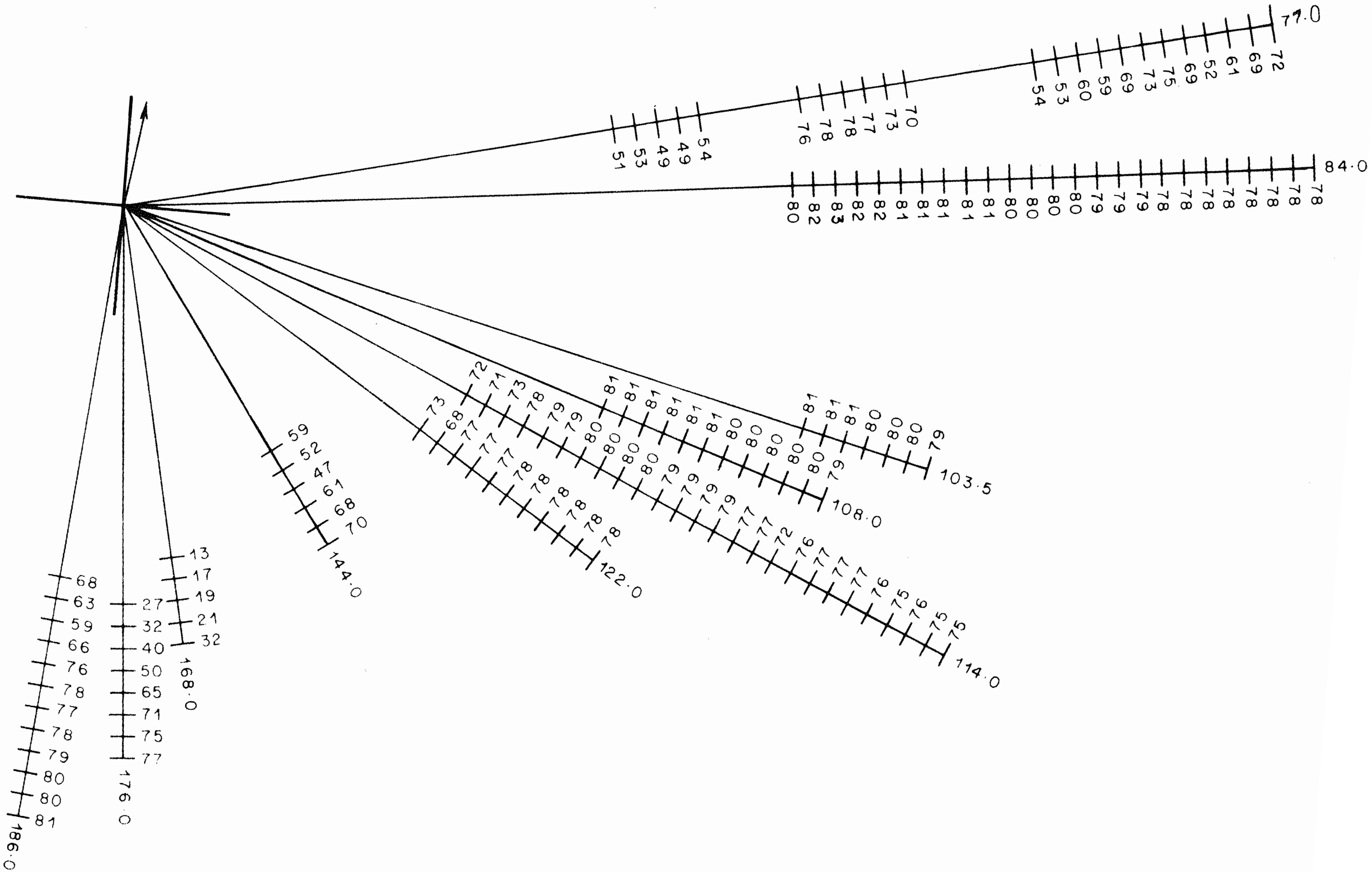

Fig. 2 · Fields along radial lines produced, to map scale, on an automatic plotter with distances to the beginning and ends of stretches of water. At least two contours beyond the receiver point must be supplied so that interpolation can take place. These data are converted into heights at a regular series of distances spaced 50 metres apart. (This is done by a subroutine named 'PROFTC' which employs a further subroutine named 'QUAD' to perform quadratic interpolation.) This process is essential at the end of the profile because of the way loss is calculated for buildings and trees and also provides heights between widely-spaced contours. The distances finally obtained are the points at which field calculations are made.

A requirement, of the computer method for interpolation, is that it should produce a profile as nearly equivalent as possible to one drawn by hand. In addition the process should give a profile independent of its direction of production. The method adopted is described although it must be observed that the choice was partly subjective.

At regular distances, D_j, from a terminal the heights, H_j, are derived from the weighting mean of two parabolic arcs. Let $(h_1 d_1)$, $(h_2 d_2)$, $(h_3 d_3)$, and $(h_4 d_4)$ be four consecutive contour height and distance pairs such that D_j lies between d_2 and d_3. A parabolic arc may be made to pass through $(h_1 d_1)$, $(h_2 d_2)$ and $(h_3 d_3)$ with constants a_A, b_A and c_A and another through $(h_2 d_2)$, $(h_3 d_3)$ and $(h_4 d_4)$ with constants a_B, b_B and c_B. Thus at distance D_j two interpolated heights may be determined.

$$\begin{aligned} H_{Aj} &= a_A D_j^2 + b_A D_j + c_A \\ H_{Bj} &= a_B D_j^2 + b_B D_j + c_B \end{aligned} \tag{1}$$

The following rules are then applied to derive a weighted mean height H_j from the above values H_{Aj} and H_{Bj}.

(a) Water between d_1 and d_2, or d_2 is the transmitter.

$$H_j = H_{Bj} \tag{2}$$

Water between d_2 and d_3

$$H_j = h_3 \tag{3}$$

Water between d_3 and d_4, or d_3 is the transmitter.

$$H_j = H_{Aj} \tag{4}$$

(b) If the vertex of either parabola lies outside the interval $d_2 d_3$, it is desirable for the profile to be made up of a curve with no discontinuity in slope. This is achieved with the interpolation:

$$H_j = \frac{H_{Aj}(d_3 - D_j) + H_{Bj}(D_j - d_2)}{d_3 - d_2} \tag{5}$$

(c) If the vertices of both parabolas lie inside the interval $d_2 d_3$ and are in opposite sense the choice of the interpolation method is arbitrary and the simplest method was adopted i.e.

$$H_j = \frac{H_{Aj} + H_{Bj}}{2} \tag{6}$$

(d) If the vertices of both parabolas lie inside the interval and are in the same sense, the interpolation is arranged to fall inside the triangle formed by the tangent to curve A at $(h_2 d_2)$, the tangent to curve B at $(h_3 d_3)$, and the line joining the points $(h_2 d_2)$ and $(h_3 d_3)$. The slopes of the tangents are:

$$S_A = 2a_A d_2 + b_A \tag{7}$$

$$S_B = 2a_A d_3 + b_B \tag{8}$$

The interpolated profile should produce a single peak and as in case (b) the slope is constructed without discontinuities. If D_j is less than the distance d_s of the junction of the tangent lines:

$$H_j = h_2 + \left[S_A + \tfrac{1}{2}\left(\frac{h_3 - h_2}{d_3 - d_2} - S_A\right)\left(\frac{D_j - d_2}{d_s - d_2}\right)\right](D_j - d_2) \tag{9}$$

and if D_j is greater than d_s:

$$H_j = h_3 + \left[S_B + \tfrac{1}{2}\left(\frac{h_3 - h_2}{d_3 - d_2} - S_B\right)\left(\frac{D_j - d_3}{d_s - d_3}\right)\right](D_j - d_3) \tag{10}$$

(e) A limit is put onto the value of H_j such that it shall not exceed the next contour value to be crossed.

