

ISSN 2310-6697

toiser—open transactions on independent scientific-engineering research

# FUNKTECHNIKPLUS # JOURNAL

Théorie—Expérimentation—Métrologie—Logiciel—Applications

ISSUE 26–27 – MONDAY 31 JANUARY 2022 – YEAR 9

REPRINT

## **Measurement Uncertainty in Network Analyzers: Differential Error Analysis of Error Models Part 6: FLOSS - Software Tools**

N.I. Yannopoulou, P.E. Zimourtopoulos



*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>*

# Measurement Uncertainty in Network Analyzers: Differential Error DE Analysis of Error Models Part 6: FLOSS - Software Tools

N.I. Yannopoulou, P.E. Zimourtopoulos

Antennas Research Group, Austria - [www.op4.eu](http://www.op4.eu)

## Abstract

Two software tools were developed to compute and illustrate the uncertainty estimation of one-port VNA measurements using Complex Differential Error Regions, DERs, and their corresponding Differential Error Intervals, DEIs, in polar and rectangular form. The first tool, [REGION], was written in Open Watcom FORTRAN F77 Compiler as a Command Line Interface for calculations and is the programming realization of the graphical DER construction presented by the authors in the previous part of this series. The second tool, [DERDEI], was written in Maxima and is used as a Graphical User Interface for illustrations. Both of them were written with these Open, Free and under continuous support software development systems, in order to be publicly available, since the corresponding previously written and used by the authors programs demand the proprietary Mathematica application. The presented tools were tested with our VNA system measurement data but they can be easily used with any other VNA data ensuring that the text files have the same, specifically defined, format, valid under SLO calibration for one-port measurements. In order to demonstrate our method a number of selected experimental results along with some extreme cases of DERs and their DEIs, under particular circumstances, are also presented. The developed software tools are available on the Internet as FLOSS Free Libre Open Source Software.

## Keywords

microwave measurements, network analyzer, differential error region, differential error interval, calibration

## Introduction

The graphical construction

of the Differential Error Regions DERs and their corresponding polar and rectangular

lar Differential Error Intervals DEIs was already presented by the authors' [1]. This graphical construction was carried out step-by-step as a sequence of figures which illustrate a more or less complicated procedure of building a complex DER with its real DEIs around a VNA measurement. For this purpose the authors developed two software applications which are presented here.

Initially, the used program for these works was written in Mathematica, an enhanced language that combines evaluation and illustration, but close to those who do not own one of its versions. This program in Mathematica's package form is limited by successive Mathematica's upgrades and unavoidable variations in the used built-in functions. Thus, we decided to replace it with two separate open software tools: the [REGION] CLI-Tool and the [DERDEI] GUI-Tool. The Open and free distribution of Watcom FORTRAN Compiler version 1.8 -a programming language that includes as built in the complex number type- was used for the needed computations of [REGION]. The Open Source MAXIMA 5.17.1 language with GnuPlot version 4.6 patch-level 5 -binary distribution for Windows, was used for [DERDEI], in order to draw

the DERs and DEIs in the complex and real plane respectively, resulting from [REGION].

These tools are appropriate for one-port measurements by assuming SLO calibration. They were tested with our Vector Network Analyzer VNA system, already described in detail [2], using an introduced by us data format which is fully explained in the following. Notably, it is easy to use the tools, with any other VNA data for one-port measurements either by keeping the same format for the input files or by direct modification of the open source [REGION] program. The source code has been released as FLOSS Free Libre Open Source Software and thus it may be freely used, copied, modified or redistributed, individually or cooperatively, by the interested user to suit her/his personal needs under the MIT license [3].

The two tools were presented for first time on 2 April 2009 by the authors through distance connection to the attendees, both local and distant, of the 31st ANAMET Club meeting of National Physical Laboratory NPL held in Winnersh, Berkshire at Agilent Technologies UK and an updated version of the presentation is available online [4].



### Working Formulas

The well-known one-port Error Model is shown in Fig. 1. To simplify notation, just one symbol was used for each one of the complex valued so called system errors: (a) D, M, R and (b) m for DUT measurements.

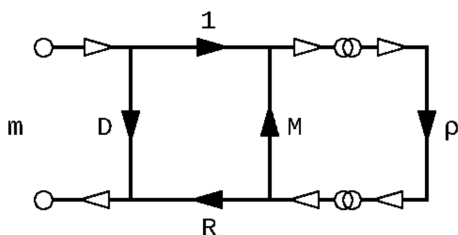


Fig. 1: Full one-port Error Model

Since the tools concern one-port measurements it is appropriate to summarize here the relations we used in programming. Thus, from [2], [5]

$$\rho = (Z - Z_0)/(Z + Z_0) \quad (1)$$

$$\rho = (m - D)/[M(m - D) + R] \quad (2)$$

$$d\rho = [-RdD - (m - D)^2dM - (m - D)dR + Rdm]/[M(m - D) + R]^2 \quad (3)$$

$$dZ = 2Z_0d\rho/(1 - \rho)^2 \quad (4)$$

where, the complex differential  $d\rho$  represents the uncertainty of reflection coefficient of any one-port DUT and  $dZ$  its corresponding impedance uncertainty with  $Z_0$  the

characteristic impedance of the system. The differentials are dependent on seven (7) complex variables, four (4) measurements and three (3) standard loads, that is on fourteen (14) real variables and their corresponding differential as we already thoroughly explained [2].

It is assumed that the user who is interested to use these tools is able to collect the measurement data of the three standard loads and the unknown DUT.

### [REGION]

In order to compute the Uncertainties, the [REGION] tool needs as its input four (4) text-files containing the measurement data of the SLO standards and the DUT with fixed names: [SH.SC], [OP.OC], [LD.LD] and [ME.ME] correspondingly, and an additional text file named [INPUT.TXT] with contents explained below.

The exact structure of the measured data with a two line example for each file is shown in Fig. 2. It must be emphasized that the text-files must have exactly these names and the format as it is detailed in Tab. 1. The empty line after each data line is required even for the last and final line of data.

