Selection of Specific S-parameters in Multiport Measurement for the Renormalization Technique using Four-port VNA

Luong Duc, Long† and Nan, Wansoo*

Abstract - This paper presents an algorithm to characterize scattering parameters of multi-port device with a four-port Vector Network Analyzer (VNA). By employing the renormalization of scattering matrices with different reference impedances at ports, data obtained from multi-port configuration measurements can be synthesized to build the full scattering matrix of the device-under-test (DUT). Although that procedure can be best used for the interconnect system in which the inside routing is quite apparent, we still need an appropriate algorithm to select specific S-parameters for the black-box model where the configuration inside is not known. This paper presents an algorithm to determine which S-parameters are suitable to be selected to reconstruct the full S-matrix of the system. Using the selected specific S-parameters, the renormalization of the scattering matrices could be synthesized to successfully estimate the S-parameters of a multiport interconnect system. A good agreement between the estimated and true S-parameters verifies the validness of the algorithm.

Keywords: Scattering parameter measurement, Multiport device, Interconnect, Four-port Vector Network Analyze

1. Introduction

It is well known that VNA is quite accurate to characterize the signal transfer characteristics in multi-port system, especially in high frequency ranges including the crosstalk characteristics [3]. However, the number of available VNA ports are usually not sufficient to acquire all S-parameters of a multi-port device, and hence, several procedures have been proposed to build the S-matrix from two-port VNA measurements using port renormalization techniques [4]-[6]. In these methods, the S-matrix reconstruction is based on a conventional formula which corrects the measured matrix caused by port mismatches [4]:

\[
S' = (I - S)^{-1} (S - \Gamma)(I - \Gamma)^{-1} (I - S)
\] (1)

where S is the scattering matrix of an N-port network with port line impedances \( \zeta_i \) (\( i=1,2,...,N \)), \( S' \) is the transformed scattering matrix when the port impedances are altered to \( Z_i \), and \( \Gamma \) is the diagonal matrix of reflection coefficients of \( Z_i \) seen from line impedances \( \zeta_i \), and I is the \( N \times N \) identity matrix. It can be pointed out that two matrix inversion terms in (1) determine the computational efficiency and accuracy.

Since conventional renormalization techniques were based on two port measurement, obviously it requires lots of time-consuming measurements to acquire all S-parameters of a multiport device [2]. For example, while it requires 28 measurements to characterize an 8-port DUT (Device Under Test) using a two-port VNA, the number of measurements are reduced only to 6 if we use a four port VNA, with more ports connected to the DUT simultaneously.

Besides the reduction of the number in measurements, four-port VNA, only if the ports connected to VNA are selected properly, provides a good way to reduce the reflected waves coming into the VNA due to impedance mismatches at un-terminated ports. With properly selected ports, the accuracy of the S-parameters estimated from renormalization technique could be enhanced significantly. [1] For the proper port selection, of course, one needs to know the routing information inside the DUT. When this information is not available, and still if the renormalization technique is to be used to characterize the multi-port measurement, the calculated S-parameters would be no more accurate and stable due to the large reflection coefficients in (1).

In this paper, an algorithm to select proper S-parameters without routing information inside the network for the port
renormalization technique using four-port VNA is presented to characterize multi-port network. The proposed algorithm is applied to an eight port interconnect pogo pin structure to characterize its S-parameters. It can be seen in the result that the calculated S-parameters showed good agreement with the S-parameters obtained by the fullwave EM analysis.

2. Renormalization with Routing Information

Fig. 1 shows an 8-port interconnect pogo pin system to be analyzed. Each pin is arranged vertically inside the hole array on the socket, and has an identical cylindrical shape with 0.51 mm radius, 5.5 mm length and they are spaced 0.8 mm (center-to-center distance) away from each other. To support the measurement, the two PCBs (Printed Circuit Board) are attached to touch the pin ends and provide a plane interface so that such fine-pitch system can be measured by the VNA through micro-probes. In this paper, the full wave simulation using HFSS was performed to determine the S-parameters of this system as the reference data.

Fig. 1. Eight-port connector pins.

