A NOVEL VECTOR NETWORK ANALYZER

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ABSTRACT

A calibration procedure for perturbation two-port vector network analyzer is presented. It consists of a variable perturbation two-port placed between a device under test and a scalar network analyzer. A measured vector reflection coefficient is determined on the basis of amplitude only readings. A full correction of systematic errors is possible. The new principle was experimentally confirmed in the frequency band up to 14 GHz.

INTRODUCTION

Vector network analyzers (VNAs) based on frequency conversion are widely used for wide band vector measurements. They enable in principle to eliminate all systematic errors if a proper calibration/correction procedure is applied. A lot of sophisticated methods have been developed, see for example [1]. The greatest disadvantage of this systems is their complexity which results in high cost. Six-port VNAs, see [2], [3], [4], offer cheaper solutions. They also enable full correction of systematic errors.

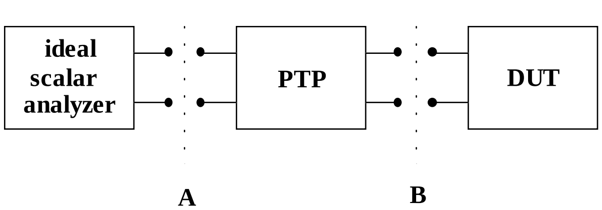

Fig.1. Measurement arrangement of the PTP vector network analyzer.

On the other hand scalar network analyzers (SNAs) are simplest and cheapest, but they provide only scalar information. Moreover, in principle, they cannot be fully calibrated to remove systematic errors, so that they provide only an approximate value of a measured amplitude, even if precise directional bridges and detectors are used.

A new concept for vector measurements based on a SNA and perturbation two-port (PTP) was suggested in [5]. The purpose of this paper is to present a new calibration procedure and first experimental results with this VNA based on SNA and PTP. The calibration procedure enables full correction of systematic errors for both vector and scalar measurements.

THEORY

Fig.1 shows the basic measurement arrangement of the PTP vector network analyzer. Reflection coefficient ρ_{DUT} of the device under test (DUT) in the reference plane B, which ought to be determined, is transformed over the perturbation two-port (PTP) to the reference plane A. Its amplitude $|\rho_M|$ is measured by an ideal scalar network analyzer. If scattering parameters S_{ij} of the PTP are known, the relation between ρ_{DUT} and ρ_M is given by

$$\rho_M = S_{11} + \frac{S_{12}\, S_{21}\, \rho_{DUT}}{1 - S_{22}\, \rho_{DUT}} \qquad (1)$$

Equation (1) forms a conformal transformation between complex planes ρ_A and ρ_B of the reflection coefficients in the reference planes A and B. Therefore circles in the complex plane ρ_A

with the radius $|\rho_M|$ are transformed by (1) into circles in the complex plane ρ_B and vice versa, see Fig. 2 and Fig. 3.

Circles in the complex plane ρ_A can be determined by the measurement of the corresponding modules of the reflection coefficients $|\rho_M|$ in the reference plane A for different settings of the PTP S-parameters. The common intersection of the corresponding circles in the complex plane ρ_B determines the desired reflection coefficient ρ_{DUT} of the DUT in the reference plane B. At least three circles are necessary for the unique determination of ρ_{DUT}. This principle is similar to the theory of the six-port VNAs. On the contrary to constant six-port S-parameters in the new concept the PTP parameters are different for the individual settings. Therefore the six-port theory cannot be used. ρ_{DUT} can be determined only if S-parameters of the PTP are known. They must be determined in the process of calibration.

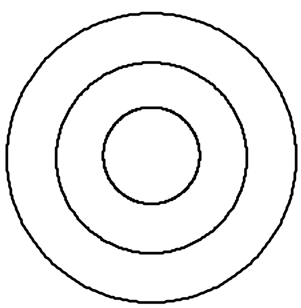

Fig. 2. Circles in the complex plane ρ_A .

