28th INTERNATIONAL SCIENTIFIC SYMPOSIUM
METROLOGY AND METROLOGY ASSURANCE 2018

MICROWAVE MULTIPORT MULTIMETER SENSOR MUTUAL REFLECTION AND ITS INFLUENCE ON SIGNAL AND TRACT PARAMETER MEASUREMENT ACCURACY

M. A. Miroshnyk, Y. N. Salfetnikova, O. B. Zaichenko, N. Y. Zaichenko,
Y. V. Pakhomov, A. N. Miroschnyk

Abstract: The research is devoted to the improvement of the signal flow graph model of sensor mutual reflections in a multiprobe microwave multimeter. A method of signal flow graph topological reduction is developed and a gain calcuation expression is proposed. The advantage of the proposed approach is its simplicity, and, therefore, the reliability of engineering calculations. Besides for metrology assurance with mutual sensor reflection uncertainty component is considered and compared with commercially available uncertainity calculator created by the leading company such Keysight Technologies.

Keywords: multiprobe microwave multimeter, sensor mutual reflection, signal flow graphs, measurement uncertainty.

1. Introduction

Measurements of microwave signals and tracts distributed parameters is important in many electronic domains such as radiolocation, telecommunication, microwave heating. They are an attractive solution especially in portable measurement systems [1]. Vector network anayzer VNA is a standard laboratory equipment intended for their measurements with a high precision. The major drawbacks of VNAs are high complexity resulting in high cost. Alternative S-parameter measurement systems, free of such disadvantages, are multiport measurement systems introduced by Engen. Scalar and vector analyzers perform the same functions, but scalar analyzers are simpler and cheaper than vector ones, because of principle of action: scalar network analyzers calculate the vector values of the complex reflection coefficient from scalar power measurements. The cheapest of the scalar network analyzers is network analyzers with fixed sensors – multiprobe microwave multimeters. Multiprobe method is based on standing wave in the waveguide research through discrete sensor placed along waveguide signal processing [2,3].

From the point of view of metrology assurance, many uncertainty components and the method of uncertainty estimating for a multiprobe microwave multimeter are similar to the method of uncertainty estimating for network analyzers [4], but there is also a feature caused by microwave block design and which appears due to reflection of the neighboring sensors. This uncertainty component was studied before [2, 3, 5] by signal flow graph and a gain was determined using the Mason's rule. The problem in this approach is increasing computation complexity as the sensor number increases. So the purpose of this research is revision of the signal flow graph gain calculation and how it influences the microwave multiprobe multimeter accuracy.

2. Modified model and method of signal flow graph gain calculation with mutual sensor reflection

The flow graph theory is an universal mathematical apparatus oriented on many applications. It can be used in the flow graph of the legacy uncertainity model with vector error correction applied [4], but a signal flow graph is used for the description of microwave devices too. Studying the mutual sensor reflection, the signal flow graph is used in second meaning, as it bound to the physical model like in other microwave devices.

The signal flow graph model is rather traditional one so we would not dwell on it. So we only remind the denotation on fig.1 x_i is the value of the signal at the nodal points, the nodal point 2 is sensors itself, y – a transformation coefficient from the microwave input to the low frequency output, p – a mutual reflection between sensors coefficient, which is the ratio between the power output of the previous sensor and the microwave input of the following sensor, t – a transfer coefficient between the input microwave and a microwave output of the sensor, e – a transmition coefficient of the waveguide part between sensors $e = e^{-i \cdot \theta}$, θ – a phase distance between sensors,

$\theta = 2\pi l/\lambda_w$, l – a physical distance between sensors, λ_w – a wavelength in the waveguide, Γ – a generator reflection coefficient, Γ_n – a termination reflection coefficient, *Pinc* – an incident power. The coefficients *y, p, t* is the slightly transformed elements of the scattering matrix. The branches between the nodes *x1* and *x2* and between the nodes *x3* and *x4* correspond to the mutual reflections between the sensors. It complicate calculation.

The gain coefficient between the nodal points x4,x8 is

$$G_n = p + \frac{t^2 e^2 \cdot \Gamma_n}{1 - e^2 \cdot \Gamma_n \cdot p}, \quad (2)$$

The signal of a sensor (fig.1) can be found like a signal flow graph gain using the Mason non-touching loop rule with the sensor mutual reflection shown in the graph as additional branches between nodal points *x1*, *x2* and *x3*, *x4* and if *Pinc*=1

$$p_1 = \frac{e \cdot y(1 - e \cdot p \cdot \Gamma_n) + e^3 \cdot t \cdot y \cdot \Gamma_n}{1 - e^2 \cdot \Gamma \cdot p - e^2 \cdot \Gamma_n \cdot p - e^4 \cdot p^2 \cdot \Gamma \cdot \Gamma_n}, \quad (1)$$

The main idea of the proposed approach is the signal flow graph telescopic folding. For example let us consider a microwave block with two sensors.

