Elektrotehniški vestnik 73(4): 179-182, 2006
Electrotechnical Review: Ljubljana, Slovenija

Self-calibration on a three-sampler network analyzer with non-standard connectors

Drago Kostevc, Jože Mlakar

Fakulteta za elektrotehniko, Univerza v Ljubljani, Tržaška 25, 1000 Ljubljana, Slovenija
E-pošta: drago.kostevc@fe.uni-lj.si

Abstract. The authors show a simple method enabling a self-calibration technique with a three-sampler automatic vector network analyzer. The main purpose is to determine internal reflections of the analyzer with standard connectors by using any calibration method for the three-sampler analyzer. The rest of the error model of the analyzer with non-standard connectors, and thus the complete model, is determined by calibrating the analyzer using one of the self-calibration techniques.

Keywords: automatic vector network analyzer, three-sampler, calibration method, self-calibrating procedure

Samokalibracijske metode za tridetektorske vektorske analizatorje vezij z nestandardnimi priključki

Povzetek. Pri visokih frekvencah se za merjenje parametrov S uporabljajo izključno vektorski analizatorji vezij, bodisi tri-, bodisi štiridetektorski. Bistven del postopka pri merjenju z vektorskim analizatorjem vezij je umerjanje analizatorja pred vsako meritvijo in ne meritev sama, ki je trivialna. Analizator je mogoče umeriti z različnimi kombinacijami normal, zato je poznanih tudi veliko kalibracijskih metod. Analizatorji s tremi detektorji pri kalibraciji potrebujejo večje število normal kot analizatorji s štirimi detektorji. Za kalibracijo se pogosto uporabljajo tako imenovane samokalibracijske metode, saj je pri njih število potrebnih kalibracijskih normal najmanjše, obenem pa veljajo za najbolj natančne. Prav posebej so samokalibracijske metode uporabne za kalibriranje vektorskih analizatorjev vezij z nestandardnimi priključki, saj je treba za te priključke vsako normalo izdelati posebej. Žal pa je neposredna uporaba samokalibracijskih metod omejena na štiridetektorske analizatorje, za kalibriranje tridetektorskih je število uporabljenih normal pri teh metodah premajhno. Vendar pa bi bila uporaba samokalibracijskih normal tudi na tridetektorskih analizatorjih zelo dobrodošla, avtomatski analizatorji vezij so namreč zelo drage naprave in tridetektorski so občutno cenejši od štiridetektorskih.
V članku bova pokazala, da je na razmeroma preprost posreden način mogoče uporabljati samokalibracijske metode tudi na tridetektorskih analizatorjih. Kalibriranje poteka v dveh korakih. V prvem na analizator priključimo kable s preciznimi standardnimi priključki, za katere je na voljo zadostno število normal, in ga kalibriramo po katerikoli standardni metodi za tridetektorske analizatorje. V tem koraku določimo tiste notranje parametre analizatorja, ki se s časom ne spreminjajo in niso odvisni od priključnih kablov in konektorjev. V drugem koraku nato pri vsaki poznejši kalibraciji merilnika z morebitnimi nestandardnimi priključki določimo ostanek parametrov s poljubno samokalibracijsko metodo z zmanjšanim številom normal.

Ključne besede: tridetektorski avtomatski vektorski analizator vezij, kalibracijske metode, samokalibracijske metode

Prejet 13. januar, 2006
Odobren 9. maj, 2006

1 Introduction

The two-sampler automatic vector network analyzer was modelled using the standard 12-parameter error model (Fig. 1 - the crosstalks, of which determination is trivial, are omitted for the purpose of clarity) and calibrated with the 'short-open-load-thru' (SOLT) [1] calibration. The so-called self-calibration method emerged later, together with six-port analyzers [2] and four-sampler analyzers ([3], [4]). The most popular self-calibration method is the 'thru-reflect-line' (TRL) calibration [2], commonly accepted as more accurate than the SOLT calibration method. As the self-calibration method needs fewer calibration standards than the SOLT calibration method, it is suitable for measurements with non-standard connectors. Selfcalibrations is, however, limited to the calibration of network analyzers that can be modelled using the two-box error model (Fig. 2), i.e. a six-port analyzer and a four-sampler analyzer.

The four- and three-sampler analyzer can also be modelled using an alternative model [5],[6], [7] (Fig. 3). Within this model the influence of switches and the internal termination are modelled by reflections e_R and e_F, which depend only on the analyzer itself. For a four-sampler analyzer, they are determined using the fourth detector, while the rest of the two-box error model is determined by self-calibration. For a three-sampler analyzer, however, they cannot be measured directly. It is thus accepted that self-calibration cannot be used to calibrate the three-sampler analyzer.