A sample of the file [INPUT.TXT] is shown in Fig. 3 and has the structure speci-

fied in Tab. 2. At the first line a "0" means that [REGION] will compute  $\rho$ -DERS while an "1" means Z-DERS. Line 2 specifies the number of frequencies. Line 3 contains five (5) real numbers with the uncertainty in magnitude of the three (3) SLO standards and the two (2) phase uncertainties for the short and open standards. In this example we decided to accept as common inaccuracy for all measurements one (1) digit of the LSD (Least Significant Digit) and this is indicated at the fourth line. Notably, it is possible to

describe the inaccuracy more precisely using the related data given by the manufacturer of Network Analyzer, but a different approach is needed which is not provided in this version of [REGION].

The above described in details five (5) files must be in the same folder with the executable REGION.EXE in order the program to accomplish correctly the evaluation of the uncertainty in  $\rho$  or Z according the user's choice. Then the program produces a number of output files, also in the same folder.

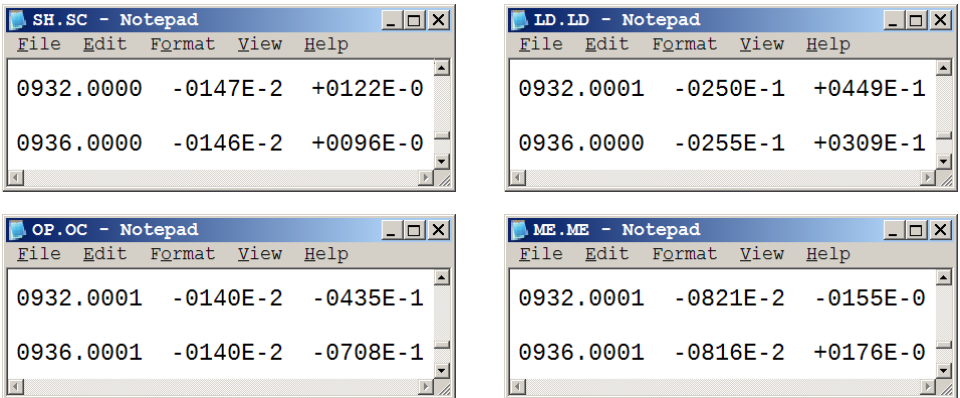


Fig. 2: Samples of the four measurement files

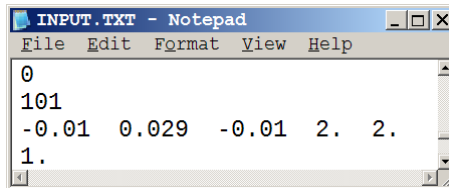


Fig. 3: Sample of INPUT.TXT file

Tab.1: Measurement Data Format

A. For **each** Data Line,  
 N = Mantissa digit, M = Exponent digit and s = Sign

#	Field	Length	Characters	Aligned	Format
1	Frequency in MHz	9	01 - 09	Right	NNNN.NNNN
2	2 spaces	2	10 - 11		
3	Magnitude in dB	8	12 - 19	Right	sNNNNEsM
4	2 spaces	2	20 - 21		
5	Phase in Degrees	8	22 - 29	Right	sNNNNEsM

B. Add **one** Empty Line after **each** Data Line

Tab.2: INPUT.TXT Structure

#	Data Type	Sample	Meaning
1	INTEGER	0	p-DER computations
		1	Z-DER computations
2	INTEGER	101	Number of frequencies
3	REAL	-0.01	Short magnitude uncertainty
		0.029	Load magnitude uncertainty
		-0.01	Open magnitude uncertainty
		2.	Short argument uncertainty in [°]
4	REAL	2.	Open argument uncertainty in [°]
		1.	Measurement inaccuracy in LSDs

Initially, the files with the specific name **NNNNR.TXT**, one for each frequency, are produced. As already clearly shown in Tab. 1 the four "N"s are the frequency in [MHz], and the letter "R" indicates

that the data represent Rectangular coordinates, i.e. points and line segments of the DER. A sample file is shown in Fig. 4 for the frequency of 932 MHz. All specific numbers of points, seg-

ments and arcs are thoroughly mentioned in [1], [2]. The first line with 0 [or 1] corresponds to  $\rho$  [or  $Z$ ] coordinates, as its real and imaginary parts, in this figure is 0 for reflection coefficient  $\rho$ . The next forty eight (48) lines give the coordinates of the forty eight (48) vertices of DER. Next, the description of the twenty four (24) line segments is given, for example, segment 2 is between points 3 and 4. The last 4 lines contain the minimum and maximum values of rectangular (1: Real and 2: Imaginary part) and polar coordinates (3: magnitude and 4: argument). Tab. 3 shows the information needed to illustrate the DER and its DEIs.

Then, the files with the specific name **NNNNA.TXT**, one for each frequency again, are produced, with the letter "A" to indicate the circular Arcs. 24 arcs are described with 7 numbers. The starting and ending point of each one, its center (X, Y), its radius R and the corresponding starting and ending arguments in radians. These data lines complete the DER description. A sample file for 932 [MHz] is shown in Fig. 5

The next produced output text files, RDEIS.TXT and PDEIS.TXT, contain the Rectangular and Polar DEIS respectively, for all frequen-

cies with the specified format as it is shown in Fig. 6. Thus the rectangular and polar differential error intervals against frequency can be drawn using the [DERDEI] tool.