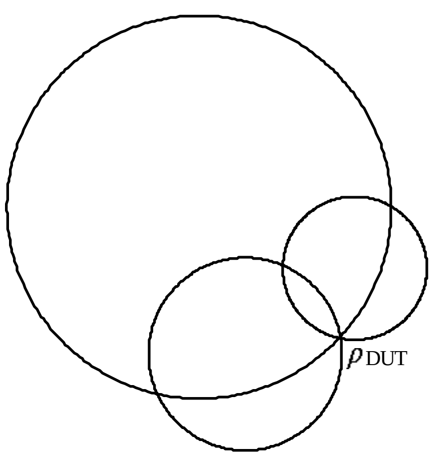

Fig. 3. Corresponding circles in the complex plane ρ_B.

Fig. 1. shows an ideal scalar analyzator with zero measurement errors considered. However, it is a well-known fact that a real scalar analyzator has always some systematic errors that can not be removed by any scalar only calibration and correction. It will be shown that in the new concept of the PTP VNA there is a possibility to overcome this fundamental obstacle.

CALIBRATION

The standard process commonly used for VNA systematic errors correction can be applied also on a real scalar analyzer. The error 2-port and the PTP can be merged into one error perturbation two-port (EPTP), see Fig. 4. Its parameters for each PTP settings should be determined during the calibration of the PTP VNA. A correct calibration of the EPTP is a corner stone of the new concept.

Only amplitude scalar measurements of $|\rho_M|$ corresponding to the full known complex reflection coefficient ρ_C of properly chosen calibration standards can be used to determine unknown S_{ij} parameters of the EPTP. The equation (1) yields

$$\left|\rho_M\right| = \left|s_{11} + \frac{s_{12}s_{21}\rho_C}{1-s_{22}\rho_C}\right| \qquad (2)$$

which can be used to form a proper system of equations. This system is non-linear and a numerical method must be used to solve it.

The EPTP is a reciprocal two-port. Therefore there are only 3 complex or 6 scalar unknown parameters in (2). Unfortunately there are only 5 independent equations in the system based on (2) and therefore only 5 scalar unknowns can be determined. One remaining unknown parameter cannot be determined and this is why the correct calibration of a scalar network analyzer alone is impossible. The physical interpretation

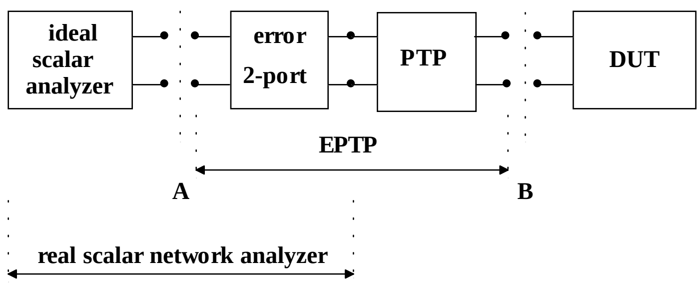

Fig. 4. Description of the scalar network analyzer systematic errors.

of this fact can be given in the following way. One can imagine that the EPTP ends in the reference plane A by a line with the characteristic impedance equal to that of the SNA. The length of this line cannot be determined by any means by the only amplitude measurement in the plane A. The length of the line determines the position of the ρ_M on corresponding circle in the plane A, see Fig. 2.

In the new concept the 6-th parameter does not need to be known for the correct determination of the complex ρ_{DUT} . The missing information is added by at least three measurements of $|\rho_M|$ for at least three different settings of the PTP. The 6-th parameter can be defined arbitrarily and no matter how it is defined the correct ρ_{DUT} is given by the common intersection of the corresponding circles, see Fig. 3. The only effect of the 6-th parameter is that circles at Fig. 3 are turned around their centres keeping the common intersection intact.

