A New Concept of PTP Vector Network Analyzer

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Abstract
A new concept for vector network analyzers design based on a perturbation two-port (PTP) is presented. The approach uses redundant states of the PTP. The best states of the PTP for a certain place in Smith chart and frequency are chosen to determine a reflection coefficient with minimum uncertainty. Four criteria for the selection are designed. The criteria were tested on measured parameters of different states of the PTP. Significant improvements in PTP bandwidth and uncertainty of measured data were achieved.

Summary
Six-port vector network analyzers (VNA) are well known for decades, [1]. Similar concept using only a scalar network analyzer and a PTP was designed in [2], where only a basic principle was designed and experimentally verified using a PTP with properties far from optimum. No recommendations for the structure of the PTP were given. Some suggestions for an optimum three state PTP can be found in [3], yet the states of the PTP are unpractical for a realization and are suitable only in a narrow frequency bandwidth. The main demand in the PTP design is to realize optimum states valid on the whole Smith chart in wide frequency band. These demands can be hardly satisfied with any minimum 3-states PTP. The solution is a new concept of the PTP vector network analyzer based on redundant multi-state PTP. It releases the demands on PTP so that they must be satisfied only in a part of Smith chart. The concept can be summarized into three key steps.

- over-determination of measured data using more than three minimum states of the PTP
- approximate determination of measured reflection coefficient in Smith chart using proper three PTP states
- state the measured reflection coefficient more precisely applying the best PTP states determined in given frequency in corresponding part of Smith chart by proper test criteria

The purpose of this paper is to present proper criteria for the PTP state selection and a new circuit solution for individual states of the 7-state PTP.

Theory
A typical arrangement of the new PTP vector network analyzer with seven switched PTP states is presented in Fig.1.

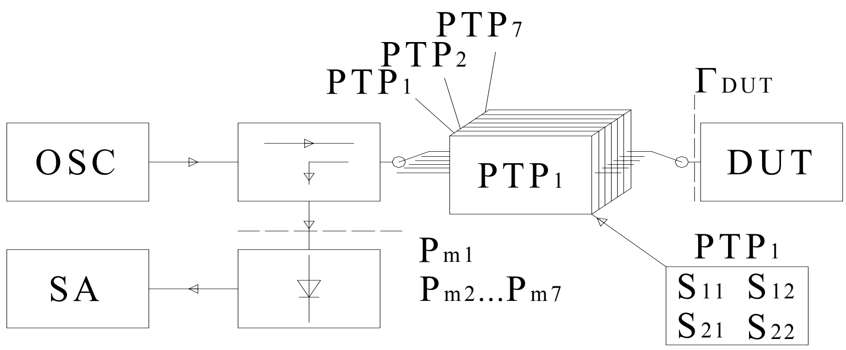


Fig. 1. Measurement system with 7-state perturbation two-port.

An unknown reflection coefficient Γ_{DUT} is transformed by s-parameters of the PTP and measured by a scalar analyzer (SA) as certain Γ_m. A corresponding relation is given by (1), see [2]. The relation can be modified to quadratic plane equation (2) where A_x, B_x, …,G_x are real constants. These seven real constants completely define the quadratic plane at one frequency above the complex plane Γ_{DUT}.The constants can be found by calibration [3].

$$P_m = \left|\Gamma_m\right|^2 = \left| S_{11} + \frac{S_{21} \cdot S_{12} \cdot \Gamma_{DUT}}{1 - S_{22} \cdot \Gamma_{DUT}} \right|^2 \tag{1}$$

$$A_x \left|\Gamma_{DUT}\right|^2 + B_x \Re(\Gamma_{DUT}) + C_x \Im(\Gamma_{DUT}) + D_x P_m \Re(\Gamma_{DUT}) + E_x P_m \Im(\Gamma_{DUT}) + F_x P_m \left|\Gamma_{DUT}\right|^2 + G_x + P_m = 0 \tag{2}$$

Fig. 2 shows an example for a 3-state optimum PTP and Γ_{DUT}=0.3+0.8j. The vertical line with diamonds corresponds to the Γ_{DUT} position. This line intersects the quadratic planes in points on certain circle counter lines. A common intersection of these circles transformed into the plane of Smith chart determines Γ_{DUT} position.