6. The attenuation relative to free space field

The principal subroutine for making calculations of attenuation relative to the free space field is named 'TCFS'. A flow chart of the procedures carried out by 'TCFS' is given in Fig. 3.

The information entering the subroutine is mainly that describing the profile. The heights are not given as values above sea level but with reference to a cartesian frame formed by the vertical at the transmitter and the tangent to sea level at this point. In converting the heights an effective earth radius of four thirds the physical value is assumed.

The first operation performed is to find the points which would be touched if a string were stretched between the transmitting and receiving aerials. A by-product of this process is the determination of the angle from the transmitter to its horizon or to the receiver whichever is the less. This angle is needed to obtain the direction most relevant for calculating the e.r.p.

The subroutine estimates the attenuation resulting from buildings and trees. This requires several applications of a function sub-program named 'FZ' which estimates the density of obstacles in a volume close to the receiver. The method of obtaining the attenuation due to buildings and trees is given in the Appendix.

The subsequent procedure depends on the answer to the question 'How many points, on the profile, are touched by the imaginary string?' Thus is the answer is:

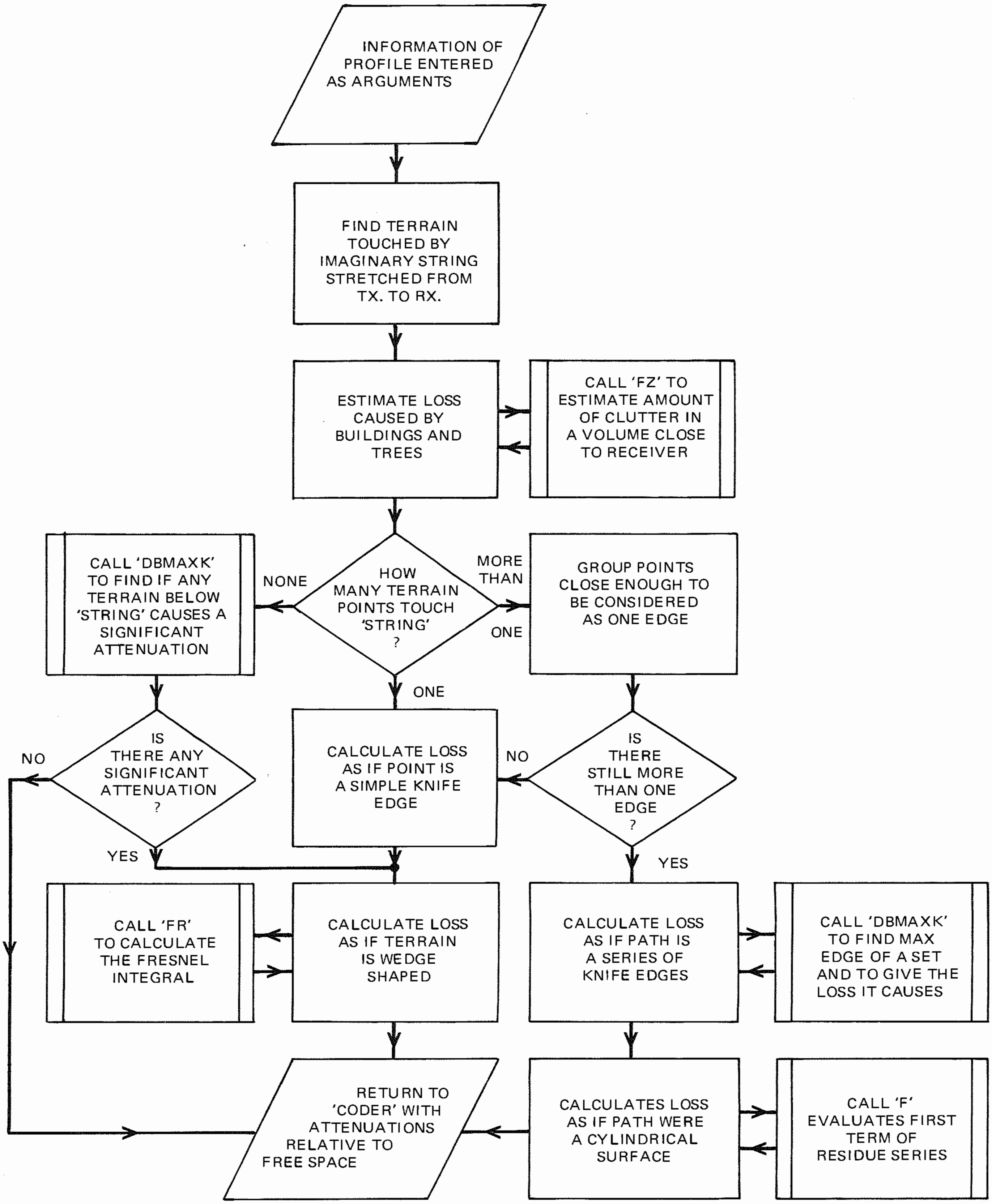

Fig. 3 - Simplified flow chart for 'TCFS'

(a) 'None'

Subroutine 'DBMAXK' determines, from the profile, the points giving the maximum knife-edge diffraction loss. If this loss is insignificant the work of 'TCFS' is complete. However, if the loss is significant two forms of diffraction loss are employed: one the knife-edge loss and the other the diffraction loss due to a wedge-shaped obstacle.

The method of calculating the loss over a wedge-shaped obstacle is described in BBC Research Department Report RA-91.[3] In the current program however, the wedge surface is not defined as in Reference 3. The stylisation of the profile is now made as follows: the apex is situated at the terrain point which gives the maximum knife-edge diffraction loss. The plane surfaces of the wedge are made to touch the terrain on either side of the apex, so as to make the internal wedge angle a maximum, provided this does not reduce the heights of the terminals above these surfaces to less than 15 feet. The part of the terrain used excludes that which is within the distances d_L^T and d_L^R kilometres from the apex, on the transmitter and receiver sides respectively. These distances are defined by:

$$d_L^T = \mathrm{MAX}\left\{0{\cdot}5,\ \frac{0{\cdot}0994\,(D - d_a)\,d_a}{D + 0{\cdot}0994\,d_a}\right\} \quad (11)$$

and

$$d_L^R = \mathrm{MAX}\left\{0{\cdot}5,\ \frac{0{\cdot}0994\,(D - d_a)\,d_a}{1{\cdot}0994\,D - 0{\cdot}0994\,d_a}\right\} \quad (12)$$

where D = total path distance (km)

d_a = distance from receiver to wedge apex (km)

(b) 'One'

The calculations are made for a single knife-edge and for wedge diffraction, with the apex at the point touched by the imaginary string.

