

ISSN 2310-6697

oiser—open transactions on independent scientific-engineering research

# FUNKTECHNIKPLUS # JOURNAL

Théorie—Expérimentation—Métrologie—Logiciel—Applications

ISSUE 10 – TUESDAY 31 MAY 2016 – YEAR 3

1 Contents

2 About

3 Editorial Board – Technical Support

4 Information for Peers – Guiding Principles

# Telecommunications Engineering – Application – Logiciel

7 [tlnomiva] : Transmission Line Nominal Values without  
Tolerance - from Cable Specifications and Technical Data  
Sheets : FLOSS for MS Windows  
N.I. Yannopoulou, P.E. Zimourtopoulos

# Electrical Engineering – Théorie

37 Insulating Properties of Graphene Oxide  
D.G. Mitrakas, M.G. Danikas



*This small European Journal is  
In the Defense of Honesty in Science and Ethics in Engineering*

**Publisher** – otoiser—open transactions on independent scientific engineering research, [www.otoiser.org](http://www.otoiser.org)—[info@otoiser.org](mailto:info@otoiser.org) : Hauptstraße 52, 2831 Scheiblingkirchen, Austria

**Language** – We emphasize the origins of the Journal by using English, German and French, as well as, a Hellenic vignette in the cover page. However, since we recognize the dominance of US English in the technical literature, we adopted it as the Journal's language, although it is not our native language.

**Focus** – We consider Radio-FUNK, which still creates a vivid impression of the untouchable, and its Technology-TECHNIK, from an Advanced-PLUS point of view, Plus-PLUS Telecommunications Engineering, Electrical Engineering and Computer Science, that is, we dynamically focus at any related scientific-engineering research regarding Théorie, Expérimentation, Métrologie, Logiciel, ou Applications.

**Scope** – We emphasize this scope broadness by extending the title of the Journal with a Doppelkreuz-Zeichen # which we use as a placeholder for substitution of our Editorial Team disciplines: # Telecommunications etc. as above, or # High Voltage, # Software Engineering, # Simulation etc. as below.

**Frequency** – We publish 3 issues per year: on 31st of January, on 31st of May, and on 30th of September, as well as, an extra issue every 3 papers and a volume every 2 years.

**Editions** – We increase the edition number of an issue only when is needed to reform one or more of its papers—thus to increase their version numbers—but we keep unchanged its 1st edition date shown on its front page and we number its pages sequentially from 1. We count the editions of *About* separately.

**Format** – We use a fixed-space font, hyphenation, justification, unfixed word spacing, and the uncommon for Journals **A5** (half A4) page size to achieve WYSIWYG printing and clear reading of 2 to 4 side-by-side pages on wide-screen displays.

**Printing-on-Demand** – We can email gratis PDF files at 300-4000 dpi in booklet page scaling of brochure and book type.

**Copyright** – We publish under a Creative Commons Attribution, CC-BY 3.0 Unported or CC-BY 4.0 International, License only.

Please download the latest *About* edition from  
<http://about.ftpj.otoiser.org>

## Editorial Team

### # **Electrical Engineering**

Professor Michael Danikas, mdanikas@ee.duth.gr  
EECE, Democritus University of Thrace, Greece

# High Voltage Engineering # Insulating Materials

Assistant Professor Athanasios Karlis, akarlis@ee.duth.gr  
EECE, Democritus University of Thrace, Greece

# Electrical Machines # Renewable Energies # Electric Vehicles

### # **Computer Science**

Professor Vasilis Katos, vkatos@bournemouth.ac.uk  
Head of Computer and Informatics Dept, Bournemouth Univ, UK

# Computer Engineering # Software Engineering # Cyber Security

Lecturer Sotirios Kontogiannis, skontog@gmail.com  
Business Administration Dept, TEI, Western Macedonia, Greece

# Internet Engineering # Learning Management Systems

Dr. Apostolos Syropoulos, asyropoulos@yahoo.com  
BSc-Physics, MSc-Computer Science, PhD-Computer Science  
Independent Researcher, Xanthi, Greece

# Hypercomputation # Fuzzy Computation # Digital Typography

### # **Telecommunications Engineering**

Dr. Nikolaos Berketis, nberketis@gmail.com  
BSc-Mathematics, MSc-Applied Maths, PhD-Applied Mathematics  
Independent Researcher, Athens, Greece

# Applied EM Electromagnetics # Applied Mathematics

Dr. Nikolitsa Yannopoulou, yin@arg.op4.eu [\*]  
Diploma Eng-EE, MEng-Telecom-EECE, PhD-Eng-Antennas-EECE  
Independent Researcher, Scheiblingkirchen, Austria

Dr. Petros Zimourtopoulos, pez@arg.op4.eu [\*]  
BSc-Physics, MSc-Radio-Electronics, PhD-Antennas-EE  
Independent Researcher, Scheiblingkirchen, Austria

# Antennas # Metrology # EM Software # Simulation # Virtual Labs

# Applied EM # Education # FLOSS # Amateur Radio # Electronics

\* Copy and Layout Editing, Proof Reading, Issue and Website  
Management, Paper and About Reprints, Volumes and Web Pages

## Technical Support

Konstantinos Kondylis, kkondylis@gmail.com  
Diploma Eng-EECE, MEng-Telecom-EECE, Doha, Qatar

Christos Koutsos, ckoutsos@gmail.com  
Diploma Eng-EECE, MEng-Telecom-EECE, Bratislava, SK

## Information for Authors

This is a small, but independent, low profile Journal, in which we are all—Authors, Reviewers, Readers, and Editors—free at last to be Peers in Knowledge, without suffering from Journal roles or positions, Professional—Amateur—Academic statuses, or established "impact factorizations", under the following guiding principles:

**Authors** – We know what Work means, we respect the Work of the Independent Researcher in Science and Engineering and we want to exhibit his Work. Thus, we decided to found this Free and Open Access Journal in which to publish this Work. Furthermore, as we care indeed for the Work of the technical author—especially a young or a beginner one—we strongly support the publication of his Work, as follows:

- 1 We do not demand from the author to transfer his own copyright to us. Instead, we only consider papers resulting from original research work only, and only if the author can assure us that he owns the copyright of his own paper as well as that he submits to the Journal either an original copy or a revised version of his own paper, for possible publication after review—or even for immediate republication, if this paper has already been published after review—but, in any case under a Creative Commons Attribution, CC-BY 3 Unported or CC-BY 4 International, License, only.
- 2 We encourage the author to submit his own paper written just in Basic English plus Technical Terminology.
- 3 We encourage the author even to select a pen name, which may drop it at any time to reveal his identity.
- 4 We encourage the author to submit an accepted for publication paper, which he was forced to decline that publication because it would be based on a review with unacceptable evaluation or derogatory comments.
- 5 We encourage the author to submit any paper that was rejected after a poor, impotent, inadequate, unreasonable, irresponsible, incompetent, or "just ticking" review.
- 6 We encourage the author to submit an unreviewed paper of his own that he uploaded on some Open Access repository.
- 7 We encourage the author to upload his published paper in our Journal to at least one Truly Free Open Repository, e.g. such as <http://viXra.org> and <https://archive.org>.

## About

- 8 We provide the author with the ability to update, at any time, the reference links of his paper.
- 9 We provide the author with a decent, express, peer review process, of up to just 4 weeks, by at least 2, either anonymous or onymous, reviewers.
- 10 We provide the author with the option to choose from 2 review processes: the traditional, anonymous, close one, as well as, a contemporary, onymous, open review in our private mailing list for Peer Discussion.
- 11 Under the Clause 1 : We immediately accept for publication a research paper directly resulting from a Project Report, or a Diploma-, Master-, or PhD-thesis, which already the author has successfully defended before a committee of experts, as long as he can mention 2 members of this committee who approved his Work.
- 12 Under the Clause 1 : We immediately accept for publication any paper which is not Openly Accessible on the Internet.
- 13 We immediately publish online a paper, as soon as it is accepted for publication in the Journal.
- 14 We quickly publish an extra issue—that is in excess of the 3 issues we publish a year—as soon as the review process of 3 papers is completed.

**Reviewers** – Every peer may voluntarily become a reviewer of the Journal in his skillfulness for as long as he wishes. In addition, each author of the Journal must review one paper in his expertness for each one of his published papers.

**Readers** – Every reader is a potential post-reviewer: we welcome comments and post-reviews in our private mailing list for Peer Discussion.

**Editors** – Every editor owns a PhD degree—to objectively prove that he really has the working experience of passing through the dominant publishing system. An editor pre-reviews a paper in order to check its compliance to our guiding principles and to select the appropriate reviewers of it. We can accept for consideration papers only in the expertise areas currently shown in the Editorial Team page, above. However, since we are very willing to amplify and extend the Scope of the Journal, we welcome the volunteer expert, in any related subject, who wants to join the Editorial Team as long as he unreservedly accepts our guiding principles.

## Electronic Publishing

We regularly use the Free Libre Open Source Software Libre Office with the Free Liberation Mono font and the Freewares PDFCreator and PDF-Xchange Viewer. We also use, with some basic html code of ours: the Free Open Source Software Open Journal System OJS by the Public Knowledge Project PKP installed in our website, and the Free Open Digital Library of Internet Archive website, where we upload the FTP#J Collection of Issues, Paper reprints, *About* documents, and Volumes, in both portrait and landscape orientations, for download or very clear online reading with the Free Open Source BookReader.

## Submissions

We can only consider papers written in the preferable and recommended odt format of LibreOffice, or even a paper in the MS Office with MathType doc format, if it would be proved that it is fully compatible with LibreOffice indeed.

**Legal Notice** – It is taken for granted that the submitter–correspondent author accepts, without any reservation, the totality of our publication conditions as they are analytically detailed here, in this *About*, as well as, that he also carries, in the case of a paper by multiple authors, the independent will of each one of his co-authors to unreservedly accept all the aforementioned conditions for their paper.

## Internet Addresses

**Submissions** : sub@ftpj.otoiser.org

**Send Updates** : updates@ftpj.otoiser.org

**Printing-on-Demand** : pod@ftpj.otoiser.org

**Technical Support TS** : technical-support@ftpj.otoiser.org

**Principal Contact** : principal-contact@ftpj.otoiser.org

**Peer Discussion List** : www.peers.ftpj.otoiser.org

**Editorial Team & TS List** : www.etts.ftpj.otoiser.org

**The FTP#J Collection at Internet Archive Digital Library** :

<https://archive.org/details/@funktechnikplusjournal>

**Sample Paper Templates** : www.template.ftpj.otoiser.org

**Reference Link Updates** : www.updates.ftpj.otoiser.org

**Internet Publishing** : www.ftpj.otoiser.org

---

*This document is licensed under a Creative Commons Attribution 4.0 International License – <https://creativecommons.org/licenses/by/4.0>*

# **[tlnomiva] : Transmission Line Nominal Values without Tolerance - from Cable Specifications and Technical Data Sheets : FLOSS for MS Windows**

N.I. Yannopoulou, P.E. Zimourtopoulos \*

Antennas Research Group, Austria

## **Abstract**

[[tlnomiva] is a visual software application developed by the authors for a transmission line characterization from the user's point of view. The numerical computations are based on the precise formulation within the distributed circuit coefficients model of a transmission line, which was theoretically developed by the authors and published in a previous paper. The use of [tlnomiva] is fully demonstrated by an example for the popular RG 214 coaxial cable. This application is Free Libre Open Source Software and provides an option for more detailed figures by calling the executable of the freely distributed source [wgnuplot].

## **Keywords**

transmission line, nominal value, propagation characteristics, circuit coefficients, floss

## **Introduction**

A lot has been published for transmission lines in general, as well as, specifically for their use at high frequencies. The software application [tlnomiva], that is under development and illustrated here, is an intermediate step in the authors' recent effort to clarify a number of obscure or confusing points on this subject. It is intended to reveal the limits in the coexistence of precise

formulas of transmission line theory with the available nominal values, usually without tolerance, which are given as cable specifications by established authorities or as data sheets from manufacturers.

The main formulas of [tlnomiva] were presented in [1], while the basic theory is cited in [2], thus only a small part of them is repeated here and just for the sake of completeness. The

cut-off frequency has not been taken into account. The data for the presented examples are publicly available through internet.

[tlnomiva] is provided both as Free Libre Open Source Software and ready to install and use executable. It is developed in MS Visual Basic 6 in MS Windows XP 32 and in order to support a more sophisticated way of plotting data and functions it optionally uses the [wgnuplot] software, version 5.0 patchlevel 3 [3]. It is tested for compatibility with various MS Windows operating systems, up to W10-64.

To the best of the authors' knowledge, there is no available FLOSS for transmission lines, especially with a precise formulation one.

### [tlnomiva]

Fig. 1 shows the main window of [tlnomiva] with the window of [About] open, while Fig. 2 contains all the menu items along with their sub-menu options numbered from 1 to 6. The application features can be divided according to their functionality in three groups:

(1) R, L, G, C intervals computation from the nominal values of: the attenuation factor  $\alpha$  or accurately A in [dB/100m], the velocity fac-

tor  $v_f$  and the characteristic impedance  $Z_0$  and plotting with respect to frequency  $f$  [MHz], using working formulas from [1], [2],

(2) a new estimation of A,  $v_f$  and  $Z_0$  using the numerical results from the previous window for the R, L, G, C, intervals either directly or reading them from a previously saved file and plotting them and

(3)  $\alpha$ ,  $\beta$ ,  $R_0$ ,  $X_0$  computation as functions of frequency considering R, L, G, C constant in a range of frequency and plotting them.

In these three groups the plot of all the involved quantities with respect to frequency is possible. Except of R, L, G, C distributed circuit coefficients and  $\alpha$ ,  $\beta$ ,  $R_0$ ,  $X_0$  propagation characteristics there are included: the A attenuation factor, the  $v_f$  velocity factor, the E, and H terms, the  $\alpha\beta$  angles as the upper and lower limit of the  $Z_0$  phase angle and finally the  $\omega L$ ,  $\omega C$  and  $f/v_f$ . The used units are remain to all forms the same: R [m $\Omega$ /m], L [nH/m], G [ $\mu$ S/m], C [pF/m],  $f$  [MHz],  $\alpha$  [Np/m], A [dB/100m],  $\beta$  [rad/m],  $R_0$ ,  $X_0$ ,  $Z_0$  [ $\Omega$ ],  $\alpha\beta$  [deg],  $\omega L$  [m $\Omega$ /m],  $\omega C$  [ $\mu$ S/m],  $f/v_f$  [MHz]. The [feet] option is disabled.

