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HF Extension of TERPEM

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HF Extension of TERPEM

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Note on extension of TERPEM to frequencies down to 1 MHz

1 Introduction

The TERPEM software has been extended to deal with frequencies down to 1 MHz, in compliance with the Statement of Work issued by the Scientific Authority. This note describes the new features of TERPEM and gives validation against GRWAVE.

TERPEM scenarios for the four test cases described in section 6 have been provided with the software (in the **HFExamples** subdirectory of the TERPEM directory). In addition, we have included a scenario for a multiple-layer ground environment and a scenario for propagation over a cliff.

2 New antenna models

Three antenna models have been added to TERPEM:

- Half-wave dipole
- Short dipole
- Quarter-wave monopole

For the first two, the user may specify frequency, height, antenna elevation and polarisation. Note that for circular or horizontal polarisation the beam pattern is the same as that of an omni-directional antenna.

With the quarter-wave monopole model, only the frequency needs to be specified. Polarisation is always vertical, antenna elevation is zero and the antenna is located on the ground.

The TERPEM engine has been modified to provide an accurate source model for antennas on or close to the ground.

3 Wide-angle algorithm

The TERPEM engine now uses a wide-angle algorithm, which can deal accurately with large propagation angles. If users select the **expert** control option, they can choose a maximum diffraction angle of up to 60 degrees. With the **automatic** control option, model optimisation automatically ensures that propagation angles up to 14 degrees are taken into account for frequencies below 300 MHz, and that for frequencies below 7.5 MHz all propagation angles are taken into account (see next section).

4 Optimisation of algorithms

Optimisation procedures in the TERPEM engine have been adapted for the HF/UHF case.

The hybrid model has been disabled for frequencies below 300 MHz, and a pure PE model is used at those frequencies. The reason for this is that the speed-up due to the use of hybrid models becomes far less significant for larger wavelengths. For example the wide-angle PE model will be reasonably accurate at all propagation angles if the vertical step size is less than a quarter of the wavelength, and this becomes easily achievable at HF.

The TERPEM engine sets the vertical step size to be always less than the wavelength for frequencies less than 300 MHz, which ensures good representation for angles up to 14 degrees or so. It also sets an overall upper limit of 10 m for the vertical step size, which automatically ensures good representation at all angles for frequencies less than 7.5 MHz. If more accurate high angle results are wanted, the user can either set the diffraction angle parameter in the **expert** control panel, or request an output grid of sufficiently fine vertical resolution.

Optimisation procedures for the maximum integration height have also been adapted to the HF/UHF case.

5 Modelling of multiple ground layers

5.1 Effective impedance model

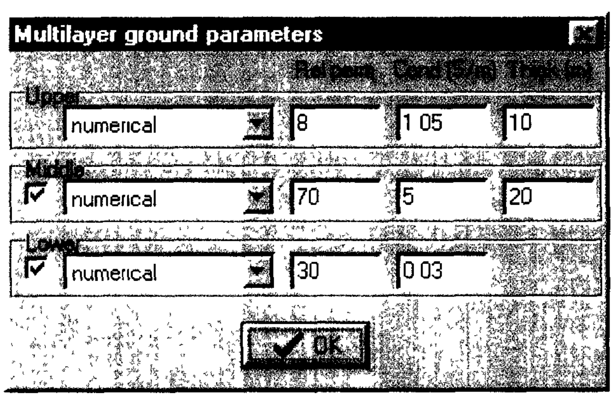
The Wait formulae for calculating effective impedance for multiple ground layers have been implemented in the TERPEM engine. Effective impedance depends on frequency, polarisation, grazing angle and layered structure of the ground. A new **multilayer** ground category has been added to the TERPEM interface, and new routines in the TERPEM engine compute effective impedance at each range based on the Wait model and the grazing angle calculated from the TERPEM ray-tracing algorithm.

Since the effective impedance calculations are carried out inside the TERPEM engine and are not visible to the user, we have provided a stand-alone Stratified Ground Calculator that allows immediate access to effective impedance and reflection coefficient values. The TERPEM Stratified Ground Calculator is described in Annex A.

It should be noted here that the TERPEM parabolic equation model computes the field above the ground only. It cannot model the trapped surface wave (or Elliott mode) which may occur when a layer of ice is present above sea water.

