RF COMMUNICATION LABORATORY

EE409/EE691; FALL 2004

Experiment 1

Measurements using power meter and an introduction to RF Laboratory Equipment and Components

Objective:
To introduce the students to microwave power measurements, RF cables, connectors, adapters, and RF laboratory facilities.

Equipment:
- Power Meter (E4419A)
- ESG signal Generator (E4433B)

Components:
- MDC 2077-10 directional coupler, Mini-Circuits 15542 ZAPD-2 Power Splitter, 1 N(M) SMA(M) adapter, 1 SMA(F)-SMA(F) adapter, 2 Midwest Microwave (2582) adapters, 2 SMA(M)-SMA(F) 90 deg elbows, 2 SMA(M)-N(F) adapters.
- Power Sensors (8487A), 2 SMA(F)-N(M) adapters
- Megaphase cable (10573 IGVT4)
- RF Cables
- RF Connectors
- RF Adapters: RG 214U, RG 58 Coax, RG 142 B/U Cables

Pre-Lab:
3. Study the handout provided to you on the use and care of APC connectors. Make notes in the laboratory notebook.
4. Convert the following powers to mW.
   a. 10 dBm   b. 13 dBm   c. 17 dBm   d. 20 dBm
5. Convert the following powers to dBm
   a. 1000mW   b. 500mW   c. 200mW   d. 5mW

Procedures:

Cables, Connectors and Adapters
1. Note down the properties of the cables (black outer cover) using the handbook “Reference Data for Radio Engineers” provided, pp. 24.32 – 24.40.
   Note: The RG type designation of the cable can be found on the cable cover.
2. Identify and note down the types of various adapters provided. Make rough sketches and show the connector type.
3. Consider the given blue colored cable with SMA connectors.
   a) Measure and note down the length of the cable (including the connectors) using a tape measure.
   b) Measure the diameters of the dielectric and center conductor of the coaxial connector attached to the
cable using vernier calipers, and note down the dimensions.
   c) Using the information you obtained in parts (a) and (b), determine the following quantities for the
blue colored cable, if \( \varepsilon_r \) (dielectric constant of the cable material) = 2.0 and \( f = 18 \text{ GHz} \).
   i) Phase shift (or phase change) for a signal (at \( f = 18 \text{ GHz} \)) passing through this cable, in
   degrees.
   ii) Characteristic impedance \( (Z_0) \) of the cable, in ohms.
   iii) If the attenuation of the cable is 1.2 dB at 18 GHz, determine the output signal power in
   dBm and mW, if the input signal power is 10 mW.
   iv) How much power (in mW) is dissipated in the cable?

4. RF Laboratory tour.
   The instructor will introduce the test/measurement equipment/facilities, and explain the precautions/care
to be exercised while using the equipment and components.

Useful Equations:
- Characteristic impedance \( (Z_0) \) of coaxial cable line = \( (60/\sqrt{\varepsilon_r}) \cdot \ln(b/a) \)
  Where, \( b \) = radius of dielectric or inner radius of outer conductor, and \( a \) = radius of center conductor.
- Phase velocity = \( U_p = c/\sqrt{\varepsilon_r}; c = 3 \times 10^8 \text{ m/sec} \).
- Wavelength, \( \lambda = U_p/f; f = \text{frequency} \).
- Phase constant = \( \beta = 2\pi/\lambda \) (rad/m).
- \( \beta l \) = Electrical length of cable (in radians).
- \( l \) = Physical length of cable.

Measurements using Power meter

Procedures
Note 1: Before making any measurements using the power meter, calibration of the power meter has to be carried
out. Follow the handout given on calibration procedures to calibrate the power meter.
Note 2: Make sure the frequency of measurement is set on the power meter using the Cal/Freq key
Note 3: The maximum input power level of the power sensors should not exceed 20 dBm.

I Insertion Loss Measurements
1. Switch on the ESG Signal generator. Set the frequency of the ESG to 4 GHz and amplitude to 0 dBm. Connect channel A of the power meter to RF output of ESG to measure this power, Pin. Switch the RF on in the ESG signal generator. Measure power (Pin) in mW and dBm.

