

3. COMMUNICATION CABLE CHARACTERISTICS

OBJECTIVE

To determine the characteristics of twisted pair transmission line as a function of frequency including: characteristic impedance, insertion loss, phase shift, cross-talk, and the effect of a bridged tap or parallel stub connection.

EQUIPMENT

Computer with LabView

Signal Generator HP33120A

Oscilloscope Tektronix TDS 210 with Scope Probes 10x and 1x

UNB Twisted Pair Test Board

Cable Terminations - short circuit, 10 Ω , 100 Ω , 200 Ω

10dB Attenuator

Cable Farm - Category 5 twisted pair cable

3 x 30 m lengths

1 x 10 m length

5 x 1 m length

- Ribbon cable 4 wire (25 m)

Patch Cords - 1 m lengths of Category 5 cable for interconnections

3.5" floppy disk, bring your own

BACKGROUND

Theory of the operation of the twisted pair test board - The test board along with a signal generator, oscilloscope and controlling computer form this instrument. The test board's function is to provide the proper impedance matching between the generator and transmission line as well as converting the unbalanced coaxial signal generator output to a balanced signal to excite the transmission line. From Figure 3.1, one can see that Z_{in} will be 50 Ω to match the signal generator while Z_{out} is 100 Ω to match the category 5 transmission line. The 1:1 transformer converts the unbalanced input to a balanced output. Balance is the symmetry of a two wire transmission line which can be measured as the impedance to ground of each wire. In a well balanced line both wires will have the same impedance to ground while an unbalanced line such as a coaxial cable has the outer conductor grounded and is thus not balanced.

The instrument can be configured for several modes of operation including: impedance measurement, transmission measurement and cross-talk measurement. In the case of an impedance measurement the oscilloscope is connected channel 1 to TP1 and channel 2 to TP2. At each frequency the voltages are measured and the impedance given as

$$Z_{in_2} = \frac{70.71}{2 \frac{V_1}{V_2} - 1}$$

This is the impedance looking into the transformer and does not account for the transformer losses and phase shift. In order to account for transformer effects a two element equivalent circuit is used consisting of elements Z1 and Z2 as shown in Figure 3.2.

The calibration procedure is to measure two known loads and solve for the values of Z1 and Z2 at each frequency. The solution takes the form of a quadratic equation which is solved in LabView as part of the calibration. Once Z1 and Z2 are known the measured input impedance is found as

$$Z_{in} = \frac{Z_1 Z_2 - Z_{in_2} Z_2}{Z_{in_2} - Z_1 - Z_2}$$

In the case of transmission measurements the same excitation is used to drive the transmission line but now the far end of the transmission line is connected back to the test board and match terminated in a balanced load. For this measurement one channel of the oscilloscope is connected to TP1 providing the input signal level and the other channel to the RXD pin which is the output signal level. Alternatively the second channel can be connected to the NEXT and FEXT pins for near and far end crosstalk respectively. A transmission calibration consists of measuring a reference zero length line to account for any internal attenuation and phase shift. The reference measurements are stored internally and removed from subsequent measurements so that only the transmission line characteristics remain.