5.2 Multilayer ground category

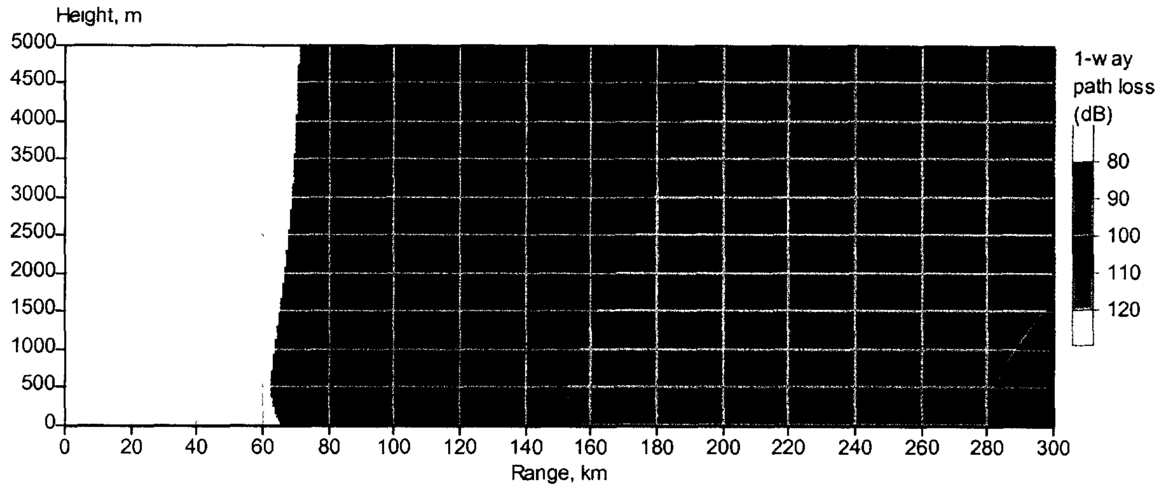
The TERPEM interface allows the user to specify up to three ground layers in the **multilayer** ground category. The TERPEM engine will actually allow up to ten layers, and the user may edit the terrain file if more than three layers are needed. In general the effects of a third layer are already negligible, and it is unlikely that this should ever be necessary.



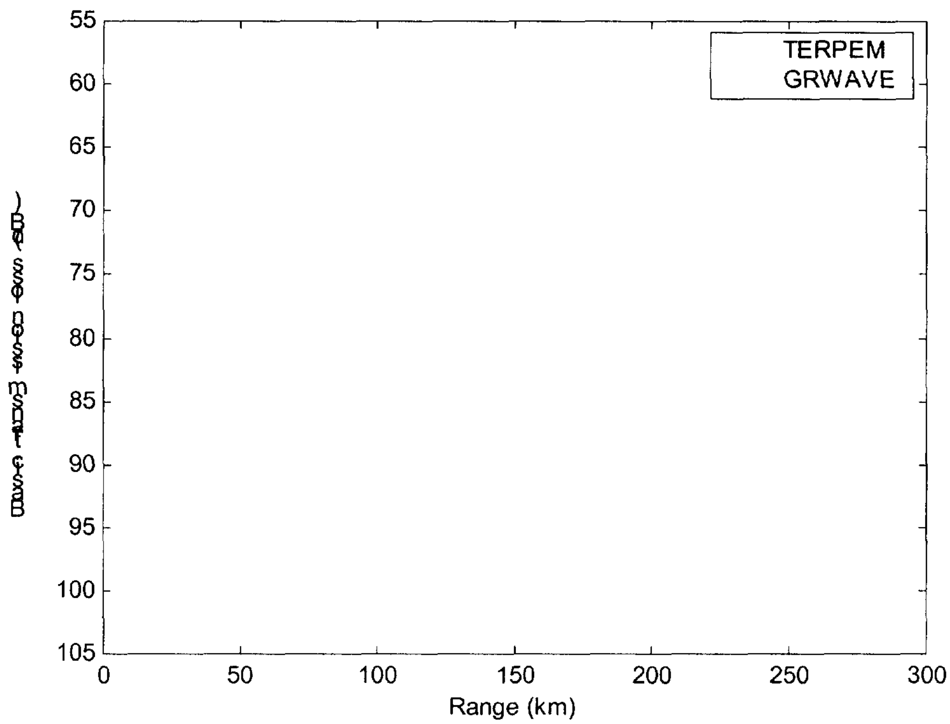
6 Validation

Four test cases have been selected. All involve a vertically polarised short dipole located on the ground. For each case, we show the vertical coverage diagram obtained in a domain extending to 300 km in range and 5000 m in height, and path loss curves at zero height for TERPEM and GRWAVE. Agreement is excellent for all cases.

