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Modeling and Experimental Support for Detection of Linear Conductors Task Authorization 5: FORTRAN GRWAVE Translation

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1 Introduction

There is an ongoing research program at Defence Research and Development Canada (DRDC) Suffield Research Centre (SRC) to explore electromagnetic (EM) scattering from linear conductors to better understand the physical phenomena governing this effect. The purpose of this contract is to provide technical expertise to supplement the efforts at DRDC by furthering the research on EM scattering through experimental and theoretical means.

The need to detect linear conductors is pertinent to military and commercial interests. A number of commercial applications would benefit from a reliable method to detect buried infrastructure such as wires, pipes, rods and other infrastructure critical to the delivery of crucial services to consumers. Detection of these conductors would help to significantly reduce the number of occurrences resulting in interruptions to power, water and communications services that result from excavation operations. This would directly result in time and money savings for businesses and consumers alike and help alleviate associated safety and environmental concerns.

A principal consideration in many of the detection schemes proposed and examined is the propagation of transmitted EM fields over different ground types. The International Telecommunications Union (ITU) developed a software application called GRWAVE that calculates these parameters (International Telecommunications Union 2007). This software was originally developed over three decades ago using the FORTRAN programming language. There is a need for a modernized version of this software that can be incorporated into different linear conduction detection models.

The original GRWAVE software has been translated into C#, a modern programming language, and has been given a graphical user interface GUI for ease of use. Several enhancements have been made to ensure the new software operates much more in line with the FORTRAN version; specifically, the new software is capable of handling horizontal polarizations and non-zero transmitter heights in the event that these are required. The outputs of this new software compare favourably to those of the original ITU version. Note that this report is a continuation of a prior report (C-CORE 2017).

This work has been carried out under Task Authorization (TA) 5 entitled “Scattering Model Streamlining and Spectrum Analyzer Comparison.” This TA is authorized under contract No. W7702-175832/001/EDM with DRDC Suffield.

1.1 Scope

This report provides an overview of the work carried out to add enhancements to the translation of the existing FORTRAN code into a modern programming language, C#. Horizontal polarizations and non-zero transmitter heights have been addressed. Comparisons between the outputs from the two versions have been made. Suggestions for further enhancement of this software are also presented.

1.2 Definitions

Acronym	Definition
AM	Amplitude Modulation

Acronym	Definition
CCIR	Consultative Committee on International Radio
DLL	Dynamic Link Library
DOS	Disk Operating System
DRDC	Defence Research and Development Canada
EM	Electromagnetic
GUI	Graphical User Interface
ITU	International Telecommunications Union
PC	Personal Computer
SRC	Suffield Research Centre
TA	Task Authorization
WKB	Wentzel-Kramers-Brillouin

2 History

The original GRWAVE program is designed to estimate the electric field strength from a vertically or horizontally polarized antenna over a range of distances along the earth's surface at low and medium frequencies. It is based solely on ground wave propagation and ionospheric reflections are ignored, though in practice they may be very important even in the AM band. For example at night, the ionization in the D-region decreases and EM waves can penetrate to heights where they can be reflected without much loss associated with electronic collisions with neutrals. The model includes a spherical homogeneous earth so that, at large distances, surface waves are the means by which propagation takes place around the curvature of the ground. In addition, it is assumed that the atmosphere refractivity decreases exponentially as recommended by the Consultative Committee on International Radio (CCIR). The variation with height typically causes refraction of rays away from the earth.

The program is based on theoretical work by Rotheram (1970, 1981a, 1981b, 1982) and original versions were coded prior to 1985 at Marconi Company. Along the way, several modifications were necessary to enable compilation on mainframe computers to accommodate minor variations in their compilers. Finally, in 1988 at the Naval Warfare Center at Dahlgren, VA, the source code was adjusted to run on a Personal Computer running Microsoft's Disk Operating System (DOS). All versions were coded in FORTRAN.

