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Automated Performance Analysis Model for Ground-Wave Communication Systems

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AUTOMATED PERFORMANCE ANALYSIS MODEL FOR GROUND-WAVE COMMUNICATION SYSTEMS

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An automated analysis model is presented for the prediction of system performance of communication circuits that use the ground wave as the primary mode of propagation. The computer program Ground Wave Automated Performance Analysis (GWAPA) is a user-friendly program that can predict propagation loss, electric field strength, received power, noise, received signal-to-noise power ratio, and antenna factors over lossy Earth. The smooth-Earth and irregular-Earth propagation loss prediction methods can be used over either homogeneous or mixed paths. A special antenna algorithm is integrated into the computer program for rapid prediction of antenna performance as a function of antenna geometry, ground constants, frequency, and azimuthal direction for a variety of antennas. A description of the computer program GWAPA, a discussion of its capabilities, instructions for its use, and illustrative sample calculations are included in this report.

Key words: ground-wave antenna model; ground-wave propagation; irregular terrain; lossy Earth; MF propagation; mixed path; smooth Earth; surface waves

1. INTRODUCTION AND BACKGROUND

For many years, the Institute for Telecommunication Sciences (ITS) has been involved in model development and analysis of ground-wave communications at high frequencies (3-30 MHz) and lower frequencies. In the past, ground-wave propagation prediction methods have been developed at ITS for both smooth and irregular Earth using elementary short dipole and monopole reference antennas. The ground-wave propagation loss prediction methods for smooth Earth include those reported by Berry and Herman (1971), L.A. Berry (OT Technical Memorandum 78-247, January 1978, limited distribution), and Stewart et al. (1983). Additional modifications were installed in 1984 by L.A. Berry (private communication, 1985). The ground-wave prediction method for irregular-Earth terrain was developed by Ott (1971) and later extended by Hill (1982). These prediction methods have been compared with measured data by Ott et al. (1979) and Adams et al. (1984). The

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measured data were taken using the same elementary antenna configurations that were used in the propagation loss prediction methods.

The U.S. Army Information Systems Engineering Agency (USAISEA) needed an analysis model that included the more complex antennas of typical communications and broadcast systems in the presence of lossy ground. This report describes the computer model Ground-Wave Automated Performance Analysis (GWAPA) developed for USAISEA. The antenna algorithms developed for this computer program are valid for all ground constants and antenna geometries. A limited number of antenna types were incorporated into the algorithm. Additional types of antennas can be added.

The main computer program GWAPA combines three propagation loss prediction methods for both smooth and irregular Earth, a system interface algorithm, a noise prediction algorithm, a reliability algorithm, and an antenna algorithm into one user-friendly analysis tool.

The computer program can be used by individuals of moderate skill levels with little or no training for rapid analysis of many different communication systems in different geographic areas and under varied operating conditions. The computer program is a complete, user-friendly analysis tool for evaluating communications and broadcast circuits. It is written in standard ANSI FORTRAN 77. It is available on the USAISEA Cyber computer system at Fort Huachuca, AZ, for use in batch mode.

Section 2 of this report describes the complete performance prediction model in program GWAPA. The subsections in this section describe all of the constituent algorithms and methods contained within the main program. References are given where necessary to provide more detail for the interested reader.

Section 3 is a users' guide for the computer model GWAPA. A complete description of the questions asked by the program to request input data is given with an explanation of what behavior will occur for different user responses. Tables of input variable range limits and default values are given. Section 4 includes sample sessions with GWAPA to provide the user with illustrative examples and a means of checking program GWAPA for proper operation.

In Section 5, conclusions are presented regarding the overall accuracy and capabilities of computer program GWAPA. Recommendations for further work are put forth.

2. THE SYSTEM PERFORMANCE PREDICTION PROGRAM GWAPA

The performance of telecommunication systems that rely on ground-wave signals depends on transmitter power, signal frequency, transmitter and receiver antenna characteristics, ground constants, noise and interference environment, and the terrain contour between the transmitter and receiver. An accurate prediction of system performance depends on how well each of the dependent variables listed above is taken into account in the calculations.

The computer program GWAPA combines three propagation loss prediction methods, a system interface algorithm, a noise prediction algorithm, and an antenna algorithm into a user-friendly analysis tool for system performance prediction. The propagation loss prediction methods, system interface algorithm, and noise prediction algorithm are valid from 10 kHz to 30 MHz. Collectively, the three propagation loss prediction methods can be used to predict propagation loss for the terrain that is either homogeneous or mixed path. The antenna algorithm for the single monopole antenna option, variable length dipole, user gain input, and electric field strength are also valid from 10 kHz to 30 MHz. The log-periodic dipole array, inverted L, terminated-sloping longwire, and vertical half-rhombic are valid only from 2.0 MHz to 30.0 MHz. The antenna algorithm gives accurate representations of equivalent antenna gain to provide reasonably good predictions for engineering analysis. The accuracy of this algorithm is discussed in a later section. The methodology of program GWAPA and its constituent algorithms and methods are discussed separately in this section.

The computer program GWAPA operates with five basic output options: transmission loss, received power, received signal-to-noise power ratio, the maximum achievable distance for a user-entered signal-to-noise ratio and reliability, and the achievable reliability for a user-entered signal-to-noise power ratio and distance. All five options can be computed at multiple frequencies and directions.

In the received signal-to-noise power ratio for multiple frequencies-and-directions option, the program predicts basic transmission loss, received electric field strength, received signal power, received signal-to-noise power ratio for a particular reliability, noise level, and antenna factors over lossy Earth. The signal-to-noise power-ratio calculations can be made for multiple seasons and times. The user enters a desired reliability for the signal-to-noise power-ratio calculation. The transmission losses for this option are calculated with one of the user-selected propagation loss prediction methods: smooth homogeneous Earth

(SE); smooth inhomogeneous (mixed path) Earth (SEMP); and irregular Earth, mixed-path (IEMP) with or without a slab representing forests, cities, etc. The terrain data base is automatically accessed by program IEMP or the user may manually enter terrain data. IEMP propagation loss computation times can be excessive for each path, resulting in prohibitively long run times. The user should exercise caution when selecting this propagation loss prediction method.

The received power option computes received power, received electric-field strength, basic transmission loss, and antenna factors over lossy earth. The basic transmission loss is computed using one of the three propagation loss prediction methods. The transmission loss option computes only basic transmission loss.

The achievable distance option calculates the maximum distance from the transmitter at which the user-input signal-to-noise power ratio and reliability are simultaneously achieved. The received power, noise level, and electric field strength are also computed. The calculations are performed for multiple frequencies, directions, seasons, and times of day. The propagation loss prediction methods using this option are limited to the SE and SEMP loss prediction methods, because the repetitious calculations required with this output option would result in prohibitively long run times if the IEMP loss prediction method were used.

The achievable reliability option computes the reliability for a user entered signal-to-noise power ratio and distance. All three propagation loss prediction methods are permitted here.

Within these five basic program output options are many alternate paths the user can take depending on the user response to the input questions. This is covered in detail in Section 3.

2.1 The System Interface Algorithm

The system interface algorithm is used to combine the propagation losses, antenna gains, and appropriate constants to calculate electric field strength and received power. The algorithm also combines the received power with a noise prediction for a desired reliability to determine signal-to-noise power ratio for a given reliability. The achievable distance for a given input reliability and signal-to-noise power ratio and the achievable reliability for a given signal-to-noise power ratio and distance are also computed with the system interface algorithm. The standard equation used in GWAPA to relate the received power (dBW), transmitter power (dBkW), antenna gains (dBi), and basic transmission loss (dB) is:

$$P_r(\mathrm{dBW}) = P_t(\mathrm{dBkW}) + G_t(\mathrm{dBi}) + G_r(\mathrm{dBi}) - \mathrm{Loss}(\mathrm{dB}) + 30 \qquad (1)$$

where

P_r(dBw) = the receiver power in decibels referenced to 1 watt
P_t(dBkW) = the transmitter power in decibels referenced to 1 kilowatt
G_t(dBi) = the transmitter antenna gain in decibels referenced to an isotropic radiator in free space
G_r(dBi) = the receiver antenna gain in decibels referenced to an isotropic radiator in free space
Loss(db) = basic transmission loss between two isotropic radiators computed from one of the three propagation models

This equation is used to calculate the received power for all program computations requiring received power (signal-to-noise power ratio, achievable distance, etc.).

The equation used to calculate electric field strength, E in dBuV/m, from the transmitted power, transmitter antenna gain, frequency, and basic transmission loss is:

$$E(\mathrm{dBuV/m}) = 131.20 + 20 \log f(\mathrm{MHz}) + P_t(\mathrm{dBkW}) + G_t(\mathrm{dBi}) - \mathrm{Loss}(\mathrm{dB}) \qquad (2)$$

where

f(MHz) = the frequency in megahertz, and the remaining variables are as defined above for the received power calculation.

This equation can be derived easily from an equation that originated in CCIR Report 112 (CCIR, 1959). The original equation in this document is an expression for propagation loss Lp(dB):

$$Lp(\mathrm{dB}) = 135.97 - Gp(\mathrm{dBi}) + 20 \log f(\mathrm{MHz}) - E(\mathrm{dBuV/m}) \qquad (3)$$

where

Gp(dBi) is the path antenna gain in decibels,

f(MHz) is the frequency in megahertz, and

E(dBuV/m) is the electric field strength in dBuV/m for 1kW radiated power from a short, vertical electric dipole over perfectly conducting ground.

The path antenna gain, Gp, for this transmitter antenna configuration is given as 4.77 dB in CCIR Report 112 (CCIR, 1959). If this is substituted into (3) and normalized to any arbitrary transmitter power, P_t(dbkW), and transmitter antenna gain, G_t(dBi), the resultant equation with E and L_p transposed is (2).

The received signal-to-noise power ratio in decibels is the received power in dBW computed with (1) minus the noise power in dBW in a 1 Hz bandwidth, which is computed from the noise prediction algorithm for each time, season, frequency, and user-selected man-made noise level.

Reliability is taken into account by a simplified algorithm that uses the median, upper decile, and lower decile of the total noise statistics. The total noise statistics are a combination of the median, upper decile, and lower decile of man-made, atmospheric, and galactic noise. This noise prediction algorithm is discussed in more detail by Spaulding and Washburn (1985) and in Section 2.3.

The reliability algorithm uses linear interpolation between the median and the upper decile value of the noise for determining the reliabilities of obtaining a specific signal-to-noise power ratio between 50 and 90 percent. Linear interpolation is performed between the median and the lower decile value of the noise for determining the reliabilities of obtaining a specific signal-to-noise power ratio between 10 and 50 percent. Linear extrapolation is used by extending the appropriate straight line segment beyond the upper or lower decile points to determine signal-to-noise power ratio reliabilities greater than 90 or less than 10 percent.

When the user enters a specific reliability in the multiple-frequency-and-direction mode, the noise level corresponding to that reliability is used for the signal-to-noise power-ratio calculation. If the user is in the achievable-distance mode, then a signal-to-noise power ratio and reliability are entered by the user. The program then uses the appropriate noise level corresponding to the input reliability and determines at what maximum distance the signal level is adequate to achieve the input signal-to-noise power ratio for the given input reliability. The result is the required received power. The system interface algorithm then calculates signal power versus distance from the transmitter until it gets to this required received power. The distance is calculated as the maximum achievable distance corresponding to the user input signal-to-noise power ratio and reliability. The use of the irregular-Earth propagation loss prediction method is prohibited in the achievable-distance option due to excessive computation time.

The achievable-reliability option computes the received signal power at the required distance and then determines the resultant noise level for the required signal-to-noise power ratio by subtracting the required signal-to-noise power ratio (dB) from the received signal power (dBW). The reliability is then computed by comparing this noise level to the actual noise level statistics of the receiver location using the reliability algorithm.

2.2 The Propagation Loss Prediction Methods

Program GWAPA contains three separate propagation loss prediction methods: a smooth-Earth (SE), a smooth-Earth, mixed-path (SEMP) and an irregular-Earth, mixed-path method that includes forested and built-up terrain over mixed paths (IEMP). The smooth-Earth and smooth-Earth, mixed-path methods are efficient programs with fast run times, but the irregular-Earth method is, in general, much slower in computation time due to the techniques used for the attenuation function calculation. The techniques used in IEMP are still the most efficient and fastest irregular-Earth computation procedures to date for general irregular-Earth terrain (Rotheram et al., 1985). The smooth-Earth methods calculate transmission loss for both vertical and horizontal polarization. The irregular-Earth method is limited to only vertical polarization. This section will briefly explain each of the three propagation methods used in GWAPA and point out the limitations of each. A description of computation times and relative accuracy of each model is given in Section 2.5.

2.2.1 The Smooth Earth Method

The smooth-Earth method is that developed by L.A. Berry ("User's Guide to Low Frequency Radio Coverage Programs," OT Technical Memorandum 78-247, January 1978, limited distribution). It is also described in Berry and Herman (1971) and

Stewart et al. (1983). Two additional computation techniques were implemented in the smooth-Earth method in 1984 by L.A. Berry (private communication, 1985). They will be described briefly in this section. The method is for computing ground-wave propagation loss over smooth homogeneous Earth. The ground wave includes the direct line-of-sight space wave, the ground-reflected wave, and the surface wave that diffracts around the curved Earth. The sky wave reflected from the ionosphere is not included in this calculation.

The formulas used in the smooth-Earth model are adapted from Abramowitz and Stegun (1964), Wait (1964), Fock (1965), King (1969), and Hill and Wait (1980). The following six computation techniques are used: flat-Earth attenuation function, flat-Earth attenuation function with curvature correction (Hill and Wait, 1980), Hill and Wait's series for small Q (Hill and Wait 1980), the residue series calculation, geometric optics, and numerical integration of full-wave theory. The flat-Earth attenuation function with curvature correction and Hill and Waits's series for small Q were added in 1984 by L.A. Berry (private communication, 1985). Antenna heights, path lengths, Earth geometries, ground constants, and frequency are used by the program to automatically select the appropriate computation technique. The losses calculated by the smooth-Earth method are in agreement with Norton's work (1941), where Norton's approximations are valid, and the CCIR curves (CCIR, 1970). The smooth-Earth method is mathematically and numerically accurate for the ground-wave predictions for frequencies from 10 kHz to 100 MHz (L.A. Berry, OT Technical Memorandum 78-247, January, 1978, limited distribution). Above 30 MHz, the irregularities of the atmosphere make statistical methods more appropriate. Irregularities in the terrain have more of an effect at higher frequencies, so an irregular terrain model is more appropriate when terrain irregularities become appreciable in size with respect to a wavelength.

The smooth-Earth method calculates field strength and converts this to propagation loss. The computation technique depends upon the relative geometry of the transmitter and receiver locations, the ground constants, and the radio frequency. The radio wave propagates as a surface wave when both the transmitter and receiver are near the Earth in wavelengths. If, in addition, the path lengths are short such that the Earth can be assumed to be flat, then the flat-Earth attenuation function (Wait, 1964) is valid. The equations are given in Stewart et al. (1983).

When the transmitter and receiver are high enough that an observer at the receiver or transmitter is well above the radio horizon when viewed from the other, the field strength involves the use of geometrical optics. The formulas are given in Stewart et al. (1983). When the receiving antenna is near the radio horizon of the transmitting antenna, the field depends upon diffraction effects in addition to the direct wave. The computation technique is then by numerical integration of the full-wave theory integral (Stewart et al., 1983).

For long path lengths, the Earth cannot be considered flat. If, in addition, the geometry is such that a straight line connecting the transmitter and receiver antennas intersects the curved Earth, then the full-wave theory integral must be evaluated using a residue series (Fock, 1965; Wait, 1964).

For cases where the antennas are close to Earth but the distances are long enough such that Earth is not flat, the computation is performed using either a flat-Earth attenuation function with a small-Earth curvature expansion or a power series expansion. The addition of these two techniques is for the purpose of reducing the use of the numerical integration of the full-wave theory integral, since it is very time consuming. These two techniques bridge the gap for loss computation between the case where the Earth is flat (flat-Earth attenuation function) and that where the receiving antenna is near the radio horizon of the transmitting antenna. The computation technique is selected depending on whether the magnitude of a factor q is small or large (Hill and Wait, 1980). The factor q is given by:

$$q = -1 \left(\frac{Ka}{2}\right)^{\frac{1}{3}} \Delta \tag{4}$$

where

$K = 2\pi/\lambda$

λ = wavelength of radio wave (meters)

a = radius of the Earth (meters)

Δ = normalized surface impedance of the ground below the antenna in question

$$= \frac{\sqrt{\varepsilon_{gc} - 1}}{\varepsilon_{gc}} \quad \text{for vertical polarization}$$

$$= \sqrt{\varepsilon_{gc} - 1} \quad \text{for horizontal polarization}$$

$$\varepsilon_{gc} = \varepsilon_g + \frac{\sigma_g}{i\omega\varepsilon_o}$$

ε_g = relative dielectric constant of the ground

σ_g = conductivity of the ground in siemens per meter

ε_o = permittivity of free space 8.85×10^{-12} farads per meter

$\omega = 2\pi f$.

The surface impedance is a function of the ground constants of the Earth's surface. If the magnitude of q is small (<.1), then a power series expansion is used for the attenuation function (Bremmer, 1958; Wait, 1956, 1958). The attenuation function is the ratio between the electric field from a short dipole over the lossy Earth's surface to that field from the same short dipole located on a flat perfectly conducting surface.

If the magnitude of q is large (≧.1) then a small curvature expansion is more appropriate for the attenuation function (Hill and Wait, 1980; Wait, 1956; Bremmer, 1958). The implementation of these two techniques reduces the need for the numerical integration technique and reduces computation time considerably.

The smooth-Earth model is valid for all combinations of antenna heights, frequency, and dielectric constants by virtue of the six computation techniques contained within its structure. It should be used only out to the maximum ranges considered useful for ground-wave propagation at each frequency, since the sky wave would become significant from that distance to points beyond. This distance is roughly 300 km at low frequencies ≤ 0.5 MHz and depends on frequency in addition to whether it is day or night. The ground-wave model is valid for path lengths ranging from 1 to 10,000 km, where the actual distance is dependent on frequency (L.A. Berry, OT Technical Memorandum 78-247, January, 1978, limited distribution).

2.2.2 The Smooth-Earth, Mixed-Path Method

The smooth-Earth, mixed-path method is a specific sequence of smooth-Earth model runs over each of the segments that are then combined in a particular order as determined by the Millington algorithm (Millington, 1949). The antenna heights are set to zero for each run over each of the segments and combination of segments required by the algorithm. A height gain function is then applied to the transmitter and receiver antennas using the ground constants under each antenna and the user-supplied heights. The result is the propagation loss over a mixed path with compensation for antenna heights. The Millington algorithm implemented in the smooth-Earth, mixed-path technique will be discussed for the three-section mixed path of Figure 1. Expansion to more sections is a straightforward process. The first step involves the calculation of losses using the smooth-Earth model over single sections and combinations of sections using the different ground constants. With T as a source we first compute the loss L_{tr} in decibels (dB),

$$L_{tr}(dB) = L_1(d_1) - L_2(d_1) + L_2(d_1 + d_2) - L_3(d_1 + d_2) + L_3(d_1 + d_2 + d_3) \quad (5)$$

where

$L_1(d_1)$ = loss in dB over distance d_1 using σ_1 ε_1

$L_2(d_1)$ = loss in dB over distance d_1 using σ_2 ε_2

$L_2(d_1 + d_2)$ = loss in dB over distance $d_1 + d_2$ using σ_2 ε_2

$L_3(d_1 + d_2)$ = loss in dB over distance $d_1 + d_2$ using σ_3 ε_3

$L_3(d_1 + d_2 + d_3)$ = loss in dB over distance $d_1 + d_2 + d_3$ using σ_3 ε_3.

With R as a source, compute the loss L_{rt} in decibels

$$L_{rt}(dB) = L_3(d_3) - L_2(d_3) + L_2(d_3 + d_2) - L_1(d_3 + d_2) + L_1(d_3 + d_2 + d_1) \quad (6)$$

where

$L_3(d_3)$ = loss in dB over distance d_3 using σ_3 ε_3

$L_2(d_3)$ = loss in dB over distance d_3 using σ_2 ε_2

$L_2(d_3 + d_2)$ = loss in dB over distance $d_3 + d_2$ using σ_2 ε_2

$L_1(d_3 + d_2)$ = loss in dB over distance $d_3 + d_2$ using σ_1 ε_1

$L_1(d_3 + d_2 + d_1)$ = loss in dB over distance $d_3 + d_2 + d_1$ using σ_1 ε_1.

The total loss $L_t(dB)$ is then computed:

$$L_t(dB) = \frac{L_{tr}(dB)}{2} + \frac{L_{rt}(dB)}{2} - 20 \log [|G(Z_t)||G(Z_r)|]. \quad (7)$$

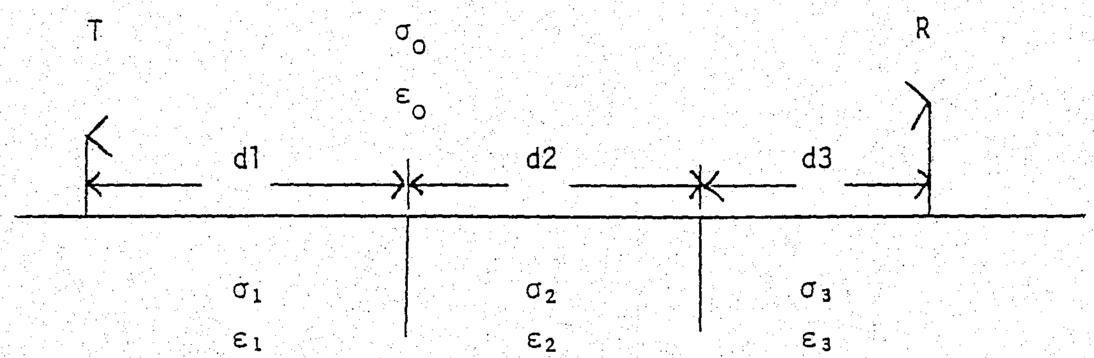


Figure 1. A three-section mixed path for the smooth-Earth, mixed-path method.

$G(Z_t)$ and $G(Z_r)$ are the height-gain functions for the transmitter and receiver antennas respectively.

$$G(Z) = 1 + iKZ\,\Delta \qquad (8)$$

where

Z = the transmitter antenna height, Z_t, or receiver antenna height, Z_r, in meters

$K = 2\,\pi/\lambda$ and λ = wavelength in meters of radio wave

Δ = normalized surface impedance of the ground below the antenna in question as defined in (4) previously.

This smooth-Earth, mixed-path method will calculate the propagation loss over a mixed path with as many as 50 segments. The main program will request the ground constants and distances for each of the segments. It is valid for the same frequency and distance ranges as in the smooth-Earth method.

2.2.3 The Irregular-Earth, Mixed-Path Method

The irregular-Earth, mixed-path (IEMP) method uses an integral equation (Hill, 1982; Ott, 1971) to compute the propagation loss of a vertically polarized electromagnetic wave over irregular terrain that is covered with forests, buildings, or snow. WAGSLAB (Hill, 1982) is an extension of program WAGNER (Ott, 1971) to model a slab representing the terrain cover. The irregular-Earth, mixed-path (IEMP) method in GWAPA is a modified version of program WAGSLAB (Hill, 1982). The terrain cover is modeled as a slab of user-specified thickness, length, conductivity, and dielectric constant. Antenna heights of the transmitter and receiver antennas without a slab are taken into account within the program using the height-gain functions discussed previously for the smooth-Earth, mixed-path method. When a slab is included, a special height-gain function (Hill, 1982) is used for antennas within or above the slab. The program can handle up to 50 different segments over a mixed path.

The modifications for the IEMP method of program GWAPA include a user friendly input/output interface, an automatic computation of distance increment based on terrain roughness and frequency, an automated capability to sample terrain height at any interval, manual terrain input capability, and an algorithm to reduce the overall run time and simultaneously maintain computation accuracy of results. In addition, GWAPA includes the antenna gains for user-selected antennas. The original WAGSLAB used only a standard dipole transmitter antenna, and no provision was made for a receiver antenna.

The integral equation approach in program IEMP is a point-to-point prediction method valid for frequencies between 10 kHz and 30 MHz. At higher frequencies, other techniques must be used that take into account the large variability of the ground wave in time and space. The analytical details of the integral equation are described in the references for WAGSLAB (Hill, 1982) and WAGNER (Ott, 1971). In both of these references, good agreement is found between this calculation method and other analytical computation methods. Comparisons of calculations with measurements have also been made (Ott et al., 1979; and Adams et al., 1984).

One problem with the original WAGNER and WAGSLAB is the excessive computation time required. The computation time is proportional to the square of the number of points at which the computation is made along the path. The number of points required is related to the terrain roughness, frequency, and the path length. The accuracy is dependent on the number of points. The larger the number of points for a given distance, the more accurate is the calculation, but too many points may result in excessive computation time.

The IEMP method contains modifications that reduce the overall computation time. A trade-off is made by the subroutine that controls the irregular-Earth calculation points of program GWAPA. It performs a tradeoff between the number of calculation points and propagation loss prediction accuracy. The terrain is examined for the path in question and a terrain roughness factor is calculated using a newly developed procedure. The frequency and path length are also used by the procedure. An increment size is then calculated based on these three factors. Using the path length and increment size, the number of points is determined.

The increment selection procedure actually uses a window that slides along the path, so that an interval size is selected for different sections along the path. This added factor accounts for a path that has mixed sections of relatively smooth, hilly, and rough terrain over the entire path, so a path section will contain more calculation points if the terrain is rough or hilly than it would if the terrain were relatively smooth. This calculation of increment size as a function of terrain roughness is based on an extensive study of irregular-Earth propagation loss prediction accuracy for different terrain roughnesses over the frequencies of 0.5 MHz to 30 MHz. The increment size selection procedure minimizes the IEMP method computation time and maximizes accuracy over a path consisting of smooth, hilly, and rough terrain sections. This is transparent to the user, since everything is done within the program with no user interaction or awareness of the complexity of the calculation.

Another subroutine within the procedure analyzes and interpolates between the results of the calculations within the IEMP method and determines what the losses are at the specific points where the user wishes to see the calculations. The user specifies the initial, incremental, and final distances during the input data questions so that the output has computation results where the user desires them. The IEMP method calculates losses at all the points necessary to maintain accuracy and reduce computation time. The user sees only the points that are specified to be output.

Even though the IEMP method is valid from 10 kHz to 30 MHz, it is not recommended for rough terrain at the higher (20-30 MHz) frequencies, because even with the speed up algorithm the IEMP method computation time can be excessive in certain cases. These frequencies do not propagate well over rough terrain. Sky-wave propagation may be more suitable for communications.

At the other end of the frequency band (10 kHz to 1.7 MHz) the smooth-Earth method or smooth-Earth, mixed-path method may give comparable accuracy to the irregular-Earth, mixed-path method, so it may be more efficient to use one of these smooth-Earth models. The relative accuracy of these methods is discussed in Section 2.5.

2.3 The Noise Prediction Algorithm

The noise prediction algorithm in program GWAPA is an updated version of the noise prediction method used in the Ionospheric Communications Analysis and Prediction Program (IONCAP) (Teters et. al., 1983). The new version contains improved noise data (Spaulding and Washburn, 1985).

The total noise statistics are a combination of the median, upper decile, and lower decile of man-made, atmospheric, and galactic noise. The noise in a 1-Hz bandwidth is computed in the noise program for each 1-hour/3-month-season, frequency, geographic location and user-selected, man-made noise level. The median (MED) for the total noise power is the average value of the total noise power in decibels with respect to one watt (dBW) exceeded for 50 percent of the hours within a 1-hour/3-month-season.

The upper decile value of noise (MED + DU) is the average noise power in decibels with respect to 1 W exceeded for 10 percent of the hours within 1-hour/3-month-season. The lower decile value of noise (MED - DL) is the average noise power in decibels with respect to 1 W exceeded for 90 percent of the hours within a 1-hour/3-month-season.

The noise level is then below MED + DU for 90 percent of the hours within a 1-hour/3-month-season, and below MED - DL for 10 percent of the time in a 1-hour/3-month-season. These percentages correspond to the reliabilities of attaining a particular signal-to-noise power ratio assuming a deterministic signal. If MED + DU is used in a signal-to-noise power-ratio calculation, the actual signal-to-noise power-ratio will be greater than that signal-to-noise power ratio 90 percent of the time in a 1-hour/3-month-season. It follows that if MED - DL is used in a signal-to-noise power-ratio calculation, the resultant signal-to-noise power-ratio will be greater than that signal-to-noise power ratio for 10 percent of the time in a 1-hour/3-month-season. Linear interpolation is used between the upper decile and median noise levels to obtain reliabilities of achieving a specific signal-to-noise power-ratio between 50 and 90 percent and between the lower decile and median noise level to obtain reliabilities of achieving a specific signal-to-noise power-ratio between 10 and 50 percent.

Linear extrapolation is used by extending the appropriate straight-line segment beyond the upper or lower decile points to obtain signal-to-noise power-ratio reliabilities greater than 90 or less than 10 percent.