In this paper the authors show an effective method wich enables self-calibration with the three-sampler analyzer. The method initially determines reflections e_R and e_F of the analyzer with standard connectors, using any calibration method for the three-sampler analyzer. When later calibrating the analyzer with non-standard connectors using one of the self-calibration methods, the rest of the alternative model, and thus the complete model, is determined.

2 Calibration

For calibration of the four-sampler analyzer the two-box error model (Fig. 1), and for three-sampler analyzer the standard model (Fig. 2) or an equivalent alternative model (Fig. 3), needs to be determined.

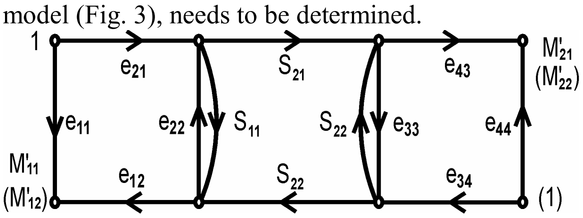

Fig. 1. Signal flow graph of the two-box error model with a DUT

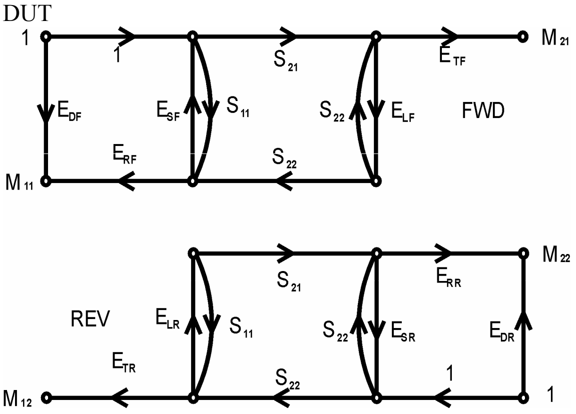

Fig. 2. Signal flow graph of the standard error model with a DUT

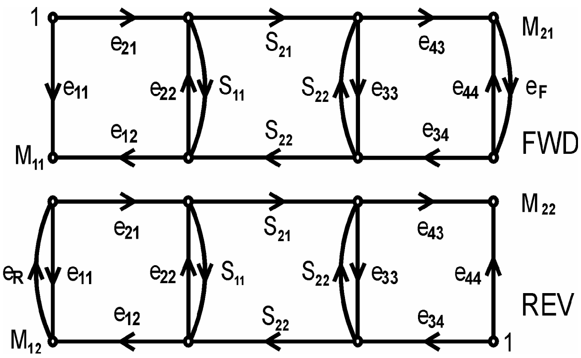

Fig. 3. Alternative error model of the three- and four-sampler network analyzer

Comparing Figs. 1 and 3, it is apparent that the alternative model is in fact the two-box error model, extended by parameters e_R and e_F. If these parameters for the three-sampler analyzer are determined beforehand, the rest of the two-box error model can be determined, as with the four-sampler analyzer, using a self-calibration method. From the standard model, e_R and e_F are determined in the following way:

From the equivalence of the flow graphs of the standard model (Fig. 1) and of the alternative model (Fig. 3), the following relations can be derived [5]:

$$E_{DF} = e_{11}$$

$$E_{RF} = e_{21}e_{12}$$

$$E_{SF} = e_{22}$$

$$E_{XF} = e_{41}$$

$$E_{TF} = \frac{e_{21}e_{43}}{1 - e_{44}e_F}$$

$$E_{LF} = e_{33} + \frac{e_{43}e_{34}e_F}{1 - e_{44}e_F}$$

$$E_{DR} = e_{44}$$

$$E_{RR} = e_{43}e_{34}$$

$$E_{SR} = e_{33}$$

$$E_{XR} = e_{14}$$

$$E_{TR} = \frac{e_{34}e_{12}}{1 - e_{11}e_R}$$

$$E_{LR} = e_{22} + \frac{e_{21}e_{12}e_R}{1 - e_{11}e_R}$$

The following equations result from these:

$$e_F = \frac{E_{LF} - E_{SR}}{E_{RR} + E_{DR}\left(E_{LF} - E_{SR}\right)}$$

$$e_R = \frac{E_{LR} - E_{SF}}{E_{RF} + E_{DF}\left(E_{LR} - E_{SF}\right)} \qquad 2)$$