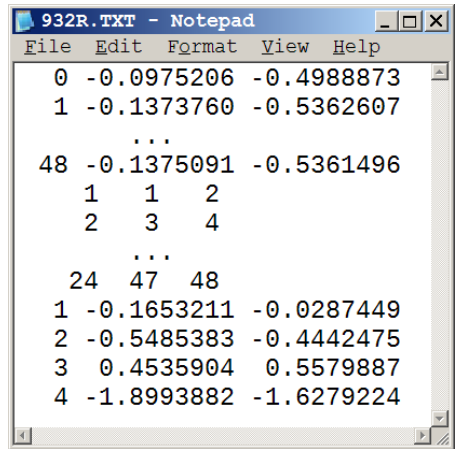


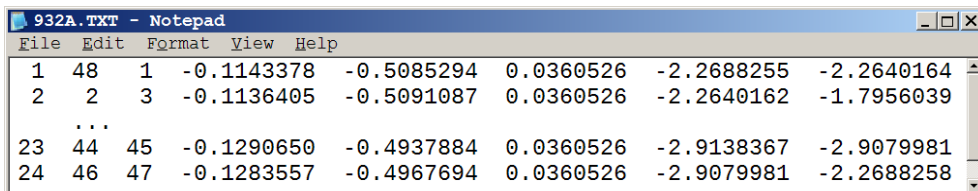
Fig. 4: Sample NNNNR.TXT file

The [REGION] tool structure is shown in Fig. 7. The main program is relied on seven (7) basic subroutines with four (4) support subroutines. The blue color and the capital letters indicate the subroutine's name, while the full name explains the usage of its one. The most important subroutine is the **FindDZDY** which finds the inaccuracy of the measurements. It depends absolutely on the specifically defined format of measured data, so any violation of it will produce unpredictable results.

Tab.3: **NNNNR.TXT** Output File Structure

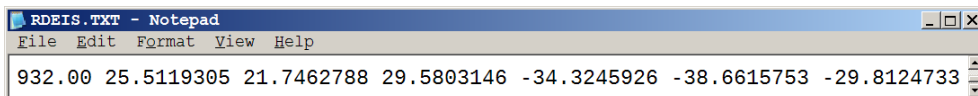
```

0 : ρ coordinates (ρ', ρ'')  1 : Z coordinates
1
...: 1 to 48 ρ-DER vertices (ρ', ρ'')
48
1
2
...: 1 to 24 segment vertices (N, M)
24
1 : Min-Max of ρ'   Real part
2 : Min-Max of ρ'' Imaginary part
3 : Min-Max of ρ   Magnitude
4 : Min-Max of ρ   Argument
    
```



#	S	E	X	Y	R	Start	End
	Point		Center		Radius	Arc in radians	

Fig. 5: Sample NNNNA.TXT file



f	Value	Min	Max	Value	Min	Max
	Real Part			Imaginary Part		
	Magnitude			Argument in radians		

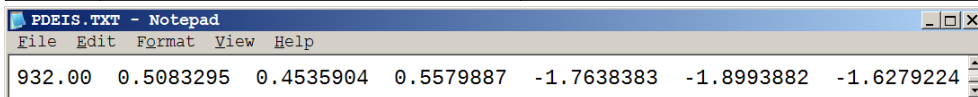


Fig. 6: Sample files for Rectangular and Polar DEIs

Main Program                      7 Basic Subroutines                      4 Support Subroutines

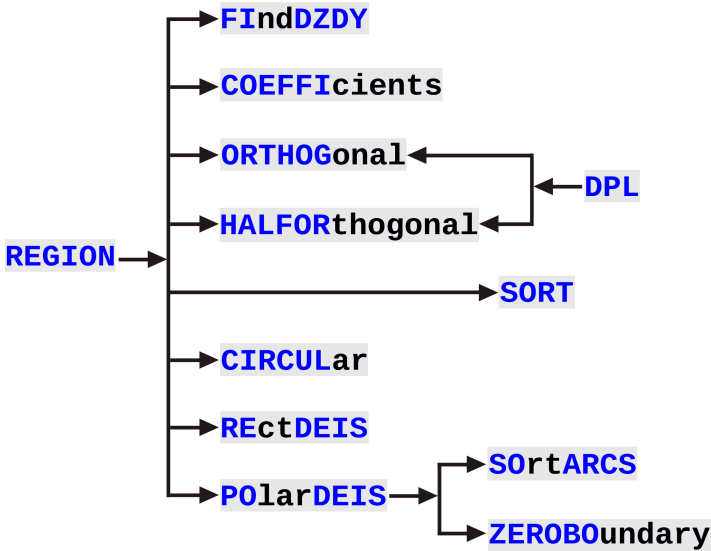


Fig. 7: REGION tool structure

**COEFFicient** subroutine computes the corresponding coefficients in relation (6) of [1]. The three types of involved basic DERs, that is, the orthogonal, half orthogonal and circular, are fully explained in [1] and they are formed in the corresponding subroutines **ORTHOGonal**, **HALFORthogonal** and **CIRCULAR**. The support subroutine **DPL** evaluates the distance between a point and a straight line and **SORT** orders the points so that it will be possible to draw the DER as a convex polygon. **REctDEIS** and **POLarDEIS** computes the corresponding DEIs.

The **SORTARCS** orders the arguments of polar DEIs and the final **ZEROboundary** subroutine treats some special cases of the polar DEIs.

In order to cover more cases concerning the polar DEIs in [REGION], which maybe met in practice, Fig. 8 (a), (b) shows two special, artificially constructed cases. In Fig. 8 (a) the origin of coordinate system 0 lies within a DER. In this case it is impossible to define an annular sector circumscribed about the complex DER that will give the Polar DEIs, so, we have to consider the circumscribed

whole circle. In Fig. 8 (b) the origin 0 coincides with a contour point of DER. The annular sector is a semicircle in this case. For both cases the circumscribed orthogonal about the complex DER, that results the rectangular DEIs, can be easily determined.

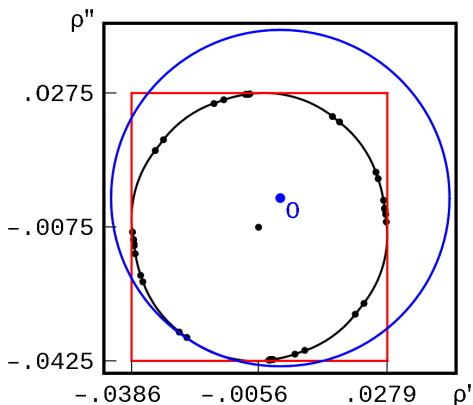
The authors are aware of the fact that additional work is needed in order to treat the special case of the non-empty intersection of  $\rho$ -DER and unit- $\rho$  circle.

