STUDY OF GROUND WAVE ELECTRIC FIELD INTENSITY USING AN IMPROVED SERVER AND SOFTWARE PACKAGE

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ABSTRACT

Ground wave electric field intensity, E is required for radio signal strength determination. In this paper, we evaluated E using an improved server and computer package. The critical frequency was also evaluated for any range of frequency up to the package maximum capacity of one hundred thousand. The server has twenty-one new methods, twenty-nine functions and seven properties, which are exposed in a client application, GWaveSoft and found to be accurate as comparison of calculated results with previous works unveiled. Calculated results with GWaveSoft depict that Norton and Braun reduction factors do not significantly affect E; and E is insensitive to dielectric constant increase. Software developers will find our improved dynamic server useful in their work. Meteorologists, Physicists, and Climatologists, as well as Communication amateurs and experts and Atmospheric Scientists, among others, will find GWaveSoft application indispensable in evaluating electric field intensity, a parameter for the practical determination of equipment requirement by system Engineers.
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Keywords: Critical frequency, Electric field intensity, GWaveCls, GWaveSoft

1. INTRODUCTION

The effective electrical characteristics of the earth's surface (conductivity σ (S/m), permittivity ε and permeability μ) influence ground wave propagation. They are very significant in medium frequency and low frequency broadcast planning where the ground wave is the primary mode of propagation [6]. Ground wave propagation, however, is primarily influenced by ε and σ, as μ is regarded equal to free space permeability $μ_o$ with numeric value of 1 when the earth is said to be non-magnetic. Besides, at broadcast frequencies (525-1605 kHz) the earth is more of a conductor than a dielectric; consequently σ is more important than ε [2]. The propagation coefficient k is related to these parameters by [6].

$$k = \sqrt{jw\mu(\sigma + jw\varepsilon)} = jw\sqrt{\mu\left(\varepsilon - j\frac{\sigma}{w}\right)} \qquad (1)$$

With reference to ground propagation, and $\mu = 1$, k becomes

$$k = j\frac{2\pi}{\lambda}\sqrt{\varepsilon_r - j60\sigma\lambda} \qquad (2)$$

Where ε_r is the relative permittivity (F/m), λ is the free-space wavelength (m).

Ajayi and Owolabi [2] computed ground wave electric field intensity, E for limited number of σ and ε_r using FORTRAN IV on IBM 360/25 digital computer. Also, Ajayi [3] calculated E with FORTRAN 77 for measured σ at several locations. At present there is no server for electric field intensity. The need to develop dynamic link library (DLL) and client application for ground wave propagation study and evaluation has been noticed [1]. Such a server and application should be used around the globe with little efforts and understanding of the computer.

Using Microsoft Visual Studio 2008, a high level computer object-orientated programming language, a class library (GWaveCls) and a client application (GWaveSoft) were developed for capacitance, conductivity, resistivity and skin depth estimation. For comprehensive discussion on these parameters see [1]. There is, however, no provision for ground wave electric field strength, E and critical frequency, C_f estimation, which the present work

seeks to address by including functionalities for E and C_f in the current versions of the server and package. With the inclusion of E and C_f all essential parameters for the design and planning of medium wave broadcast are in a single location for system Engineers to use to determine equipment requirement for medium wave transmitter; as well as other stakeholders, both amateurs and professionals, in communication and atmospheric science. Field strength is expected to be calculated, and from the estimated results propagation curves are to be plotted.

2. MODELS

The medium frequency band is extensively used for broadcasting. There exist prediction models for

$$A = \frac{2+0.3S}{2+S+0.6S^2} - Sin\,(b)\,\sqrt{\frac{S}{2}}\,\exp\left(\frac{-5S}{8}\right)$$
(4)

This factor, which accounted for the effect of ground losses, depends on conductivity, σ dielectric constant, ε frequency, f (kHz) and distance, d (km). This relationship is clearly seen in the numerical distance, S given by [10]

$$S = \frac{\pi D}{x\lambda} \cdot \frac{Cos^2 b''}{Cosb'}$$
(5)