The total noise statistics are computed from the statistics of the atmospheric, galactic, and man-made noise using the following expressions:

$$MED = 10 \log_{10} \left(10^{ATNOS/10} + 10^{GNOS/10} + 10^{MMNOS/10}\right) \qquad (9)$$

$$DU = \left| 10 \log_{10}\left(10^{(ATNOS + DUA)/10} + 10^{(MMNOS + DUM)/10} + 10^{(GNOS + DUG)/10}\right) - MED \right| \qquad (10)$$

$$DL = \left| 10 \log_{10}\left(10^{(ATNOS + DLA)/10} + 10^{(GNOS + DLG)/10} + 0^{(MMNOS + DLM)/10}\right) - MED \right| \qquad (11)$$

where

ATNOS = median atmospheric noise in dBW

GNOS = median galactic noise in dBW

MMNOS = median man-made noise in dBW

DUA = difference in decibels between upper decile and median value of atmospheric noise

DLA = difference in decibels between median and lower decile value of atmospheric noise.

DUG = difference in decibels between upper decile and median value of galactic noise

DLG = difference in decibels between median and lower decile value of galactic noise

DUM = difference in decibels between upper decile and median value of man-made noise

DLM = difference in decibels between median and lower decile value of man-made noise

MED = median total noise in dBW

DU = difference in decibels between upper decile and median value of total noise

DL = difference in decibels between median and lower decile value of total noise.

All statistical parameters above are for a 1-hour/3-month-season time period. The statistics for atmospheric noise are determined from a computer subroutine called GNOIS using the latest noise coefficients as described in Spaulding and Washburn (1985). The man-made noise and galactic noise are determined using the expression (CCIR, 1982):

$$\begin{matrix} \text{GNOS} \\ \text{or} \\ \text{MMNOS} \end{matrix} = C - D\log f - 204 \tag{12}$$

where C and D are described in Table 1, and f equals frequency in megahertz.

Table 1. Man-made and Galactic Noise Coefficients

Environmental Category	C	D
Business	76.8	27.7
Residential	72.5	27.7
Rural	67.2	27.7
Quiet Rural	53.6	28.6
Galactic	52.0	23.0

The user chooses the environmental category for man-made noise. The galactic and man-made noise values are always calculated using the coefficients of Table 1. The upper and lower decile values of galactic and man-made noise are fixed within the noise prediction algorithm and are assigned the following values: DUM = 9, DLM = 7, DUG = 2, and DLG = 2. The noise value for the signal-to-noise calculation for single or multiple frequency and direction, and achievable distance is the noise value associated with the user entered reliability.

2.4 The Antenna Algorithm

The performance of antennas near or on the surface of the Earth can be very dependent on the interaction with the lossy Earth and surface-wave propagation. The effects of the lossy Earth for different antenna types and ground constants are in general difficult to predict. A quantitative estimate of performance in terms of an "equivalent gain" or "enhancement factor" also is difficult to obtain directly in general formulas for different practical antenna types. Presently available techniques with computer algorithms are time consuming and require conversion or normalization for use in system computations. An antenna model was developed at ITS to provide an "equivalent gain" for use in communication systems analysis. The model quickly provides a number for "equivalent gain" and is normalized properly for systems calculations.

The antenna algorithm is used to compute the equivalent gain of several antenna types as a function of the independent variables: antenna geometry, ground conductivity, ground dielectric constant, frequency, and azimuth. The equivalent gain calculated represents the effectiveness of the antenna in launching or receiving the ground wave. In general, this gain is not the same as the conventional antenna gain used in communication systems analysis. The antenna algorithm uses look-up tables and simple algebraic equations to determine the equivalent gain. The look-up tables and equations were derived from behavior analyses of extensive method-of-moments calculations using the computer program Numerical Electromagnetics Code, version 3 (NEC-3) (Burke and Poggio, 1977; Burke and Miller, 1983). The antenna algorithm allows fast prediction of equivalent gain since all time consuming calculations have been previously performed "off-line."

The gain required for systems analysis calculations is usually with respect to an isotropic radiator in free space or some other reference antenna. Conventional methods for a gain calculation could not be used due to the close proximity of the antennas with respect to a lossy Earth. The gain calculation method used for deriving the antenna algorithm within GWAPA results in an equivalent gain with respect to an isotropic radiator in free space.

A short dipole was selected as a reference antenna due to its simplicity for analysis and convenience in measurement. Many loss calculations in ground-wave analysis are referenced to short dipoles or monopoles. The computer program NEC-3 is used to determine the equivalent gain of a short dipole over lossy Earth with respect to an isotropic radiator in free space for all ground conductivities, ground dielectric constants, and frequencies. The relative performance of the subject antenna with respect to the short dipole is then determined using the program NEC-3. These two factors are then combined to obtain the equivalent gain with respect to an isotropic radiator in free space.

The gain of a short dipole antenna at the surface of a lossy Earth referenced to an isotropic radiator in free space can be derived from some basic relationships. The field intensity or power density in free space due to an isotropic radiator in free space is given by Norton (1959):

$$\frac{e^2}{\eta} = \frac{P_r}{4\ \pi D^2} \qquad (13)$$

where

$e(V/m)$ = the electric field strength in volts per meter

$\eta(\text{ohms})$ = the impedance of free space in ohms = $120\ \pi$

$D(m)$ = the distance from the antenna in meters

$P_r(W)$ = the radiated power in watts.

Taking the square root of both sides and rearranging terms, the primary electric field strength from an isotropic antenna is:

$$e(V/m) = \frac{\sqrt{30\ Pr(W)}}{D(m)} . \tag{14}$$

The primary electric field strength from an antenna in free space is:

$$e(V/m) = \frac{\sqrt{30\ P(W)g}}{D(m)} \tag{15}$$

where g is the equivalent antenna gain ratio referenced to an isotropic radiator in free space and P is the transmitter input power in watts. If the units are changed, the above equation becomes:

$$e(mV/m) = \frac{173\sqrt{P(kW)g}}{d(km)} \tag{16}$$

where

e(mV/m) = the electric field strength in millivolts per meter

P(kW) = the transmitter power in kilowatts

d(km) = the distance in kilometers.

If the antenna is a short vertical element (g=3) at the surface of a perfectly conducting Earth, then

$$e(mV/m) = \frac{300\sqrt{P(kW)}}{d(km)} . \tag{17}$$

and this is the familiar 300 mV/m at 1 km for a 1 kW input over perfectly conducting Earth.

The electric field strength for a lossy Earth and arbitrary gain, g, is given by Terman (1955) as:

$$e(mV/M) = \frac{173\ A\sqrt{P(kW)g}}{d(km)} \tag{18}$$

where A is the Norton approximation (Norton, 1941) to the Sommerfeld attenuation function (Sommerfeld, 1909). If this expression is rearranged to solve for g and the logarithm of both sides is taken, the gain of a short dipole antenna at the surface of a lossy Earth referenced to an isotropic radiator in free space is

$$G_d(\text{dB}) = 10 \log \frac{e^2(\text{mV/m})\ d^2(\text{km})}{(173)^2\ P(\text{kW})\ A^2} \quad . \tag{19}$$

The effectiveness of an antenna in launching a surface wave "equivalent gain" is then determined by first calculating a ratio called the relative communication efficiency for each subject antenna as a function of the ground constants, frequency, antenna geometry, and azimuthal direction. The relative communication efficiency in decibels (dB) is then added to the reference dipole gain. The relative communication efficiency (RCE) (Fenwick and Weeks, 1963) of a subject antenna is defined by:

$$\text{RCE(dB)} = 10 \log \frac{|E_t|^2 P_r}{|E_r|^2 P_t} \tag{20}$$

where

E_r(V/m) = electric field strength predicted by NEC-3 at reference distance d and input power P_r for a short dipole

P_r(W) = dipole antenna input power from NEC-3 used to compute E_r

E_t(V/m) = electric field strength predicted by NEC-3 at reference distance d and input power P_t for the subject antenna

P_t(W) = subject antenna input power from NEC-3 used to compute E_t.

The "equivalent gain" G_a (dBi) of the subject antenna over lossy Earth referenced to an isotropic radiator in free space is given by:

$$G_a\ (\text{dBi}) = G_d\ (\text{dBi}) + \text{RCE (dB)} \tag{21}$$

where G_d and RCE are as defined above. The "equivalent gain" referenced to an isotropic radiator in free space can now be used for communications system analysis.

The antenna types modeled for USAISEA include: a monopole on a ground stake or ground screen; a variable length dipole, a vertical log-periodic dipole array, an inverted L, a terminated sloping longwire, and a vertical half-rhombic. An electric field strength option and a user gain option have also been included. The user is asked to select an antenna type or one of the two options for the transmitter and receiver antennas. After the antenna type or one of the two options has been selected, the user is then asked certain questions whose answers describe the antenna. This information, the frequency and ground constants are used to determine the "equivalent gain" of the antenna from the look-up tables and algorithms. The "equivalent gain" numbers are then added to the signal level calculations of the systems interface algorithm for determination of signal-to-noise power ratio.

Although the questions that request the antenna input parameters are relatively straightforward and easy to understand, each of the antenna types modeled requires some explanation for an appreciation as to its limitations and general capability.

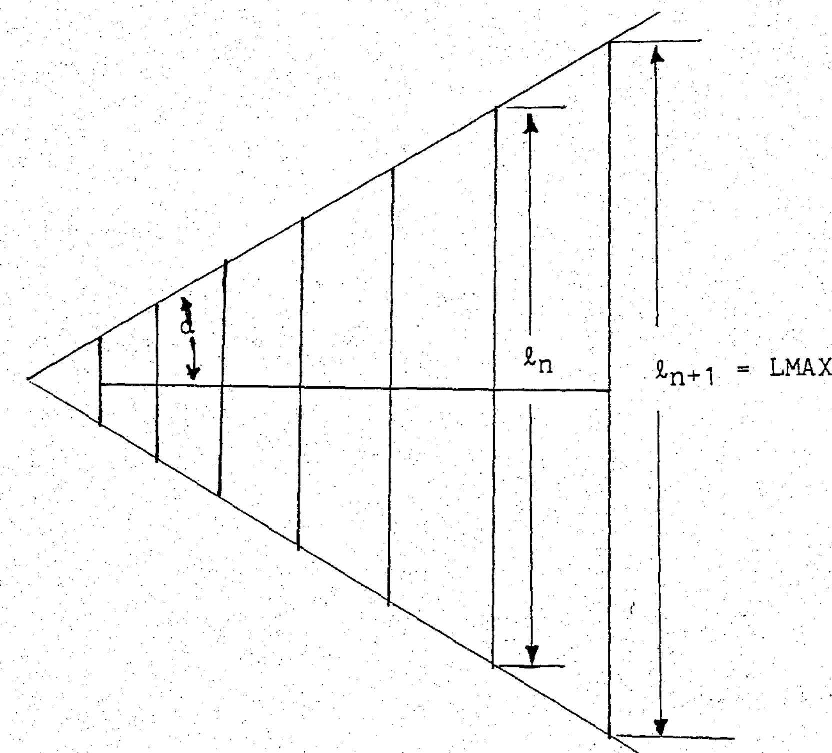
The monopole antenna is valid for all frequencies from 0.01 MHz to 30 MHz. The valid range for lengths depends on the wavelength of the radio frequency. The smallest monopole length is .01 wavelength at the lowest frequency and the largest length is 0.7 wavelength at the highest frequency. The user can elect to use a radial-wire ground screen with a user-specified radius from .01 wavelength at the lowest frequency to any finite number of wavelengths, and with 5-360 radials. The maximum ground screen radius actually used in the calculations is 0.6 wavelengths, since any increase in ground-screen size beyond this radius has a negligible effect on antenna performance.

If the user does not specify a ground screen, then the calculations are performed for the monopole on a ground stake. The ground stake is assumed to be between 0.04 and 0.1 free space wavelengths in length and 10^{-4} wavelengths in radius. Over this range, the relative communication efficiency is insensitive to changes in the ground-stake length.

The monopole length-to-radius ratio is assumed to be greater than or equal to 25 . This is a thin monopole assumption.

The vertical dipole antenna is a standard thin dipole whose length-to-diameter ratio is greater than or equal to 50. It's length can vary from .01 wavelength to a full wavelength. The dipole antenna as modeled is valid from 10 kHz to 30 MHz. The length of the dipole antenna must be less than or equal to twice the antenna height, so that the dipole antenna is above ground level. The program will prevent the user from entering lengths greater than this.

The vertical log periodic dipole antenna has the standard log-periodic design geometry shown in Figure 2. The antenna as modeled is valid from 2 to 30 MHz. Care must be taken in choosing the longest element length so that it is less than or equal to twice the antenna height for the same reason as with the dipole



$$\tau = \frac{\ell_n}{\ell_{n+1}}$$

Figure 2. Vertical log-periodic antenna geometry.

antenna. The log-periodic antenna algorithm can accommodate from 4 to 20 radiating elements and log-periodic scaling factors from $\tau=.82$ to $\tau=.99$. The design parameters are all defined in the antenna geometry of Figure 2. User constraints on required input data are described in Section 3. The antenna has directional characteristics that are taken into account by permitting the user to specify a beam direction.

The inverted L antenna geometry is shown in Figure 3. This antenna algorithm is valid from 2 to 30 MHz. The sum of the vertical and horizontal element lengths must be less than a wavelength and greater than .4 wavelengths. The inverted L is for all practical purposes omnidirectional in azimuth.

The terminated, sloping-longwire antenna geometry is shown in Figure 3. This antenna algorithm is valid from 2 to 30 MHz. The sloping-longwire antenna length can be from 2 to 12 wavelengths. The antenna has a beam maximum in a direction from the feed toward the termination. The off-beam performance of this antenna is too unpredictable to model. The gains computed are for the beam maximum. User constraints on required input data are contained in Section 3.

The vertical half-rhombic antenna geometry is shown in Figure 4. This antenna algorithm is valid from 2 to 30 MHz. Directional characteristics are taken into account in the model. The length of one leg can be specified by the user in a range from .6 wavelength to 4.6 wavelengths. The angle between the wire and ground can be from 0 to 30 deg. Additional user information for supplying input data is contained in Section 3.

An antenna efficiency can be specified for all of the above antennas. This is the last input parameter requested by the antenna algorithm. It is the ratio in percent of the power radiated by the antenna to the power at the antenna input terminals.

The electric field strength option will calculate the "equivalent gain" of any antenna if the electric field strength at a reference distance with a reference input power is known. This information can be obtained easily from the NEC-3 program as output for any antenna the user chooses to model; however, any other means of obtaining these three parameters may be used. This model is valid from .01 to 30 MHz.

The user gain option allows the user to specify gains at all input frequencies. This gain is any gain the user desires between -100 dBi and +100 dBi and allows parameterizing calculations with gain.

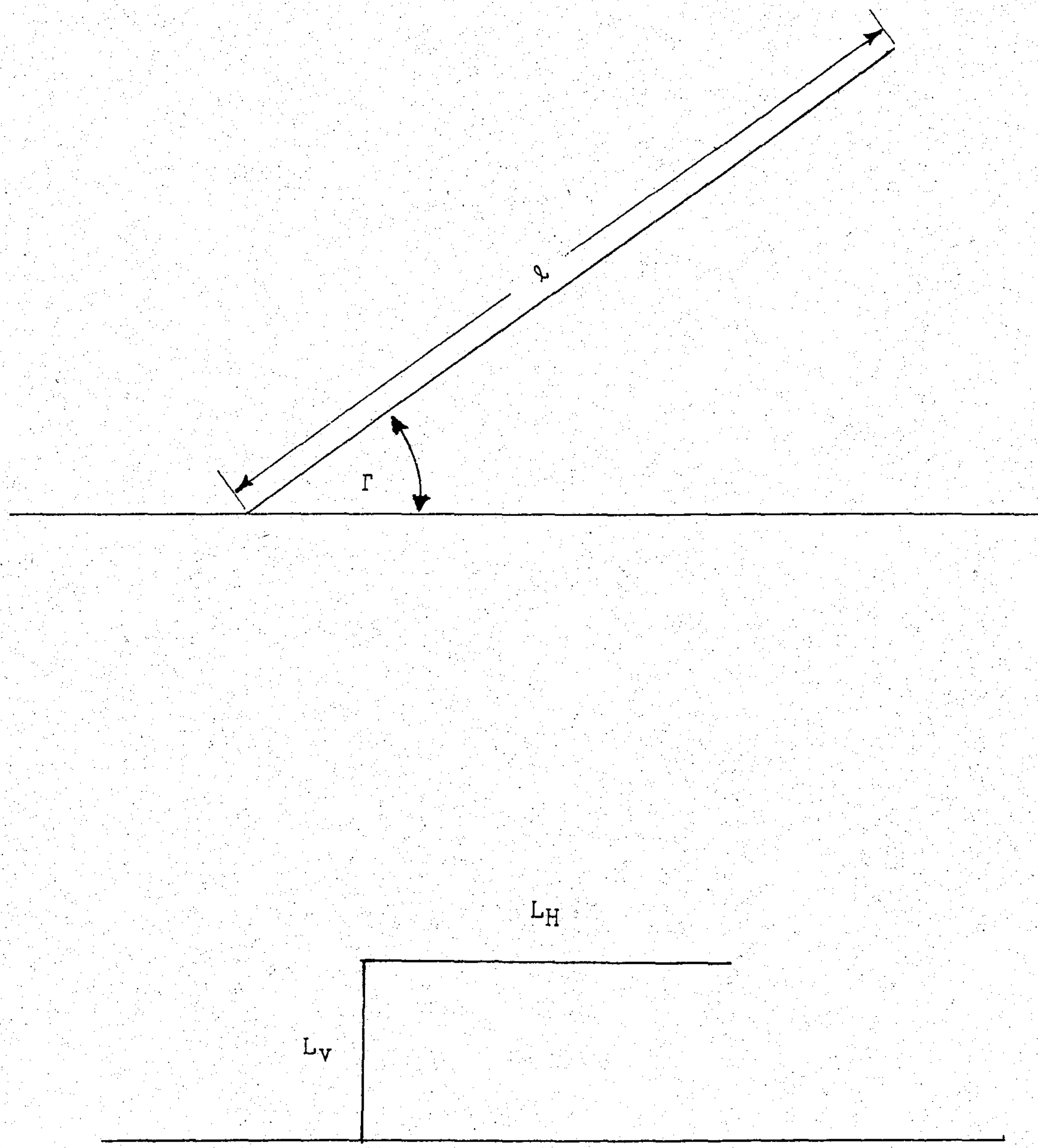


Figure 3. Terminated sloping-longwire and inverted-L antenna geometries.

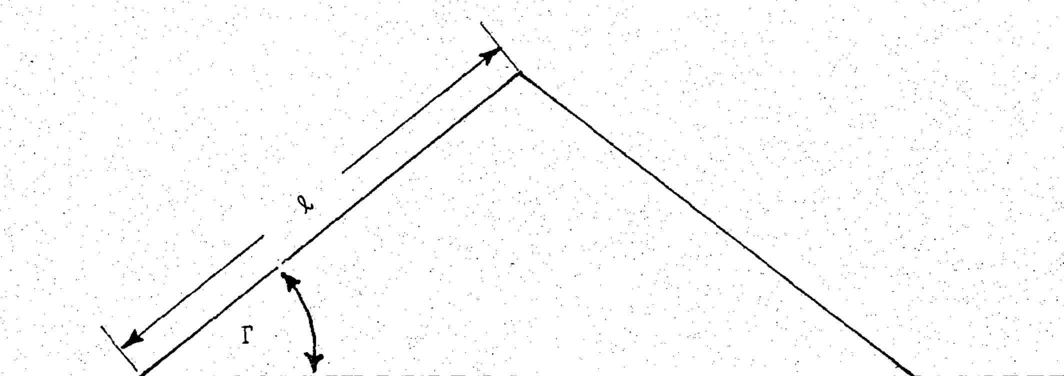


Figure 4. Vertical half-rhombic antenna geometry.

2.5 Run Time And Accuracy Algorithm

A set of time and accuracy algorithms has been developed to help the user decide whether to use a smooth-Earth propagation loss prediction method or an irregular-Earth loss prediction method. The irregular-Earth loss prediction method in most cases gives a more accurate prediction than a smooth-Earth method, but usually has a longer run time. The set of equations predicts run time and approximate accuracy with respect to measured data and run time for each of the three propagation methods.

The accuracy of the irregular-Earth propagation loss method also depends upon the terrain data available for use by the method. Some areas of the world have sparse data if any at all. In other areas, only coarse terrain data is available with spacings of approximately 8 km. The ITS terrain data file contains data every 30 seconds in latitude and longitude (approximately 1 km at the Equator) Spies and Paulson (1981). This is available for most of the United States.

The accuracy equations in GWAPA take terrain data file spacing into account when predicting propagation method accuracy. In many cases at lower frequencies (below 1.6 MHz) the equations indicate that a smooth-Earth propagation method can achieve similar results when compared to an irregular-terrain method. The user is cautioned that time and accuracy estimates are approximate. The purpose of these estimates is to give the user some insight into selecting one propagation loss prediction method over another. This is described in the next subsection.

2.5.1 Time And Accuracy Tradeoffs

The run times of the irregular-Earth method can be excessive in many communications analyses. The program GWAPA incorporates a feature that allows the user to obtain approximate run times and propagation model prediction accuracy for the runs being made. The accuracy was calculated with a limited amount of measured data. The time models were developed empirically from many runs of each of the three propagation methods. The time and accuracy prediction is not absolute, but it allows the user to gain an appreciation for the program run time and accuracy of each of the three propagation methods: smooth Earth, smooth Earth mixed path, and irregular Earth. The run time prediction allows the user to terminate a computer run if the time is excessive or to change computation methods. The accuracy prediction provides the user the same options if a similar accuracy can be obtained using a propagation loss prediction method that runs faster.

The user enters all of the input data at the start of a GWAPA run. If the user chooses a smooth-Earth (SE) or smooth-Earth, mixed-path (SEMP) method, the run time or accuracy will not be given since the irregular-Earth method is not involved. The run times of SE and SEMP are too short to be concerned about.

If the user chooses the irregular-Earth propagation loss prediction method, the GWAPA program will print out a table with the run times and accuracies of all three propagation models. The run times are in seconds. The accuracies are the mean and standard deviations in decibels of the approximate relative error in electric field strength with respect to measured data. If the mean is positive, then the propagation method prediction will result in a higher field strength than that of the measured data. If the mean is negative, then the prediction is below the measured data. It is emphasized here that both time and accuracy are approximate. They are provided only to give the user comparisons between the respective propagation loss prediction methods and a limited amount of measured data. The user is then given the option of deciding to process, modify or terminate the pending GWAPA run. The user can change the propagation loss prediction method if the irregular-Earth method run time is excessive. Comparable accuracy may be obtained by using one of the smooth-Earth methods, usually in a much shorter run time. Or the user can terminate the run if run times are excessive.

2.5.2 Terrain And Frequency Effects On Accuracy

The frequency and terrain roughness can profoundly affect the accuracy of propagation loss predictions. When the average terrain roughness (difference in height between adjacent terrain samples) is large with respect to a wavelength, the irregular-Earth method will produce better predictions than the smooth-Earth method. The accuracy is also a function of the terrain sample spacings of the terrain data base. The standard terrain file on the ITS Telecommunications Analysis Services computer contains data every 30 s of arc in latitude and longitude, which is a terrain data spacing of approximately 1 km at the Equator. These data are available for most of the United States. Another terrain file contains data every 5 min of arc, which is approximately every 8 km at the Equator. An irregular-Earth propagation loss prediction obviously will not be as accurate when using the coarse terrain as with the standard terrain file. There are areas where only coarse terrain data is available. The advantages of using an irregular-Earth method for better prediction accuracy when limited to a coarse terrain data set will be fewer for lower frequencies. The smooth-Earth method may be as accurate as an irregular-Earth method with coarse terrain.

The accuracy algorithm described previously takes into account whether the terrain data is coarse or standard.

In the AM broadcast band of 0.5 MHz to 1.6 MHz the user may indeed find the smooth-Earth propagation loss prediction methods adequate for communications performance predictions. A study was performed over this frequency range to investigate the relative accuracies between the smooth-Earth and irregular-Earth methods. It was found that if terrain data is available only every 8 km, then the smooth-Earth prediction is as good or better than an irregular-Earth method of prediction for the total path over rough terrain at frequencies between 0.5 MHz and 1.6 MHz. If terrain data is available every 1 km , then the irregular-Earth method prediction better follows the terrain details, but on the average is similar to the 8 km predictions over the total path. Where the path starts also determines where the 8 km samples are taken. Many of the coarse features of rough terrain could in effect be smoothed out by such a sampling. Precautions were taken during the generation of this data, so that this would not occur. The 8-km irregular-Earth prediction and the smooth-Earth prediction have fairly good agreement over the 0.52 MHz to 1.62 MHz band for rough terrain.

Figure 5 is an example of homogeneous rough terrain (Canyonlands), and Figure 6 is an example of mixed-path, hilly terrain (Santa Rita Mountains). Figures 7 through 9 compare irregular-Earth method loss predictions with 1 and 8 km terrain spacing for rough terrain from Figure 5 at the lower, middle, and upper frequencies in the band. The differences in loss prediction between 1 and 8 km terrain spacing increases as frequency is increased. Figures 10 through 12 compare the irregular-Earth method loss predictions for a hilly path from Figure 6 with 1 and 8 km terrain spacing. The difference in loss predictions again increases with increasing frequency, but the difference is less than for rough terrain over the total path. The loss predictions would be identical for smooth terrain when comparing 1 and 8 km terrain spacing.

Figures 13 through 18 compare the rough-terrain loss predictions of the irregular-Earth method for both 1 and 8 km terrain spacing with the smooth-Earth method. The 8 km irregular-Earth method loss prediction agrees quite favorably with the smooth-Earth method loss predictions over the AM broadcast band.

Figures 19 through 24 made the same comparison in loss predictions for a hilly mixed path. The 1 and 8 km irregular-Earth method loss predictions both

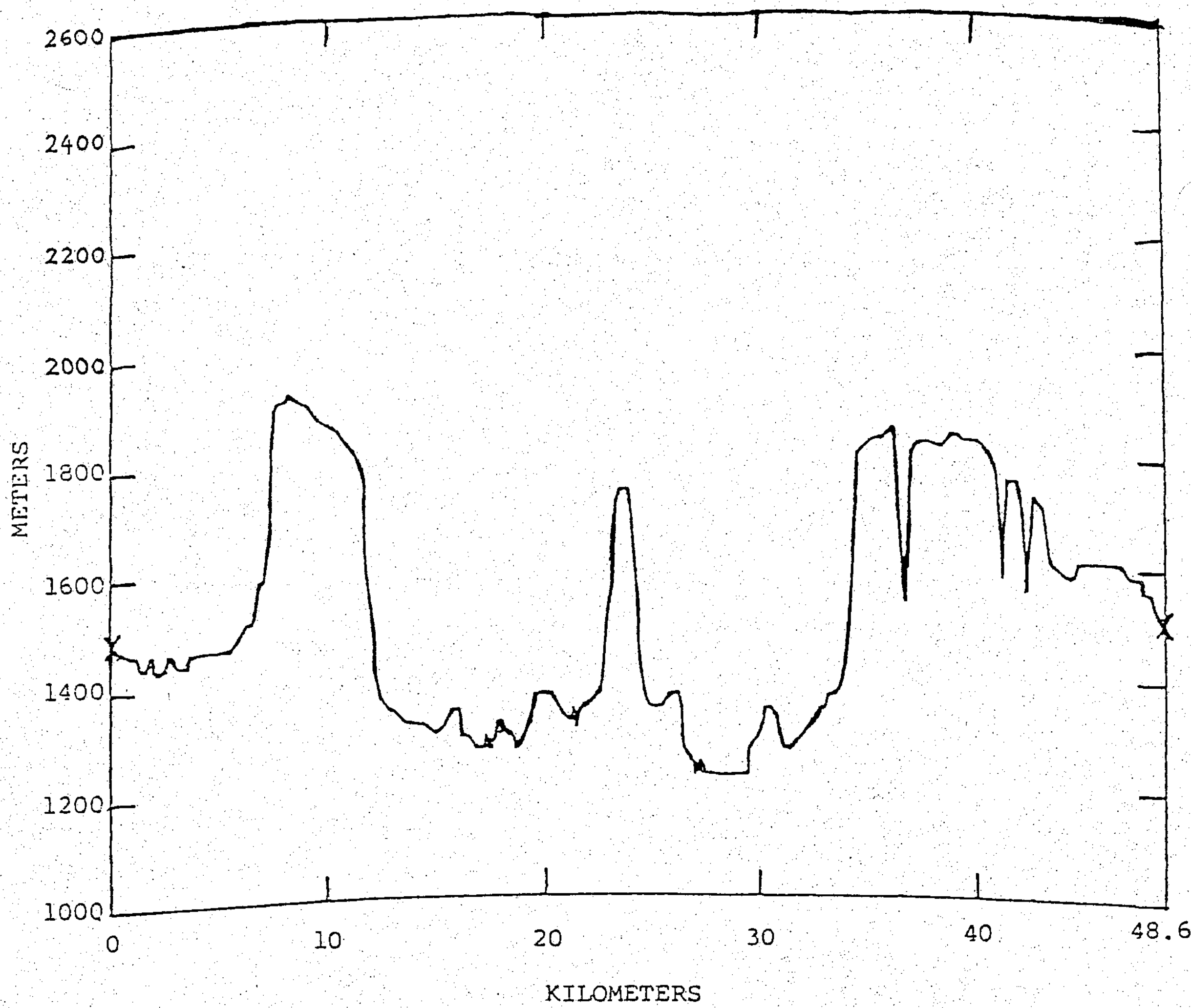


Figure 5. Path profile for Canyonlands, Utah (rough terrain).