**[DERDEI]**

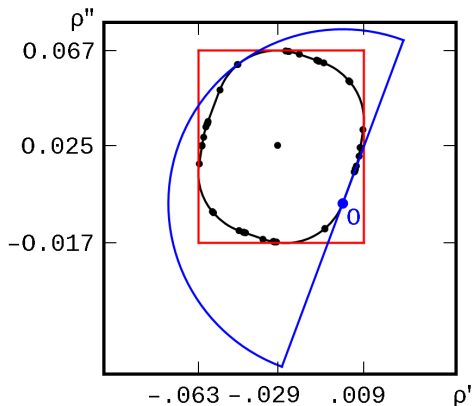
The [DERDEI] tool is the package DERDEI.MC developed for Maxima in order to plot the complex DER at each frequency, that is, a combination of line segments and circular arcs. This is not such an easy task, as it may seem, that can be carried out using simple applications that permit plotting data-lists of 2d functions, e.g. such as Excel. In addition [DERDEI] plots the rectangular and polar differential error intervals against frequency.

Fig. 9 shows the four needed steps in order to use this package: (a) run Maxima, (b) select from the file menu [Batch file Silently], (c) open the package [DERDEI.MC] and (d) the package is loaded in Maxima and contains four (4) functions. The der func-

tion reads the two files, (NNNMR.TXT, NNNNA.TXT) with the information for vertices, lines and arcs and plots the complex DER for each frequency.



(a) 0: internal point



(b) 0: contour point

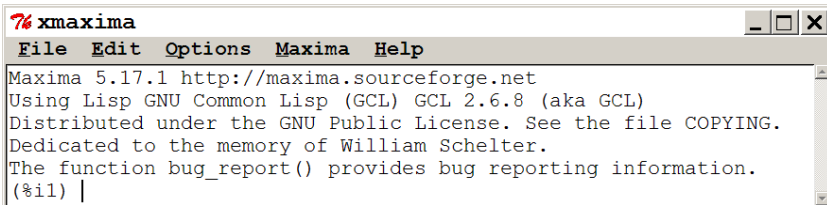
Fig. 8: Special polar  $\rho$ -DEIs

The deisRM function reads from the text file RDEIS.TXT

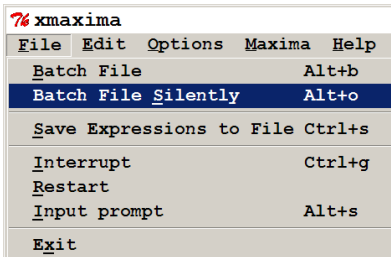
or PDEIS.TXT, n lines, and plots the DEIs of Real Part or Magnitude respectively, in terms of frequency. The labels of the graph are specified as labelx and labely.

The deisIA function plots the DEIs of Imaginary Part or Argument respectively, using the same input data as the

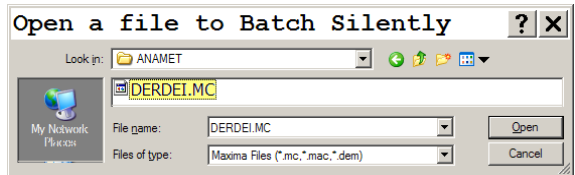
previous function. The deis function plots the DEIs of Real and Imaginary Part together at the same graph or the DEIs of Magnitude and Argument. The exact syntax of these four functions is shown directly in Maxima's main window as it is shown in Fig. 9 (d).



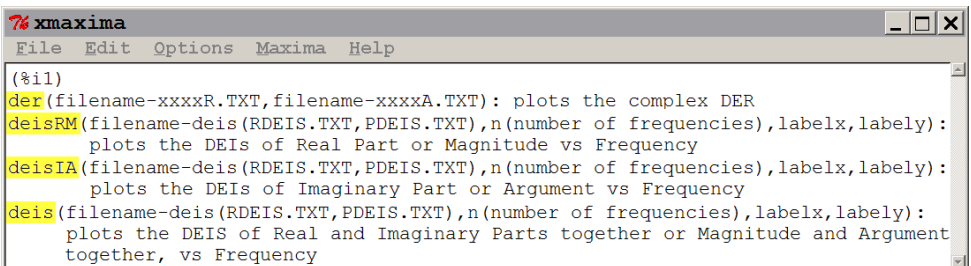
(a)



(b)



(c)



(d)

Fig. 9: Using [DERDEI] in 4 steps



## Application

As we mentioned in Introduction the user must prepare the required four (4) files of measurements and the INPUT.TXT file. This can be done either manually, for a small number of measurements, e.g. 10 or 20 or whatever, or automatically, e.g. using a data acquisition system.

For this purpose we developed the [ANALYZE] GUI software tool using Visual Basic 3, to control our Automated Network Analyzer System [2], via HP-IB. The application takes as input the current physical state, recorded by the operator for a future statistical use, the frequency range and the file name for each measurement, as shown in Fig. 10 and gives as GUI output a draft plot of measured magnitude in [dB] and phase in degrees [ $^{\circ}$ ] against frequency as shown in Fig. 11. [ANALYZE] also produces the output text file with corresponding measurement, three for the three (3) calibration standards SLO and one (1) for the unknown device, for further data processing. This program is instrument dependent and it will be available some time in the future as FLOSS.

It must be emphasized that [ANALYZE] is simply a measurement data collector, thus

it is not involved at all into the application of the presented tools.

A practical application of the developed software tools is given for a UHF ground plane antenna measured from 600 to 1000 MHz with 4 MHz step. Therefore, as it is explained above, the "number of frequencies" in the second line of "INPUT.TXT" is  $101 = (1000 - 600)/4 + 1$ .

Fig. 12 shows how the three tools (in blue color) transfer data between them (red color). Data are given as input to [ANALYZE] that it is responsible to collect the measurements from our VNA system and to provide the four (4) files for the four (4) measured loads. These 4 files together with the input file are then passed to [REGION] which will output two files (2) for each frequency, total two hundred two ( $101 \times 2 = 202$ ) files for the current example, that fully describe the DERs. It also produces a file with the rectangular DEIs for all frequencies and a corresponding one for Polar DEIs. All that files can be used with the [DERDEI.MC] package in Maxima to illustrate the results. Fig. 13 shows Maxima's window with all the built function's and the corresponding input files for the plots.