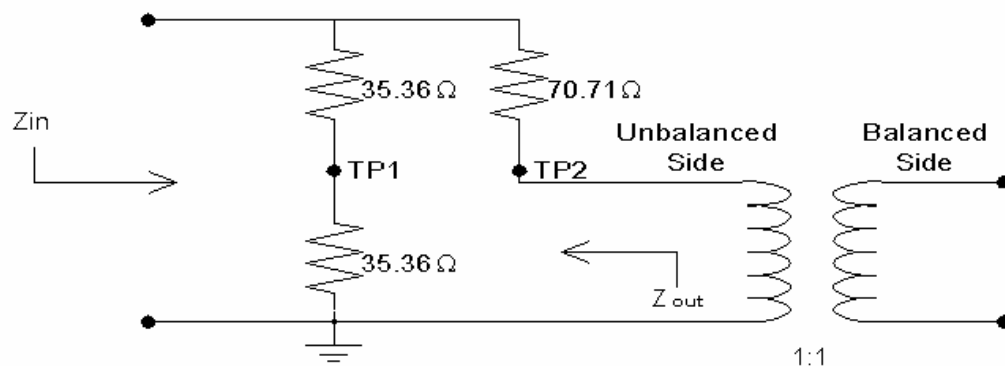


Figure 3.1

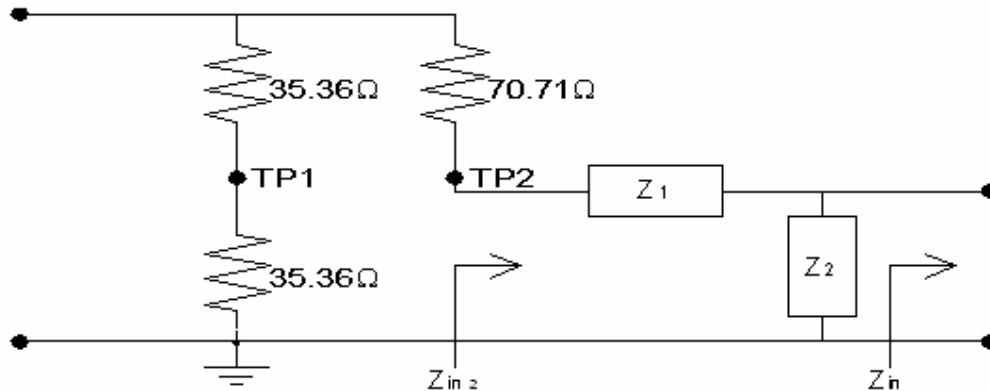


Figure 3.2

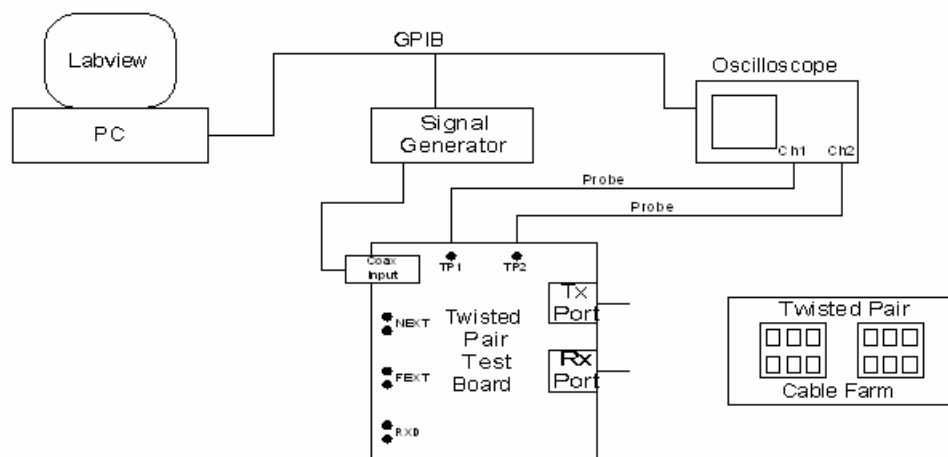


Figure 3.3

INSTRUCTIONS

A. Impedance Measurements

1. Connect the hardware as shown in Figure 3.3. (Will be ready by the lab time)
2. Open the data acquisition software.
3. Select the start and stop frequencies for the measurement, the minimum is 200 kHz limited by the transformer while the maximum is 15 MHz limited by the signal generator. Use the maximum sweep width available (i.e. 200 kHz to 15 MHz).
4. Select the number of data points. An impedance measurement of 100 m of transmission line will require approximately one sample each 150 kHz in order to accurately sample the response. This will provide ten data points over each cycle of the measured waveform. Longer lines will require more samples to accurately obtain these waveforms. Using more samples requires more time and since this acquisition process becomes long we will use only 80 samples.
5. Averaging will cause the oscilloscope to take multiple samples and average them