The phase constant, b is expressed as

$$b = 2b'' - b'$$
(6)

It determines the validity of A, and A can only be used when $b \le 90^o$. The select case statement in our code effectively handles this as can be seen in The E_o parameter is related to output power, P (kW) of the transmitter and the transmitting antenna gain directed at the remote receiving point, G by

$$A = \frac{2+0.3S}{2+S+0.6S^2} - \sqrt{\frac{S}{2}}.\exp(-1.44S\log\varepsilon).Sin(\beta)$$
(11)

Where $S = 1.75x10^{-4}\,\dfrac{fCos(\beta)d.10^3}{\sigma\lambda}$ (12)

The phase constant, $\beta = \tan^{-1}\left[\dfrac{(\varepsilon+1)f}{18000\sigma}\right]$ (13)

2.2. Critical Frequency Model

The critical frequency in MHz, C_f is given by

electric field intensity, E and critical frequency, C_f evaluation.

2.1. Electric Field Strength Model

The surface wave field intensity, E is given by [2, 10]

$$E = \frac{AE_o}{d}$$
(3)

This expression in micro-Volt per metre (µV/m), for homogeneous terrain, is valid under two assumptions. The aerial heights effects, which are usually less than a quarter of a wavelength, for medium wave aerial, are neglected. Besides, the curvature of the earth is also ignored for distances close to the transmitter. The reduction factor, A is related to numerical distance, S by [2, 10]

appendix A. dvEfResult is set equal to NoCal (a string constant declared at class level for PhaseAngle > 90°) if b>90°; and the function returns, else calculation continues. b' and b'' are defined thus:

$$b' = \tan^{-1}\frac{\varepsilon-1}{x}$$
(7)

$$b'' = \tan^{-1}\frac{\varepsilon}{x}$$
(8)

$$x = \frac{18\sigma}{f}$$
(9)

$$E_o = 3\,x\,10^5\,\sqrt{PG}$$
(10)

For Braun [5] model, the attenuation reduction factor, A is related to numerical distance, S by

$$C_f = 80f^{\frac{-1}{3}}$$
(14)

All the fractions are converted to decimal before use such as 1/3 which is equal to 0.3333. These equations are modularized in our server, GWaveCls, so that future maintenance will be easier to carry out.

3. DATA

The data used for this work were collected from five sites in Nigeria. Ground electrical conductivity

measurements were carried out using portable Soil Test Resistivity Meter equipment Model R-50 and the Wenner array probe method was used. The measurements, which details could be found in [3], cover the two major seasons of dry and wet in Nigeria. Besides, arbitrary inputs will also be utilized to test various parts of the server and package. Data accepted for use for f and d could be in range or non-range form. The range form saves time and efforts in keying-in large data for use. The provision of the two forms gives flexibility to the user of our package which modern application is expected to provide.

Data can be keyed-in interactively through a good looking user interface like the one shown in figure1 and it can be uploaded from user's supplied file when Upload Data menu of figure1 is clicked. Graphical display of propagation curves is not presented extensively in this work so that results could be seen directly, and accuracy of our server and package could be ascertained. We shall discuss only Electric field strength and Critical frequency main menus of figure 1, since other main menus have been treated in previous version [1].

4. ENHANCED SERVER

Servers are the backbone of any application; with them, applications could accurately and swiftly be developed. All servers have functionalities that could be exposed in client applications.

4.1. Classes and Methods

Classes are blueprints utilized to create new objects [8, 11]. A base class, a class without *inherits keyword modifier*, will be declared for this work. Thus, there is no need to declare a derived class before it could be used. There are twenty-one new methods in GWaveCls class. We declare some arguments as object data type, so as to allow any data type (integer, double etc) to be used for calculation without any problem.

Any reference argument is to return a new value. For instance, the Microsoft DataGridView (DGV) control holds both the inputs and the result(s), which permits easy viewing of inputs and output result(s) together.