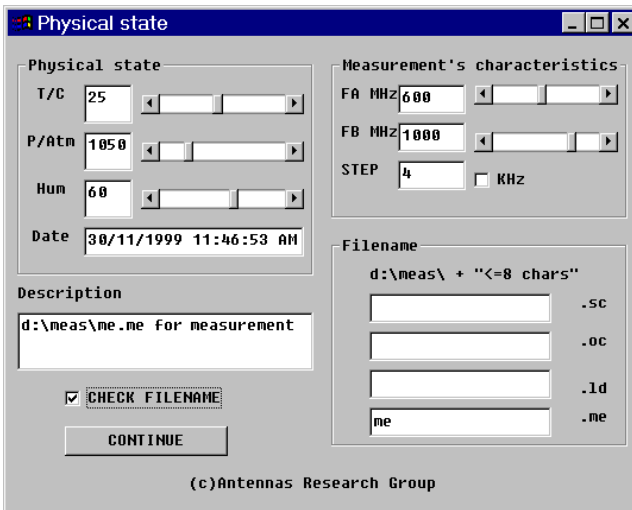


Fig.10: [ANALYZE]-Input

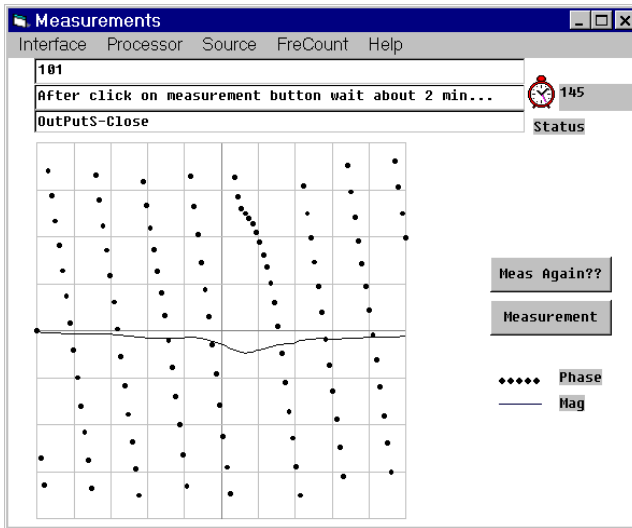


Fig. 11: [ANALYZE]-Output

Fig. 14 shows (a) the already published by the authors input impedance [2], and (b) the output graph of deis function from Maxima with the rectangular DEIs for both Real and Imaginary Part together at the same plot. Fig. 15 shows the result DERs for reflection coefficient (left column) and input impedance (right column) for the ground plane antenna, at the selected frequency. At the first line, the graphs are from Mathematica (a, d), at the middle are the published graphs with data from Mathematica package that we used (b, e), and at the last line are the Maxima graphs exactly as they are outputted (c, f). Finally, Fig. 16 shows the result graphs from Maxima and the functions deisRM and deisIA for Magni-

tude and Argument of reflection coefficient and Fig. 17 for Real and Imaginary Part of the input impedance exactly as they are produced.

**GUI-Input**  
**ANALYZE**  
**SH.SC**  
**LD.LD**  
**OP.OC**  
**ME.ME**  
**INPUT.TXT**  
**REGION**  
**NNNNA.TXT(101)**  
**NNNNR.TXT(101)**  
**RDEIS.TXT**  
**PDEIS.TXT**  
**DERDEI**  
**GUI-Output**

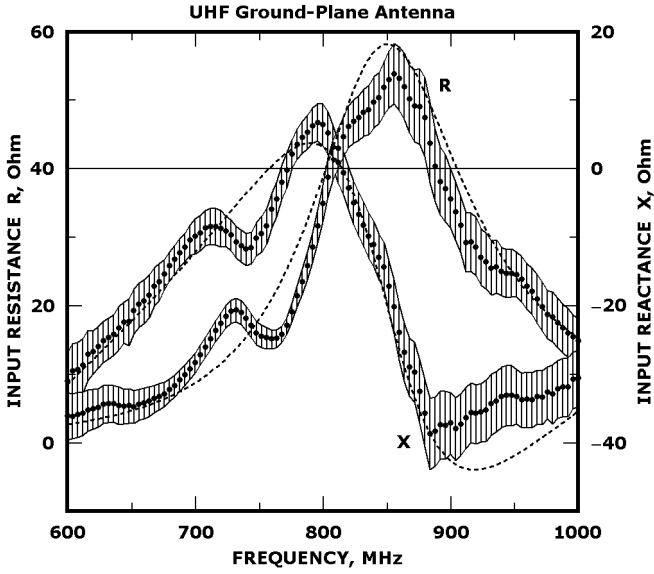
Fig. 12: Software Tools Interoperability

```

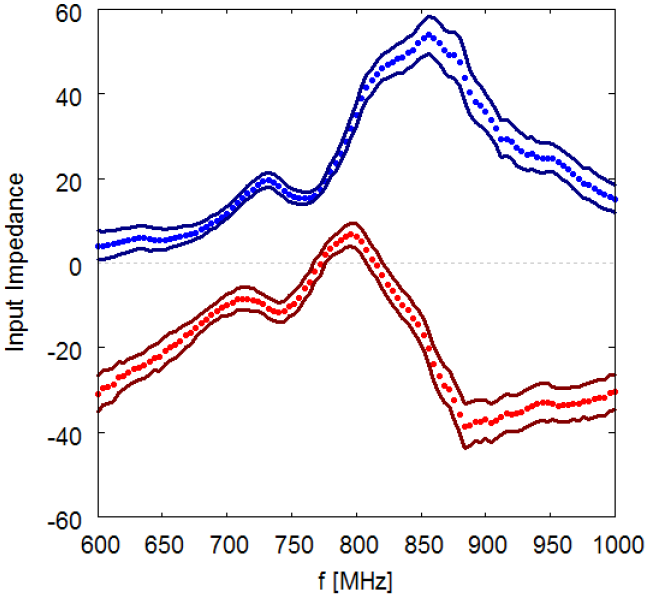
% xmaxima
File Edit Options Maxima Help

(%i2) der("D:\\ANAMET\\932R.TXT", "D:\\ANAMET\\932A.TXT");
(%o2)
(%i3) deisRM("D:\\ANAMET\\RDEIS.TXT", 101, "f [MHz]", "Input Resistance");
(%o3)
(%i4) deisIA("D:\\ANAMET\\RDEIS.TXT", 101, "f [MHz]", "Input Reactance");
(%o4)
(%i5) deis("D:\\ANAMET\\RDEIS.TXT", 101, "f [MHz]", "Input Impedance");
(%o5)
(%i6) deisRM("D:\\ANAMET\\PDEIS.TXT", 101, "f [MHz]", "Magnitude of RHO");
(%o6)
(%i7) deisIA("D:\\ANAMET\\PDEIS.TXT", 101, "f [MHz]", "Argument or RHO [rad]");
    
```