GRWAVE has been adopted by the ITU for frequencies between 10 kHz and 30 MHz (International Telecommunications Union 2007) but it probably provides adequate estimates well above 30 MHz and possibly up to 1 GHz. At 30 MHz and below, the earth is characterized by its relative permittivity and its conductivity, which are approximately constant with frequency (International Telecommunications Union 2017). The principal factor affecting ground properties is its moisture content. As this rises, both the relative permittivity and the conductivity increase. GRWAVE is believed to render valid estimates from very dry, through very wet soils to sea water.

The ITU (International Telecommunications Union 2007) provides a set of graphs derived from GRWAVE and these illustrate the ground wave propagation characteristics as a function of frequency and soil moisture conditions. They are for transmitters and receivers at zero height.

The program can be downloaded from the ITU at <https://www.itu.int/en/ITU-R/study-groups/rsg3/Pages/iono-tropo-spheric.aspx>.

3 Running Original Version

The original GRWAVE program runs under Microsoft DOS and, on modern 32 bit machines, requires the Command Prompt. There are several different ways in which the program can be run and these are described in the GRWAVE manual ("GRWAVE Manual" 1985). The most convenient running mode involves entering the input data into a file and automatically reading this file at runtime. At the same time, the output data can be written to an output file, which is stored.

There are three options for the output, which are associated with the keyword "DEBUG". Basic output can be chosen, when this is set to zero. When set to two, a very detailed output is provided and this has been used to correct and validate the new 64 bit version.

3.1 Limitations

The principal limitation of the original GRWAVE executable, which is available from the ITU, is that it is compiled for a Personal Computer running a Microsoft DOS or Windows operating system on a 286 or 386 CPU. It does not run on modern 64-bit machines using Microsoft Windows. Moreover, it is written for a Microsoft FORTRAN Version 4.0 compiler in an old unstructured style, which is not conducive to understanding or easy modification. While it may be possible to adjust the code for a modern FORTRAN compiler, it is not certain that this would be an easy or simple task.

When run on a desktop or laptop machine, the Command Prompt must be used along with DOS commands. This is not a very intuitive approach and involves the typing of commands, which can be time consuming.

FORTRAN has been largely superseded by C-style languages. In particular, stand-alone processor boards designed for embedded applications, such as those that may be incorporated in detection systems, typically require programming in C or C++. The original source code requires translating to accommodate these boards.

3.1.1 FORTRAN

There are about 60 pages of FORTRAN code in the original version. Approximately 50 pages contain the relevant algorithms and the remainder represent modifications necessary for the program to run on different machines with various compilers.

The code is written in a style that was common in the 1970s and early 1980s. Until the advent of FORTRAN 77, structured code was rare and the original GRWAVE program reflects this. Only when modifications to the code have been made late in the development is structured code employed and this appears only once. Therefore, branching in almost all the code is accomplished using "goto" statements. Some of these are easily replaced by structured equivalents but others are a problem.

A further issue is related to the compilers at the time that the code was developed. These were quite unsophisticated and it was necessary to actively consider the influence of the code on the run time. This

led to strange constructions involving global variables to reduce run times. These require some effort to replace.

Object-oriented code was starting to appear by 1985 but was not adopted in GRWAVE. Therefore, the code is just a sequence of routines, which are not packaged rationally.

The original code is heavily commented. This has proved valuable in translating it to another language. The comments refer to reports SRI, SRII and SRIII. These are believed to be the documents by Rotheram (1981a, 1981b, 1982) respectively.

3.2 Algorithms

The code is based on work by Rotheram (1970) to include an exponentially decreasing atmospheric density (and refractivity) and a spherical earth. In this 1970 paper, he describes the effect of the exponential variation of refractivity on the effective radius of the earth, which is approximately 4/3 of the real radius. He shows that this, rather than a linear approximation, is important for frequencies less than 30 MHz.

The propagation over short distances is treated by Rotheram (1981a). This uses an extension of the flat earth theory of Sommerfeld. The extension employs an earth-flattening transformation of the equations. It is valid for small ranges and small transmitter and receiver heights. Propagation is handled in terms of the Wentzel-Kramers-Brillouin (WKB) approximation and Airy integrals.