The dvCalElectricfieldStrength_Norton method is overloaded to compute field intensity, E for non-range inputs. The six inputs for E evaluation are sent in as object data type. The last object reference argument returns the computed E value. The second overload method has a reference DGV control. The inputs are read from the DGV control, validated and utilized to evaluate E. The result is stored in the last column of the control. Both overloads call dvCalNortonParasA function to compute reduction factor, A (eqn. 4).

Another method to compute E using Norton reduction factor inputs with range of frequency f and distance d values exist. The remaining inputs of σ, P, G and ε are in a reference DGV control. Similar methods that function like that for Norton model discussed above exist for Braun model; and the methods call dvCalBraunParasA Function to calculate Braun reduction factor (eqn. 11). There exist two methods for calculating E for Norton and Braun together using their reduction factors for non-range and range inputs, and obtain the percentage difference between them, which could be used for analysis.

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To compute critical frequency C_f, the dvCriticalFreq method is utilized, and it is overloaded. The reference input DGV control holds the frequency (Hz) values to use in the first column and the computed C_f in the last column. The second overload has frequency f range values and the result is returned in a reference DGV control. The last overload accepts a single f (given in Hz) argument and returns a single C_f in a reference object argument. In all cases the f is converted to MHz and returns f in MHz as Table 1 depicts.
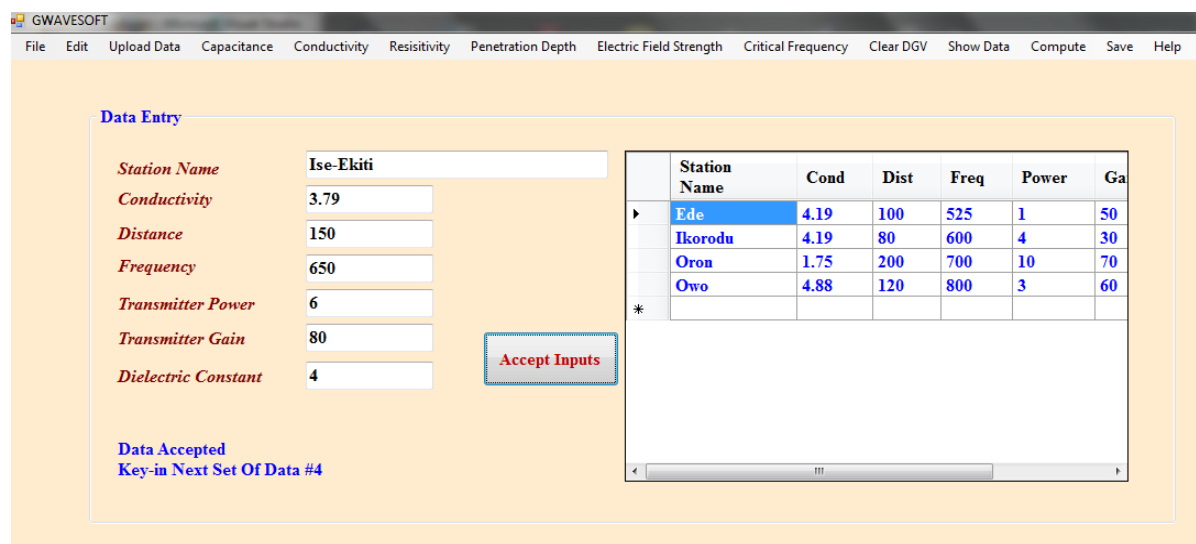
Figure 1: GWaveSoft Package User Interface

4.2. Functions and Properties

Functions in servers, unlike methods, are not accessible in any client applications. In our functions and methods, we check whether or not inputs are valid for use; if found unworthy, error message is returned, else OK and computation proceeds. Our functions are heavily overloaded and where we deem mistake(s) or error(s) is probably to occur, apart from input(s) check, we inserted error trapping(s). The dvCalNortonParasA and dvCalBraunParasA functions, for instance, calculate reduction factor A, using Norton and Braun parameters respectively and return the result in the last reference object argument. They have similar structure; and the codes for Norton reduction factor is shown in Appendix A with comments to which you are referred. With the available functions in our class, flexibility is achieved in doing what are required to be done at a particular point and future maintenance is guaranteed. There are seven properties in GWaveCls for setting the value of f, P, G, d, σ and ε. The user supplied values are assigned to private data members.