Fig. 13: A sample application of [DERDEI.MC] package

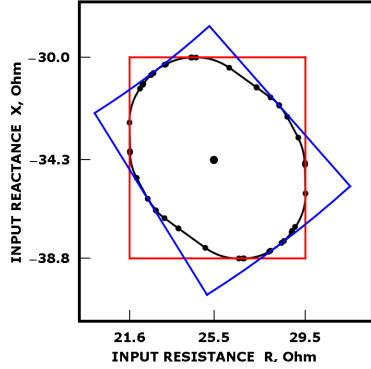
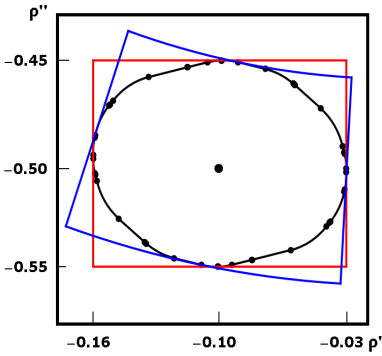


(a) Published [2]



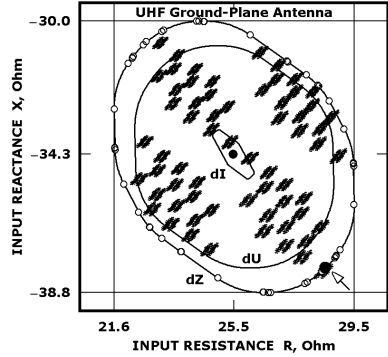
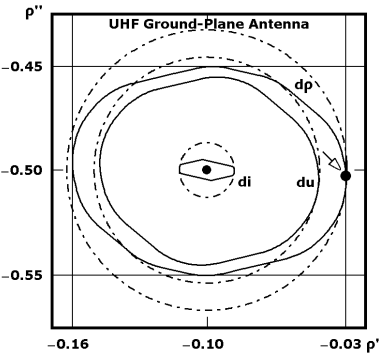
(b) deis function exact output

Fig. 14: Input Impedance versus frequency



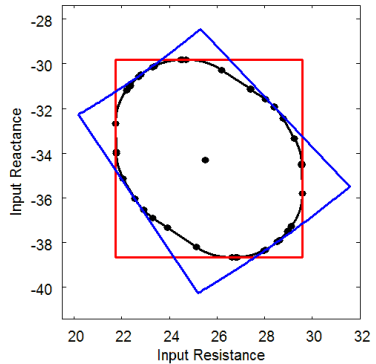
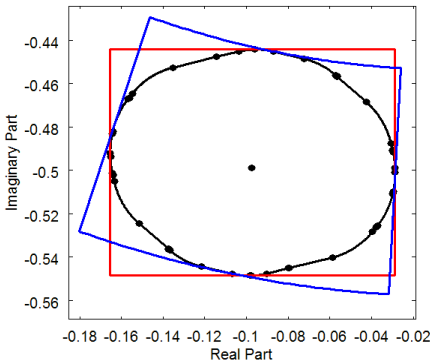
Mathematica: (a)  $\rho$ -DER