With small transmitter and receiver heights and at long distances well beyond the earth's horizon, another method must be used and this is described in Rotheram (1981b). It is based on a representation in terms of a series of residues from an integral in the complex plane. There is typically a large overlap between the extended Sommerfeld theory and the residue approach and in GRWAVE differences between the two for the same range are typically less than 0.1 dB.

Finally, when the transmitter height is large and the receiver is above the radio horizon, geometrical optics is employed (Rotheram 1981b). The differences between the geometrical optics method and the other two are typically less than 1 dB.

Sets of curves are presented in Rotheram (1982) for the electric field strength against range for a number of frequencies between 10 kHz and 30 MHz. Graphs for a vertically polarized transmitter at ground level are provided for several ground conductivities from very dry ground to sea water. (For solid ground, the relative permittivity is assumed to be 4, which is reasonable only for dry grounds.) The transmitter power is assumed to be about 1 kW and it is assumed that the transmitter is always located on a conducting ground plane.

It is worth noting that the constants, such as π , the speed of light and the permittivity of free space are usually approximate. The replacement by more accurate values could lead to minor changes in the outputs.

4 Newer Version

A new version of GRWAVE has been coded in the C# language. This was chosen because it is very close to C++ but avoids the use of pointer variables.

4.1 Program Description

The new program is a translation from FORTRAN to C#. It was created using Microsoft's Visual Studio 2010 and runs on a 32 or 64-bit PC with a Windows operating system. Unlike the original, the program processes only one transmitter and one receiver (as a pair) at a time. The GUI is pre-loaded with standard input data in text boxes; these can be altered. The input data includes the transmitter coordinates and the parameters frequency, polarization and height above ground. The receiver parameters are the minimum and maximum distance and height. The atmospheric parameters are the scale height and refractivity, while the ground parameters are the relative permittivity and conductivity.

The outputs are the electric field amplitude (in dB $\mu\text{V}/\text{m}$) and the transmission loss in dB as a function of receiver distance. These are written to a "Listview" box. It is possible to save the output data to a file.

The program architecture is similar to that of the original program. The GUI simply calls a function "Grwave", which is located in a class "GRWAVE". This class contains most of the code but there are additional classes containing the Runge-Kutta algorithm and various coefficient lists.

On a typical computer, the output appears almost instantaneously after the "Go" button is clicked.

In practice, the output must often be compared with the ambient radio noise at the receiver. Information on this can be found in ITU-R P.372-13 (International Telecommunications Union 2015).

4.2 Ground Properties

Some basic default ground properties can be found in the ITU report "Ground-wave Propagation Curves for Frequencies between 10 kHz and 30 MHz" (International Telecommunications Union 2007). These are for soils ranging from very dry to very wet. Fresh and salt water are also included.

A more comprehensive description of typical ground properties is provided by the International Telecommunications Union in Recommendation ITU-R P.527-3 (International Telecommunications Union 1992). Again the range of frequencies of interest is from 10 kHz to 30 MHz. At frequencies below about 50 MHz, the relative permittivity and conductivity of typical ground types as a function of frequency are almost constant.

The principal factor affecting the ground properties of soils is the moisture content. In the previous ITU report (International Telecommunications Union 1992), the ground relative permittivity and conductivity varies smoothly from 3.0 and 10^{-4} S/m for very dry soils to 40 and 0.03 S/m for very wet soils. In the latest report (International Telecommunications Union 2017), information is provided on different types of soils, which are a combination of sand, clay and silt. This is based on a soil texture triangle, which identifies soils, such as sandy loam, silty clay and silty clay loam, in terms of the percentage of their constituents.

Unfortunately, one axis in the report is not stated (sand) and the clay axis is reversed. Formulae for the dielectric properties are provided as functions of the three constituent's percentages and the percentage of water.

To use the soil texture triangle, it must be appreciated that the coordinate lines for clay are horizontal, those for sand are upwards and slanted to the left, while those for silt are slanted to the right. It can soon be verified that any two of clay, sand and silt can be used unambiguously provided the three constituents add to 100 percent.

In all cases, it should be appreciated that soils may have complex permittivities, which are not typical, and that soils are usually not homogeneous but are often layered with different levels of moisture content. In such cases, an effective complex permittivity may be estimated.