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

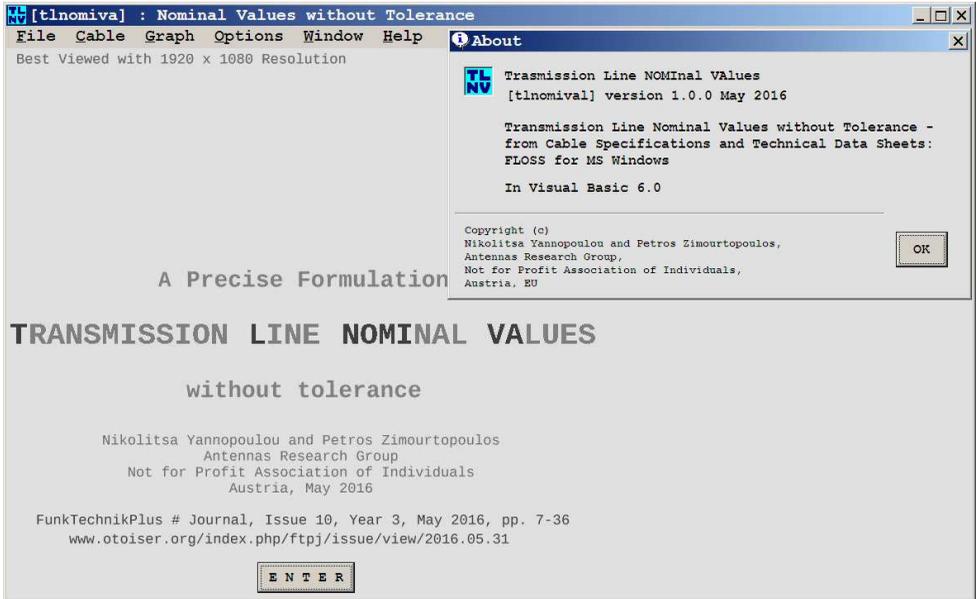


Fig. 1: [tlnomiva] : The main window

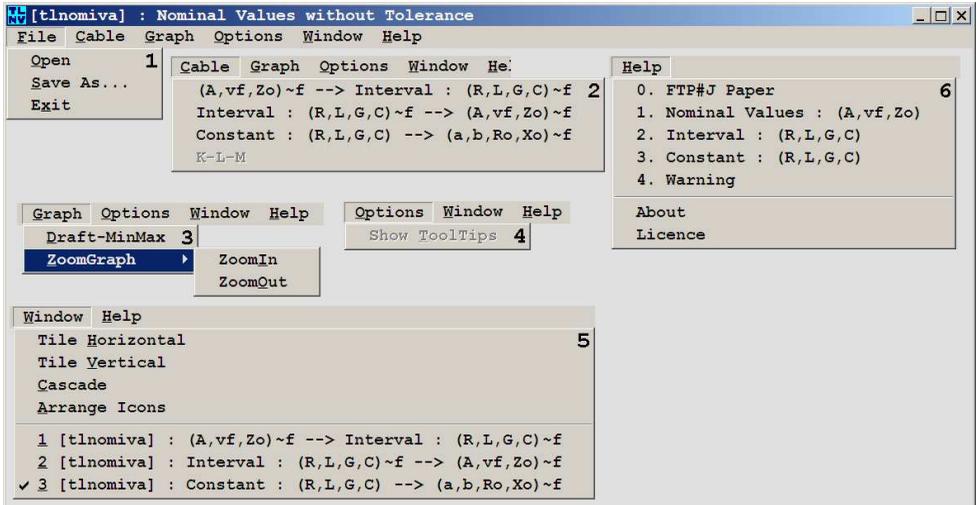


Fig. 2: Main window: The unfolded menu items

**Working Formulas**

The basic expressions between the nominal values of  $A$ ,  $\nu f$  and  $Z_0$  and the  $R$ ,  $L$ ,  $G$ ,  $C$  distributed circuit coefficients of a line are given in [1] and repeated here as:

$$R = \alpha R_0 - \beta X_0 \quad (1)$$

$$L = (\alpha X_0 + \beta R_0) / \omega \quad (2)$$

$$G = (\alpha R_0 + \beta X_0) / Z_0^2 \quad (3)$$

$$C = (-\alpha X_0 + \beta R_0) / (\omega Z_0^2) \quad (4)$$

It is obvious that if the nominal value of  $Z_0$  is substituted with  $R_0$ , then  $X_0$  will be zero and the above expressions will be actually independent of frequency, a case that will be examined last. Thus, we have to consider  $Z_0$ , as it is usually given in data sheets of cables, as the amplitude of  $\dot{Z}_0$ . Then by using the standard relation

$$Z_0^2 = R_0^2 + X_0^2 \quad (5)$$

where

$$R_0 = Z_0 \cos(z_0) \quad (6)$$

$$X_0 = \pm Z_0 |\sin(z_0)| \quad (7)$$

the above (1)-(4) become functions of the  $z_0$  phase angle.

Since:

i. the interval of  $z_0$  is the open interval  $(\pi/4, \pi/4)$ ,

ii. the four quantities  $R$ ,  $L$ ,  $G$ ,  $C$  do not have an extreme inside this interval. This results from the fact that the phase angle of  $\dot{Z}_0$ , which is the angle  $(z - y)/2$ , and of  $\dot{y}$ , which is the angle  $(z + y)/2$  [1], can not be equal inside this interval but only for the case of  $y = 0$  which is impossible since  $y \neq 0$  always,

we have to look for the two extreme values only at the ends of the open interval. Furthermore, since the four functions (1)-(4) are continuous with respect to  $z_0$  in the above closed interval, the mentioned extremes will be the values of the continuous extension of these functions at the closed interval, at its ends. Three separated cases are distinguished:

$$\alpha < \beta : -\alpha/\beta < X_0/R_0 < \alpha/\beta \quad (8)$$

$$\beta < \alpha : -\beta/\alpha < X_0/R_0 < \beta/\alpha \quad (9)$$

$$\alpha = \beta : -1 < X_0/R_0 < 1 \quad (10)$$

Tab. 1 contains the two extreme values for the four coefficients and for the  $H$  term if we consider that

$$H = \omega L G - \omega C R \quad (11)$$

Tab. 1: RLGC and H Open Intervals

	$\alpha < \beta$	$\alpha > \beta$	$\alpha = \beta$
R	$(0, \frac{2\alpha\beta}{Y} Z_0)$	$(\frac{\alpha^2 - \beta^2}{Y} Z_0, Y Z_0)$	$(0, Y Z_0)$
L	$(\frac{\beta^2 - \alpha^2}{\omega Y} Z_0, \frac{1}{\omega} Y Z_0)$	$(0, \frac{2\alpha\beta}{\omega Y} Z_0)$	$(0, \frac{1}{\omega} Y Z_0)$
G	$(0, \frac{2\alpha\beta}{Y Z_0})$	$(\frac{\alpha^2 - \beta^2}{Y Z_0}, \frac{Y}{Z_0})$	$(0, \frac{Y}{Z_0})$
C	$(\frac{\beta^2 - \alpha^2}{\omega Y Z_0}, \frac{Y}{\omega Z_0})$	$(0, \frac{2\alpha\beta}{\omega Y Z_0})$	$(0, \frac{Y}{\omega Z_0})$
H	$(-2\alpha\beta, +2\alpha\beta)$	$(-2\alpha\beta, +2\alpha\beta)$	$(-Y^2, +Y^2)$

The reverse relations of  $\alpha$ ,  $\beta$ ,  $R_0$  and  $X_0$  from the RLGC values are also presented in [1] and repeated here as

$$Z_0 = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{R^2 + X_L^2}{G^2 + X_C^2}} \quad (16)$$

$$\alpha = \frac{\sqrt{ZY + RG - X_L X_C}}{\sqrt{2}} \quad (12)$$

**RLGC Intervals from A, vf, Z<sub>0</sub> Nominal Values**

The most usual case of available cable data concerns the attenuation factor per some length of cable, i.e. 100 [m] or 1000 [ft], denoted here as A, the velocity factor vf as a number between 0 and 1, and the characteristic impedance Z<sub>0</sub> [Ω], or more accurately its amplitude Z<sub>0</sub>, of the cable. Fig. 3 shows the first window of [tlnomiva] where it is possible from these data to calculate an interval for R<sub>0</sub>, X<sub>0</sub>, and R,

$$\beta = \frac{\sqrt{ZY - RG + X_L X_C}}{\sqrt{2}} \quad (13)$$

$$R_0 = \frac{\sqrt{ZY + RG + X_L X_C}}{\sqrt{2} Y} \quad (14)$$

$$X_0 = \text{sgn}(LG - RC) \frac{\sqrt{ZY - RG - X_L X_C}}{\sqrt{2} Y} \quad (15)$$

where  $X_L = \omega L$  and  $X_C = \omega C$ , or directly for Z<sub>0</sub> from its definition as

L, G, C coefficients in a [Single] frequency. The user must first type the frequency in [MHz] and then the three data A, vf,  $Z_0$ . The application will evaluate all the other quantities through (1)-(11), and display them at the corresponding text boxes using the indicated units. The letter m stands for the minimum and the letter M for maximum for all the quantities.

The  $m\alpha\beta$  [°] is significant since it results the boundary angle inside which  $Z_0$  will be. This angle is defined by both  $-m\alpha\beta$  and  $+m\alpha\beta$  and depends on the relation between  $\alpha$  and  $\beta$  as it is described in (8)-(10) above. Fig. 4 shows the three cases with the grayed horizontal and verti-

cal thick lines to represent the values range of  $R_0$ ,  $X_0$ .

When the option [Multiple] is selected a grid opens where the values for each frequency will be written and two more buttons appear at the right part of the window: [Add Values to Grid] and [Estimation]. The user must give the first and last frequency. Then type each frequency at the text box above and the corresponding A, vf,  $Z_0$  as in [Single] option. By pressing the [Add Values to Grid] button all the calculated values are transferred to a grid line, as it is shown in Fig. 5. In any time it is possible to select from the [File] menu the [Save As] item and save these data to a text file for later use.

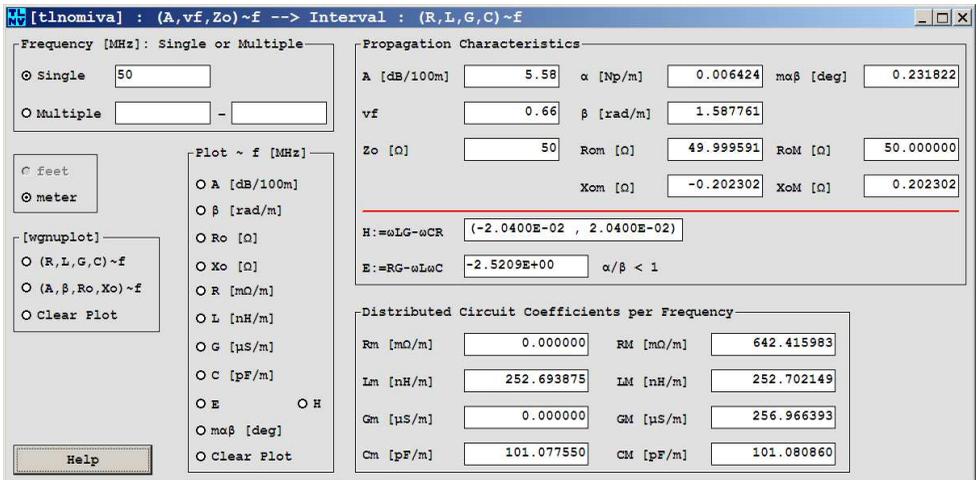


Fig. 3: [(A,vf,Z<sub>0</sub>)~f --> Interval : (R,L,G,C)] - [Single]

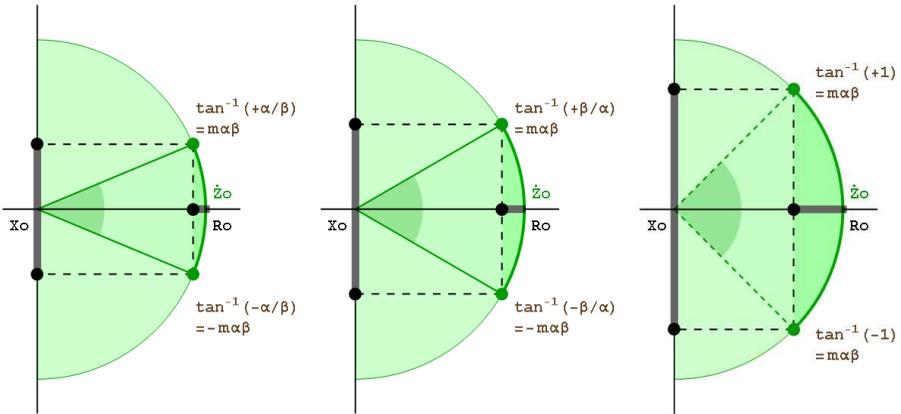


Fig. 4:  $\pm m\alpha\beta$  angle: Intervals for  $R_0$ ,  $X_0$

The [Multiple] option enables simultaneously all the buttons in frames [Plot ~ f [Mhz]] and [wgnuplot], but if there is no data available a message will appear to the screen to guide the user. It is possible to enter as many frequency data as it is desired but not for frequencies below or above the first and last frequency respectively.

The user may either plot all the quantities versus  $f$  [MHZ], directly in the application, as for example is illustrated in Fig. 6 where A [dB/100m] is selected or to use [wgnuplot] and take one of the two possible quadruples as shown in Figs. 7 and 8. Only the points are plotted in wgnuplot application while inside [tlnomiva] it is possible to plot either points with lines, the default state, or only points

if the user uncheck the box [Show Lines] at the right of the picture. The lines used here between points are only straight segments of lines.

The chart inside [tlnomiva] is movable with the left mouse button. Two very useful features have been added under the [Graph] menu: [Draft-MinMax] and [Zoom-Graph] with two items [Zoom In] and [ZoomOut] as it is shown in Fig. 2 (3). The first produces a plot exactly with min and max values for both vertical and horizontal axis, and with the second a much bigger chart appears for the plot, centered at the screen. The access to both features is also possible through their shortcut keys Alt+G+D and Alt+G+ Z+I or Alt+G+Z+O and in addition through the (+) and (-) from the keyboard's numerical pad.

Fig. 9 shows an example for the L coefficient, where it is obvious that the points of different color and shape for its interval ends reveals the existing too small difference between them.

The user may not enter one by one the frequencies and the corresponding nominal values of A,  $v_f$  and  $Z_0$  but just to read them from an already existing text file using the [File][Open] menu item. An example of such a file is given in Fig. 10, where the first line is a text line. The second contains the number of frequencies (10 in this example) and the common characteristics of the cable

as 0.66 for  $v_f$ , 50. for  $Z_0$ , separated by spaces. Then a list of f in MHz and A in dB/100m couples follows. The grid will be filled in automatically after reading the file. The width of the grid columns is adjustable to ensure the visibility of all the produced values.

Another way is to open an already existing file with previously saved data from this application, as in Fig. 11. Then, again the grid contains the read values while all the text boxes for all the quantities are remain blank except the  $v_f$ ,  $Z_0$ , and the first and last frequency as it shown in Fig. 6.

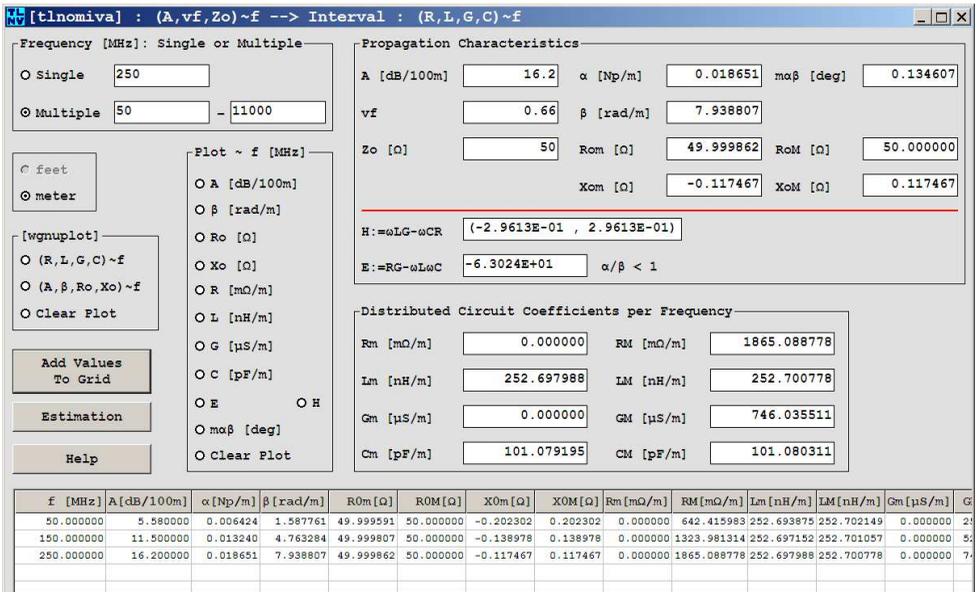


Fig. 5: [(A,  $v_f$ ,  $Z_0$ )~f --> Interval : (R, L, G, C)~f] - [Multiple]