(d) Z-DER



Published: (b)  $\rho$ -DER

(e) Z-DER



Maxima: (c)  $\rho$ -DER exact output

(f) Z-DER

Fig. 15: Antenna DER uncertainty estimation comparison

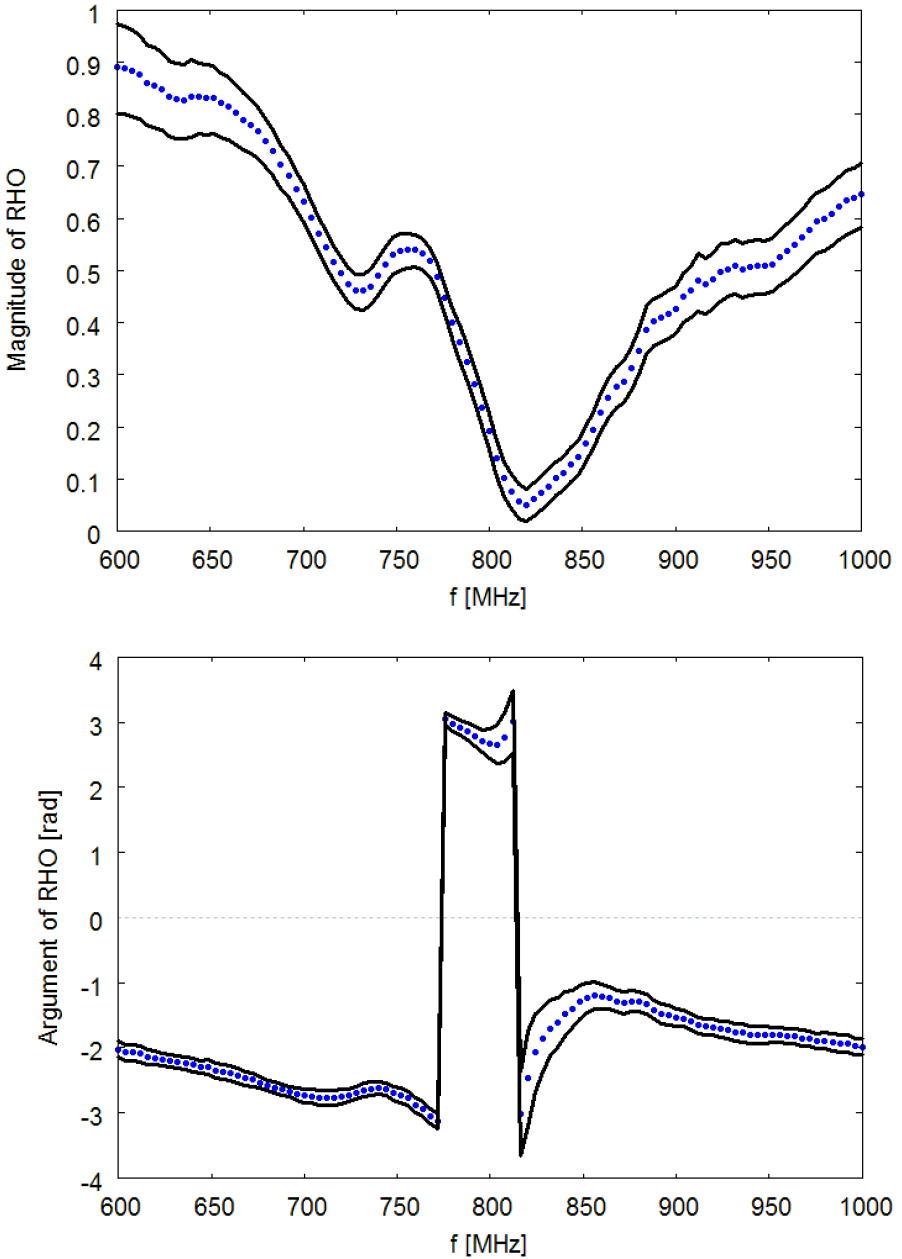


Fig. 16: Reflection coefficient  $\rho$  versus frequency

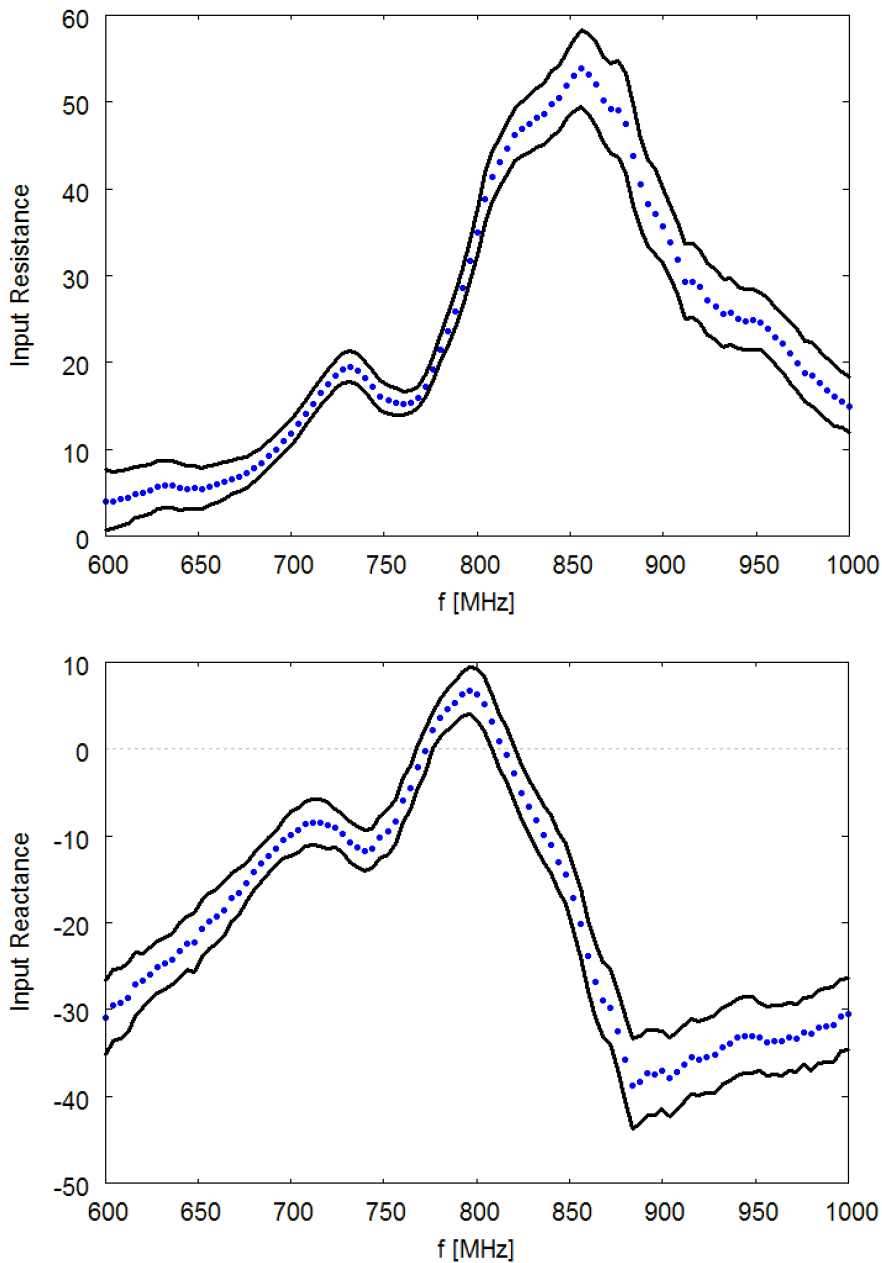


Fig. 17: Input impedance versus frequency

## Conclusion

Two developed FLOSS tools were presented. Both of them implement the technique we invented for the error estimation in VNA measurements. These tools produce and cross-check the results needed to construct DERs and DEIs. The [REGION] tool was developed using Open Watcom FORTRAN in fixed format [6]. The [DER DEI] tool, was developed using Maxima [7] as a package of it.