5. COMPUTATIONS

The field intensity of medium frequency varies in space and time according to the dependent inputs of which σ is a dominant factor [2]. The extent to which inputs f, σ, P, G and ε affect E will be looked into shortly.

5.1. Navigation and Results

Figure 2 is the user interface of our improved GWavSoft application showing the submenus under Electric Field Strength main menu. There are six submenus under Electric Field Strength main menu (hereinafter referred to as E menu or E main menu). In each of them, there are at least three submenus for single result computation and for multiple results which data is either from uploaded file or interactively keyed-in (see figure 2). A single result is returned if single result submenu is clicked. The multiple results submenus return results in a reference DGV control. By clicking the second submenu of Norton parameters submenu of E menu, user is prompted to supply f range. After successful acceptance of f, user is prompted again to supply d range; thereafter user is prompted to key-in other inputs. When done and compute main menu clicked, E will be computed and result displayed. Whether or not operation is successful, message is issued, thus user is carefully and fully informed on what transpired in the package via dvReport property.

Table 2 is the result for using Norton reduction factor when the second submenu of E main menu is clicked. Cond is the conductivity (mS/m) value, d (km) is the distance, f is the frequency (kHz), P is the power (kW), G is the directivity gain of the transmitter, DC is the dielectric constant, FSNorton is the field intensity calculated using Norton reduction factor. Similar result is obtained for Braun parameters submenu. Results for E, when Norton and Braun reduction factors were used, are shown in Table 3. FSBraun is the field intensity calculated using Braun reduction factor. Pd_NB is the percentage difference (pd) between the computed fields. The effects of σ, ε, P, and G on E could be seen in Tables 4-7.

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5.2. Variation of Field Intensity

The field E obtained in CondField1 column for σ values in column Cond1 (or column CondField2, σ values of column Cond2) of Table 4 for varying Cond1 and Cond2 (σ) and d values while keeping other inputs fixed show that σ has effect on E.
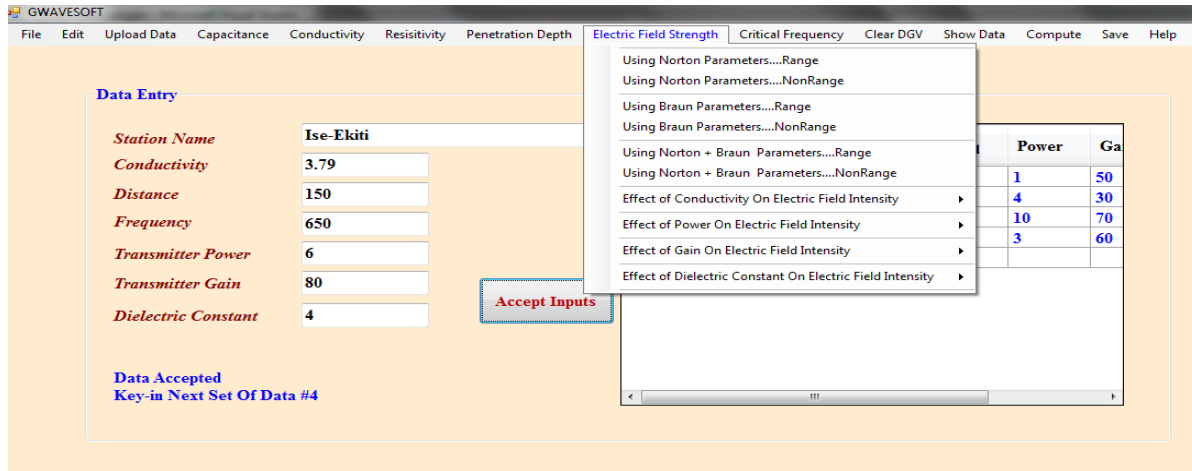
Figure 2: Showing Electric Field Strength Submenus

Table 1: Critical Freq

f (MHz)	Cdr
2.45E+07	2.75E-01
5.25E+08	9.92E-02
7.00E+08	9.01E-02
8.00E+08	8.62E-02
6.00E+07	2.04E-01