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

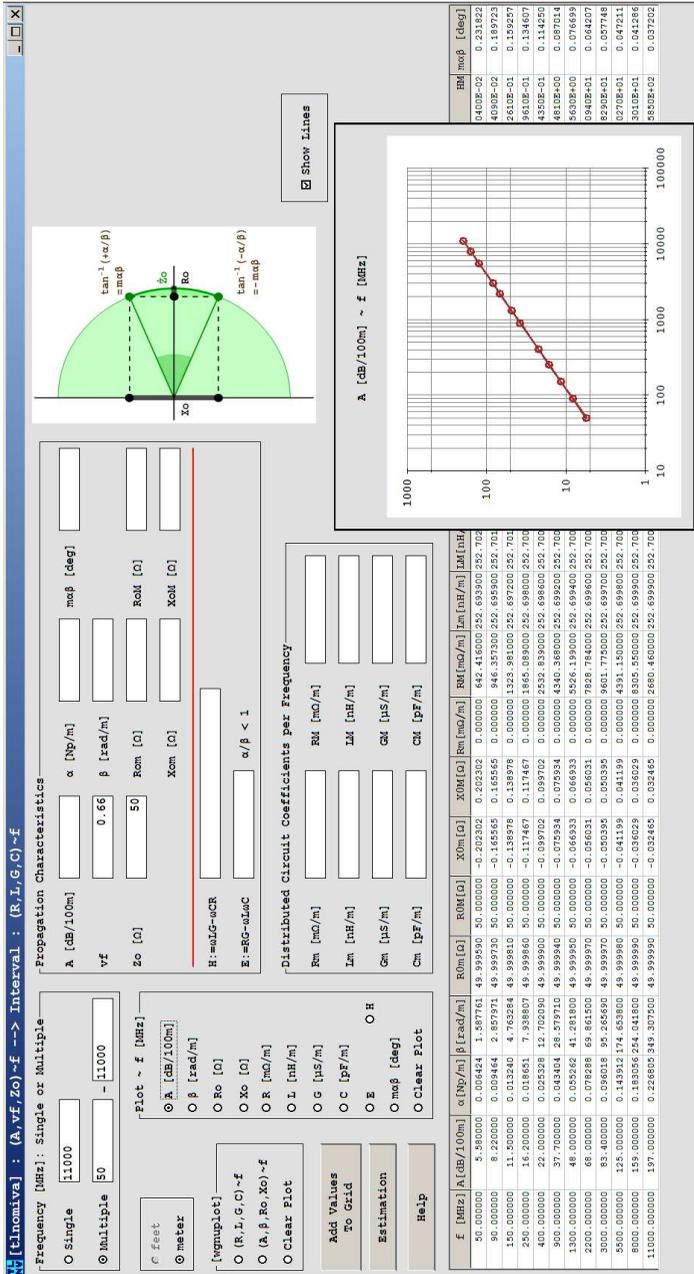


Fig. 6: [(A, vf, Z<sub>0</sub>)~f --> Interval : (R, L, G, C)~f] - Plot

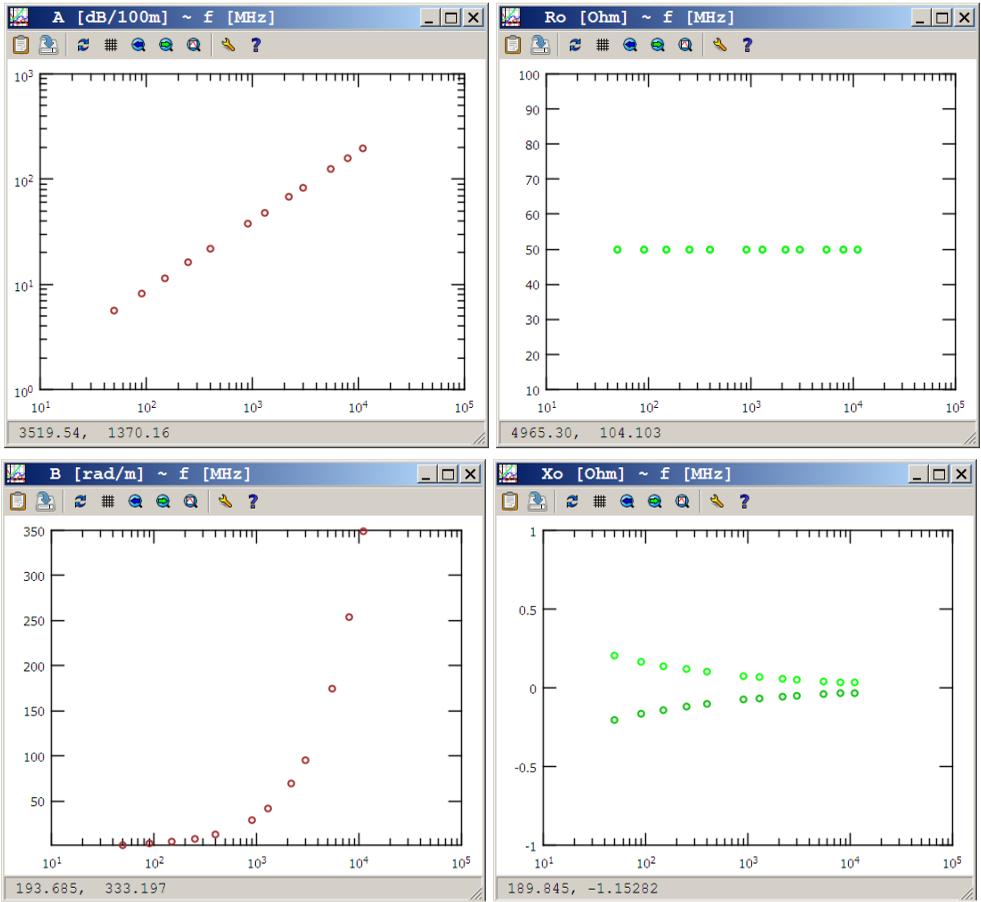


Fig. 7:  $A$ ,  $\beta$ ,  $R_0$ ,  $X_0$  versus frequency from [wgnuplot]

```

RG214-NominalValues.txt - Notepad
File Edit Format View Help
CableData: #f[MHz], vf, Z0: 1st line ad f[MHz], A[dB/100m]: list
12 0.66 50.
50 5.58
90 8.22
150 11.50
250 16.20
400 22.00
900 37.70
1300 48.00
2200 68.00
3000 83.40
5500 125.00
8000 159.00
11000 197.00
    
```

Fig. 10: Nominal data values in a text file

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

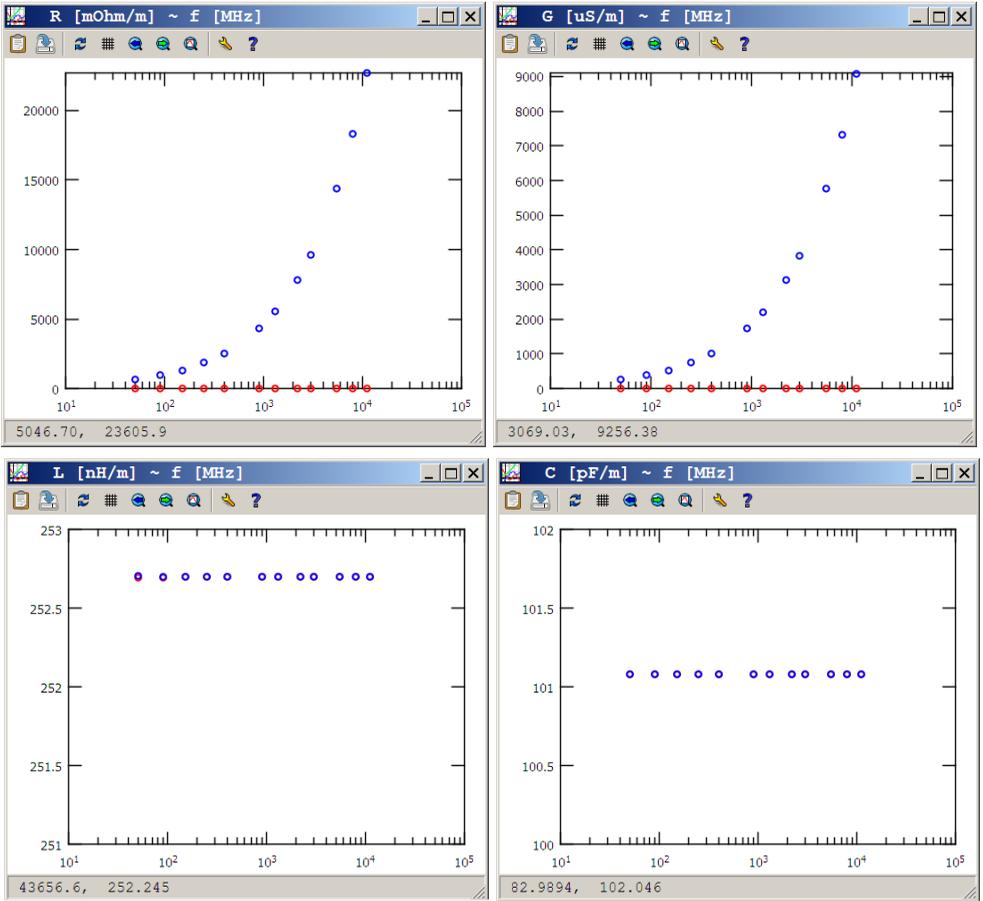


Fig. 8: R, L, G, C, coefficients versus frequency from [wgnuplot]

```

RG214-RIGG-Intervals.txt - Notepad
File Edit Format View Help
12      20      0.66      50
50      5.50    0.096424  1.507761  49.99959  50  -0.202302  0.202302  0.642.416  252.6939  252.7021  0.256.9664  101.0776  101.0009  -2.5209  -0.02040  0.02040  0.231922
90      8.22    0.009464  2.857971  49.99973  50  -0.165565  0.165565  0.946.357  252.6959  252.7015  0.378.5429  101.0784  101.0086  -8.1679  -0.05409  0.05409  0.189723
150     11.50   0.013240  4.763284  49.99981  50  -0.138978  0.138978  0.1323.981  252.6972  252.7010  0.529.5925  101.0789  101.0084  -22.609  -0.12610  0.12610  0.159257
250     16.20   0.018651  7.938807  49.99986  50  -0.117467  0.117467  0.1865.089  252.6980  252.7008  0.746.0355  101.0792  101.0083  -63.024  -0.29610  0.29610  0.134607
400     22.00   0.025328  12.70209  49.99990  50  -0.099702  0.099702  0.2532.039  252.6986  252.7006  0.1013.135  101.0794  101.0082  -161.34  -0.64350  0.64350  0.114200
900     37.70   0.043404  26.57971  49.99994  50  -0.075934  0.075934  0.4340.369  252.6992  252.7004  0.1735.147  101.0797  101.0081  -415.00  -1.49100  1.49100  0.087014
1300    48.00   0.055262  41.28180  49.99995  50  -0.066933  0.066933  0.5526.199  252.6994  252.7003  0.2210.480  101.0798  101.0081  -1794.2  -4.56300  4.56300  0.076599
2200    60.00   0.070280  69.86150  49.99997  50  -0.056031  0.056031  0.7028.784  252.6996  252.7002  0.3131.514  101.0798  101.0081  -4800.6  -10.9400  10.9400  0.064207
3000    83.40   0.0896018  95.26569  49.99997  50  -0.050395  0.050395  0.9081.775  252.6997  252.7002  0.3840.719  101.0799  101.0081  -9075.5  -18.2900  18.2900  0.057748
5000   125.00  0.1143912  174.6530  49.99998  50  -0.041199  0.041199  0.14391.15  252.6996  252.7002  0.5756.461  101.0799  101.0081  -30504  -50.2700  50.2700  0.047211
8000   150.00  0.130305  254.0418  49.99999  50  -0.036029  0.036029  0.15035.55  252.6999  252.7001  0.7322.219  101.0800  101.0081  -64537  -93.0100  93.0100  0.041206
11900  197.00  0.226805  349.3075  49.99999  50  -0.032465  0.032465  0.22680.46  252.6999  252.7001  0.9072.104  101.0800  101.0081  -122920  -158.500  158.500  0.037202
    
```

Fig. 11: Previously saved Data in a text file

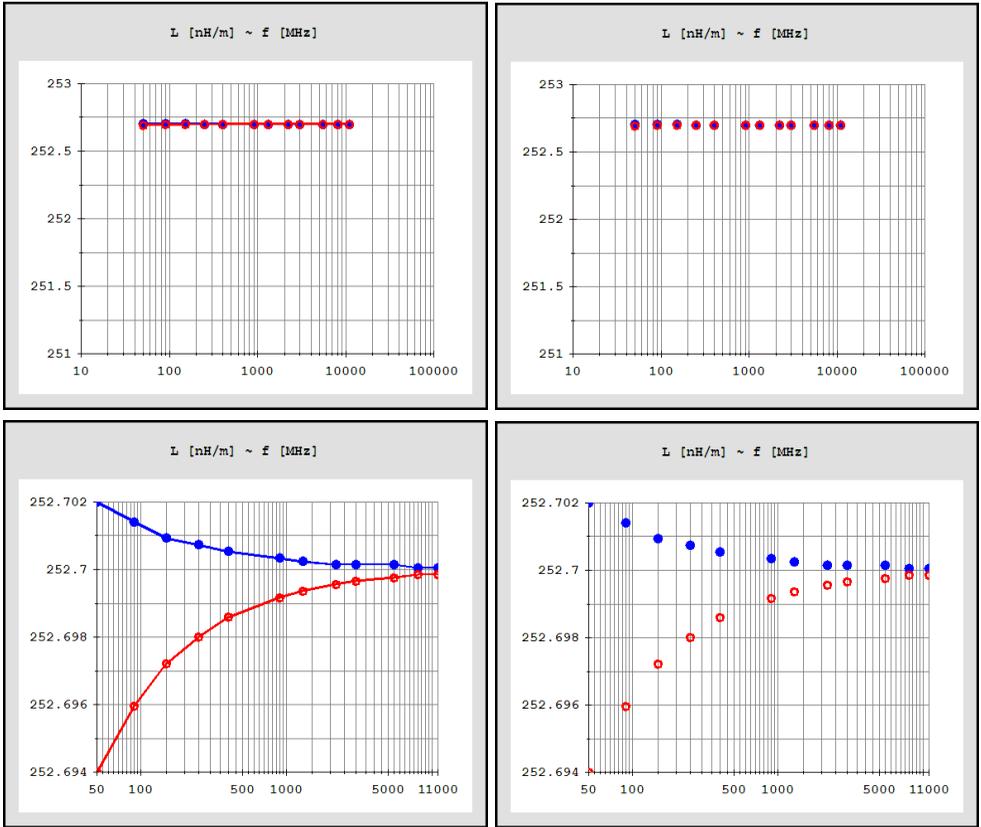


Fig. 9: L with-without lines and [Draft-MinMax]

The first line of this file contains four (4) numbers: two (2) integers, the number of lines and columns, and two (2) reals,  $\nu f$  and  $Z_0$ . The following lines are exactly the same as the grid lines of the window.

Fig. 12 shows  $R_0$ ,  $X_0$ ,  $m\alpha\beta$  and  $H$  with the [Draft-MinMax] enabled. The difference of  $R_0$  from 50 [ $\Omega$ ] is small enough and the values of  $m\alpha\beta$  permit

a small imaginary part  $X_0$ , since they are less than a quarter of  $1^\circ$  in both sides of the horizontal line of real  $Z_0$ . It is also evident that for lower frequencies the  $H$  intervals are, initially, closer to zero (0) which means closer to the Heaviside condition while more data are needed to characterize the line as capacitive or inductive.

This window generates eight (8) files in the directory of

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

[tlnomiva] which are used from the [wgnuplot.exe], with specific filenames of obvious meaning:

R-points	L-points
G-points	C-points
A-points	B-points
Ro-points	Xo-points

Finally, the [Clear Plot] button in the [wgnuplot] frame just closes all occurrences

of the wgnuplot application [4] while the same button in the [Plot ~ f [MHz]] frame clears the displayed plot, leaving the chart empty. A short help is available by pressing the [Help] button. The [Estimation] button opens the next window of [tlnomiva] that uses the intervals of RL GC circuit coefficients for a new estimation of A, vf, Z<sub>0</sub>.

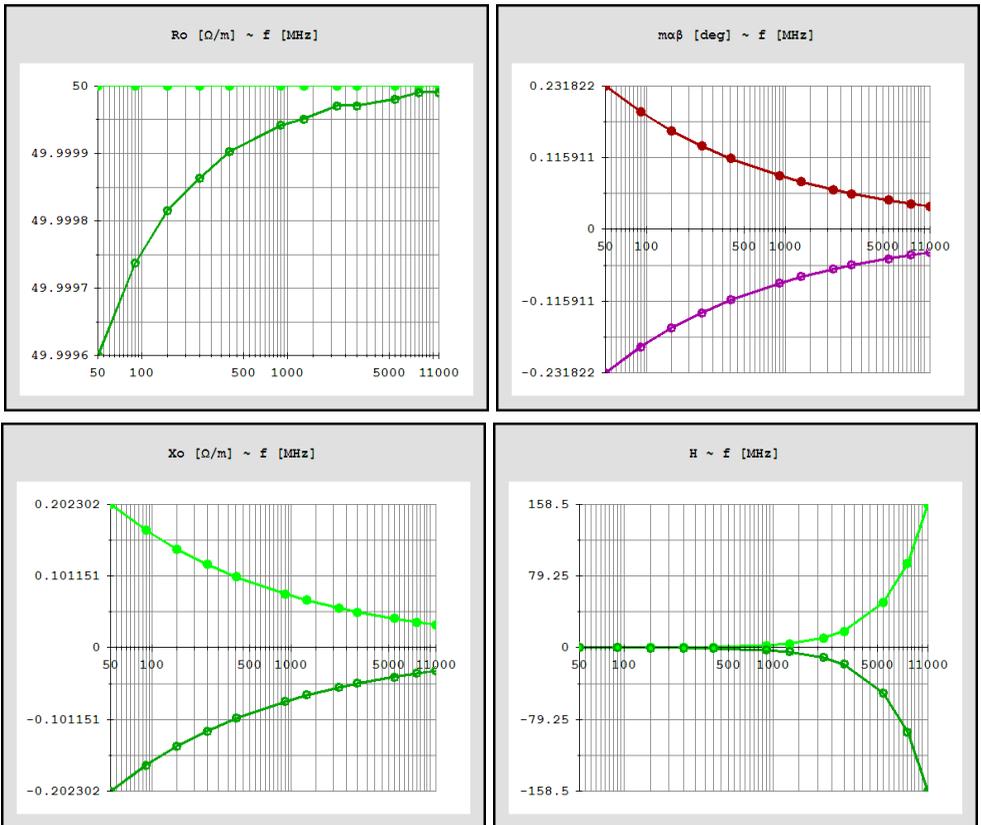


Fig. 12:  $R_0$ ,  $X_0$ ,  $\mu\alpha\beta$  and H with [Draft-MinMax]

### A, $v_f$ , $Z_0$ estimation from RLGC Intervals

Relations (12)-(16) are actually result directly from the definition of  $Z_0$  and  $\dot{y}$ . The problem is that R, L, G and C are not easily determined. They are closely related to the geometrical characteristics of the line and as distributed quantities not measured directly. Here, an attempt is presented to determine some values for A,  $v_f$ ,  $Z_0$  and thereafter for  $\alpha$ ,  $\beta$ , H, E,  $m\alpha\beta$  using the RLGC intervals from the previous window of [tlnomiva]. Additionally, the  $\omega L$ ,  $\omega C$  and  $f/v_f$  are also given.

