WAVE PROPAGATION II: HIGH FREQUENCY SLOTTED LINE AND REFLECTOMETER MEASUREMENTS

OBJECTIVES:
> To build greater familiarity with transmission line concepts; to observe, measure and analyze the voltage standing wave ratio (VSWR) and reflection coefficient associated with various transmission line terminations; to measure **directly** the attenuation of electromagnetic waves propagating in lossy media.

EQUIPMENT:
> Hewlett-Packard, Model 8648C, Signal Generator (9 kHz-3.2 GHz)
> Tektronix, Model 2213A, 60 MHz Dual-channel oscilloscope
> 2-Hewlett-Packard, Model 805C, Slotted Lines (one modified to contain fluids)
> Hewlett-Packard, Model 766D, Dual Directional Coupler
> Hewlett-Packard, Model 536A, Frequency Meter
> 2-Stanford Research Systems, Model SR560, Low-noise Preamplifiers
> General Radio, Type 874-VQ, Voltmeter Detector
> Bird, Model 74, Coaxial Switch
> Mounts for 1N21B and 1N23B microwave crystal diodes
> Miscellaneous coaxial components *viz.* UHF Rigid (RG-44/U), GR Type 847 and
>   Type N coaxial components, connectors, terminations and adapters

1. SLOTTED LINE VSWR MEASUREMENTS:

EXPERIMENTAL SETUP
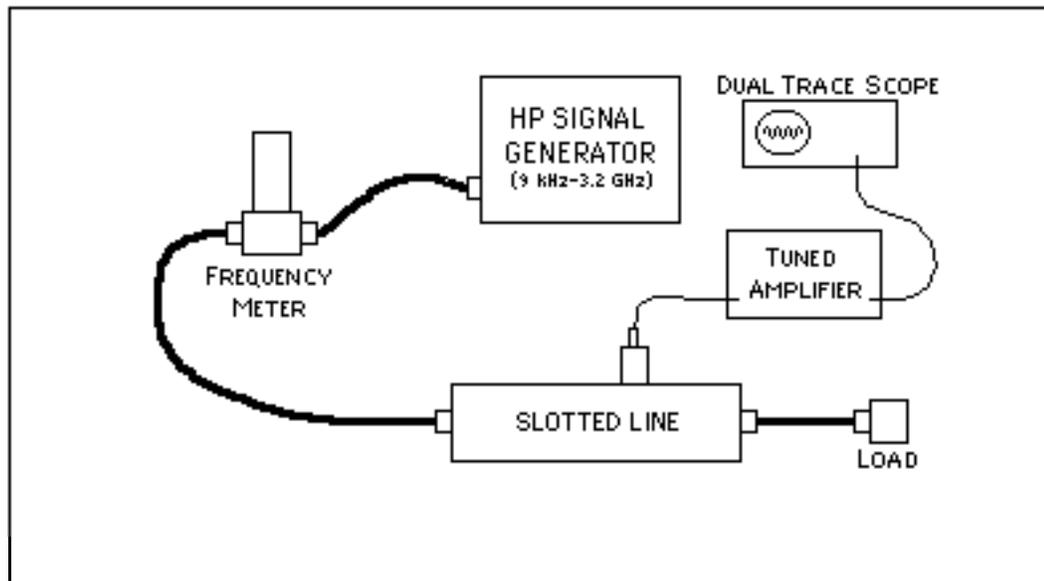
Measurements and observations:
> Slotted line measurements are of critical importance in the design and testing of high frequency (sub-optical) communication systems. Here a HP (Hewlett-Packard) section of slotted line is used as a means to determine impedances values at frequencies in the 0.5 to 4 GHz range. Before starting your experiments, inspect one of these devices and you will note that there