6.1 Oversea propagation at 3 MHz

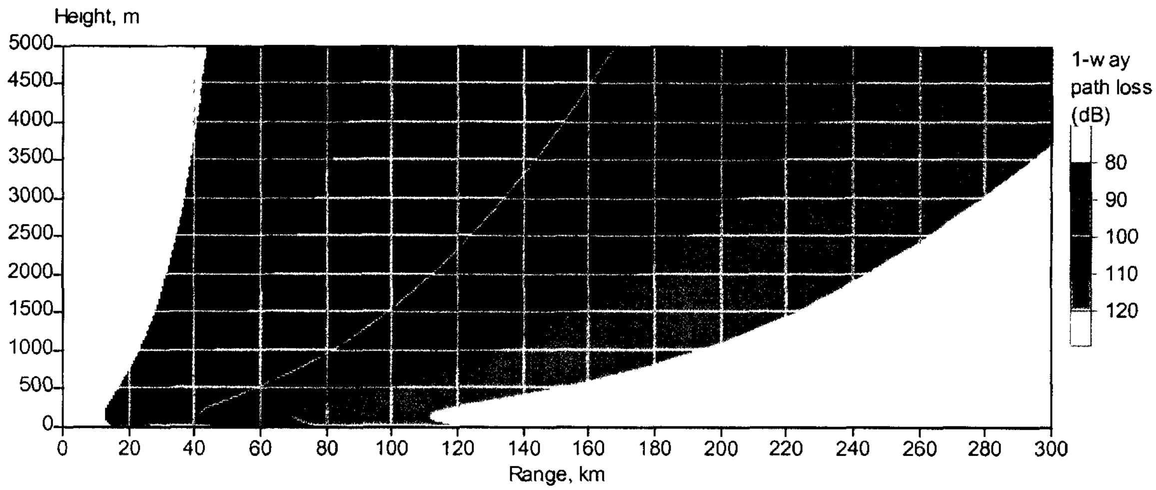


Vertical coverage diagram for oversea propagation at 3 MHz

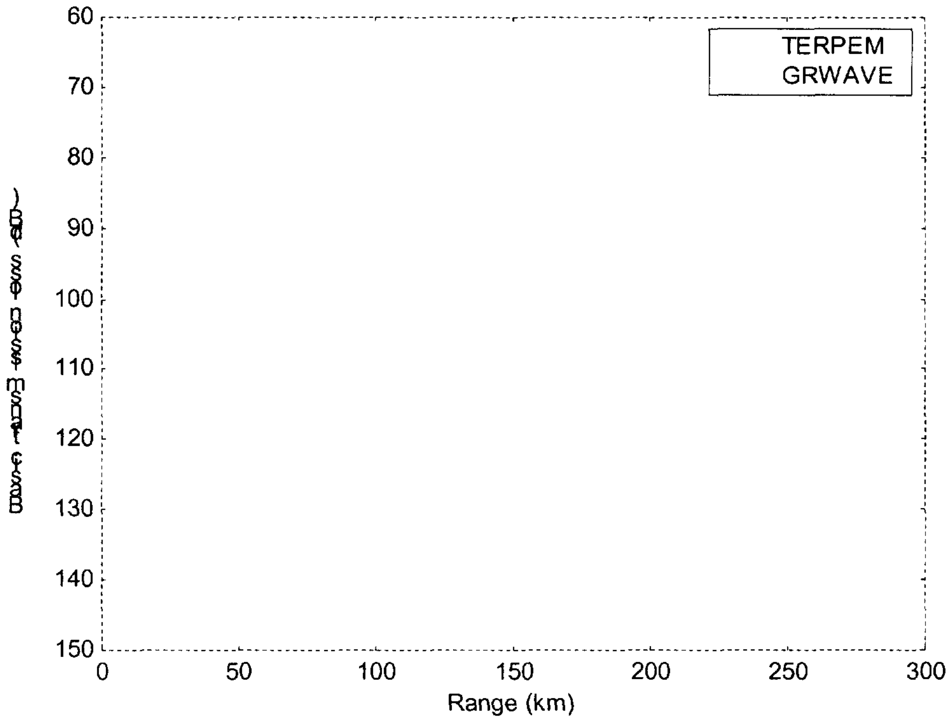


Comparison of TERPEM and GRWAVE results at zero height for oversea propagation at 3 MHz

