# Lab1 RF equipment fundamentals

EERF – 6396

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**9/17/2017**

## 1. Introduction

**Objectives:**

a. To measure RF/ microwave scalar power, insertion loss of various components.
b. Estimate the speed of light by measuring the length of standing waves.

**Apparatus:**

a. Signal Generator: Agilent N5181A (250 kHz – 6 GHz)
b. Power Sensor: Agilent E9301H (10 MHz – 6 GHz, 10 nW – 1W)
c. Power Meter: Agilent E4419B
d. N-type to SMA cable
e. SMA to N-type connector
f. SMA Attenuators: 3dB, 6dB, 10 dB, 20 dB
g. Band pass Filter: vbfz-2340-s+ (2020 MHz – 2660 MHz)
h. Cheese Slices

## 2. Pre-Lab Discussion

1) A transmission line is a pair of electrical conductors that carry electromagnetic signals. When the wavelength (λ) of the signal becomes comparable to the size of components and the length of the conductors then it is imperative to take into consideration the transit delay effects. Therefore we use transmission line theory to analyze RF circuits rather than circuit theory. The transmission line take into consideration distributed R, L, G and C of the line. For a transmission line:

   The characteristic impedance and propagation constant are given by -

   $$Z_0 = \sqrt{\frac{(R+j\omega L)}{(G+j\omega C)}} \qquad \gamma = \alpha + j\beta = \sqrt{(R+j\omega L)(G+j\omega C)}$$

   Where R = Resistance per unit length (Ω/m)
   L = Inductance per unit length (L/m)
   G = Conductivity per unit length (mho/m)
   C = Capacitance per unit length (C/m)
   ω = Angular frequency
   α = Attenuation constant
   β = Phase constant

2) Studied the manual of Agilent power sensor and understood its working
3) Studied the working of Microwave ovens.

   There are many other ways to measure the speed of light:

   i) By measuring the time delay between the predicted time of eclipses of Jupiter's moons
   ii) Using rotary mirrors to reflect light beams and measuring time in between.
   iii) Microwave interferometer and Kerr cell shutter.
   iv) Using laser and atomic clocks.

## 3. Procedure

**Part I: Experiment to measure the speed of light**

1) Remove the turning plate from the microwave
2) Place a food item (cheese slice) in a container and keep it in the microwave
3) Operate the microwave with 15 sec intervals until the two distinguishable melting spots are observed
4) Measure the distance (d) in meters between the spots. Here d = $\lambda/2$
5) Calculate the speed of light using the formula: c = 2 x d x frequency of Microwave oven
   $c = 2 \times d \times 2.45\times10^{9}$ m/s

**Part II: Scalar power measurements**

1) Perform zero check and power calibration of the power sensor
2) Set the signal generator to 3 GHz, 0 dBm
3) Turn RF on only while taking measurements and again turn it off
4) Connect the power sensor directly to the signal generator and note the reading on the power meter
5) Now connect the RF wire between the signal generator and power sensor and note the power meter reading
6) Add a 3 dB attenuator in between RF cable and coupler to the power sensor, repeat the procedure with 6 dB, 10 dB, 20 dB attenuators and note the readings
7) Measure the transmitted power of the filter from 1 – 4 GHz, incremented with 200 MHz

## 4. Data

**Part I:**

d = 0.063 m (observed)
$c = 2 \times 0.063 \times 2.45\times10^{9}$ m/s
$c = 308.7\times10^{6}$ m/s

**Analysis:**

The actual speed of light is 299,792,458 m/s
Difference between actual and observed = 8,907,542
This means +2.97% deviation error
I would say this is acceptable given the scope and nature of the experiment

**Part II:**
Length of RF Cable – 0.80 m ; Attenuation – -0.57dBm
Attenuation per unit length of cable ($\alpha$): -0.57dBm / 80cm = -0.7125dB/m

Readings with Signal generator at 3 GHz, 0dBm

| Sr. No | Component | Power meter reading | Insertion Loss (dB) | Difference from rated value |
|---|---|---|---|---|
| 1 | 3 dB SMA attenuator | -3.84 dBm | (-0.57) - (-3.84) = 3.27 | 9% |
| 2 | 6 dB SMA attenuator | -6.67 dBm | (-0.57) - (-6.67) = 6.1 | 1.6% |
| 3 | 10 dB SMA attenuator | -10.38 dBm | (-0.57) - (-10.38) = 9.81 | 0.19% |
| 4 | 20 dB SMA attenuator | -20.28 dBm | (-0.57) - (-20.28) = 19.71 | 0.0145% |

