Multiport Measurement Method Using a Two-Port Network Analyzer With Remaining Ports Unterminated

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***Abstract*—A practical multiport measurement method is presented for the precise characterization of an N-port device using a two-port vector network analyzer. Because the $N-2$ unused ports need not be terminated with matched loads, a test fixture can be simplified. Any influence of the reflections from the unterminated ports can be deembedded by port renormalization. The proposed method was verified with a coupled microstrip line structure.**

***Index Terms*—Connector and cable, multiport network, port renormalization, S-parameter measurement.**

I. INTRODUCTION

TODAY'S high-speed multimedia interfaces, including high-definition multimedia interfaces (HDMI), digital visual interfaces (DVI), unified display interfaces (UDI) and serial advanced technology attachment (SATA) carry two to four differential channels between sources and sinks. There is a common requirement to be able to characterize these channels using a vector network analyzer (VNA) that has a smaller number of measurement ports. For example, HDMI cables and connectors accommodate four high-speed differential channels, while a four-port VNA has become popular in recent years. Since the transformation of $2N$-port single-ended scattering parameters (S-parameters) into differential N-port S-parameters is straightforward [1], it returns to the old subject of characterizing an N-port ($N > 2$) device with a two-port VNA.

A conventional means of performing such a measurement is to make several partial two-port measurements with a two-port VNA connected to various two-port combinations of an N-port device. From the definition of the S-parameters, the $N-2$ unused ports of the device must be terminated with perfectly matched loads to avoid reflections. However, this requirement cannot be met in practice with sufficient accuracy because the fabrication of broadband matched terminations is difficult. Furthermore, redundant traces are required to connect the matched loads due to their physical dimension as shown in Fig. 1, but their parasitic effect is rarely deembedded.

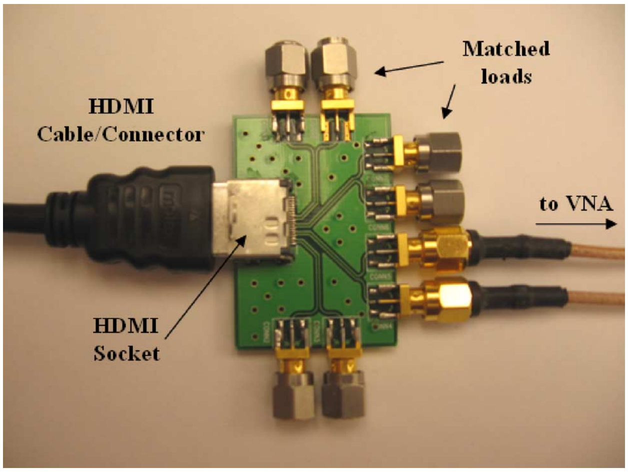

Fig. 1. Conventional HDMI cable test fixture.

In this letter, a practical multiport measurement method is presented, in which unused ports remain unterminated, but measured S-parameters are calibrated as if they were terminated with matched loads based on port renormalization theory [2], [3]. The proposed method enables a test fixture and corresponding test procedure to be simplified. It has been applied to characterizing a coupled microstrip line structure, by which its validity is successfully verified.

II. PROPOSED MULTIPORT MEASUREMENT METHOD

If the terminations of unused ports are mismatched, measured S-parameters are distorted by the reflective characteristics of the terminations. However, the original S-parameters of a multiport device could be reconstructed if only the reflection coefficient at each port were known, by virtue of the port renormalization. The matrix form of the port renormalization was given by Tippet [2] as

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

where S is the original S-parameters normalized to a given set of port impedances ζ_i, S' is the transformed S-parameters normalized to a new set of port impedances Z_i, I is the N-by-N identity matrix, and Γ is an N-by-N diagonal matrix containing the reflection coefficients Γ_i of the loads Z_i as seen from the lines of characteristic impedance ζ_i. Since Tippet's algorithm fails if one of the terminations is perfectly reflecting, Rolfes' algorithm [3] resolves this with rather complicated matrix manipulations. However, the singularity in the original algorithm can be avoided in practice because even an unterminated port has nonzero pad parasitics [4].

