INTRODUCTION TO MICROWAVE MEASUREMENTS: DETECTION OF RF POWER AND DEVELOPMENT OF A SCALAR REFLECTOMETER
Lab #2

   The purpose of this lab is to become familiar with the use of dual-directional couplers and diode detectors to make basic RF/microwave measurements. A scalar reflectometer, which is suitable for measuring |Γ| of an external device under test (i.e. a device that is not part of the measurement set-up itself), will be constructed in the lab and used to characterize simple microwave components.

   The experiments in this lab fall into two main sections. In the first, we investigate the behavior and performance of a diode detector for detecting microwave power. The second part of the lab utilizes detectors of this type, along with a dual-directional coupler and digital multimeter, to make a simple reflectometer to measure the reflection coefficient of components or circuits. Please review the demonstration video before coming to lab; it shows some of the key concepts we'll need for the lab.

Reminder: as you go through this lab, be sure to take notes in your lab notebook about what you are doing, how you are doing things, what devices you have measured, what data vector and filenames you use, etc.

Detection of Microwave Power:
   A fundamental requirement for nearly all microwave measurement techniques is a means for detecting microwave power. Most microwave detection schemes fall into one of two categories, so-called "square-law" detectors and heterodyne systems. Heterodyne detection is referred to as linear detection since the output of the detector in this type of system is directly proportional to the RF voltage (including phase) applied to the detector. Heterodyne systems are the basis for phase-sensitive measurements and communication systems, but can be complicated to implement. Square-law detectors, on the other hand, are very simple but produce detector outputs that are proportional to the square of the applied RF voltage, and thus the detector output is proportional to the microwave power. Phase information, however, is lost. Common square-law detectors in use for low-level RF power include diode (sometimes also called "crystal") detectors, bolometers, and thermistors. Properly calibrated, thermistors are useful for absolute measurement of power; however, in many applications of practical interest, it is sufficient to measure the ratio of the power between two or more different signals; this can be done without extensive calibration. The range of power levels that can be accurately measured with square-law detectors is limited at the low end by detector and circuit noise, and at high power levels by deviations from square-law behavior due to non-linear effects. In this experiment, the response of a diode detector (in this case, a GaAs Schottky diode) will be evaluated.

   a. Being careful to use correct technique for mating the connectors (be especially careful not to let the center pin rotate during connection), connect the large type-N connector on the detector to the E4421B signal generator's RF output port. Set the signal frequency to 1 GHz without modulation. Using a standard BNC cable, connect the DC output of the detector to the HP3455 DMM, in DC voltage mode.

   b. For a square-law detector, the detector's DC output voltage should (ideally) be proportional to the square of the input RF voltage, or (equivalently) directly proportional to the input RF power. To check that everything is working as expected, spot-check this by setting the signal generator power level to a few different power levels in the range from -50 dBm to +10 dBm, and check the detector output voltage. Since power in dBm

is given by $10*\log10(P_{out}/1\ mW)$, a linear change in P_{out} (in dBm) should result in an exponential change in the detector output voltage. Note: due to the polarity of the diode in our detectors, the output voltage will be negative. That's OK.

c. To be more quantitative, we want to investigate the power dependence of the detector output voltage. To help with the data collection, a Matlab script is available from the course website (psweep.m). This script will ask you for a start power (in dBM), a stop power, and the number of points, and will return the Matlab vectors of the power and detector voltage. Running "[x,y]=psweep;" will set the signal generator frequency to 1 GHz, and return the power values (in dBm) in the vector x and the measured detector voltage corresponding to each power value in the elements of the vector y. For microwave powers from -50 dBm to 10 dBm, use this script to measure the detector output voltage vs. microwave power, and plot the results on a semilog scale (linear x axis = microwave power in dBm, logarithmic y axis = |detector voltage|). Be sure to record the results in your notebook.

d. From this plot, determine the square-law region (the range of input powers for which the detector exhibits square-law operation; this is the region where the semilog plot in part (c) is linear). For most measurements, it is important to operate the detector in this range to avoid distortion. A key performance parameter for a detector is its sensitivity (i.e., the conversion factor from RF power in to DC voltage out, in V/W). From your measured data, estimate the sensitivity in the square-law region, and indicate this (along with your plot) in your lab notebook.

Scalar Reflectometer:

Measurement of impedance at microwave frequencies fundamentally depends on the ability to measure incident and reflected signals from a device under test. For measurements of scalar quantities (e.g. $|\Gamma|$, without phase information), this problem reduces to measuring magnitudes of incident and reflected microwave power. As seen above, a diode detector can be used to measure microwave power. To implement a full scalar reflectometer requires a means to separate the forward- and reverse-traveling waves that are present in a transmission line so that the power carried by these waves can be measured separately. This separation can be accomplished in practice by using a directional coupler. Directional couplers are passive, transmission-line based devices that implement this separation of forward and reverse waves through multiple weakly-coupled sections of transmission line; the undesired component (forward or reverse) is caused to interfere destructively with itself in the multiple coupled sections, causing only the desired component to remain on the coupled line. A modification of the directional coupler is the dual directional coupler; this device is functionally identical to the directional coupler, except that it isolates both the forward and reverse waves, routing them to separate ports on the device. A schematic diagram of a dual-directional coupler is shown below, with the input/output ports labeled.
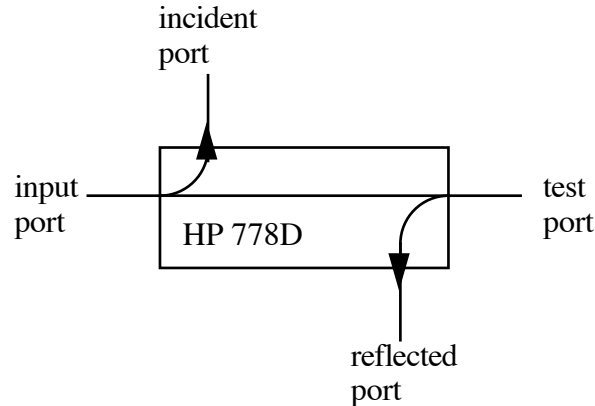
        In this device, (nearly) all of the power applied to the input port is coupled to the test port,
with the exception of a small amount of the forward-traveling wave, which is transferred to the
"incident" port. Likewise, all of the power applied to the "test" port is coupled back to the input
port, except for a small amount of the reverse-traveling wave which is coupled to the "reflected"
port. The coupling factor of a coupler indicates the fraction of the power that is tapped off of the
main line (between the input and test ports) into the incident and reflected ports. For the HP
778D coupler, the coupling factor is 20 dB. Thus a signal observed at the "incident" port is 20
dB (a factor of 100) lower than the forward-traveling portion of the signal present at the input
port. Likewise, a signal observed at the "reflected" port is 20 dB smaller than the reverse-
traveling portion of the signal present at the "test" port. This, in conjunction with the power-
measuring capabilities of a diode detector, can be used to make a simple reflectometer.