In particular three values are evaluated: the one that corresponds to the lower end of the RLGC intervals, the mean value and the one from the upper end of the intervals. The nominal values are given, respectively, where they are available. The main purpose of this effort is to estimate A,  $v_f$ , and  $Z_0$  and to achieve a closer approach of RLGC by means of the known nominal values.

Fig 13 shows the second window of [tlnomiva], when it is opened from the [Cable] [Interval : (R,L,G,C)~f-->(A,  $v_f$ ,  $Z_0$ )~f] menu. The table contains the values at the frequency selected from the drop down list box, 400 [MHz]

here. Initially, the table has no values and the message of Fig. 14 is at the top of the window. After pressing the [Load Data] the well known in windows users [Open] dialog box appears to select a file to read. The first line in Fig. 13 shows the path of this data file. If the window is accessed through the [Estimation] button of the previous window [(A, $v_f$ , $Z_0$ )~f-->Interval : (R, L,G,C)~f] then there is no message at the top and the table is filled automatically with the values corresponding to the first frequency.

The first four (4) lines of the table shows the values of RLGC as described above. The next eight (8) lines in the red frame contain the new estimated values. Their corresponding nominal values are shown at the right. To plot one of these quantities versus frequency, its option button under the label [Plot] must be selected. The colored little squares beside its data column (Red for minimum, Green for mean value, Blue for maximum) and the Black larger square above the nominal values correspond to the used color for the plot and they are buttons. Their default state is on. Pressing one of them or all, changes the state to off and the corresponding data are removed

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

from the plot for each line.

1300 [MHz] in this example. Since all the colored buttons are on, all the values are plotted. The menu item [Draft -MinMax] is active for a closer view of the plot as described in the previous section and it is selected here.

Fig. 15 shows the full window with the plot of A [dB/100m] in the chart. The light blue open circles in the plot indicate the current frequency which is selected from the drop down list box,

Interval : (R,L,G,C)~f --> (A,vf,Zo)~f

C:\Lines\RG214-RLGC-Intervals.txt Load Data

Unit	Frequency [MHz]	min	Max	Plot
R [mΩ/m]	400	0.000000	2532.839000	<input type="checkbox"/>
L [nH/m]	400	252.698600	252.700600	<input type="checkbox"/>
G [μS/m]	400	0.000000	1013.135000	<input type="checkbox"/>
C [pF/m]	400	101.079400	101.080200	<input type="checkbox"/>

Parameter	min	Max	Plot	Nominal Values	
A [dB/100m]	0.000000	21.999954	43.999908	<input type="checkbox"/>	22.000000
vf	0.659999	0.660001	0.660004	<input type="checkbox"/>	0.660000
Z0 [Ω]	50.000009	50.000010	50.000011	<input type="checkbox"/>	50.000000
H: Capac.	0.0000E+00	-7.2869E-08	-1.3117E-07	<input type="checkbox"/>	±6.4350E-01
E: α/β < 1	-1.6134E+02	-1.6134E+02	-1.6134E+02	<input type="checkbox"/>	-1.6134E+02
α [Np/m]	0.000000	0.025328	0.050657	<input type="checkbox"/>	0.025328
β [rad/m]	12.702014	12.702065	12.702115	<input type="checkbox"/>	12.702090
μαβ [deg]	0.000000	0.114250	0.228498	<input type="checkbox"/>	±0.114250

ωL [mΩ/m]	635100.835024	635103.366092	635105.897161	<input type="checkbox"/>
ωC [μS/m]	254040.238136	254041.244811	254042.251486	<input type="checkbox"/>
f/vf [MHz]	606.056924	606.059333	606.061741	<input type="checkbox"/>

Show Lines

Nominal Values

Fig. 13: [Interval : (R,L,G,C,)~f --> (A,vf,Z<sub>0</sub>)~f] - Table

Read File as saved from  
 [Cable] [(A,vf,Zo)~f --> Interval : (R,L,G,C)~f] : Load Data

Fig. 14: Initial message: Load Data

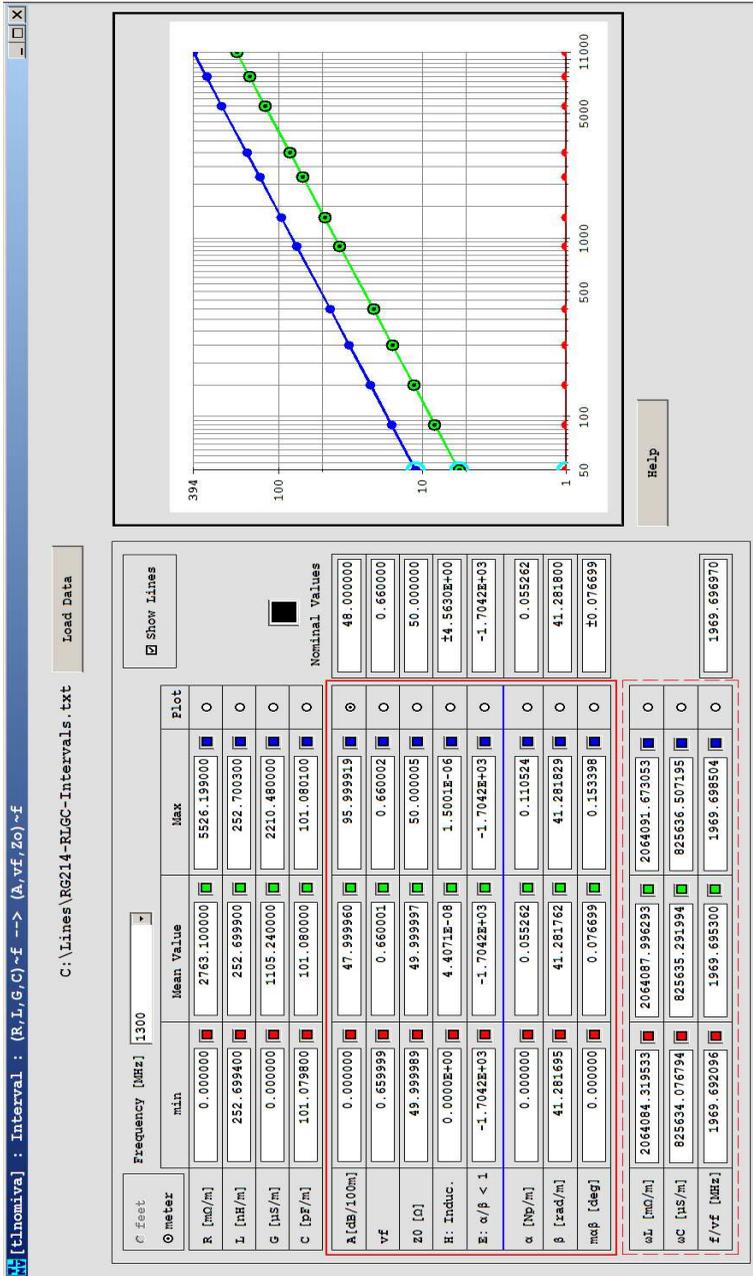


Fig. 15: [Interval : (R,L,G,C,)~f --> (A,vf,Z<sub>0</sub>)~f] - Plot

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

The minimum value results from (12) to be zero since the lower limits for R and G are equal to zero and the same is true for  $m\alpha\beta$  and H, for this cable. It is obvious that the nominal value of A is achieved for the mean value as shown in Fig. 16 where the green and black colored points are plotted. The light blue point corresponds to the values shown above the chart. Velocity factor is illustrated in Fig. 17 and in Fig. 18  $m\alpha\beta$  is given. Both of them are shown with [Draft-MinMax] enabled. For  $m\alpha\beta$  only the positive number is written at the table, while at the plot both

plus and minus  $m\alpha\beta$  is shown. Fig. 19 contains  $Z_0$  in both scales, where it is obvious that the difference from nominal value can not be denoted and Fig. 20 shows the H term, almost zero, similarly. If it is positive/ negative in both mean and maximum value then a Capacitive/Inductive label is added. For completeness Figs. 21-22 shows  $\alpha$  and  $\beta$  respectively.

The [feet] option is again disabled, the [Show Lines] acts the same as in the previous window, while the [Zoom Graph] item with its sub-items is disabled in the current [tlnomiva] version.

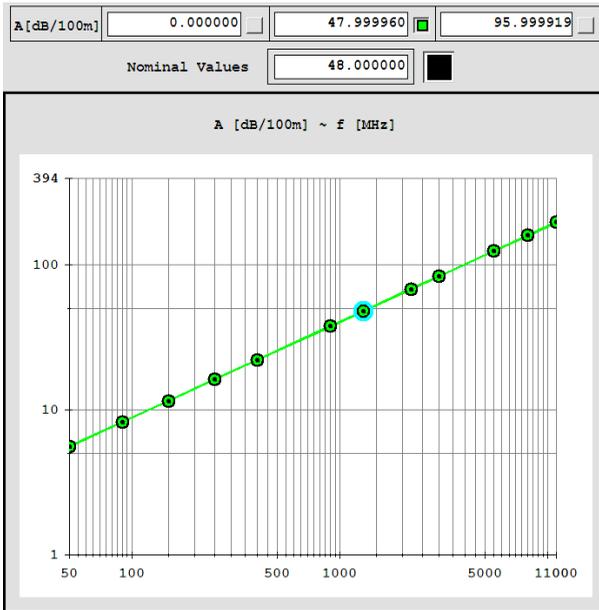


Fig. 16: Attenuation factor estimation and nominal value

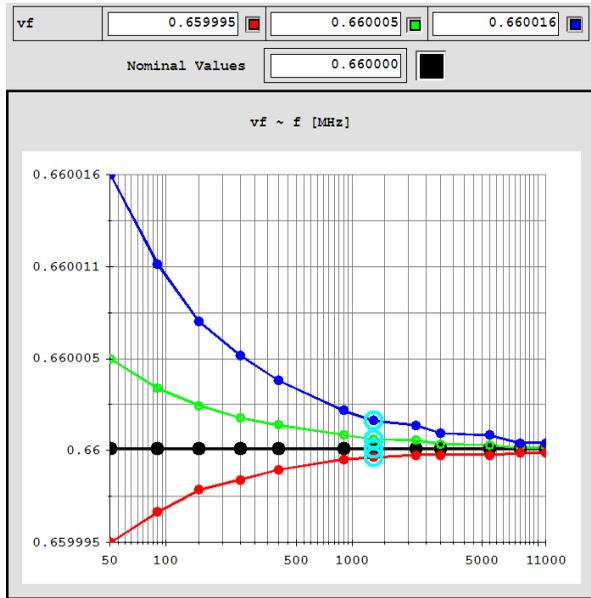


Fig. 17: Velocity factor estimation and nominal value

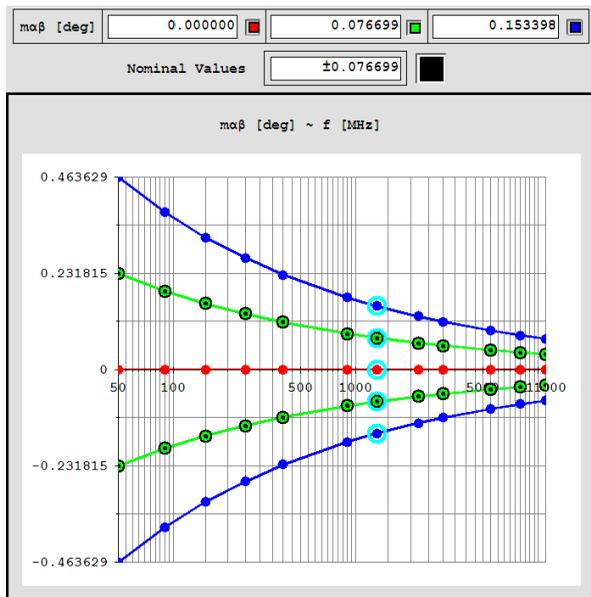


Fig. 18:  $\alpha\beta$  estimation and nominal values

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

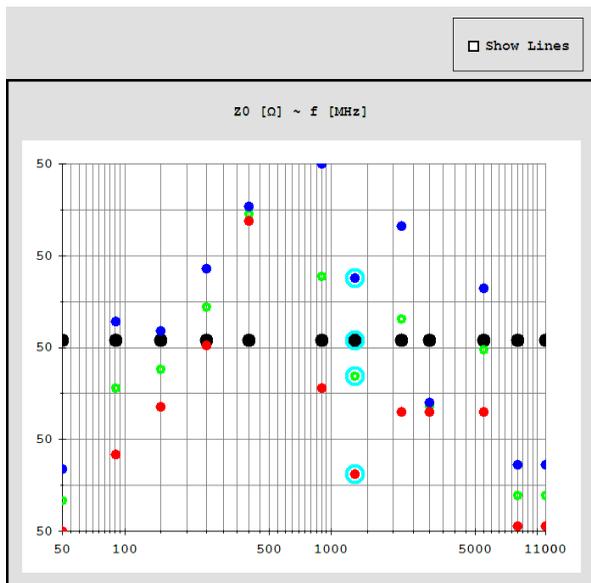
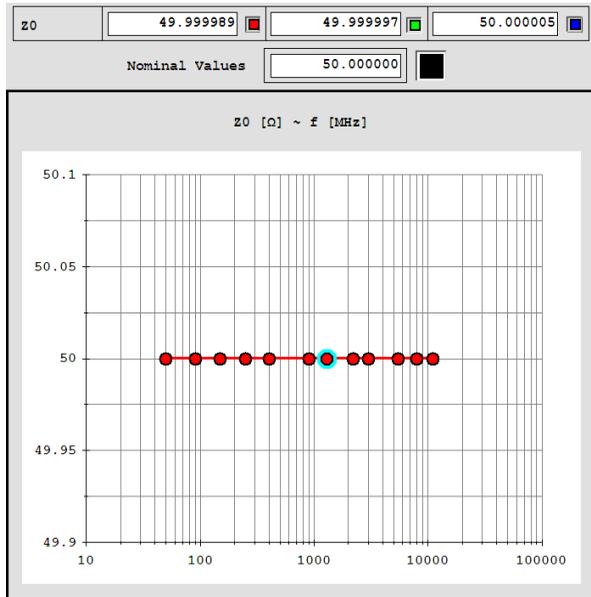