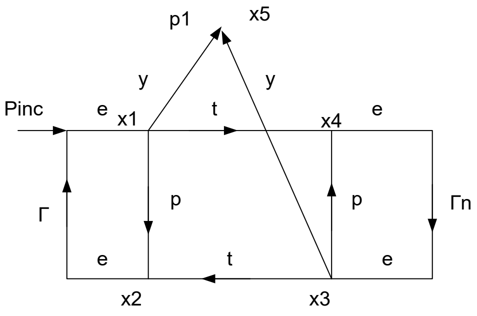


Fig. 1. The signal flow graph of the microwave multimeter with one sensor

The appearance of the flow graph (Fig.2) can be transformed to the signal flow graph for one sensor (fig.1) with difference that due to the previous transformation G_n in the expression (3) stands on the place of Γ_n in the expression (1)

$$p_1 = \frac{e \cdot y(1 - e \cdot p \cdot G_n) + e^3 \cdot t \cdot y \cdot G_n}{1 - e^2 \cdot \Gamma \cdot p - e^2 \cdot G_n \cdot p - e^4 \cdot p^2 \cdot \Gamma \cdot G_n}, \quad (3)$$

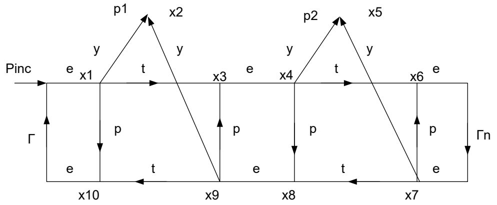


Fig. 2. The signal flow graph for two sensors

It is a result of signal flow graph transformation that consists in the telescopic graph shortening. Its termination now is G_n according the expression (2). The signal flow graph has an appearance like a graph in the fig.1 with one exception: its leftmost branch now G_n. If the sensor number is increased the next termination reflection coefficient is calculated on the basis of the previous reflection coefficient, the conclucion partly coincide with the known method of the signal flow graph topologic reduction [6].

3. Metrology assurance with mutual sensor reflection uncertainty

The differences between the legacy methodology and the Guide to the Expresion of Uncertainity in Measurement (GUM) methodology are not based on what error terms are included, but rather how they are included. The main difference between the legacy and GUM methodologies is the GUM methodology normalizes the errors to a coverage factor of k=1 prior to computing all of the uncertainties and then uses an expanded uncertainty on the final result while the legacy methodology uses the expanded uncertainties during the computation [4].

The main conclusions from the previous chapter are a sensor signal p1 has a functional dependence from the sensor mutual reflection p and the topological signal flow graph reduction use in the gain calculation.

The sensor mutual reflection uncertainty

$$\delta = \frac{p_1^2}{p_{01}^2} - 1, \quad (4)$$

where p_1 – a sensor signal with a reflection *p*=0.01, p_{01} – a sensor signal without a reflection *p*=0.

Then the corrected reflection coefficient is substituted in the formula for the signal of the first sensor. The uncertainity definition correction coefficient is

$$c = \frac{1}{1 + \delta}, \quad (5)$$

The measured sensor signals have to be multiplied by this coefficient before further proceeding with the algorithm, which is necessary to get from the sensor signals information about a modulus and a phase of a reflection coefficiet and a passing power.

Despite of the correction the non-excluded remainder of uncertainty is left. The non-excluded remainder of the mutual sensor reflection uncertainity dependence from the reflection coefficient modulus Γ_n, the reflection coefficient phase φ and the mutual reflection p uncertainities is analyzed applying RSS formula

$$\Delta\delta = \sqrt{\left(\frac{d\delta}{d\Gamma_n}\right)^2 (\Delta\Gamma_n)^2 + \left(\frac{d\delta}{d\varphi}\right)^2 (\Delta\varphi)^2 + \left(\frac{d\delta}{dp}\right)^2 (\Delta p)^2}$$

The multiprobe microwave multimeter allows to measure both the tract parameters, like a network analyzer, and the signal parameters, that is, the power, like a wattmeter. The price of such universality is a complication of the metrology assurance [5].

