

Characterising Air Lines using VNA Loss Measurements

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Abstract — Air lines can be used as reference devices, or standards, for impedance measurements at high frequencies. However, in order to use any given line in a reliable fashion, it is important to consider the lossy rather than lossless performance of the line. The lossy behaviour of a line is primarily due to metallic loss found in the conductors of the line. This paper presents a simple method to determine the loss in a line based on measurements using a vector network analyser (VNA). The determined loss can then be used to accurately characterise the line for high precision metrology applications.

I. INTRODUCTION

Precision air dielectric coaxial transmission lines (or air lines, for short) can be very useful as references, or standards, for impedance measurement at RF and microwave frequencies. In order to use an air line as such a reference device, it is necessary to know the complex characteristic impedance, Z , or complex propagation constant, γ , or both, of the line. For example, a value of Z is needed when the line provides a defined impedance value (e.g. during a vector network analyser (VNA) line-based calibration scheme such as TRL [1], or during the so-called ripple technique [2]). A value of γ is needed when the line is used as a phase reference (e.g. for verifying VNA phase measurements [3]).

It has been shown that, at RF and microwave frequencies, Z and γ can be given by the following two models [4]:

$$Z = g(f, a, b, \mu_r, \epsilon_r, \rho), \quad (1)$$

$$\gamma = h(f, a, b, \mu_r, \epsilon_r, \rho), \quad (2)$$

where

- f = frequency (Hz),
- a = radius of the line's centre conductor (m),
- b = inner radius of the line's outer conductor (m),
- μ_r = relative permeability of the line's dielectric,
- ϵ_r = relative permittivity of the line's dielectric,
- ρ = resistivity of the line's conductors ($\Omega \cdot m$)

and g and h describe the functional relationship between the input and output quantities of the models.

Values for the inputs f , a , b , μ_r and ϵ_r in (1) and (2) can easily be determined: f can be measured accurately using a frequency counter; a and b can be determined from mechanical measurements; $\mu_r = 1$ and $\epsilon_r \approx 1$ for air. However, to date, there has been little information available concerning measured values of ρ .

The scientific literature [5] suggests that textbook values for ρ are inappropriate for air lines as they refer to bulk samples of material whereas a line's conductors have often been formed using composite materials that have been electroplated and machined. These processes significantly affect the properties of these materials. The resistivity produces a first-order

correction to both Z and γ and hence an accurate determination is required in order to use these lines effectively as impedance standards.

This paper presents an easy to implement method for determining the resistivity of air lines using VNA transmission measurements. The derived value of resistivity enables accurate determinations of both Z and γ for a given line to be made. This, in turn, enables very accurate impedance measurements to be made (e.g. complex S -parameter measurements using VNAs).

II. EXPERIMENTAL METHOD

The following expression can also be used for γ :

$$\gamma = \alpha + j\beta, \quad (3)$$

where

α = attenuation constant ($Np \cdot m^{-1}$),

β = phase constant ($Rad \cdot m^{-1}$).

The attenuation constant is related to a transmission coefficient (say, S_{21}) of a length, l , of line, by

$$\alpha = \frac{-\log_e |S_{21}|}{l} \quad Np \cdot m^{-1}. \quad (4)$$

It has been shown that, to a first-order approximation at high frequencies, the resistivity, ρ , of a line is related to α as follows [6]:

$$\rho \approx \left[\frac{200 \alpha b}{1 + (b/a)} \right]^2 \frac{\pi}{\mu_0 f} \quad \Omega \cdot m, \quad (5)$$

where

μ_0 = permeability of free space ($= 4\pi \times 10^{-7} \text{ H} \cdot m^{-1}$).

From equations (4) and (5) it is clear that, at any given frequency, ρ can be determined from a measurement of S_{21} (made, for example, using a VNA). This value of ρ can then be used with equations (1) and (2) to determine the characteristics Z and γ of the air line.

