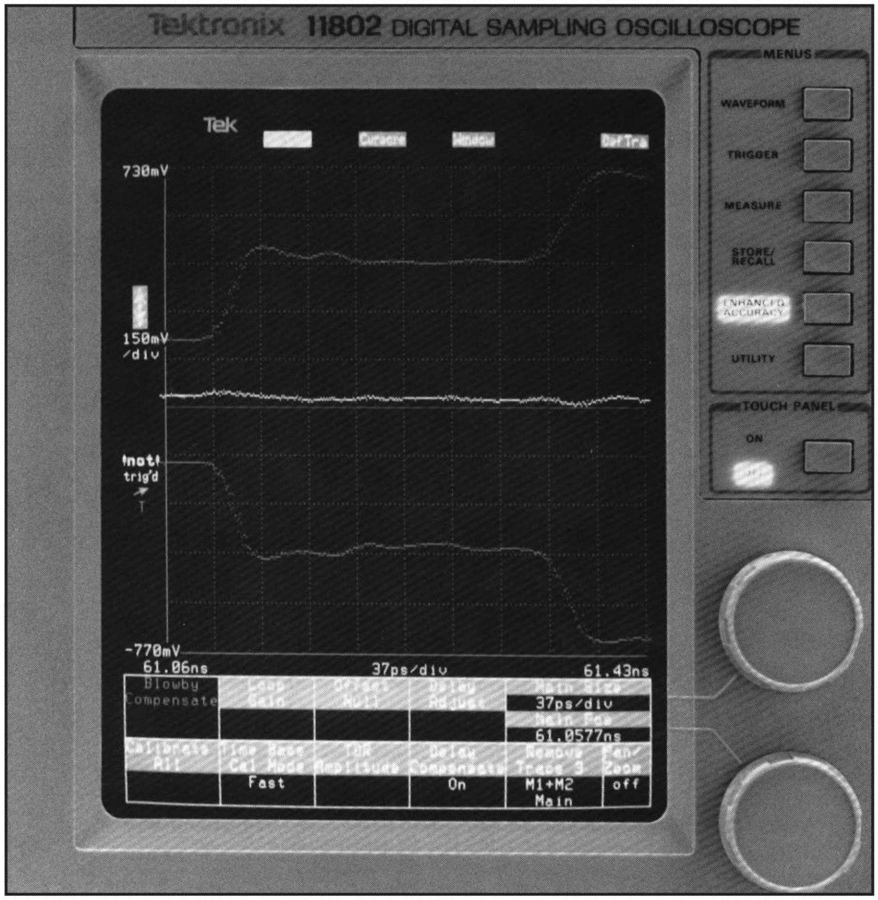
DIFFERENTIAL OHMS MEASUREMENT WITH THE 11800-SERIES OSCILLOSCOPE



The 11800-Series Oscilloscopes are the first to measure impedances in differential systems. Therefore, some precedent must be set in terms of the conventions used while performing these measurements.

There are numerous ways to characterize a differential line. Several typical conventions used in measuring impedance are characteristic impedance, differential impedance, common mode impedance, odd mode impedance, and even mode impedance. Because there is some ambiguity in the definitions of the terms characteristic impedance, differential impedance, and common mode impedance, the 11800-Series Oscilloscopes use the two terms that are more clearly defined; that is, odd mode impedance and even mode impedance. The odd mode impedance of a differential line is one-half of the characteristic impedance or the differential impedance, and the even mode impedance is twice the common mode impedance. These terms will become more intuitive after you review the rest of this technical brief.

You can use a three resistor model to represent the impedances between two conductors of a differential line, and between each conductor and ground. You can use either a pi or tee model because both models have identical terminal characteristics (see Figure 1). Using these models, the differences between the terms characteristic impedance, differential impedance, common mode impedance, odd mode impedance, and even mode impedance are easy to understand.

Note: To simplify the models and concepts, the systems that follow are assumed to be balanced with respect to ground.

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Characteristic impedance (Z_{char}) is a term commonly used by cable manufacturers and buyers and is defined as the impedance between the two conductors when they are isolated from ground. Unfortunately, the term characteristic impedance has a different definition when used in the design of transmission line couplers (and perhaps elsewhere). From the pi and tee models of Figure 1 you can see that removing the conductors from ground causes R_b to disappear from the pi model and R_2 to disappear from the tee model. Figure 2 shows the equivalent pi and tee models when the conductors are not grounded. In this figure, R_{ai} and R_{1i} represent the new values of R_a and R_1 when the conductors are isolated from ground. With these models you can see that the characteristic impedance = R_{ai} (pi model) or $2R_{1i}$ (tee model).