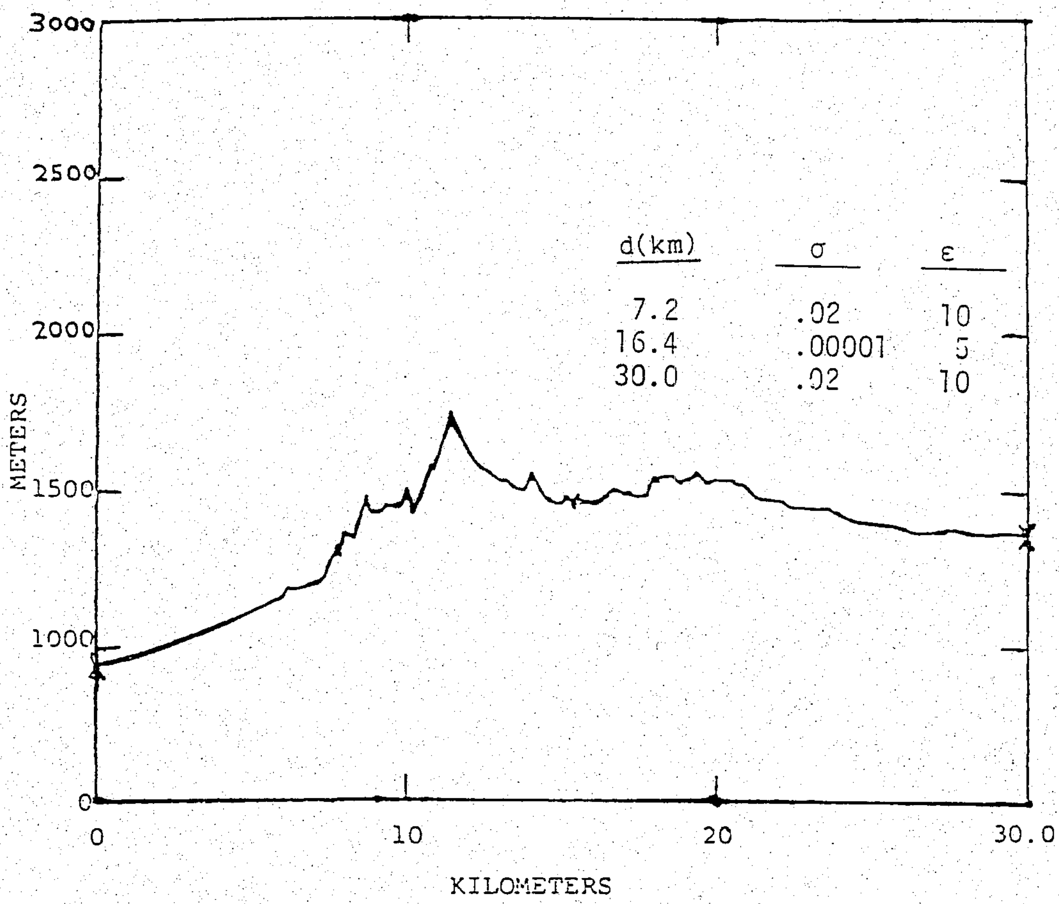


Figure 6. Path profile for Santa Rita Mountains, Arizona (hilly terrain).

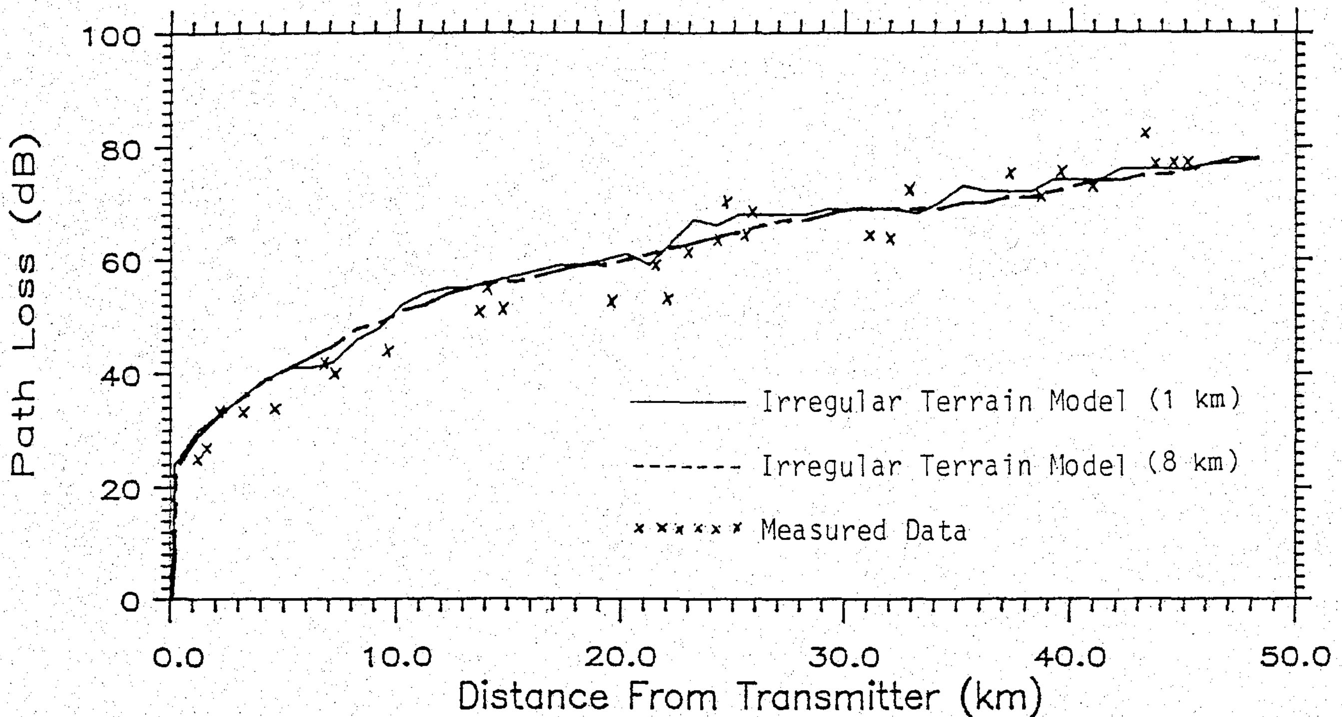


Figure 7. Propagation loss predictions for the irregular-Earth method using 1 and 8 km terrain data spacing at .52 MHz over rough terrain.

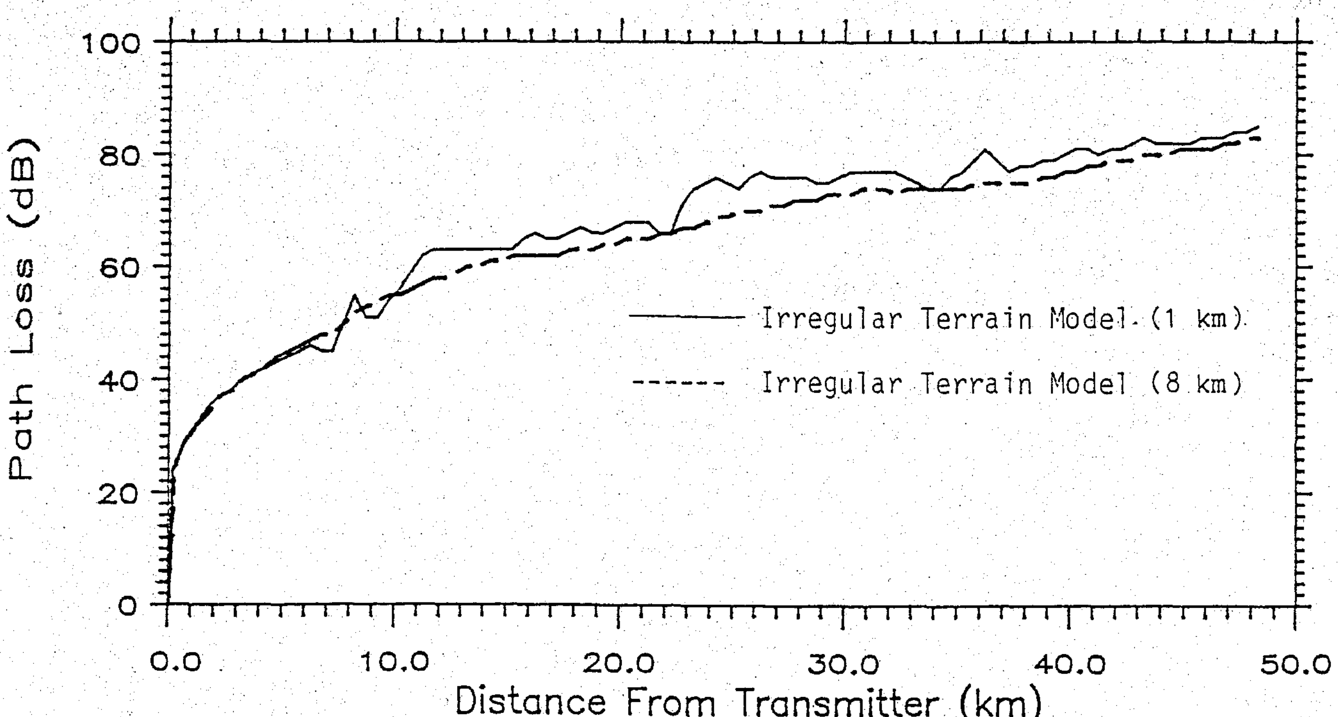


Figure 8. Propagation loss predictions for the irregular-Earth method using 1 and 8 km terrain data spacing at 1.00 MHz over rough terrain

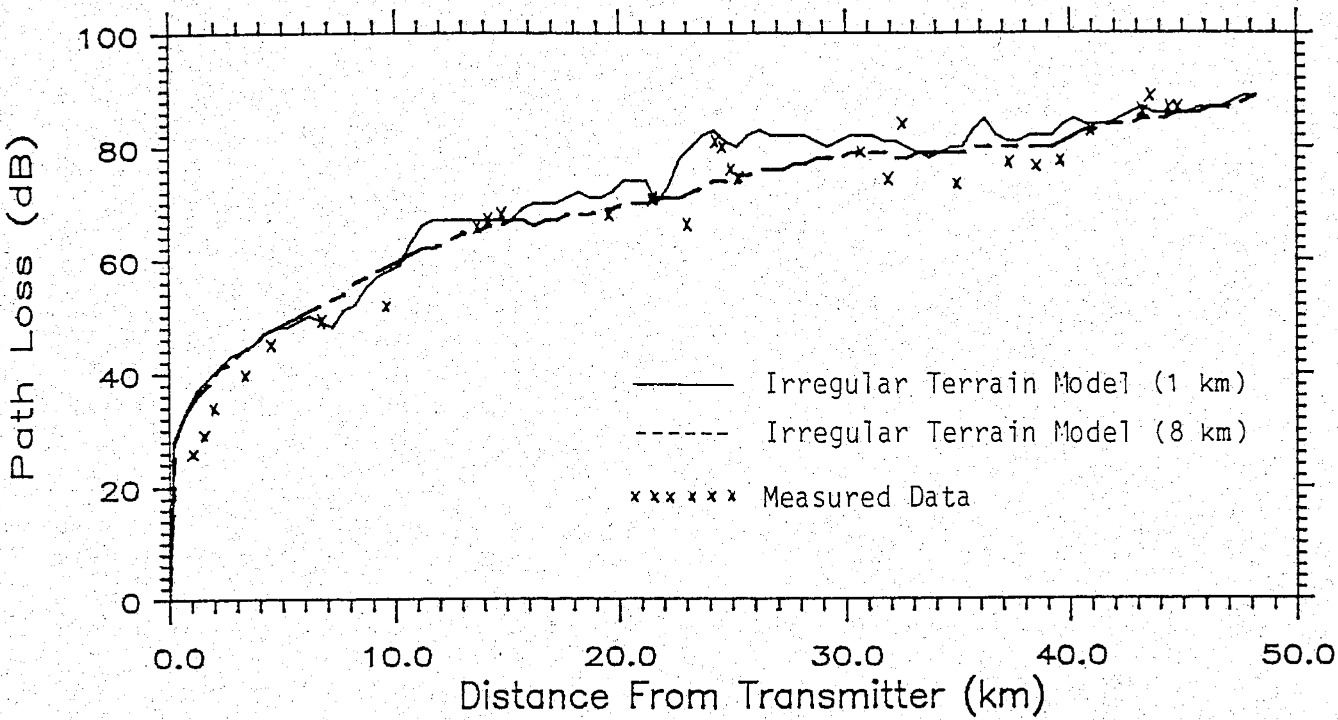


Figure 9. Propagation loss predictions for the irregular-Earth method using 1 and 8 km terrain data spacing at 1.62 MHz over rough terrain.

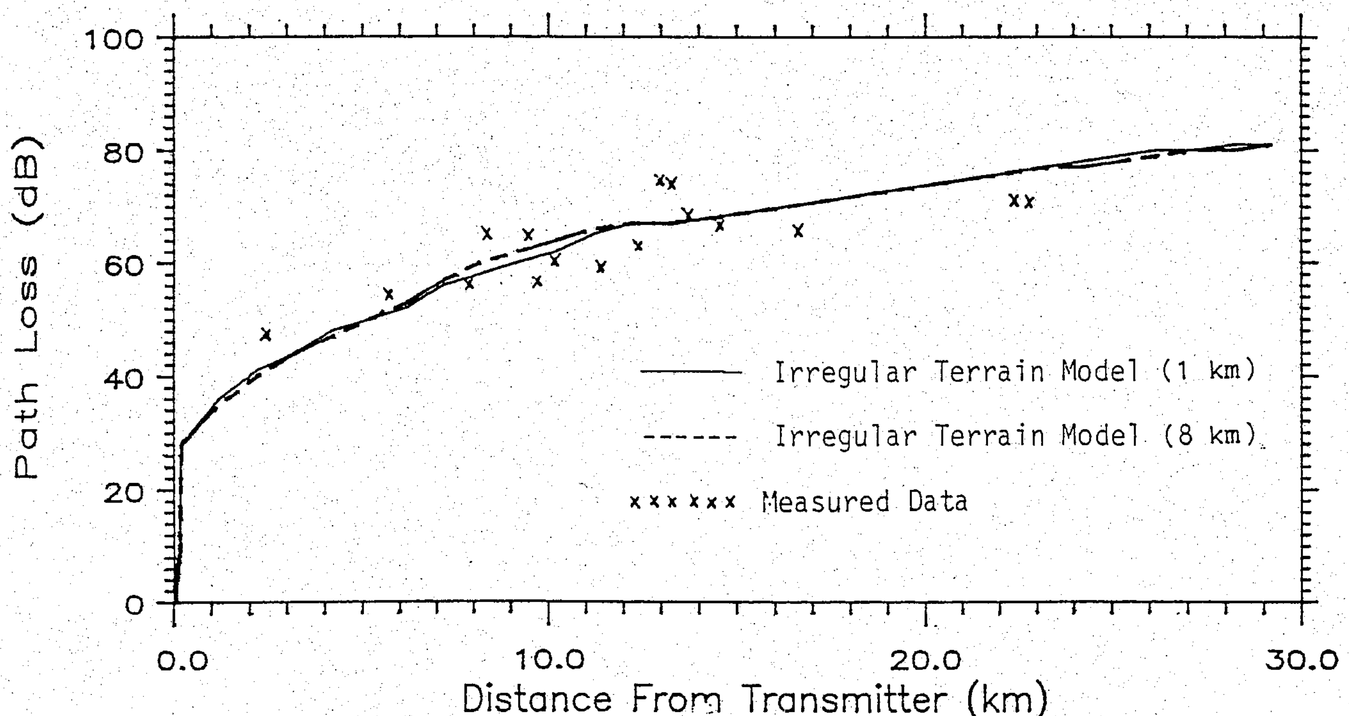


Figure 10. Propagation loss predictions for the irregular-Earth method using 1 and 8 km terrain data spacing at .52 MHz over hilly terrain.

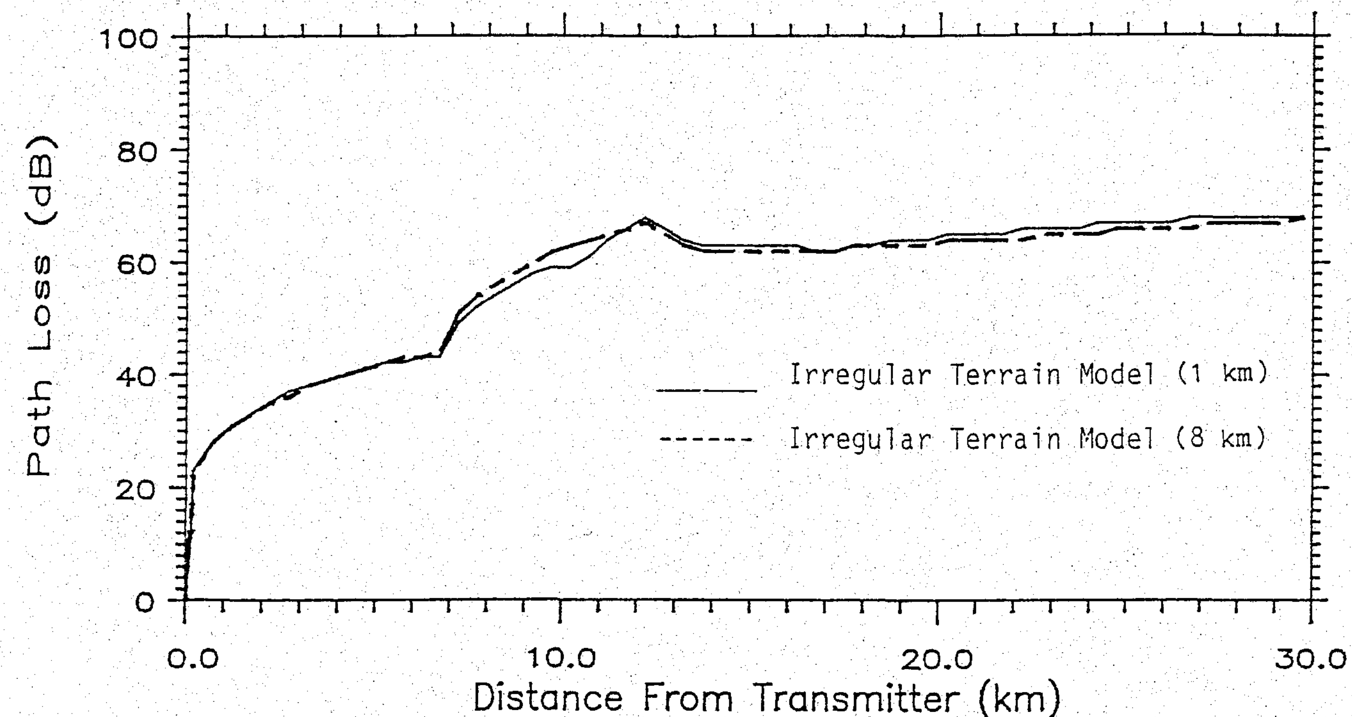


Figure 11. Propagation loss predictions for the irregular-Earth method using 1 and 8 km terrain data spacing at 1.00 MHz over hilly terrain.

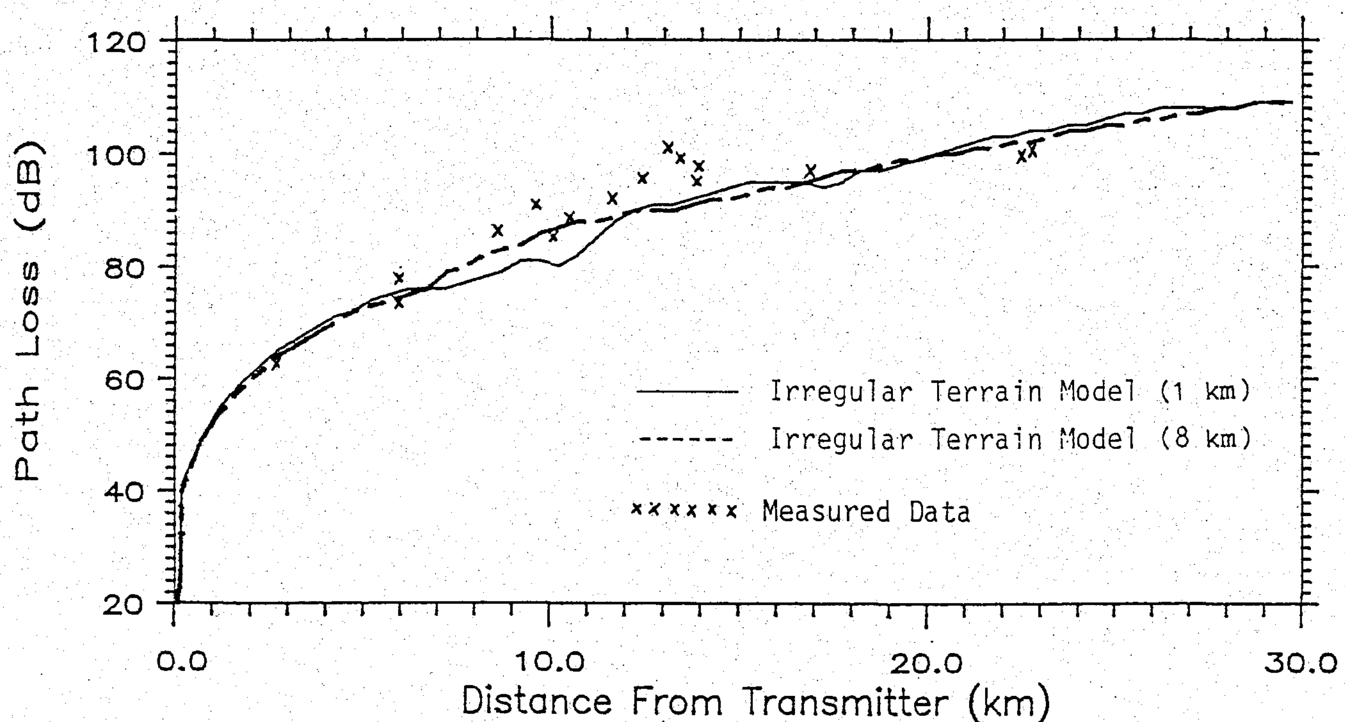


Figure 12. Propagation loss predictions for the irregular-Earth method using 1 and 8 km terrain data spacing at 1.62 MHz over hilly terrain.

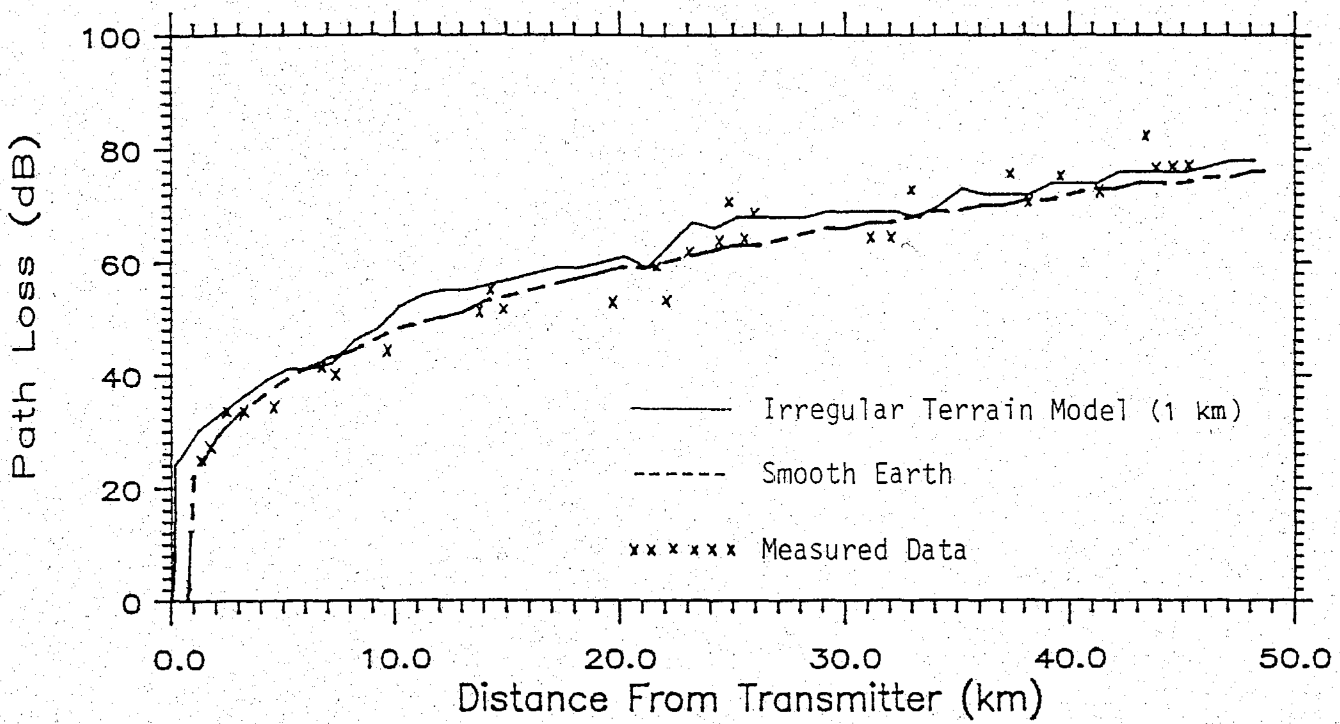


Figure 13. Propagation loss prediction comparison for the irregular-Earth method using 1-km terrain spacing versus the smooth-Earth method at .52 MHz over rough terrain.

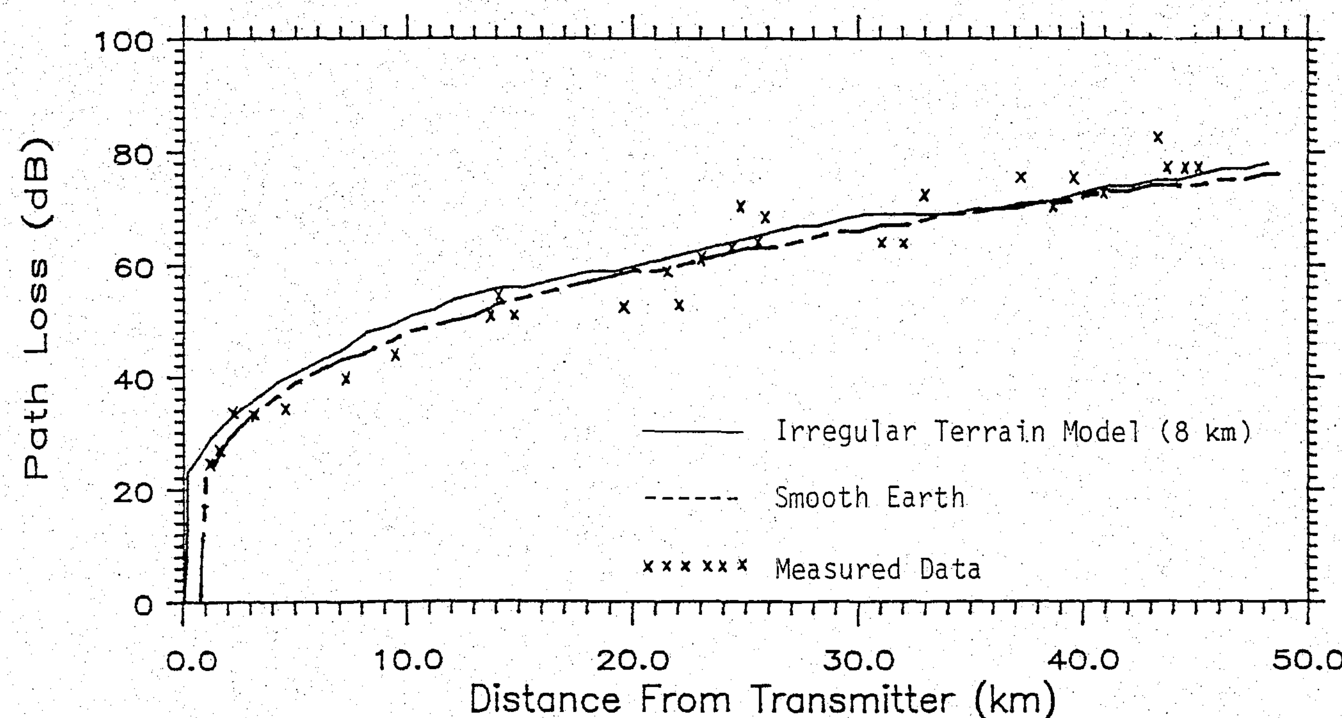


Figure 14. Propagation loss prediction comparison for the irregular-Earth method using 8-km terrain spacing versus the smooth-Earth method at .52 MHz over rough terrain.