is a wire probe which penetrates into the region adjacent to the center conductor of the "slotted" coaxial line. This probe is essentially a receiving antenna which picks up the transverse component of the propagating electric field at that particular position. The field parallel to the probe induces a voltage along the wire which is impressed across an internal crystal diode/low-pass filter network (see sketch below). Thus, if a modulated signal is propagating along the slotted line section, a small fraction of that signal is picked up by the probe and demodulated by the rectifying network (Remember the demodulation setup in Computer Laboratory 1?).   The modulation envelope is available for measurement as a voltage output from the device's BNC output connector. By tracing the spatial dependence of the modulation, one may directly determine the wavelength and the VSWR.
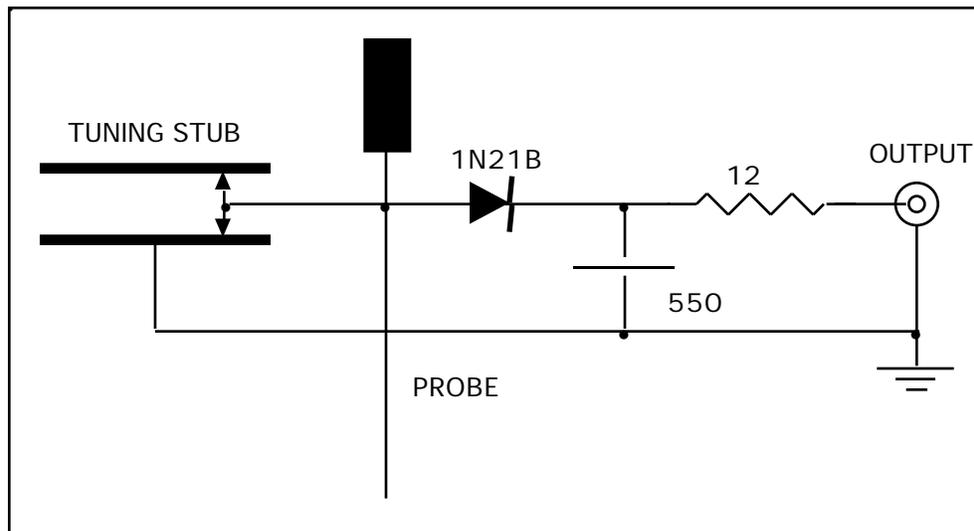
To start your measurements, excite the coaxial circuit, illustrated above, with a modulated signal from the HP Signal Generator (*e.g.* a 1.4 GHz carrier modulated at 1 KHz). Observe the modulation of the propagating signal by displaying the amplified output of the HP Slotted Line device on the dual trace scope. Measure the VSWR as well as the locations of maxima and minima for the following loads[†] (See comments below on the use of the "substitution" method):

a. A short-circuit (GR Termination 874-WN).   This measurement establishes the all important reference length to be used in all the measurements that follow.

b. An offset short-circuit (GR Termination 874-WN3). Compare result with that found for GR Termination 874-WN.

c. An offset open-circuit (GR Termination 874-WO3)

d. A 50 termination (BNC 50 Termination).

[†]   From the operating manual of the slotted line: "A general rule in slotted line work is that the penetration of the sampling probe into the line should be held to a minimum. Since the sampling probe must extract power from the line in order to supply the detector and indicating device, it is to be expected that the probe can have an effect on the fields within the line" and "…that this effect is usually greater as the penetration is increased." You may find it helpful to look through the operating manual which has other hints on good measurement techniques.

    e. An unknown termination (??? is a secret homemade element: **don't peek inside**!).

    f. A shorted coupling capacitor (GR Coupling element 874-K plus GR Termination 874-WN).

    g. An adjustable stub (GR Adjustable line/stub 874-D20l) as a function of length.

    h. A resonator: (GR Adjustable line/stub 874-D20l in parallel with shorted GR Coupling capacitor 874-K) observe resonance and measure VSWR at resonance.

Report:

    a. A complete graph of modulation amplitude *vs.* position **for one particular load value**.

    b. The VSWR and the reflection coefficient (magnitude and phase) associated with **each** of the terminating loads.

    c. Using a Smith Chart, find the impedance associated with **each** of the terminating loads.

    d. Compare the frequency setting of the HP Signal Generator and values measured by means of the slotted line and the HP Frequency Meter.