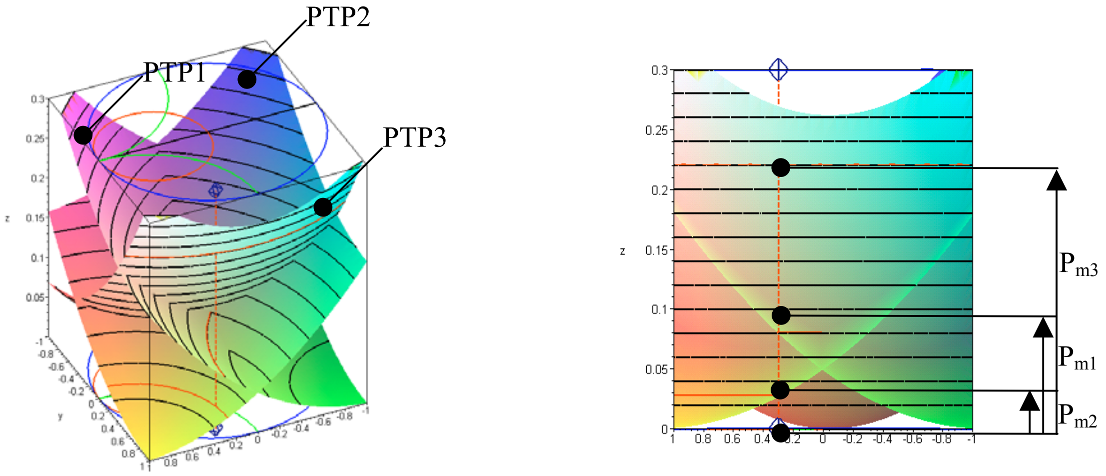


Fig. 2. Example of 3-state optimally spaced PTP quadratic planes.

At least 3-state PTP must be used for a unique determination of measured Γ_{DUT}, see [1]. In real measurements some noise error signal superimposed on measured power must be considered. This noise will produce error at the Γ_{DUT} space determination. A multi-state PTP makes possible to choose the best states for a certain area in the Smith chart. Four test criteria were developed for its selection.

Gradient criterion:

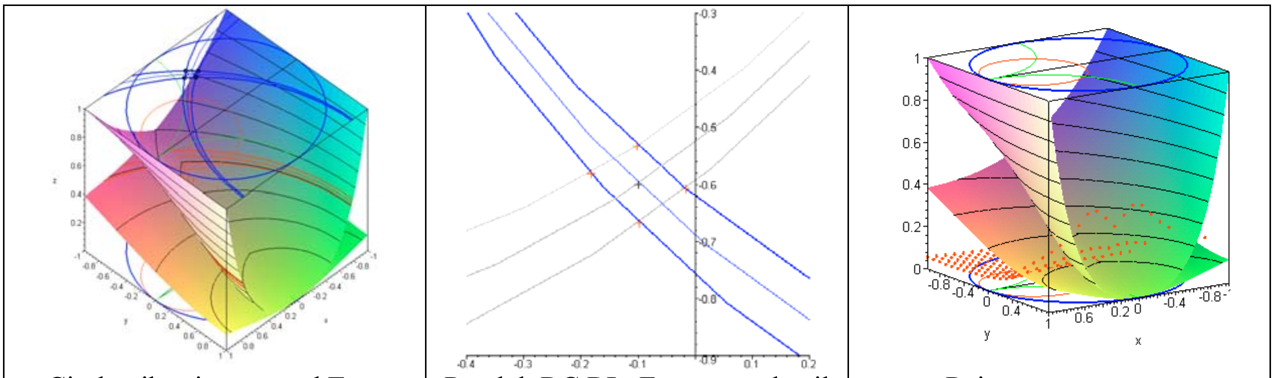
The criterion discovers areas in the quadratic plane where even a small noise error in measured reflected Γ_m. will produce a significant error at Γ_{DUT} determination.