4.3 Comparison of Results and Examples from Original Program

The original program was run with a wide range of parameters; the frequency was varied from 0.01 to 1000 MHz, the ground varied from very dry to sea water, the polarization was vertical and horizontal. The transmitter and receiver heights were varied from 0 to 10,000 m in vertical polarization. In horizontal polarization, the heights were varied from a few metres—owing to the fact that at near-zero heights, there is no transmission due to field cancellation—to 10,000 m. It was noted that, using the new version, the changeover distance from the flat earth to the residue model was often slightly different but the field strengths were never different by more than about 0.1 dB and usually much less. The reason for the small differences is not known but could be due to the use of slightly different constants, such as "PI".

The differences for vertical polarization are typically very small and are greatest for horizontal polarization.

4.3.1 Example 1

This is for very dry ground at a frequency of 5 MHz with vertical polarization.

```
*****GRWAVE (RELEASE 2 AT 23/10/1985 )*****  
*****COPYRIGHT (C) GEC PLC 1985 *****  
CCIR Personal Computer Version 1989 Study Group 5 IWP5/1
```

```
GRWAVE COMPUTES FIELD STRENGTH-DISTANCE VARIATIONS  
FOR A HOMOGENEOUS CURVED EARTH WITH EXPONENTIALLY  
DECREASING REFRACTIVE INDEX
```

```
ATMOSPHERIC CONSTANTS  
REFRACTIVITY =315.00 (N-UNITS)  
SCALE HEIGHT = 7.350 KM
```

```
GROUND CONSTANTS  
RELATIVE PERMITTIVITY = 4.000
```

CONDUCTIVITY = 1.0000D-04 SIEMENS/METRE

VERTICAL POLARISATION

MINIMUM DISTANCE = 10.000 KILOMETRES
MAXIMUM DISTANCE = 200.000 KILOMETRES
DSTEP = 10.000 KILOMETRES

FREQUENCY = 5.000 MHZ

TRANSMITTER HEIGHT = 100.0 METRES
RECEIVER HEIGHT = 100.0 METRES

DISTANCE KM	FIELD STRENGTH DB(UV/M)	BASIC TRANSMISSION LOSS DB	
10.00	69.68	80.29	(F)
20.00	57.60	92.37	
30.00	50.31	99.67	
35.41	47.25	102.73	
			(R)
35.41	47.32	102.66	
40.00	45.03	104.94	
50.00	40.73	109.24	
60.00	37.09	112.88	
70.00	33.89	116.09	
80.00	30.99	118.98	
90.00	28.34	121.64	
100.00	25.86	124.12	
110.00	23.52	126.46	
120.00	21.29	128.69	
130.00	19.15	130.83	
140.00	17.08	132.90	
150.00	15.07	134.90	
160.00	13.12	136.86	
170.00	11.20	138.78	
180.00	9.32	140.66	
190.00	7.46	142.51	
200.00	5.64	144.34	

Stop - Program terminated.

For comparison the output of GRWAVE-64 for this same situation can be found in Figure 1.