Fig. 19:  $Z_0$  estimation and nominal values

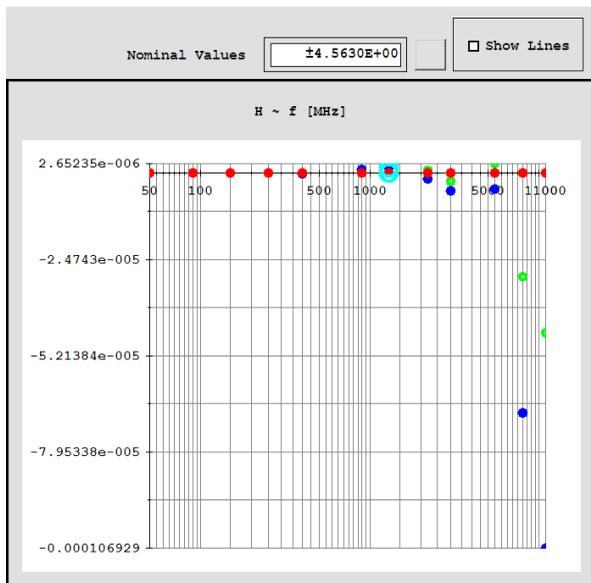
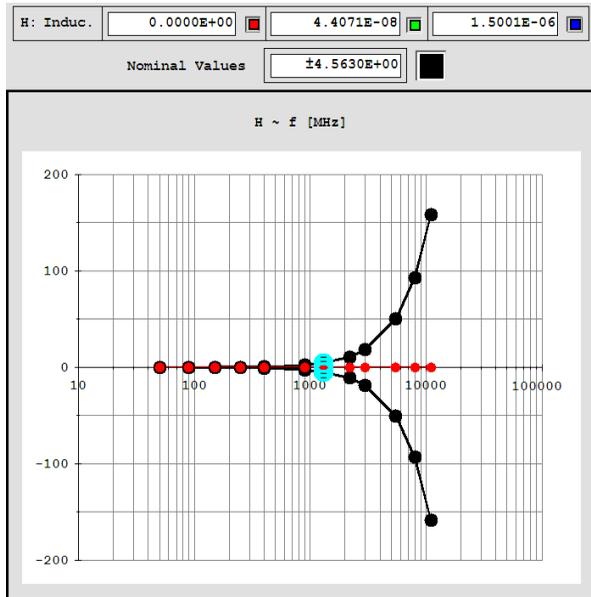


Fig. 20: H estimation and nominal values

[tInomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

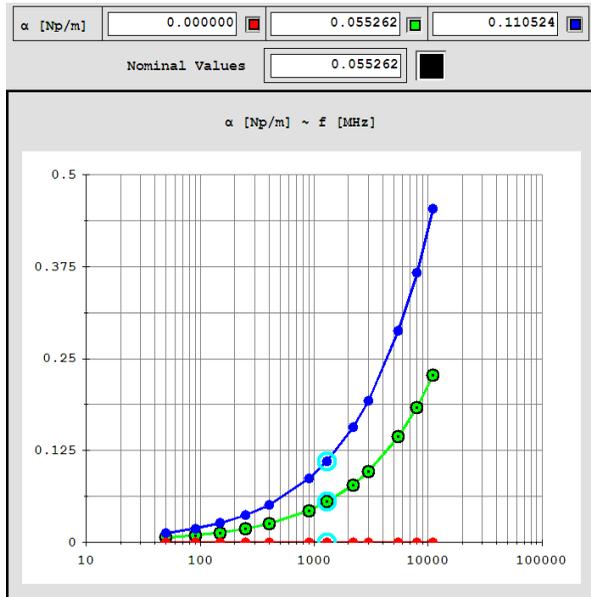


Fig. 21:  $\alpha$  estimation and nominal values

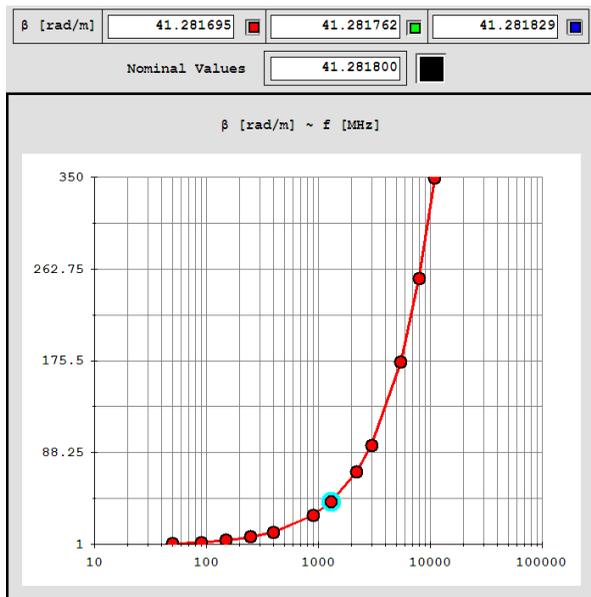


Fig. 22:  $\beta$  estimation and nominal values

### $\alpha$ , $\beta$ , $R_0$ , $X_0$ from Constant $R$ , $L$ , $G$ , $C$

The next window of [tl-nomiva] concerns the investigation of the propagation characteristics behavior with frequency when the circuit coefficients remain constant. The question is, is there any possibility this case to be true in real transmission lines or it is simply a matter of theoretical research as a mathematical exercise?

Well, even if it is only an academic problem it has a considerable interest by itself. From the one hand, (1)-(4) show that if  $X_0 = 0$  then  $R$ ,  $L$ ,  $G$ ,  $C$  become frequency independent. But this means the Heaviside term is equal to zero. From the other hand, the  $C$  distributed circuit coefficient is almost constant over a wide frequency range and  $L$  has a small variation. Thus,  $R$  and  $G$  are the most variable coefficients, and  $G$  has in most cases rather small values compared with  $R$  [2]. In addition, as it is stated in [2], there is a range of low frequencies over which  $R$ ,  $L$ ,  $G$ ,  $C$  can be considered effectively constants. Thus, it is worthwhile to examine the relation of all the four propagation characteristics with frequency as the four circuit coefficients take specific values.

The developed window of [Constant : (R,L,G,C)-->( $\alpha$ , $\beta$ ,

$R_0, X_0$ )~f] is shown in Fig. 23. It opens with the [Single] frequency as the default state and with some predefined values. The user may type the RLGC coefficients and the desired frequency or frequency range. When [Range] is activated then the text boxes contain the values of all the quantities at the middle frequency and the buttons for plots are enabled. In this figure the predefined values for RLGC was used and the range [0.001, 1000] [MHz] was selected. A in [dB/100m] is depicted in the chart with the [Draft-Min Max] enabled and with [Show Lines] unchecked.

Fig. 24 shows A of the line used in previous sections, with RLGC almost equal to their mean value at the lower frequency, to the whole permitted range, from 1 Hz to 100 GHz. Evidently there is a limit to what can be drawn in this application. The [wgnuplot A,  $\beta$ ,  $R_0$ ,  $X_0$ ,  $\alpha\beta$ ,  $\nu f$ ] produces the two triples of Fig. 25, where at the right top side of the plots the RLGC values are written. The white area indicates the band of the line operating frequency. In wgnuplot application the developed script plots the (12)-(16) as functions of frequency, that is, curves are plotted and not evaluation in specific number of points.

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

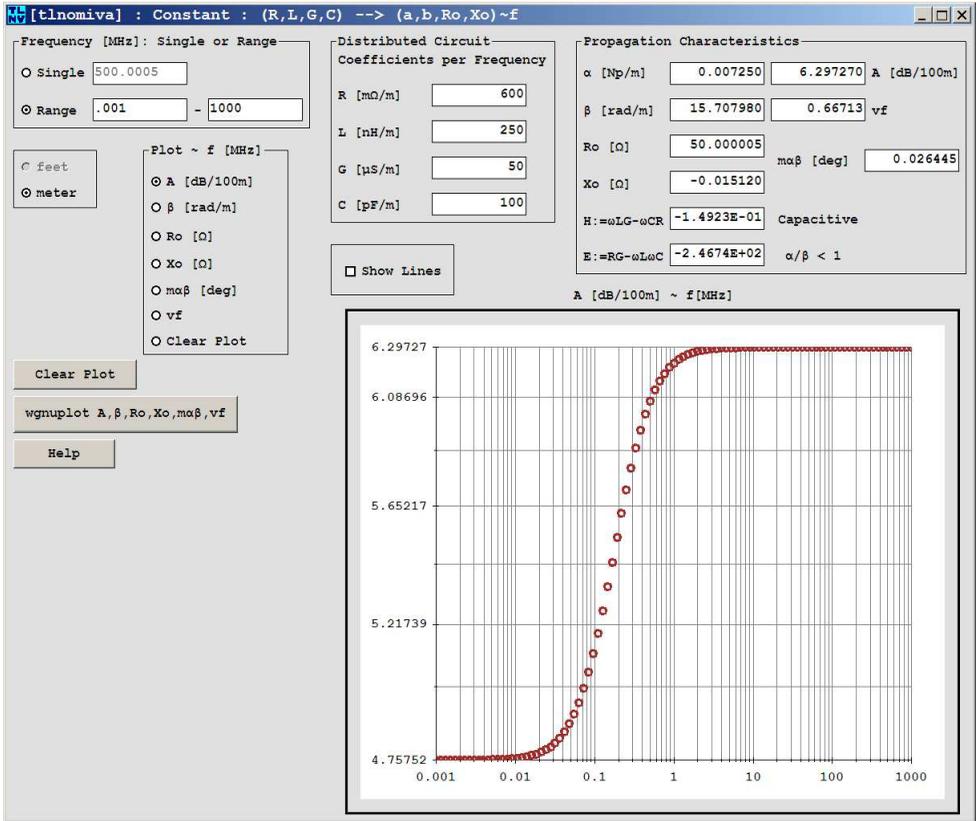


Fig. 23: [Constant : (R,L,G,C) --> (α,β,Ro,Xo,~)f] - [Range]

Thus, considering a much lower frequency range and a range for A between its minimum and maximum value, which substantially differ slightly, and plotting A function in wgnuplot, we get Fig. 26, where we distinguish the form of "S" we have seen before in Fig. 23 for the first line example.

Six text files are written in the directory of [tlnomiva], which are used from the

[wgnuplot.exe], with specific filenames of obvious meaning:

- |              |             |
|--------------|-------------|
| A-function   | B-function  |
| Ro-function  | Xo-fuction  |
| maβ-function | vf-function |

In order to emulate the curve structure in the current version of [tlnomiva], the mentioned relations are evaluated in 100 points equally spaced in the logarithmic scale of frequency f in [MHz].

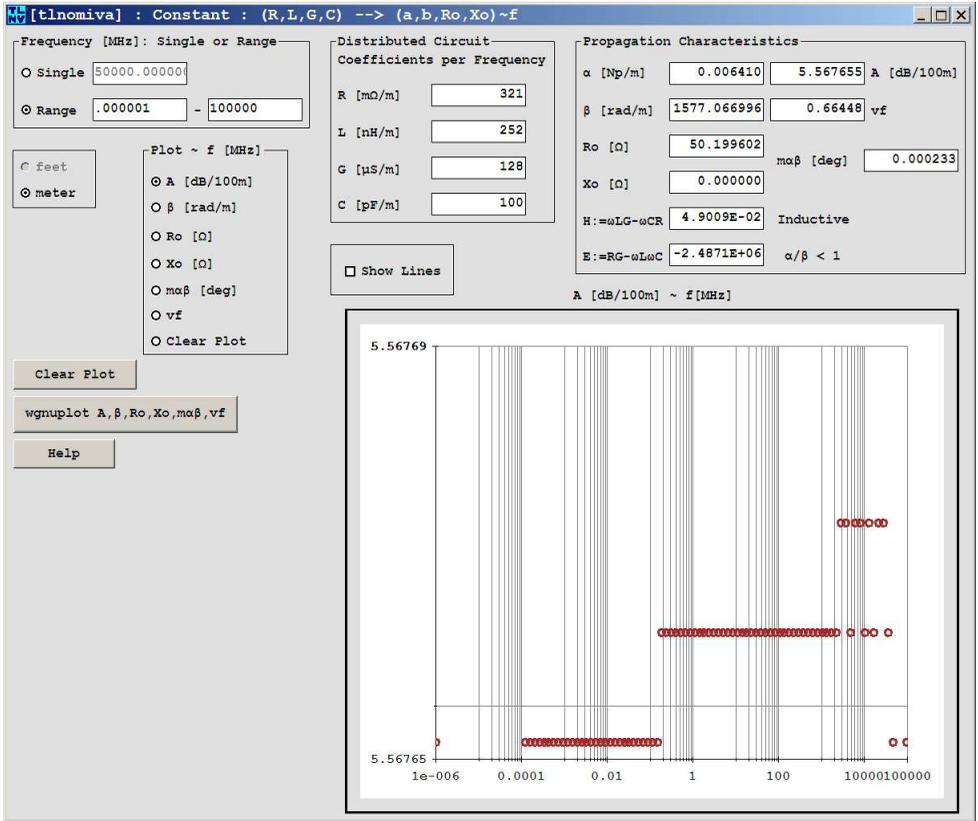


Fig. 24: A [dB/100m] versus f [MHz] with Draft-MinMax

A significant characteristic of this window is that when the [Range] is selected and one of the six quantities is plotted, then every change to the value of any of the four RLGC will immediately cause the change of the plot. All the other features are the same with the previous windows.

Using this feature of some kind of interaction and varying slightly by one (1) the

value of C and particularly by varying the value of L significantly, we get Fig. 27 for a transmission line with R, L, G, C equal to 321 [mΩ/m], 111 [nH/m], 128 [μS/m] and 100 [pF/m], where the velocity factor seems to take values larger than its upper limit of unit (1) (red), from 2.6 [MHz] and above. A fact that needs further research, and restates the issue of line definition.

[tInomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

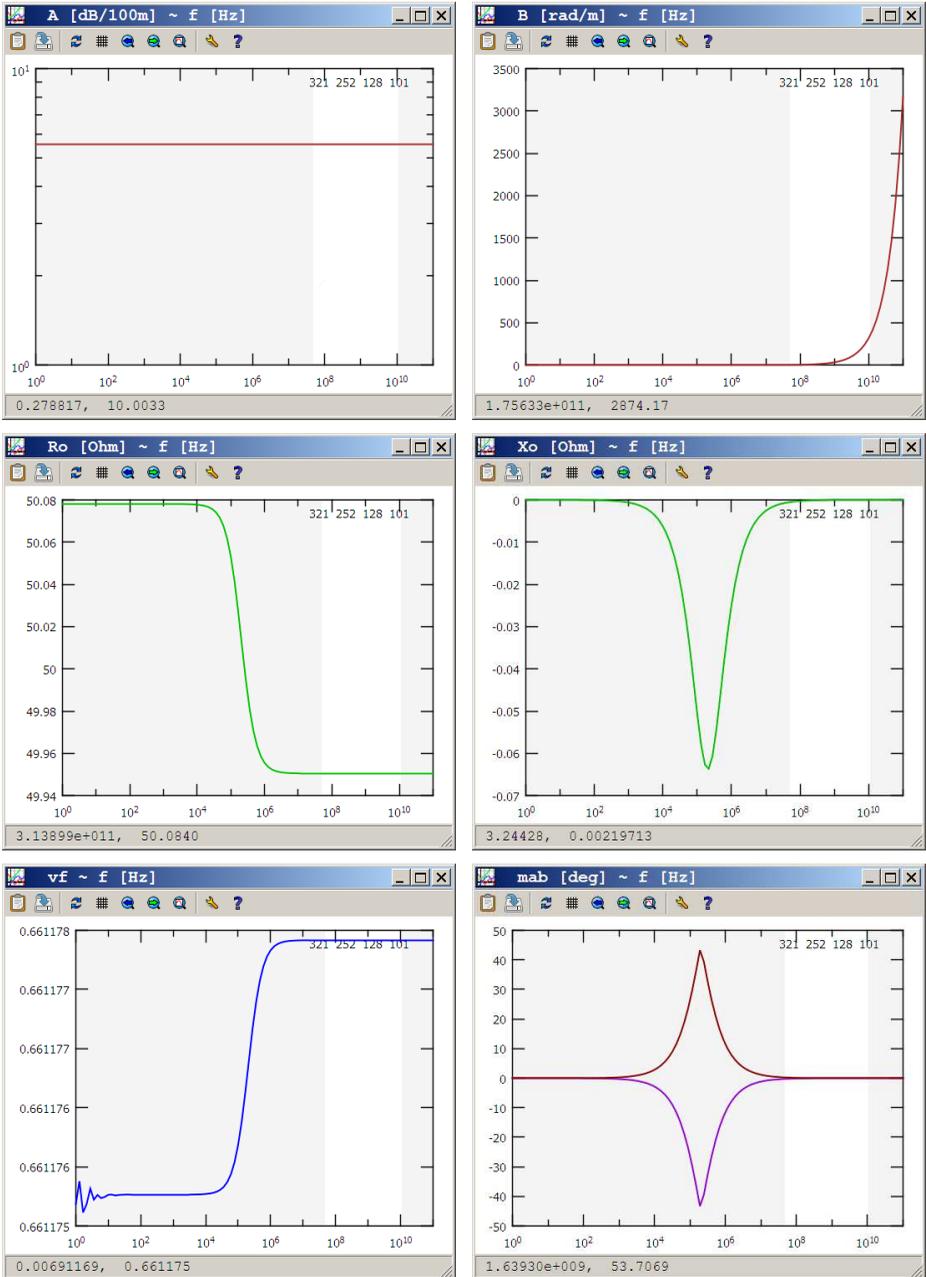


Fig. 25:  $A$ ,  $\beta$ ,  $R_o$ ,  $X_o$ ,  $v_f$ ,  $mab$  from [wgnuplot]

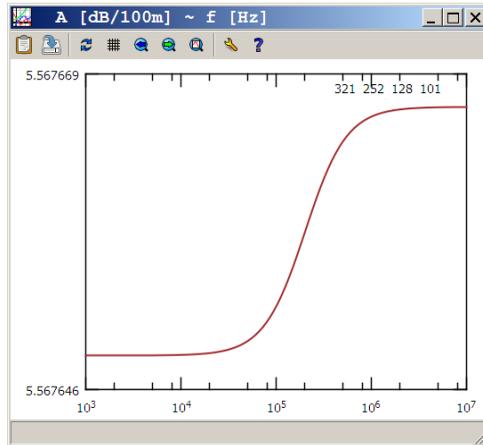


Fig. 26: A [dB/100m] versus f [MHz] from [wgnuplot]

### Final Remarks

There are two important matters. The first concerns the application [tlnomiva] itself and the second the way that the available cable specifications can be exploited.

