2포트 회로망 분석기를 이용한 다중포트 시스템의 S파라미터 측정에 관한 컨버전 알고리즘

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Conversion Algorithm for measuring Scattering Parameters of Multiport System with a 2-port Network Analyzer

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Abstract - This paper presents an algorithm applied to measure scattering parameters of a Multiport device with a 2-port Vector Network Analyzer (VNA). By employing the conversion of Scattering matrix with different reference impedances at ports, data obtained from 2-port configuration measurements can be synthesized to build the full scattering matrix of this device. A good agreement of estimated and measured parameters verified the performance of the algorithm.

1. Introduction

The challenges of digital interconnections lies in the combination of dense and close data lines in more than one plane excited by high frequencies [5]. Due to the requirements for characterizing coupling (crosstalk) in adjacent structures of high speed system, VNA shows its effective performance for determining scattering parameters [4]. However, it is the fact that the number of available VNA ports might not be sufficient to acquire all S-parameters of a multiport device-under-test (DUT), and hence, several procedures were proposed to build this S-matrix from 2-port matching configuration measurements using port renormalization technique [1]-[3]. In this method, basically, the S-matrix reconstruction is based on a conventional formula which corrects the measured matrix for port mismatch [1].

$$S' = (I-S)^{-1}(S-\Gamma)(I-S\Gamma)^{-1}(I-S) \tag{1}$$

where S is the scattering matrix of an n port with port line impedances ζ, S' is the transformed scattering matrix when the port impedances are altered to Z, and Γ is the diagonal matrix of reflection coefficients of Z seen from line impedances ζ, and I is the identity matrix.

It can be pointed out in (1) that two matrix inversion terms determines the method computational efficiency and accuracy. Consequently, in order to improve this, some error analyses were done to assess how different auxiliary terminations affect the accuracy of (1) and some matrix approximations were proposed to reduce the numbers of matrix inversion terms [6].

In this paper, a conversion algorithm with a new formula will be described. Considering each two ports of the n-port DUT are connected to the VNA while remaining ports are terminated to given terminations, measured submatrices are converted to different matrices referenced to different impedances. After that, obtained matrices are combined and converted again to the required full n×n S-matrix. Estimated S-parameters can be compared to the exact ones if the DUTs have fewer than 4 ports.

2. Method Description

2.1 Conversion formula

Providing the n-port DUT with two ports connected to the instrument and (n-2) remaining ports are terminated with given loads. The proposed matrix transformation uses the following formula:

$$S' = \left(U - \frac{Z_0' - Z_0}{Z_0' + Z_0} S\right)^{-1} \left(S - \frac{Z_0' - Z_0}{Z_0' + Z_0} U\right) \tag{2}$$

where S', S is the scattering matrix referenced to load impedances Z_0', Z_0, respectively, and U is the identity matrix. In this case, Z_0 = 50Ω due to equivalent internal impedance of VNA instrument and Z_0' is determined based on reflection coefficient when attaching only load Z_0' to the VNA [4]. The impedance-frequency dependence of the load Z_0' can be showed as in Fig. 1.

2.2 Conversion Algorithm

As described above, our interest in (2) is that each matrix S' gives the effect of matrix transformation respect to 50Ω and Z_0'. It means that obtained S'-parameters can be considered as if all DUT terminations are attached to the load impedance Z_0'. In other words, the DUT is assumed to be measured with a network analyzer with internal impedance Z_0'.

According to this analysis, the conversion algorithm is proposed to determine S-parameters of a n-port DUT with a 2 port VNA as follows:

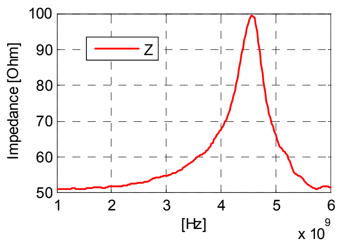
1. Measure S-parameters from each two ports of the DUT whose (n-2) others ports are terminated with load Z_0'. All test configurations are depicted in Fig. 2 as an example of measuring an 4-port DUT.
2. Convert the measured 2×2 S-matrix (with respect to 50Ω at two matched ports) to a matrix S' (with respect to the impedance Z_0' at all ports).
3. Repeat this procedure for all 2-port configurations. Combine parameters to fill the full n×n S'-matrix.
4. Reconvert acquired n×n S'-matrix to expected S-matrix (with respect to 50Ω at all ports).

In case of the two unterminated ports are let open, it means that the impedance Z_0' becomes infinity and can be considered to have a kΩ -MΩ value in calculation.