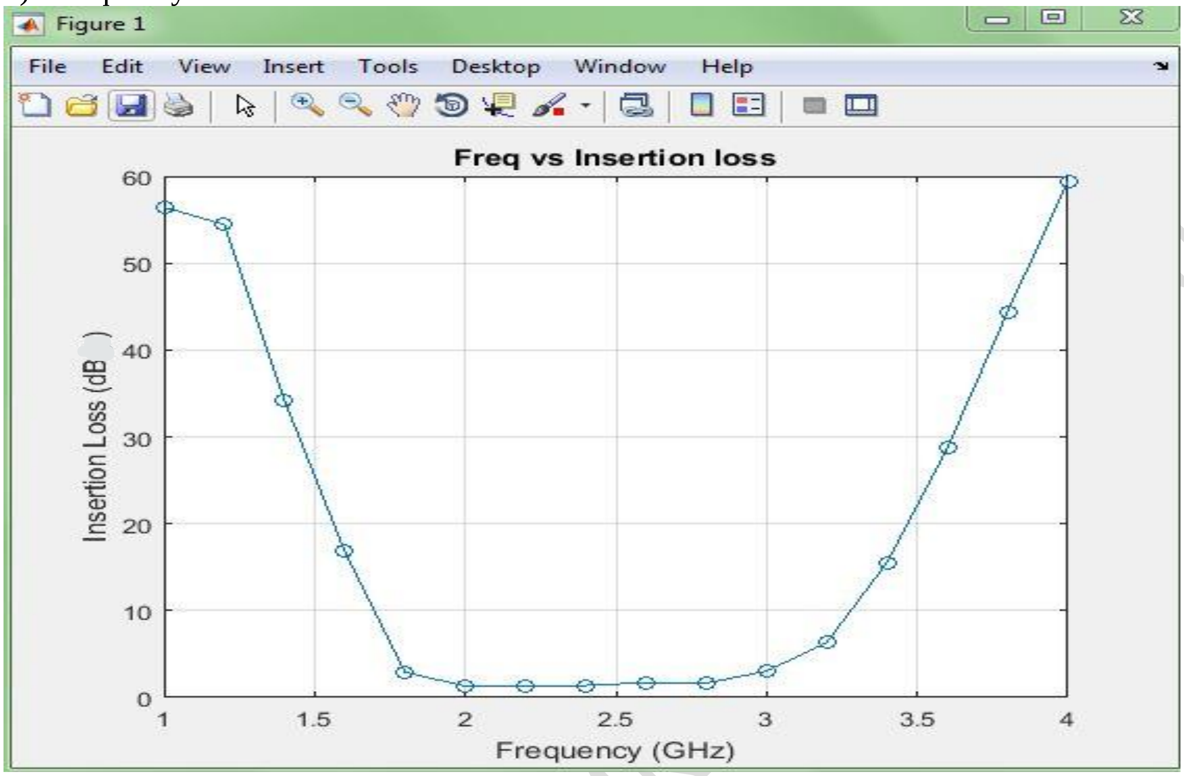
Readings for filter:

| Sr. No | Frequency (GHz) | Power meter reading (dBm) | Insertion loss without the RF cable (dB) |
|---|---|---|---|
| 1 | 1.0 | -57 | 56.43 |
| 2 | 1.2 | -55 | 54.43 |
| 3 | 1.4 | -34.8 | 34.23 |
| 4 | 1.6 | -17.4 | 16.83 |
| 5 | 1.8 | -3.49 | 2.92 |
| 6 | 2.0 | -1.87 | 1.3 |
| 7 | 2.2 | -1.96 | 1.39 |
| 8 | 2.4 | -1.96 | 1.39 |
| 9 | 2.6 | -2.28 | 1.71 |
| 10 | 2.8 | -2.24 | 1.67 |
| 11 | 3.0 | -3.60 | 3.03 |
| 12 | 3.2 | -6.91 | 6.34 |
| 13 | 3.4 | -16.13 | 15.56 |
| 14 | 3.6 | -29.30 | 28.73 |
| 15 | 3.8 | -45 | 44.43 |
| 16 | 4.0 | -60 | 59.43 |

Based on the readings the filter is of Band Pass type.

**Plots:**

1) Frequency vs Insertion Loss




2) Frequency vs Power at load


Maximum power = -1.87 dBm. So -3 dB = -4.87 dBm

Bandwidth = $f_{B-A}^{3\,dB} = f_B - f_A$ = (2.880 – 1.797) GHz = 1.083GHz

## 5. Summary

**Speed of Light Experiment:**

Microwave ovens are used to heat food by agitating the water molecules in the food by using microwaves of 2.45 GHz frequency. Due to the interference between the reflected waves, hot spots are formed on the materials placed inside the microwave. These are the spots where waves have interfered. The distance between two consecutive spots is equal to $\lambda/_2$. We can use this to find the velocity of light.

- The data collected in this experiment is inherently prone to human error and hence would yield approximate results. Since the melting spots have a variance in size and width the measurements would be adversely affected.
- Considering the effective permittivity of the medium ($\varepsilon_{eff}$) used would yield better results as speed of light is different in different materials.

**Working of microwave ovens:**

Microwave ovens are used to heat food by agitating the water molecules in the food by using microwaves of 2.45 GHz frequency. The EM energy is absorbed by the food molecules and cook up.

**Importance of Calibration:**

- Calibration is necessary to record reliable, accurate and consistent readings.
- Calibration of power meter eliminates offset and stray voltages from previous measurements

**Effect of Impedance mismatch at DUT:**

- Impedance mismatch at DUT leads to a portion of the signal form the generator to reflect back from the DUT to the RF cable
- Impedance mismatch leads to performance degradation of the system and decreases the efficiency
- Impedance mismatch causes return loss in the RF cable