1. In order to avoid unpredictable errors in calculations, caused by the different notation of decimal symbol used in various local MS Windows versions, a decision has to be made. Thus, the dot "." was selected to be the decimal symbol, as well as, the comma "," as the digit grouping symbol - although the later is not used at all here. Notably, this choice is a mandatory requirement for [wgnuplot], which does not recognize comma as decimal symbol. Hence, the window of Fig. 28 appears on the screen just after opening the appli-

cation when a non-dot definition exists in the Regional Settings of Control Panel.

2. The transmission line used to serve as an example of the features of the [tlnomiva], is the RG 214 cable and its specifications which are given in [5]. Since, only four (4) values for the attenuation factor A in [dB/100ft] are explicitly reported there, we decided to use the accompanying chart, which covers the whole operating frequency range from 50 [MHz] to 11 [GHz].

Fig. 29 shows a straight line for A in the logarithmic chart. Such a line can be represented by:

$$y = k x^\lambda \quad (17)$$

that is:

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

$$= a \log(x) + b \quad (18)$$

where  $a=\lambda$  and  $b=\log(k)$ , and from (17) and (18) we take:

$$y = 10^b x^a \quad (19)$$

Then, we graphically estimate the coordinates of the starting and ending points of the straight line in Fig. 29, as well as, we cross check the results by using the [Opti-Graph] application [6] as it is shown in Fig. 30. After that, we formulate and solve the following linear system:

$$\begin{aligned} \log(1.7) &= a \log(50) + b \\ \log(60) &= a \log(11000) + b \end{aligned} \quad (20)$$

and by using the Aurora Scientific Calculator SC 500 Plus [7], the solution for  $a$  and  $b$  is given, with nine (9) decimal digits, as follows:

$$a = +0.660727178$$

$$b = -0.892106736$$

from which we finally have:

$$A_{[\text{dB}/100\text{m}]} = \frac{0.128201546}{0.3048} f_{[\text{MHz}]}^{0.660727178}$$

In this way, since  $A$  has now an analytical expression in terms of frequency, we can determine as many points as we like, that is, for example, those of three (3) significant figures we put in

the grid of Fig. 6.

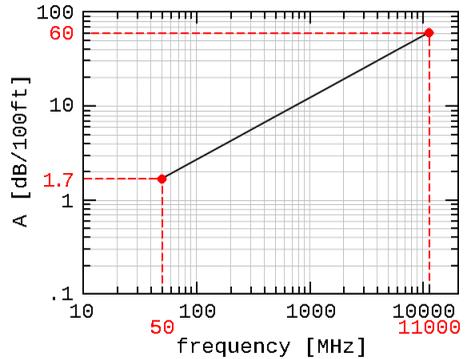


Fig. 29: Extracting analytical expression from a LogLog plot

### Conclusion

The limits of what can be estimated or predicted using precise formulation from the nominal values without tolerance of  $A$ ,  $v_f$ , and  $Z_0$ , which are usually given nowadays as cable specifications for transmission lines, without taken into account the cut-off frequency, was investigated in this paper.

It seems that the curves for all the involved quantities have more or less the same form, as it was expected and explained by their defining expressions, with a possible differentiation of course in their slope. These curves are strongly depended on how wide is the considered frequency window. Therefore, it is most important to pay special attention in the op-

erating frequency range in order to be sure that the model presented in this paper describes adequately the tran-

mission line characteristics in accordance with its specifications.

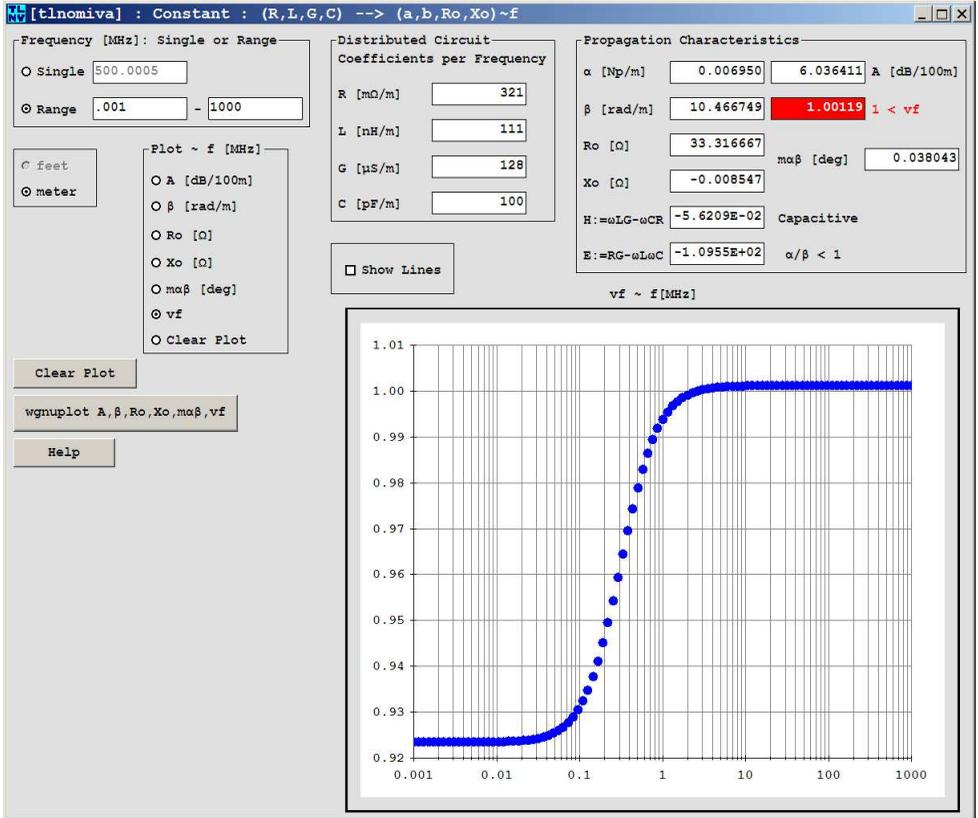


Fig. 27: RLGC for  $vf > 1$

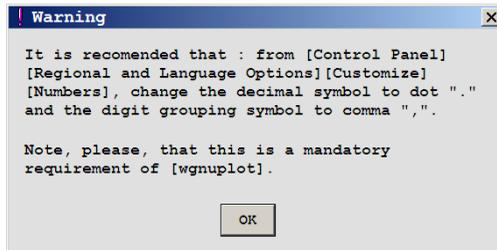


Fig. 28: Warning Message

[tlnomiva] : TRANSMISSION LINE NOMINAL VALUES WITHOUT TOLERANCE...

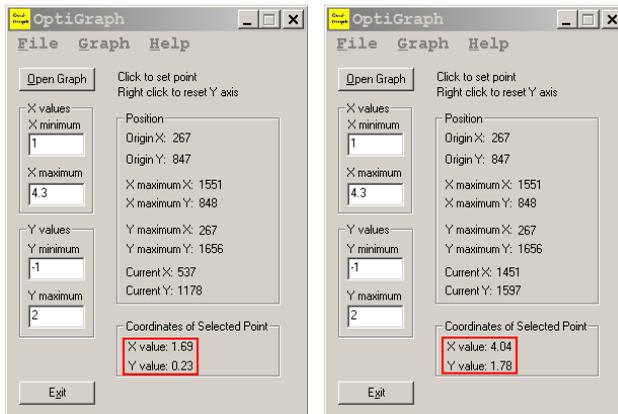


Fig. 30: [OptiGraph] : Starting and Ending points

The [tlnomiva] application is developed and presented as a research tool. The intention is to be used: (1) as a reference in the study of the already existing approximate techniques for finding the distributed circuit coefficients and the propagation characteristics, and 2) to be expandable in order to cover: (2a) not only the case of the RLCG theoretical calculation from the cable geometrical characteristics, but in addi-

tion (2b) the case of using the new approximation method for the determination of attenuation factor, which is under current development by the authors.

Finally, the whole of [tlnomiva] software, that is the MIT licensed source code, the installation package, as well as, its future improvements, updates and upgrades, can be always downloaded from the author's website address [8].

## References

- [1] Yannopoulou N., Zimourtopoulos P., "Transmission Lines - Part 1: A Precise Formulation within the Distributed Circuit Model", FunkTechnikPlus # Journal, Issue 9, Year 3, 2016, pp. 369 - 389, under revision with expanded additions  
[www.otoiser.org/index.php/ftpj/issue/view/2016.01.31](http://www.otoiser.org/index.php/ftpj/issue/view/2016.01.31)
- [2] Chipman R.A., "Transmission Lines", McGraw-Hill, 1968, pp. 15, 17, 26, 31 - 32, 42, 44, 47, 58 - 60

- [3] gnuplot,  
"Version 5.0 patchlevel 3 last modified 2016-02-04":  
<https://sourceforge.net/projects/gnuplot/files/gnuplot/>
  - [4] "How To Programmatically Close a Single Instance of a  
Windows-Based Program",  
<https://support.microsoft.com/en-us/kb/176391>
  - [5] "Detail, Specification Sheet: Cable, Radio Frequency, Fle-  
xible, Coaxial, 50 Ohms, M17/75-RG 214 and M17/75-RG365,  
MIL-DTL-17/75F, w/Amendment 2", 23 February 2010,  
<https://assist.dla.mil/online/start/>
  - [6] Yap Chun Wei, Optical Graph Recognition and Manipulation  
Util for Win32, OptiGraph, Version 1.0, 28 January 2000  
First release,  
<ftp://ftp.sk.debian.org/pub/pc/educult/>
  - [7] Aurora Scientific Calculator SC 500 Manual,  
[www.arg.op4.eu/aurora/sc500p/](http://www.arg.op4.eu/aurora/sc500p/)
  - [8] [tlnomiva],  
<http://arg.op4.eu/software/tlnomiva/>
- \*Active Links: 19.05.2016 - Inactive Links : FTP#J Link  
Updates: <http://updates.ftpj.otoiser.org/>

### **Previous Publication in FUNKTECHNIKPLUS # JOURNAL**

"Transmission Lines - Part 1: A Precise Formulation within the  
Distributed Circuit Model", Issue 9, Year 3, pp. 369 - 390

### **\* About The Authors**

*Nikolitsa Yannopoulou*, Issue 9, Year 3, p. 390  
[yin@arg.op4.eu](mailto:yin@arg.op4.eu)

*Petros Zimourtopoulos*, Issue 9, Year 3, p. 390  
[pez@arg.op4.eu](mailto:pez@arg.op4.eu)

---

*This paper is licensed under a Creative Commons Attribution 4.0  
International License - <https://creativecommons.org/licenses/by/4.0/>*

# Insulating Properties of Graphene Oxide

D.G. Mitrakas, M.G. Danikas \*

Department of Electrical and Computer Engineering,  
Power Systems Laboratory,  
Democritus University of Thrace, Xanthi, Greece

## Abstract

Many researchers concentrated recently their efforts on the investigation of the physical properties of graphene, such as its electrical and thermal conductivity and its strength. Its flexibility and transparency opened new possibilities regarding numerous applications, such as electronics, energy storage devices, polymers and electrodes. Relatively little was reported w.r.t. the insulating properties of graphene oxide. It is the purpose of the present paper to investigate whether graphene oxide can be suitable as insulating material for high voltage applications.

## Keywords

Graphene oxide, insulating properties, insulation lifetime, enclosed cavities

## Introduction

Graphene concentrated the lights of publicity and the scientific interest of numerous researchers around the globe for its physical properties, such as the very high electrical and thermal conductivity and its strength. Its transparency and its flexibility opened new roads for many applications, such as, among others, composite polymers, transparent electrodes and storage energy devices. A. Geim and K. Novoselov re-

ceived the Nobel prize in physics for "groundbreaking experiments regarding the two-dimensional material graphene" [1].

## Properties of Graphene

A graphene film is -at the moment- the thinnest known material, the gases cannot penetrate it, and it has higher mechanical strength than stainless steel. Its properties open new inroads regarding novel applications. At room temperature, its thermal conduc-

tivity is very high, higher than that of diamond, and of the order of  $5000 \text{ W m}^{-1} \text{ K}^{-1}$ . Graphene is almost transparent, absorbing only 2.3% of light. It is an excellent electrical conductor, having a high charge mobility of  $200000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ . Such properties were recorded with very thin graphene samples of the highest quality and of small surface. It was also reported that graphene properties (such as electronic properties, thermal conductivity, hardness and elasticity) may change with the sample thickness [2].

### **Possible Applications of Graphene**

Many industrial applications were proposed, such as energy storage devices, transistors, electrodes, composite polymers, nanocomposites, sensors etc. The quantity and morphology of graphene for each of the above applications may vary, depending on the application itself. For example, sensors or transparent electrodes require thin graphene films, whereas batteries, super-capacitors and synthetic polymers require quantities of nano-films or graphene platelets. Graphene dispersion in the matrices of the base polymer should be as good as possible.

### **Graphene Oxide as Insulating Material**

The reply to the question whether graphene oxide is a good insulating material, is not easy to be given since the chemical structure of graphene oxide is sensitive to the temperature. The electrical conductivity of graphene oxide can be studied with the aid of dielectric spectroscopy [3]. Dielectric spectroscopy records the change of dielectric properties of a material with the frequency and the temperature. It gives indications as to the insulating properties of the material, taking into account the relaxation phenomena. The latter change the dielectric behavior of the material and allow the storage of more electric energy in the volume of the material.

It is evident that the conductivity of graphene oxide increase is a function of temperature and of frequency (Fig. 1a). The frequency spectrum is in the range of 0.1 Hz up to  $10^6$  Hz and the range of temperature is in the range of  $-40^\circ \text{ C} - 30^\circ \text{ C}$ . The slope of the conductivity curve with frequency decreases as the temperature increases. The dielectric constant takes low values and presents a rather small dependency on frequency at low

temperatures. However, this changes at higher temperatures (Fig. 1b) (note the same ranges of frequency and temperature for Figs. 1a and 1b) [4].

Fig 2a shows the conductivity in the temperature range 40<sup>o</sup> C – 90<sup>o</sup> C. It shows a stepwise increase at lower frequencies and reaches a plateau value at higher frequencies. Fig. 2b shows a decrease of dielectric constant with frequency increase for the same temperature range as in Fig. 2a [4].

Fig. 3a shows conductivity changes from 100<sup>o</sup> C to 150<sup>o</sup> C. The conductivity plateau value appears also at higher temperatures. The transition from plateau value to the exponential increase moves to higher temperatures as the temperature increases. It is to be noted that conductivity increases dramatically as the temperature increases above 100<sup>o</sup> C. Fig. 3b shows that the dielectric constant changes significantly as the frequency decreases [4].

Fig. 4 shows conductivity as a function of temperature at the frequency of 0.1 Hz. One may see three transitions from -40<sup>o</sup> C to 150<sup>o</sup> C. Two transitions from the region of insulating material to the region of semiconduction at about 10<sup>o</sup> C and 100<sup>o</sup> C and one

transition from the region of semiconduction to the region of insulating material at 90<sup>o</sup> C. At room temperature electrical conductivity has semiconductive characteristics but at lower temperatures has insulating characteristics. Fig. 5 shows the variation of the dielectric constant with temperature at various frequencies [4].

It should be noted that graphene oxide is hydrophilic material and it is very sensitive to humidity variations. Its resistance is 10<sup>8</sup> Ω for relative humidity of 15% but it becomes ten times smaller when the relative humidity is 95%. The relationship of its resistance with humidity, renders the aforementioned material ideal as humidity sensor [5].