2. REFLECTOMETER MEASUREMENTS:

EXPERIMENTAL SETUP
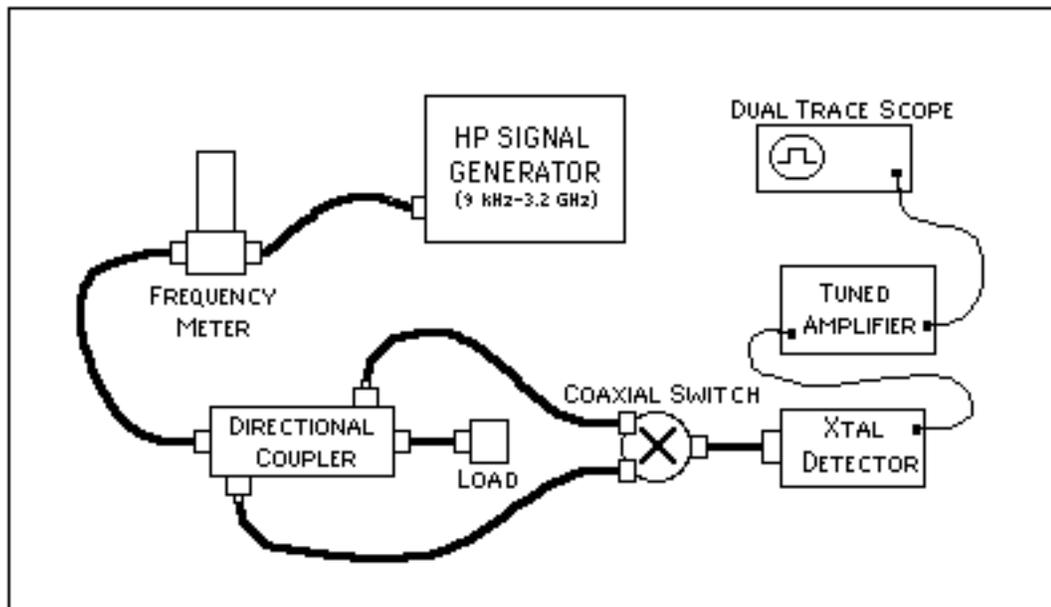
Measurements and observations:

Reflectometer measurements are also of critical importance in the design of communication systems and, particularly, in the evaluation of optical communication links. In our observations, we make use of a HP Dual Directional Coupler as the key element of a coaxial reflectometer. In a directional coupler, a small fraction (-20dB in this case) of a signal propagating through the device in a <u>particular direction</u> is coupled into a separate output channel. In the HP Dual Directional Coupler a fraction of

the "right moving" component of the signal is coupled to one of the output channels of the device and the same fraction of the "left moving" component of the signal is coupled to the other channel. Thus, by measuring the ratio of the two outputs, one has a direct measure of the **magnitude** of the reflection coefficient of waves traveling through the device. When a crystal mount (*viz.* an integrated crystal diode/low-pass filter network) is sequentially connected to the output channels of the coupler, the ratio of modulated signals can be measured directly by comparing the attenuator settings required to observe equal signals on the oscilloscope (see comment below on "substitution" method).
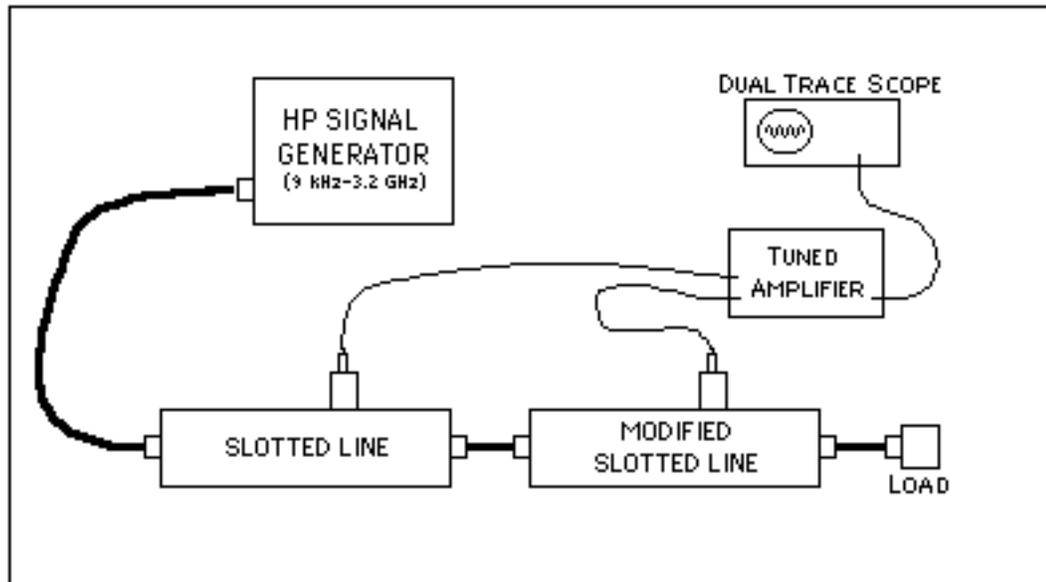
Again to start your measurements, excite the coaxial circuit, illustrated above, with a 1.4 GHz modulated signal from HP Signal Generator. Using the coaxial switch, alternatively observe the directional coupler output signals by means of a single crystal mount. Preamplify the demodulated signal from the crystal mount and display it on the dual trace scope. By this means measure the reflection coefficients of the set of terminating loads studied with the slotted line. (Again, see comments below on the use of the "substitution" method.)

