Error in Phase Verification Results for Vector Network Analyzer Measurements in Coaxial Line System

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Abstract— This paper presents error analysis of a simple method for verifying the phase of transmission measurements — for example, as made using instruments such as Vector Network Analyzers (VNAs). Phase verification method by using air line as a phase standard has been published by N. Ridler and M. Horibe. Examples are given that show the method being used at millimeter wavelengths (i.e., at frequencies up to 33 GHz) in the 3.5 mm coaxial line size. It is trusted that the method will be suitable for use by calibration laboratories seeking verified and/or accredited measurements in VNAs. An air dielectric coaxial line (air line) is commonly used as the reference impedance and absolute phase standard in a VNA measurement. In the method, phase measurement accuracy is verified by comparing between dimensional length and electrical length, analyzed by measured value of transmission phase, of air line. However, reflection characteristics of air line at connection interfaces affects to error of analytical results of electrical length.

1. INTRODUCTION

Precision coaxial unsupported air lines are used as reference standards of impedance at RF and microwave frequencies [1–3]. In this paper, we use the air lines as phase standards against which the phase of transmission measurements can be verified in a vector network analyser (VNA) measurements. In advance, the air lines are characterised by their measured mechanical dimensions and measured insertion loss. The electrical length of the air line is calculated from the phase values of the transmission measurements made by the VNA being verified and this is then corrected to take into account the measured insertion loss. Subsequently, the calculated electrical length of the air lines is compared with the measured mechanical length of the air line. If the electrically derived length agrees with the mechanically measured length, then verification process of the phase measurements in VNA is passed.

The above method has previously been proposed elsewhere (see, for example [4–6]). However, in this paper, we extend this work by analysing the error in the calculation of electrical length from the S-parameter measurement results.

2. CALCULATION OF ELECTRICAL LENGTH

At first, the characteristic impedance, Z_a, of the air line should be verified by using dimensional measurements of the radii of the center conductor, a, and outer conductor, b, using:

$$Z_a \approx 59.939\ 045 \times \ln\left(\frac{b}{a}\right) \tag{1}$$

And, the physical length of the air line, l_m, should be determined by using dimensional measurements with traceability back to the SI base unit of length, the metre.

Then, the complex-valued S-parameters of the air line, at a range of frequencies, are obtained by the VNA measurement system that is to be verified. Note that, the measured reflection coefficient magnitudes, $|S_{11}|$ and $|S_{22}|$, should be sufficiently small to approximate the match condition for the line at all measured frequencies in the VNA measurement.

Using measured values of magnitude and phase of S_{21} and S_{12}, the resistivity, ρ, and electrical length for the air line, l_e are determined by the method presented in Ref. [6].

3. ANALYSIS OF PHASE VERIFICATION IN VNA

When ideal air lines having no reflection characteristics, $|S_{11}| = |S_{22}| = 0$, is used, transmission magnitude and phase characteristics are only depends on length and resistivity of conductivity of the air lines.

$$S_{21} = S_{12} = e^{-(\alpha + j\beta) l_e} \tag{2}$$

However, usual air lines have some mismatch effect at the connector interface, then $|S_{11}|$ and $|S_{22}|$ are non-zero values, i.e., $Z_a = 50\,\Omega$.

$$S_{21} = S_{12} = \frac{2\left(\cosh^2(\alpha + j\beta) - \sinh^2(\alpha + j\beta)\right)}{2\cosh(\alpha + j\beta) + \left(\frac{Z_0}{Z_a} + \frac{Z_a}{Z_0}\right)\sinh(\alpha + j\beta)} \tag{3}$$

Here, Z_0 is system impedance of VNA, i.e., $50\,\Omega$.

In the case of S_{11} and S_{22} being not small, There is no longer simple equation shown in Eq. (3) compared to Eq. (2).

In the next section, this paper presents the VNA phase verification result compering to physical length of the air lines, and then investigate and discussion the relationship between phase verification errors and S_{ii} of the air lines.