- for improved accuracy. This operation delays data acquisition significantly when a large number of samples are averaged therefore use averaging of 4.
6. Run the program by selecting the arrow in the upper left of the window tool bar.
 7. Follow the instructions for **Calibration** which will require placing a $10\ \Omega$ resistor standard on the test board Tx Port followed by a $200\ \Omega$ resistor. These measurements are used to solve for the equivalent circuit of the transformer.
 8. In order to verify the calibration of the instrument it is necessary to measure a known impedance. For this use a $100\ \Omega$ termination and view the results to make sure they are within 10 % of the expected impedance. If the results are not acceptable then repeat the calibration. Now the system is ready to measure unknown impedances over the selected frequency range. If you want to use other frequency limits or number of samples it will be necessary to recalibrate.
 9. Assemble a 100 m length of transmission line, terminate it in $100\ \Omega$ and measure the input impedance. The impedance magnitude should decrease with frequency at low frequencies and then become a stable $100\ \Omega$. Save this data to disk as **zin8**.
 10. Determine the transmission line properties by measuring the input impedance of an approximately 100m length of line with the end open circuited then short circuited. Record this data as **zioc9** and **zisc9**.
 11. A bridged-tap occurs on twisted pair lines when a second transmission line is connected in parallel with the first, as in the case of an extension phone. To create this situation in the lab start with a 30 m line and use the splitter provided to connect to another 30 m line and to a 10 m line as shown below. Match terminate the 10 m line and leave the 30 m line open circuited as shown in Figure 3.4. Measure the input impedance of this line over the 200 kHz - 15 MHz band and record as **zin10**.

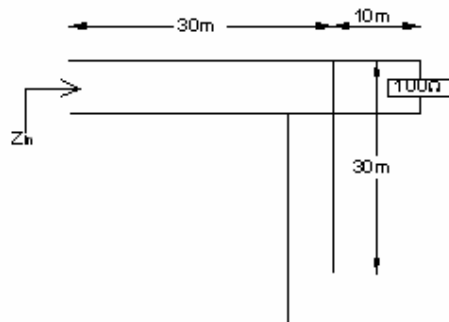


Figure 3.4

Note: Insertion Loss and Attenuation - There is a subtle difference between insertion loss and attenuation that you should be aware of before continuing in the laboratory. When measuring transmission line loss it is common to use a signal generator at one end of the line and some form of detector at the other end. The generator and detector each have an impedance that may or may not be equal to the characteristic impedance of the transmission line being measured. the general case of this type of measurement is insertion loss where the generator and detector impedances don't necessarily equal the transmission line characteristic impedance and part of the loss will be the result of

reflections at the generator transmission line interface and at the transmission line detector interface. Under conditions where the generator and detector impedances are equal to the transmission line characteristic impedance then there will be no reflections and the insertion loss becomes the line attenuation.

B. Insertion Loss and Phase Shift

1. For these measurements it will be necessary to move the oscilloscope channel 2 probe to the RXD pins of the test board. Use the insertion loss/phase shift software in LabView and again setup the frequency range and number of data points.
2. Calibration is achieved by connecting a zero length line (short length of cable) between the input and output ports and measuring the insertion loss and phase shift of the equipment alone. This measurement is saved internally and will be removed from all subsequent measurements in order to correct for system errors.
3. Verification is achieved by measuring another known which in this case is a 10 dB attenuator which should measure within 0.5dB.
4. Measure the insertion loss and phase shift of a 100 m length of line and verify that the attenuation at 10 MHz is 6.5 dB or less. A velocity of propagation of 2×10^8 m/s results in a wavelength of 20 m at the 10 MHz operating frequency. This makes the transmission line five wavelengths long or 1800° . In order to verify that there are five cycles of the waveform on the transmission line it will be necessary to examine the phase data from the start frequency of 200 kHz, where the wavelength is 1000 m, up to 10 MHz. By counting the number of discontinuities or “phase jumps” in the data the number of cycles on the line can be determined. Allowing for a 10% error in phase would result in acceptable measurements being within $\pm 180^\circ$ of the expected 1800° phase shift.
5. Record the insertion loss and phase shift of 100 m of transmission line in the file **trans5**.
6. Connect the bridged-tap circuit as in Part A but now replace the terminated end with the detector for this two port measurement. Record the transmission response of this transmission line in the file **trans6**.