Table 2: Result for Norton reduction factor

Site	Cond	Dist	f	P	G	DC	FSNorton
Ede	4.19	5	600	1	50	4	4.24E+05
Owo	4.88	80	525	1	50	4	2.65E+04
Oron	1.75	100	600	1	50	4	2.11E+04
Ikorodu	9.54	50	800	2	90	2	8.04E+04
Ede	4.19	80	525	5	531	4	1.93E+05

Table 3: Norton and Braun Reduction Factor Result

Site	Cond	Dist	f(kHz)	Power	Gain	DC	FSNorton	FSBraun	PdNB
Ede	4.19	5	600	1	50	4	4.24E+05	4.24E+05	0.00049502
Owo	4.88	80	525	1	50	4	2.65E+04	2.65E+04	0.000301977
Oron	1.75	100	600	1	50	4	2.11E+04	2.11E+04	0.001420196
Ikorodu	9.54	50	800	2	90	2	8.04E+04	8.04E+04	0.000198898

Table 4: Conductivity Variations

f	P	G	DC	Cond1	Cond2	d	CondField1	CondField2	PdField12
525	1	1	4	1	50.00	10	3.00E+04	3.00E+04	0.00
525	1	1	4	20	9.12	20	1.50E+04	1.50E+04	0.00
525	1	1	4	12	44.00	30	1.00E+04	1.00E+04	0.00
525	1	1	4	5.9	100.00	40	7.50E+03	7.50E+03	0.00
525	1	1	4	10	23.00	50	6.00E+03	6.00E+03	0.00

Table 5: Power Effect on Field Intensity

f	P1	P2	G	DC	Cond	d	PField1	PField2	PdField12

525	1	730	50	4	4.5	10	2.12E+05	5.73E+06	185.7237
525	525	40	50	4	4.5	20	2.43E+06	6.71E+05	113.4732
525	102	900	50	4	4.5	30	7.14E+05	2.12E+06	99.25555
525	600	100	50	4	4.5	40	1.30E+06	5.30E+05	84.04084
525	50	1500	50	4	4.5	50	3.00E+05	1.64E+06	138.2452

Table 6: Gain Effect on Field Intensity

f	P	G1	G2	DC	Cond	d	GainField1	GainField2	PdField12
525	50	102	531.0	4	4.6	10	2.14E+06	4.89E+06	78.10973
525	50	50	800.0	4	4.6	20	7.50E+05	3.00E+06	120.0000
525	50	134	4.9	4	4.6	30	8.18E+05	1.56E+05	135.7887
525	50	15	525.0	4	4.6	40	2.05E+05	1.21E+06	142.1638
525	50	100	450.0	4	4.6	50	4.24E+05	8.99E+05	71.84910

Table 7: Dielectric Constant, ε Variation

f	P	Gain	DC1	DC2	Cond	d	DCField1	DCtField2	PdField12
525	50	531	1	4	4.6	10	4.89E+06	4.89E+06	0.00
525	50	531	14.5	9.12	4.6	20	2.44E+06	2.44E+06	0.00
525	50	531	4	4.9	4.6	30	1.63E+06	1.63E+06	0.00
525	50	531	15	12.9	4.6	40	1.22E+06	1.22E+06	0.00
525	50	531	10	23	4.6	50	9.77E+05	9.77E+05	0.00

Table 8: Frequency Effect on Field Intensity

(Cond=4.19, P=1, G=50, DC=4)