III. RESULTS AND DISCUSSION

To test this method, measurements were made of a range of air lines in three different precision connector line sizes: 14 mm, 7 mm and 1.85 mm.

Three lines in the 14 mm line size were measured, of nominal lengths 100 mm, 150 mm and 300 mm. Table 1 shows the results obtained using the method described here and Figure 1 shows the results for the 300 mm line plotted as a function of frequency.

Table1: measured resistivity for 14 mm lines

Line length (mm)	Measured resistivity (n Ω .m)	
	Mean value	Standard deviation
100	25	10
150	22	7
300	26	7

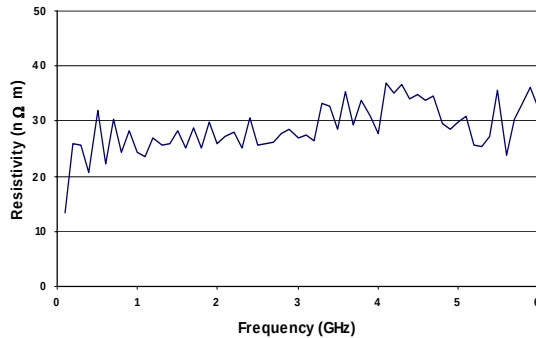


Figure 1: measured resistivity for a nominal 300 mm length of line in the 14 mm line size.

An earlier determination of ρ for the same 150 mm and 300 mm lines, reported in [6], showed that ($16 < \rho < 63$) n Ω .m. This agrees well with the values given in Table 1.

Several lines in the 7 mm line size were also measured. An example of the results obtained is shown in Figure 2 for a line of nominal length 100 mm. The observed values are close to the value of 150 n Ω .m that has been predicted elsewhere for these lines [3].

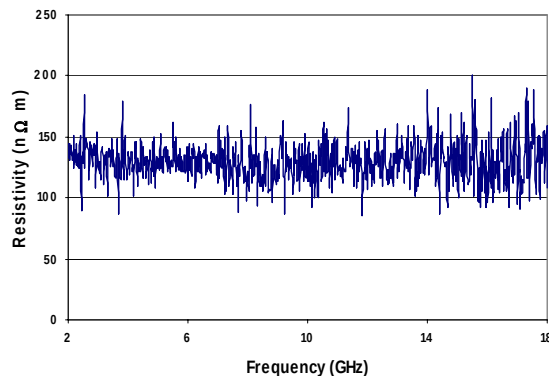


Figure 2: measured resistivity for a nominal 100 mm length of line in the 7 mm line size.

Finally, a nominal 50 mm length of line in the 1.85 mm line size was measured. This line size was chosen since it can operate to 65 GHz and hence expose any significant dependence of ρ with frequency. The results obtained, shown in Figure 3, do not indicate significant frequency dependence.

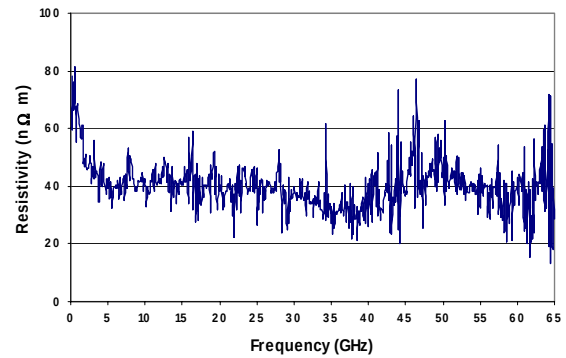


Figure 3: measured resistivity for a nominal 50 mm length of line in the 1.85 mm line size.

IV. CONCLUSIONS

A simple method has been presented for establishing the characteristics of air lines based on determining the line's resistivity using VNA transmission measurements. The method will be valuable in characterising these lines for use as standards of Z [1, 2] and γ [3].

V. ACKNOWLEDGEMENT

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VI. REFERENCES

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