(c) 'More than one'

The edges are examined to see if they may be put into groups. Groups are formed if:

$$d_{i+1} - d_i \leqslant 0{\cdot}5 \text{ km} \quad (13)$$

or

$$0{\cdot}9095 \leqslant \frac{d_i\,(D - d_{i+1})}{d_{i+1}\,(D - d_i)} \quad (14)$$

where d_i and d_{i+1} are a pair of adjacent edges touched by the string. Should it be necessary to group a set of edges, the set is replaced by a single virtual edge formed by using the first and last edges of the original set. This grouping may produce one virtual edge, in which case the calculation is made for a knife-edge and the wedge, but with d_L^T and d_L^R spaced from the horizon points rather than the wedge apex.

If two or more edges still exist a calculation is made for a series of knife-edges using the modified Deygout method described in Reference 3. To obtain a stylised surface in this case the first procedure adopted is to create a virtual edge from the terminal horizon rays, and then test the position of this edge in relation to the outermost edges. If the virtual edge and either of the outermost edges fall within the grouping criteria given by Equations (13) and (14), the virtual edge is used as the apex of the wedge stylisation.

If the virtual edge is not close to either of the outermost edges, a surface is constructed which consists of four right-circular cylinders with slope continuity at their 'joins' (Reference 3). The outer cylindrical surfaces are made to fit the terrain in a similar way to that used for the wedge surfaces.

In the multi-edge branch of the calculation, subroutine 'DBMAXK' finds the edge which produces the maximum loss and the losses due to subsidiary knife-edges, as required. The approximation to the first term of the residue series, needed to calculate the diffraction loss over a cylindrical surface is performed with a function sub-program named 'F'.

When the above operations are complete the program control is returned to 'CODER' with a series of values of attenuation relative to free space. These are A_{CL}, A_k, A_c and A_w for clutter, knife-edges, cylinders and wedges respectively.

7. The calculation of effective radiated power

The e.r.p. from the transmitting aerial is required to determine the free space field at the receiver. The information needed for the calculation of free-space field is the transmitter power, details of the transmitting aerial, and the distance from transmitter to receiver.

Two principal sub-programs process the aerial data. The first, 'STADAT', reads in information concerning the elements of which the aerial is composed, and the feeder loss. Information about the aerial may be given in the form of a tabulation of horizontal radiation pattern and vertical radiation pattern in which case a subroutine named 'TABIN' is used. If the aerial pattern has the so-called 'cardioid' shape it is not necessary to tabulate the pattern, for this is held in a subroutine named 'CARD16'.

It is common practice for standard panels of 2λ to be used in various combinations to form a transmitting aerial. In this case it is only necessary to state the orientation and relative position of each panel on the mast, the pattern being derived from a subroutine named 'UHPAN'.

The program will also accept combinations of types of aerial elements.

'STADAT' puts the h.r.p. and v.r.p. (both amplitudes and phases) for each element type into a 'common block' and returns the program control to 'CODER'. The flow chart, for the operations performed in 'STADAT', is shown in Fig. 4.

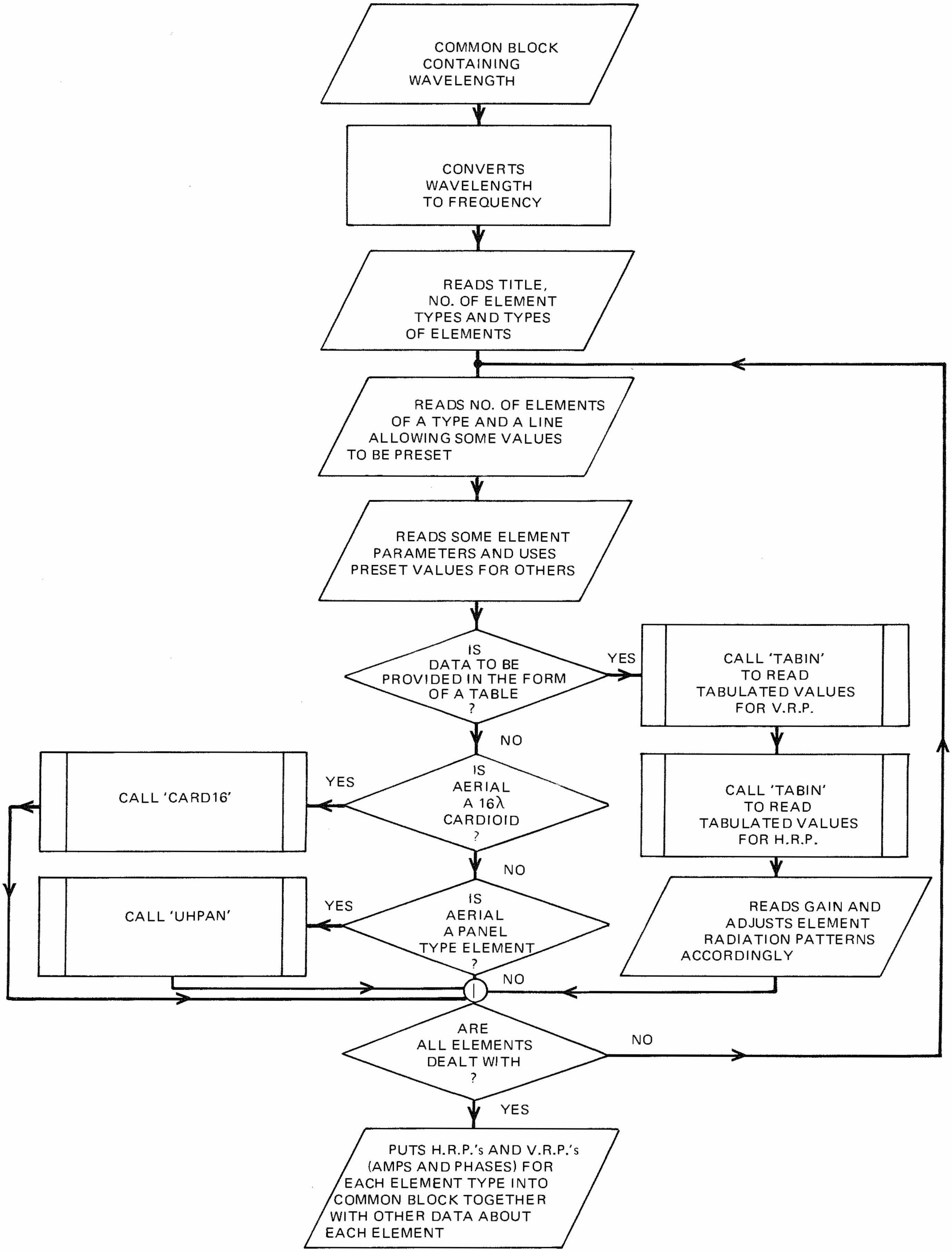

Fig. 4 - Simplified flow chart for 'STADAT'