6.2 Overland propagation at 3 MHz

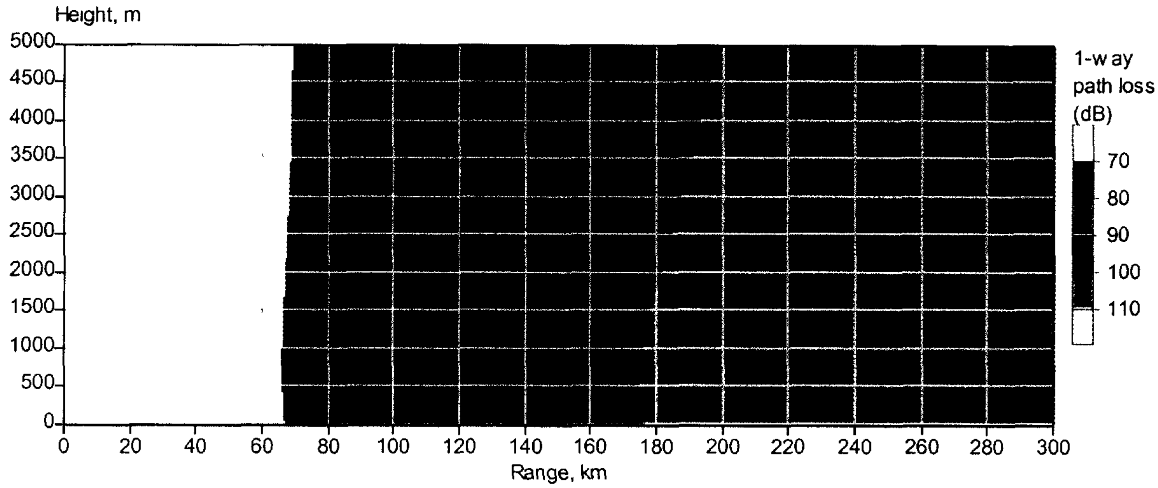


Vertical coverage diagram for overland propagation at 3 MHz

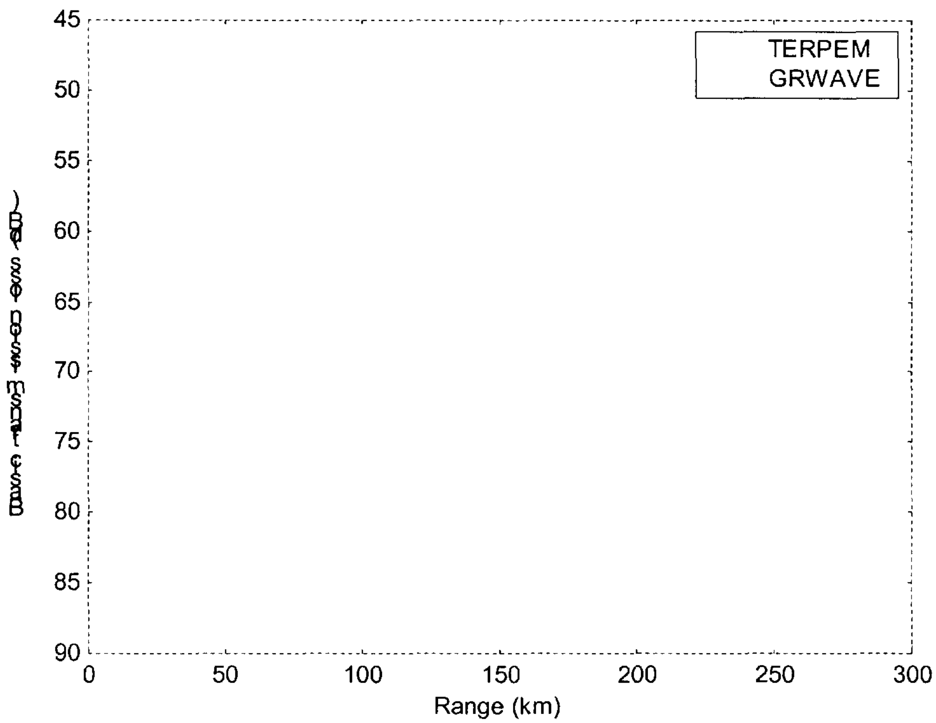


Comparison of TERPEM and GRWAVE results at zero height for overland propagation at 3 MHz