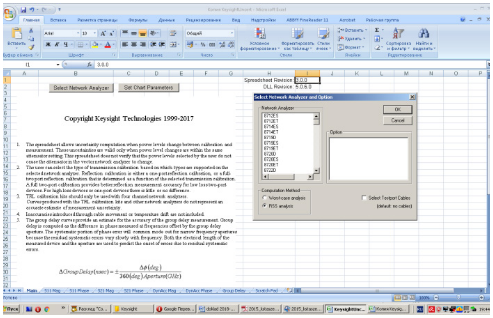
In the uncertainity budget all sources of the uncertainity are ranked and listed in the descending order, grouped according to the coefficients corresponding to the accepted law of the distribution within the boundaries. For a uniform distribution law, the coefficient corresponding to the distribution law is 1,73, and for the arcsine law 1,41 (Table 1).

The microwave multiprobe multimeter could be verified by measuring their S-parameters with a VNA. So the connector uncertainty for the mutiprobe microwave multimeter is inherited from a vector network anayzer and so take part in the uncertainty budget caculation.

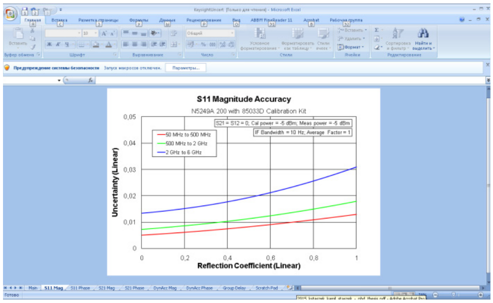
The uncertainty caculator [8] performs such procedure as selecting network analyzer and options, selecting frequency bandwidth and average factor, select the network anayzer calibration (omit isoation, caibration kit, incude manua thru). The uncertainty caculator outputs are the graphics of the magnitude dynamic accuracy, the phase accuracy, where shown the dependence of the uncertainty from the transmission coefficient (dB) (Fig.3). In prospect we intend create the uncertainty calculator for the multiprobe microwave multimeter too.

4. Conclusion

The development of the model in the form of signal flow graphs and methods for calculating their gain uses topological graph reduction and an iteration algorithm, which is based on the Mason



a



b

Figure 3. KeySight Technology uncertainity calculator [4] a – a selecing network analyzer procedure, b – S-parameters uncertainty dependence from reflection coefficient

non-touching loop rule to calculate the gain of the graph. The advantage of the proposed approach is the simplicity, and, therefore, the reliability of engineering calculations and it is convenient for metrological purposes. Our research is directed to the improvement of the model of mutual sensor reflections uncertainty in a multiprobe microwave multimeter. The caculation of mutiprobe microwave mutimeter uncertainty budget shows that the mutual sensor reflection uncertainty has large contribution in it. The uncertainty calculator is a powerful tool for uncertainty estimation simultaneously with the measurement.

References

[1] **Odrobina S., Staszek K., Wincza K., Gruszczynski S.** Wideband six-port reflectometer. In Advanced Trends in Radioelecrtronics, *Telecommunications and Computer Engineering (TCSET), 2018 14th International Conference on*

Table1. The multiprobe microwave multimeter uncertainity budget

Input quantity	Estimation of input quan-tity,	Standard uncertainty, %	Number of degrees of freedom	Distri-bution law	Sensiti-vity coefficient	Uncer-tainty contri-bution %
Reflection coefficient modulus	0,5	1	9	normal	1	1
Sensors mutual reflection	–	2,31	∞	uniform	1	2,31
Sensor dimension	–	2,31	∞	uniform	1	2,31
Processing	–	1,73	∞	uniform	1	1,73
Sensor non identity	–	1,15	∞	uniform	1	1,15
Finite conductivity of absorbig wall sensor	–	1,15	∞	uniform	1	1,15
Frequency dependence	–	0,57	∞	uniform	1	0,57
Temperature dependence	–	0,28	∞	uniform	1	0,28
Sensor non linearity	–	0,28	∞	uniform	1	0,28
Generator higher modes	–	0,06	∞	uniform	1	0,06
Waveguide dimension	–	0,06	∞	uniform	1	0,06
Output quantity	Estim-ation of output quantity,	Combined uncertainty, %	Effective numbers of degrees of freedom	Coverage probability	Coverage factor	Expan-ded uncer-tainty, %
Y	0,5	4,9	5188	0,95	1,96	9,8

IEEE. (2018, February). ISBN: 9781538625576, pp. 597-601.

[2] **Klychnyk I. I., Miroshnyk M. A., Tcekhmistro R. I., Warsza Z. L., Zaichenko O. B.** Modelling of influences of sensor reflections on the accuracy of a microwave reflectometer. *Pomiary, automatyka, kontrola* 60 (4), (2014), ISSN 0032-4110, 223-227 s.

