Open-Short 방식의 임피던스 측정에 의한 분포정수의 보정

Igor P. ANANIEV*, 조기연, 변영복, 서정일, 김은수, 김태진
Agrophysical Research Institute Russia*, 한국전기연구소

A LOSSY LINE DISTRIBUTED PARAMETERS CALCULATION USING DATA OF OPEN-SHORT IMPEDANCE MEASURING METHOD

Igor P. ANANIEV*, Ki Yeon Joe, Young Bok Byun, Jeong Il Seo, Eun Soo Kim, Tae Jin Kim
Agrophysical Research Institute Russia*, Korea Electrotechnology Research Institute

Abstract – The paper contains design formulas and an execution algorithm for calculation of distributed parameters as well as wave and impedance parameters of a uniform transmission line using data of the line input impedance measurements by the OPEN-SHORT method. In difference from published before works on the OPEN-SHORT method application for line parameters determination, in which the lines with small losses are considered /1-3/, the obtained formulas allow to calculate parameters of transmission lines with arbitrary losses. It opens new possibilities of the OPEN-SHORT method utilization for development and application of the probe – type lossy dielectric media parameters meters based on transmission lines, including probe-type moisture material meters.

1. INTRODUCTION

Electrical parameters of lossy dielectric liquid and granular materials in RF, VHF and UHF bands can be defined by inserting in the material a uniform transmission line and measuring the input impedance of the line with its other end opened or shorted (the OPEN-SHORT method) with help of a vector impedance analyzer [4]. Electromagnetic interaction of the transmission line and the material leads to the line distributed parameters variation. These parameters and their variation can be calculating on the base of measuring information received by the OPEN-SHORT method use. The relation between the line distributed parameters variation and the material electric parameters can be determined by means of Maxwell's equations solution or by an experimental calibration in model media. In some particular cases when testing material fills in all the volume of a line electromagnetic field, simple equations of relationship between the line distributed parameters and the material parameters are derived [4].

2. MEASUREMENT AND CALCULATION PROCEDURE

2.1. Transmission Line Distributed Parameters and Open-Short Impedance Measuring Method

The theory of a transmission line as linear electrical circuit /5/ is constructed on consideration of its distributed parameters (see fig.), represented by parameters of a line section of a unit length: L_0 - series distributed inductance [H/m], R_0 - series distributed resistance [Ω/ m], C_0 - parallel distributed capacitance [F/m] and G_0 - parallel distributed conductance [S/m].

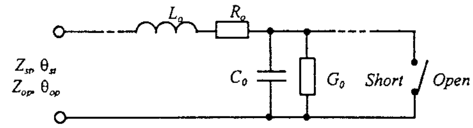

Fig. Using the Open-Short method of impedance measurements for a lossy transmission line parameters determination

All parameters of a transmission line, including wave parameters(characteristic impedance, propagation constant, attenuation constant, phase constant, phase velocity of wave propagation), and also the impedance parameters (input impedance of a line with arbitrary load on its end) express through the distributed parameters of a line. Therefore determination of the distributed parameters of a uniform transmission line were in a free space, gives a comprehensive information about properties of this line. Accordingly, the determination of the distributed parameters of a line entered into model lossy dielectric media, which parameters are known (ε - the relative dielectric permittivity, $\tan\delta$ - the loss tangent), allows to determine connection of a media parameters with a line parameters for various constructions of lines and measuring probes with use of transmission lines.

The technique of determination of a uniform transmission line distributed parameters with use the OPEN-SHORT method is, that with the help of a vector impedance analyzer one measures the module and phase angle of a line input impedance with the output line end shorted or opened:

Z_{st}, θ_{st} - module and phase angle of an input impedance for a line with shorted end, (1)

Z_{op}, θ_{op} - module and phase angle of an input impedance for a line with opened end.

Using these four parameters one can found by means of calculation the four distributed parameters of a line: L_0, R_0, C_0, G_0.