Table 1. Proposed four-port measurement scheme

<table>
<thead>
<tr>
<th>Port Measuring Procedure.</th>
<th>Choose S-parameters from ports…</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2, 3, 4</td>
<td>None</td>
</tr>
<tr>
<td>1, 2, 5, 6</td>
<td>1, 6</td>
</tr>
<tr>
<td>1, 2, 7, 8</td>
<td>2, 8</td>
</tr>
<tr>
<td>3, 4, 5, 6</td>
<td>3, 5</td>
</tr>
<tr>
<td>3, 4, 7, 8</td>
<td>4, 7</td>
</tr>
<tr>
<td>5, 6, 7, 8</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 1 shows how to connect four ports, out of eight ports of DUT, to VNA to reduce reflections coming into VNA. Since the routing information inside the connect system is available as in Fig. 1 (a), it is quite simple to choose ports to connect to four-port VNA: ports (1, 2, 3, 4), (1, 2, 5, 6), … etc. can be connected to VNA, but we never connect port (1, 2, 3, 5), or (1, 3, 5, 7) to VNA because it is apparent that those connections could introduce large reflections due to the mismatches at the un-terminated ports.

Fig. 3 shows many $S_{11}$ parameters renormalized from different port selections. It seems that each $S_{11}$ parameter should be dissimilar to one another, because of different port mismatches in each case. However, after being transformed by (1), $S_{11}$ from ports (1, 2, 3, 4), (1, 2, 5, 6), (1, 2, 7, 8), and (1,2) showed good agreement with little reflections, and $S_{11}$ from ports (1,3), (1,4), (1,5), (1,6), (1,7), and (1,8) formed another group with large reflections.

Fig. 2. Eight port test model. a) with known routing information b) with unknown routing information

Fig. 3. Transformed reflection coefficients at port 1 based on infinity reference impedance with different measurement configurations.
Fig. 4 shows part (four) of the $S$-parameters calculated from renormalization techniques. The red, blue and green lines represent the true $S$ parameters, the renormalized $S$ parameters from the four-port VNA scheme, and the calculated $S$-parameters from the conventional two-port renormalization scheme, respectively. It is clear that the blue dashed lines coincide very nice to the red lines in both magnitude and phase. It seems that the green dot lines also show a good coincidence to the red lines in some ranges, however, they show much discrepancies, especially in frequency under 0.5GHz. This can be explained that the conventional two-port renormalization scheme has no way to avert the reflected waves coming into the VNA port because it has only two ports to measure, meanwhile the
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The four-port renormalization scheme has some freedom to take the ports, minimizing the reflected waves coming into the VNA. Notice that all the S-parameters in Fig. 4 are from the fullwave EM simulation.

3. Port Selection Without Routing Information

From the previous section, it seems that the renormalization technique using four-port VNA would be very useful for the multi-port measurements. However for the multi-port system in general, e.g. the packaged multiport system, the routing information may not be available. In this case one needs to find a way to select ports which minimizes the reflections from the un-terminated ports.

Fig. 2 (b) depicts a black box of interconnect circuit whose inside structure is unknown. The DUT has 8 ports and each port is numbered randomly. In this case the difficulty lies in that how to select the two terminals which minimizes the reflections. Fig. 5 shows $S_{11}$ using different four ports, and the top picture is the enlargement of below one. As one can see the four $S_{ij}$ parameters from ports (1, 2, 3, 4), and (1, 2, 7, 8) are much different from the $S_{11}$ parameter from port (1, 2, 5, 6). It means that the reflection coefficients at port 1 in the former two cases of measurement are similar, and the opposite end of transmission lines that included port 1 might be in open states. So none of ports (2, 3, 4, 7, 8) can be the appropriate port. Instead of these five ports, port 5 and 6 might be the appropriate port that minimizes the reflections. Repeating the similar procedures for other ports, each pair of ports which belongs the same transmission line can be determined correctly. Fig. 6 shows the proposed algorithm to select specific S-parameters in multiport measurement using four-port VNA.

4. Conclusion

In this paper four port renormalization techniques for multi-port measurement using four port VNA with unknown routing information inside the network is described. Without routing information inside, one needs to develop an appropriate port selection method to minimize the reflections from the un-terminated ports. This paper proposes an algorithm to properly select ports to be connected to VNA, which minimizes the reflections coming back to VNA. Using the proposed method the proper port selection could be made and renormalization technique using 4 port VNA could be successfully applied to the eight port interconnect system, showing its effectiveness.

References


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