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Phy 462

Electrical Waves and Impedance Matching

Introduction:

In a given system, the propagation of waves is characterized by the impedance of the particular medium. An interface between two media with different wave impedances, Z_1 and Z_2, will cause a traveling wave propagating along medium 1 to be partially reflected from the interface with medium 2. This reflection process is described by the following expression:

$$\Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1}, \tag{1}$$

where Γ is a complex quantity relating the amplitude and phase of the reflected wave. When $Z_2 = Z_1$, $\Gamma = 0$ and there is no reflection. In this case, the system is said to be impedance matched. Thus, to deliver the maximum power to a particular load, the characteristic impedance of the transmission line must be matched to that of the load.

Objectives

- Use a pulse propagation technique to measure the velocity of wave propagation along a coaxial cable.
- Learn about the characteristic impedance for a transmission line.
- Characterize impedance mismatches by measuring pulses reflected from the mismatch interface.
- Learn about the behavior of a microstrip transmission line.
- Fabricate a microstrip line to achieve a particular impedance.

Suggested Reading: Read a treatment of coaxial cables in an electromagnetism textbook, such as Griffiths, *Introduction to Electrodynamics*. Read about impedance matching in a microwave engineering text, such as *Planar Microwave Engineering* (Cambridge), by T.H. Lee.

Suggested Apparatus:

1. Agilent arbitrary waveform generator, 33250A
2. Digital oscilloscope – the 2-channel Instek scopes are sufficient
3. Mini-circuits power splitter, ZFRSC-42
4. BNC-SMA adapters, BNC cables (several lengths), 50Ω terminators
5. Circuit board pieces and SMA connectors for microstrip fabrication

Instructions - Investigating arbitrary waveform generator This instrument can output various waveforms, including narrow pulses or arbitrary shape.

- Connect to oscilloscope with 50 Ω terminator and BNC tee.
- Try outputting continuous waveforms – vary frequency, amplitude.
- Next try generating pulses – set amplitude, pulse height, width, edge time.
- Explore the behavior of the sync signal and its possible use for triggering the scope.

Instructions - Power splitter

- Connect one side of power splitter to output of arbitrary waveform generator.
- Connect each of the other two ends to separate channels on the oscilloscope, each with terminators. Observe the two signals on the scope and compare with the output of the generator.
- Switch the order of the connections on the splitter and observe the results.
- Disconnect one of the cables from the splitter to the scope and observe the result on the remaining scope channel. Attach a terminator directly to the connector on the splitter which is now free and observe the result.
- Discuss the power splitter with the instructor and sketch out a possible configuration for the routing of the signals inside the splitter.

Instructions - Reflections; measuring velocity Before starting these measurements, compute the impedance and propagation velocity on a BNC coaxial cable. Next, you will measure the propagation velocity directly.

- With the output of the arbitrary waveform generator attached to one port of the splitter and another port connected to the scope with a terminator, attach a long BNC cable to the remaining terminal. Attach a terminator to the free end of the long BNC cable.
- Send narrow pulses from the generator and observe the signal on the oscilloscope.
- Remove the terminator from the end of the long BNC cable and record the resulting waveform from the oscilloscope. Try varying the pulse width from the generator and record the result.
- Try at least five different lengths for the BNC cable and for each one, record the shape of the resulting waveform from the oscilloscope. Compute the delay of the pulse that travels along the long BNC cable. Be sure to account for the complete path taken by the, including the number of times it passes through the splitter.
- Plot the time delay of the pulse against the relevant length based on the free BNC cable, and use this to determine the propagation velocity on the coaxial cable. Compare with your expected value and describe any anomalies.

Instructions - Characterizing impedances In this section, you will explore the influence of the particular termination at the end of the free BNC cable on the nature of the reflected pulse. Send pulses through the splitter arrangement from the previous section using a long enough BNC cable to allow the outgoing and reflected pulses to be resolved. Try attaching the following impedances onto the end of the free BNC cable:

- 50 Ω terminator
- Open circuit (as in previous section)
- Shorting cap
- Resistors soldered from the signal to ground of a BNC bulkhead connector. Try at least one resistor somewhat above 50 Ω and one somewhat below.

- Inductor soldered from the signal to ground of a BNC bulkhead connector.
- Capacitor soldered from the signal to ground of a BNC bulkhead connector.
- Microstrip line(s) (see below)
- In each case, use the measurement of the reflected pulse waveform and the previously calibrated outgoing pulse waveform to compute the impedance at the end of the long BNC cable using Eq. 1. The discussion in the Lee microwave textbook is particularly relevant here.

Instructions - Microstrip lines

- Compute Z for different microstrip geometries
- Using a razor blade, cut out the copper on the circuit board pieces to produce a microstrip line. Solder SMA launchers onto either end of the board.
- Observe the reflected waveform and interpret this in terms of the computed Z and your previous measurements of various terminating impedances.