Angle criterion:

This criterion determines the circle cross angle for the whole x-y plane. Angles between 30-90 degrees are acceptable producing low errors in Γ_{DUT} determination process.

Vector product criterion:

It is a more complex criterion. For two quadratic planes we can explain two gradient vectors in each point of the x-y plane. The module of the vector product of the gradient vectors displayed at the x-y plane gives information including both gradient and angle results.



Circle vibrating around Γ_{DUT} | Paralel_RC,RL_Error area detail | Points=error vector

Fig. 3. Noise error test.

Noise error criterion:

A noise error signal superimposed on measured reflection coefficient moves the positions of circle counter lines which determine the Γ_{DUT} position. It results in the error area with four border cross points. If the geometric distance between the Γ_{DUT} position and the most outlaying point is computed and displayed at x-y plane, the measurement noise dependency can be obtained, see Fig.3.

7-State PTP

The novel 7-state PTP consists of switched elementary two ports composed of a thru connection and serial and parallel RC, RL and R combinations connected to a 50Ω microstrip line. It was designed for the frequency band 240-1600 MHz. The structure and the values of components of this PTP were optimized using the new test criteria. Corresponding quadratic planes are shown in Fig.4. The elements were chosen so that the individual quadratic planes were sufficiently different in the whole frequency band.

Experimental results

The above declared test criteria were tested on two PTPs. The first one was a 6-state PTP based on FET transistors mounted into a 7mm coaxial structure and designed for the frequency bandwidth 7-14 GHz (used for experiments in [1]). This first sample of a PTP was not optimized with respect to minimization of measurement uncertainties.
The second one was the new 7-state PTP.
The tests were carried out by the following way. The complex plane of a reflection coefficient was scanned with the step of 0.1. In each point on the frequency of interest all combinations of quadratic plane pairs were tested and the best and the second best results were chosen to be displayed. 7-state to 3-state optimum PTP reduction was carried out by this way.
Results for the noise error test applied on both PTP can be seen on Fig 4 and Fig.5. The amplitude of noise in measurement of reflection coefficient was supposed 0.005. It can be seen that the optimized PTP makes possible to achieve 3 times smaller uncertainty of measured reflection coefficient in the same frequency band or 3 times wider frequency band for the same uncertainty of measured reflection coefficient.

Conclusion

The new concept for vector network analyzer based on scalar network analyzer and multi-state PTP was designed. New test criteria for multi-state to 3-state PTP reduction were developed and verified by computer simulations using s-parameters of realized and measured PTP structures. New 7-state PTP structure was designed, optimized with the new criteria and tested on the basis of measured data.
This approach makes possible a simple realization of individual states of the PTP, low measurement uncertainties and wider frequency band for the PTP vector network analyzer.

Acknowledgment

This work has been conducted at the Dept. of Electromagnetic Field of Czech Technical University in Prague and supported by grant “Microwave phase interferometry” No.: 102/04/0898 of Czech Grant Agency.