The relation between the alternative model (Fig. 3) and the two-box error model (Fig. 2) is shown in a signal flow graph (Fig. 4). **M’** stands for the set of the equivalent two-box error model measurements (compare Fig. 2) and **M** stands for the set of three-sampler measurements (compare Figs. 1 and 3). From the flow graph the following relations between **M’** and **M** result: [6]

$$M'_{11} = \frac{M_{11} - M_{12}M_{21}e_F}{1 - M_{12}M_{21}e_F e_R}$$

$$M'_{12} = \frac{M_{12} - M_{11}M_{12}e_R}{1 - M_{12}M_{21}e_F e_R}$$

$$M'_{21} = \frac{M_{21} - M_{22}M_{21}e_F}{1 - M_{12}M_{21}e_F e_R}$$

$$M'_{22} = \frac{M_{22} - M_{21}M_{12}e_R}{1 - M_{12}M_{21}e_F e_R}$$

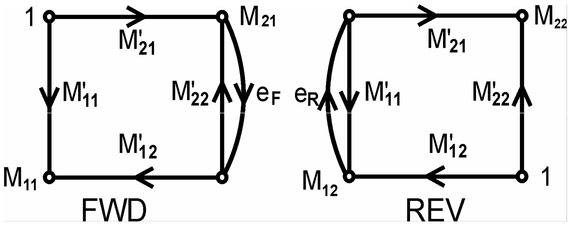

Fig. 4. Signal flow graph of the relation between the two-box error model and the alternative error model

Thus, from the set of three-sampler measurements **M**, using the known e_R and e_F, one can determine the set of equivalent two-box error model measurements **M’** (Eq. 3). From this set the two-box error model can be determined, using any self-calibration method. The two-error box model constitutes, together with parameters e_R and e_F, the complete alternative model (Fig. 3), from which the standard model can also be calculated (Eq. 1). In short, when e_R and e_F parameters of a three-sampler analyzer are known, the analyzer is calibrated in the same way as a four-sampler analyzer. The determined standard model is then used directly for error correction of raw measurements [1].

3 Verification

All measurements were performed on an HP8720C three-sampler analyzer. When measuring with APC7 connectors, a Maury 2650F calibration kit was used; when measuring with APC3.5 connectors, a Maury 8050F calibration kit was used.

Internal reflections e_R and e_F were determined using the SOLT calibration method on an analyzer with APC7 connectors. To verify the proposed method, we used the TMR self-calibration method [3] on an analyzer with APC3.5 connectors to measure an APC3.5 Maury 8021C2 male-to-female adapter. The S_{11} and S_{21} parameters of the measured adapter are shown in Figs. 5 to 8 (solid line). For reference, the same adapter was also measured by SOLT calibration on APC3.5 connectors (Figs. 5. to 8, dotted line).

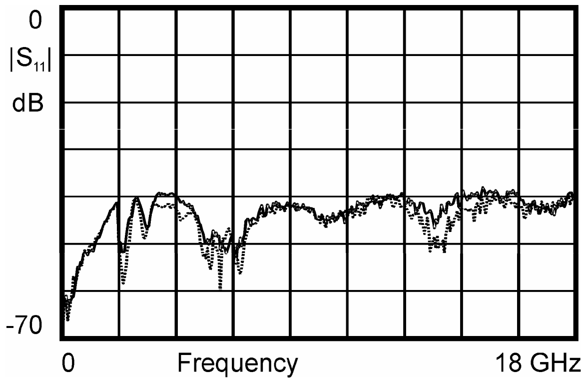

Fig. 5. Absolute value of S_{11} for the APC3.5 Maury 8021C2 male to-female adapter

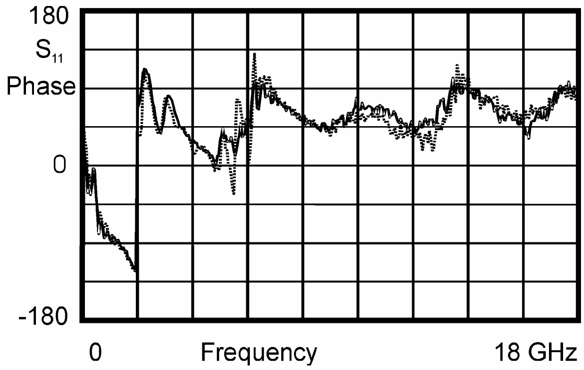

Fig 6. Phase of S11 for the APC3.5 Maury 8021C2 male to-female adapter

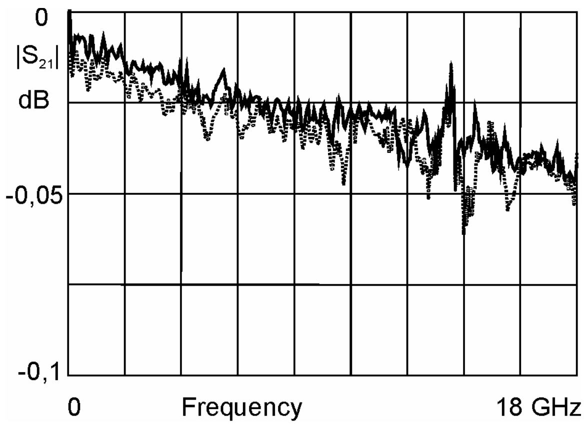

Fig 7. Absolute value of the S_{21} for APC3.5 Maury 8021C2 male to-female adapter

