Errata

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HP References in this Application Note

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Measuring The Characteristic Impedance of Balanced Cables

Introduction

The HP 4194A Impedance/Gain-Phase Analyzer can measure balanced cables (such as twisted pair cables) quickly and efficiently. This application information describes how to measure the characteristic impedance of balanced cables by using an open/short method which is useful for cable manufacturers and cable users (telecommunications, telephone, TV, computer, and instrument manufacturers).

Application Issue

Characteristic impedance is the most often used parameter for evaluating the transmission characteristics of cables. Measuring the characteristic impedance of a balanced cable is not as easy as it is for an unbalanced cable, though, because a balanced measurement circuit is required. In the past, the following techniques have been used.

* Impedance Bridge
  Time consuming test and requires a highly skilled user.

* LCR Meter with a Balun
  An LCR Meter’s test terminals are unbalanced, so it is necessary to insert a balun between the LCR Meter measurement terminals and the test device (in this case a cable). This requires complicated calculations to compensate for the transmission errors in balun (a complicated compensation program to run on an external computer must and the measurement speed suffers accordingly).

Solutions Offered by the HP 4194A

* Easy to setup Balanced Measurements and High Measurement Speed
  The HP 4194A has powerful compensation functions, so errors due to the balun can be easily compensated for, and measurement speed is not lost by having to make lengthy calculations to correct for the presence of a balun in the circuit.

* Wide Frequency/Measurement
  The HP 4194A has a frequency range of 100Hz to 400MHz for impedance measurements (10kHz) to 100MHz with the HP 41941A/B), and a measurement range of 10mΩ to 100MΩ (0.1Ω to 1MΩ with the HP 41941A/B). This measurement range is wide enough to make open/short measurements of cables.

* Secondary Parameter Analysis
  After a measurement is made, the measurement data can be used to calculate and display the characteristic impedance of the cable, and other secondary parameters.

* Gain-Phase and Additional Impedance Evaluation
  The HP 4194A can also be used to determine other impedance parameters such as inductance, capacitance, and the dielectric constant of cable materials. The HP 4194A's Gain-Phase measurement function can be used to measure transmission characteristics such as cross-talk, attenuation, and delay time.
* Auto Sequence Program (ASP)

The 4194A's Auto Sequence Program (ASP) feature, an internal programming function, allows the automatic execution of measurement condition setup, compensation, measurement, calculation and display. Figure 1 shows a sample ASP program for balanced cable measurements. This program uses a unique application of the calibration function of the HP 4194A. The following is a brief discussion of programmed calibration, measurement, and analysis.

Line 170 to 290: Calibration using the 0Ω/OS/50Ω standards

Lines 300 - 360: OS standard (HP PN 04191-85302) Calibration data input

The reference values to calculate the theoretical calibration data for each calibration standard, OS + 0F for the OS standard, 0Ω + OS for the OS standard, and 50Ω + OS for the OS standard, are prestored into the HP 4194A. Each time the HP OS standard (OS + 0,082pF) is used, its data should be restored. Lines 310 to 350 perform the OS standard frequency simulation, and line 360 inputs the simulation data into the calibration data standard.

Lines 370 to 450: Zero Open/Short offset for the HP 16093B

Performs Zero offset compensation for the fixtureing from the calibration terminal (APC-7) to the test device connection terminal (HP 16093B).

Lines 460 to 860: Cable measurement

This ASP program uses the Open-Short method (based on the following equation) to calculate secondary parameters.

Characteristic Impedance:

\[ Z = \sqrt{\frac{1}{\text{Zop}}} \times \frac{Zst}{\text{Zop}} \times \frac{\text{Zst}}{\text{Zop}} \]

\[ \theta = \frac{\text{Zop} \times \text{Zst}}{\theta_{\text{op}} \times \theta_{\text{st}}} \]

\[ \text{Zop}, \theta_{\text{op}}: \text{Measured values from open measurement} \]

\[ \text{Zst}, \theta_{\text{st}}: \text{Measured values from short measurement} \]

\[ a = \frac{1}{2} \log \left( \frac{1+R}{1-R} \right) \times 9865.9 \text{ [dB/km]} \]

\[ P = \frac{\sqrt{\text{Zst} \times \text{Zop}}}{\text{X}} \times 1000 \text{ [rad/km]} \]

\[ \phi = \frac{\left( \theta_{\text{st}} - \theta_{\text{op}} \right) \times 2}{\pi} \]

\[ R = \text{P} \times \text{Cos} \phi \]

\[ \text{X} = \text{P} \times \text{Sin} \phi \]

\[ 1: \text{Cable length [m]} \]

Figure 1 ASP Balanced Cable Measurement Program Listing
Figure 2 and 3 shows the results of a calculation using this ASP Program to evaluate the characteristic impedance and attenuation/phase constants of a twisted pair cable (170 m long).

Balun Requirement

- The balun should have flat impedance characteristics over the required frequency range. That is, the variation in insertion loss over the frequency range should not exceed 3 dB.

- The balun's short impedance value \( |Z_o| \) should be as low as possible, approximately one-tenth (or less) the characteristic impedance of the cable being tested. The lower the value of the short impedance, the smaller the additional error will be. For example, if the short impedance of the balun is one-tenth that of the cable, the additional error will be a maximum of 20% of the measurement instruments accuracy (inst. accuracy x 1.2).

- The open impedance value \( |Z_o| \) of the balun, conversely, should be as high as possible, at least ten times greater than the cable's characteristic impedance.

The higher the value of the balun’s open impedance, the smaller the additional error will be.

The sample balun used in Figure 4, HP PN 9100-0855, is sufficient for cable measurements at high frequencies (above 100 kHz).

For low frequency measurements (below 100 kHz), a transformer which has a higher open impedance \( |Z_o| \) at low frequencies should be used. Generally, a transformer's impedance decreases at lower frequencies and the cable's impedance increases, so errors due to \( |Z_o| \) become significant. Transformers which have a higher impedance, such as those used for communications, are recommended.