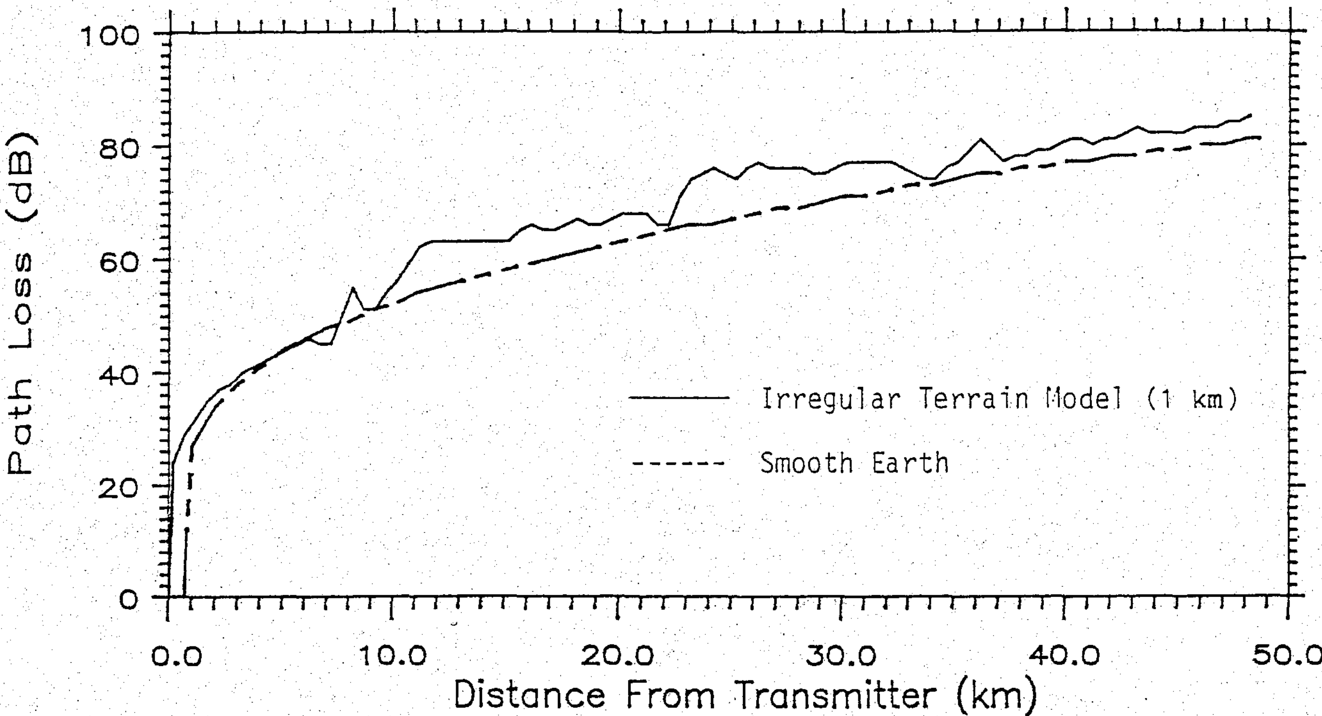


Figure 15. Propagation loss prediction comparison for the irregular-Earth method using 1-km terrain spacing versus the smooth-Earth method at 1.00 MHz over rough terrain.

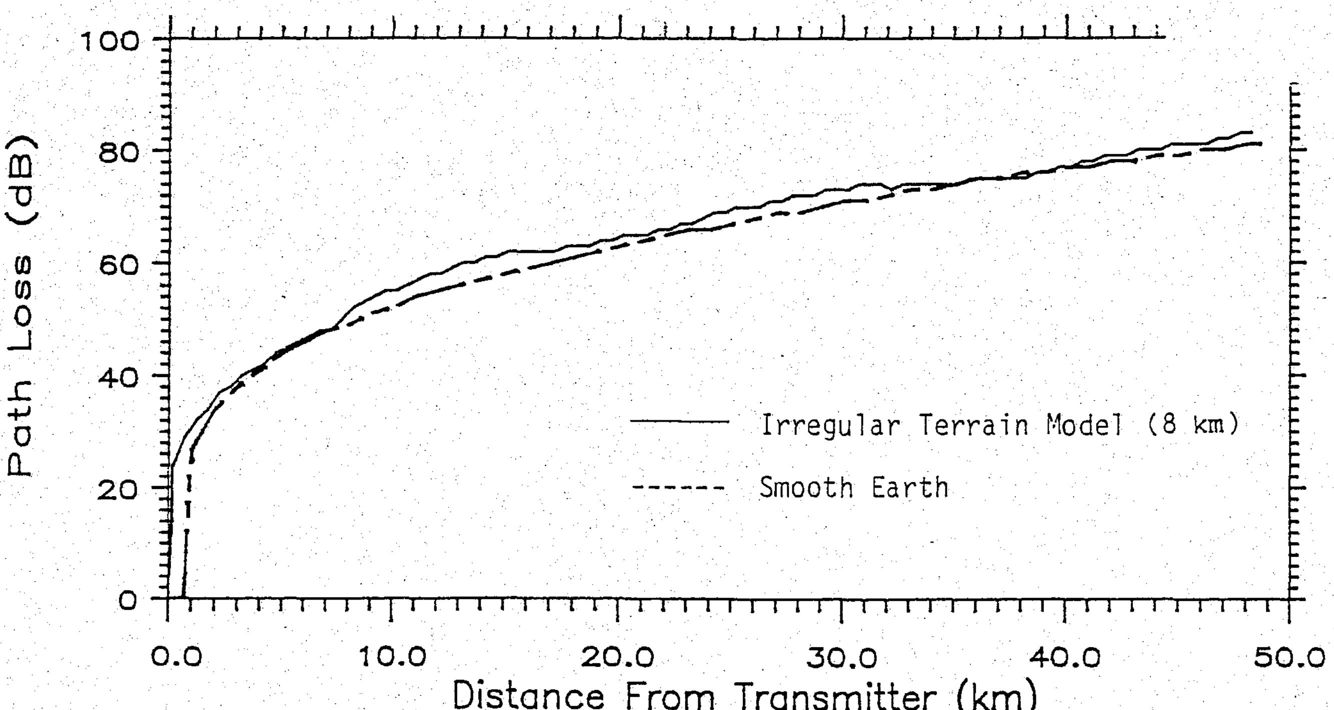


Figure 16. Propagation loss prediction comparison for the irregular-Earth method using 8-km terrain spacing versus the smooth-Earth method at 1.00 MHz over rough terrain.

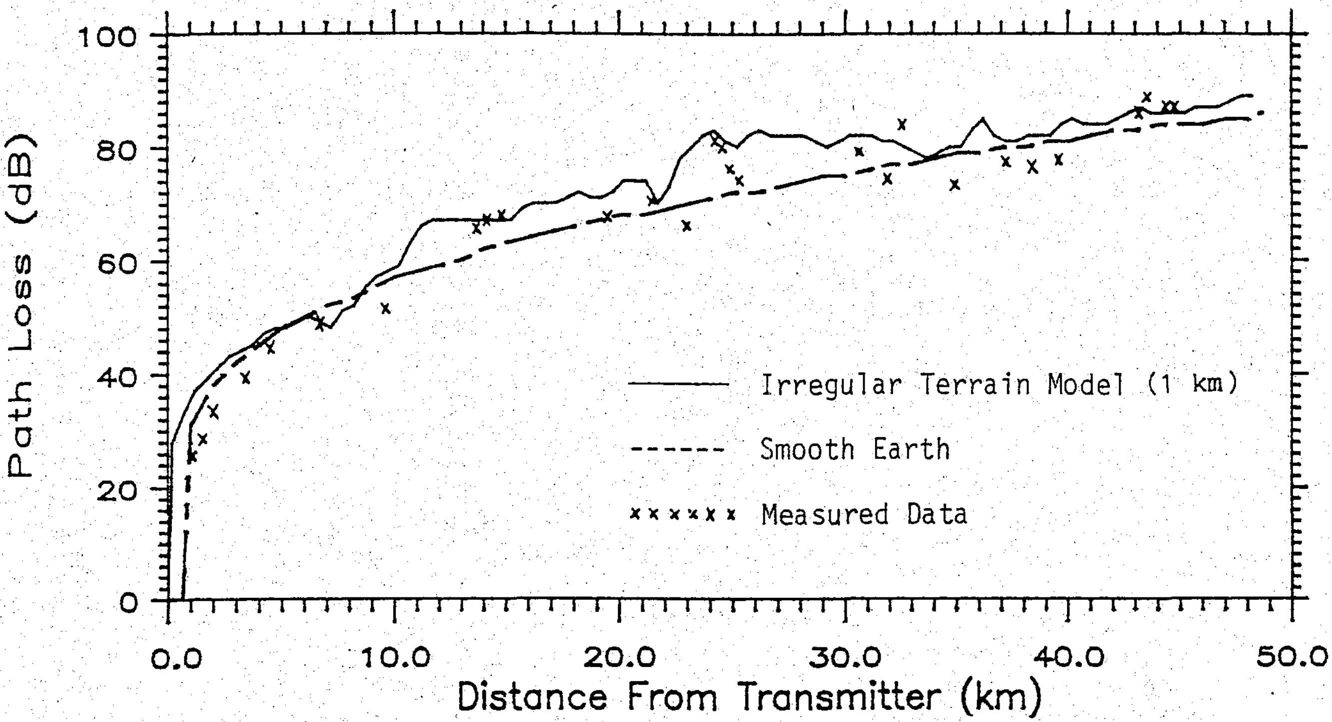


Figure 17. Propagation loss prediction comparison for the irregular-Earth method using 1-km terrain spacing versus the smooth-Earth method at 1.62 MHz over rough terrain.

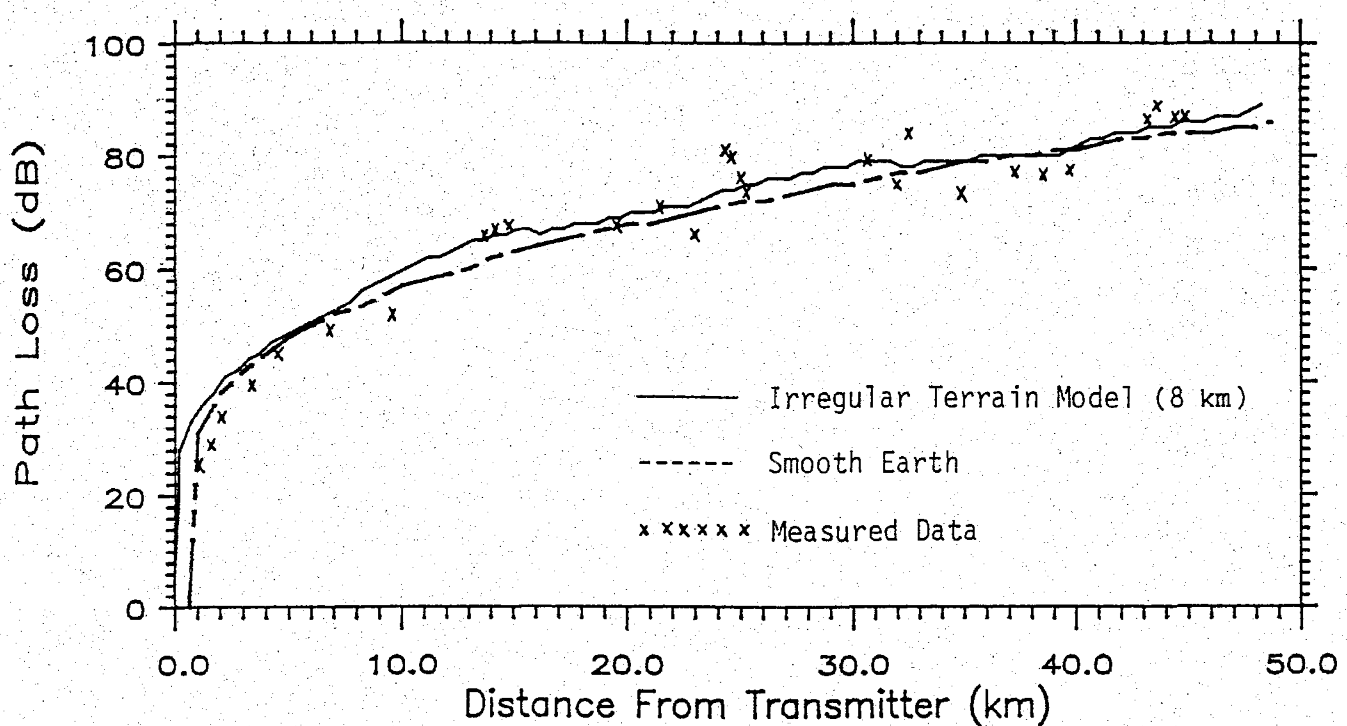


Figure 18. Propagation loss prediction comparison for the irregular Earth method using 8-km terrain spacing versus the smooth-Earth method at 1.62 MHz over rough terrain.

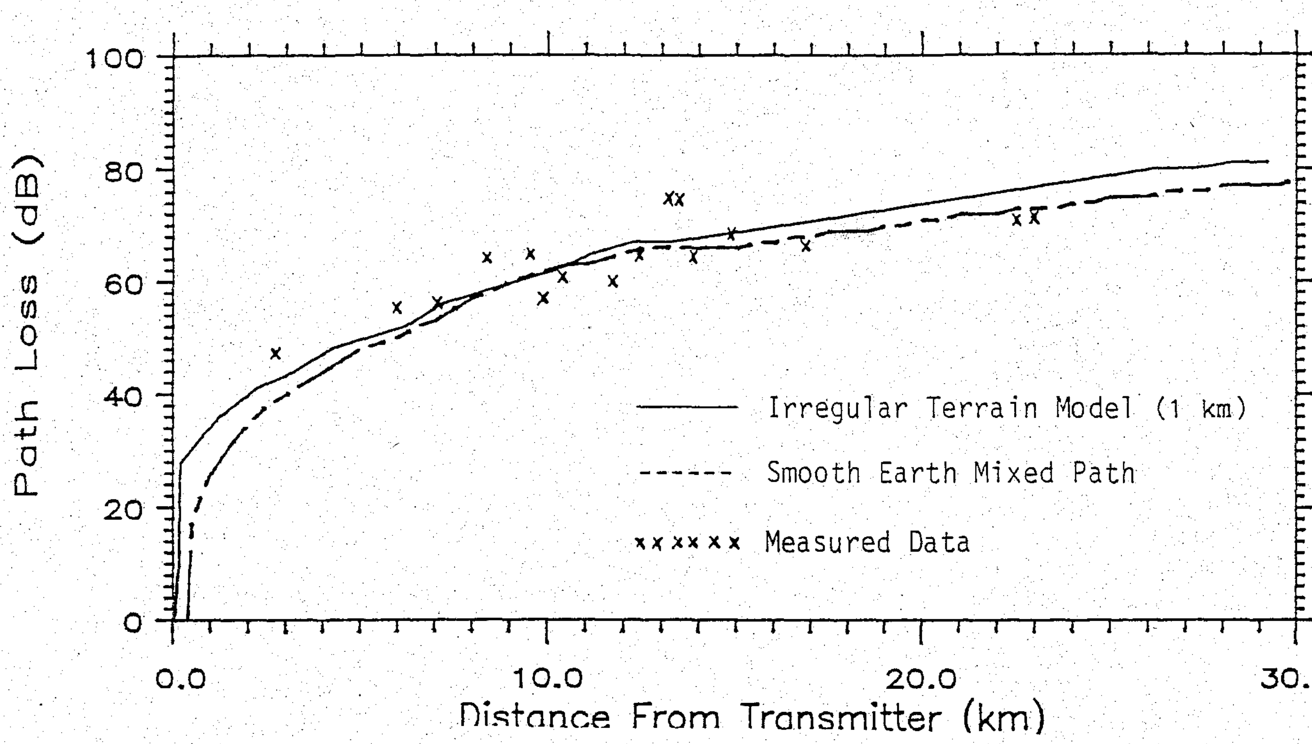


Figure 19. Propagation loss prediction comparison for the irregular-Earth method using 1-km terrain spacing versus the smooth-Earth, mixed-path method at .52 MHz over hilly terrain.

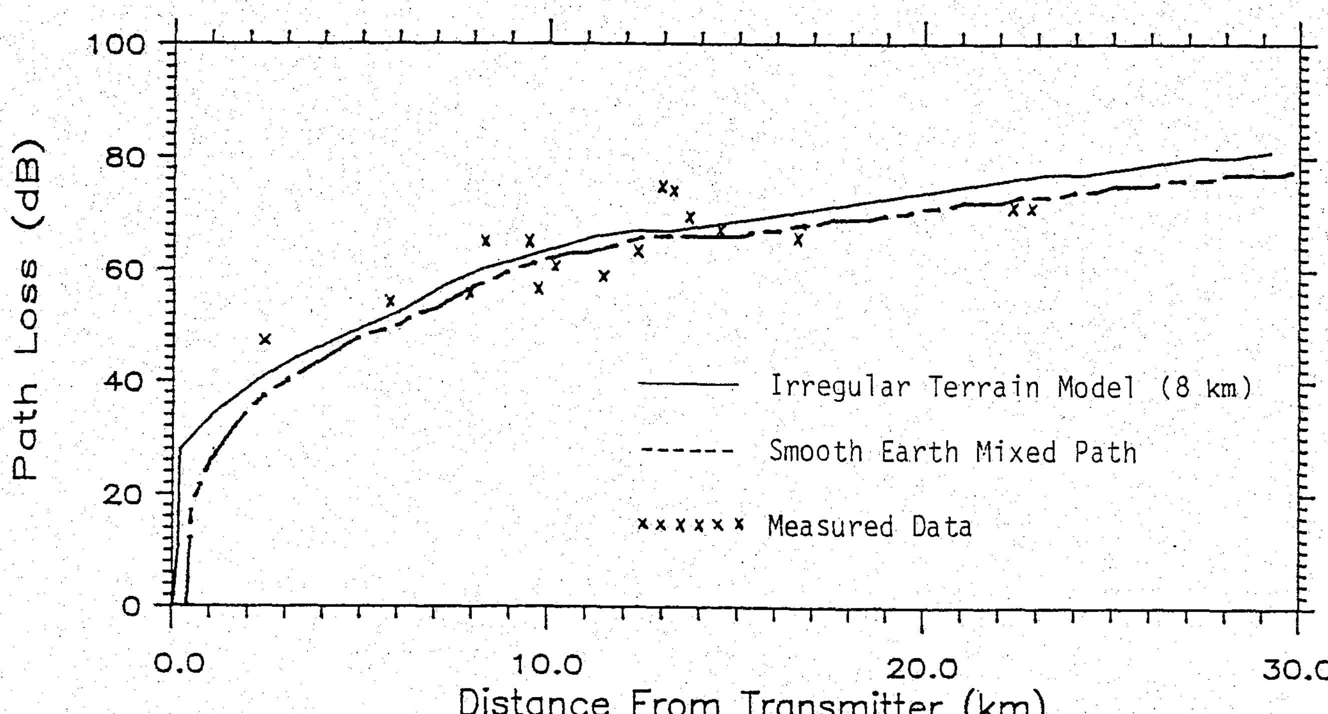


Figure 20. Propagation loss prediction comparison for the irregular-Earth method using 8-km terrain spacing versus the smooth-Earth, mixed-path method at .52 MHz over hilly terrain.

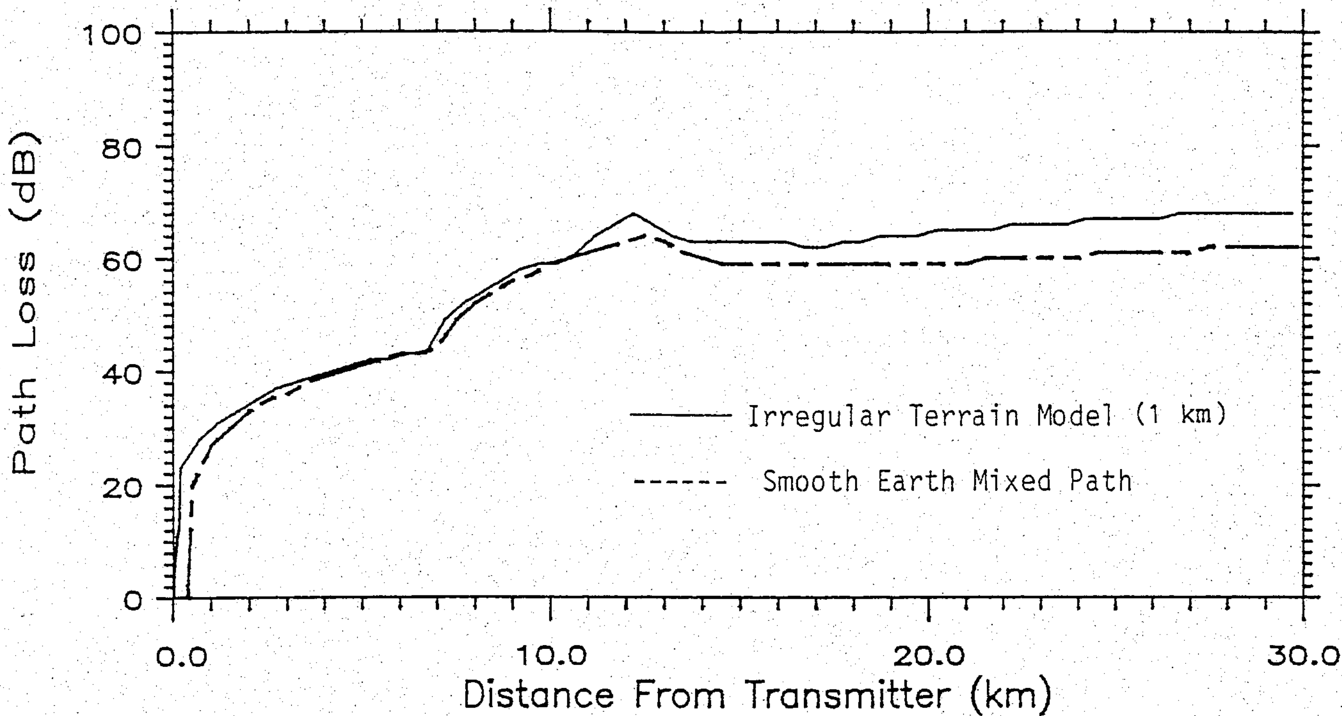


Figure 21. Propagation loss prediction comparison for the irregular-Earth method using 1-km terrain spacing versus the smooth-Earth, mixed-path method at 1.00 MHz over hilly terrain.

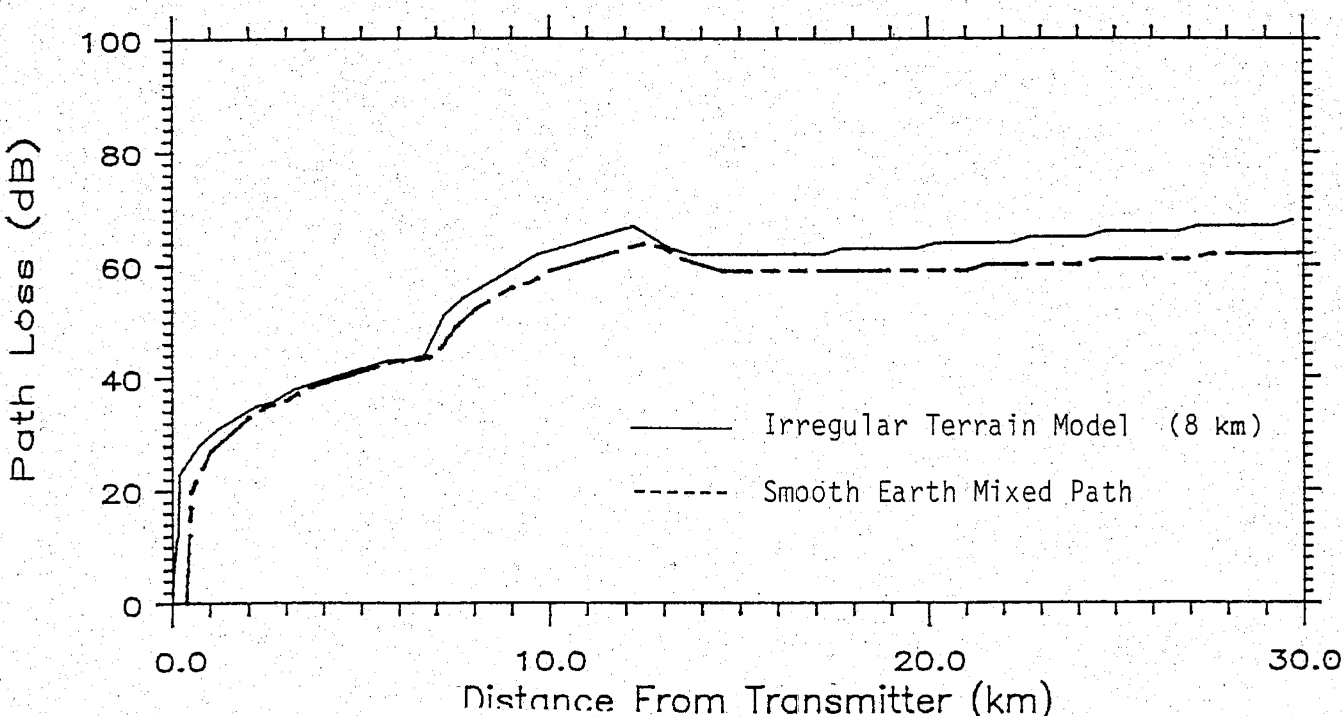


Figure 22. Propagation loss prediction comparison for the irregular-Earth method using 8-km terrain spacing versus the smooth-Earth, mixed-path method at 1.00 MHz over hilly terrain.

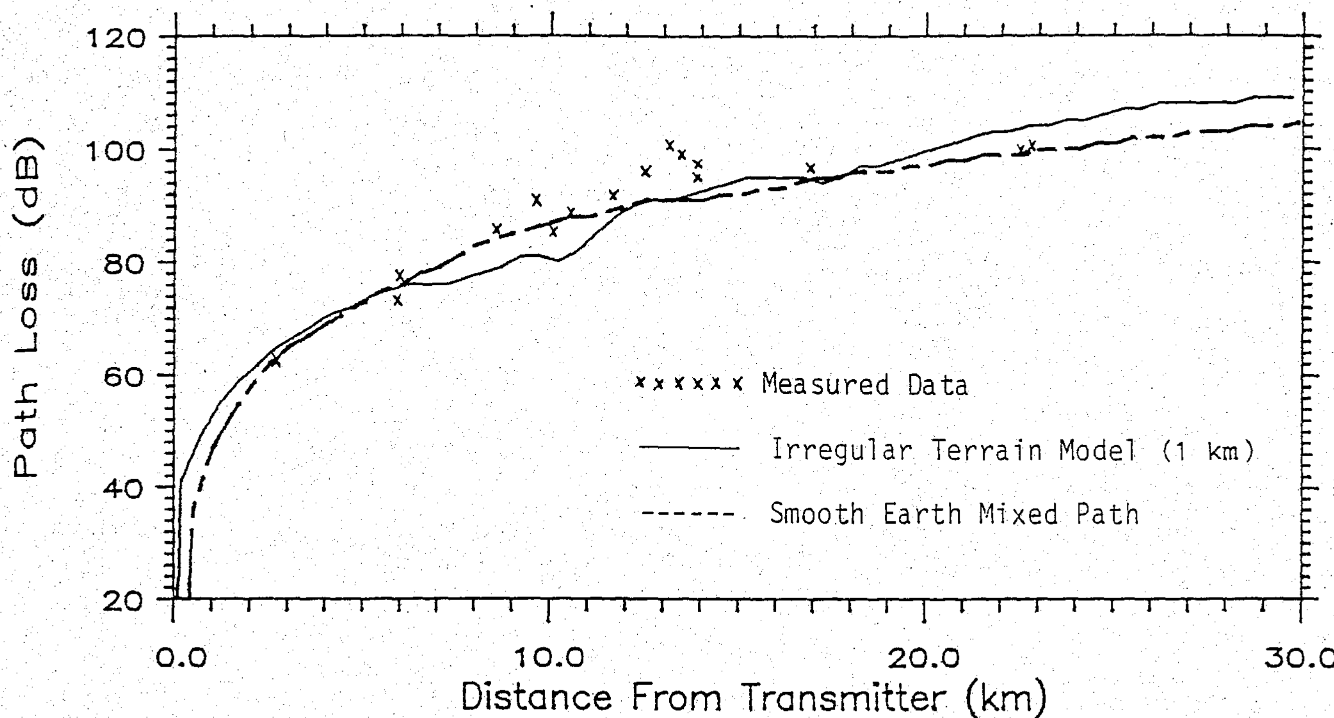


Figure 23. Propagation loss prediction comparison for the irregular-Earth method using 1-km terrain spacing versus the smooth-Earth, mixed-path method at 1.62 MHz over hilly terrain.