2. Connect one end of the DUT (Megaphase cable) to the ESG and the other end to the Sensor A.

3. Before connecting the cable to the sensor connect an SMA(F)-SMA(F) adapter to the end of the cable, then connect the Midwest microwave (2582) adapter, then connect the given N(M)-SMA(F) adapter (for sensor A).

4. Measure the output power (Pout) of the cable on the power meter in mW and dBm.

Tabulate your observations as follows

<table>
<thead>
<tr>
<th>DUT</th>
<th>Pin, dBm</th>
<th>Pin, mW</th>
<th>Pout, dBm</th>
<th>Pout, mW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.3</td>
<td>0.331</td>
<td>-1.12</td>
<td>-0.773</td>
</tr>
</tbody>
</table>

II Directional Coupler Measurements

Note: Where a, b and c at the through port are:
- a: SMA(M) – SMA(F) adapter
- b: Midwest Microwave (2582) adapter
- c: Given N(M) – SMA(F) adapter with the respective sensor A or B
Do not re-calibrate the power meter, as the frequency is set to 4 GHz.

1. Do not change the settings on the ESG
2. Measure the input power Pin in mW and dBm as in part I(1).
3. Connect port 1 of the coupler to the ESG.
4. Connect an SMA (F)-SMA (M) adapter to port 2 and port 3, then connect the Midwest microwave (2582) adapter, then connect the SMA (F)-N (M) adapter.
5. Now connect the sensors A and B to port 2 and port 3 respectively

Tabulate your observations as follows:

Table 2

<table>
<thead>
<tr>
<th>Channel</th>
<th>dBm</th>
<th>mW</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-12.30</td>
<td>0.057</td>
</tr>
<tr>
<td>B</td>
<td>-19.6</td>
<td>0.642</td>
</tr>
</tbody>
</table>

\( p_{1} = -0.36 \) \( p_{2} = 0.021 \)

III Power Divider Measurements

![Power Divider Diagram]

Note: Where a, b and c are
a: 90 deg elbows
b: Midwest Microwave (2582) adapter
c: Given N(M) – SMA(F) adapter with the respective sensor A or B

1. Calibrate the power meter for 1.5 GHz.
2. Set the frequency on the ESG to 1.5 GHz and the amplitude to 0 dBm
3. Connect port S of the power divider to the ESG.
4. At port 1 of the power divider connect and SMA(F)-SMA(M) 90 deg bend adapter, then connect the Midwest microwave (2582) adapter, to this connect the given N(M)-SMA(M) adapter and connect it to sensor A.
5. Repeat the same adapter connections at port 2 of the divider but connect to sensor B.

Tabulate your observations as follows

<table>
<thead>
<tr>
<th>Channel</th>
<th>dBm (or dB)</th>
<th>mW</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-3.73</td>
<td>0.4223</td>
</tr>
<tr>
<td>B</td>
<td>-3.23</td>
<td>0.4335</td>
</tr>
<tr>
<td>A/B</td>
<td>-0.001</td>
<td>-</td>
</tr>
</tbody>
</table>

Report:
The report for this Laboratory is what you have already documented in your laboratory notebook during the Lab.
POINT OF INTEREST: Decibels and Nepers

Often the ratio of two power levels, \( P_1 \) and \( P_2 \), in a microwave system is expressed in decibels (dB) as

\[
10 \log \frac{P_1}{P_2} \text{ dB}.
\]

Thus, a power ratio of 2 is equivalent to 3 dB, while a power ratio of 0.1 is equivalent to \(-10\) dB. Using power ratios in dB makes it easy to calculate power loss or gain through a series of components, since multiplicative loss or gain factors can be accounted for by adding the loss or gain in dB for each stage. For example, a signal passing through a 6 dB attenuator followed by a 23 dB amplifier will have an overall gain of \(23 - 6 = 17\) dB.