The calibration/correction procedure of the PTP was modelled and experimentally verified in the frequency band 2 - 2.5 GHz. A simple PTP in the coplanar waveguide structure was realized for this purpose. 5 calibration standards Open, Short, Offset Open, Offset Short and Match were used for the simulation and the experiment. It was discovered and subsequently theoretically explained that unique and correct solution for the ρ_{DUT} can be achieved only if one at least partially known calibration standard is added to the calibration set. Therefore 5 and "half" full known different calibration standards is a theoretical minimum demand on the calibration set for the PTP VNA calibration. One or two additional calibration standards can be recommended to obtain a wider frequency band and greater robustness of the numerical solution.

EXPERIMENTAL RESULTS

To verify correctness of the whole calibration and correction algorithm a simple voltage controlled PTP in the structure of CPW was designed and realized. Match, Short and 5 Offset Shorts were used for calibration to achieve a wider frequency band. The offset shorts were realized in the structure of the air 7 mm coaxial line with APC7 connectors. 3 dB attenuator with APC7 connectors terminated with short was used to test the measurement ability of the PTP VNA. The reflection coefficient of this load (3 dB attenuator plus short) was measured on the VNA (a computer controlled HP 8410 VNA with a correction method applied) and on the PTP VNA in the frequency band 8 - 14 GHz. HP 8757 E SNA was used to create the PTP VNA. A numerical algorithm similar to [6] was used to calculate ρ_{DUT} .

Fig. 5. is a comparison between phases of the test DUT obtained by the new method and the phases measured by the "classic" VNA. As can be seen, good general agreement of both traces on the majority of the frequency band has been achieved. This general agreement confirms correctness of the calibration/correction procedure. As far as the authors know this is the first published result of a phase measurement obtained by this procedure. The differences of both traces are typically in the order of several degrees and correspond more or less to errors of the first experimental results obtained with the six-port VNA, [7]. The noise in the results presented is believed to be caused mainly by the fact that the process was not automated, eg. collecting all the data for calibration and measurement at 401 frequency points took about six hours. Therefore a lot of time has been

left for equipment instability. Manually controlled PTP settings also did not assure top reproducibility.

CONCLUSION

The calibration/correction procedure for the PTP VNA was developed and experimentally verified. The new vector network analyzer system based on scalar measurement only was realized as an addition to a commercially available SNA. The viability of the new system was experimentally verified and confirmed.

The PTP VNA with the calibration/correction procedure developed opens the possibility of developping VNAs as an extension of current scalar network analyzers not only in microwave band, but also in mm and submillimetre frequency bands. Moreover, if such an improved scalar network analyzer is used for scalar measurements only, the full correction of its systematic errors is possible.

The simplicity of the PTP VNA promises low cost of the whole system.

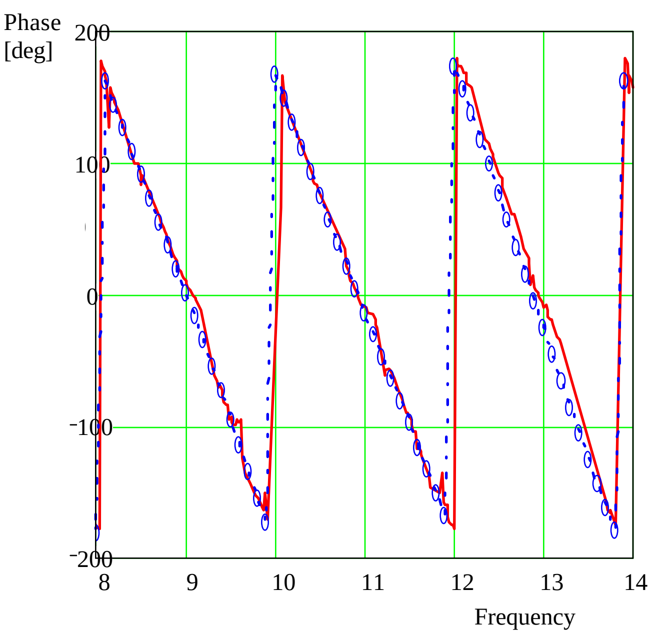

Fig. 5. The phase of the reflection coefficient measured on VNA (o-o-o) and PTP VNA (___). No averaging nor data smoothing used.

Acknowledgment

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