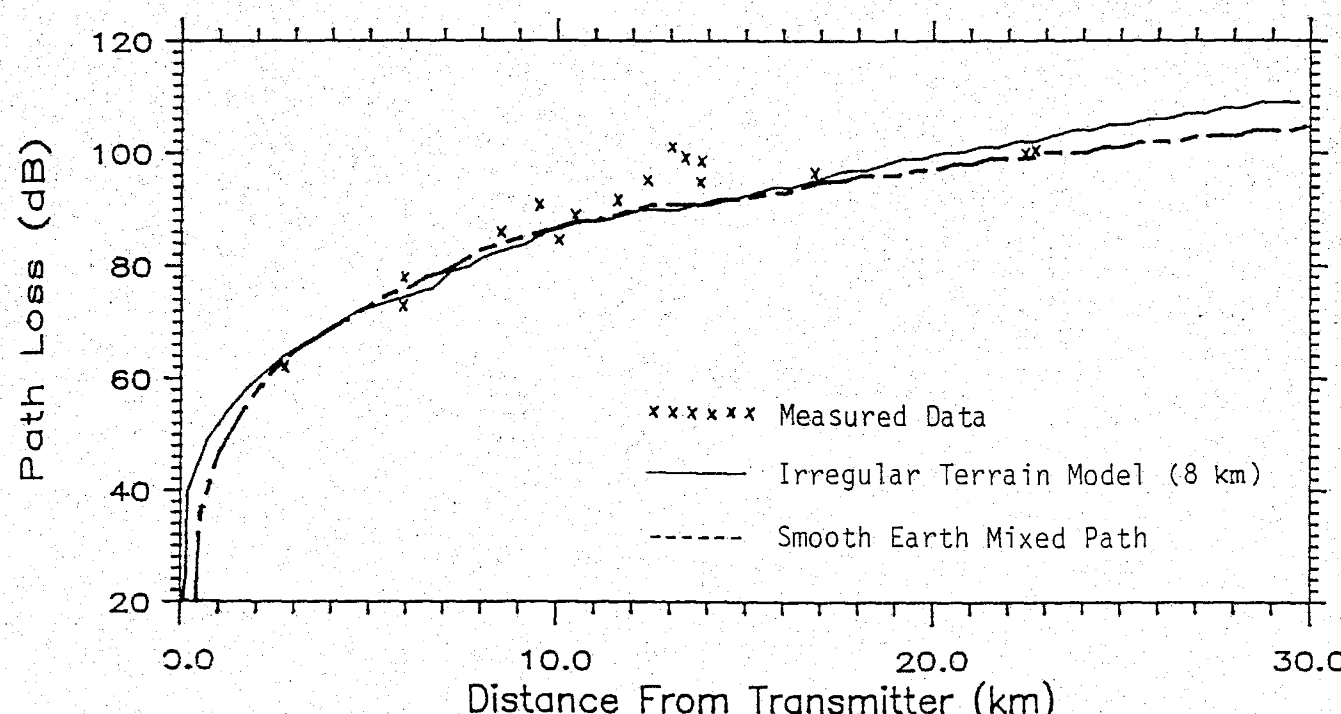


Figure 24. Propagation loss prediction comparison for the irregular-Earth method using 8-km terrain spacing versus the smooth-Earth, mixed-path method at 1.62 MHz over hilly terrain.

follow the smooth-Earth, mixed-path method loss predictions reasonably well. The comparison of the 1 and 8 km terrain spacing using the irregular-Earth method prediction over a smooth path would be identical to the smooth-Earth, mixed-path prediction.

The curves of Figures 7 through 24 are intended to give the user some idea of the relative accuracies obtained when comparing the irregular-Earth method with the smooth-Earth method propagation loss predictions. The accuracy algorithm within GWAPA will provide a statistical description of the approximate relative accuracy in electric field strength with respect to measured data for the actual terrain path being considered in the analysis. This will further serve to guide the user in making a decision between a smooth-Earth and irregular-Earth method for loss prediction. The accuracy algorithm automatically takes terrain data file spacing into account when predicting the relative accuracy. In this process, the model examines the spacing of the terrain data points and also calculates the terrain roughness factor. For the AM broadcast band, there is little improvement in relative loss prediction accuracy when using the 8 km irregular-Earth method over a smooth-Earth method prediction, but the user can make the final decision based on the particular application.

3. A USER'S GUIDE TO PROGRAM GWAPA

The computer program GWAPA is written in ANSI Fortran 77 and is presently available on the USAISEA Cyber computer system at Fort Huachuca, AZ. Instructions for obtaining access to programs on this computer are contained in the appropriate system manuals for this computer. Log-on procedures required by the Cyber computer system at Fort Huachuca, AZ, will not be covered in this user's guide. This section will describe the specific operation of program GWAPA after normal log-on procedures have been completed.

The computer program GWAPA will operate with five basic options: transmission loss, received power, received signal-to-noise power ratio, the achievable distance for a user-entered signal-to-noise power ratio and reliability, and the achievable reliability for a user entered signal-to-noise power-ratio and distance. All five options can be computed for multiple frequencies and directions.

The option to compute received signal-to-noise power ratio for multiple frequencies and directions predicts basic transmission loss, received electric field strength, received signal power, received signal-to-noise power ratio, noise level, and antenna factors over lossy Earth. The signal-to-noise power ratio calculations can be made for several seasons and times. The user also specifies a desired reliability for the signal-to-noise power ratio. The reliability is defined as the percent of time the signal-to-noise power ratio is achieved or exceeded in a 1-hour/3-month-season time period for a given frequency and geographic location. The transmission losses for this option are calculated with one of the user-selected propagation loss prediction methods: smooth homogeneous Earth (SE), smooth inhomogeneous (mixed path) Earth (SEMP), and irregular homogeneous or inhomogeneous Earth (IEMP) with or without a slab representing forests, cities, etc. The terrain data base is automatically accessed by program IEMP or the user may enter manual terrain data.

The option to compute received power also includes a computation for electric field strength and transmission loss. The noise parameters: season, time, location, and reliability are not required, since a noise computation is not made. The option to compute transmission loss also does not require the noise parameters for the same reason. The transmission loss option does not require antenna parameters except for antenna height.

The achievable-distance output option calculates the maximum distance from the transmitter at which the user-specified signal-to-noise power ratio and reliability are simultaneously achieved. The received power, noise level, and electric field strength are also computed at this distance. The calculations are performed for multiple frequencies, directions, seasons, and time of day. The propagation loss prediction methods using this option are limited to the SE and SEMP propagation loss prediction methods, because the repetitious calculations required with this option would result in prohibitively long run times if program IEMP were used.

The achievable-reliability option calculates the reliability for the user-entered signal-to-noise power ratio and distance. The received power, noise level, and electric field strength are also computed at this distance. The calculations are performed for multiple frequencies, directions, seasons, and time of day. The IEMP propagation loss prediction may be used for this option if desired.

Within these five basic output options are many alternate paths the user can take depending on the user response to the input questions. The remainder of this section will describe the questions that are asked by program GWAPA to obtain the necessary input parameters from the user. Input parameters are self-explanatory;

however, to provide additional assistance in understanding the input questions, Table 2 contains a complete explanation of these questions. The meaning of each question, the acceptable range of user input responses, and the default values are also given in Table 2. The acceptable range of values appears before the numbered line of each question. The default value appears on the numbered line in parentheses after each question.

After logging on to the Cyber computer, the user must type in a series of Cyber commands to access program GWAPA. This procedure is listed in Table 3. The user is then presented with a menu so the user may choose to edit files, obtain a summary of data, write data to a file, proceed, quit, or choose between a concise or verbose dialogue for the questions. Verbose dialogue is recommended until the user becomes familiar with program operation. The user is then presented with a choice between the five basic output options: transmission loss, received power, received signal-to-noise power ratio, achievable distance, or achievable reliability.

The question session starts and the user is asked to supply input answers in response to the questions described in Table 2.

Table 2. Signal-to-Noise Power-Ratio and Achievable-Distance Prediction Questions, Their Meaning, and Acceptable Range of Values

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
1) Frequency (MHz) Up to 15 values. 999 indicates end of list Frequency No. 1> Frequency No. 2> Frequency No. 3>	The user is asked to enter up to 15 different frequencies at which a prediction is to be made. Three nines (999) input by the user indicate the end of the frequency list. The user must enter at least one frequency. Acceptable value range is .01 to 30.00 MHz. There is no default value.
Transmitter antenna height 0.0 to 12,000.0 m 2) Transmitter antenna height (2.0m.)>?	The antenna height is the actual height of the antenna feed point above the surrounding terrain. It is not necessarily the height of the structure. Acceptable value range is 0.0 to 12,000.0m. The default value is 2.0m.
Receiver antenna height 0.0 to 12000.0 m. 3) Receiver antenna height (2.0m.)>?	The antenna height is the actual height of the antenna feed point above the surrounding terrain. It is not necessarily the height of the structure. Acceptable value range is 0.0 to 12,000.0m. The default value is 2.0m.

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
1) Lats and longs of both antennas 2) Lat & long of transmitter, bearing and distance to receiver 4) Antenna range options (1)>?	The user may choose how the transmitter and receiver locations will be input to the program. The locations may be input by either the latitudes or longitudes of both the receiver and transmitter, or the latitude and longitude of the transmitter with bearing and distance to the receiver. The default is option 1.
Distance between antennas 1.00 to 21000.00 km. Distance between antennas 5) (100.00 km)>?	If option 2 of question 4 is elected, the user is asked to input the distance between the transmitter and receiver antennas. Acceptable value range is 1.0 to 21,000.0 km. The default is 100 km.
Transmitter latitude -90.00 to 90.00 Inputs of the form X, Y, Z imply degrees, minutes, seconds Inputs of the form X.Y imply decimal degrees 6) Transmitter latitude (40.03)>?	If either option 1 or 2 of question 4 is elected, the user is asked to enter the latitude of the transmitter location. Acceptable value range is -90.00 to +90.00 deg. Positive degrees are north of the Equator. Negative degrees are south of the Equator. The default value is 40.03 deg.
Transmitter Longitude -180.00 to 180.00 7) Transmitter longitude (-105.30)>?	If either option 1 or 2 of question 4 is elected, the user is asked to enter the longitude of the transmitter location. Acceptable value range is -180.00 to +180.00 deg. Positive degrees are east of the prime meridian. Negative degrees are west of the prime meridian. The default value is -105.30 deg.
Receiver latitude -89.99 to 89.99 8) Receiver latitude (39.59)>?	If option 1 of question 4 is elected, the user is asked to enter the latitude of the receiver location. Acceptable value range is -89.99 to +89.99 deg. Positive degrees are north of the Equator. Negative degrees are south of the Equator. The default value is 39.59 deg.
Receiver longitude -180.00 to 180.00 9) Receiver longitude (-104.50)>?	If option 1 of question 4 is elected, the user is asked to enter the longitude of the receiver location. Acceptable value range is -180.00 to +180.00 degrees. Positive degrees are east of the prime meridian. Negative degrees are west of the prime

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	meridian. The default value is -104.50 degrees.
Bearing 0.00 to 360.00 10) Bearing (10.00)>?	If option 2 of question 4 is elected, the user is asked to enter the bearing angle measured from the transmitter to the receiver in degrees clockwise from true north. Acceptable value range is 0.00 to 360.00 deg. The default is 10.00 deg. This format for bearing is used for the signal-to-noise power-ratio prediction with single frequency and direction. Multiple directions are covered in questions 11 through 13.
Initial bearing 0.00 to 360.00 11) Initial bearing (10.00)>?	If the user elected the signal-to-noise power-ratio or achievable-distance option with multiple frequencies and directions, this question will ask for the initial bearing angle in degrees clockwise from north at which the user desires to begin computation (i.e., North=0 deg, East=90 deg, South=180 deg, and West=270 deg). The acceptable value range is 0.00 to 360.00 deg. The default value is 10.00 deg.
Bearing increment .00 to 360.00 12) Bearing increment (10.00)>?	If the user elected the signal-to-noise power-ratio or achievable-distance option with multiple frequencies and directions, this question will ask for the amount the user desires to increment from the initial bearing angle in degrees. Computations will be performed at each incremental bearing determined by adding the bearing increment to the initial bearing or previous bearing until the final bearing is reached. The acceptable value range is 0.00 to 360.00 deg. The default value is 10.00 deg.
Final bearing 0.00 to 360.00 13) final bearing (100.00)>?	If the user elected the signal-to-noise power-ratio or achievable-distance option with multiple frequencies and directions, this question will ask for the final bearing at which the user wishes to perform the computation. Computation is performed at each incremental bearing until the final

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	bearing is reached. If the final bearing is made equal to the initial bearing, the computation is only performed at the initial bearing. This allows the user to make computations at many frequencies for one bearing. The acceptable value range is 0.00 to 360.00 deg. The default value is 100.00 deg.
1) Vertical (V) 2) Horizontal (H) 14) Antenna Polarization (1)>?	The user is asked to enter the polarization of the transmitter and receiver antennas. The acceptable input values are either 1, 2, V, or H. The default is 1 for vertical polarization.
1) Vertical Monopole (VM) 2) Vertical Dipole (VD) 3) Vertical Log Periodic (LP) 4) Inverted L (IL) 5) Sloping Longwire Terminated (SL) 6) Vertical Half Rhombic (HR) 7) Field Strength Option (FS) 8) User Gain Input (UG) 15) Transmitter Antenna Type (1)>?	The user is asked to select the transmitter antenna type from this list. The acceptable input values are number 1 2, 3, 4, 5, 6, 7, and 8 or VM, VD, LP, IL, SL, HR, FS, and UG opposite each of the antenna types in the list. The default is 1 or VM or the vertical monopole. After selection of an antenna type, the user will be asked additional information about the antenna selected.
The following questions depend on which antenna was selected in answer to question 15.	
Monopole Antenna	
Transmitter Monopole Length $.01\lambda$ to $.7\lambda$ Transmitter Monopole Length ($.01\lambda$)>?	The user is asked to enter the length of the monopole antenna in the units of length previously chosen at the start of the program runs (meters or feet). The range of acceptable values depends on wavelength, but will be displayed with the question in the length units previously chosen by the user (meters or feet). The shortest monopole length permitted is 0.01 wavelengths at the lowest frequency that was input to question 1. The longest acceptable value for monopole length permitted is 0.7 wavelength at the highest frequency that was input to question 1. If the program GWAPA is being run at a single frequency, the lengths are based on that

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	single frequency. The default value is 0.01 wavelength at the lowest frequency or single frequency.
1) YES (Y) 2) NO (N) Do you want a ground screen (1)>?	The user is asked if the monopole antenna has a ground screen in the Earth beneath it. If the response is yes the user will be asked for the radius of this radial-wire ground screen and the number of radial wires. (The ground screen is a standard circular, radial-wire, ground screen.) If the response is no, the monopole is assumed to be used with a ground stake. Acceptable responses are 1 for Y for yes, and 2 or N for no. The default value is 1 for yes.
Transmitter ground screen radius 0.01λ to any finite number Transmitter ground screen radius (.01λ)>?	The user is asked to enter the radius of the radial wire ground screen in the units of length previously chosen at the start of the program run (meters or feet). The range of acceptable values depends on wavelength. The smallest ground screen radius permitted is 0.01 wavelengths at the lowest frequency. The largest radius permitted is any finite number. The default is 0.01 wavelengths at the lowest frequency.
Transmitter number of radials 5. to 360. Transmitter number of radials (5.)>?	The user is asked to enter the number of radial wires in the ground screen. The acceptable range is from 5 to 360 radials. The default is 5 radials.
Transmitter Monopole Efficiency 1 - 100 Percent Transmitter Monopole Efficiency (100%)>?	The user is asked to enter the overall efficiency of the monopole antenna in percent. The acceptable range of values is 1 to 100 percent. The default value is 100 percent.
Vertical Dipole Antenna	
Transmitter dipole length .01λ to λ Transmitter dipole length (.01λ)>?	The user is asked to enter the dipole length in the units of length previously chosen at the start of the program runs (meters or feet). The range of acceptable values depends on wavelength and antenna height, but will be displayed with the question in the length units previously chosen by the user (meters or feet). The

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	shortest dipole length permitted is .01 wavelengths at the lowest frequency that was input to question 1 or twice the antenna height, whichever is less. The longest acceptable value for dipole length permitted is a wavelength at the highest frequency that was input to question 1 or twice the antenna height, whichever is less. If program GWAPA is being run at a single frequency, the lengths are based on that single frequency. The default value is .01 wavelength at the lowest frequency of twice the antenna height, whichever is less.
Transmitter dipole efficiency 1.00 to 100.00% Transmitter dipole efficiency (100.00%)>?	The user is asked to enter the overall efficiency of the dipole antenna in percent. The acceptable range of values is 1 to 100 percent. The default value is 100 percent.
<u>Vertical Log-Periodic Antenna</u>	
Transmitter longest element length .5λ to any finite number Transmitter longest element length (.5λ)>?	The user is asked to enter the longest element length for the log-periodic antenna. The user must ensure that the longest element length is less than twice the antenna height entered in question 2. The acceptable range for element length is from one-half wavelength at the lowest frequency input to question 1 up to any finite number. The default value is one-half wavelength. The units are those chosen by the user at the beginning of the program.
Transmitter number of elements 4.00 to 20.00 Transmitter number of elements (12.00)>?	The user is asked to enter the number, N of radiating dipole elements of the antenna. The acceptable range of values are the integers from 4 to 20. The default value is 12 elements.
Transmitter scaling factor .82 to .99 Transmitter scaling factor (.93)>?	The user is asked to enter the log-periodic scaling factor. This is the ratio τ of the lengths of any two adjacent lengths. The acceptable range of values is .82 to .99. The default value is .93.
Transmitter angle bet. boom and tip of LMAX (α to 60.00 DEG)>?	The user is asked to enter the angle between the center boom of the antenna and

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
Transmitter angle bet. boom and tip of LMAX (10.00 DEG)>?	the tip of the longest element. The acceptable range of values for this angle is between $\tan^{-1}\left[\frac{6.16\,(1-\tau)^2}{(\frac{1}{\tau})^{N-1} - .88}\right]$ and 60 deg. The default value is 10 deg, unless α as computed above is greater than 10 deg.
Transmitter boresight bearing (E of N) .00 to 360.00 deg. Transmitter boresight bearing (E of N) (.00 deg.)	The user is asked to enter the angle in degrees east of north (clockwise from true North) that the antenna beam points. The reference angles are: North = 0 deg., East = 90 deg., South = 180 deg., and West = 270 deg. The acceptable range of values are 0.00 to 360.00 deg. The default value is either zero degrees or the clockwise angle to the receiver measured from the transmitter for a single bearing. For a multiple bearing case, the initial bearing to the receiver is taken as the default. The default angle is zero when the transmitter and receiver locations (latitudes and longitudes or latitude and longitude of transmitter with bearing and distance to receiver) have not been specified, and the user enters only the distance between the transmitter and receiver.
Transmitter station pointing angle (E of N) .00 to 360.00 deg. Transmitter station pointing angle (E of N) (.00 deg.)	The user is asked to enter the angle in degrees east of north (clockwise from true North) that specifies the angular direction from transmitter to receiver. The reference angles, acceptable range of values, and default value are the same as those specified for the transmitter boresight bearing. This question is asked only if the user does not specify transmitter and receiver locations via latitudes and longitudes or latitude and longitude of the transmitter with bearing and distance to receiver. The angle is calculated from this information.
Transmitter antenna efficiency 1.00 to 100.00%	The user is asked to enter the overall efficiency of the log-periodic antenna in

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
Transmitter antenna efficiency (100.00%)>?	percent. The acceptable range of values is 1 to 100 percent. The default value is 100 percent.
Inverted L	
Transmitter vertical element length 1 m (3.28 ft) to λ Transmitter vertical element length (.4 λ)	The user is asked to enter the vertical element length, L_V, in the units chosen at the beginning of the program. The acceptable range of values for the vertical element length is from 1 m to a wavelength at the highest frequency. The default value is 0.4 wavelength at the highest frequency.
Transmitter horizontal element length .00 to $(\lambda - L_V)$ Transmitter horizontal element length (.00)>?	The user is asked to enter the horizontal element length in the units chosen at the beginning of the program. The acceptable range of values for the horizontal element length is from zero to the difference between a wavelength at the highest frequency and the vertical element length entered previously. The total length $L_V + L_H$ of the inverted L antenna (vertical element length, L_V, horizontal element length L_H) must be greater than or equal to 0.4 wavelength and less than or equal to 1 wavelength at the highest frequency $(.4\ \lambda \leqq L_V + L_H \leqq \lambda)$. The default value is that required to make $L_V + L_H \geqq .4\ \lambda$ at the lowest frequency.
Transmitter antenna efficiency 1.00 to 100.00% Transmitter antenna efficiency (100.00%)>?	The user is asked to enter the overall efficiency of the inverted L antenna. The acceptable range of values is 1 to 100 percent. The default value is 100 percent.
Sloping Longwire Terminated	
Transmitter wire length 2λ to 12λ Transmitter wire length (10λ)>?	The user is asked to enter the total length, ℓ, of the sloping longwire. The units are those specified by the user at the beginning of the program. The acceptable range of values for wire length is from 2 wavelengths at the lowest frequency to 12 wavelengths at the highest frequency. The default value is 10 wavelengths at the highest frequency.

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
Transmitter angle between wire and ground 2.86 deg. to Γ Transmitter angle between wire and ground (5.00 deg.)>?	The user is asked to enter the angle between the sloping longwire and ground in degrees. The acceptable range of values is from 2.86 deg to $\Gamma = \sin^{-1} 2\lambda/\ell(\lambda)$ where λ is the wavelength and $\ell(\lambda)$ is the length of the sloping longwire in wavelengths. The default value is 5 deg.
Transmitter antenna efficiency 1.00 to 100.00% Transmitter antenna efficiency (100%)>?	The user is asked to enter the overall efficiency of the sloping longwire antenna. The acceptable range of values is 1 to 100 percent. The default value is 100 percent.
<u>Vertical Half-Rhombic</u>	
Transmitter length of one leg .6λ to 4.6λ Transmitter length of one leg (3λ)>?	The user is asked to enter the length of one leg of the vertical half-rhombic antenna. The units are those specified by the user at the beginning of the program. The acceptable range of values is from 0.6 wavelength at the lowest frequency to 4.6 wavelengths at the highest frequency. The default value is 3 wavelengths at the highest frequency.
Transmitter angle between wire and ground .00 to 30.00 deg. Transmitter angle between wire and ground (10.00 deg.)>?	The user is asked to enter the angle between the wire and ground in degrees. The acceptable range of values is from .00 to 30.00 deg. The default value is 10 deg.
Transmitter boresight bearing (E of N) .00 to 360.00 deg. Transmitter boresight bearing (E of N) (.00 deg.)>?	The user is asked to enter the angle in degrees east of north (clockwise from true North) that the antenna beam points. The reference angles are: North = 0 deg., East = 90 deg., South = 180 deg., and West = 270 deg. The acceptable range of values are 0.00 to 360.00 deg. The default value is either zero degrees or the clockwise angle to the receiver measured from the transmitter for a single bearing. For a multiple bearing case, the initial bearing to the receiver is taken as the default. The default angle is zero when the transmitter and receiver locations (latitudes and longitudes or latitude and longitude of the transmitter with bearing

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	and distance to the receiver) have not been specified and the user has entered only the 1dstance between the transmitter and receiver.
Transmitter station point angle (E of N) .00 to 360.00 deg. Transmitter station point angle (E of N) (.00 deg.)>?	The user is asked to enter the angle in degrees east of north (clockwise from true North) that specifies the angular direction from transmitter to receiver. The reference angles, acceptable range of values, and default value are the same as the specified for the transmitter boresight bearing. This question is asked only if the user does not specify transmitter and receiver locations via latitudes and longitudes or latitude and longitude of the transmitter with bearing and distance to the receiver. The angle is calculated from this information.
Transmitter antenna efficiency 1.00 to 100.00% Transmitter antenna efficiency (100.00%)>?	The user is asked to enter the overall efficiency of the vertical half-rhombic antenna. The acceptable range of values is 1 to 100 percent. The default value is 100 percent.
<u>Field Strength Option</u>	
Transmitter field intensity at ref. point, 1×10^{-4} to 1×10^{8} mV/m Transmitter field intensity at ref. point, (300 mV/m)>?	The field strength option can compute the equivalent gain of an antenna if the user supplies the electric field strength at a reference distance with a given reference input power. The field intensity at a reference point is the first input asked for when this option is elected. The acceptable range of values is from 1×10^{-4} to 1×10^{8} mV/m. The default value is 300 mV/m.
Transmitter input reference power, .001 to 10,000 kW Transmitter input reference power, (1.0 kW)>?	The user is asked to enter the transmitter input reference power required to produce the field strength at the reference distance. The acceptable range of values is .001 to 10,000 kW. The default value is 1 kW. This is not effective radiated power. It is transmitter input power to the antenna terminals.

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
Transmitter reference distance, λ to 1000 km Transmitter reference distance, (the greater of λ or 1 km)>?	The user is asked to enter the reference distance at which the transmitter field intensity is produced with the transmitter reference power. The acceptable range of values is 1 wavelength to 1,000 km. The default is 1 km or 1 wavelength, whichever is greater.
<u>User Gain Input</u>	
Transmitter gain -100.00 to 100.00 Transmitter gain (0.00)>?	The user is asked to enter a gain for the transmitter antenna in decibels referenced to an isotropic radiator. The acceptable value range is -100.00 to 100.00 dB. The default value is 0.00 dB.
1) Vertical Monopole (VM) 2) Vertical Dipole (VD) 3) Vertical Log-periodic (LP) 4) Inverted L (IL) 5) Sloping longwire terminated (SL) 6) Vertical Half-Rhombic (HR) 7) Field Strength Option (FS) 8) User Gain Input (UG) 16) Receiver Antenna Type (1)>?	The user is asked to supply the receiver antenna type from the list given. The acceptable input values are identical to those for the transmitter. After selection of an antenna type, the user will be asked additional information about the antenna selected in a manner identical to that described for the transmit antenna. The word "transmitter" will be replaced by "receiver" in all of the questions. The boresight bearing and station pointing angles are from the receiver to the transmitter.
Actual transmitter input power .0001 to 100000.00 kw 18) Actual transmitter input power (1.00 kw)>?	This question asks for the value of transmitter input power. The acceptable value range is .0001 to 10,000 kW. The default value is 1.00 kW.
21) Local time of day (format HHMM) Up to 24 values. 999 indicates end of list. Time No. 1> Time No. 2> Time No. 3> etc.	The user is asked for the times of day in local time at the transmitter site at which the prediction is to be made. The format is four digits. The first two digits are the hour on a 24-hour clock and the last two digits are minutes. (For example, 1200 is 12 o'clock noon, 1830 is 6:30 pm.) The acceptable value range is 0000 to 2400. There is no default. The user must enter at least one time and a 999 to indicate an end of list. The user can enter up to 24 times. A 999 must be supplied immediately

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	after the last time on the next line if less than 24 times are submitted.
22) Seasons Up to 4 values, 999 indicates end of list. 1) Dec, Jan, Feb (DJF) 2) Mar, Apr, May (MAM) 3) Jun, Jul, Aug (JJA) 4) Sept, Oct, Nov (SON) Season No. 1> Season No. 2>	The user is asked to enter the seasons at which the prediction is to be made. The user may enter up to four seasons. The acceptable value range for each season is one of the digits 1 thru 4 or DJF, MAM, JJA, SON. The user must enter at least one season and a 999 to indicate an end of list. A 999 must be supplied immediately after the last season on the next line if less than four seasons are submitted. There is no default option.
Required reliability 0 to 100.00% 23) Required reliability (90.00%)>?	The user is asked to enter the required reliability of attaining the computed signal-to-noise power ratio. A 90 percent reliability implies that the computer signal-to-noise power ratio for a signal-to-noise power-ratio prediction, or the required signal-to-noise power ratio for an achievable-distance calculation will be achieved 90 percent of the time in a 1-hour/3-month-season time block for the season, local time of day, and frequency. The acceptable value range is zero to 100 percent. The default value is 90 percent.
1) 140.4 Business 2) 144.7 Residential 3) 150.0 Rural 4) 164.1 Quiet Rural 24) Man-made noise (-dBW) at 3 MHz (1) >?	This is the man-made noise level enter by the user. The numerical values given are in decibels below 1 W at 3 MHz. Four options are given ranging from a "noisy" business level to a "quiet" rural level. The computer program calculates the noise level for the frequencies at which the predictions are made. Acceptable value range is one of the four digits 1 through 4. The default value is a 1 for business (-140.4 dBW).
Required signal/noise ratio 1.00 to 200.00 dB. 25) Required signal/noise ratio (2.00 dB)>?	This is the required signal-to-noise power ratio that the user wishes to obtain in the achievable distance computation. this question is only asked for the achievable distance option. The acceptable value range is 1.00 to 200.00 dB. The default value is 2.00 dB.