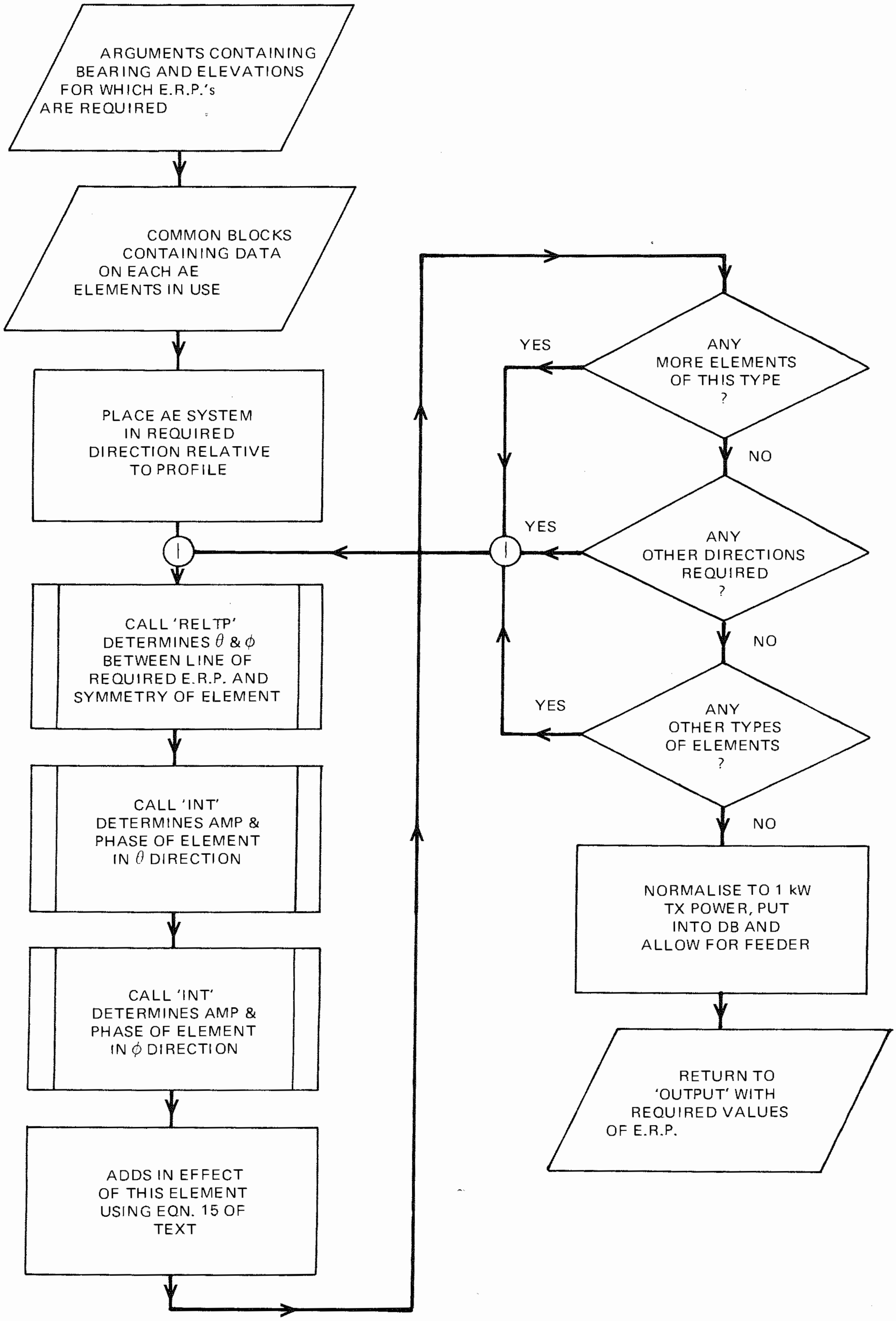

Fig. 5 - Simplified flow chart for 'AEPAT'

The second sub-program necessary to produce the e.r.p. is named 'AEPAT'. Its use is controlled from a subroutine named 'OUTPUT' to be described in the next section. The main task of 'AEPAT' is to compute the formula.

$$E = \left| \sum_{k} A_k R_k e^{j[Q_k + P_k + \frac{2\pi}{\lambda}(lx_k + my_k + nz_k)]} \right| \tag{15}$$

where E is the field intensity in a direction defined by the direction cosines (l, m, n). The relative drive current in the k^{th} element is given by $A_k e^{jQ_k}$ and its radiation field in the specified direction is given by $R_k e^{jP_k}$. The effective position of the k^{th} element in cartesian co-ordinates is given by (x_k, y_k, z_k).

The production of the various parameters required above is aided by two further subroutines named 'RELTP' and 'INT'. Their use can be seen in Fig. 5 which is a flow chart of the operations of 'AEPAT'. In any one application of 'AEPAT' 200 values of e.r.p. may be determined for various angles of elevation with one value of azimuth corresponding to a profile line. In practice the e.r.p. values produced are for a standard transmitter power of one kilowatt.

8. The subroutine 'OUTPUT'

As already stated the subroutine 'OUTPUT' controls the use of 'AEPAT' thus acquiring the e.r.p. values. The various losses produced by 'TCFS' are combined to produce a single attenuation value relative to free space; this combination process is described in Section 9. The field is produced using these values in the following form:

$$F = 106{\cdot}9 - 20 \log_{10} D + P + T - A \tag{16}$$

where F is the field strength in dB relative to 1 μV/m (dBμ), D is the distance from transmitter to receiver in km, P the e.r.p. in decibels relative to one kW (for Tx power 1 kW), T is the transmitter power in decibels relative 1 kW and A is the attenuation relative to free space.

The subroutine 'OUTPUT' prints results in tabular form. An example of a table for one profile line is shown in Fig. 6. The information at the head of the table is self-explanatory. The columns have the following meanings:

1. Distance from transmitter to test receiver point.
2. The predicted field-strength in dBμ, assuming the receiving aerial is at 10 metres above ground level, although other heights may be taken.
3. The predicted loss as a result of trees and buildings on the path.
4. The predicted loss assuming profile is a series of knife-edges.
5. The predicted loss assuming profile is of cylindrical form.
6. The predicted loss assuming profile is of wedge form.
7. The combined attenuation relative to a free space field
8. The effective radiated power in the direction of receiver
9. The angle between the horizontal and the 'string' at the transmitter. The sign convention is positive downwards.

9. The optimisation process

The values obtained in 'TCFS' are derived on a theoretical basis. However, to obtain such values simplifying stylisations of the profile are made and this means the figures cannot be relied upon without some form of empiricism. For this purpose a measurement project was undertaken. The measurements were within 50 metres of radial lines from the transmitters. The radial lines were divided up into 100 metre intervals and all measurements within the 100 metre square were used to produce a single value to represent the area. These were then taken as the values to be used in optimising the calculation system. The total number of such areas obtained was 377, these being along 17 radial lines from four transmitters. By this method it was hoped to cover as many types of path as was economically feasible.