The also presented application example covers the case of the least uniform inaccuracy at discrete, uniformly stepped, multiple frequencies - e.g. in the commonly known "CW mode".

Notably, the presented results are exactly the same as they are produced by the corresponding developed by us Mathematica package. The illustrations from GNUplot [8], which is called by Maxima, are purposely presented exactly as they are produced, that is without any additional processing of them - a work which we left on user's choice - e.g. we use Paint Shop Pro 5.03 [9].

Since [REGION] tool concerns only one port measurements with full one port SLO calibration, it is obvious that further development of it is needed in order to include the full two port measurements as they are presented in [10] and [11], either for zero-length or for non-zero-length through standard, or even for the simplest short calibration case [12]. Similarly, further development of the corresponding Maxima package [DERDEI]. This work is in the author's future plans, together with the development of a GUI application which will integrate in one application both the data evaluation and the graphical representation, as well as the possibility of using another form of input data for the case of non-uniform inaccuracy available from more detailed manufacturer's data [13]

However, the immediate authors' plans include the presentation of their work with a substantially different method of data collection in the case of NanoVNA measurements [14].



## References

- [1] Yannopoulou N.I., Zimourtopoulos P.I., "Measurement Uncertainty in Network Analyzers: Differential Error DE Analysis of Error Models Part 5: Step-by-Step Graphical Construction of Complex DE Regions and Real DE Intervals", FunkTechnikPlus # Journal, Issue 16, Year 5, 2018, pp. 7 - 25  
[www.otoiser.org/index.php/ftpj/article/view/61/54](http://www.otoiser.org/index.php/ftpj/article/view/61/54)
- [2] Yannopoulou N., Zimourtopoulos P., "Total Differential Errors in One Port Network Analyzer Measurements with Application to Antenna Impedance", Radioengineering, Vol. 16, No. 2, June 2007, pp. 1 - 8  
[www.radioeng.cz/fulltexts/2007/07\\_02\\_01\\_08.pdf](http://www.radioeng.cz/fulltexts/2007/07_02_01_08.pdf)
- [3] Complex Differential Error Regions: Software Tools, References, Computer Programs, Updated Material  
<http://ftpj.otoiser.org/issues/21/38/>
- [4] Yannopoulou N.I., Zimourtopoulos P.I., "Complex Differential Error Regions: Software Tools",  
[http://resource.npl.co.uk/docs/networks/anamet/members\\_only/meetings/31/yannopoulou.pdf](http://resource.npl.co.uk/docs/networks/anamet/members_only/meetings/31/yannopoulou.pdf)  
31st ANAMET Club Meeting 02/04/2009 - Update 23/09/2019  
[www.op4.eu/anamet/31](http://www.op4.eu/anamet/31)
- [5] Yannopoulou N.I., Zimourtopoulos P.E., "Measurement Uncertainty in Network Analyzers: Differential Error Analysis of Error Models Part 1: Full One-Port Calibration", FunkTechnikPlus # Journal, Issue 1, Year 1, October 2013, pp.17 - 22  
[www.otoiser.org/index.php/ftpj/article/view/42/37](http://www.otoiser.org/index.php/ftpj/article/view/42/37)
- [6] Watcom FORTRAN Compiler version 1.8,  
<http://ftp.openwatcom.org/archive/open-watcom-f77-win32-1.8.exe>
- [7] MAXIMA 5.17.1,  
<https://sourceforge.net/projects/maxima/files/Maxima-Windows/5.17.1-Windows/>
- [8] GNUplot version 4.6 patchlevel 5  
<https://sourceforge.net/projects/gnuplot/files/gnuplot/4.6.5/>

- [9] JascSoftware, "Paint Shop Pro 5" cd-ware, "Practical internet", Issue 79, April 2003, Internet Archive <https://archive.org/details/practical-internet-79-at120pi-collection>  
<https://archive.org/details/fav-at120pi>
- [10] Yannopoulou N., Zimourtopoulos P., "S-Parameter Uncertainties in Network Analyzer Measurements with Application to Antenna Patterns" Radioengineering, Vol. 17, No. 1, April 2008, pp. 1 - 8  
[www.radioeng.cz/fulltexts/2008/08\\_01\\_01\\_08.pdf](http://www.radioeng.cz/fulltexts/2008/08_01_01_08.pdf)
- [11] Yannopoulou N.I., Zimourtopoulos P.I., "Measurement Uncertainty in Network Analyzers: Differential Error Analysis of Error Models Part 4: Non-Zero Length Through in Full Two-Port SLOT Calibration", FunkTechnikPlus # Journal, Issue 11, Year 4, 2016, pp. 7 - 29  
[www.otoiser.org/index.php/ftpj/article/view/60/53](http://www.otoiser.org/index.php/ftpj/article/view/60/53)
- [12] Yannopoulou N.I., Zimourtopoulos P.I., "Measurement Uncertainty in Network Analyzers: Differential Error Analysis of Error Models Part 3: Short One-Port Calibration - Comparison", FunkTechnikPlus # Journal, Issue 2, Year 1, 2013, pp. 41 - 49  
[www.otoiser.org/index.php/ftpj/article/view/44/39](http://www.otoiser.org/index.php/ftpj/article/view/44/39)
- [13] HP Operating and Service Manual 8505A Network Analyzer, August 1979, Santa Rosa California, USA, pp. A1-5 - A1-8
- [14] "errors of "error" models", Online discussion, 21.09.2019 - and counting  
<https://groups.io/g/nanovna-users/topic/34237712>
- \* Active Links: 22.01.2022 - Inactive Links : FTP#J Link Updates: <http://updates.ftpj.otoiser.org/>

[ This Page Intentionally Left Blank ]

[ This Page Intentionally Left Blank ]

[ 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)