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
1 - Smooth Earth (SE) 2 - Smooth Earth, Mixed Path (SEMP) 3 - Irregular Earth, Mixed Path (IEMP) 26) Processing Method (1)>?	The user must select the propagation model to be used in the computation. All three propagation models are available only in the single-frequency-and-direction signal-to-noise power-ratio prediction. If the multiple-frequency and direction signal-to-noise power-ratio prediction or the achievable-distance prediction were elected at the beginning of the program, then only options 1 and 2 of this question would be presented. Acceptable value ranges are 1,2, or 3 and SE, SEMP, and IEMP, except as explained above. IEMP is the irregular-terrain propagation model. The default is 1 for the smooth-Earth propagation model.
Earth radius ratio .500 to 3.000 27) Earth radius ratio (1.333)>?	The user may select the effective Earth-radius ratio to account for standard refraction of the atmosphere. It is the ratio between the effective Earth radius and the actual Earth radius. Acceptable value range is .500 to 3.000. The default value is 1.333 (4/3).
1 - Single calculation at the receiver 2 - Incremental calculations between xmitter and receiver 28) Type of output (1)>?	This question is asked only for the single- and multiple-frequency-and-direction signal-to-noise power-ratio predictions. The user may select between a single calculation at the receiver location (1) or incremental calculations between the transmitter and receiver at user-selected points along the path (2). The acceptable responses are a 1 or a 2. The default is a 1 for a single calculation at the receiver. If option 2 is selected, then questions 29, 30, and 31 are asked to define computed output locations.
Field calculations will be performed according to the following parameters.	This message is printed if option 2 of question 28 is selected.
Minimum distance for xmitter λ Km to receiver distance 29) Minimum distance for xmitter (receiver distance)>?	This is the minimum distance at which the user desires to make the first computation between the transmitter and receiver. The acceptable value range is (a wavelength at

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	the lowest frequency) in kilometers or miles to the receiver distance in kilometers or miles. The default value is the receiver distance. The acceptable value range will be printed for each case with the question.
Incremental distance .0001 to receiver distance km. 30) Incremental distance (1.00000 km.)>?	This is the increment size at which the user desires to make each successive computation. This increment is added repeatedly to the distance input for the minimum distance of question 29 until the maximum distance is reached. The acceptable value range is .0001 km to the receiver distance in kilometers. The default value is 1.0 km. The acceptable value range will be printed for each case with the question.
Maximum distance from xmitter R29 to receiver distance km. 31) Maximum distance from xmitter (receiver distance)>?	This is the maximum distance from the transmitter along the transmitter to receiver path at which the user wants the computation made. It does not have to be at the receiver distance. The acceptable value range is R29 kilometers to the receiver distance. R29 is the user response to question 29. The default value is the receiver distance. The acceptable value range will be printed for each case.
32) Ground Constants Sigma = Conductivity (.00001-100. siemens/meter) Epsilon=Relative permittivity (1-100) Sigma .0000001 to 100.0000000 Sigma (.1000000)>? Epsilon 1.000 to 100.000 Epsilon (1.000)>?	If the smooth-Earth option is elected, the required inputs are the conductivity and relative permittivity of the ground along the path that are required. the acceptable range for conductivity is .00001 to 100 siemens per meter. The acceptable range for relative permittivity is 1 to 100. The default value for conductivity (sigma) is 0.1 siemens per meter. The default value for the relative permittivity is 1. Ground constants will be requested at each radial direction.
32) Ground constants You may specify up to 50 ground segments. Your total distance is the receiver distance in km.	If the smooth-Earth, mixed-path option is elected, the required inputs are the conductivity and relative permittivity of each segment along the path and the segment length. The user may specify up to 50

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
Sigma = conductivity (.00001-100. siemens/meter) Epsilon = relative permittivity (1-100) Segment No. 1 Sigma .0000001 to 100.0000000 Sigma .1000000)>? Epsilon 1.000 to 100.000 Epsilon (1.000)>? Segment length 0.000 to 10,000.00km Segment length (1.000 km.)>? distance remaining is the receiver distance minus the length of segment No. 1 in kilometers. Segment No. 2 Sigma .0000001 to 100.0 Sigma (.1000000)>? Epsilon 1.000 to 100.00 Epsilon (1.000)>? Segment length 0.000 to 10,000.00km Segment length (1.000 km)>?	segments. The program will ask for the ground constant of each segment in order from the transmitter to the receiver. The program keeps track of the segment length and informs the user of the path length remaining to the receiver location. Acceptable value ranges for the ground constants are identical to those for a homogeneous path. Default values are also the same. The segment length acceptable value range is any nonzero value less than or equal to the transmitter-to-receiver distance. There is no default value. Ground constants will be requested at each radial direction.
32) Ground constants You may specifiy up to 50 ground segments 1 - Yes (Y) 2 - NO (N) Will you want to define a slab on any of the ground segments? (2)>? Your total distance is the receiver distance in km. Sigma = conductivity (.00001 - 100. siemens/meter) Epsilon = relative permittivity (1-100)	If the irregular-terrain model is elected, the user can enter ground constants and segment lengths for up to 50 segments. The acceptable value range and defaults are identical for smooth-Earth, mixed-path. In addition, a slab can be placed on each segment of ground with a conductivity and relative permittivity and slab thickness. The ground constants for the slab have the same aceptable ranges and defaults as the ground constants of the ground. The acceptable value range for slab thickness is 0 t0 700 m. The default is 1 m. The program keeps track of the segment lengths and informs the user of the distance

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
Segment No. 1	remaining. Ground constants will be requested at each radial direction.

Sigma .0000001 to 100.0000000
Sigma (.1000000)>?

Epsilon 1.000 to 100.000
Epsilon (1.000)>?

Segment length 0.000 to 10,000.00km
Segment length (1.000 km.)>?

1 - Yes (Y)
2 - No (N)

Do you want a slab on this
segment? (0) >?1
Slab input

Sigma .000010 to 100.00000
Sigma (1.000000)>?

Epsilon 1.000 to 100.000
Epsilon (1.000)>?

Slab thickness 0.000 to 700.000 M.
Slab thickness (1.000 M.)>?
Distance remaining is receiver
distance - length of segment 1 in km.
Segment No. 2

Sigma .0000001 to 100.0000000
Sigma (.1000000)>?
Epsilon 1.000 to 100.000
Epsilon (1.000)>?
Segment length 0.000 to 10,000.00km.
Segment length (1.000 km.)>?

1 - Yes (Y)
2 - No (N)

Do you want a slab on this segment (1)>? 2
Distance remaining is the receiver distance
minus the lengths of segments No. 1 and 2
in kilometers.

Choose from the Menu:
C = Concise dialog

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
V = Verbose dialog E = Edit data S = Summary of data P = Proceed W = Write data to file Q = Quit	
Menu (Write)?	At this point in the program run, the user has entered all of the input data. The user may obtain a summary of all input data by using a carriage return or may edit the data by entering an E. If the user is satisfied with the data, it is now necessary to write the data to file. The menu will then be presented again after the data is written to the file. If a P is entered, two events can occur depending on whether or not the user elected the irregular-Earth terrain model in question 26. If the user did not elect the irregular-Earth terrain model, the terrain data will not be required. If the user elected the irregular-Earth terrain model, then the terrain data management question follows to ask the user what terrain data to use.
Input title 1 to 60 characters	User is asked to name data file.
1) Use resident terrain data 2) Input terrain data manually 3) Obtain terrain data from user file Terrain data management (1)>?	This question occurs only if the user elects to use the irregular-Earth terrain model. If the user responds with a 1, then the terrain data is obtained from the resident terrain data base using the LAT LONG user inputs that were asked for previously in questions 5 through 13. Option 3 is used to access a terrain data file previously entered manually by user. User will be asked for a file name for option 3.

The following series of questions result if the user elects to input terrain data manually (Option 2).

Interval size .01 km to receiver distance Internal size (1 km)>	If the response to the terrain input question is 2) input terrain manually, the user is asked for the spacing between terrain points. The acceptable range of

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
	input values is 0.1 km to the receiver distance. The default value is 1 km.
1) Altitude at 0.00 km from xmitter (0.00 m)? 2) Altitude at 1 km from xmitter (0.00 m)? 3) Altitude at 2 km from xmitter (0.00)? etc.	After the user specified the interval size above, the user will be asked to supply terrain heights along the path at each interval until the receiver is reached. The computer will ask for the specific terrain height at each interval. The acceptable value range is any height from 0.00 to any finite height in units previously input by the user.
1) Use resident terrain data 2) Input terrain data manually 3) Obtain terrain data from user file 4) Summary of terrain data 5) Edit terrain data 6) All done Terrain data management (1)>?	If the user elected option 2, input terrain data manually, and completes the above questions by entering the terrain data, the user is given the remaining options of obtaining data from user file (3), summarizing the data (4), editing the terrain data (5), or all done (6). Option (6) allows the user to proceed with the program and exit the terrain data management. The table, with run times and accuracies, is then presented.

	Run time (sec)	Approx. Rel. Error (field strength) WRT Meas. Data: Mean (dB)	Stnd.Dev. (dB)
IEMP	57.2	9.2	1.3
SEMP	10.6	10.2	1.5
SE	4.6	10.2	1.5

If the irregular-terrain model IEMP was elected for question 26, a table is presented with the run times and accuracies for each propagation model listed. The user can decide if using the irregular terrain model is worth the extra run time. The run time is in seconds and the errors are in decibels.

The user can elect to run this data or not based on a decision made from the information in the above table. The user is returned to the main menu to edit data, write data, input new data, or quit.

Question number 32 is the last question needed to supply input parameters. If the user elected either the signal-to-noise power-ratio prediction for multiple frequencies and direction or the achievable-distance prediction, question number 32 would be repeated for each bearing. The program does the computation after all the ground constants are entered for each bearing.

The remaining questions are program control related.

Table 2 (Cont.)

Question Descriptions, Acceptable Value Ranges, Default Values	Meaning
Menu (summary)?	A carriage return will print a summary of the input data, since the default value is summary. Any of the main menu commands are acceptable input. "E" for edit will permit user to edit the data input file. A "P" will cause the program to proceed to the data process question.
Input Title, 1 to 60 characters	The program asks for a title from 1 to 60 characters. The user must enter at least one character and then a carriage return.
Choose proceed to input new data set Edit to modify data C = Concise Dialog V = Verbose dialog E = Edit data S = Summary of Data P = Proceed W = Write data to file Q = Quit Menu (Proceed)?	If the user elects option 2 to not process this data, this response appears and the main menu is presented. The user can respond with any menu item as an acceptable response. The default is "proceed." This allows the user to edit the data set, enter a new data set, or abort the run with a QUIT command. The "write" response permits the user to write the data to a file.

After a data set has been entered, the user can edit the data, obtain a summary, write the data to a file, proceed, or quit.

Choose proceed to input a new data set Edit to modify data	If the user responds with a "P", the main menu appears again and a new data set may be entered or the present one edited. If the user elects proceed "P" to input a new data set, the default values for the questions will be those of the previous data set.
Quit to stop program	
Menu (QUIT)=?	
STOP PROGRAM GWAPA TERMINATED	If the user responds with a "Q" for quit. The program will be terminated.

Table 3. Batch-Mode Commands and Descriptions for Running GWAPA

Command	Description
/GET, GRID = JGGRID/UN=ABEP004	This command gets one of the 5-minute terrain files.
/GET, ELEV = JGELEV/UN = ABEP004	This command gets the other of the 5-minute terrain files.
/ATTACH, TOPO = TOPOUS/UN = PEB4, PN = DD52, R = DJ	This command attaches the 30-second terrain file.
/GET, GWINTB/UN = ABEP004	This command gets the binary version of the interactive program that creates the GWAPA input data file.
/GWINTB	This command runs the binary version of the interactive program that creates the GWAPA input data file. The user will now be asked the questions that appear in Table 2 to create an input file on TAPE 77.
/REWIND, TAPE 77	The rewind command causes the computer to start at the beginning of the file on TAPE 77. The user is now ready to call the program that runs GWAPA in batch mode using this data input file.
/GET, GWBTCHB/UN = ABEP004	This command gets the binary version of the GWAPA batch program.
/GET, NCFS = JCNCFS/UN = ABEP004	This command gets the noise coefficient file for the noise model.
/GWBTCHB	This command runs the GWAPA batch program using the input data file on TAPE 77 and creates an output file on TAPE 66 with answers.
/REPLACE, TAPE 66	This command saves the output file. At this point the user could send the file to the printer.

4. SAMPLE SESSIONS WITH GWAPA

This section contains illustrative examples of running sessions with program GWAPA. The examples demonstrate most of the cases the user is expected to encounter.

Example 1. Signal-to-noise power-ratio prediction for a single frequency and direction, multiple seasons, and times using the smooth-Earth propagation loss prediction method.

Example 2. Signal-to-noise power-ratio prediction for a single frequency and direction, multiple seasons, and times using the smooth-Earth, mixed-path propagation loss prediction method.

Example 3. Signal-to-noise power-ratio prediction for a single frequency, direction, season, and time using the irregular-Earth propagation loss prediction method with manual terrain input over a mixed path with slabs.

Example 4. Signal-to-noise power-ratio prediction for multiple frequencies, directions, times, and seasons using the smooth-Earth propagation loss prediction method.

Example 5. Achievable distance prediction for multiple frequencies, directions, times, and seasons using the smooth-Earth propagation loss prediction method.

Example 6. Achievable reliability prediction for multiple frequencies and times for a single time and season using the smooth-Earth propagation loss prediction method.

The following sessions assume the user has already logged onto the computer and has selected program GWAPA. A carriage return is required on the terminal after the user enters a response. If the user does not make a data entry and responds with a carriage return, the default value is entered as data. A carriage return with no user data entry is indicated in the following examples as no reponse after the question mark.

EXAMPLE 1

INSTITUTE FOR TELECOMMUNICATIONS SCIENCES

GROUND WAVE AUTOMATED PERFORMANCE ANALYSIS(GWAPA)
over Smooth and Irregular Homogeneous or Inhomogeneous
Earth with Linear Atmosphere
Version 6.0, 8/01/86
TUE 02 SEP 1986 12:00:04

```
CHOOSE FROM THE MENU:

     C=CONCISE DIALOG
     V=VERBOSE DIALOG
```

Note: A carriage return is required on the terminal after user enters a response to each question. If no data entry is made, a carriage return will enter the default value as data.

```
MENU(VERBOSE)=?

     1)  TRANSMISSION LOSS                               (TL)
     2)  RECEIVED POWER                                  (RP)
     3)  RECEIVED SIGNAL/NOISE                           (NM)
     4)  ACHIEVABLE RELIABILITY                          (RM)
     5)  ACHIEVABLE DISTANCE                             (DM)
PROCESSING OPTION( 1) >? 3
INPUT DATA
CR TO SPECIFY DEFAULT OPTIONS AS SHOWN IN PARENS

     1)  DISTANCE UNIT = KM, HEIGHT UNIT = METERS
     2)  DISTANCE UNIT = MILES, HEIGHT UNIT = FT.
METRIC OR ENGLISH( 1) >?

1)  FREQUENCY (MHZ)
      UP TO 15 VALUES.  999 INDICATES END OF LIST.
FREQUENCY NO. 1>1
FREQUENCY NO. 2>999

TRANSMITTER ANTENNA HEIGHT (      0.0 TO  12000.0)
 2) TRANSMITTER ANTENNA HEIGHT(      2.0 M. )? 0

RECEIVER ANTENNA HEIGHT (      0.0 TO  12000.0)
 3) RECEIVER ANTENNA HEIGHT(      2.0 M. )? 0

     1)  LATS AND LONGS OF BOTH ANTENNAS
     2)  LAT&LONG OF TRANSMITTER, BEARING AND DISTANCE TO RECEIVER
 4) ANTENNA RANGE OPTIONS            ( 1) >?2

DISTANCE BETWEEN ANTENNAS (      1.00 TO 21000.00)
 5) DISTANCE BETWEEN ANTENNAS(    100.00 KM.)?
```

EXAMPLE 1 (cont.)

```
TRANSMITTER LATITUDE ( -89.99 TO   89.99)
INPUTS OF THE FORM X,Y,Z IMPLY DEGREES,MINUTES,SECONDS
INPUTS OF THE FORM X.Y IMPLY DECIMAL DEGREES
 6) TRANSMITTER LATITUDE(  40.03 )?

TRANSMITTER LONGITUDE (-180.00 TO  180.00 )
 7) TRANSMITTER LONGITUDE(-105.30 )?

INITIAL BEARING (0.00 TO 360.00)
11) INITIAL BEARING (10.00)?

BEARING INCREMENT (.01 TO 360.00)
12)  BEARING INCREMENT (10.00)?
FINAL BEARING (0.00 TO 360.00)
13)  FINAL BEARING (100.00)?  10

     1)  VERTICAL  (V)
     2)  HORIZONTAL(H)
14) ANTENNA POLARIZATION          ( 1) >?

     1)  VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
     4)  INVERTED L                     (IL)
     5)  SLOPING LONGWIRE TERMINATED    (SL)
     6)  VERTICAL HALF RHOMBIC          (HR)
     7)  FIELD STRENGTH OPTION          (FS)
     8)  USER GAIN INPUT                (UG)
15) TRANSMITTER ANTENNA TYPE     ( 1) >?

TRANSMITTER MONOPOLE LENGTH (   3.000 TO  210.000 )
TRANSMITTER MONOPOLE LENGTH(  5.000 M. )>? 25

     1)  YES (Y)
     2)  NO  (N)
DO YOU WANT A G ROUND SCREEN( 1) >?

TRANSMITTER GROUND SCREEN RADIUS (    3.000 TO 100000.000 )
TRANSMITTER GROUND SCREEN RADIUS(    3.000 M. )>? 150

TRANSMITTER NUMBER OF RADIALS (  5. TO 360. )
TRANSMITTER NUMBER OF RADIALS(  5. )>? 120

TRANSMITTER MONOPOLE EFFICIENCY (  1.00 TO 100.00%)
TRANSMITTER MONOPOLE EFFICIENCY(100.00%)>? 50

     1 - VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
     4)  INVERTED L                     (IL)
     5)  SLOPING LONGWIRE TERMINATED    (SL)
```

```
     6)  VERTICAL HALF RHOMBIC          (HR)
     7)  FIELD STRENGTH OPTION          (FS)
     8)  USER GAIN INPUT                (UG)
16) RECEIVER ANTENNA TYPE        ( 1)  >?8
FREQUENCY =  1.000

RECEIVER    GAIN (-100.000 TO  100.000 )
RECEIVER    GAIN(   0.000 )>? 3

ACTUAL TRANSMITTER INPUT POWER (      .0001  TO 10000.0000 )
18) ACTUAL TRANSMITTER INPUT POWER(    1.0000 Kw)?

21) LOCAL TIME OF DAY (FORMAT HHMM)
    UP TO 24 VALUES.  999 INDICATES END OF LIST.
TIME      NO. 1>1200
TIME      NO. 2>1800
TIME      NO. 3>999

22) SEASONS
    UP TO 4 VALUES, 999 INDICATES END OF LIST.
1)  DEC,JAN,FEB(DJF)
2)  MAR,APR,MAY(MAM)
3)  JUN,JUL,AUG(JJA)
4)  SEP,OCT,NOV(SON)
SEASON    NO. 1>1
SEASON    NO. 2>999

REQUIRED RELIABILITY (    .01 TO 100.00%)
23) REQUIRED RELIABILITY( 90.00%)?

     1)  140.4   BUSINESS
     2)  144.7   RESIDENTIAL
     3)  150.0   RURAL
     4)  164.1   QUIET RURAL
     5)  USER INPUT
24) MAN MADE NOISE(-DBW) AT 3 MHZ ( 1) >?4

     1)  SMOOTH EARTH             (SE  )
     2)  SMOOTH EARTH, MIXED PATH(SEMP)
     3)  IRREG. EARTH, MIXED PATH(IEMP)
26) PROCESSING METHOD             ( 1) >?

EARTH RADIUS RATIO ( .500 TO 3.000 )
27) EARTH RADIUS RATIO(1.333 )?

     1)  SINGLE CALCULATION AT THE RECEIVER
     2)  INCREMENTAL CALCULATIONS BETWEEN XMITTER AND RECEIVER
28) TYPE OF OUTPUT                ( 1) >?2
FIELD CALCULATIONS WILL BE PERFORMED ACCORDING TO THE FOLLOWING PARAMETERS.

MINIMUM DISTANCE FROM XMITTER  (    .3000 TO  100.0000  )
29) MINIMUM DISTANCE FROM XMITTER( 100.0000 KM.)? 10
```

```
INCREMENTAL DISTANCE (    .00010 TO 100.00000 )
30) INCREMENTAL DISTANCE(  1.00000 KM.)? 10

MAXIMUM DISTANCE FROM XMITTER (  10.0000 TO  100.0000 )
31) MAXIMUM DISTANCE FROM XMITTER( 100.0000 KM.)?

32)  GROUND CONSTANTS FOR BEARING 10.000
SIGMA = CONDUCTIVITY (.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)

SIGMA (     .0000001 TO 100.0000000 )
SIGMA(     .1000000 )>? .01
EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 10

CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(WRITE)=? S
 1)  RF FREQUENCY                        1.00000 MHz
 2)  TRANSMITTER ANTENNA HEIGHT          0.00000 M.
 3)  RECEIVER ANTENNA HEIGHT             0.00000 M.
 4)  ANTENNA RANGE OPTIONS
               LAT&LONG OF TRANSMITTER, BEARING AND DISTANCE TO RECEIVER
 6)  TRANSMITTER LATITUDE               40.03000
 7)  TRANSMITTER LONGITUDE            -105.30000
 5)  DISTANCE BETWEEN ANTENNAS         100.00000 KM.
10)  BEARING                            10.00000
          RECEIVER LATITUDE                 40.916  COMPUTED
          RECEIVER LONGITUDE              -105.093  COMPUTED
14)  ANTENNA POLARIZATION             VERTICAL
15)  TRANSMITTER ANTENNA TYPE         VERTICAL MONOPOLE
          TRANSMITTER MONOPOLE LENGTH                           25.0000 M.
          TRANSMITTER GROUND SCREEN RADIUS                     150.0000 M.
          TRANSMITTER NUMBER OF RADIALS                        120.0000
          TRANSMITTER MONOPOLE EFFICIENCY      100.0000%
16)  RECEIVER ANTENNA TYPE            USER GAIN INPUT
          FREQUENCY =   1.00   RECEIVER     GAIN =    3.0000
18)  ACTUAL TRANSMITTER INPUT POWER    1.00000 Kw
21)  TIME OF DAY(HHMM)
           1) 1200    1) 1800
22)  SEASON
                              1) DEC,JAN,FEB
23)  REQUIRED RELIABILITY              90.00000%
24)  MAN MADE NOISE(-DBW) AT 3 MHZ  164.1   QUIET RURALDB BELOW ONE WATT
26)  PROCESSING METHOD              SMOOTH EARTH
```

```
27)  EARTH RADIUS RATIO                    1.33333
28)  TYPE OF OUTPUT
               INCREMENTAL CALCULATIONS BETWEEN XMITTER AND RECEIVER
29)  MINIMUM DISTANCE FROM XMITTER     10.00000 KM.
30)  INCREMENTAL DISTANCE              10.00000 KM.
31)  MAXIMUM DISTANCE FROM XMITTER    100.00000 KM.
32)  GROUND CONSTANTS BEARING 10.000
 NO.   SIGMA    EPSILON
 1     .0100    10.00

MENU(EDIT)=?
DATA NUMBER>?1
 1) RF FREQUENCY( 1.00 MHZ)? 2
DATA NUMBER>?

MENU(EDIT)=? W

INPUT TITLE, 1 TO 60 CHARACTERS
EXAMPLE 1
DATA TO FILE COMPLETE
CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(QUIT)=?

STOP PROGRAM GWAPA TERMINATED
```

EXAMPLE 1
RECEIVED SIGNAL/NOISE, MULTIPLE INPUT
PROCESSING METHOD = SMOOTH EARTH

TRANSMITTER ANTENNA HEIGHT = 0.0 M. RECEIVER ANTENNA HEIGHT = 0.0 M.
TRANSMITTER SITE DISTANCE
40.03N - 105.30W 100.0KM 62.1MI

ANTENNA POLARIZATION = VERTICAL
TRANSMITTER ANTENNA TYPE = VERTICAL MONOPOLE
TRANSMITTER MONOPOLE LENGTH 25.0000 M.

TRANSMITTER GROUND SCREEN RADIUS 150.0000 M. TRANSMITTER NUMBER OF RADIALS 120.0000
RECEIVER ANTENNA TYPE = USER GAIN INPUT
FREQUENCY = 2.00 RECEIVER GAIN = 3.0000

EFFECTIVE EARTH RADIUS/ACTUAL EARTH RADIUS = 1.333
TRANSMITTER INPUT POWER = 1.0KW
MAN MADE NOISE(-DBW) AT 3 MHZ = 164.1 0DBW REQUIRED RELIABILITY = 90.0%

SIGMA(CONDUCTIVITY) = .0100000 EPSILON(DIELECTRIC CONSTANT) = 10.00

FREQ (MHZ)	BEARING (DEG)	SEASON	TIME (LT)	DISTANCE (KM.)	LOSS (DB)	RECEIVED POWER (DBW)	NOISE (DBW)	RECEIVED S/N (DB)	E FIELD (DBU V/M)	XMTR GAIN (DB)	RCVR GAIN (DB)	RECEIVER COORDINATES LAT.	LONG.
SIGMA(CONDUCTIVITY) =					.0100000		EPSILON(DIELECTRIC CONSTANT) =			10.00			
2.0	10.0	DEC,JAN,FEB	1200	10.0	61.5	-26.7	-149.0	122.3	77.5	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	20.0	74.1	-39.3	-149.0	109.7	64.9	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	30.0	82.5	-47.7	-149.0	101.3	56.5	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	40.0	88.4	-53.6	-149.0	95.4	50.6	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	50.0	92.9	-58.1	-149.0	90.9	46.1	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	60.0	96.6	-61.8	-149.0	87.2	42.4	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	70.0	99.8	-65.0	-149.0	84.0	39.3	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	80.0	102.5	-67.7	-149.0	81.3	36.6	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	90.0	104.9	-70.1	-149.0	78.8	34.1	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1200	100.0	107.2	-72.4	-149.0	76.6	31.8	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	10.0	61.5	-26.7	-139.7	113.0	77.5	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	20.0	74.1	-39.3	-139.7	100.4	64.9	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	30.0	82.5	-47.7	-139.7	92.0	56.5	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	40.0	88.4	-53.6	-139.7	86.1	50.6	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	50.0	92.9	-58.1	-139.7	81.6	46.1	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	60.0	96.6	-61.8	-139.7	77.9	42.4	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	70.0	99.8	-65.0	-139.7	74.7	39.3	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	80.0	102.5	-67.7	-139.7	72.0	36.6	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	90.0	104.9	-70.1	-139.7	69.6	34.1	1.8	3.0	40.9	-105.1
2.0	10.0	DEC,JAN,FEB	1800	100.0	107.2	-72.4	-139.7	67.3	31.8	1.8	3.0	40.9	-105.1