The minimising of differences between calculation and measurement was done by a non-linear optimision technique based on a method by Dickinson.[4] This involved programs which were used in the development stage only. They consisted of three subroutines; one to read in data and print results; another to compute the function to be minimised; and the third which did the search for a minimum. The final attenuation relative to free space was made up from the values given by 'TCFS' in the following manner:

$$A = x_1 A_k + x_2 A_c + x_3 A_w + x_4 + x_5 A_{CL} + x_5 A_{CL}^2 \tag{17}$$

where the various values of A are defined at the end of Section 6 and where x_1 etc. are values to be determined by optimisation. The function to be minimised was

$$y = \Sigma\,(A - A_M)^2 \tag{18}$$

where the summation is over all the available samples and A_M is the measured attenuation relative to free space.

The result obtained was:

$$A = 0{\cdot}503 A_k + 0{\cdot}45 A_c + 0{\cdot}38 A_w + 2{\cdot}4 +$$

$$+ 6{\cdot}5 A_{CL} - 0{\cdot}175 A_{CL} \tag{19}$$

The standard deviation of the differences between A_M and the values of A given by Equation (19) was 4·28 dB and the largest differences were 11·8 and −12·9 dB. These results are plotted in Fig. 7 and compared with the zero difference line.

14502 NGR SJ205421 CH. 51

145.02 LLANGOLLEN TWIN 90 4L PANELS BRG 50 BT 5.0 ERP 50W

TRANSMITTER POWER(DB.REL.1KW) -20.
TRANSMITTER AERIAL HEIGHT 75.0
AERIAL GAIN 10.61DB. FEEDER LOSS 4.0DB.

GRID BEARING 99.00 TRUE BEARING 98.05

DISTANCE (KM)	F/S DB MU	ACL DB.	AK DB.	AC DB.	AW DB.	A DB.	ERP DB.	ALPHA DEG BELOW HORIZ
6.10	75.5	2.7	.0	.0	.0	2.7	-13.0	2.27
6.20	75.1	2.9	.0	.0	.0	2.9	-13.1	2.05
6.30	75.3	2.4	.0	.0	.0	2.4	-13.2	1.72
6.40	75.1	2.4	.0	.0	.0	2.4	-13.3	1.36
6.50	67.1	10.2	.0	.0	.0	10.2	-13.3	1.39
6.60	45.6	12.3	14.1	.0	32.1	31.6	-13.3	1.43
6.70	39.4	13.6	18.4	.0	39.0	37.7	-13.3	1.43
6.80	36.5	14.1	20.4	.0	42.4	40.5	-13.3	1.43
6.90	35.9	13.4	21.3	.0	44.0	40.9	-13.3	1.43
7.00	50.8	9.8	12.4	.0	25.8	25.9	-13.3	1.43
7.10	55.3	12.1	6.6	.0	15.4	21.3	-13.3	1.43
7.20	45.6	12.8	13.3	.0	29.9	30.9	-13.3	1.43
7.30	26.2	9.3	28.1	59.4	.0	50.1	-13.3	1.43
7.40	29.7	9.1	24.7	55.5	.0	46.5	-13.3	1.43
7.50	31.1	9.5	27.0	48.8	.0	45.0	-13.3	1.43
7.60	33.6	10.2	24.5	44.0	.0	42.4	-13.3	1.43
7.70	31.8	10.1	26.3	46.2	.0	44.1	-13.3	1.43
7.80	32.3	10.3	25.8	45.0	.0	43.5	-13.3	1.43
7.90	34.8	10.6	23.6	40.7	.0	40.8	-13.3	1.43
8.00	38.7	10.8	21.0	34.3	.0	36.8	-13.3	1.43
8.10	43.4	10.8	15.6	.0	35.2	32.0	-13.3	1.43

Fig. 6 - An example of the tabulated output

10. Profile plotting

A program has been written to plot the ground profile on an x-y incremental plotter. Thus the user has a pictorial representation of his problem from which he may make decisions such as altering certain transmitter parameters,