6.3 Oversea propagation at 1 MHz

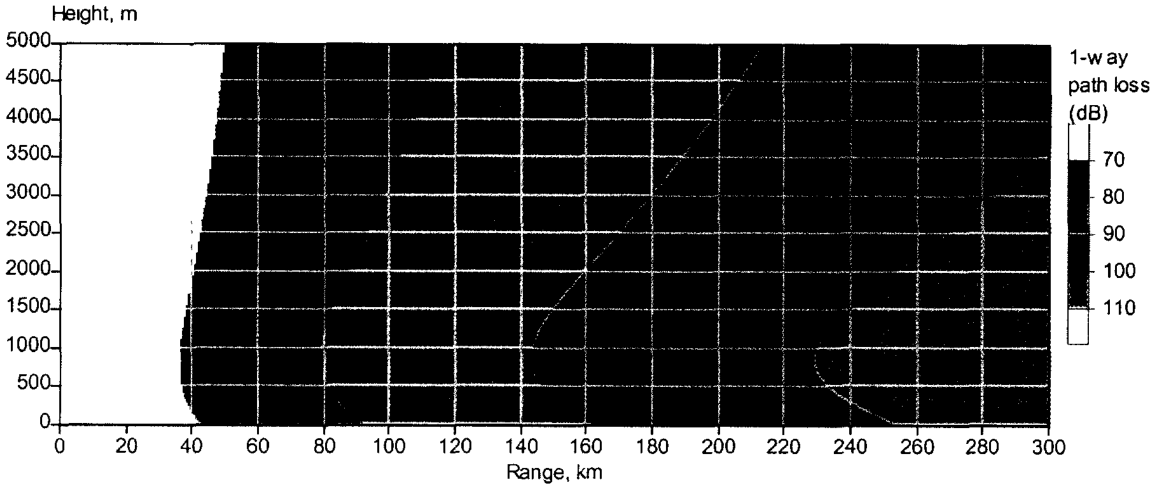


Vertical coverage diagram for oversea propagation at 1 MHz

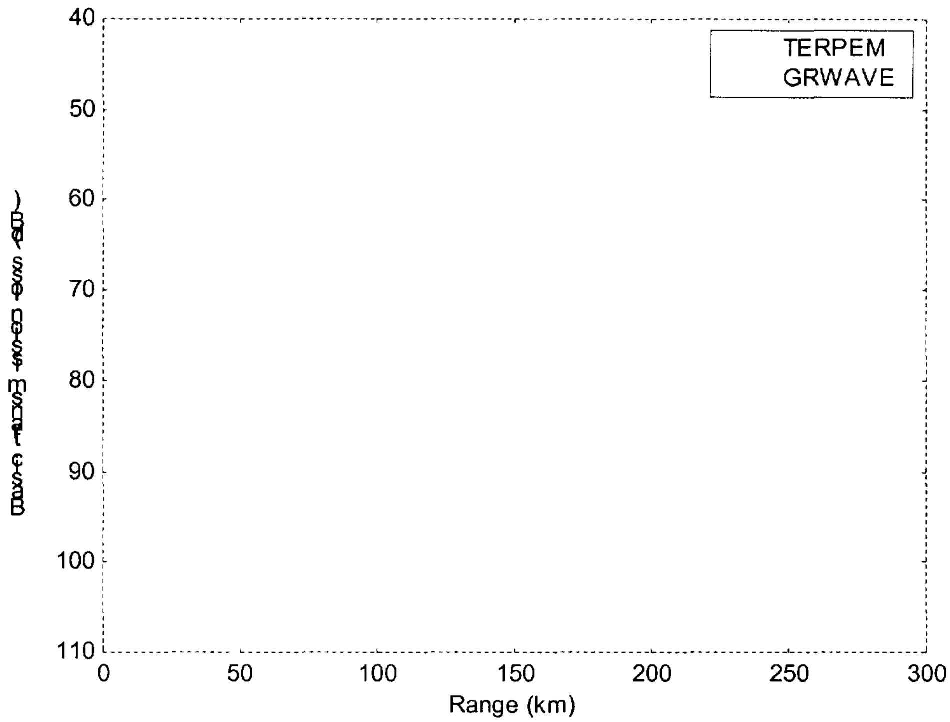


Comparison of TERPEM and GRWAVE results at zero height for oversea propagation at 1 MHz