Differential impedance (Z_{diff}) is defined as the impedance measured between the two conductors. Figure 3 shows the equivalent pi and tee models for calculating the differential impedance. With these models you can see that the differential impedance = $R_a||(2R_b)$ (pi model) or $2R_1$ (tee model). In the special case where the conductors are isolated from ground, the differential impedance is equal to the characteristic impedance.

Common mode impedance (Z_{cm}) is defined as the impedance of the two conductors, when the conductors are connected together, relative to ground. Figure 4 shows the equivalent pi and tee models for calculating the common mode impedance. With these models you can see that the common mode impedance = $R_b/2$ (pi model) or $R_1/2 + R_2$ (tee model). You must be careful when using the terms differential impedance and common mode impedance, because for some applications the terms are used differently than described here.

a) pi model b) tee model

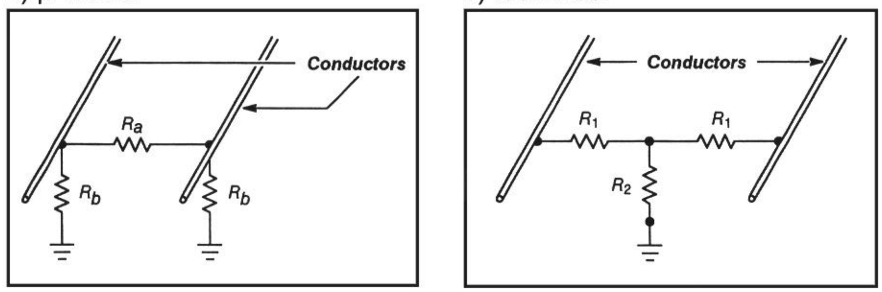

Figure 1. Pi and Tee Models of the Impedance of a Differential Line.