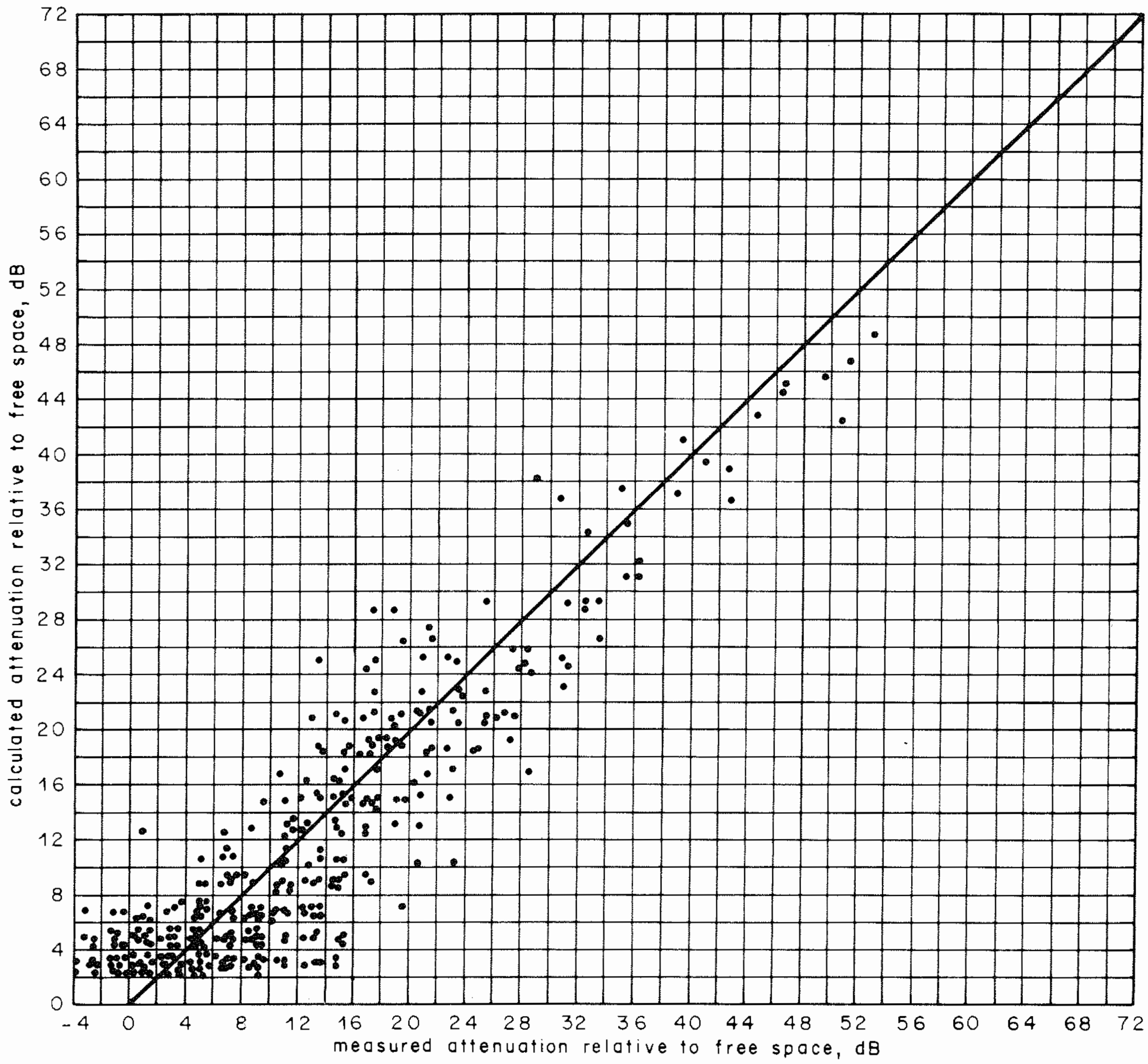

Fig. 7 - Comparison of measured and calculated attenuations

including more receiving sites when situations are critical or removing them where results are obvious. He may decide that more profiles are necessary when he sees from existing profiles that the situation is critical in certain areas. The profile plot may also help to identify errors occurring in the terrain coding or interpolation processes. An example of a plot is given in Fig. 8 (the original is in two colours; red and black). The crosses along the profile line represent the original figures supplied by the terrain coder; the line is that produced by the interpolation using these values. Each receiving aerial position investigated is marked by a small cross on the top of a vertical line. Along the axis of the profile are representations of buildings and trees (trees being shown taller). These are not shown on the profile itself because this would present technical difficulties.

11. Conclusions

A computer program has been developed to predict service areas of relay stations as an aid to service planning in the UHF Bands. This program can be employed in suitable cases as an alternative to making measurements in the field which are relatively costly and time-consuming. As the average cost for obtaining the service area of a small relay station by means of the program is small, it will be appreciated that considerable savings may be made. In addition to the saving in cost, the prediction can be made in a relatively short time and therefore also produces a saving in effort. This program, in conjunction with other programs designed to take account of co-channel interference, is already in use and experience is rapidly being gained in their operation. The accuracy obtained as compared with measurements appears to be adequate.

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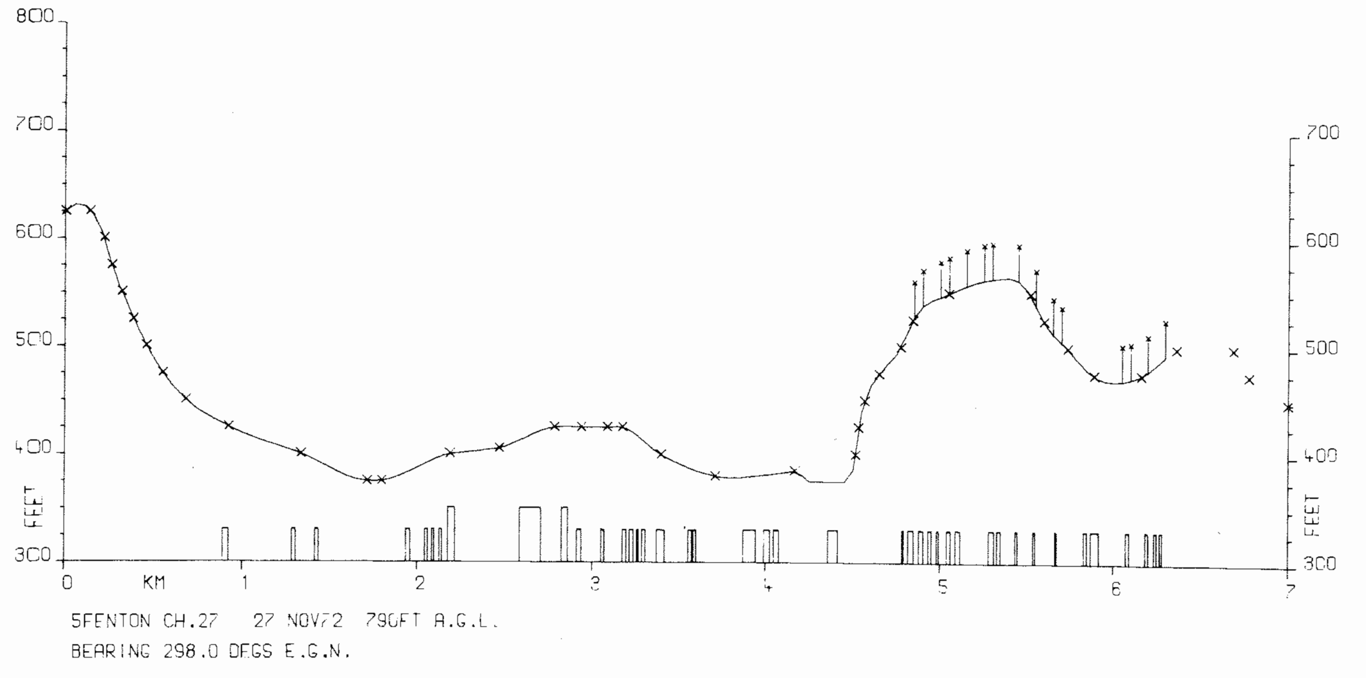

Fig. 8 - An example of a profile produced on an automatic plotter

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Appendix

The Effects of Buildings and Trees

Most domestic reception of broadcast signals takes place with receiving aerials at roof top level and for prediction purposes this is taken to be 10 metres a.g.l. At such a height, and at u.h.f., there is liable to be considerable attenuation caused by trees and buildings in front of the receiving aerials. Measurements have indicated that the average loss is about 10 dB but that it could be higher than 30 dB. A routine has been devised to give a value for the loss due to this cause.

An example of the problem requiring solution is depicted in Fig. 9 which shows the receiver end of a path and demonstrates how the direct ray may be obstructed by buildings and trees.

Ground heights are usually slowly varying (rarely does a slope exceed 45 degrees) but the buildings and trees have predominately vertical sides, are of many different heights and many of them usually occur in a small area. Because of the many paths that must be dealt with it is not possible for each obstruction to be identified and even if such data were collected it is doubtful if a method could be devised to use it.

The most economic way of collecting the required data is from Ordnance Survey maps. However, this has several disadvantages:

1. No heights of the objects are given.
2. Only woodland trees are shown, not trees in hedgerows, road-sides or gardens.
3. The areas covered by buildings are exaggerated to a highly variable extent.

The exaggeration of buildings shown on various types of maps was investigated and it was found that 1:63,360 Ordnance Survey maps exaggerated by an average of 3 times, with a large scatter about this value. The 1:25,000 old series Ordnance Survey maps exaggerated by 1·5 times, but the new series is not significantly exaggerated.

Without having definitive data on the heights of the required objects the next best approach is to employ some form of statistical information. A study of this subject resulted in a probability distribution for these objects exceeding a given height above ground. These are shown in Fig. 10 as f_B and f_T for buildings and trees respectively.

There is a high probability that the final signal will result from a complex combination of many forms of propagation mechanism.

There are:

1. Multiple diffraction over obstacles.
2. Multiple diffraction round them.
3. Many reflections off many objects (scattering).
4. Transmission through a combination of obstacles.

