VECTOR MEASUREMENT WITH SCALAR ANALYSER

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Abstract

A novel method for vector scattering parameter measurement is presented. The method is based on scalar (SWR) measurement only. Vector data is obtained using a controlled perturbation two-port (CPTP). The method promises broadband operation and cost-effectiveness for both reflection and transmission measurements. Design considerations for CPTP synthesis are presented.

Keywords
microwave measurement, scalar measurement, vector measurement

1. Introduction

It is a well-known fact that inserting a two-port between scalar network analyser and the device under test (DUT) could result in a change of the measured SWR. Similarly connecting a two-port in parallel to the DUT may influence measured transmission coefficient. This factum may be used in order to gain vector information from several scalar only measurements, provided that the two-port is known and selected properly. Moreover, this perturbation two-port (PTP) can be fully calibrated using scalar measurements. That makes the method suitable for vector analyser construction.

2. Basic principles

The measurement arrangement can be seen from Fig. 1. Scalar analyser, PTP and DUT are connected in a cascade. A complex reflection coefficient ρ_Z in the plane B is to be measured. In the plane A scalar SWR measurements for different PTPs are taken. A computer controlled PTP (CPTP) can be used for this purpose so that no de-mounting is necessary during measurement. Based on these (scalar) readings and full knowledge of PTP parameters complex reflection coefficient of the DUT can be reconstructed.

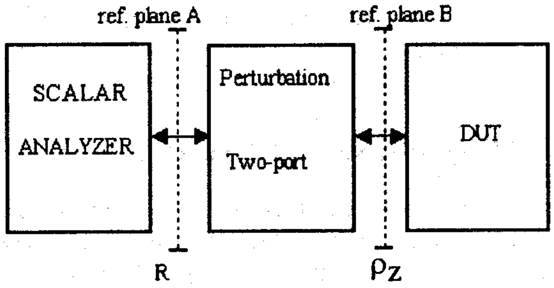

Fig. 1. Basic measurement arrangement

3. Measurements and evaluations.

The reflection coefficient R in the reference plane A resulting from DUT reflection coefficient measured through the PTP is given by Fig. 1.

$$R = s_{11} + \frac{s_{12}s_{21}\rho_z}{1 - s_{22}\rho_z} \qquad (1)$$

where s_{ij} stand for PTP parameters. However, only amplitude is measured using the scalar analyser. Equation (1) would enable us to determine unknown (complex) without ambiguities if three measured reflection magnitudes corresponding to different PTPs were available. For convenience, Fig. 2. shows corresponding measured constant SWR traces plotted in the complex plane. After transforming these traces through the PTP to the DUT reference plane B, another set of circles is obtained. The intersection of these loci determines desired complex reflection (see Fig. 3).

Basic theory and computer simulations have proven that the PTP should possess such parameters that: a) it will cause a noticeable change in the SWR measured; b) it is not pure resistive; c) the signal damping in PTP is be small (6 dB at maximum) and d) it will not change the impedance seen from DUT port rather far from usual 50 ohm. These requirements are necessary in order to enable for accurate measurement (a to c) and DUT stability. Let us spend some time examining practical attainability of these conditions.

The above-mentioned conditions and figures 2. and 3. are based on an assumption of an ideal scalar analyser (namely noiseless and infinitely precise) and exact PTP knowledge. Unfortunately, this is rarely the case of a real measurement. That is why the effects of measurement errors as well as noise should be taken into account. Presence of these effects results in the horrible fact that the respective circles have no common intersection point (for convenience, compare Fig. 3. to Fig. 4.).

Once measurement errors cannot be neglected, the important point is to make the method as nonsensitive to them as possible. This can be achieved by both using more than three PTP settings and selecting such settings so that these enable for sufficient precision. Expressing this in the graphic manner it corresponds to several circles, of those at least some should intersect at an angle close to 90 degrees.

4. PTP synthesis, first results.

As said in the last part, the key element is the perturbation two-port (PTP). Any non-trivial two-port can theoretically serve as the PTP, provided it causes measurable changes in the SWR. For the practical use the most important task in the application of the new method is an appropriate selection of the PTP structure. For the first designs we have tried a simple (but rather time consuming) random method, based on selecting of three different PTP settings. These were simulated as structures composed of resistors, capacitances and inductances.