a) pi model b) tee model

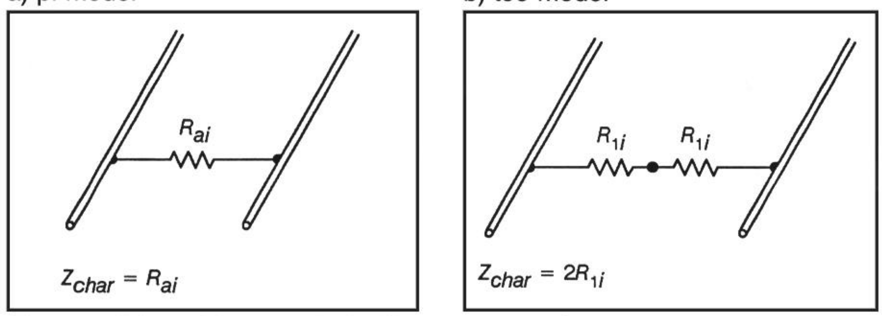

Figure 2. Pi and Tee models for Measuring the Characteristic Impedance

a) pi model b) tee model

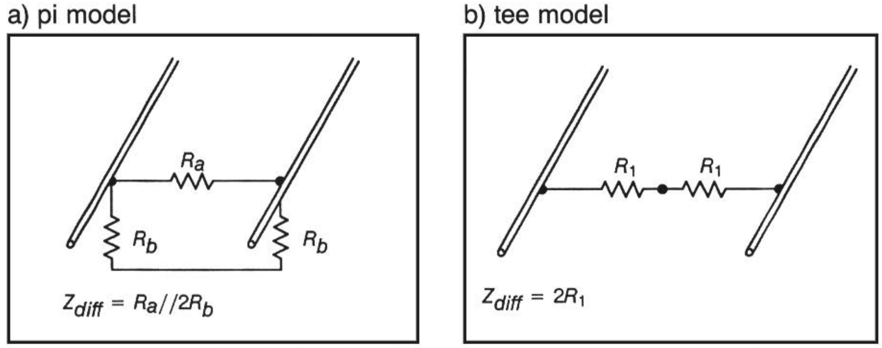

Figure 3. Pi and Tee Models for Measuring the Differential Impedance

a) pi model b) tee model

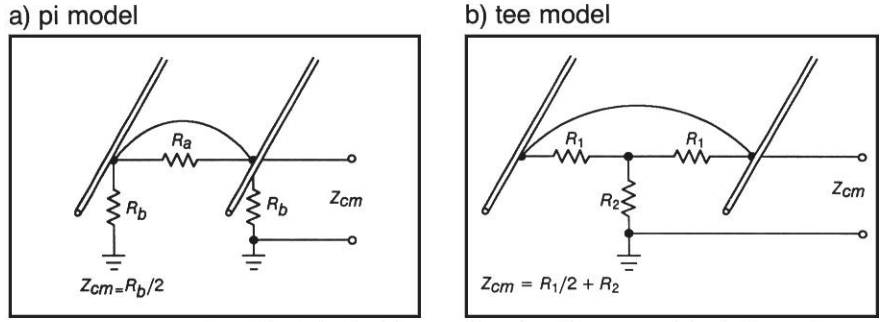

Figure 4. Pi and Tee Models for Measuring the Common Mode Impedance

Odd mode impedance ($Z_{\phi o}$) and even mode impedance ($Z_{\phi e}$) are terms commonly used by designers and users of transmission line structures (particularly in microwave applications). The odd mode impedance is the impedance of either conductor with respect to ground when the pair is driven differentially. Figure 5 shows the equivalent pi and tee models for calculating the odd mode impedance. (The V_g denotes a virtual ground that is created in the circuit when the conductors are driven with differential signals.) Using these models you can see that the odd mode impedance = $(R_a/2)||R_b$ (pi model) or R_1 (tee model). The even mode impedance is the impedance of either conductor when the pair is driven with identical, same-polarity signals. Figure 6 shows the equivalent pi and tee models for calculating the even mode impedance. (The V_o denotes a virtual open circuit that is created when there is no current flowing between two nodes of the circuit.) Using these models you can see that the even mode impedance = R_b (pi model) or $R_1 + 2R_2$ (tee model).

Comparing Figure 5 with Figure 3, and Figure 6 with Figure 4 you can see, as related earlier, that the odd mode impedance is one-half the differential impedance and the even mode impedance is twice the common mode impedance. And, when the differential line is isolated from ground, the odd mode impedance is one-half the characteristic impedance.

When driving the two conductors with two TDR step generators, the 11800-Series Oscilloscopes ohms cursors always display the odd mode impedance if the step generators are of opposite polarity and the even mode impedance if the step generators are the same polarity. This relationship is true whether observing only one TDR waveform or adding (for same-polarity excitation) or subtracting (for opposite-polarity excitation) two TDR waveforms. To obtain the common mode impedance of a balanced differential line you must drive the line with TDR steps of the same polarity and then divide the ohms readout by two. Alternatively, you can connect the two conductors together and drive the system with a single step-generator to obtain the common mode impedance. To obtain the differential impedance or characteristic impedance you must drive the line differentially and then multiply the ohms readout by two. Of course, the differential line must also be isolated from ground to measure the characteristic impedance.

The 11800-Series of Digital Sampling Oscilloscopes are the only instruments available today that can directly measure odd mode impedance and even mode impedance on balanced or unbalanced systems. With the explanation of the terms and concepts given in this technical brief you will now be able to take full advantage of the ohms measurement capabilities in the 11800-Series Oscilloscopes.

a) pi model

b) tee model

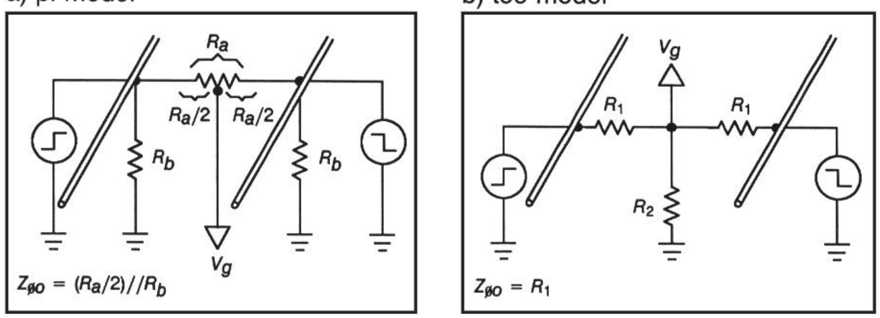

Figure 5. Pi and Tee Models for Calculating the Odd Mode Impedance

a) pi model

b) tee model

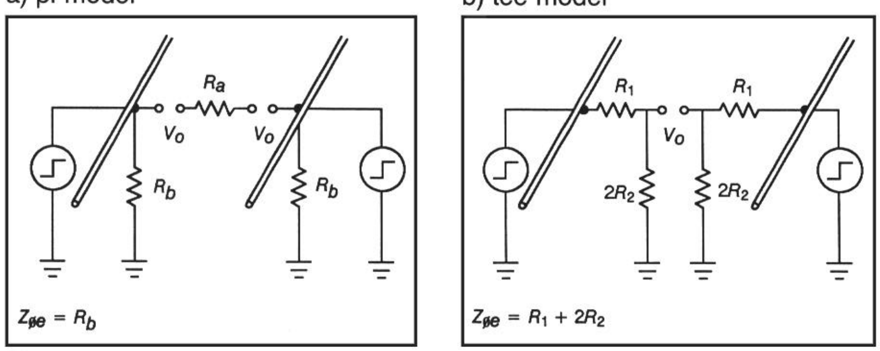

Figure 6. Pi and Tee Models for Calculating the Even Mode Impedance

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