4. RESULT AND DISCUSSION

Four air lines with 50 mm long length and 3.5 mm connectors at the both ends were used in the VNA phase verification. Length difference between electrical and physical is drawn in Figure 1. The electrical lengths of three lines, A, C and D, has less than 10 µm difference from physical length of air lines. However, electrical length is approximately 30 µm longer than physical length for line B. According to Ref. [6], uncertainty of this type of comparison is approximately 10 µm when use of typical air lines, i.e., low reflection loss at the connector interface. Then electrical lengths of the lines, A, C and D are good agreement with their physical lengths. However, line B has large error in the phase verification result.

In order to understanding the difference between electrical and physical lengths, reflection characteristics were obtained and drawn in Figure 2. Three air lines, A, C and D, show small reflection characteristics, S_{ii}, within 0.02. Line B has larger reflection characteristics, i.e., maximum value of

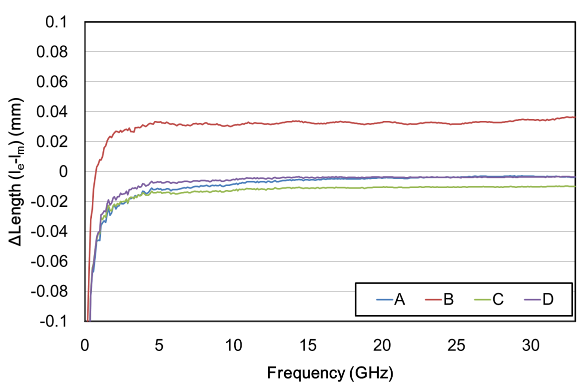

Figure 1: Difference between electrical and physical lengths of the 50 mm air lines.

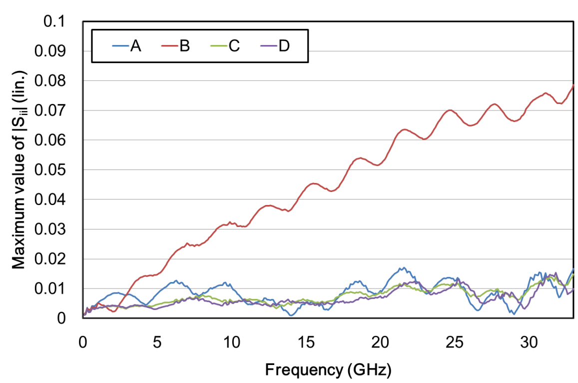

Figure 2: Maximum values of measured $|S_{11}|$ or $|S_{22}|$ for the air lines.

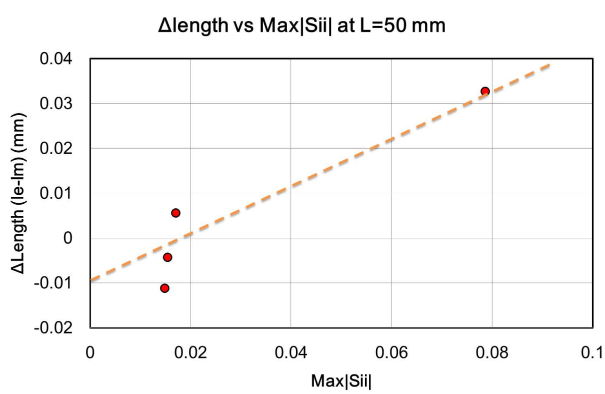

Figure 3: Dependence of length difference on reflection characteristics of the air lines.

0.08. As the results, length difference depends on reflection characteristics. Figure 3 shows plots of relationship between length difference and maximum $|S_{ii}|$. This graph indicates one of major error source in VNA phase verification is measured reflection characteristics of the air lines.

This means that the air line should have a small reflection characteristics in the VNA phase verification.

5. SUMMARY

This paper has described an error source in the VNA phase verification of transmission coefficients, based on determining the electrical length of precision beadless air lines. The method is good way to verify the phase measurement accuracy, but the result strongly depends on reflection characteristics of air lines.

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