These DUTs were fed into a simulation program enabling for scanning all possible values of ρ_Z and evaluating the reflection coefficient measured using three scalar SWR readings. This method has helped us in the beginning of the application, but it was clear, that it would need too much time to arrive to any really useful result. In order to avoid that, we tried to develop a more suitable synthesis and simulation method, permitting faster interpretation of the results and capable of decision on changing of the PTP structure. Next step was to find some concrete synthesis rules to achieve the best set of PTPs.

In order to be able to distinguish between "good" and "bad" PTP sets one needs to set up a criterion. We have used a couple of those. We have found useful to express them not only as numbers, but as rectangular plots as well. Two kinds of plots have provided important information. The error in DUT parameters found as a result of our measurements is minimised if the angle of intersection (measured between intersecting circles) is maximal. In order to test for this condition, plots have been arranged in this way: on top of a complex plane window (say one finds and plots the largest intersection angle found between all considered circles (resulting from different PTPs). A good set of PTPs should not possess small intersection angle values inside the standard Smith Chart. In the ideal case (Fig. 3.), the intersection is easily found using analytical expressions. Once there is no more an intersection, the solution is to be found by the means of numerical minimisation. One should find a value of that minimises the sum of differences between measured reflections R and reflections calculated using (1).

As all known optimisation methods suffer if the criterion function possesses false minimums, it is important to ascertain that there are none - or, at least, that these spurious minimums are located far from the true minimum. To investigate that, another type of plots have been used. Both of these plots have led to a conclusion that optimum PTP sets should behave so that they produce a set of reflection curves depicted on Fig. 5. Again, the diagram is plotted on top of DUT reflection coefficient plane. The plotted value is the magnitude of the reflection coefficient as measured by the scalar analyser, e.g.. after transformation through the PTP. Such a set of PTPs results in large intersection angles over the range of interest (see Fig. 7.).

As mentioned before, at least one of PTPs must not be pure resistive. This is achieved if a reactive element of a proper value is introduced into the circuit. Due to the fact that the immitances of any reactive element are frequency dependent, it comes out that such a reactive PTP is capable of doing its job in a limited frequency band only. Once the frequency is shifted from the optimum one, the contour plots from Fig. 5. evolve into less encouraging set depicted at Fig. 6., and the maximum angle of contour intersection degrades as plotted in Fig. 8. Our simulations have shown that bandwidths over 1:10 should make use of several reactive PTPs, each covering one fraction of the bandwidth.

5. Conclusion

All above mentioned results have shown that the PTP can be realised. This important factum makes the new measurement method attainable.

Literature

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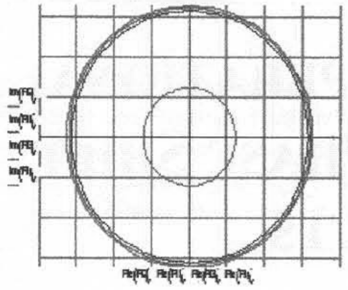

Fig.2: A set of scalar measurements taken in the plane A.

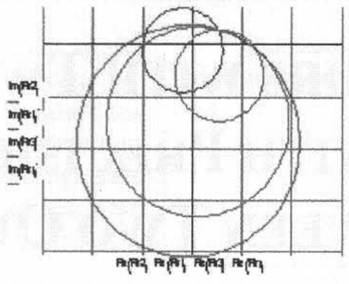

Fig. 3. The circles from Fig. 2. transformed through the PTP to plane B. The intersection marks DUT vector reflection.

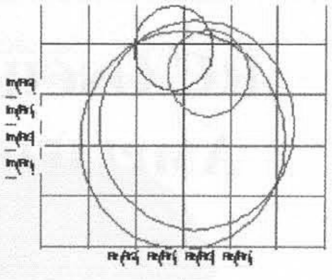

Fig. 4. Measurement errors cause circles no more possess one common point. (The same case as at Fig. 3 in the case of a noisy environment.

