THE UNIVERSITY OF BRITISH COLUMBIA
Department of Electrical and Computer Engineering

EECE 411 - Antennas and Propagation
Fall 2016

Problem Set 1 - Vector Network Analyzers

When one is asked to evaluate the terminal characteristics of an antenna, a vector network analyzer is an essential piece of test and measurement equipment. The purpose of these twelve review questions and ten problems is to help you master the principles of vector network analyzer function and operation. In all cases, answers should be short and to the point. Clarity, conciseness, and presentation all count.

Review Questions

1. How does a vector network analyzer detect the power reflected from a DUT (device under test)?
2. Why does a vector network analyzer sample the power incident from the RF source?
3. Why are S-parameters a particularly useful way to represent the response of two-port devices at RF and microwave frequencies?
4. When measuring S_{11} or S_{22} of a two-port device, what should be done to the free port?
5. What is group delay? Why is the group delay of a TEM transmission line constant with frequency while the group delay of a waveguide or filter is not?
6. How can one recover the true impulse response from that obtained by taking the inverse Fourier transform of a frequency response of finite width?
7. Describe a circumstance under which time domain gating might be useful.
8. What does Foster's reactance theorem teach us about the manner in which a plot of impedance traverses the Smith chart?
9. What three types of errors affect measurement accuracy? What are the recommended methods for dealing with each?
10. What does SOLT stand for?
11. What three calibration options are typically given by vector network analyzer? When would each be employed? What are the calibration steps in each case?
12. What is the twelve-term error model?

Problems

1. *Smith Chart.* An embedded systems programmer has written a routine that draws a conventional Smith Chart on a computer display with $R/Z_0 = 1$ at the origin and $R = 0$ mapped onto the unit circle. Derive an expression which the programmer can use to determine the screen coordinates at which to plot an arbitrary impedance Z. What sort of valid data checking might one recommend that the programmer include?

2. *Signal Flow Graphs.* Draw the signal flow graph representations of the following standard components. Explain why the signal flow graph concept is useful in RF/microwave circuit analysis.

   (a) a matched load;
   (b) a short circuit;
   (c) an open circuit;
   (d) an ideal transmission line of length 0;
   (e) an ideal transmission line of length $\lambda/4$.

3. *Transformation of S-parameters with Line Length.*

   (a) Given a two-port device with known S-parameters, derive an expression for the S-parameters one would measure with a vector network analyzer if one were to attach transmission lines of length ℓ_1 to port 1 and ℓ_2 to port 2.
   (b) Given measured S-parameters, derive the correspoonding expression that will allow us to recover the true S-parameters in the above case.

4. *Transformation of S-parameters with Frequency.*

   (a) A short-circuit is attached to the calibration plane of a vector network analyzer. On a Smith chart, sketch the manner in which S_{11} varies over the frequency range 1-2 GHz.
   (b) A short-circuit is attached to a 30-cm length of RG-58/U coax that is attached to the calibration plane of a vector network analyzer. On a Smith chart, sketch the manner in which S_{11} varies over the frequency range 1-2 GHz.

5. *Vector Network Analyzers.* Sketch and label a block diagram of a typical vector network analyzer. Explain the function and operation of the VNA.

6. *Applications of Vector Network Analyzers.* Describe and explain various ways in which an engineer might use a vector network analyzer to characterize an antenna or wireless link.

7. *Novel Applications of Vector Network Analyzers.* If the S-parameter test set is removed or bypassed, a vector network analyzer can be configured for use as a general-purpose dual-channel receiver. One possible application of such a receiver is to measure the polarization state of an incoming wave. Explain how this would work.

8. *Sources of Error in Vector Network Analyzers.* Define and explain the significance of the following sources of error in vector network analyzer measurements:

   (a) directivity error;

   (b) tracking error;

   (c) source match error.

9. *One-Port Error model.* The one-port error model described in class is a subset of the full twelve-term error model. It applies to impedance measurements made using a single port of a vector network analyzer. Given measurements of the reflection coefficients of a matched load, short circuit, and open circuit, find an expression that will allow one to recover Γ_A from Γ_M in the general case.

10. *Resonant Circuits.* Consider a parallel resonant circuit with inductance $L = 1\ \mu$H, capacitance $C = 3$ pF, and resistance $R = 75\ \Omega$. It is attached to a vector network analyzer through a section of 50-ohm coaxial cable.

    (a) Assume that the calibration plane is located at the point at which the resonant circuit is attached to the cable. Derive an expression for S_{11}. Use MATLAB to evaluate the response over the range from 10 MHz to 1 GHz. Plot the result on a Smith chart. Find the minimum value of Γ.

    (b) Repeat the above for the case where the resonant circuit is connected to the calibration plane by a 1-metre length of RG-58/U coax.