Decibels are used only to represent power ratios, but if \( P_1 = V_1^2/R_1 \) and \( P_2 = V_2^2/R_2 \), then the result in terms of voltage ratios is

\[
10 \log \frac{V_1^2 R_2}{V_2^2 R_1} = 20 \log \frac{V_1}{V_2} \sqrt{\frac{R_2}{R_1}} \text{ dB}.
\]

where \( R_1, R_2 \) are the load resistances and \( V_1, V_2 \) are the voltages appearing across these loads. If the load resistances are equal, then this formula simplifies to

\[
20 \log \frac{V_1}{V_2} \text{ dB}.
\]

The ratio of voltages across equal load resistances can also be expressed in terms of nepers (Np) as

\[
\ln \frac{V_1}{V_2} \text{ Np}.
\]

The corresponding expression in terms of powers is

\[
\frac{1}{2} \ln \frac{P_1}{P_2} \text{ Np},
\]

since voltage is proportional to the square root of power. Transmission line attenuation is often expressed in nepers. Since 1 Np corresponds to a power ratio of \( e^2 \), the conversion between nepers and decibels is

\[
1 \text{ Np} = 10 \log e^2 = 8.686 \text{ dB}.
\]

Absolute powers can also be expressed in decibel notation if a reference power level is assumed. If we let \( P_2 = 1 \text{ mW} \), then the power \( P_1 \) can be expressed in dBm as

\[
10 \log \frac{P_1}{1 \text{ mW}} \text{ dBm}.
\]

Thus a power of 1 mW is 0 dBm, while a power of 1W is 30 dBm, etc.
POINT OF INTEREST: Coaxial Connectors

Most coaxial cables and connectors in common use have a 50 Ω characteristic impedance, with an exception being the 75 Ω coax used in television systems. The reasoning behind these choices is that an air-filled coaxial line has minimum attenuation for a characteristic impedance of 77 Ω (Problem 2.26), while maximum power capacity occurs for a characteristic impedance of 30 Ω (Problem 3.27). A 50 Ω characteristic impedance thus represents a compromise between minimum attenuation and maximum power capacity. Requirements for coaxial connectors include low SWR, higher-order-mode-free operation at a high frequency, high repeatability after a connect-disconnect cycle, and mechanical strength. Connectors are used in pairs, with a male end and a female end (or plug and jack). Below we describe some of the most common microwave coaxial connectors.

Type-N connector. This connector was developed in 1942 and named after P. Neill, who worked on its design at Bell Labs. The male and female connectors thread together; the outer diameter of the female connector is about 0.625 in., so this is a relatively large connector. The recommended upper operating frequency ranges from 11 to 18 GHz, depending on cable size. The SWR for a mated connector pair is typically less than 1.07.

SMA connector. The need for a smaller and lighter connector led to the development of the subminiature SMA connector in the early 1960s. The outer diameter of the female end of the SMA connector is about 0.250 in. It can be used up to 25 GHz, and is probably the most frequently used microwave connector today. Increasing demand for millimeter wave components has led to the development of two popular variations of the SMA connector: the K-connector (usable to 40 GHz) and the 2.4 mm connector (usable to 50 GHz).

SSMA connector. The SSMA (sealed SMA) connector is similar in design to the SMA connector, but smaller in size. The outer diameter of the female end is about 0.192 in., and the maximum operating frequency is about 38 GHz.

APC-7 connector. This is a precision connector (Amphenol precision connector) that can repeatably achieve an SWR less than 1.04 at frequencies up to 18 GHz. The connectors are "sexless," with butt contact between both the inner conductors and the outer conductors.

The BNC (baby N connector) and TNC (a threaded BNC connector) are commonly used at RF and IF frequencies, but not for microwave work.

USE

To Connect:

1. On one connector, retract the coupling sleeve by turning the coupling nut counterclockwise until the sleeve and nut disengage.

2. On the other connector, fully extend the coupling sleeve by turning the coupling nut clockwise. To engage coupling sleeve and coupling nut when the sleeve is fully retracted, press back lightly on the nut while turning it clockwise.

3. Push the connectors firmly together, and thread the coupling nut of the connector with retracted sleeve over the extended sleeve. Leave the other coupling nut in the original position: closing the gap between coupling nuts tends to loosen the electrical connection.