Site	d	f	FSNorton
Ede	5	600	4.24E+05
Ede	5	700	4.24E+05
Ede	5	750	4.24E+05
Ede	5	800	4.24E+05
Ede	10	600	2.12E+05
Ede	10	700	2.12E+05
Ede	10	750	2.12E+05
Ede	10	800	2.12E+05
Ede	80	600	2.65E+04
Ede	80	700	2.65E+04
Ede	80	750	2.65E+04
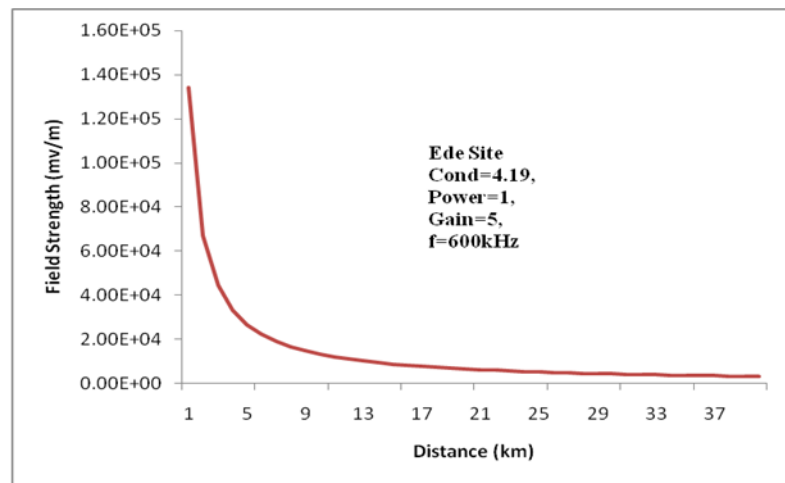
Figure 3: Plot of E against d for Ede site

E increases with increasing σ values; hence it couldn't be overlooked in medium frequency system design and planning. However, for the same fixed inputs in a given area, increase in σ has negligible effect on E as pd in pdField12 column shows. If σ is increased, as it should, it is to prevent short circuiting of radio frequency signal degradation, apart from preventing heat built-up on the antenna mast during

severe thunderstorm which could damage the antenna and its mast [4].

The implication is that a well-chosen σ for a given area is adequate for planning and designing. The effect of varying output power of a transmitter on E is given in Table 5. The power input columns, P1 and P2 produce field results of columns pdField1 and pdField2 respectively. The percentage difference, pd is in the last column, pdField12. High power inputs generates high field. For instance, 525 kW of column 2, row 2 produces 4.86E+06 field, while 730kW of column 3, row1 generates 5.73E+06. The pd between 525 kW and 600kW clearly indicates the difference in the fields obtained with the powers. Besides, with far distance d, E is low or attenuated. When d is 10km, for instance, the field, pField1 and pField2 (see column 8) is very high as against the low value gotten at 50km distance. As expected, for small d values and increase values of G, E increases as columns 3 and 4 inputs for columns 8 and 9 results respectively of Table 6 shows. The percentage difference (pd) between field results of columns 8 and 9 is significant, indicating that G should be carefully selected for planning coverage area. For fixed inputs other than ε and d, E does not change appreciably. ε in column 4 of Table 7 generates E value of column 8; ε in column 5 produces E of column 9. The fine detail of the result in shown in the pd column which is essentially zero to three decimal place. E is significantly unaffected with changing ε. This observation is in line with previous results [6,2].

Table 8 shows that for changing f and d values and other input parameters fixed, E varies slightly. This could be seen by comparing the first four lines when d = 5km, and lines 5-8 (d =10km) and 9-12 (d = 80). The reasonable conclusion here is that for a given fixed parameters in a particular area increasing f value does not generate increasing signal strength. Since medium electrical properties vary from one area to another according to area conditions, which include nature and moisture content of the soil, general geological structure of the ground, vegetation cover and surface objects, there is constant need to evaluate E for given frequencies under different conditions which GWaveSoft package has adequate

7. CONCLUSION

An existing flexible and accurate dynamic server and client application have been enhanced for ground wave electric field intensity, E and critical frequency

answer for with one hundred thousand input data capacity.

The effect of seasonal variation on ground wave propagation loss, according to studies [6], depends on the ratio of the depth of the soil exhibiting seasonal changes to skin depth. On the other hand, skin depth depends on f and σ. Consequently, varying f and σ values will cause seasonal variation on ground wave propagation. We observed a good mix of the inputs for a particular area will produce strong signal. Generally, with well-selected fixed parameter values, reliable medium band equipment could be designed for a given coverage area. Also, areas of weak signal could be identified for installation of booster station (s). Therefore, there is no need for booster station(s) where the signal is strong for good reception. However, for large d values and low values of G, E is very small with poor expected reception unless booster station(s) is put in place.