Graphene oxide can be selected to be added to polymer matrices because of its high mechanical strength and its high thermal conductivity. Pure graphene oxide is thermally unstable. The decomposition of graphene oxide nanosheets (GO<sub>n</sub>) is not valid for nanocomposites GO/PVDF because of the strong interactions between its constituents. Fig. 6 shows that the permittivity of such a nano-composite (GO/PVDF) with concentrations above 1 wt% is higher than that of pure PVDF.

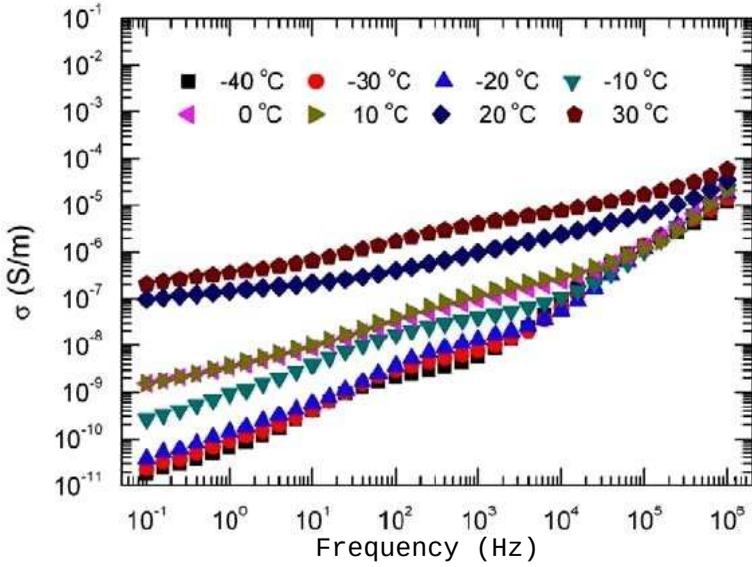


Fig. 1a Conductivity of graphene oxide with frequency and temperature

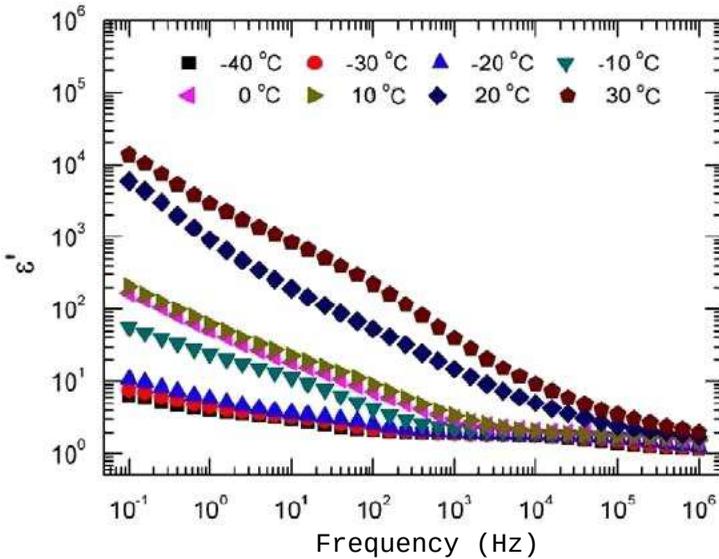


Fig. 1b Dielectric constant of graphene oxide with frequency and temperature

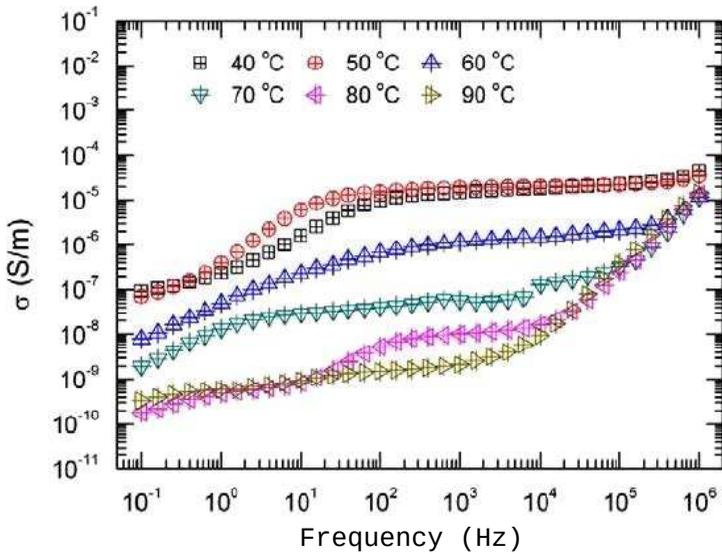


Fig. 2a Conductivity of graphene oxide with frequency and temperature

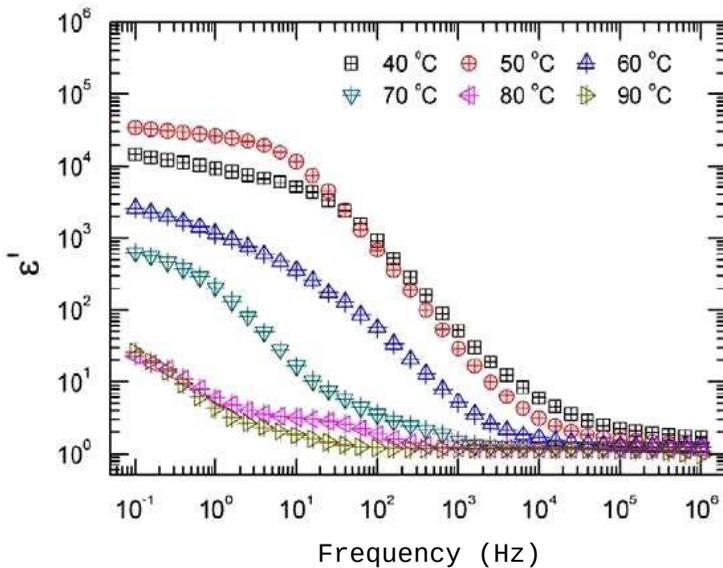


Fig. 2b Dielectric constant of graphene oxide with frequency and temperature

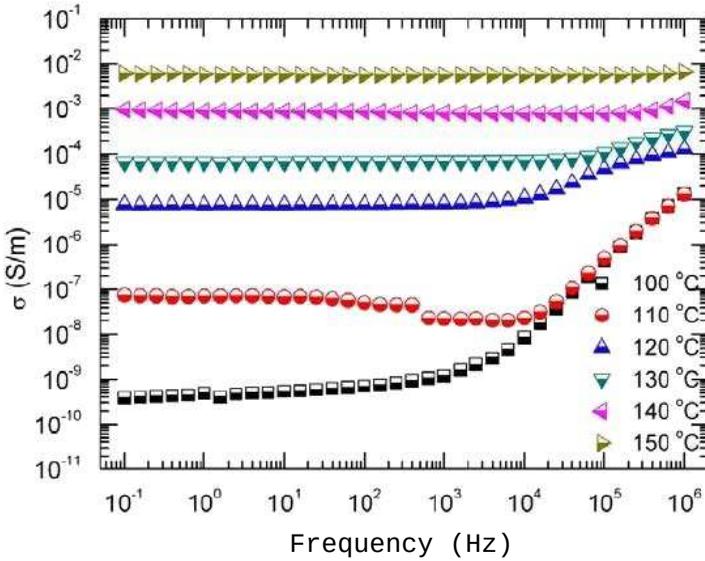


Fig. 3a Conductivity of graphene oxide with frequency and temperature

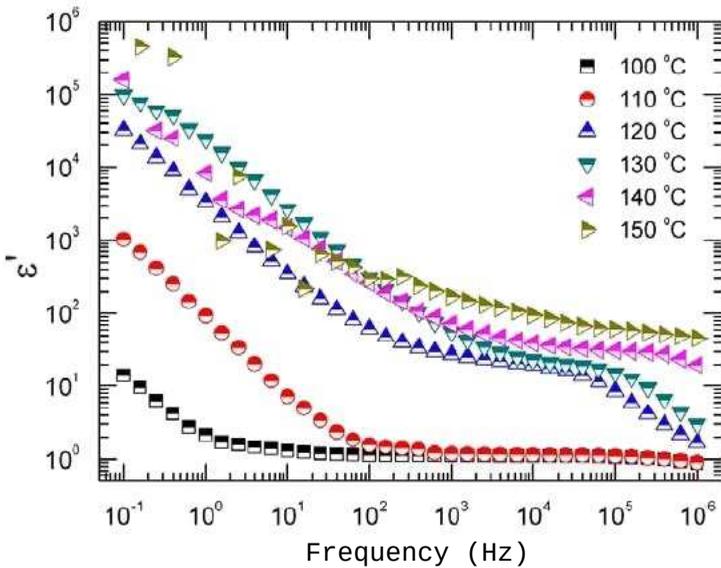


Fig. 3b Dielectric constant of graphene oxide with frequency and temperature

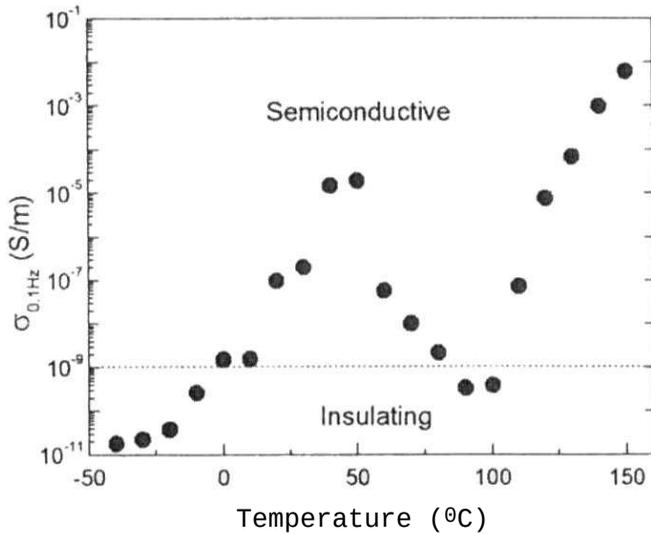


Fig. 4 Conductivity of graphene oxide with temperature at frequency 0.1 Hz

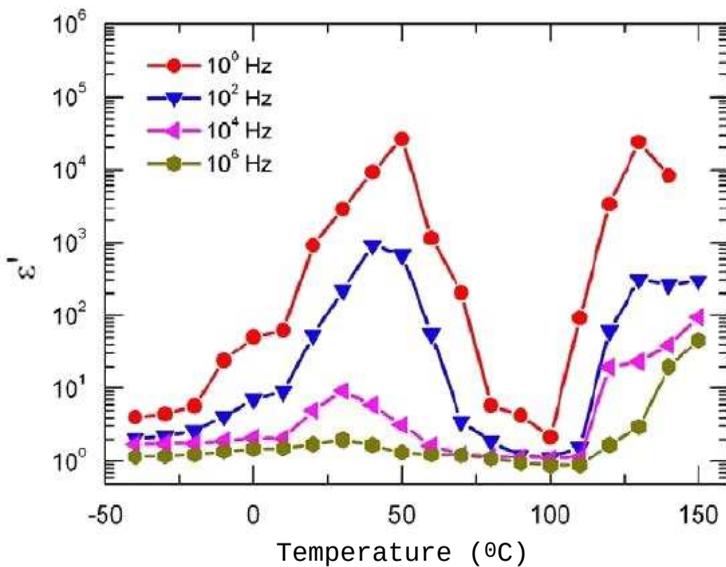


Fig. 5 Dielectric constant of graphene oxide

However, for concentrations of GO lower than 0.5 wt%, permittivity is lower than that of pure PVDF. Fig. 7 shows that the presence of GO in various concentrations does not result in a change of

electrical conductivity of the nanocomposite in relation to the pure PVDF at higher frequencies, whereas small differences (increase of conductivity) are observed as the frequency decreases [6].

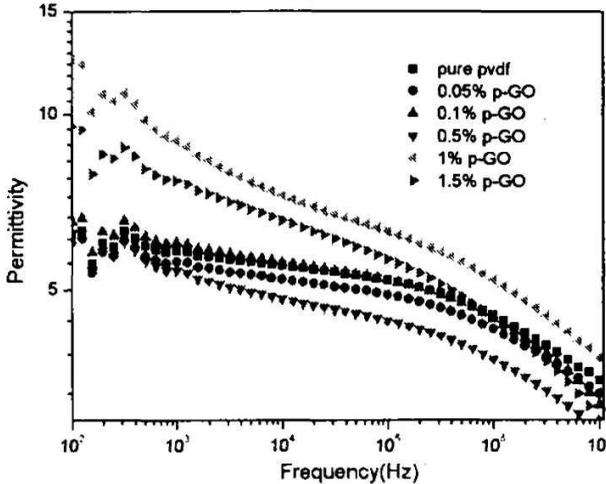


Fig. 6 Dielectric constant of Gon/PVDF

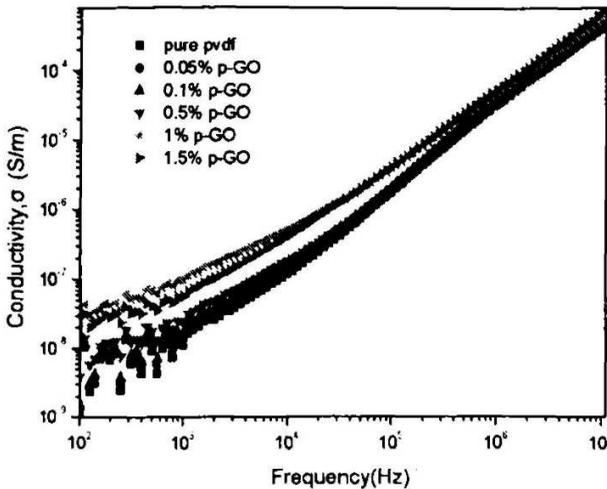


Fig. 7 Conductivity of Gon/PVDF

Graphene oxide in combination with silicon oxide may be used as thin coatings in XLPE. As evaluation index of such a combination the OIT (oxidative induction time) was used, an evaluation which

is taken during accelerated ageing at 120°C. Fig. 8 shows OIT values as a function of time for the pure polymer, the combination XLPE-SiO<sub>2</sub> as well as for the combination XLPE-GO-SiO<sub>2</sub>.

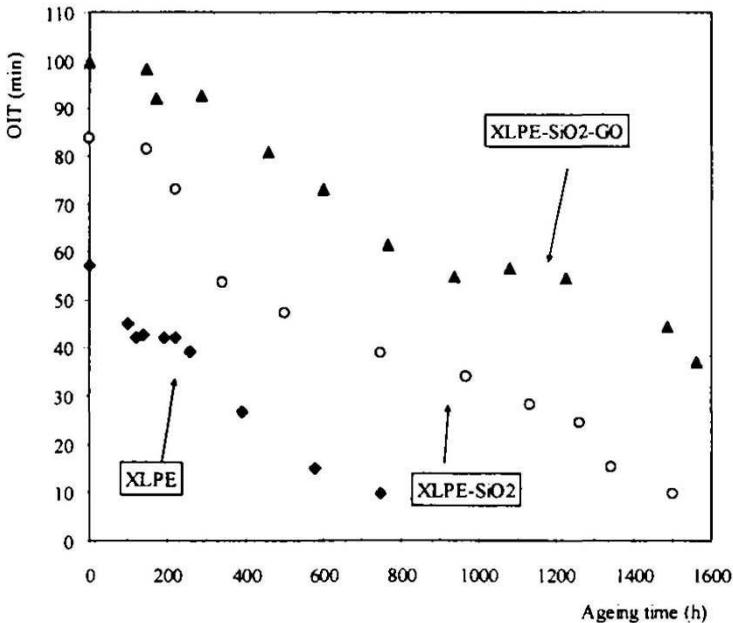


Fig. 8 Values of OIT with time

It is evident that such coatings contribute to the increase of resistance in the thermal oxidation. The presence of 0.5 wt% GO gives even more higher values of OIT. All coatings seem to increase the surface resistivity but the coating with GO is the better one. The presence of GO contributes to the hindrance of oxygen and of oxidation of the polymer.

Moreover, the change in coating structure are adequate in improving the thermal stability of XLPE [7].

Work done with epoxy resin with graphene oxide up to 0.5 wt% showed that there is no difference between pure epoxy resin and the one with GO regarding the dielectric behavior. The addition of GO does not render any better the epoxy resin (Fig. 9) whereas

there is a marked difference with epoxy resin nanocomposite after thermal treatment (Fig. 10) [8].