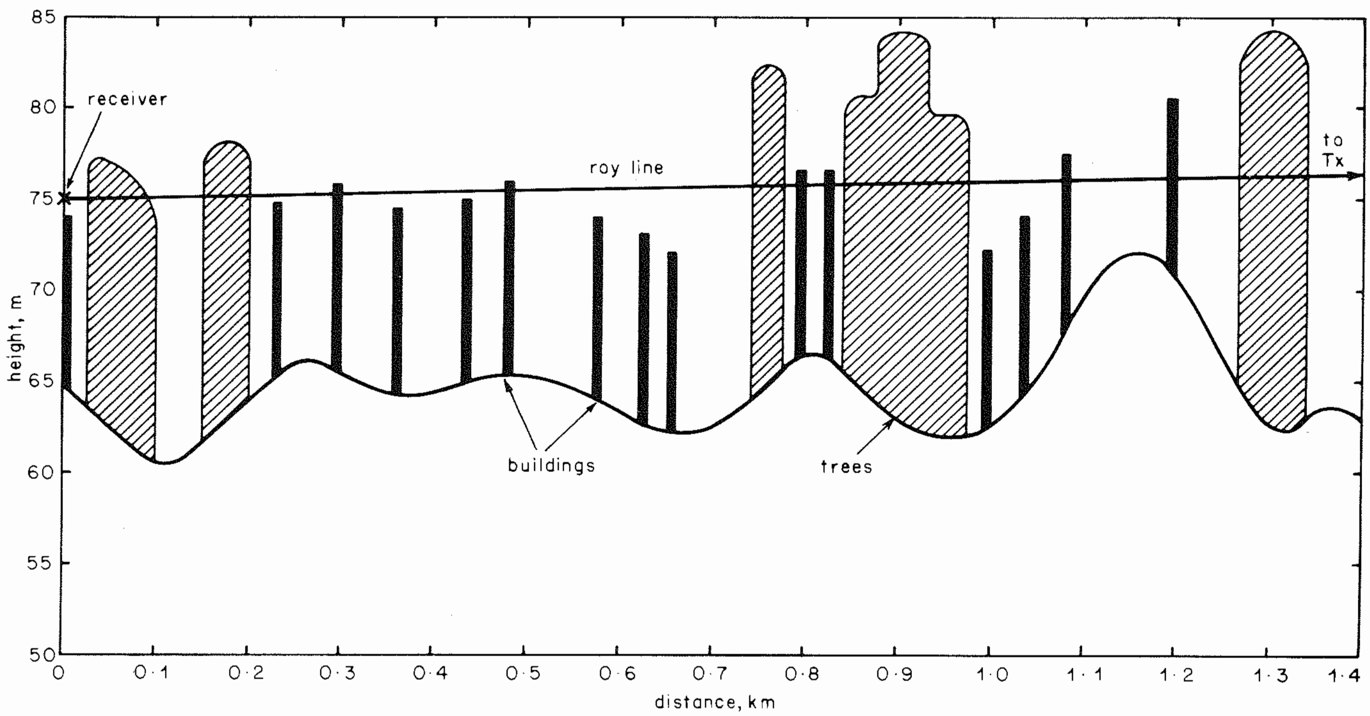

Fig. 9 - An illustration of the obstruction caused by buildings and trees

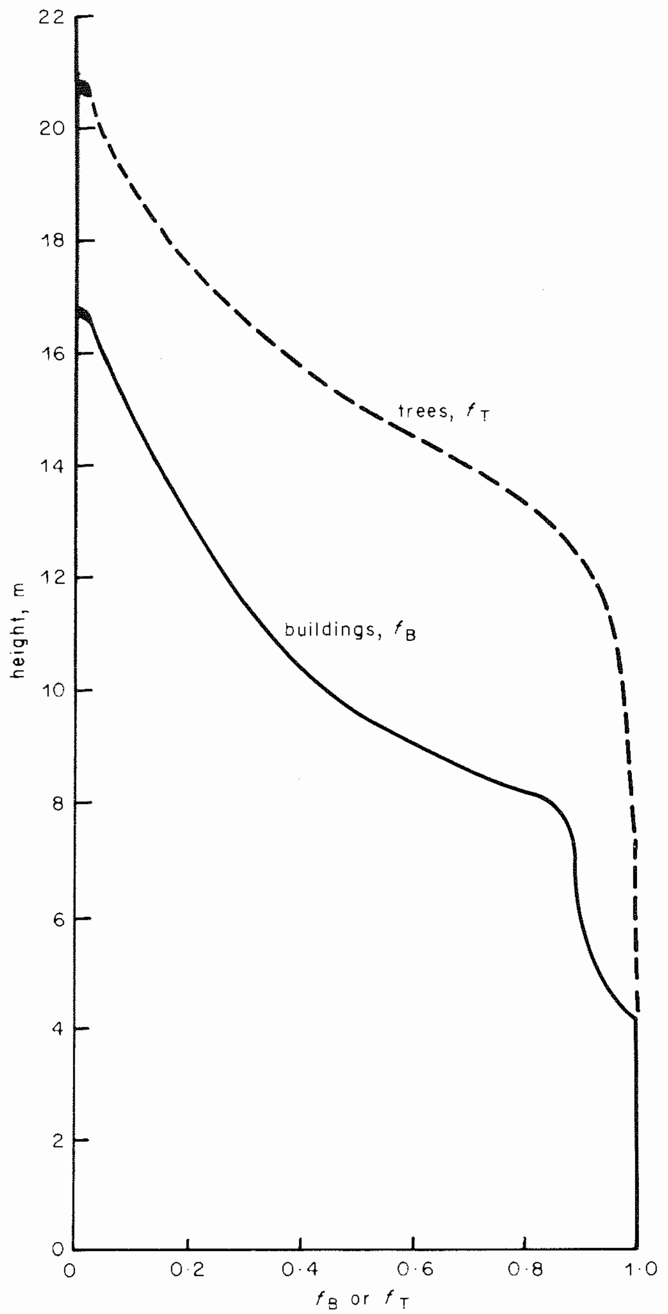

Fig. 10 - Probability of obstacles exceeding a given height

The theory for any of these is difficult; to combine them is not feasible. These means of propagation may produce a high location variation, because interference effects give the so called 'standing wave' patterns. Time variations may also result if for example these patterns are varied by the movement of trees in the wind. To reproduce these patterns by calculation is clearly not possible, but if some form of clutter data are given it should be possible to calculate a good representative figure for the area.

Theories only exist for cases where features at right angles to the propagation path vary slowly or the changes are regular, as with a diffraction grating. However, it is possible to devise a method which takes some recognition of the various theories and at least gives an indication of the important parameters. It is then necessary to find a relationship between these parameters and a set of measurements. Ideal controlled experiments to determine parameters by measurement can be thought of but it is not practical to adopt these.

In the absence of the ideal approach all that can be done is to take a set of measurements covering as much of the problem as possible and devise a mathematical model which includes various constants determined by minimising the error between measurements and calculations.