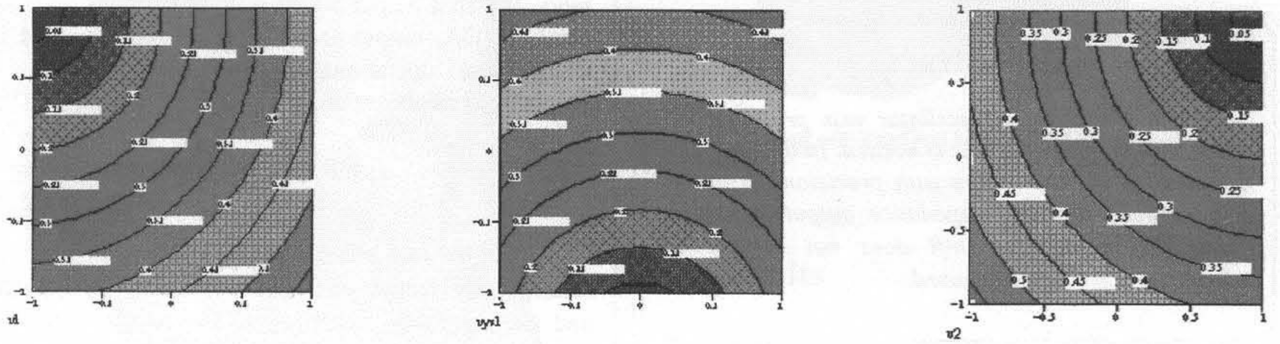

Fig. 5. Reflection coefficient magnitudes resulting from measurement of arbitrary passive loads through well-chosen set of PTP's.

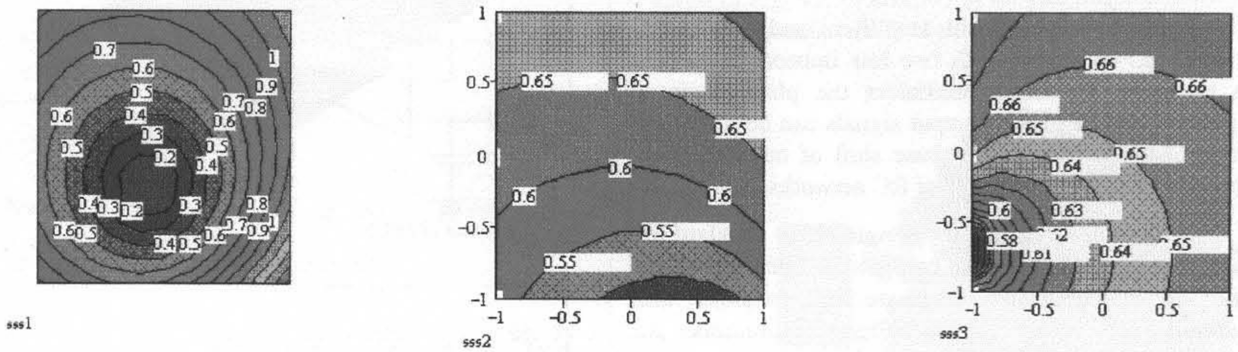

Fig. 6. Reflection coefficient magnitudes resulting from measurement of arbitrary passive loads through the same set of PTP's, frequency increased 40 times. This set of contours is no more optimal.

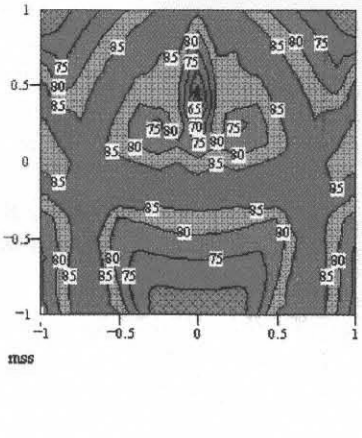

Fig. 7. Maximum intersection angle, plotted for the situation from Fig. 5. (left)

Fig. 8. Maximum intersection angle, resulting from the situation at Fig. 6. There is a large area possessing angle less than 30 degrees, resulting in ill conditioned measurement evaluation.