EXAMPLE 2

```
                    INSTITUTE FOR TELECOMMUNICATIONS SCIENCES

                 GROUND WAVE AUTOMATED PERFORMANCE ANALYSIS(GWAPA)
            Over Smooth and Irregular Homogeneous or Inhomogeneous
                         Earth with Linear Atmosphere
                           Version 6.0, 8/01/86
                         TUE 02 SEP 1986   12:56:54

CHOOSE FROM THE MENU:
     C=CONCISE DIALOG
     V=VERBOSE DIALOG

MENU(VERBOSE)=?

     1)  TRANSMISSION LOSS                                   (TL)
     2)  RECEIVED POWER                                      (RP)
     3)  RECEIVED SIGNAL/NOISE                               (NM)
     4)  ACHIEVABLE RELIABILITY                              (RM)
     5)  ACHIEVABLE DISTANCE                                 (DM)
PROCESSING OPTION( 1) >? 3
INPUT DATA
CR TO SPECIFY DEFAULT OPTIONS AS SHOWN IN PARENS

     1)  DISTANCE UNIT = KM, HEIGHT UNIT = METERS
     2)  DISTANCE UNIT = MILES, HEIGHT UNIT = FT.
METRIC OR ENGLISH( 1) >?

1)  FREQUENCY (MHZ)
      UP TO 15 VALUES.  999 INDICATES END OF LIST.
FREQUENCY NO. 1>1
FREQUENCY NO. 2>999

TRANSMITTER ANTENNA HEIGHT (      0.0 TO  12000.0)
 2) TRANSMITTER ANTENNA HEIGHT(      2.0 M. )? 0

RECEIVER ANTENNA HEIGHT (      0.0 TO  12000.0)
 3) RECEIVER ANTENNA HEIGHT(      2.0 M. )? 0

     1)  LATS AND LONGS OF BOTH ANTENNAS
     2)  LAT&LONG OF TRANSMITTER, BEARING AND DISTANCE TO RECEIVER
 4) ANTENNA RANGE OPTIONS          ( 1) >?2

DISTANCE BETWEEN ANTENNAS (      1.00 TO 21000.00)
 5) DISTANCE BETWEEN ANTENNAS(    100.00 KM.)?

TRANSMITTER LATITUDE ( -89.99 TO   89.99)
INPUTS OF THE FORM X,Y,Z IMPLY DEGREES,MINUTES,SECONDS
INPUTS OF THE FORM X.Y IMPLY DECIMAL DEGREES
 6) TRANSMITTER LATITUDE(  40.03 )?
```

```
TRANSMITTER LONGITUDE (-180.00 TO  180.00 )
 7) TRANSMITTER LONGITUDE(-105.30 )?

INITIAL BEARING (0.00 TO 360.00)
11) INITIAL BEARING (10.00)?

BEARING INCREMENT (.01 TO 360.00)
12)  BEARING INCREMENT (10.00)?
FINAL BEARING (0.00 TO 360.00)
13)  FINAL BEARING (100.00)?  10

     1)  VERTICAL  (V)
     2)  HORIZONTAL(H)
14) ANTENNA POLARIZATION           ( 1) >?

     1)  VERTICAL MONOPOLE             (VM)
     2)  VERTICAL DIPOLE               (VD)
     3)  VERTICAL LOG PERIODIC         (LP)
     4)  INVERTED L                    (IL)
     5)  SLOPING LONGWIRE TERMINATED   (SL)
     6)  VERTICAL HALF RHOMBIC         (HR)
     7)  FIELD STRENGTH OPTION         (FS)
     8)  USER GAIN INPUT               (UG)
15) TRANSMITTER ANTENNA TYPE      ( 1) >? 7

TRANSMITTER FIELD INTENSITY AT REF. POINT, (            .0001 TO 100000000.0000M)
TRANSMITTER FIELD INTENSITY AT REF. POINT,(        300.0000MV/M)>?

TRANSMITTER INPUT REFERENCE POWER (       .001  TO  1000.000 )
TRANSMITTER INPUT REFERENCE POWER(      1.000 KW)>?

TRANSMITTER REFERENCE DISTANCE (       .300 TO  000.000 )
TRANSMITTER REFERENCE DISTANCE(      1.000 KM.)>?

     1 - VERTICAL MONOPOLE                 (VM)
     2)  VERTICAL DIPOLE               (VD)
     3)  VERTICAL LOG PERIODIC         (LP)
     4)  INVERTED L                    (IL)
     5)  SLOPING LONGWIRE TERMINATED   (SL)
     6)  VERTICAL HALF RHOMBIC         (HR)
     7)  FIELD STRENGTH OPTION         (FS)
     8)  USER GAIN INPUT               (UG)
16) RECEIVER ANTENNA TYPE          ( 1) >?8
FREQUENCY = 1.000

RECEIVER   GAIN (-100.000 TO  100.000 )
RECEIVER   GAIN(   0.000)>? 5

ACTUAL TRANSMITTER INPUT POWER (       .0001 TO 10000.0000 )
18) ACTUAL TRANSMITTER INPUT POWER(     1.0000 Kw)? 4
```

```
21) LOCAL TIME OF DAY (FORMAT HHMM)
    UP TO 24 VALUES.  999 INDICATES END OF LIST.
TIME        NO. 1>0600
TIME        NO. 2>1600
TIME        NO. 3>999

22) SEASONS
    UP TO 4 VALUES, 999 INDICATES END OF LIST.
1)  DEC,JAN,FEB(DJF)
2)  MAR,APR,MAY(MAM)
3)  JUN,JUL,AUG(JJA)
4)  SEP,OCT,NOV(SON)
SEASON     NO. 1>1
SEASON     NO. 2>2
SEASON     NO. 3>999

REQUIRED RELIABILITY (   .01 TO 100.00%)
23) REQUIRED RELIABILITY(90.00%)? 85

     1)  140.4   BUSINESS
     2)  144.7   RESIDENTIAL
     3)  150.0   RURAL
     4)  164.1   QUIET RURAL
     5)  USER INPUT
24) MAN MADE NOISE(-DBW) AT 1 MHZ ( 1) >?4

     1)  SMOOTH EARTH             (SE)
     2)  SMOOTH EARTH, MIXED PATH(SEMP)
     3)  IRREG. EARTH, MIXED PATH(IEMP)
26) PROCESSING METHOD             ( 1) >?2

EARTH RADIUS RATIO ( .500 TO 3.000 )
27) EARTH RADIUS RATIO(1.333 )?

     1)  SINGLE CALCULATION AT THE RECEIVER
     2)  INCREMENTAL CALCULATIONS BETWEEN XMITTER AND RECEIVER
28) TYPE OF OUTPUT                ( 1) >?

32)   GROUND CONSTANTS FOR BEARING 10.000
YOU MAY SPECIFY UP TO 50 GROUND SEGMENTS
YOUR TOTAL DISTANCE IS          100.000 KM.
SIGMA = CONDUCTIVITY(.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)
SEGMENT NO.  1

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(    .1000000 )>? .01

EPSILON (  1.000 TO 100.00 )
EPSILON(  1.000 )>? 10
```

```
SEGMENT LENGTH (       0.000 TO 1000000.000 )
SEGMENT LENGTH(       1.000 KM.)>? 45
DISTANCE REMAINING IS    55.00 KM.
SEGMENT NO.  2

SIGMA (   .0000001 TO 100.0000000 )
SIGMA(   .1000000 )>? 5

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 80

SEGMENT LENGTH (       0.000 TO 1000000.000 )
SEGMENT LENGTH(       1.000 KM.)>? 25
DISTANCE REMAINING IS    30.00 KM.
SEGMENT NO.  3

SIGMA (   .0000001 TO 100.0000000 )
SIGMA(   .1000000 )>? .05

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 15

SEGMENT LENGTH (       0.000 TO 1000000.000 )
SEGMENT LENGTH(       1.000 KM.)>? 30

CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(WRITE)=?

INPUT TITLE, 1 TO 60 CHARACTERS
EXAMPLE 2
DATA FILE COMPLETE

CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(QUIT)?

STOP PROGRAM GWAPA TERMINATED
```

EXAMPLE 2
RECEIVED SIGNAL/NOISE; MULTIPLE INPUT
PROCESSING METHOD = SMOOTH EARTH, MIXED PATH

TRANSMITTER ANTENNA HEIGHT = 0.0 M. RECEIVER ANTENNA HEIGHT = 0.0 M.
TRANSMITTER SITE DISTANCE
40.03N - 105.30W 100.0KM 62.1MI

ANTENNA POLARIZATION = VERTICAL
TRANSMITTER ANTENNA TYPE = FIELD STRENGTH OPTION
TRANSMITTER FIELD INTENSITY AT REF. POINT, 300.0000mv/m TRANSMITTER REFERENCE POWER 1.0000 Kw
TRANSMITTER REFERENCE DISTANCE 1.0000 KM.
RECEIVER ANTENNA TYPE = USER GAIN INPUT
FREQUENCY = 1.00 RECEIVER GAIN = 5.0000
EFFECTIVE EARTH RADIUS/ACTUAL EARTH RADIUS = 1.333
TRANSMITTER INPUT POWER = 4.0KW
MAN MADE NOISE(-DBW) AT 3 MHZ = 164.1 DBW REQUIRED RELIABILITY = 85.0%

GROUND SEGMENT AND SLAB DATA

NO.	SIGMA	EPSILON	KM. FROM XMITTER	LENGTH (KM.)
1	.0100	10.00	0.00	45.00
2	5.0000	80.00	45.00	25.00
3	.0500	15.00	70.00	30.00

FREQ (MHZ)	BEARING (DEG)	SEASON	TIME (LT)	DISTANCE (KM.)	LOSS (DB)	RECEIVED POWER (DBW)	NOISE (DBW)	RECEIVED S/N (DB)	E FIELD (DBU V/M)	XMTR GAIN (DB)	RCVR GAIN (DB)	RECEIVER COORDINATES LAT.	LONG.

GROUND SEGMENT AND SLAB DATA

NO.	SIGMA	EPSILON	KM. FROM XMITTER	LENGTH (KM.)
1	.0100	10.00	0.00	45.00
2	5.0000	80.00	45.00	25.00
3	.0500	15.00	70.00	30.00

1.0	10.0	DEC,JAN,FEB	0600	100.0	76.7	-30.6	-130.2	99.6	65.6	5.1	5.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1600	100.0	76.7	-30.6	-139.3	108.8	65.6	5.1	5.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	0600	100.0	76.7	-30.6	-129.8	99.2	65.6	5.1	5.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1600	100.0	76.7	-30.6	-126.5	95.9	65.6	5.1	5.0	40.9	-105.1

EXAMPLE 3

INSTITUTE FOR TELECOMMUNICATIONS SCIENCES

GROUND WAVE AUTOMATED PERFORMANCE ANALYSIS(GWAPA)
over Smooth and Irregular Homogeneous or Inhomogeneous
Earth with Linear Atmosphere
Version 6.0, 8/01/86
TUE 02 SEP 1986 12:00:04

```
CHOOSE FROM THE MENU:

     C=CONCISE DIALOG
     V=VERBOSE DIALOG
```

Note: A carriage return is required on the terminal after user enters a response to each question. If no data entry is made, a carriage return will enter the default value as data.

```
MENU(VERBOSE)=?

     1)  TRANSMISSION LOSS                          (TL)
     2)  RECEIVED POWER                             (RP)
     3)  RECEIVED SIGNAL/NOISE                      (NM)
     4)  ACHIEVABLE RELIABILITY                     (RM)
     5)  ACHIEVABLE DISTANCE                        (DM)
PROCESSING OPTION( 1) >? 3
INPUT DATA
CR TO SPECIFY DEFAULT OPTIONS AS SHOWN IN PARENS

     1)  DISTANCE UNIT = KM, HEIGHT UNIT = METERS
     2)  DISTANCE UNIT = MILES, HEIGHT UNIT = FT.
METRIC OR ENGLISH( 1) >?

1)  FREQUENCY (MHZ)
     UP TO 15 VALUES.  999 INDICATES END OF LIST.
FREQUENCY NO. 1>.2
FREQUENCY NO. 2>999

TRANSMITTER ANTENNA HEIGHT (     0.0 TO  12000.0)
 2) TRANSMITTER ANTENNA HEIGHT(     2.0 M. )? 0

RECEIVER ANTENNA HEIGHT (     0.0 TO  12000.0)
 3) RECEIVER ANTENNA HEIGHT(     2.0 M. )? 0

     1)  LATS AND LONGS OF BOTH ANTENNAS
     2)  LAT&LONG OF TRANSMITTER, BEARING AND DISTANCE TO RECEIVER
 4) ANTENNA RANGE OPTIONS          ( 1) >?2

DISTANCE BETWEEN ANTENNAS (     1.00 TO 21000.00)
 5) DISTANCE BETWEEN ANTENNAS(   100.00 KM.)?
```

EXAMPLE 3 (cont.)

```
TRANSMITTER LATITUDE ( -89.99 TO   89.99)
INPUTS OF THE FORM X,Y,Z IMPLY DEGREES,MINUTES,SECONDS
INPUTS OF THE FORM X.Y IMPLY DECIMAL DEGREES
 6) TRANSMITTER LATITUDE(  40.03 )?

TRANSMITTER LONGITUDE (-180.00 TO  180.00 )
 7) TRANSMITTER LONGITUDE(-105.30 )?

INITIAL BEARING (0.00 TO 360.00)
11) INITIAL BEARING (10.00)?

BEARING INCREMENT (.01 TO 360.00)
12)  BEARING INCREMENT (10.00)?

FINAL BEARING (0.00 TO 360.00)
13)  FINAL BEARING (100.00)?  10

     1)  VERTICAL  (V)
     2)  HORIZONTAL(H)
14) ANTENNA POLARIZATION          ( 1) >?

     1)  VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
     4)  INVERTED L                     (IL)
     5)  SLOPING LONGWIRE TERMINATED    (SL)
     6)  VERTICAL HALF RHOMBIC          (HR)
     7)  FIELD STRENGTH OPTION          (FS)
     8)  USER GAIN INPUT                (UG)
15) TRANSMITTER ANTENNA TYPE     ( 1) >?

TRANSMITTER MONOPOLE LENGTH ( 15.000 TO 1050.000 )
TRANSMITTER MONOPOLE LENGTH( 15.000 M. )>? 30

     1)  YES (Y)
     2)  NO  (N)
DO YOU WANT A GROUND SCREEN( 1) >?

TRANSMITTER GROUND SCREEN RADIUS (   15.000 TO 100000.000 )
TRANSMITTER GROUND SCREEN RADIUS(  15.000 M.  )>? 100

TRANSMITTER NUMBER OF RADIALS (  5. TO 360. )
TRANSMITTER NUMBER OF RADIALS(  5. )>? 60

TRANSMITTER MONOPOLE EFFICIENCY (  1.00 TO 100.00%)
TRANSMITTER MONOPOLE EFFICIENCY(100.00%)>? 25

     1 - VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
```

```
     4)  INVERTED L                      (IL)
     5)  SLOPING LONGWIRE TERMINATED     (SL)
     6)  VERTICAL HALF RHOMBIC           (HR)
     7)  FIELD STRENGTH OPTION           (FS)
     8)  USER GAIN INPUT                 (UG)
16) RECEIVER ANTENNA TYPE         ( 1)  >?

RECEIVER    MONOPOLE LENGTH (    15.000 TO 1050.000 )
RECEIVER    MONOPOLE (   30.00 M. )>?

     1)  YES(Y)
     2)  NO (N)
DO YOU WANT A GROUND SCREEN( 1) >?

RECEIVER    GROUND SCREEN RADIUS (     15.00 TO 100000.000 )
RECEIVER    GROUND SCREEN RADIUS(    100.00 m. )>?

RECEIVER    NUMBER OF RADIALS (  5. TO 360. )
RECEIVER    NUMBER OF RADIALS( 60. )>?

RECEIVER    MONOPOLE EFFICIENCY (  1.00 TO 100.00%)
RECEIVER    MONOPOLE EFFICIENCY( 25.00%)>?

ACTUAL TRANSMITTER INPUT POWER (      .0001 TO 10000.0000 )
18) ACTUAL TRANSMITTER INPUT POWER(     1.0000 Kw)? 2

21) LOCAL TIME OF DAY (FORMAT HHMM)
    UP TO 24 VALUES.  999 INDICATES END OF LIST.
TIME       NO. 1>1200
TIME       NO. 2>999

22) SEASONS
    UP TO 4 VALUES, 999 INDICATES END OF LIST.
1)  DEC,JAN,FEB(DJF)
2)  MAR,APR,MAY(MAM)
3)  JUN,JUL,AUG(JJA)
4)  SEP,OCT,NOV(SON)
SEASON     NO. 1>1
SEASON     NO. 2>999

REQUIRED RELIABILITY (    .01 TO 100.00%)
23) REQUIRED RELIABILITY( 90.00%)?

     1)  140.4   BUSINESS
     2)  144.7   RESIDENTIAL
     3)  150.0   RURAL
     4)  164.1   QUIET RURAL
     5)  USER INPUT
24) MAN MADE NOISE(-DBW) AT 3 MHZ ( 1) >?4

     1)  SMOOTH EARTH            (SE  )
```

```
     2)  SMOOTH EARTH, MIXED PATH(SEMP)
     3)  IRREG. EARTH, MIXED PATH(IEMP)
26) PROCESSING METHOD              ( 1) >?3
EARTH RADIUS RATIO ( .500 TO 3.000 )
27) EARTH RADIUS RATIO(1.333 )?

     1)  SINGLE CALCULATION AT THE RECEIVER
     2)  INCREMENTAL CALCULATIONS BETWEEN XMITTER AND RECEIVER
28) TYPE OF OUTPUT                 ( 1) >?

32)  GROUND CONSTANTS FOR BEARING 10.000
YOU MAY SPECIFY UP TO 50 GROUND SEGMENTS

     1)  YES(Y)
     2)  NO (N)
WILL YOU WANT TO DEFINE A SLAB ON ANY OF THE GROUND SEGMENTS?( 2) >?1
YOUR TOTAL DISTANCE IS           20.000 KM.
SIGMA = CONDUCTIVITY(.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)
SEGMENT NO.  1

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(    .1000000 )>? .01

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 10

SEGMENT LENGTH (       0.000 TO 1000000.000 )
SEGMENT LENGTH(       1.000 KM.)>? 5

     1 - YES(Y)
     2 - NO (N)
DO YOU WANT A SLAB ON THIS SEGMENT?( 2) >?1
SLAB INPUT

SIGMA (  .000010 TO 100.00000 )
SIGMA( 1.000000 )>? .0005

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 5

SLAB THICKNESS (  0.000 TO 700.000 )
SLAB THICKNESS(  1.000 M. )>? 10
DISTANCE REMAINING IS    15.00 KM.
SEGMENT NO.  2

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(    .1000000 )>? .05

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 15
```

```
SEGMENT LENGTH (       0.000 TO 1000000.000 )
SEGMENT LENGTH(       1.000 KM.)>? 5

     1 - YES(Y)
     2 - NO (N)
DO YOU WANT A SLAB ON THIS SEGMENT?( 1) >?2
DISTANCE REMAINING IS     10.00 KM.
SEGMENT NO.  3

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(    .1000000 )>? .01

EPSILON ( 1.000 TO 100.000 )
EPSILON( 1.000 )>? 15

SEGMENT LENGTH (       0.000 TO 1000000.000 )
SEGMENT LENGTH(       1.000 KM.)>? 10

     1 - YES(Y)
     2 - NO (N)
DO YOU WANT A SLAB ON THIS SEGMENT?( 2) >?1
SLAB INPUT

SIGMA (   .000010 TO 100.00000 )
SIGMA( 1.000000 )>? .001

EPSILON (   1.000 TO 100.000 )
EPSILON(   1.000 )>? 15

SLAB THICKNESS (   0.000 TO 700.000 )
SLAB THICKNESS(   1.000 M. )>? 5

CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(WRITE)=?
INPUT TITLE, 1 TO 60 CHARACTERS
EXAMPE 3

TERRAIN DATA FOR BEARING 10.000

     1)  USE RESIDENT TERRAIN DATA
     2)  INPUT TERRAIN DATA MANUALLY
     3)  OBTAIN TERRAIN DATA FROM USER FILE
```

```
TERRAIN DATA MANAGEMENT( 1) >?2
YOU WILL BE ASKED FOR ALTITUDE VALUES AT POINT BETWEEN XMITTER AND RCVR.
THESE POINTS ARE DETERMINED BY THE SIZE OF INTERVAL YOU SPECIFY.
INTERVAL SIZE(    1.00000 KM.)>? 2
 1) ALTITUDE AT      0.000 KM. FROM XMITTER(    0.00 M. )? 50
 2) AT      2.000 KM.(    0.00 M. )? 40
 3) AT      4.000 KM.(    0.00 M. )? 30
 4) AT      6.000 KM.(    0.00 M. )? 50
 5) AT      8.000 KM.(    0.00 M. )? 40
 6) AT     10.000 KM.(    0.00 M. )? 20
 7) AT     12.000 KM.(    0.00 M. )? 40
 8) AT     14.000 KM.(    0.00 M. )? 40
 9) AT     16.000 KM.(    0.00 M. )? 50
10) AT     18.000 KM.(    0.00 M. )? 70
11) AT     20.000 KM.(    0.00 M. )? 60

     1)  USER RESIDENT TERRAIN DATA
     2)  INPUT TERRAIN DATA MANUALLY
     3)  OBTAIN TERRAIN DATA FROM USER FILE
     4)  SUMMARY OF TERRAIN DATA
     5)  EDIT TERRAIN DATA
     6)  ALL DONE
TERRAIN DATA MANAGEMENT( 6) >?5
DATA NUMBER>?7

ALTITUDE AT     12.000 KM. FOR XMITTER (     0.00 TO 40000.00)
 7) ALTITUDE AT     12.000 KM. FROM XMITTER(   40.00 M. )? 45
DATA NUMBER>?

     1)  USE RESIDENT TERRAIN DATA
     2)  INPUT TERRAIN DATA MANUALLY
     3)  OBTAIN TERRAIN DATA FROM USER FILE
     4)  SUMMARY OF TERRAIN DATA
     5)  EDIT TERRAIN DATA
     6)  ALL DONE
TERRAIN DATA MANAGEMENT( 6) >?
DATA TO FILE COMPLETE
                         APPROX. RELATIVE ERROR
                           (FIELD STRENGTH)
                           WRT MEASURED DATA
       RUN TIME            MEAN     STND. DEV.
        (SEC)              (dB)       (dB)
IEMP      4.3               -.4        4.7
SEMP      9.6               2.8        4.2
SE        4.0               2.8        4.2

MENU(QUIT)=?

STOP PROGRAM GWAPA TERMINATED
```

EXAMPLE 3
RECEIVED SIGNAL/NOISE; SINGLE FREQ & DIRECTION
PROCESSING METHOD = WAGNER

RF FREQUENCY = .20
TRANSMITTER ANTENNA HEIGHT = 0.0 M. RECEIVER ANTENNA HEIGHT = 0.0 M.

TRANSMITTER SITE	BEARING	DISTANCE		RECEIVER SITE
40.03N - 105.30W	10.0	20.0KM	12.4MI	40.21N - 105.26W

ANTENNA POLARIZATION = VERTICAL
TRANSMITTER ANTENNA TYPE = VERTICAL MONOPOLE
TRANSMITTER MONOPOLE LENGTH 30.0000 M.
TRANSMITTER GROUND SCREEN RADIUS 100.0000 M. TRANSMITTER NUMBER OF RADIALS 60.0000
RECEIVER ANTENNA TYPE = VERTICAL MONOPOLE
RECEIVER MONOPOLE LENGTH 30.0000 M.
RECEIVER GROUND SCREEN RADIUS 100.0000 M. RECEIVER NUMBER OF RADIALS 60.0000
EFFECTIVE EARTH RADIUS/ACTUAL EARTH RADIUS = 1.333
TRANSMITTER INPUT POWER = 2.0KW TRANSMITTER ANTENNA GAIN = -12. RECEIVER ANTENNA GAIN = -12.
MAN MADE NOISE(-DBW) AT 3 MHZ = 164.1 DBW REQUIRED RELIABILITY = 90.0%

GROUND SEGMENT AND SLAB DATA

					SLAB		
NO.	SIGMA	EPSILON	KM. FROM XMITTER	LENGTH (KM.)	SIGMA	EPSILON	THICKNESS (M.)
1	.0100	10.00	0.00	5.00	.0005	5.00	10.00
2	.0500	15.00	5.00	5.00			
3	.0100	15.00	10.00	10.00	.0010	15.00	5.00

DEC,JAN,FEB 1200LT

NO.	DISTANCE FROM XMITTER (KM.)	TRANSMISSION LOSS (DB)	RECEIVED POWER (DBW)	E FIELD (DBU V/M)	NOISE (DBW)	RECEIVED S/N (DB)
1	20.0	109.0	-100.1	-.8	-113.9	13.9

EXAMPLE 4

```
                    INSTITUTE FOR TELECOMMUNICATIONS SCIENCES

                  GROUND WAVE AUTOMATED PERFORMANCE ANALYSIS(GWAPA)
              over Smooth and Irregular Homogeneous or Inhomogeneous
                         Earth with Linear Atmosphere
                              Version 6.0, 8/01/86
                             TUE 02 SEP 1986  12:00:04

CHOOSE FROM THE MENU:

     C=CONCISE DIALOG
     V=VERBOSE DIALOG

MENU(VERBOSE)=?

     1)  TRANSMISSION LOSS                                 (TL)
     2)  RECEIVED POWER                                    (RP)
     3)  RECEIVED SIGNAL/NOISE                             (NM)
     4)  ACHIEVABLE RELIABILITY                            (RM)
     5)  ACHIEVABLE DISTANCE                               (DM)
PROCESSING OPTION( 1) >? 3
INPUT DATA
CR TO SPECIFY DEFAULT OPTIONS AS SHOWN IN PARENS

     1)  DISTANCE UNIT = KM, HEIGHT UNIT = METERS
     2)  DISTANCE UNIT = MILES, HEIGHT UNIT = FT.
METRIC OR ENGLISH( 1) >?

1)  FREQUENCY (MHZ)
      UP TO 15 VALUES.  999 INDICATES END OF LIST.
FREQUENCY NO. 1>2
FREQUENCY NO. 2>10
FREQUENCY NO. 3>999

TRANSMITTER ANTENNA HEIGHT (      0.0 TO  12000.0)
 2) TRANSMITTER ANTENNA HEIGHT(      2.0 M. )? 0

RECEIVER ANTENNA HEIGHT (      0.0 TO  12000.0)
 3) RECEIVER ANTENNA HEIGHT(      2.0 M. )? 0

     1)  LATS AND LONGS OF BOTH ANTENNAS
     2)  LAT&LONG OF TRANSMITTER, BEARING AND DISTANCE TO RECEIVER
 4) ANTENNA RANGE OPTIONS           ( 1) >?2

DISTANCE BETWEEN ANTENNAS (      1.00 TO 21000.00)
 5) DISTANCE BETWEEN ANTENNAS(   100.00 KM.)?
```

```
TRANSMITTER LATITUDE (-89.99 TO   89.99 )
INPUTS OF THE FORM X,Y,Z IMPLY DEGREES,MINUTES,SECONDS
INPUTS OF THE FORM X.Y IMPLY DECIMAL DEGREES
 6) TRANSMITTER LATITUDE(  40.03 )?

TRANSMITTER LONGITUDE (-180.00 TO  180.00 )
 7) TRANSMITTER LONGITUDE(-105.30 )?

INITIAL BEARING (  0.00 TO 360.00 )
11) INITIAL BEARING( 10.00 )?

BEARING INCREMENT (    .01 TO 360.00 )
12) BEARING INCREMENT( 10.00 )?

FINAL BEARING (  0.00 TO 360.00 )
13) FINAL BEARING(100.00 )? 20

     1)  VERTICAL   (V)
     2)  HORIZONTAL (H)
14) ANTENNA POLARIZATION                 ( 1) >

     1)  VERTICAL MONOPOLE                 (VM)
     2)  VERTICAL DIPOLE                   (VD)
     3)  VERTICAL LOG PERIODIC             (LP)
     4)  INVERTED L                        (IL)
     5)  SLOPING LONGWIRE TERMINATED       (SL)
     6)  VERTICAL HALF RHOMBIC             (HR)
     7)  FIELD STRENGTH OPTION             (FS)
     8)  USER GAIN INPUT                   (UG)
15) TRANSMITTER ANTENNA TYPE             ( 1) >?8
FREQUENCY = 1.000

TRANSMITTER GAIN (-100.000 TO  100.000 )
TRANSMITTER GAIN(   0.000 )>? 2
FREQUENCY = 10.000

TRANSMITTER GAIN (-100.000 TO  100.000 )
TRANSMITTER GAIN(   0.000 )>? 7

     1)  VERTICAL MONOPOLE                 (VM)
     2)  VERTICAL DIPOLE                   (VD)
     3)  VERTICAL LOG PERIODIC             (LP)
     4)  INVERTED L                        (IL)
     5)  SLOPING LONGWIRE TERMINATED       (SL)
     6)  VERTICAL HALF RHOMBIC             (HR)
     7)  FIELD STRENGTH OPTION             (FS)
     8)  USER GAIN INPUT                   (UG)
16) RECEIVER ANTENNA TYPE                ( 1) >?8
FREQUENCY =  1.000
```

EXAMPLE 4 (cont.)

```
RECEIVER    GAIN (-100.000 TO  100.000 )
RECEIVER    GAIN(    0.000 )>? 2
FREQUENCY = 10.000

RECEIVER    GAIN (-100.000 TO  100.000 )
RECEIVER    GAIN(    0.000 )>? 7

ACTUAL TRANSMITTER INPUT POWER (     .0001 TO 10000.0000 )
18) ACTUAL TRANSMITTER INPUT POWER(    1.0000 Kw)?

21) LOCAL TIME OF DAY (FORMAT HHMM)
    UP TO 24 VALUES.  999 INDICATES END OF LIST.
TIME      NO. 1>1200
TIME      NO. 2>1800
TIME      NO. 3>999

22) SEASONS
    UP TO 4 VALUES, 999 INDICATES END OF LIST.
1)  DEC,JAN,FEB(DJF)
2)  MAR,APR,MAY(MAM)
3)  JUN,JUL,AUG(JJA)
4)  SEP,OCT,NOV(SON)
SEASON    NO. 1>1
SEASON    NO. 2>2
SEASON    NO. 3>999

REQUIRED RELIABILITY (    .01 TO 100.00%)
23) REQUIRED RELIABILITY( 90.00%)?

     1)  140.4   BUSINESS
     2)  144.7   RESIDENTIAL
     3)  150.0   RURAL
     4)  164.1   QUIET RURAL
     5)  USER INPUT
24) MAN MADE NOISE(-DBW) AT 1 MHZ ( 1) >?

     1)  SMOOTH EARTH              (SE   )
     2)  SMOOTH EARTH, MIXED PATH(SEMP)
     3)  IRREG. EARTH, MIXED PATH (IEMP)
26) PROCESSING METHOD             ( 1) >?

EARTH RADIUS RATIO ( .500 TO 3.000 )
27) EARTH RADIUS RATIO(1.333 )?

     1)  SINGLE CALCULATION AT THE RECEIVER
     2)  INCREMENTAL CALCULATIONS BETWEEN XMITTER AND RECEIVER
28) TYPE OF OUTPUT                ( 1) >?2
FIELD CALCULATIONS WILL BE PERFORMED ACCORDING TO THE FOLLOWING PARAMETERS.

MINIMUM DISTANCE FROM XMITTER (     .3000 TO  100.0000 )
29) MINIMUM DISTANCE FROM XMITTER( 100.0000 KM.)? 20
```

```
INCREMENTAL DISTANCE (    .00010 TO 100.00000 )
30) INCREMENTAL DISTANCE(  1.00000 KM.)? 20

MAXIMUM DISTANCE FROM XMITTER (  20.0000 TO  100.0000 )
31) MAXIMUM DISTANCE FROM XMITTER( 100.0000 KM.)?

32)  GROUND CONSTANTS FOR BEARING =  10.00
SIGMA = CONDUCTIVITY (.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(    .1000000 )>? .01

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 10

32) GROUND CONSTANTS FOR BEARING =  20.00
SIGMA = CONDUCTIVITY (.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(    .1000000 )>? .05

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 15

CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(WRITE)=?

INPUT TITLE, 1 TO 60 CHARACTERS
EXAMPLE 4
DATA TO FILE COMPLETE
CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(QUIT)=?

STOP PROGRAM GWAPA TERMINATED
```

EXAMPLE 4
RECEIVED SIGNAL/NOISE; MULTIPLE INPUT
PROCESSING METHOD = SMOOTH EARTH

TRANSMITTER ANTENNA HEIGHT = 0.0 M. RECEIVER ANTENNA HEIGHT = 0.0 M.