2.2. Calculation of the Distributed Parameters of a Transmission Line with Arbitrary Losses Using Data of Open-Short Impedance Measuring Method

These formulas are obtained by a solution of the equations connecting the input impedance of a uniform transmission line with arbitrary losses, shorted and opened on its end with the distributed parameters of the line. Not staying on a bulky procedure of deriving equations, we shall reduce the final formulas and algorithm of calculations permitting to find both the distributed parameters, and main wave parameters of a line with the help of measured parameters (1).

1. The module Z_c and phase angle θ_c of a characteristic impedance of a line are calculated (these formulas have the same appearance, as for a line with small losses):

$$Z_c = \sqrt{Z_{op} \cdot Z_{st}} \quad [\Omega], \tag{2}$$

$$\theta_c = \frac{\theta_{op} + \theta_{st}}{2} \quad [rad]. \tag{3}$$

2. Settle up the attenuation constant α and phase constant β of a line (l - line length):

$$\alpha = \frac{1}{2\lambda} ln \frac{1 + \frac{Z_{st}}{Z_{op}} + 2\sqrt{\frac{Z_{st}}{Z_{op}}} cos \frac{\theta_{st} - \theta_{op}}{2}}{\sqrt{1 + \frac{Z_{st}^2}{Z_{op}^2} - 2\frac{Z_{st}}{Z_{op}} cos(\theta_{st} - \theta_{op})}} \quad [\frac{Np}{m}], \tag{4}$$

$$\beta = \frac{1}{2\lambda} arccos \frac{1 - \frac{Z_{st}}{Z_{op}}}{\sqrt{1 + \frac{Z_{st}^2}{Z_{op}^2} - 2\frac{Z_{st}}{Z_{op}} cos(\theta_{st} - \theta_{op})}} \quad [\frac{rad}{m}]. \tag{5}$$

3. The betweennesses active and reactive distributed parameters of a line: $a = \frac{R_0}{\omega L_0}$ and $b = \frac{G_0}{\omega C_0}$ are calculated with use of settlement outcomes (3-5):

$$a = \frac{R_0}{\omega L_0} = \frac{1 + \frac{2\alpha\beta}{\beta^2 - \alpha^2} tan 2\theta_c + \sqrt{[1 + \left(\frac{2\alpha\beta}{\beta^2 - \alpha^2}\right)^2] \cdot (1 + tan^2 2\theta_c)}}{\frac{2\alpha\beta}{\beta^2 - \alpha^2} - tan 2\theta_c}, \tag{6}$$

$$b = \frac{G_0}{\omega C_0} = \frac{1 + \frac{4\alpha\beta}{\beta^2 - \alpha^2} tan 2\theta_c - tan^2 2\theta_c + \sqrt{[1 + \left(\frac{2\alpha\beta}{\beta^2 - \alpha^2}\right)^2] \cdot (1 + tan^2 2\theta_c)}}{\frac{2\alpha\beta}{\beta^2 - \alpha^2}(1 - tan^2 2\theta_c) - 2 tan 2\theta_c - (tan 2\theta_c) \cdot \sqrt{[1 + \left(\frac{2\alpha\beta}{\beta^2 - \alpha^2}\right)^2] \cdot (1 + tan^2 2\theta_c)}} \tag{7}$$

4. There is the phase constant of a lossless line β_0 with use (4-7):

$$\beta_0 = \sqrt{\frac{2\alpha\beta}{a - b}} \quad [\frac{rad}{m}]. \tag{8}$$

5. The characteristic impedance of the lossless line Z_{c0} with use (2,6,7) is determined:

$$Z_{c0} = Z_c \cdot \frac{\sqrt{1 + a^2}}{\sqrt[4]{(1 + a \cdot b)^2 + (a - b)^2}} \quad [\Omega]. \tag{9}$$