To Disconnect:

1. Loosen the coupling nut of the connector showing the wider gold band.
2. IMPORTANT: Part the connectors carefully to prevent striking the inner conductor contact.

CARE


2. Protect the contacting surfaces when the connector is not in use by leaving the coupling sleeve extended.

3. Use lintless material and/or firm-bristled brush such as tooth brush for cleaning. If a cleaning fluid is needed use isopropyl alcohol. IMPORTANT: Do not use aromatic or chlorinated hydrocarbons, esters, ethers, terpenes, higher alcohols, ketones, or ether-alcohols such as benzene, toluene, turpentine, dioxane, gasoline, cellosolve acetate, or carbon tetrachloride. Keep exposure of the connector parts to both the cleaning fluid and its vapors as brief as possible.
HP 8487A
POWER SENSOR

SERIAL NUMBERS

This supplement applies directly to instruments with serial numbers prefixed 2742A.

For additional important information about serial numbers see INSTRUMENTS COVERED BY MANUAL on page 4.
Figure 1. HP 8487A Power Sensor with Adapter
The HP 8487A Power Sensor is a thermocouple power sensor. It measures power levels in a range from -30 dBm to +20 dBm (1 µW to 100 mW). The HP 8487A measures at frequencies from 50 MHz to 50 GHz. (Specifications for the Power Sensor is in Table 1.)

The Power Sensor contains two thermocouples with two thin film resistors on a silicon chip. The thermal mechanical layout of the thermocouple is selected to give a hot junction at the resistor (center of the chip) and a cold junction at the outer edge of the chip.

When the resistor at the hot junction converts the applied microwave energy to heat, the temperature difference between the hot and cold junctions generates a dc voltage (thermoelectric emf). The dc voltage is proportional to the power from the rf source. The dc voltage thus generated is a very low-level voltage and requires amplification before it can be transferred on standard cables.

The amplification is provided by an input amplifier assembly which consists of a chopper (sampling gate) and an input amplifier. The dc voltage is routed on gold wires to the chopper circuit which converts the low-level dc voltage to an ac voltage. To do this, the chopper uses two field effect transistors (FETs) controlled by a 220 Hz square wave generated by the power meter. The result is an ac output signal proportional to the dc input. The ac signal is then amplified by the input amplifier. The relatively high-level ac signal output can now be routed by standard cables.

The HP 8487A Power Sensor is compatible with the HP 435A, HP 435B, HP 436A, HP 437B, and HP 438A power meters.

In application, the Power Sensor is connected between a microwave source and a compatible power meter. The Power Sensor provides a 50Ω load for the microwave source. This load is determined by the thermocouples which are each 100 ohms and are parallel to the source. The very low SWR to 50 GHz is possible because of the low parasitics of the thermocouple chip and the constant impedance transition from coax to the thermocouple chip. The power meter indicates the power dissipated in the thermocouples in Watts or in dBm.

Accessories

Included with each Power Sensor is the HP 08487-60001 Type N to 2.4 mm 50 ohm coaxial adapter (shown in Figure 1).
The Type N to 2.4 mm adapter is intended for use only at the 50 MHz POWER REF output of the power meter. Its usefulness as a calibration reference may be compromised if used for other purposes.

### Specifications

The specifications listed in Table 1 are the performance standards or limits against which the Power Sensor may be tested.

**Table 1. HP 8487A Specifications**

<table>
<thead>
<tr>
<th>Characteristics and Conditions</th>
<th>Limits</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency Range</strong></td>
<td>50 MHz to 50 GHz</td>
<td></td>
</tr>
<tr>
<td><strong>Power Range</strong></td>
<td>1 μW to 100 mW (-30 dBm to +20 dBm)</td>
<td></td>
</tr>
<tr>
<td><strong>Impedance</strong></td>
<td>50Ω</td>
<td>Nominal</td>
</tr>
<tr>
<td><strong>Connectors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calibration adapter</td>
<td>Type N (Male) to 2.4 mm Coax (Female)</td>
<td>For calibration only</td>
</tr>
<tr>
<td>Power Measurements</td>
<td>2.4 mm Coaxial (Male)</td>
<td></td>
</tr>
</tbody>
</table>