[3] **Zaichenko O. B., Klychnyk I. I., Miroshnyk M. A., Tzekhmistro R. I.** The comparative analysis of a multiprobe microwave multimeters with involvement of processing by Kalman filtering and the least squares methods with regard for re-reflection of probes. *Telecommunications and Radio Engineering*. T. 74(1), (2015), ISSN0040-2508, 79-86 s.

[4] **Blackham D.** Trends for computing VNA uncertainties. *In Microwave Measurement Conference (ARFTG), 2017 89th ARFTG IEEE.* (2017), ISBN:9781538627488, pp.1-4.

[5] **Zaychenko O. B., Klyuchnik I. I.** Novyy vzglyad na byudzhet neopredelennosti mnogozondovogo mikrovolnovogo mul'timetra. Метрологія та прилади (2014), ISSN 2307-2180, 70-73 s.

[6] **Bryant G. H.** Principles of microwave measurement.: P. Peregrinus Ltd. on behalf of the Institution of Electrical Engineers, London, 1988, ISBN 0863411355, 377 p.

[7] **Zaharov I. P. , Sergienko M. P., Chepela B. N., Nikitin D. S.** otsenivaniye neopredelennosti pri provedenii metrologicheskikh rabot. Metodicheskiy

dokument po metrologii PMKH 33.1405-2005. Khar'kov, 2008.-48 s.

[8] **Agilent, "Vector Network Analyzer Uncertainty Calculator,"** hhttp://www. keysight.com/main/facet.jspx?t=80055.k.3&cc=PL&lc=eng&sm=g&sortKey=titlettp://www.keysight.com/main/facet.jspx?t=80055.k.3&cc=PL&lc=eng&sm=g&sortKey=title.

[9] **Metrology Option VNA Uncertainty Calculator** Available at: https: // youtu.be/00aKyhPQFOM.

Information about the Authors:

Miroshnyk Maryna Anatolievna. Kharkiv National University of radio electronics (1994). Д.т.н. (2013); National Technical University "Kharkiv Polytechnic Institute" Professor (2015); Ukrainian State University of Railway Transport, Department of Specialized Computer Systems. Scientific interests: SAPR, automation, computer systems and components, testing, diagnostics. Place of work - Ukrainian State University of Railway Transport, Faculty of Information Control Systems and Technology, Department of Specialized Computer Systems. Mailing address: 61002 Ukraine, Kharkov, pl. Feuerbach, 7.

Web address: *http://kart.edu.ua*

e-mail: marinagmiro@gmail.com

Salfetnikova Julia Nikolaevna. National Technical University "Kharkov poytechnica institute", Department of multimedia system and technology. Science interests information management systems, multimedia system and technology.

61002, Kharkov, Kirpichov St., 2

Web-address: *www.kpi.kharkov.ua/en/*

Zaichenko Olga Borisovna. Kharkov Technical University of RadioElectronics electronic devices (1994). Ph.D. (2015). Kharkov National University of Radio Electronics. Department of Design and Operation of Electronic Devices. Science interests: measuring the parameters of microwave signals and tracts. 61166, Kharkov, Science Av., 14

Web-address: *http://nure.ua*

e-mail: olha.zaichenko@nure.ua

Zaichenko Natalia Yaroslavovna. Kharkov National University of Radio Electronics. Department of Computer-Integrated Technologies, Automation and Mechatronic, scientific interests: computer integrated technologies

61166, Kharkov, Science Av., 14

Web-address: *http://nure.ua*

Pakhomov Yuriy Vasilievich. O.M. Beketov national university of urban economy in Kharkiv, (1974). O.M. Beketov national university of urban economy in Kharkiv, Department of Exploitation of gas and heat systems. Scientific interests: computer systems and components. Place of work - O.M. Beketov national university of urban economy in Kharkiv, Department of Exploitation of gas and heat systems. Mailing address: Marshal Bazhanov str. 17, 61002 Kharkiv, Ukraine,

Web address: *http://www.kname.edu.ua*

e-mail: abc050073@gmail.com

Miroshnyk Anatoliy Nikolaevich. National Technical University "Kharkiv Polytechnic Institute", Department of Automation and Control in Technical Systems (2018). Student - Department of Automation and Control in Technical Systems. Scientific interests: computer systems and components. Place of work - National Technical University "Kharkiv Polytechnic Institute", Department of Automation and Control in Technical Systems. Mailing address: Kirpichov str. 2, 61002 Kharkiv, Ukraine

Web address: *http://www.kpi.kharkov.ua*

e-mail: miroshnikanatoliy@gmail.com