6. Settles up the distributed inductance L_0 and distributed capacitance C_0 per unit length of a line with use (8,9) and significance of radial frequency of measurements ω:

$$L_0 = \frac{Z_{c0} \cdot \beta_0}{\omega} \quad [\frac{H}{m}], \tag{10}$$

$$C_0 = \frac{\beta_0}{\omega Z_{c0}} \quad [\frac{F}{m}]. \tag{11}$$

7. Is calculated the distributed resistance per unit length R_0 and distributed conductance per unit length G_0 with use (6-9):

$$R_0 = a \cdot Z_{c0} \cdot \beta_0 \quad [\frac{\Omega}{m}], \tag{12}$$

$$G_0 = b \cdot \frac{\beta_0}{Z_{c0}} \quad [\frac{S}{m}]. \tag{13}$$

8. The phase velocity of wave propagation along a line v with the help of (5) is determined:

$$v = \frac{\omega}{\beta} \quad [\frac{m}{sec}]. \tag{14}$$

9. Factor of slowing down of a line n, i.e. factor of a diminution of a wave phase velocity in a line on a comparison with a wave velocity in a free space c, with the help of (14) or (5) is calculated:

$$n = \frac{c}{v} = \frac{c \cdot \beta}{\omega}. \tag{15}$$

2.3. Application of the Procedure

The considered procedure of a lossy transmission line distributed parameters determination can be used for development and application of methods of measuring electrophysical parameters of lossy dielectric media with the help of inserted transmission lines, and also for development of special probe-type meters of granular material moisture.

The application of the considered procedure to a research of properties of helical transmission lines used for a measurement of dielectric liquids parameters or materials moisture /6/ is of interest as the helical lines have wave properties on low on a comparison with usual lines frequencies (unit - tens megahertz).

With the help of considered procedure the character of influence of a lossy dielectric media parameters on the transmission lines distributed parameters in a broad band of frequencies for various constructions of lines and probes on their basis can be investigated. That is necessary for means of measuring dielectric parameters and materials moisture development.

As vector impedance analyzers for the OPEN-SHORT impedance measuring method can be used: Hewlett-Packard 4194A Impedance/Gain-Phase Analyzer in frequency range 100 kHz ...40 MHz and Hewlett-Packard 4395A Network/Spectrum/Impedance Analyzer in frequency range 100 kHz ...500 MHz.

As model liquid dielectric media can be used water (ε = 81), ethylene glycol (ε = 41), ethyl alcohol (ε = 24), transformer oil (ε = 2,1...2,4) / 7/, and also emulsion water - transformer oil (ε = 3...80). The dielectric media with losses receive by the component salt NaCl in water or emulsion in different amounts.

The model liquid lossy dielectric media parameters measurement for a research of their influence on the distributed parameters of a line can be carried out with the help of Hewlett-Packard 4194A c Hewlett-Packard 16452A Liquid Test Fixture in frequency range 100 kHz ...30 MHz and with the help of Hewlett-Packard 85070B Dielectric Probe Kit, on-line to Hewlett-Packard 8752C RF Network Analyzer in frequency range 300 kHz ... 1.3 GHz.

3. CONCLUSION

The procedure of distributed parameters determination for a uniform transmission line with arbitrary losses is developed. It consists of a usual input vector impedance measurement using the OPEN-SHORT method and calculation of distributed parameters with help of received new formulas and an algorithm for lines with any losses. The next step is to evaluate the accuracy of calculated results in dependence of measurement errors.

REFERENCES:

[1] The Impedance Measurement Handbook. A Guide to Measurement Technology and Techniques (by M.Honda). Yokogawa-Hewlett-Packard, 1987, pp.5-22...5-24.

[2] Application Note 339-4. Measuring the Characteristic Impedance of Balanced Cables. Hewlett-Packard, 1986, 3 pp.

[3] Application Note 380-2. Measuring Cable Parameters. Hewlett-Packard, 1986, 15 pp.

[4] E.J.KIRKSCETHER. Ground Constant Measurements Using a Section of Balanced Two-Wire Transmission Line. IRE Transactions on Antennas and Propagation, 1960, Vol.Ap-8, pp.307-312.

[5] R.W.P.King. Transmission-Line Theory. New York: Dover Publications, 1965.

[6] U.S.Patent 5818241. Moisture sensor using helical transmission line. IPC: G01N 27/12. Filed: May 30, 1996. Issued: Oct.6, 1998.

[7] Von Hippel A.R. Dielectric Materials and Applications. The Technology Press of M.I.T. and John Wiley and Sons, New York, 1954.