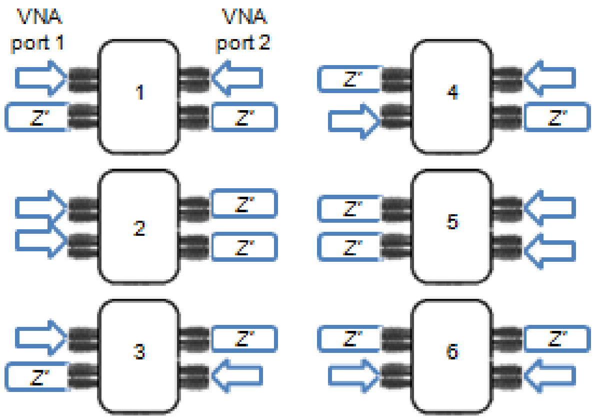
2.3 Measure Technique

In order to verify the conversion algorithm, the test experiment was carried out with a 4-port coupled microstrip line structure whose exact S-parameters could be determined with a 4-port VNA. The traces have a similar shape of 1 mm width, 12 mm length, 18 μm thickness and spaced 0.5 mm from others on a FR4 substrate (Fig. 3). Each end of trace is SMA connector used to be adapted with VNA port conveniently. To acquire the precise S-parameters of this circuit, we connect its ports to a 4-port VNA.

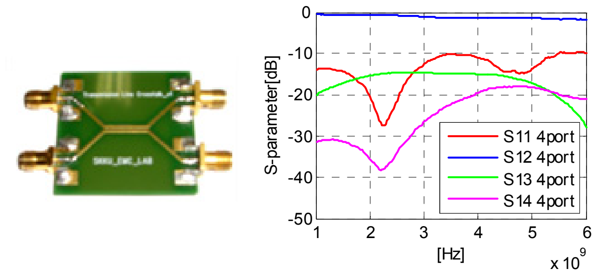
With each 2-combination of a set 4 ports are measured, the proposed method requires 6 measurements. It is obvious that S-parameters performed in different measurements are dissimilar to each other, cause of different port mismatch in specific case.



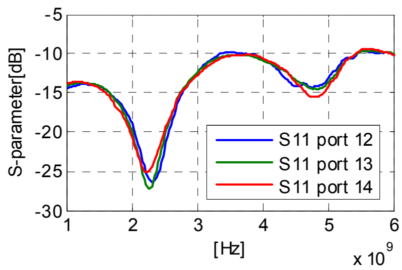
<Figure 1> Impedance of test load impedance



<Figure 2> Six cases of test configurations



<Figure 3> Experimental device under test and scattering parameters at ports



<Figure 4> Transformed reflection coefficients at port 1 with different measurement configurations

However, after being transformed by formula (2), reflection coefficients obtained in each port must have a good agreement in definition. As can be seen in Fig. 4, the reflections S11 at port 1 performed in port 1-2, 1-3, 1-4 are well matched after being applied the transformation,

Once finishing all measurements and transformations, the acquired parameters can be completely filled the 4×4 S'-matrix of the DUT as follows:

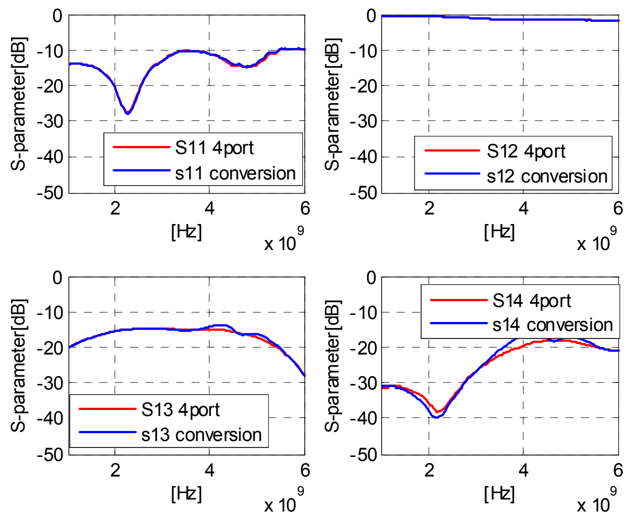
$$\mathbf{S}' = \begin{bmatrix} S'_{11} & S'_{12} & S'_{13} & S'_{14} \\ S'_{21} & S'_{22} & S'_{23} & S'_{24} \\ S'_{31} & S'_{32} & S'_{33} & S'_{34} \\ S'_{41} & S'_{42} & S'_{43} & S'_{44} \end{bmatrix}$$

To be more specific, any reflection parameters can be used to fill this S'-matrix with no inaccuracy.

Finally, this matrix is converted again to the expected S-matrix and then each parameters are compared with the accurate corresponding data from 4 port VNA. Fig. 5 reveals that the proposed method can get a high accuracy to characterize S-parameters of a multiport device.

3. Conclusion

A robust algorithm has been described to measure scattering



<Figure 5> Original and estimated scattering parameters of the 4-port test circuit

parameters of a multiport device with a 2-port vector network analyzer. Application of an available 4-port VNA helped testing the validity of the conversion algorithm, showed in a good agreement between the estimated and original S-parameters. Improvement of simple proposed formula that enhances the accuracy of the algorithm due to only one matrix inversion calculation can be extended in more complex configuration measurements with available VNAs.

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