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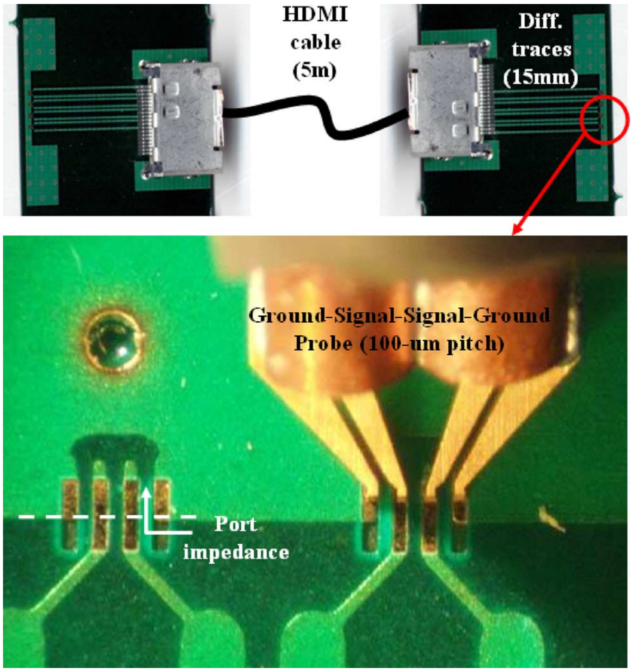

Fig. 2. Proposed measurement setup.

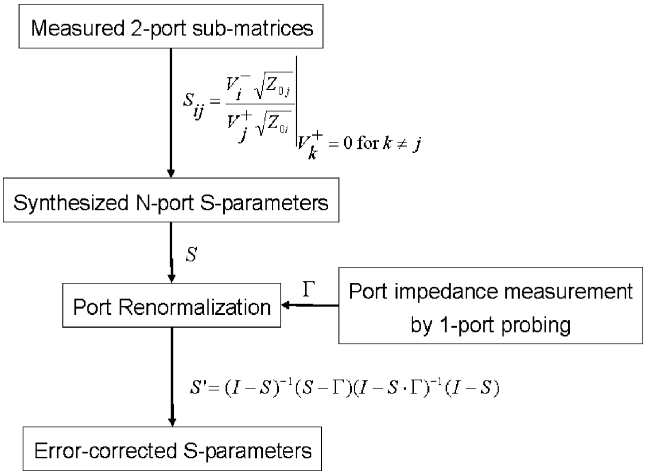

Fig. 3. Proposed measurement procedure.

Fig. 2 shows the proposed measurement setup for characterizing a 16-port HDMI cable assembly, where only four ports of the device under test (DUT) are connected with a VNA through microprobes, and all the other 12 ports remain unterminated. After all partial four-port measurements are complete, each probing pad is cut along the dotted line and the port impedance can be determined by one-port dual-probing measurement [5]. Finally, error-corrected S-parameters are calculated in the subsequent port renormalization procedure with the measured port impedances based on Tippet's algorithm, as shown in Fig. 3.