   a. Connect the equipment in a scalar reflectometer configuration as shown in the figure
       below. Although reflection measurements can be done at a single frequency, it is usually
       more useful to sweep the frequency of the source over a range of frequencies and record
       the reflection coefficient as a function of frequency. To facilitate the data collection
       process, a Matlab script (srefl.m) is available to control the instruments and collect the
       data. Running the script "[x,y]=srefl;" will prompt you for a start frequency, stop
       frequency, and number of points, and returns two vectors; x is the frequency vector and y
       is the vector of measured DC voltage values from the detector (it is best to choose more
       descriptive variable names).
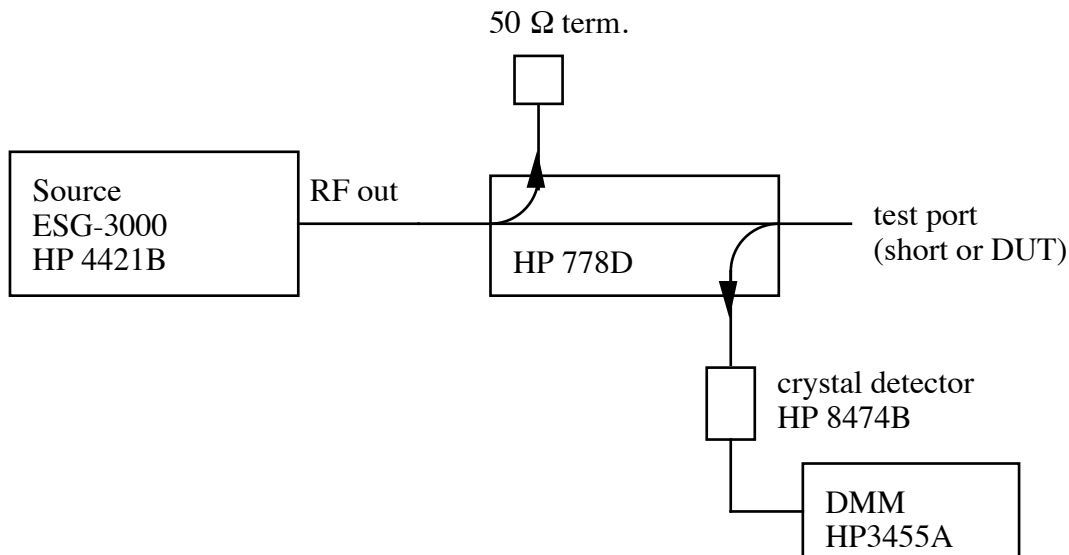
b. Connect a short to the test port, and run the "srefl" script using descriptive variable names to avoid confusion (you'll need to use this data later in the lab). Choose a start frequency of 100 MHz, a stop frequency of 3 GHz, and about 100 points (117 points will give you data every 25 MHz). Plot the results, and include it in your lab notebook. Comment in your lab notebook about the "expected" result for this measurement, and explain any deviations from this expected behavior that you observe.

c. Replace the short termination with the "microstrip stub" circuit, with a 50 Ω termination on the "far" end of the microstrip stub circuit during the measurement. Measure (using the srefl.m script) and plot the reflection vs. frequency response that results for a frequency sweep from 100 MHz to 3 GHz for the microstrip stub circuit, and make a note of the detector voltages at 500 MHz, 1000 MHz, 1500 MHz, and 2500 MHz. Remember to document everything in your notebook.

d. In your lab notebook, derive a formula to find the return loss (in dB) from the data collected in parts (b) and (c) above. Note that the detector voltage vs. frequency for a short termination (whose reflection coefficient is known to be -1, at least ideally) gives you the ability to correct for any variations in source output power or directional coupler performance with frequency. From the data collected in parts (b) and (c), use Matlab to compute the return loss (in dB) of the microstrip stub circuit at each measurement frequency, and tabulate and plot the results as a function of frequency.

e. As was noted above, for measurements based on diode detectors it is important to make sure the detector is operating (as much as possible) in the square-law region. The "srefl.m" script sets the signal generator output power to +10 dBm. Does that match with the square law region for your detector? Be sure to consider the coupling factor of the directional coupler in your analysis.

f. Have a look at your return loss results. Do the results look reasonable, or is there anything that seems surprising or that does not match your expectations? Be sure to document your observations in your lab notebook.