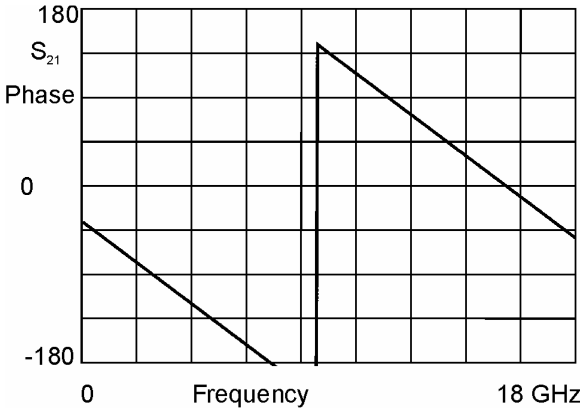

Fig 8. Phase of the S_{21} for APC3.5 Maury 8021C2 male to-female adapter

The reference measurement is much simpler and more accurate with precise connectors than with non-standard connectors. On the other hand, verification must prove only that parameters e_R and e_F are independent of the connectors of the analyzer. That is why parameters e_R and e_F were determined on an analyzer with precise APC7 connectors, and then used for verification in self-calibration on precise APC3.5 connectors.

4 Conclusions

We demonstrate an effective method enabling self-calibration of the three-sampler analyzer. To determine e_R and e_F internal reflection, one of the three-sampler analyzer calibrations is still required. But they can be determined in advance when the analyzer is equipped with precise standard connectors, for which all calibration standards are available. Later, for the measurement of devices with non-standard connectors, for which usually only a reduced number of calibration standards is available, the known internal reflections together with any of the self-calibration methods can be used for calibration.

As the internal termination of the analyzer does not change with time, it does not need to be measured before every calibration but, has to be only occasionally verified. So the proposed method is also suitable for calibrating the analyzer with standard connectors.

5 Acknowledgements

The authors wish to thank the Dielectric Laboratory of the Jožef Stefan Institute in Ljubljana for providing measuring equipment.

6 References

1) J. Fitzpatrick, Error Models for System Measurement, *Microwave Journal,* May 1978, pp. 63-66

2) G. F. Engen, C. A. Hoer, "Thru-Reflect-Line": An Improved Technique for Calibrating the Dual Six-Port Automatic Network Analyzer, *IEEE Trans. MTT*, Vol. MTT-27, No. 12, Dec. 1979, pp. 987-993

3) H. J. Eul, B. Schiek, Thru-Match-Reflect: One Result of a Rigorous Theory for De-embedding and Network Analyzer Calibration, *18th European Microwave Conference Proceedings*, Sept. 1988, pp. 909-914

4) J. Silvonen, A General Approach to Network Analyzer Calibration, *IEEE Trans. MTT*, Vol. MTT-40, No. 4, Apr. 1992, pp. 754-759

5) D. Kostevc, Samokalibracijske metode za tridetektorske vektorske analizatorje vezij, ERK 2002, Portorož, pp. 155-158

6) D. Kostevc, The Measurements of S-Parameters by Vector Analyzers, *Electrotechnical Review*, Ljubljana, Vol. 61, (1-2), 1994, pp. 29-36 (in Slovene)

7) J. A. Jargon, R. B. Marks, D. K. Rytting, Robust SOLT and Alternative Calibrations For Four-Sampler Vector Network Analyzers, *IEEE Trans. MTT*, Vol. MTT-47, No. 10, Oct. 1999, pp. 2008-2013

Drago Kostevc

Drago Kostevc received his dipl. ing., MS and DSc degrees from the Faculty of Electrical Engineering, University of Ljubljana, Slovenia in 1974, 1981, and 1985, respectively. Upon graduation, he stayed with the University of Ljubljana. The research fields he has worked in include design and modeling of microwave circuits and microwave measurements. Currently, he is an Associate Professor of Microwave Engineering.

Joze Mlakar

Joze Mlakar was born in Ljubljana, Slovenia, in 1941. He received his PhD in 1975 from the University of Ljubljana, Faculty of Electrical Engineering. Currently, he is a Professor of Electric Circuits and Electromagnetic Waves at the Faculty of Electrical Engineering, University of Ljubljana. His research interests include microwave circuits and measurements and numerical TLM technique for modelling electromagnetic fields.