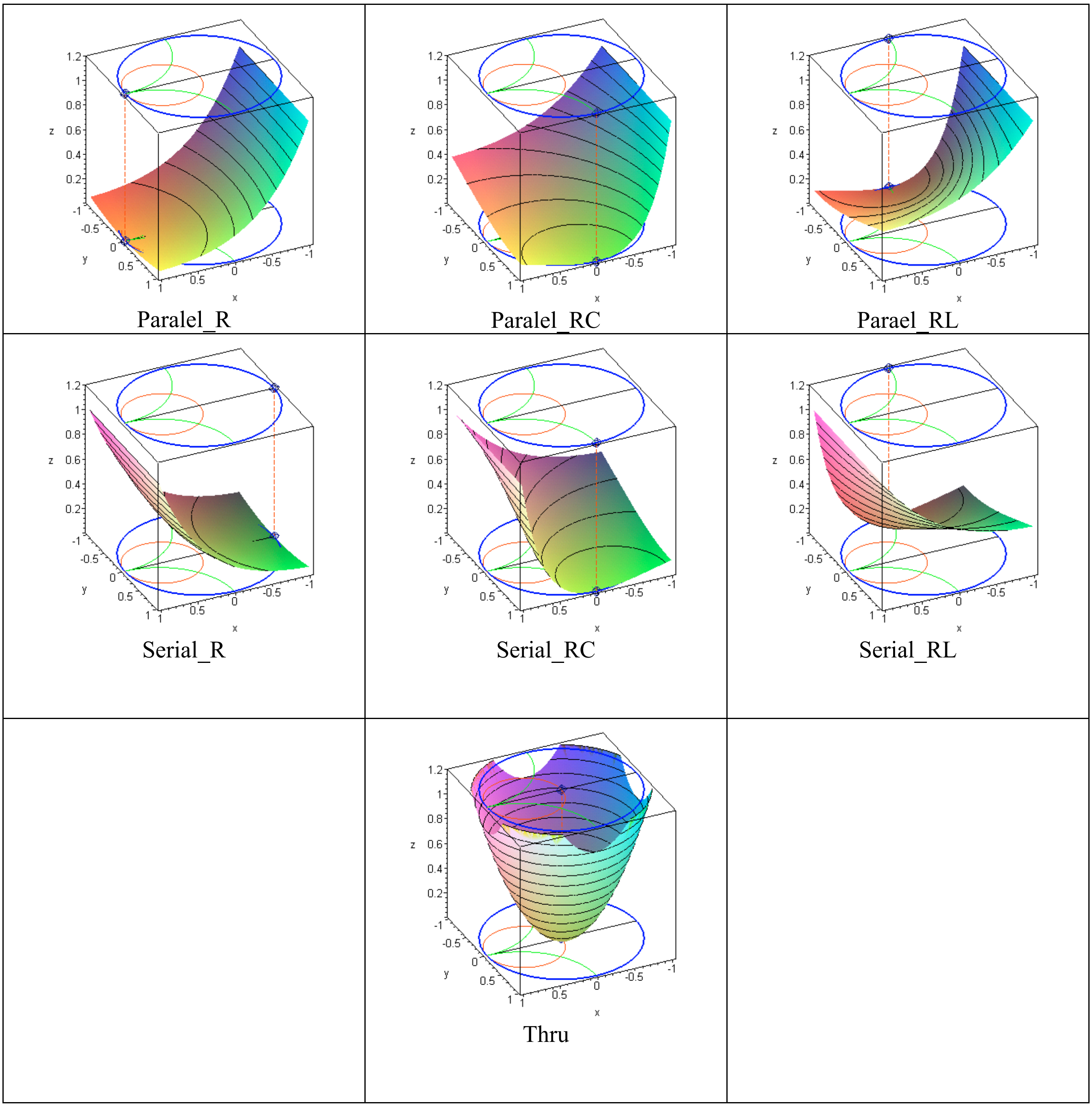
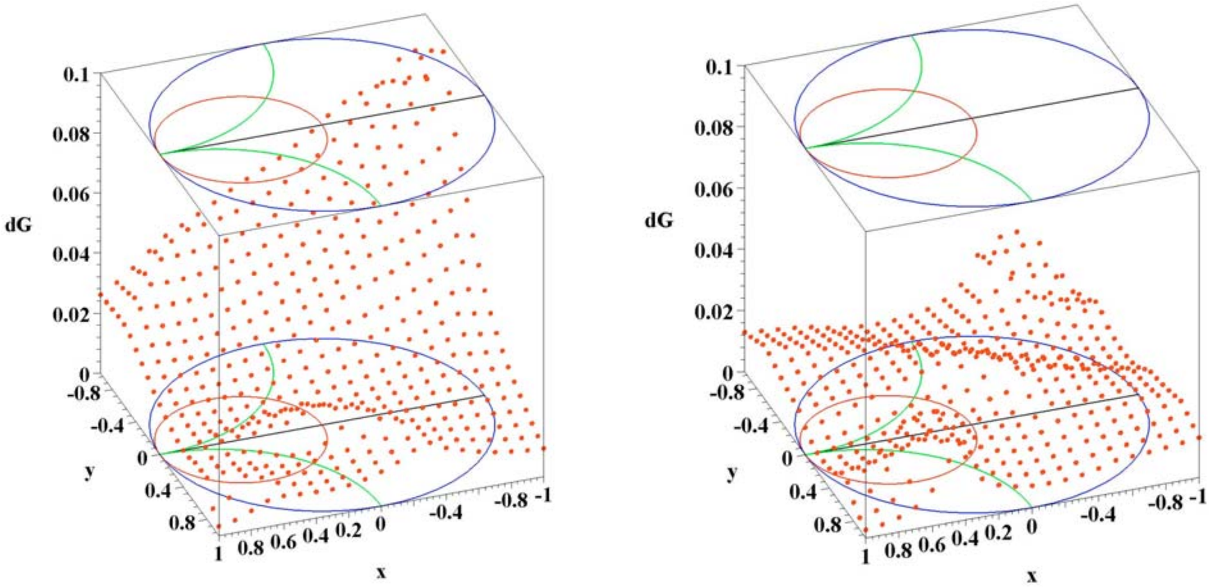
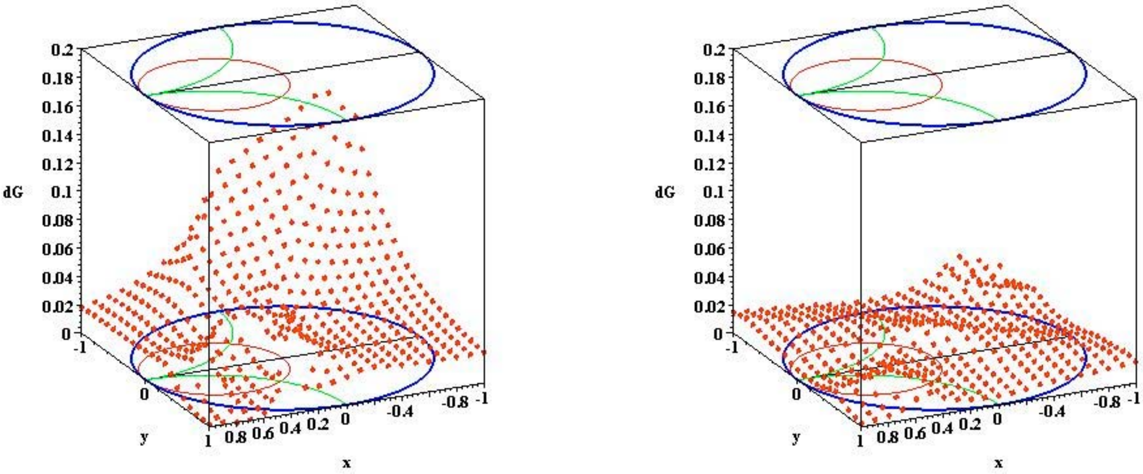


Fig. 4 Examples of 7-state PTP quadratic planes



a) 6-state PTP f_0=10.5GHz   b) New 7-state PTP f_0=930MHz

Fig. 5 PTP-noise error criterion, best layer



a) 6-state PTP f=0.66*f_0=7GHz   b) New 7-state PTP f=0.66*f_0=607MHz

Fig. 6. PTP-noise error criterion, best layer

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