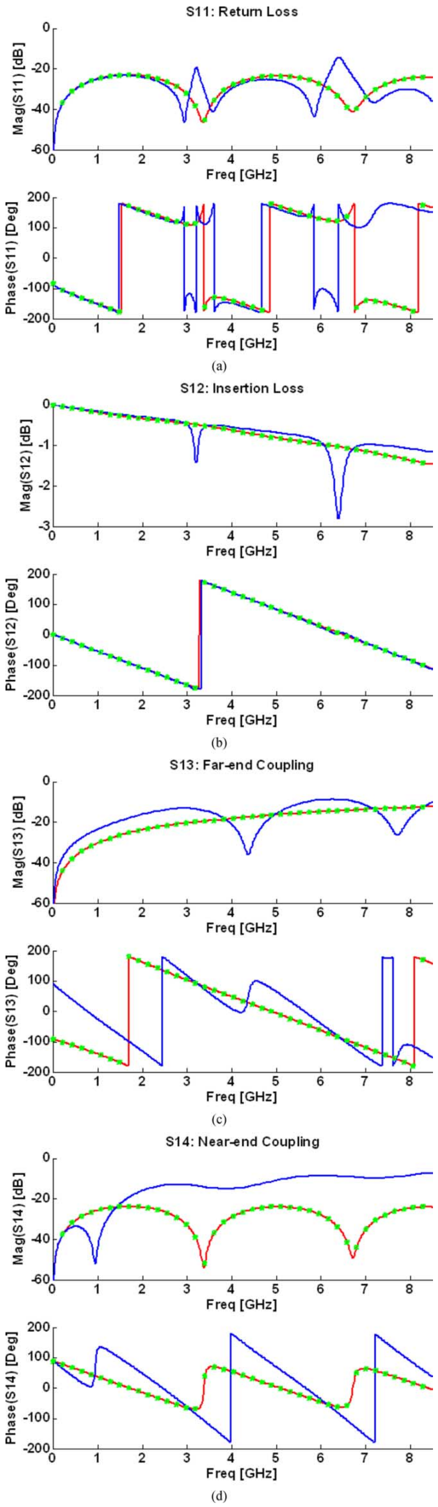

Fig. 4. Validity check of the proposed method: original S-parameters by four-port measurement (shown in red curves), S-parameters by two-port measurement (blue curves) and error-corrected S-parameters (green curves marked with stars). (a) S11. (b) S12. (c) S13. (d) S14.

In order to demonstrate the method, coupled microstrip lines were characterized. Each line is 1 mm wide and 25 mm long on 0.5-mm-thick FR4 substrate and the space between the two lines is 1 mm from edge to edge. This four-port device was first measured using a four-port VNA through four ground-signal-ground (GSG) microprobes, and the measured S-parameters are shown in red curves in Fig. 4. The same device was measured using only two microprobes. While two ports were connected to the VNA through the microprobes, the remaining two ports were left unterminated. The measured S-parameters are distorted by

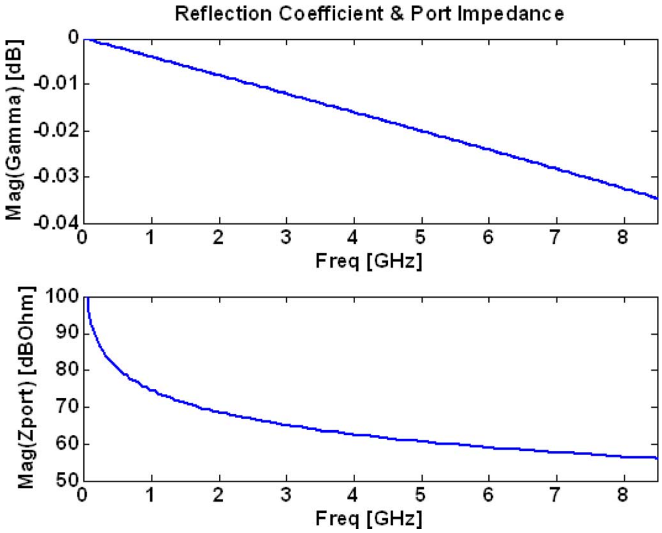

Fig. 5. Port impedance calculated from the reflection coefficient measurement at a probing pad.

the reflections from the unterminated ports as shown in blue curves. Nevertheless, the original S-parameters can be reconstructed if only the reflection coefficient at each unterminated port is known, and it is revealed from the one-port measurement of a probing pad as shown in Fig. 5. Finally, error-corrected S-parameters were restored according to the proposed method, as shown in green curves marked with stars in Fig. 4. The original S-parameters and the error-corrected ones are almost equivalent and the lines are indistinguishable on the figure.

Furthermore, the measurement bandwidth of the conventional method is limited by the auxiliary loads, and is typically lower than 10 GHz. Recently, multiport test sets have become commercially available, offering port extension up to 12$\sim$14 ports [6], but these are very costly. On the other hand, because the measurement bandwidth is limited only by a VNA or microprobes, the proposed method can be a practical solution for characterizing future high-speed serial links at frequencies in excess of several tens of GHz.

III. CONCLUSION

The measurement method based on the port renormalization of nonideal open terminations has been presented for the simple characterization of a multiport device with a two-port VNA. Although unused ports remain unterminated, measured S-parameters are calibrated as if they were terminated with matched loads. This enables a test fixture and corresponding test procedure to be simplified. The proposed method was successfully verified with a coupled microstrip line structure. It can be applied to characterizing multiport networks overcoming the complexity and bandwidth limitation of the conventional method.

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