Report:

a. The magnitude of the reflection coefficient for each of the terminating loads considered above in the slotted line section.

b. Compare these results with the slotted line results above.

3. DIRECT OBSERVATION OF PROPAGATION IN A LOSSY MEDIUM:

EXPERIMENTAL SETUP

Measurements and observations:

Here we use slotted line measurements as a direct means for studying electromagnetic propagation in a lossy medium. One of the HP Slotted Line devices has been modified so that fluids may be retained in the region where electromagnetic fields propagate. Thus, the probe may be used to sense the

transverse electric field **within the fluid** at positions along the slotted coaxial section.

To start your measurements, excite the coaxial circuit, illustrated above, with an AM output from the HP Signal Generator (set to a carrier frequency of, say, 800 MHz). Directly observe the modulated signal propagating through the fluid by displaying the preamplified output of the modified HP Slotted Line device on the dual trace scope (you may want to *sync* the scope display from the modulation source). To obtain a sharp standing wave pattern in the slotted line terminate it in a short circuit (GR Termination 874-WN). Also, observe the reflection of the signal by the fluid with VSWR measurements in the unmodified HP Slotted Line.

Measure the reflection coefficient of the water filled slotted line, the penetration or skin depth, and the wavelength of the field propagating in the water. Repeat these measurements at 100 MHz intervals from 100 MHz to around 1400 MHz (or to frequency at which propagation becomes minuscule).

Report:

    a.   Plot your measured values of the skin depth in water *vs.* frequency.

    b.   Plot the **ratio** of your measured values of the wavelength in water to the corresponding value of free space wave length as a function of frequency.[†]

    c.   Comment on whether or not the frequency dependence of the results in (a) and (b) are consistent with the theory of propagation in a "good conductor."

Comment on the "substitution" method

In general, it is very difficult to make an absolute power measurement in the high frequency realm. To accomplish such a measurement the detecting device (a diode, in our case) must have an accurately known response law -- *e.g.* voltage output as function of power input. The most difficult requirement is that the response law must be know at all power levels over the dynamic range of interest. In most cases, we are interested in relative power measurements; the so called "substitution" method is widely used in such measurements. The substitution method takes advantage of the fact that it is much less difficult to build precision variable attenuators with appreciable dynamic ranges than it is to precisely characterize the response of detectors.

In using the substitution method, a precision variable attenuator is connected at some convenient point between the generator and an indicating detector (The HP Signal Generator has a precise built-in attenuator that is particularly convenient to use.) At one power level of interest, the attenuator is adjusted to some convenient reference level and the detector output observed and noted. At a second power level of interest, the attenuator level is adjusted to **restore** the detected signal to it original value and the reading difference of the attenuator's calibrated scale yields directly the power ratio of the two levels independent of the characteristics of the detector.

[†]   Note that the ratio of the wavelength in free space to the wavelength in the medium is **the index of refraction of the medium**.