C. Cross Talk

1. These measurements are similar to Part B except that now one twisted pair is driven with the signal generator while the output of another pair is measured. To do this move the oscilloscope channel 2 probe from the RXD pins to the NEXT pins. Because the signal level is low it will be necessary to use a x1 oscilloscope probe.
2. Connect 100 m of cable between the signal generator and the RX port and record the near end cross talk (NEXT) as a function of frequency in the file **next2**.
3. Connect 25 m of ribbon cable between the generator and the RX port, record the NEXT in file **next3**.

PROJECT

The objective is to simulate the above transmission line measurements using MATLAB and classroom theory and compare the simulated and measured results.

1. From Part A plot the input impedance of the line from file zin8 which contains three columns of data as follows: frequency, real (impedance), imaginary (impedance). Plot the absolute value of the impedance versus frequency. Why is the impedance higher at the low frequency end of the sweep? The specified impedance from 1 MHz to 100 MHz is given as $100 \Omega \pm 15 \Omega$. Compare the measurements with the specifications by drawing the specification limit lines on the input impedance graph.
2. Determine the transmission line properties (R, L, C, G) at each of the measured frequencies by using **zisc9**, **zioc9** and the equations at the end of laboratory exercise 1. Plot the four property values as functions of frequency. Are these values frequency dependent? Why or why not? Is the lumped parameter model a good choice for this transmission line simulation?
3. Use the transmission matrix and MATLAB to simulate the bridged-tap transmission line configuration. Plot the input impedance on the same graph as the measured results and compare them. What effect does the bridged-tap have?
4. The file **trans5** contains the insertion loss and phase shift information of 100 m of cable. Plot the insertion loss of the line as a function of frequency and compare to the maximum specified values of attenuation given as

1	MHz	2.1 dB/100 m
4	MHz	4.3 dB/100 m
8	MHz	5.8 dB/100 m
10	MHz	6.6 dB/100 m
16	MHz	8.2 dB/100 m

Is this cable within specification? For distortionless transmission the attenuation must be independent of frequency. Is this transmission line distortionless over the measured frequency band? Is it distortionless over a portion of the band? Use the transmission matrix model of part 3 above to determine the insertion loss of the line over the band. The insertion loss of the line is given by

$$IL = \frac{AZ_L + B + CZ_S Z_L + DZ_S}{Z_S Z_L}$$

where A, B, C, D are from the transmission matrix, Z_S is the source impedance, 50Ω , and Z_L is the load impedance, 100Ω . Plot these results on the same graph as the measured results. Why are they different?

5. Extract the phase information from the **trans5** file and plot the results as a function of frequency. For distortionless transmission the phase shift must be a linear function of frequency. Compare the measured phase to the ideal by plotting a straight line through the measured data. It will be necessary to remove the phase

- jumps from the data set which can be done using the MATLAB function “unwrap”. Is this transmission line distortionless over the measured frequency band? Is it distortionless over a portion of the band? Use the transmission matrix model of part 3 above to determine the phase shift of the line over the band. Plot these results on the same graph as the measured results. Why are they different? What is the velocity of propagation on this transmission line at 10 MHz? Is the velocity of propagation a function of frequency?
6. Plot the insertion loss and phase shift of the bridge-tapped line and comment on the distortion caused by the tap. Would it make a difference if the tap line were shorted, opened or match terminated? Simulate the bridged-tap line configuration using the transmission matrix then plot the insertion loss and phase shift as a function of frequency for the three cases.
 7. Plot the near end cross talk (NEXT) as a function of frequency and compare it to the given minimum levels specified by the manufacturer (category 5)
 - 1 MHz 62 dB
 - 4 MHz 53 dB
 - 8 MHz 49 dB
 - 10 MHz 47 dB
 - 16 MHz 44 dB

Does this cable meet specifications? Why is NEXT an important cable characteristic?