6. APPLICATIONS

Ajayi and Owolabi [2] used normalized effective radiated power of 1kW, produce propagation curves for 557 kHz, 656 kHz and 1088 kHz with two ε values: (4 is representative of an average ground and 15). The σ values range between 1-10 mho/m; the distance covers 10km to 130km. A set of ground wave curves for a range of standard f (10 kHz-30MHz) and ground characteristics were generated for the determination of ground wave field strength [7, 9].

This is required owing to the complexity of the field calculation which individual researcher and system Engineer has to embark upon from time to time in order to obtain the required parameters for medium and low frequencies system design. However, with available software package, required parameters could swiftly be generated thus eliminating the need to produce propagation curves before parameters are gotten for use. GWaveSoft was applied to compute E for 1 kHz-50MHz in step of 5 for 1-200km and for 2-30mS/m being representative for both Norton and Braun reduction factor. A plot of E against d is shown in figure 3 for Ede site for the parameters shown.

with the provision of robust functionalities. The functionalities are comprehensively tested and reported and their applications to five tropical sites in

Nigeria generated some useful data and information that could be employed for medium wave broadcast design and planning. There is no significant difference between E gotten for using Norton and Braun reduction factors; thus either could be utilized without result being significantly affected. Our package has easy-to-follow-and-use user interface and menus. To make GWaveSoft package entirely self-contained, there is need to include plotter in it.

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APPENDIX A

```
Private Function dvCalNortonParasA(ByVal Sigma As
Object, ByVal f As Object, ByVal DieConstIn As
Object,ByVal DistIn As Object, ByRef AttnF As Object)
As String
 ' Variables' declaration omitted to save space.
'Trap error, if any occurs unexpectedly and report to user.
    Try
 'Compute X,Don't Format since value will be used for
 further computations.
        X1 = 18.0 * Sigma
        X = X1 / f
        'Calculate Wavelength, Lamda
        Lamda = m_LightSpeed / f
 'Compute_FieldParas B, B Prime,BP and B Prime Prime,
 BPP. Before passing angle to Atan, Sin and Cos , convert
 value to radian. This is omitted to save space.
        BP1 = (DieConstIn - 1.0) / X
        BP = Atan(BP1)
        BPP1 = DieConstIn / X
        BPP = Atan(BPP1)
        'Compute Phase Constant,b
        b = (2.0 * BPP) - BP
        'Model Validity, b <=90
        Select Case b
'Reduction factor,A cannot be computed. Model Validity Violated.
        Case Is > 90.0
            dvEfResult=NoCal  'NoCal=PhaseAngle>90
            Return NoCal   'Operation not Successful
        Case Else
 ' Check Model Validity Okay. Continue with Calculation
    'Compute Numerical distance, s. Split the equations
    for easy maintainance
            s1 = PI * DistIn
            s2 = X * Lamda
            s3 = s1 / s2
            s4 = Cos(BPP) * Cos(BPP)
            s5 = Cos(BP)
            s6 = s4 / s5
            s = s3 * s6
            'Calculate Attenuation Reduction  Factor,A
            Dim A1, A2, A3, A4, A5, A6, A7 As Object
            A1 = 2.0 + (0.3 * s)
            A2 = 2.0 + s + (0.6 * s * s)
            A3 = A1 / A2
            A4 = s / 2.0
            A4 = Sqrt(Abs(A4))
            A5 = Exp(-0.625 * DistIn)  '5/8=0.625
            A6 = Sin(b)
            A7 = A6 * A4 * A5
            AttnF = A3 - A7
        End Select
    Catch ex As Exception
        dmsg = ex.Message.ToString
        MsgBox(dmsg, MsgBoxStyle.Critical, _
        "Computing Reduction Factor using Norton
        Parameters")
        Return  dmsg
    End Try
    Return  dcom  'Operation Successful. dcom=OKAY
EndFunction
```