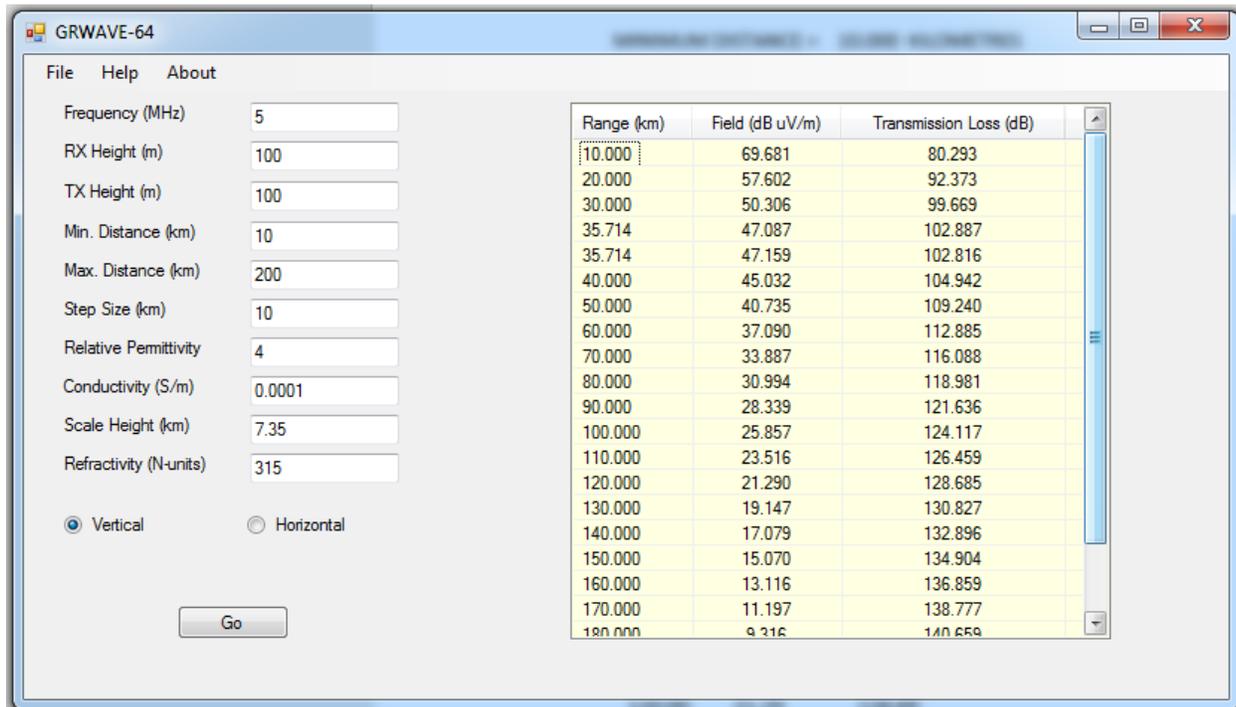


Figure 1. GRWAVE-64 output screen capture for example 1.

4.3.2 Example 2

This is for medium ground at a frequency of 5 MHz with horizontal polarization.

```
*****GRWAVE (RELEASE 2 AT 23/10/1985 )*****
*****COPYRIGHT (C) GEC PLC 1985 *****
CCIR Personal Computer Version 1989 Study Group 5 IWP5/1
```

GRWAVE COMPUTES FIELD STRENGTH-DISTANCE VARIATIONS
 FOR A HOMOGENEOUS CURVED EARTH WITH EXPONENTIALLY
 DECREASING REFRACTIVE INDEX

ATMOSPHERIC CONSTANTS
 REFRACTIVITY =315.00 (N-UNITS)
 SCALE HEIGHT = 7.350 KM

GROUND CONSTANTS
 RELATIVE PERMITTIVITY = 22.000
 CONDUCTIVITY =3.0000D-03 SIEMENS/METRE

HORIZONTAL POLARISATION

MINIMUM DISTANCE = 10.000 KILOMETRES
MAXIMUM DISTANCE = 200.000 KILOMETRES
DSTEP = 10.000 KILOMETRES

FREQUENCY = 5.000 MHZ

TRANSMITTER HEIGHT = 100.0 METRES
RECEIVER HEIGHT = 100.0 METRES

DISTANCE KM	FIELD STRENGTH DB(UV/M)	BASIC TRANSMISSION LOSS DB	(F)
10.00	69.79	79.62	
20.00	57.52	91.88	
30.00	50.14	99.26	
35.66	46.92	102.48	
			(R)
35.66	47.00	102.41	
40.00	44.83	104.58	
50.00	40.49	108.91	
60.00	36.82	112.59	
70.00	33.59	115.82	
80.00	30.67	118.74	
90.00	27.99	121.42	
100.00	25.48	123.92	
110.00	23.11	126.29	
120.00	20.87	128.54	
130.00	18.70	130.70	
140.00	16.61	132.79	
150.00	14.58	134.83	
160.00	12.60	136.80	
170.00	10.66	138.74	
180.00	8.76	140.65	
190.00	6.88	142.52	
200.00	5.04	144.37	

Stop - Program terminated.