6.4 Overland propagation at 1 MHz



Vertical coverage diagram for overland propagation at 1 MHz

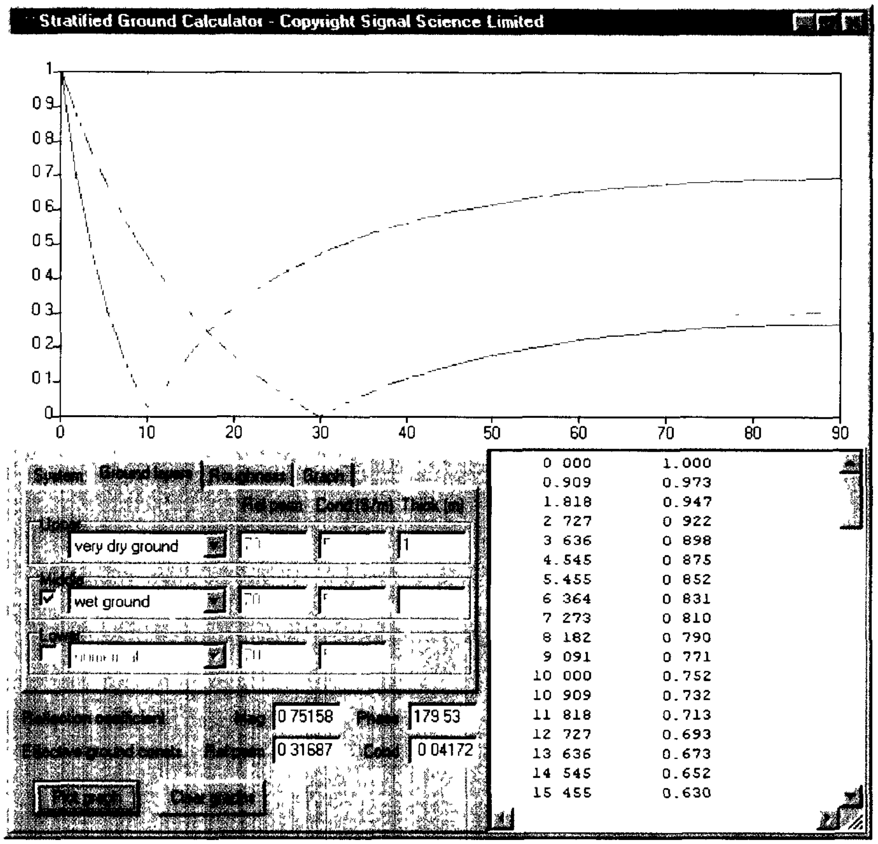


Comparison of TERPEM and GRWAVE results at zero height for overland propagation at 1 MHz

Annex A: TERPEM Stratified Ground Calculator

A.1 Introduction

The TERPEM Stratified Ground Calculator is a stand-alone tool for displaying various quantities (for example, reflection coefficients, impedance, effective ground constants) relevant to the reflection properties of stratified media. Graphs of these quantities can be plotted as a function of several physical quantities (angle, frequency and layer thickness).



A.2 Using the calculator

The calculator is displayed by running the **Groundcalc.exe** program. The calculator displays 3 areas:

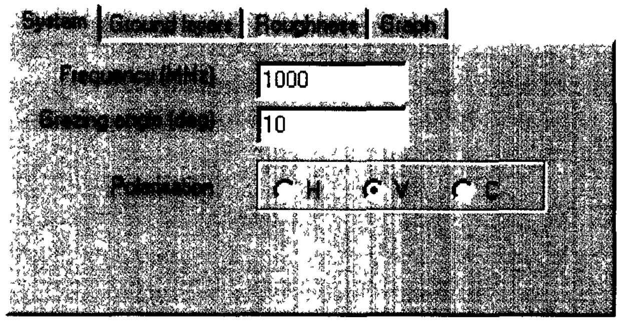
1. at the top is the graphical display; this is initially blank
2. at the bottom right is a table of values of the last graph displayed; this is initially blank
3. at the bottom left is the data entry area where parameters are edited and displayed

The first thing the user must do is to define system and ground parameters. This is done by selecting the **System**, **Ground layers** and **Roughness** tabs in the data entry area. The **Graph** tab is used to define parameters for graph plotting.