In general, for relatively low and higher voltages, it can be said that GO cannot be used as insulating material because for practical atmospheric conditions above 40°C, it does not show insulating behavior except for the temperature range between 90°C and 100°C and also below 10°C. Such temperature ranges, however, are very specific and do not generally satisfy ordinary industrial applications, especially in the high voltage industry. In very low voltages, i.e. in electronics applications, GO has in general a semiconducting character and as such is investigated in the scientific bibliography. In some specific cases, such as in very low humidity or in very low temperature, GO has an insulating behavior, which can have particular applications.

### Cavity Considerations and Graphene Oxide

It is known that the electric field  $E_c$  inside an enclosed cavity in an insulating material of dielectric constant  $\epsilon_r$  is given by the equation

$$E_c = 3 \epsilon_r E / (2 \epsilon_r + 1) \quad (1)$$

where,  $E$  is the applied electric field to the insulating material.

It is also known that, assuming a uniform electric field  $E$  applied to the insulating material, the expected lifetime  $L$  is given by the equation

$$L = k (E d)^{-n} \quad (2)$$

with  $k$  and  $n$  constants depending on the material and the quality of its construction, and  $d$  the thickness of the material.

Combining Equations (1) and (2), we have that

$$L = k [E_c d (2\epsilon_r + 1) / 3\epsilon_r]^{-n} \quad (3)$$

which gives a relation between the lifetime of the material in terms of the thickness of the material.

Based on Fig. 11, and considering that in a sample the cavity has a radius  $R$ , the applied field to the sample is  $E$ ,  $E_c$  is the field inside the cavity,  $d$  is the overall thickness of the sample and  $\alpha$  as in Fig. 11, and having in mind that  $d = 2\alpha + 2R$ , Equation (3) becomes]

$$L = k [2 E_c (\alpha + R) * (2\epsilon_r + 1) / 3\epsilon_r]^{-n} \quad (4)$$

Consequently we have a relation between the lifetime  $L$  and the radius  $R$  of the spherical cavity.

In the case of graphene oxide (GO), for temperature  $t = 90^{\circ}\text{C}$  and from Fig. 2b, the dielectric constant is given as  $\epsilon_r = 2$ ,  $f = 50\text{ Hz}$ , with insulation thickness  $d = 0.1\text{ mm}$ ,  $k = 4$ ,  $n = 10$ , we finally get the curve of Fig. 12. This shows the change in lifetime in hours w.r.t. the electric field  $E_c$  inside the cavity in GO.

It is evident from Fig. 12, that as the electric field becomes larger, lifetime becomes shorter with a given cavity size.

In the case of GO, for power frequency, and various temperatures  $T = -10^{\circ}\text{C}$  (from Fig. 1b we have  $\epsilon_r = 9$ ),  $T = 0^{\circ}\text{C}$  (from Fig. 1b  $\epsilon_r = 15$ ),  $T = 10^{\circ}\text{C}$  (from Fig. 1b,  $\epsilon_r = 21$ ),  $T = 90^{\circ}\text{C}$  (from Fig. 2b  $\epsilon_r = 2$ ),  $T = 100^{\circ}\text{C}$  (from Fig. 3b,  $\epsilon_r = 1.8$ ), we have correspondingly the lines L1, L2, L3, L4 and L5 in Fig. 13.

Fig. 13 shows the lifetimes in hours at various temperatures and in function of various electric field values inside the cavity in GO. We observe that lifetime changes w.r.t. temperature and therefore w.r.t. the dielectric constant of the material. Smaller dielectric constant means smaller lifetime.

From Equation (4), for a constant electric field value

$E_c = 0.12\text{ kV/mm}$ ,  $k = 4$ ,  $\alpha = 1\text{ mm}$ ,  $\epsilon_r = 2$ ,  $n = 10$  and for different values of cavity radius, we find that the corresponding lifetime is

Tab. 1

R (mm)	L (hours)
0.2	6308812
0.1	15060285
0.05	23980986
0.01	35362772
0.005	37162029
0.001	38674015
0.0001	39023459

Cavities decrease the lifetime of insulation. By increasing the cavity radius  $R$ , lifetime decreases. As the cavity radius goes at about  $0.001\text{ mm}$  and smaller, the difference in lifetimes becomes small or in other words, cavities of such magnitudes do not significantly decrease the lifetime of GO. It must be noted that the above Tab. 1 is rather qualitative rather than quantitative. It is evident from the above results that the electric behavior of GO depends on the temperature. In regions between  $90^{\circ}\text{C}$  -  $100^{\circ}\text{C}$  as well as below  $10^{\circ}\text{C}$ , GO presents insulating behavior. In normal applications, however, under normal atmospheric conditions, its insulating behavior is lost.

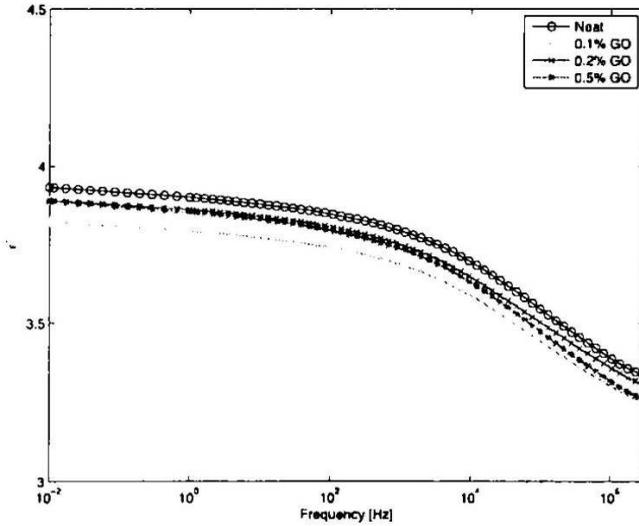


Fig. 9 Dielectric constant epoxy nanocomposite with GO at 20<sup>o</sup> C

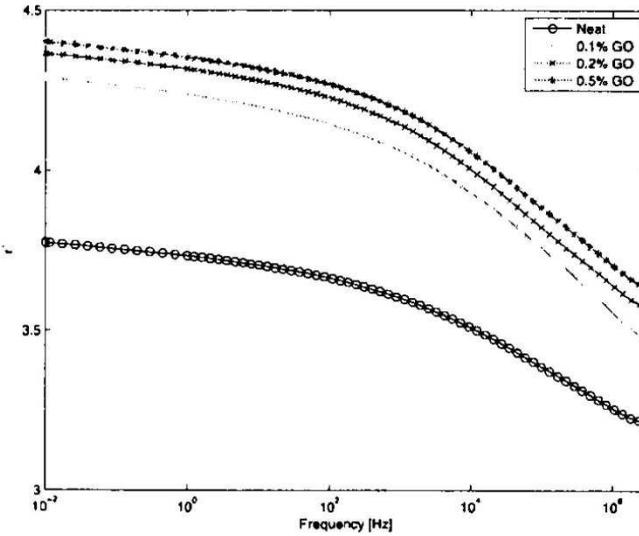


Fig. 10 Dielectric constant of epoxy nanocomposite with GO after thermal treatment

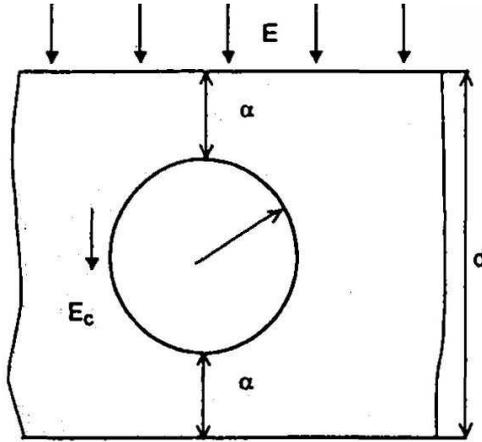


Fig. 11 Enclosed cavity in a solid dielectric

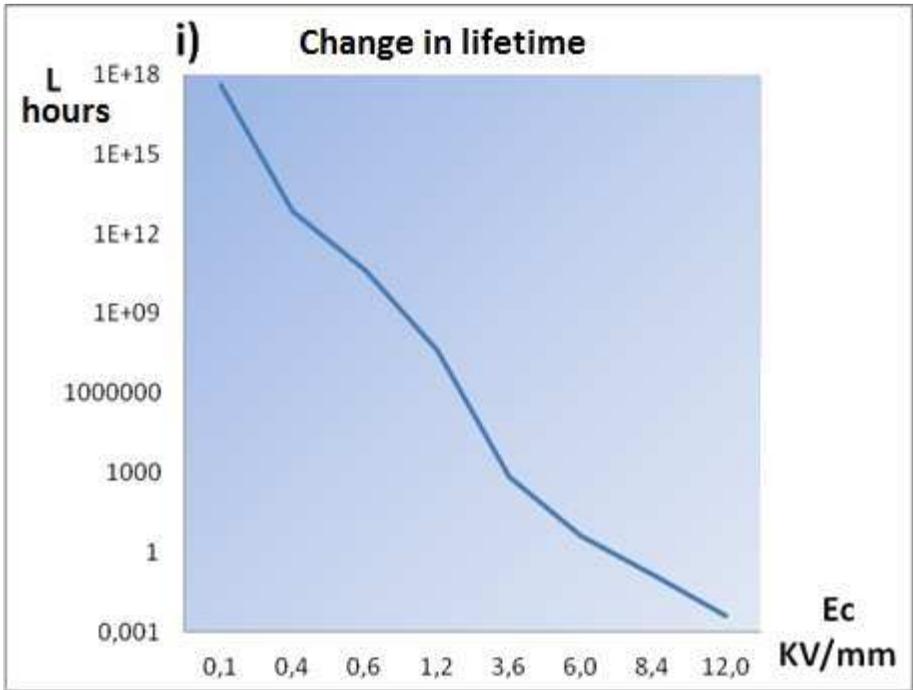


Fig. 12 Change in lifetime in (hours) with the electric field  $E_c$  in (KV/mm)

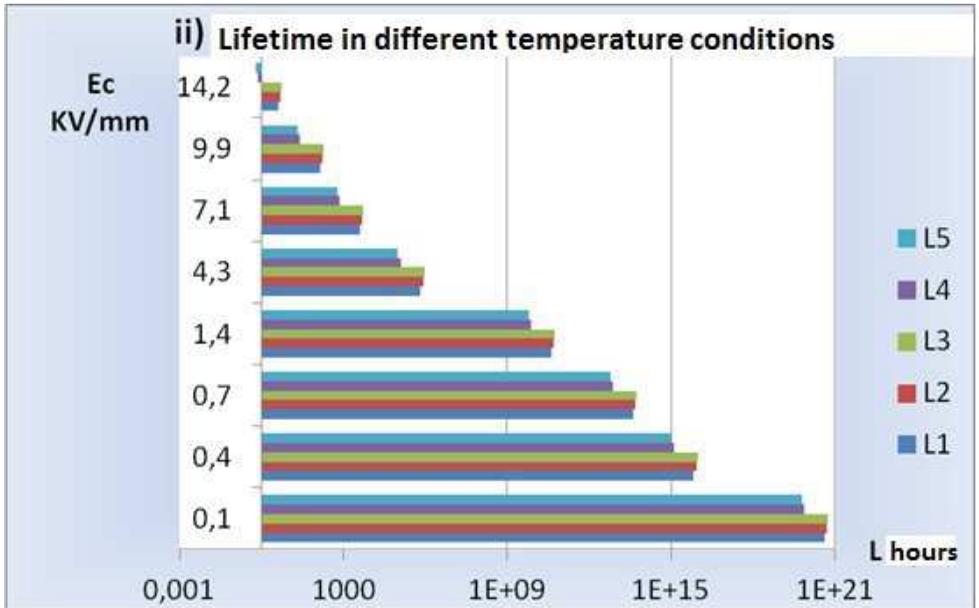


Fig. 13 Change in lifetime in (hours) with the electric field  $E_c$  in (KV/mm) and with different temperature conditions

### Conclusion

Graphene is an excellent novel material for a variety of applications. However, graphene oxide is not suitable

for high voltage applications since its insulating properties are confined to a small temperature range.

### References

- [1] [http://www.nobelprize.org/nobel\\_prizes/physics/laureates/2010/](http://www.nobelprize.org/nobel_prizes/physics/laureates/2010/)
- [2] Edwards R.S., Coleman K.S., "Graphene synthesis: Relationship to applications", *Nanoscale*, Vol. 5, 2013, pp. 38-51
- [3] Huang X., Liu F., Jiang P., Tanaka T., "Is graphene oxide an insulating material?", *Proceedings of the 2013*

- IEEE International Conference on Solid Dielectrics, 30th June - 4th July 2013, Bologna, Italy, pp. 904-907
- [4] Huang X., Zhi C., Jiang P., Golberg D., Bando Y., Tanaka T., "Temperature-dependent electrical property transition of graphene oxide paper", *Nanotechnology*, Vol. 23, 2012, pp. 1-10
- [5] Yao Y., Chen X., Zhu J., Zeng B., Wu Z., Li X., "The effect of ambient humidity on the electrical properties of graphene oxide", *Nanoscale Research Letters*, Vol. 7, 2012, pp. 363-370  
<http://link.springer.com/article/10.1186/1556-276X-7-363>
- [6] M Liu F., Huo R., Huang X., Jiang P., "Effect of processing method on the dielectric behaviour of graphene oxide/PVDF nanocomposites", *Proceedings of the 2013 IEEE International Conference on Solid Dielectrics*, 30th June - 4th July 2013, Bologna, Italy, 2013, pp. 919-922
- [7] Cavallini A., Fabiani D., Sacconi A., Toselli M., "Thermo-oxidative resistance of crosslinked PE coated by hybrid coatings containing graphene oxide", *Proceedings of the 2013 IEEE International Conference on Solid Dielectrics*, 30th June - 4th July 2013, Bologna, Italy, 2013, pp. 912-914
- [8] Mancinelli P, Fabiani D., Sacconi A., Toselli M., Heid T., Frechette M., Savoie S., David E., "Preparation and dielectric behavior of epoxy resin containing graphene oxide", *Proceedings of the 2013 IEEE International Conference on Solid Dielectrics*, 30th June - 4th July 2013, Bologna, Italy, 2013, pp. 915-918
- [9] Danikas M.G., Vassiliadis G.E., "Models of partial discharges (PD) in enclosed cavities in solid dielectrics", *Journal of Electrical Engineering*, Vol. 54, No. 5-6, 2003, pp. 132-135

**Previous Publication in FUNKTECHNIKPLUS # JOURNAL**

"Thoughts on the Possibility of Damage of High-Voltage Electrical Insulation below the So-Called Inception Voltage: A Proposed Solution and Some Further Comments - Part II",  
Issue 9, Year 3, pp. 355-367

**\* About The Authors**

*D.G. Mitrakas*, received his degree from Democritus University of Thrace, Department of Electrical and Computer Engineering in May 2014. Since then, he is a self-employed electrical engineer with a particular interest in power systems applications.

*Michael Danikas*, Issue 2, Year 1, 2013, p. 39

[ This Page Intentionally Left Blank ]

[ This Page Intentionally Left Blank ]

In case of any doubt,  
download the genuine papers from  
**[genuine.ftpj.otoiser.org](http://genuine.ftpj.otoiser.org)**

**ARG NFP AoI**

Antennas Research Group

Not-for-Profit Association of Individuals [\*]

[www.arg.op4.eu](http://www.arg.op4.eu) – [arg@op4.eu](mailto:arg@op4.eu)

Hauptstraße 52, 2831 Scheiblingkirchen, Austria

Telephone: 0 6646311483 – International: 0043 6646311483

\* The Constitution of Greece, Article 12(3) – 2008:

[www.hellenicparliament.gr/en/Vouli-ton-Ellinon/To-Politevma](http://www.hellenicparliament.gr/en/Vouli-ton-Ellinon/To-Politevma)

\* The Hellenic Supreme Court of Civil and Penal Law:

[www.areiospagos.gr/en](http://www.areiospagos.gr/en) – Court Rulings:Civil|A1|511|2008

---

## FRONT COVER VIGNETTE

A faded synthesis of an anthemion rooted in a meandros

The thirteen-leaf is a symbol for a life tree leaf.  
"Herakles and Kerberos", ca. 530–500 BC,  
by Paseas, the Kerberos Painter,  
Museum of Fine Arts, Boston.

[www.mfa.org/collections/object/plate-153852](http://www.mfa.org/collections/object/plate-153852)

The simple meandros is a symbol for eternal immortality.  
"Warrior with a phiale", ca. 480–460 BC,  
by Berliner Maler,  
Museo Archeologico Regionale "Antonio Salinas" di Palermo.

[commons.wikimedia.org/wiki/File:Warrior\\_MAR\\_Palermo\\_NI2134.jpg](https://commons.wikimedia.org/wiki/File:Warrior_MAR_Palermo_NI2134.jpg)