TRANSMITTER SITE 40.03N - 105.30W DISTANCE 100.0KM 62.1MI

ANTENNA POLARIZATION = VERTICAL
TRANSMITTER ANTENNA TYPE = USER GAIN INPUT
FREQUENCY = 1.00 TRANSMITTER GAIN = 2.0000 FREQUENCY = 10.00 TRANSMITTER GAIN = 7.0000
RECEIVER ANTENNA TYPE = USER GAIN INPUT
FREQUENCY = 1.00 RECEIVER GAIN = 2.0000 FREQUENCY = 10.00 RECEIVER GAIN = 7.0000
EFFECTIVE EARTH RADIUS/ACTUAL EARTH RADIUS = 1.333
TRANSMITTER INPUT POWER = 1.0KW
MAN MADE NOISE(-DBW) AT 3 MHZ = 140.4 DBW REQUIRED RELIABILITY = 90.0%

FREQ (MHZ)	BEARING (DEG)	SEASON	TIME (LT)	DISTANCE (KM)	LOSS (DB)	RECEIVED POWER (DBW)	NOISE (DBW)	RECEIVED S/N (DB)	E FIELD (DBU V/M)	XMTR GAIN (DB)	RCVR GAIN (DB)	RECEIVER COORDINATES LAT.	LONG.
		SIGMA(CONDUCTIVITY) =			.0100000		EPSILON(DIELECTRIC CONSTANT) =			10.00			
1.0	10.0	DEC,JAN,FEB	1200	20.0	57.1	-23.1	-118.2	95.1	76.1	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1200	40.0	67.3	-33.3	-118.2	84.9	65.9	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1200	60.0	74.6	-40.6	-118.2	77.6	58.6	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1200	80.0	80.4	-46.4	-118.2	71.8	52.8	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1200	100.0	85.2	-51.2	-118.2	67.0	48.0	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1800	20.0	57.1	-23.1	-118.0	94.9	76.1	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1800	40.0	67.3	-33.3	-118.0	84.7	65.9	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1800	60.0	74.6	-40.6	-118.0	77.4	58.6	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1800	80.0	80.4	-46.4	-118.0	71.6	52.8	2.0	2.0	40.9	-105.1
1.0	10.0	DEC,JAN,FEB	1800	100.0	85.2	-51.2	-118.0	66.8	48.0	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1200	20.0	57.1	-23.1	-118.2	95.1	76.1	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1200	40.0	67.3	-33.3	-118.2	84.9	65.9	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1200	60.0	74.6	-40.6	-118.2	77.6	58.6	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1200	80.0	80.4	-46.4	-118.2	71.8	52.8	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1200	100.0	85.2	-51.2	-118.2	67.0	48.0	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1800	20.0	57.1	-23.1	-113.6	90.5	76.1	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1800	40.0	67.3	-33.3	-113.6	80.3	65.9	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1800	60.0	74.6	-40.6	-113.6	73.1	58.6	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1800	80.0	80.4	-46.4	-113.6	67.2	52.8	2.0	2.0	40.9	-105.1
1.0	10.0	MAR,APR,MAY	1800	100.0	85.2	-51.2	-113.6	62.4	48.0	2.0	2.0	40.9	-105.1
		SIGMA(CONDUCTIVITY) =			.0100000		EPSILON(DIELECTRIC CONSTANT) =			10.00			
10.0	10.0	DEC,JAN,FEB	1200	20.0	118.8	-74.8	-145.8	71.0	39.4	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1200	40.0	131.9	-87.9	-145.8	57.8	26.3	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1200	60.0	140.3	-96.3	-145.8	49.5	17.9	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1200	80.0	146.8	-102.8	-145.8	42.9	11.4	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1200	100.0	152.5	-108.5	-145.8	37.3	5.7	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1800	20.0	118.8	-74.8	-145.5	70.7	39.4	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1800	40.0	131.9	-87.9	-145.5	57.6	26.3	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1800	60.0	140.3	-96.3	-145.5	49.2	17.9	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1800	80.0	146.8	-102.8	-145.5	42.7	11.4	7.0	7.0	40.9	-105.1
10.0	10.0	DEC,JAN,FEB	1800	100.0	152.5	-108.5	-145.5	37.0	5.7	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1200	20.0	118.8	-74.8	-145.7	70.9	39.4	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1200	40.0	131.9	-87.9	-145.7	57.8	26.3	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1200	60.0	140.3	-96.3	-145.7	49.5	17.9	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1200	80.0	146.8	-102.8	-145.7	42.9	11.4	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1200	100.0	152.5	-108.5	-145.7	37.3	5.7	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1800	20.0	118.8	-74.8	-144.1	69.3	39.4	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1800	40.0	131.9	-87.9	-144.1	56.2	26.3	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1800	60.0	140.3	-96.3	-144.1	47.8	17.9	7.0	7.0	40.9	-105.1
10.0	10.0	MAR,APR,MAY	1800	80.0	146.8	-102.8	-144.1	41.3	11.4	7.0	7.0	40.9	-105.1

10.0	10.0	MAR,APR,MAY	1800	100.0	152.5	-108.5	-144.1	35.6	5.7	7.0	7.0	40.9	-105.1
		SIGMA(CONDUCTIVITY) =		.0500000			EPSILON(DIELECTRIC CONSTANT) =			15.00			
1.0	20.0	DEC,JAN,FEB	1200	20.0	53.4	-19.4	-118.2	98.8	79.8	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1200	40.0	60.5	-26.5	-118.2	91.7	72.7	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1200	60.0	65.0	-31.0	-118.2	87.1	68.2	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1200	80.0	68.6	-34.6	-118.2	83.6	64.6	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1200	100.0	71.6	-37.6	-118.2	80.6	61.6	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1800	20.0	53.4	-19.4	-118.0	98.6	79.8	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1800	40.0	60.5	-26.5	-118.0	91.5	72.7	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1800	60.0	65.0	-31.0	-118.0	86.9	68.2	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1800	80.0	68.6	-34.6	-118.0	83.4	64.6	2.0	2.0	40.9	-104.9
1.0	20.0	DEC,JAN,FEB	1800	100.0	71.6	-37.6	-118.0	80.4	61.6	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1200	20.0	53.4	-19.4	-118.2	98.8	79.8	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1200	40.0	60.5	-26.5	-118.2	91.7	72.7	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1200	60.0	65.0	-31.0	-118.2	87.1	68.2	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1200	80.0	68.6	-34.6	-118.2	83.6	64.6	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1200	100.0	71.6	-37.6	-118.2	80.6	61.6	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1800	20.0	53.4	-19.4	-113.6	94.2	79.8	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1800	40.0	60.5	-26.5	-113.6	87.1	72.7	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1800	60.0	65.0	-31.0	-113.6	82.5	68.2	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1800	80.0	68.6	-34.6	-113.6	79.0	64.6	2.0	2.0	40.9	-104.9
1.0	20.0	MAR,APR,MAY	1800	100.0	71.6	-37.6	-113.6	76.0	61.6	2.0	2.0	40.9	-104.9
		SIGMA(CONDUCTIVITY) =		.0500000			EPSILON(DIELECTRIC CONSTANT) =			15.00			
10.0	20.0	DEC,JAN,FEB	1200	20.0	105.5	-61.5	-145.8	84.3	52.7	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1200	40.0	118.8	-74.8	-145.8	71.0	39.4	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1200	60.0	127.1	-83.1	-145.8	62.7	31.1	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1200	80.0	133.6	-89.6	-145.8	56.1	24.6	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1200	100.0	139.3	-95.3	-145.8	50.5	18.9	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1800	20.0	105.5	-61.5	-145.5	84.0	52.7	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1800	40.0	118.8	-74.8	-145.5	70.7	39.4	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1800	60.0	127.1	-83.1	-145.5	62.4	31.1	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1800	80.0	133.6	-89.6	-145.5	55.9	24.6	7.0	7.0	40.9	-104.9
10.0	20.0	DEC,JAN,FEB	1800	100.0	139.3	-95.3	-145.5	50.3	18.9	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1200	20.0	105.5	-61.5	-145.7	84.3	52.7	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1200	40.0	118.8	-74.8	-145.7	71.0	39.4	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1200	60.0	127.1	-83.1	-145.7	62.6	31.1	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1200	80.0	133.6	-89.6	-145.7	56.1	24.6	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1200	100.0	139.3	-95.3	-145.7	50.5	18.9	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1800	20.0	105.5	-61.5	-144.1	82.6	52.7	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1800	40.0	118.8	-74.8	-144.1	69.3	39.4	7.0	7.0	40.9	-104.9
10.0	20.0	MAR,APR,MAY	1800	60.0	127.1	-83.1	-144.1	61.0	31.1	7.0	7.0	40.9	-104.9

EXAMPLE 5

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                    INSTITUTE FOR TELECOMMUNICATIONS SCIENCES

                 GROUND WAVE AUTOMATED PERFORMANCE ANALYSIS(GWAPA)
             over Smooth and Irregular Homogeneous or Inhomogeneous
                        Earth with Linear Atmosphere
                           Version 6.0, 8/01/86
                          TUE 02 SEP 1986  12:00:04

CHOOSE FROM THE MENU:

     C=CONCISE DIALOG
     V=VERBOSE DIALOG

MENU(VERBOSE)=?

     1)  TRANSMISSION LOSS                                    (TL)
     2)  RECEIVED POWER                                       (RP)
     3)  RECEIVED SIGNAL/NOISE                                (NM)
     4)  ACHIEVABLE RELIABILITY                               (RM)
     5)  ACHIEVABLE DISTANCE                                  (DM)
PROCESSING OPTION( 1) >? 5
INPUT DATA
CR TO SPECIFY DEFAULT OPTIONS AS SHOWN IN PARENS

     1)  DISTANCE UNIT = KM, HEIGHT UNIT = METERS
     2)  DISTANCE UNIT = MILES, HEIGHT UNIT = FT.
METRIC OR ENGLISH( 1) >?

1)  FREQUENCY (MHZ)
      UP TO 15 VALUES.  999 INDICATES END OF LIST.
FREQUENCY NO. 1>1
FREQUENCY NO. 2>5
FREQUENCY NO. 3>999

TRANSMITTER ANTENNA HEIGHT (      0.0 TO  12000.0)
 2) TRANSMITTER ANTENNA HEIGHT(      2.0 M. )? 0

RECEIVER ANTENNA HEIGHT (      0.0 TO  12000.0)
 3) RECEIVER ANTENNA HEIGHT(      2.0 M. )? 0

TRANSMITTER LATITUDE ( -89.99 TO   89.99)
INPUTS OF THE FORM X,Y,Z IMPLY DEGREES,MINUTES,SECONDS
INPUTS OF THE FORM X.Y IMPLY DECIMAL DEGREES
 6) TRANSMITTER LATITUDE(  40.03 )?

TRANSMITTER LONGITUDE (-180.00 TO  180.00 )
 7) TRANSMITTER LONGITUDE(-105.30 )?
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```
INITIAL BEARING (   0.00 TO 360.00 )
11) INITIAL BEARING( 10.00 )?

BEARING INCREMENT (    .01 TO 360.00 )
12) BEARING INCREMENT( 10.00 )?

FINAL BEARING (   0.00 TO 360.00 )
13) FINAL BEARING(100.00 )? 20

     1)  VERTICAL   (V)
     2)  HORIZONTAL (H)
14) ANTENNA POLARIZATION               ( 1) >?

     1)  VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
     4)  INVERTED L                     (IL)
     5)  SLOPING LONGWIRE TERMINATED    (SL)
     6)  VERTICAL HALF RHOMBIC          (HR)
     7)  FIELD STRENGTH OPTION          (FS)
     8)  USER GAIN INPUT                (UG)
15) TRANSMITTER ANTENNA TYPE      ( 1) >?8
FREQUENCY =  1.000

TRANSMITTER GAIN (-100.000 TO  100.000 )
TRANSMITTER GAIN(    0.000 )>? 2
FREQUENCY = 5.000

TRANSMITTER GAIN (-100.000 TO  100.000 )
TRANSMITTER GAIN(    0.000 )>? 4

     1)  VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
     4)  INVERTED L                     (IL)
     5)  SLOPING LONGWIRE TERMINATED    (SL)
     6)  VERTICAL HALF RHOMBIC          (HR)
     7)  FIELD STRENGTH OPTION          (FS)
     8)  USER GAIN INPUT                (UG)
16) RECEIVER ANTENNA TYPE              ( 1) >?8
FREQUENCY = 1.000

RECEIVER   GAIN (-100.000 TO  100.000 )
RECEIVER   GAIN(    0.000 )>? 2
FREQUENCY = 5.000

RECEIVER   GAIN (-100.000 TO  100.000 )
RECEIVER   GAIN(    0.000 )>? 4

ACTUAL TRANSMITTER INPUT POWER (      .0001 TO 10000.0000 )
18) ACTUAL TRANSMITTER INPUT POWER(     1.0000 Kw)?
```

```
21) LOCAL TIME OF DAY (FORMAT HHMM)
    UP TO 24 VALUES.  999 INDICATES END OF LIST.
TIME       NO. 1>1200
TIME       NO. 2>999

22) SEASONS
    UP TO 4 VALUES, 999 INDICATES END OF LIST.
1)  DEC,JAN,FEB(DJF)
2)  MAR,APR,MAY(MAM)
3)  JUN,JUL,AUG(JJA)
4)  SEP,OCT,NOV(SON)
SEASON     NO. 1>1
SEASON     NO. 2>999

REQUIRED RELIABILITY (    .01 TO 100.00%)
23) REQUIRED RELIABILITY( 90.00%)?

     1)  140.4    BUSINESS
     2)  144.7    RESIDENTIAL
     3)  150.0    RURAL
     4)  164.1    QUIET RURAL
     5)  USER INPUT
24) MAN MADE NOISE(-DBW) AT 1 MHZ ( 1) >?4

REQUIRED SIGNAL/NOISE RATIO (  1.00 TO 200.00 )
25) REQUIRED SIGNAL/NOISE RATIO(  2.00 DB)? 70

     1)  SMOOTH EARTH             (SE)
     2)  SMOOTH EARTH, MIXED PATH(SEMP)
26) PROCESSING METHOD            ( 1) >?

EARTH RADIUS RATIO ( .500 TO 3.000 )
27) EARTH RADIUS RATIO(1.333 )?

32) GROUND CONSTANTS FOR BEARING =  10.00
SIGMA = CONDUCTIVITY (.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(   .1000000 )>? .01

EPSILON (  1.000 TO 100.000 )
EPSILON(  1.000 )>? 10

32) GROUND CONSTANTS FOR BEARING =  20.00
SIGMA = CONDUCTIVITY (.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)

SIGMA (    .0000001 TO 100.0000000 )
SIGMA(   .1000000 )>? .07
```

```
EPSILON (   1.000 TO 100.000 )
EPSILON(   1.000 )>? 15

MENU(EDIT)=? P

CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(WRITE)=?

INPUT TITLE, 1 TO 60 CHARACTERS
EXAMPLE 5
DATA TO FILE COMPLETE
CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(QUIT)=?

STOP PROGRAM GWAPA TERMINATED
```

EXAMPLE 5 (cont.)

EXAMPLE 5
ACHIEVABLE DISTANCE, MULTIPLE INPUT
PROCESSING METHOD = SMOOTH EARTH

TRANSMITTER ANTENNA HEIGHT = 0.0 M. RECEIVER ANTENNA HEIGHT = 0.0 M.
TRANSMITTER SITE
40.03N - 105.30W

ANTENNA POLARIZATION = VERTICAL
TRANSMITTER ANTENNA TYPE = USER GAIN INPUT
FREQUENCY = 1.00 TRANSMITTER GAIN = 2.0000 FREQUENCY = 5.00 TRANSMITTER GAIN = 4.0000

RECEIVER ANTENNA TYPE = USER GAIN INPUT
FREQUENCY = 1.00 RECEIVER GAIN = 2.0000 FREQUENCY = 5.00 RECEIVER GAIN = 4.0000

EFFECTIVE EARTH RADIUS/ACTUAL EARTH RADIUS = 1.333

TRANSMITTER INPUT POWER = 1.0KW
MAN MADE NOISE(-DBW) AT 3 MHZ = 164.1 DBW REQUIRED RELIABILITY = 90.0% REQUIRED SIGNAL/NOISE = 70.0DB

AZIMUTH = 20.0
SIGMA(CONDUCTIVITY) = .0700000 EPSILON(DIELECTRIC CONSTANT) = 15.00

FREQUENCIES IN MEGAHERTZ
1.00 5.00

DEC,JAN,FEB TIME = 1200LT

NOISE DBW	-141	-159
TRANSMITTER ANTENNA DB	2	4
RECEIVER ANTENNA DB	2	4
SIGNAL DBU	29	22
ACHIEVABLE DISTANCE(KM)	540	159
RECEIVER LATITUDE	44.6	41.4
RECEIVER LONGITUDE	-103.0	-104.6
RECEIVED POWER DBW	-71	-89

45.4
-102.5

42.2
-104.2

GWAPA 7
Run

If one used ~~great~~ independent great circle calculations to compute distance between transmitter and receiver the ~~distance~~ are 639 and 259 Km

EXAMPLE 6

INSTITUTE FOR TELECOMMUNICATIONS SCIENCES

GROUND WAVE AUTOMATED PERFORMANCE ANALYSIS(GWAPA)
over Smooth and Irregular Homogeneous or Inhomogeneous
Earth with Linear Atmosphere
Version 6.0, 8/01/86
TUE 02 SEP 1986 12:18:04

```
CHOOSE FROM THE MENU:

     C=CONCISE DIALOG
     V=VERBOSE DIALOG

MENU(VERBOSE)=?

     1)  TRANSMISSION LOSS                                   (TL)
     2)  RECEIVED POWER                                      (RP)
     3)  RECEIVED SIGNAL/NOISE                               (NM)
     4)  ACHIEVABLE RELIABILITY                              (RM)
     5)  ACHIEVABLE DISTANCE                                 (DM)
PROCESSING OPTION( 1) >? 4
INPUT DATA
CR TO SPECIFY DEFAULT OPTIONS AS SHOWN IN PARENS

     1)  DISTANCE UNIT = KM, HEIGHT UNIT = METERS
     2)  DISTANCE UNIT = MILES, HEIGHT UNIT = FT.
METRIC OR ENGLISH( 1) >?

1)  FREQUENCY (MHZ)
      UP TO 15 VALUES.  999 INDICATES END OF LIST.
FREQUENCY NO. 1>1
FREQUENCY NO. 2>5
FREQUENCY NO. 3>999

TRANSMITTER ANTENNA HEIGHT (      0.0 TO  12000.0)
 2) TRANSMITTER ANTENNA HEIGHT(      2.0 M. )? 0

RECEIVER ANTENNA HEIGHT (      0.0 TO  12000.0)
 3) RECEIVER ANTENNA HEIGHT(      2.0 M. )? 0

     1)  LATS AND LONGS OF BOTH ANTENNAS
     2)  LAT&LONG OF TRANSMITTER, BEARING AND DISTANCE TO RECEIVER
 4) ANTENNA RANGE OPTIONS          ( 1) >?2

DISTANCE BETWEEN ANTENNAS (      1.00 TO 21000.00)
 5) DISTANCE BETWEEN ANTENNAS(    100.00 KM.)? 150

TRANSMITTER LATITUDE ( -89.99 TO   89.99)
INPUTS OF THE FORM X,Y,Z IMPLY DEGREES,MINUTES,SECONDS
INPUTS OF THE FORM X.Y IMPLY DECIMAL DEGREES
```

```
 6) TRANSMITTER LATITUDE(  40.03 )?
TRANSMITTER LONGITUDE (-180.00 TO  180.00 )
 7) TRANSMITTER LONGITUDE(-105.30 )?

INITIAL BEARING (  0.00 TO 360.00 )
11) INITIAL BEARING( 10.00 )?

BEARING INCREMENT (    .01 TO 360.00 )
12) BEARING INCREMENT( 10.00 )?

FINAL BEARING (  0.00 TO 360.00 )
13) FINAL BEARING(100.00 )? 20

     1)  VERTICAL    (V)
     2)  HORIZONTAL  (H)
14) ANTENNA POLARIZATION                ( 1) >?

     1)  VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
     4)  INVERTED L                     (IL)
     5)  SLOPING LONGWIRE TERMINATED    (SL)
     6)  VERTICAL HALF RHOMBIC          (HR)
     7)  FIELD STRENGTH OPTION          (FS)
     8)  USER GAIN INPUT                (UG)
15) TRANSMITTER ANTENNA TYPE      ( 1) >?8
FREQUENCY =  1.000

TRANSMITTER GAIN (-100.000 TO  100.000 )
TRANSMITTER GAIN(    0.000 )>? 1
FREQUENCY = 5.000

TRANSMITTER GAIN (-100.000 TO  100.000 )
TRANSMITTER GAIN(    0.000 )>? 2

     1)  VERTICAL MONOPOLE              (VM)
     2)  VERTICAL DIPOLE                (VD)
     3)  VERTICAL LOG PERIODIC          (LP)
     4)  INVERTED L                     (IL)
     5)  SLOPING LONGWIRE TERMINATED    (SL)
     6)  VERTICAL HALF RHOMBIC          (HR)
     7)  FIELD STRENGTH OPTION          (FS)
     8)  USER GAIN INPUT                (UG)
16) RECEIVER ANTENNA TYPE               ( 1) >?8
FREQUENCY = 1.000

RECEIVER   GAIN (-100.000 TO  100.000 )
RECEIVER   GAIN(    0.000 )>? 1
FREQUENCY = 5.000

RECEIVER   GAIN (-100.000 TO  100.000 )
```

```
RECEIVER   GAIN(   0.000 )>? 2

ACTUAL TRANSMITTER INPUT POWER (      .0001 TO 10000.0000 )
18) ACTUAL TRANSMITTER INPUT POWER(    1.0000 Kw)?

21) LOCAL TIME OF DAY (FORMAT HHMM)
    UP TO 24 VALUES.  999 INDICATES END OF LIST.
TIME       NO. 1>1200
TIME       NO. 2>999

22) SEASONS
    UP TO 4 VALUES, 999 INDICATES END OF LIST.
1)  DEC,JAN,FEB(DJF)
2)  MAR,APR,MAY(MAM)
3)  JUN,JUL,AUG(JJA)
4)  SEP,OCT,NOV(SON)
SEASON     NO. 1>1
SEASON     NO. 2>999

REQUIRED RELIABILITY (    .01 TO 100.00%)
23) REQUIRED RELIABILITY( 90.00%)?

     1)  140.4   BUSINESS
     2)  144.7   RESIDENTIAL
     3)  150.0   RURAL
     4)  164.1   QUIET RURAL
     5)  USER INPUT
24) MAN MADE NOISE(-DBW) AT 3 MHZ ( 1) >?4

REQUIRED SIGNAL/NOISE RATIO (  1.00 TO 200.00 )
25) REQUIRED SIGNAL/NOISE RATIO(  2.00 DB)? 70

     1)  SMOOTH EARTH             (SE)
     2)  SMOOTH EARTH, MIXED PATH(SEMP)
     3)  IRREG. EARTH, MIXED PATH (IEMP)
26) PROCESSING METHOD             ( 1) >?

EARTH RADIUS RATIO ( .500 TO 3.000 )
27) EARTH RADIUS RATIO(1.333 )?

32) GROUND CONSTANTS FOR BEARING =  10.00
SIGMA = CONDUCTIVITY (.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)

SIGMA (    .1000000 )>? .01
EPSILON(   1.000 )>? 10

32) GROUND CONSTANTS FOR BEARING =  20.00
```

```
SIGMA = CONDUCTIVITY (.00001 - 100. SIEMENS/METER)
EPSILON = RELATIVE PERMITTIVITY (1 - 100)

SIGMA (    .100000 )>? .05
EPSILON(   1.000 )>? 15

CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(WRITE)=?

INPUT TITLE, 1 TO 60 CHARACTERS
EXAMPLE 6
DATA TO FILE COMPLETE
CHOOSE FROM THE MENU:
     C = CONCISE DIALOG
     V = VERBOSE DIALOG
     E = EDIT DATA
     S = SUMMARY OF DATA
     P = PROCEED
     W = WRITE DATA TO FILE
     Q = QUIT

MENU(QUIT)=?

STOP PROGRAM GWAPA TERMINATED
```

EXAMPLE 6
ACHIEVABLE RELIABILITY; MULTIPLE INPUT
PROCESSING METHOD = SMOOTH EARTH

TRANSMITTER ANTENNA HEIGHT = 0.0 M. RECEIVER ANTENNA HEIGHT = 0.0 M.
TRANSMITTER SITE DISTANCE
40.03N - 105.30W 150.0KM 93.2MI

ANTENNA POLARIZATION = VERTICAL
TRANSMITTER ANTENNA TYPE = USER GAIN INPUT
RECEIVER ANTENNA TYPE = USER GAIN INPUT

EFFECTIVE EARTH RADIUS/ACTUAL EARTH RADIUS = 1.333
TRANSMITTER INPUT POWER = 1.0KW
MAN MADE NOISE(-DBW) AT 3 MHZ = 164.1 DBW REQUIRED SIGNAL/NOISE = 70.0DB

AZIMUTH = 10.0 DEG. SITE = 41.4, -105.0
SIGMA(CONDUCTIVITY) = .0100000 EPSILON(DIELECTRIC CONSTANT) = 10.00

FREQUENCIES IN MEGAHERTZ
1.00 5.00

DEC,JAN,FEB TIME = 1200LT

NOISE DBW	-148	-165
TRANSMITTER ANTENNA DB	1	2
RECEIVER ANTENNA DB	1	2
SIGNAL DBU	38	3
RECEIVED POWER DBW	-62	-110
ACHIEVABLE RELIABILITY(%)	100	0

EXAMPLE 6 (Cont.)

EXAMPLE 6

ACHIEVABLE RELIABILITY; MULTIPLE INPUT
PROCESSING METHOD = SMOOTH EARTH

TRANSMITTER ANTENNA HEIGHT = 0.0 M. RECEIVER ANTENNA HEIGHT = 0.0 M.

TRANSMITTER SITE 40.03N - 105.30W
DISTANCE 150.0KM 93.2MI

ANTENNA POLARIZATION = VERTICAL

TRANSMITTER ANTENNA TYPE = USER GAIN INPUT
RECEIVER ANTENNA TYPE = USER GAIN INPUT

EFFECTIVE EARTH RADIUS/ACTUAL EARTH RADIUS = 1.333

TRANSMITTER INPUT POWER = 1.0KW
MAN MADE NOISE(-DBW) AT 3 MHZ = 164.1 DBW REQUIRED SIGNAL/NOISE = 70.0DB

AZIMUTH = 20.0 DEG. SITE = 41.3, -104.7
SIGMA(CONDUCTIVITY) = .0500000 EPSILON(DIELECTRIC CONSTANT) = 15.00

FREQUENCIES IN MEGAHERTZ
1.00 5.00

DEC,JAN,FEB TIME = 1200LT

NOISE DBW	-148	-165
TRANSMITTER ANTENNA DB	1	2
RECEIVER ANTENNA DB	1	2
SIGNAL DBU	55	18
RECEIVED POWER DBW	-46	-95
ACHIEVABLE RELIABILITY(%)	100	51

5. CONCLUSIONS

Program GWAPA is a versatile and user-friendly analysis model for systems performance prediction of communication circuits that use the ground wave as the primary mode of propagation. It provides computation results with reasonable accuracy for engineering analysis.

One primary feature of this computer program is its ability to accurately predict antenna performance for certain antenna types over lossy Earth. Other antenna types can be added to the antenna algorithm. The gains of most antennas can vary radically over a lossy Earth depending on the antenna height, geometry, and ground constants. The antenna algorithm within GWAPA is believed to be accurate to within 1-2 dB depending on the actual antenna type. This accuracy is with respect to actual computations performed with NEC-3. The antenna algorithm does not agree with program NEC-3 exactly, because a certain degree of data smoothing was performed to represent the antenna behavior with simple algebraic equations and look-up tables. The model could be improved to reduce this error by further refinement of the look-up tables and equations. An antenna measurement program to verify the antenna algorithm is needed that would determine its relative accuracy with respect to measured data.

A second feature of this program is that it combines a smooth-Earth and irregular-Earth propagation loss prediction capability for homogeneous and inhomogeneous Earth into one unified and user-friendly analysis tool. Electric field strength and received signal-to-noise power ratio are also available as outputs. A reliability prediction is available in the signal-to-noise power-ratio computation. The achievable distance output option is a convenient tool for obtaining coverage contours for different signal-to-noise power ratios and reliabilities.

Recommendations for future work include the following: expanding the antenna algorithm to include other practical antenna types, verifying the antenna algorithm with measured data and using this data to refine the algorithm, and investigating further methods of speeding up the irregular-Earth propagation loss prediction method without sacrificing loss prediction accuracy.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

An automated analysis model is presented for the prediction of system performance of communications circuits that use the ground wave as the primary mode of propagation. The computer program Ground-Wave Automated Performance Analysis (GWAPA) is a user-friendly program that can predict propagation loss, electric field strength, received power, noise, received signal-to-noise power-ratio, and antenna factors over lossy Earth. The smooth-Earth and irregular-Earth propagation loss prediction methods can be used over either homogeneous or mixed paths. A special antenna algorithm is integrated into the computer program for rapid prediction of antenna performance as a function of antenna geometry, ground constants, frequency, and azimuthal direction for a variety of antennas. A description of the computer program GWAPA, a discussion of its capabilities, instructions for its use, and illustrative sample calculations are included in this report.

16. Key Words *(Alphabetical order, separated by semicolons)*

ground-wave antenna model; ground-wave propagation; irregular terrain; lossy Earth; MF propagation; mixed path; smooth Earth; surface waves

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