**Maximum Standing Wave Ratio (SWR) and Reflection Coefficient (Rho)**

<table>
<thead>
<tr>
<th>Frequency</th>
<th>SWR</th>
<th>Rho</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 to 100 MHz</td>
<td>&lt;1.15</td>
<td>0.070</td>
</tr>
<tr>
<td>100 MHz to 2 GHz</td>
<td>&lt;1.10</td>
<td>0.048</td>
</tr>
<tr>
<td>2 to 12.4 GHz</td>
<td>&lt;1.15</td>
<td>0.070</td>
</tr>
<tr>
<td>12.4 to 18 GHz</td>
<td>&lt;1.20</td>
<td>0.091</td>
</tr>
<tr>
<td>18 to 26.5 GHz</td>
<td>&lt;1.25</td>
<td>0.111</td>
</tr>
<tr>
<td>26.5 to 40 GHz</td>
<td>&lt;1.30</td>
<td>0.130</td>
</tr>
<tr>
<td>40 to 50 GHz</td>
<td>&lt;1.50</td>
<td>0.200</td>
</tr>
<tr>
<td>Calibration adapter</td>
<td>1.01</td>
<td>0.005</td>
</tr>
<tr>
<td>Characteristics and Conditions</td>
<td>Limits</td>
<td>Comments</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Maximum Average Power</td>
<td>300 mW</td>
<td></td>
</tr>
<tr>
<td>Maximum Peak Power</td>
<td>15 W</td>
<td></td>
</tr>
<tr>
<td>Maximum Energy/Pulse</td>
<td>30 W·μs</td>
<td></td>
</tr>
<tr>
<td>Worst Case Power Linearity</td>
<td>+2% to -4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+10 dBm to +20 dBm</td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>0 to 55 °C</td>
<td></td>
</tr>
<tr>
<td>Net Weight</td>
<td>0.14 kg (0.28 lb)</td>
<td></td>
</tr>
<tr>
<td>Dimensions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length: 94 mm (3.7 in)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width: 38 mm (1.5 in)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height: 30 mm (1.19 in)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calibration Factor (CF) and Reflection Coefficient (Rho)**

CF and Rho data at 2 GHz increments are provided on a label attached to the sensor cover. Calibration factor and Reflection coefficient data are given at 1 GHz increments on a data sheet included with the Power Sensor. This data is unique to each sensor. If you have two sensors, match the serial number on the data sheet with the serial number on the Power Sensor to avoid confusion. Maximum uncertainties of the CAL FACTOR data are listed in Table 3. The CAL FACTOR compensates for the frequency response of the sensors.

Reflection Coefficient (Rho, or ρ) relates to SWR according to the following formula:

\[ \text{SWR} = \frac{(1+\rho)}{(1-\rho)} \]
BEFORE CONNECTING THE POWER SENSOR TO OTHER INSTRUMENTS ensure that all instruments are connected to the protective (earth) ground. Any interruption of the protective earth grounding will cause a potential shock hazard that could result in personal injury.

Operating Environment

The operating environment for the Power Sensor should be within the following limits:

- Temperature: 0 to 55°C
- Relative humidity: less than 95%
- Altitude: less than 4550 metres (15,000 feet)

Operating Precautions

If the following energy and power levels are exceeded, the power meter system may be damaged.

a. Maximum Average Power: 300 mW
b. Maximum Peak Power: 15W
c. Maximum Energy/Pulse: 30 W·μs

Maximum torque at the 5/16 hex should not exceed 90 N·cm (8 inch pounds) to avoid damage to the connector.

Connect the Power Sensor by turning only the knurled portion or hex of the connector. Damage can occur if torque is applied to the Power Sensor body.

The Type-N connector plastic insulator bead deteriorates when contacted by any chlorinated or aromatic hydrocarbons such as acetone, trichlorethylene, carbon tetrachloride, benzene, etc. Clean the connector face with a cotton swab saturated in isopropyl alcohol only.