A.3 System parameters

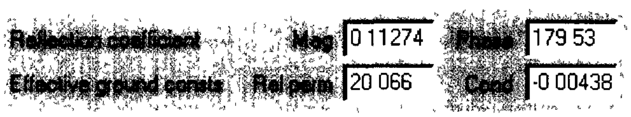
The basic physical parameters are entered in the **System** tab. These are:

- Frequency (in MHz)
- Grazing angle (in degrees)
- Polarisation (Horizontal, Vertical or Circular).



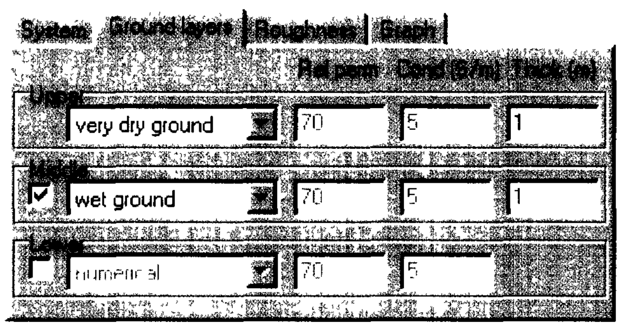
As the parameters are modified, note that the information display below the tabs is updated to display the values corresponding to the parameters. The information shows:

- Reflection coefficient (magnitude and phase, in degrees)
- "Effective" ground constants for the ground parameters specified in the **Ground layers** tab.



A.4 Ground layer parameters

For a homogeneous ground, or a ground comprising up to 3 layers, the ground constants are entered in the **Ground layers** tab.



For a single layer (ground), uncheck the tick boxes for the Middle and Lower layers. The homogeneous ground parameters are then entered in the Upper layer box. In this case, the layer thickness parameter will be disabled (because the layer is assumed to extend to infinity). The drop down list allows selection of the ground types in the same way as for the TERPEM ground information editor. The ground types are:

- numerical
- perfect conductor
- wet ground
- medium dry ground
- very dry ground

- sea water
- fresh water

For ground types other than **numerical** and **perfect conductor**, the relative permittivity and conductivity are calculated according to frequency, using a trilinear fit to the curves given in CCIR Rec. 527-1 (in accordance with the algorithms in TERPEM).

A **perfect conductor** is modelled as a material with a relative permittivity of 1.0 and a very high (but finite) conductivity. This model has changed from the previous (single ground-layer) versions of TERPEM, and has been done to allow the input of multiple ground layers that include a perfect conductor, and to model all polarisations correctly. This is an excellent approximation to a perfect conductor, but it is possible to observe small deviations from a true perfect conductor if, for example, the reflection coefficient is calculated for extremely small angles, or for extremely thin perfect conducting layers.

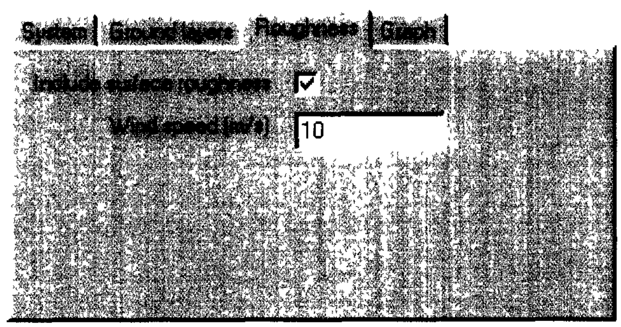
The **numerical** ground type option allows the user to enter the relative permittivity and conductivity explicitly. These constants are assumed to be independent of frequency. (Bear in mind that the electrical constants are generally frequency dependent, so take care when plotting reflection parameters as a function of frequency. For the other ground types, the frequency dependence of the ground constants *will* be correctly taken into account.)

A two-layer ground is modelled by checking the tick boxes for the Middle layer. The ground parameters for the underlying layer should then be entered in the Middle layer box. In addition, the thickness of the Upper layer must be entered.

Similarly, a three-layer ground is modelled by checking the tick boxes for the Middle and Lower layers. In this case the ground parameters of all three layers should be entered, as well as the thickness of both the Upper and Middle layers.