For comparison the output of GRWAVE-64 for this same situation can be found in Figure 2.

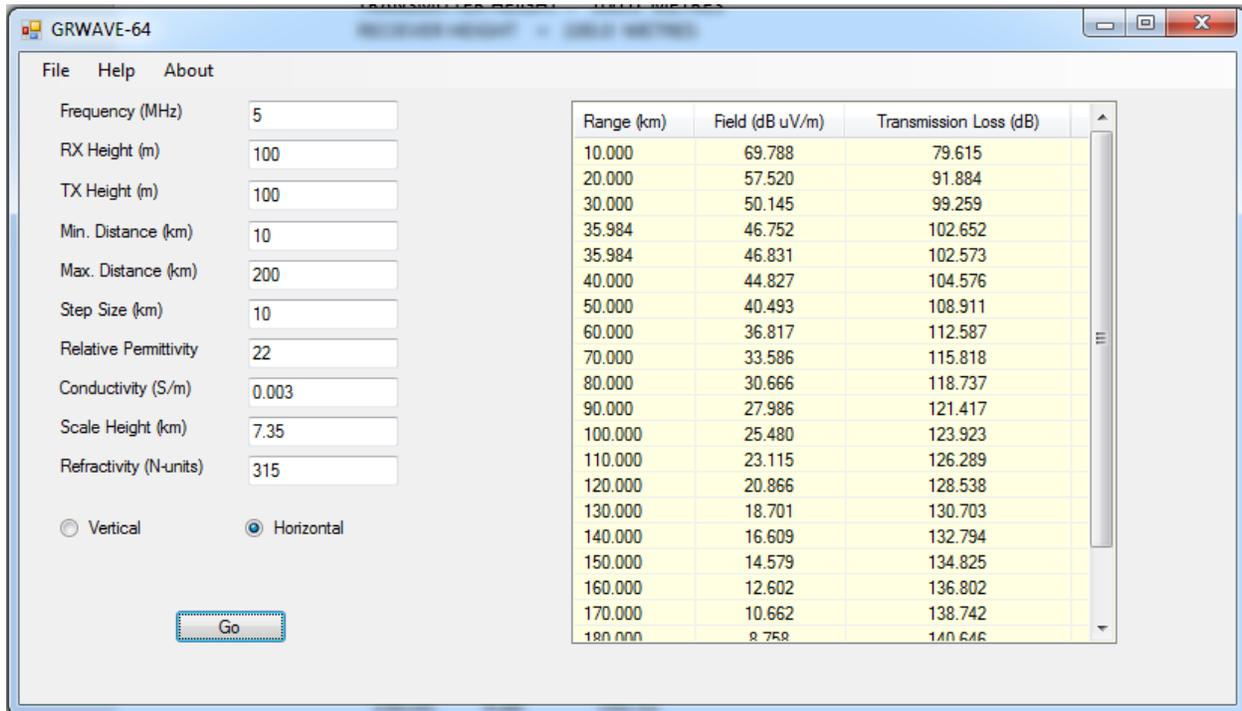


Figure 2. GRWAVE-64 output screen capture for example 2.

5 Conclusions

A newer version of the 1985 software GRWAVE was produced in C#—a modern programming language—which replicates the functionality of the original program. With the exception of a few “goto” statements—whose replacement would have produced unpredictable results—this software has been written to modern object-oriented programming standards. The new program is also equipped with an intuitive GUI. As mentioned in Section 4.3, comparison between the outputs of the modern version and those of the older version indicate excellent agreement, with a maximum discrepancy of 0.1 dB. The current version of this software is ready to use in modelling and experimental applications where calculations regarding ground wave propagation are required, such as in the detection of linear conductors.

6 References

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The original GRWAVE software has been translated into C#, a modern programming language, and has been given a graphical user interface GUI for ease of use. Several enhancements have been made to ensure the new software operates much more in line with the original FORTRAN version; specifically, the new software is capable of handling horizontal polarizations and non-zero transmitter heights. The outputs of this new software compare favourably to those of the original ITU version across a wider range of conditions.