Along these lines Kinase[5] has written of a method using a single parameter symbolised by Γ. The strict interpretation of his parameter is the percentage of 'clutter' occupying the volume of the first Fresnel zone. However, Kinase allows the parameter to have a less rigid meaning for practical purposes; i.e. the percentage, of the area in question, occupied by 'clutter' exceeding 10 metres above ground level. Even with this reduced meaning some explicit knowledge of heights is required. To obtain this would be too expensive for the purpose in hand. In any case Γ is not considered to be the best that can be done in terms of a parameter because the field received is highly dependent on the way in which the first Fresnel zone is filled. To illustrate this point consider an absorbant screen placed in one of three positions (1, 2 and 3) shown in Fig. 11. The fractional volume filled will be the same in each case but the effect on the received field will be very different.

Buildings will only transmit a small amount of energy so the principal mechanisms will be diffraction and reflection. For simple knife-edge diffraction the relevant parameter is the Fresnel 'ν' variable. Little can be done about reflections except to say that when the diffraction by buildings severely reduces the direct signal, reflected fields will tend to increase the average received signal.

Most practical cases will be covered if we consider a volume of revolution about the line of an assumed string stretched between transmitter and receiver over the ground profile with radius given by:

$$r_f = \left[\frac{\lambda s\,(D - s)}{2D}\right]^{1/2} \qquad (20)$$

where D is transmitter to receiver distance and s is the distance from the receiver for the required radius. The ν parameter may be written in terms of this variable and the height, h, of the edge from the centre of the circle, i.e.:

$$\nu = \frac{h}{r_f} \qquad (21)$$

However, in this particular problem there is no definitive knowledge of h. The proposed procedures are based on the division of the volume (defined above) at right angles to the main axis is shown by the dotted lines in Fig. 11. Then values, F_s, for the fractional filling of each of these slices may be derived using the formula:

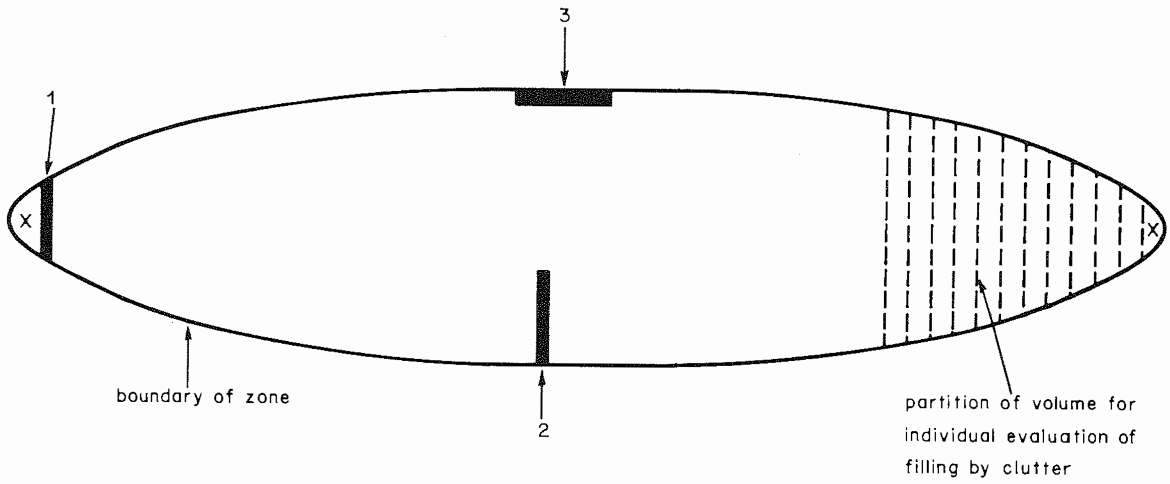

Fig. 11 - Obstructions in the first Fresnel zone

$$F_s = \frac{2}{\pi r_f^2} \int_{H - r_f}^{H + r_f} \left[r_f^2 - (H-y)^2 \right]^{½} f_B(y)\, dy \qquad (22)$$

where H is the height of the ray line above ground level, y is a variable height above ground and $f_B(y)$ is the probability of any object exceeding height y.

Within the context of the problem in hand, trees differ from buildings in two respects; firstly they are usually taller and are thus more liable to be above the top of the volume and secondly they allow a signal to be transmitted through them which may well exceed the signal diffracted round or over them. A paper on the subject of this transmitted energy was published by Saxton and Lane[6] where results are given in terms of decibels per metre. If this were the only mechanism acting, the loss (in decibels) along a ray line would be given by:

$$A_T = x \int_0^D p(s)\, ds \qquad (23)$$

where p(s) represents the likely density distribution of trees over a reasonable distance and x is the loss per unit distance through the trees. Of course, x may be a function of several factors such as frequency, polarisation, type of trees and season.

The mechanism of Equation (23) will predominate when the diffracted signal is low and the depth of trees is not great as is likely to be the case with trees close to the receiver. Under these conditions the loss through a length ΔS may be written as:

$$A_{\Delta S} = x F_S \Delta S \qquad (24)$$

If many intervals have clutter in them an attempt must be made to combine these, but there does not appear to be any feasible analytic way of solving this problem. However, knife-edge diffraction theory does lead to two conclusions which can be used. Firstly, the overall diffraction loss is dominated by the greatest of the individual losses and secondly this domination is the greater the closer subsidiary edges are to the dominant edge. For buildings this means it is reasonable to take only a maximum value for each small interval, and then emphasise the maximum value of many of these small intervals by taking the square root of the sum of squares to these values.

The work of Saxton and Lane[6] and Sofaer and Bell[7,8] leads to a figure of 0·2 dB per metre at u.h.f., for attenuation through trees, and ignoring differences due to polarisation and season should not lead to errors of more than 4 dB. However, for a certain depth of trees the largest signal will be received by diffraction over their tops. Thus if it assumed that the diffraction loss caused by a clump of trees at, say, 1 km from a receiver is about 10 dB diffraction will be the dominant mechanism if the trees are more than 50 metres deep. If ΔS is chosen as 50 metres and each interval is multiplied by the thickness of trees in it the result will be in close agreement to the values of Reference 6. With these thoughts in mind the loss parameter is taken as:

$$A_{CL} = \left[\sum_i (P_{bi} F_{bi} + P_{ti} F_{ti})^2 \right]^{½} \qquad (25)$$

where i labels each interval of width ΔS

P_{bi} is 0 if no buildings are shown on the map in the interval and 1 if any buildings are shown

F_{bi} and F_{ti} are assumed fillings of the volumes in question

P_{ti} is the fraction ground coverage by trees, shown on the map in the appropriate interval.

In practice the main contribution to the parameter will come from the part of the path which is close to the receiver. This is because in the rest of the path the top of the volume is well clear of clutter, transmitters being built with aerials higher than those of domestic receivers. Errors will not usually be greater than a few decibels if the only clutter values used are those within 2 kilometres of the receiver.

The ground is likely to be included in the volume, but the loss resulting from this is dealt with separately so it is not reasonable to include it again.

It is evident that the influence of buildings and trees on field strengths cannot be calculated definitively. However, it is not the intention to calculate the field at a point but to obtain a representative field for a small area, thus some 'averaging out' of errors is bound to occur. Nonetheless, large errors may occur if a tall building lies in front of the aerial, or many trees exist there and are not shown on the maps.

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Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP