Letters

Comments on "An Accurate Measurement Technique for Line Properties, Junction Effects, and Dielectric and Magnetic Parameters"

Michael B. Steer, Steven B. Goldberg, and Paul D. Franzon

In the above paper[1] Enders develops an iterative technique so that "the characteristic impedance, the propagation constant, and the parameters of the connections with the measurement setup can be calculated if the coefficients of three different lengths of the line being investigated are measured." The purpose of this letter is to point out that the characteristic impedance of the lines cannot be determined using the technique proposed.

In the first part of his paper, Enders considers the problem of determining the network parameters of identical fixtures using three different lengths, $l^{(m)}$, $m = 1, 2, 3$, of an inserted transmission line, as in Fig. 1. The chain matrix (or ABCD) parameters of the fixtures are a_{11}, a_{12}, a_{21} and a_{22}, the characteristic impedance of the measurement system is Z_0, and the characteristic impedance and propagation constant of the unknown line are Z_p and γ respectively. The calculated transmission and reflection parameter of the three structures are then

$$T_{\text{calc}}^{(m)} = \frac{2}{A \cosh [\gamma l^{(m)}] + B \sinh [\gamma l^{(m)}]}$$
$$\Gamma_{\text{calc}}^{(m)} = \frac{C \cosh [\gamma l^{(m)}] + D \sinh [\gamma l^{(m)}]}{A \cosh [\gamma l^{(m)}] + B \sinh [\gamma l^{(m)}]} \tag{1}$$

where

$$A = 2\left(a_{11}a_{22} + a_{12}a_{21} + Z_0 a_{21}a_{22} + \frac{1}{Z_0} a_{11}a_{12}\right)$$
$$B = \frac{Z_p}{Z_0} a_{11}^2 + \frac{1}{Z_p Z_0} a_{12}^2 + Z_0 Z_p a_{21}^2 + \frac{Z_0}{Z_p} a_{22}^2 + 2Z_p a_{11}a_{21} + \frac{2}{Z_p} a_{12}a_{22}$$
$$C = 2\left(\frac{1}{Z_0} a_{11}a_{12} - Z_0 a_{21}a_{22}\right)$$
$$D = \frac{Z_p}{Z_0} a_{11}^2 + \frac{1}{Z_p Z_0} a_{12}^2 - Z_0 Z_p a_{21}^2 - \frac{Z_0}{Z_p} a_{22}^2 \tag{2}$$

where the 4th term on the right hand side of the equation for B is a correction. Note that A, B, C, and D in (2) are not *the* ABCD parameters. It is claimed that a_{11}, a_{12}, a_{21} and a_{22} and Z_p can be obtained iteratively by equating the calculated reflection and transmission parameters in (1) to those derived from S-parameter measurements. However, we will demonstrate that the fixture parameters and Z_P can not be uniquely determined using the procedure presented.

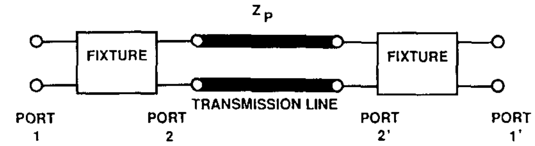

Fig. 1. Equivalent circuit of an unknown transmission line inserted between unknown but identical fixtures.

It has been argued several times that without a known lossy impedance reference inserted in the measured line [1]–[3] or additional physical insight [4]–[6], the characteristic impedance of an embedded transmission line can not be determined from measurements made at the external ports of the test fixtures. That is, referring to Fig. 2, using external measurements only, it is not possible to differentiate between the actual fixture and the effective fixture, or between the actual characteristic impedance of the line and its effective characteristic impedance. That is, the external characteristics will be identical if a transformer of turns ratio α is inserted in the fixture together with a corresponding change of the characteristic impedance of the inserted line by a factor of α^2.

This can be seen by examining (1). Suppose $\hat{a}_{11}$, $\hat{a}_{12}$, $\hat{a}_{21}$, $\hat{a}_{22}$ and $\hat{Z}_p$ are the actual junction parameters and characteristic impedance of the inserted line. Corresponding to these $\hat{A}$, $\hat{B}$, $\hat{C}$, $\hat{D}$ are the solutions of (2), and $\hat{T}$ and $\hat{\Gamma}$ are the actual transmission and reflection coefficients. Suppose that during iterative solution of (1), the current estimate of $Z_p = \alpha^2 \hat{Z}_p$. Then substituting[2]

$$a_{11} = \frac{1}{\alpha}\hat{a}_{11}$$
$$a_{12} = \alpha\hat{a}_{12}$$
$$a_{21} = \frac{1}{\alpha}\hat{a}_{21}$$
$$a_{22} = \alpha\hat{a}_{22} \tag{3}$$

in (2) we obtain

$$A = 2\frac{\alpha}{\alpha}\left(\hat{a}_{11}\hat{a}_{22} + \hat{a}_{12}\hat{a}_{21} + Z_0\hat{a}_{21}\hat{a}_{22} + \frac{1}{Z_0}\hat{a}_{11}\hat{a}_{12}\right) = \hat{A}$$
$$B = \frac{\alpha^2}{\alpha^2}\left(\frac{\hat{Z}_p}{Z_0}\hat{a}_{11}^2 + \frac{1}{\hat{Z}_p Z_0}\hat{a}_{12}^2 + Z_0\hat{Z}_p\hat{a}_{21}^2 + \frac{Z_0}{\hat{Z}_p}\hat{a}_{22}^2 + 2\hat{Z}_p\hat{a}_{11}\hat{a}_{21} + \frac{2}{\hat{Z}_p}\hat{a}_{12}\hat{a}_{22}\right) = \hat{B}$$

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[1] A. Enders, *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 598–605, Mar. 1989.

[2] These fixture parameters are just those of an effective fixture in Fig. 2 with a transformer of turns ratio α at the internal port of the fixture.

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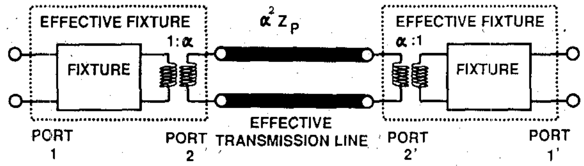

Fig. 2. Equivalent circuit of an transmission line of effective characteristic impedance $\alpha^2 Z_P$ inserted between unknown fixtures.

$$C = 2\frac{\alpha}{\alpha}\left(\frac{1}{Z_0}\hat{a}_{11}\hat{a}_{12} - Z_0\hat{a}_{21}\hat{a}_{22}\right) = \hat{C}$$

$$D = \frac{\alpha^2}{\alpha^2}\left(\frac{\hat{Z}_p}{Z_0}\hat{a}_{11}^2 + \frac{1}{\hat{Z}_p Z_0}\hat{a}_{12}^2 - Z_0\hat{Z}_p\hat{a}_{21}^2 - \frac{Z_0}{\hat{Z}_p}\hat{a}_{22}^2\right) = \hat{D} \tag{4}$$

and hence

$$T_{\text{calc}}^{(m)} = \hat{T}_{\text{calc}}^{(m)}$$
$$\Gamma_{\text{calc}}^{(m)} = \hat{\Gamma}_{\text{calc}}^{(m)} \tag{5}$$

Thus, since α can be any complex number the fixture parameters and the characteristic impedance of the line cannot be resolved. Consequently this technique cannot be used to determine material parameters.

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[2] J. P. Mondal and T-H. Chen, "Propagation constant determination in microwave fixture de-embedding procedure," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-36, Apr. 1988, pp. 706–714.

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[5] R. B. Marks and D. F. Williams, "Characteristics impedance determination using propagation constant measurements," *IEEE Microwave Guided Wave Lett.* vol. 1, pp. 141–143, June 1991.

[6] W. J. Getsinger, "Measurement and modeling of the apparent characteristic impedance of microstrip," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 624–632, Aug. 1983.

Author's Reply[3]

A. Enders

This comment concentrates on the characteristic impedance Z_p of the investigated transmission line especially whether it can be determined by the method given in my paper. The authors show that there is an ambiguity in the determination of Z_p expressed by a scaling factor. This is correct, as well as the correction of one term in the expression for the value B.

However, in their last sentence they conclude, that the technique can not be used to determine material parameters. This is simply wrong. For the calculation of the material parameters only the propagation constants γ are needed (see formulas (4), (5) in my paper), the Z_p are not used. The authors themselves show in their calculations (formula (4)) that under scaling transformations of Z_p the factors A, B, C, D are unaffected because of the canceling out of the scaling factor. Consequently the determination of the γ (see formulas 1, 2 of my paper) is uneffected and thus also the determination of the material parameters.

The problem of ambiguity in the determination of Z_p remains, of course, and its transformation will alter the junction parameters, too. However, I would like to point out that this ambiguity is not a problem of the proposed measurement method but an inherent problem because of the ambiguity in the definition of the characteristic impedance. In the following it will become clear that in the most general case it makes no sense to differentiate between junction ("fixture") effects and ratios of characteristic impedances so that the second last sentence of the comment is right but simply a statement of the inherent ambiguity which can't be resolved at all.

I suppose that the authors have in mind a well-defined characteristic impedance of the feeding transmission lines and that the characteristic impedance of the line under test is also *consistently* well-defined and should be determined in relation to the feeding lines. But this situation is not given in the general case, e.g. the waveguides having different cross-sections and/or loading configurations which are dealt with in my work. Generally speaking the characteristic impedance as a ratio of integrated field quantities becomes ambiguous because the integrations are path-dependent and thus not comparable for waveguides having different electrical cross sections. Thus it becomes pointless to differentiate between reflections being caused by junction (higher order mode) effects or being caused by alterations of the arbitrarily defined characteristic impedance. This, in fact, is the very reason, that the measurable transmission/reflection-coefficients are not altered by the scaling of the characteristic impedance Z_p as shown in the comment. The scaling is just equivalent to another definition of the characteristic impedance.

If, on the other hand, the characteristic impedance is defined by certain properties allowing a relation e.g. to the wave vector of the investigated transmission line, then, of course, there is the possibility to determine it by the method given in my paper and therefore I just mentioned this possibility. However, this was neither done nor needed in the further description of experimental work in my paper (concentrating on the material parameter determination by transmission measurements only). Therefore I did not discuss the topic further as is now done in the comment and my reply.

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