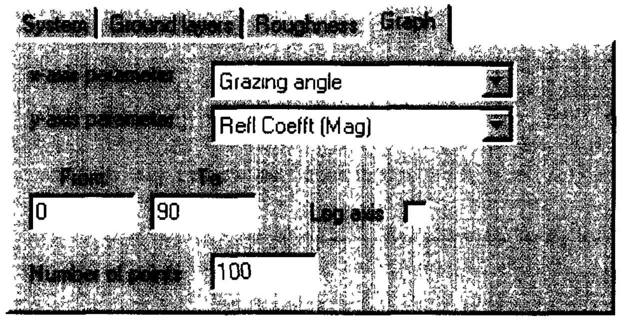
A.5 Surface roughness parameters

The effects of surface roughness can be included by ticking the **Include surface roughness** box in the **Roughness** tab, and entering a wind speed (in metres/second). Note that the roughness calculation uses the same Miller-Brown and Phillips models as are used in TERPEM. *These models are only appropriate for sea paths, and should not be used at low frequencies (say, below 1 GHz).*



A.6 Plotting graphs

One of the most useful features of the calculator is its capability of plotting graphs of various reflection parameters as a function of several physical quantities. The graph parameters are entered in the **Graph** tab.



The two drop down lists specify the graph ordinate (y-axis) and abscissa (x-axis) quantities. The y-axis quantities are:

- Refl coefft: the reflection coefficient.
- Impedance: this is the (complex) normalised surface impedance (i.e. relative to free space, 377Ω).
- Wait's Q factor: this is the Q term introduced in Chapter II of "Electromagnetic Waves in Stratified Media" by J.R. Wait. Q is the ratio of the normalised surface impedance of the multi-layered ground to the surface impedance of the upper layer. The factor is therefore 1.0 for a homogeneous ground.
- Effective rel perm and cond (S/m): these ground constants are the "effective" values for homogeneous ground that would yield the same (complex) value of the reflection coefficients as the actual multi-layered ground. For a homogeneous ground, the "effective" value will be the true value of the constants (which will depend on frequency, but will be independent of angle). For a multi-layer ground, the effective ground constants will depend on angle as well as frequency, and may be unphysical (for example, may have negative values).

The first three quantities are complex numbers whose magnitude and phase (in degrees) can be plotted.

The x-axis quantities are:

- Grazing angle (in degrees)
- Frequency (in MHz)
- Upper layer thickness (in metres)
- Middle layer thickness (in metres)

From and **To** define the minimum and maximum values of the x-axis parameter. The **Number of points** to plot can also be specified. The graph can be plotted using a pseudo-logrithmic x-axis by ticking the **Log axis** box. The graph is *pseudo*-logarithmic because, although the plotting routine uses a true logarithmic transform of the x-axis, the scale numerals depict the power-of-ten exponents, rather than the x-values directly. (The table of values does give the x- and y-values correctly).

When calculating the y-axis values for a graph, the value of the x-axis parameter is used instead of the value of that parameter given in the data entry area. All other system and ground values are as specified in the data entry area.

A graph is plotted by clicking the **Plot graph** button. This button is visible even if the **Graph** tab is not selected. This allows graphs to be plotted while entering or editing parameters on one of the other tabs. Each time the **Plot graph** button is pressed, another graph is overlaid on the existing graphs. Up to 10 graphs can be overlaid. The graphs can be deleted at any time by clicking the **Clear graphs** button. Each time a graph is plotted, the corresponding table of x-y values is also displayed.

Both the table of values and an image of the graph can be copied to the clipboard for pasting into other applications. This is done by clicking the right mouse button.

The graph axes scales can be changed by using the "zoom-in" graphics mechanism used in TGRAPH: zoom-in or out by clicking and dragging the "scaling" rectangle to select a region of interest; when the left mouse button is released, the graph will be scaled to the selected region. (Zooming out is achieved by selecting a point below, or to the right of, the axes before clicking and dragging.) Double-clicking on the graph with the left mouse button will set the graph to autoscale to the data limits.

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The document is the report of work carried out by Signal Science Limited under contract W7714-010484/A-GBL. It describes the extension of the algorithms incorporated in the TERPEM software package to enable the models to operate down to 1MHz The extensions include

- new HF antenna models
- a wide-angle algorithm
- optimising the model parameters for the HF band
- adding the capability of modelling multiple ground layers
- comparisons between the extended TERPEM algorithms and results from the GRWAVE software

This ~~technical note~~ contract report describes the new algorithms and presents the validation comparisons with GRWAVE.

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Surface wave propagation
Antenna models
Propagation over multiple ground layers

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