EEEE-816
Design and Characterization of Microwave Systems

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EE816 Design and Characterization of Microwave Systems

I. Course Structure - 4 credits
II. Pre-requisites – Microwave Circuits (EE717) and Antenna Theory (EE729)
III. Course level – Graduate

IV. Course Objectives

Electromagnetics education has been rejuvenated by three emerging technologies, namely mixed signal circuits, wireless communication and bio-electromagnetics. As hardware and software tools continue to get more sophisticated, there is a need to be able to perform specific tasks for characterization and validation of design, working within the capabilities of test equipment, and the ability to develop corresponding analytical formulations

There are two primary course objectives.

(i) Design of experiments to characterize or measure specific quantities, working with the constraints of measurable quantities using the vector network analyzer, and in conjunction with the development of closed form analytical expressions.
(ii) Design, construction and characterization of microstrip circuitry and antennas for a specified set of criteria using analytical models, and software tools and measurement techniques.

Microwave measurement will involve the use of network analyzers, and spectrum analyzers in conjunction with the probe station. Simulated results will be obtained using some popular commercial EM software for the design of microwave circuits and antennas.

V. Textbook and References

1. Microwave Engineering by D.M. Pozar (3^{rd} Ed)
2. Antenna Theory by C. A. Balanis
3. IEEE Journal Papers

VI. Course Content

(i) Design of experiments
Characterizing phase shift, modeling discontinuities, measuring dielectric constant, cavity resonances, dispersive waveguides, impedance matching.
(ii) Microwave circuit design projects
Microstrip power dividers, corporate feed system, matching circuits, coupled line couplers, branchline couplers, hybrid ring couplers, and resonators Low pass and band pass filters
(iii) Microwave measurement techniques
Scattering matrix, reflection and input characteristics, transmission characteristics

Course Requirements:
Tests / quizzes: 30%
Lab: 30%
Projects:40%

Design of Experiments
for the Characterization of Microwave Circuits

Microwave Circuit Design Projects

Appendix

Experiment 1
Dispersion Characteristics of Rectangular Waveguides

Objective

This experiment provides an introduction to the dispersive characteristics of waveguides and the techniques for waveguide measurements. It is up to you to explore the problem to the extent necessary, to learn how precision measurements can be made.

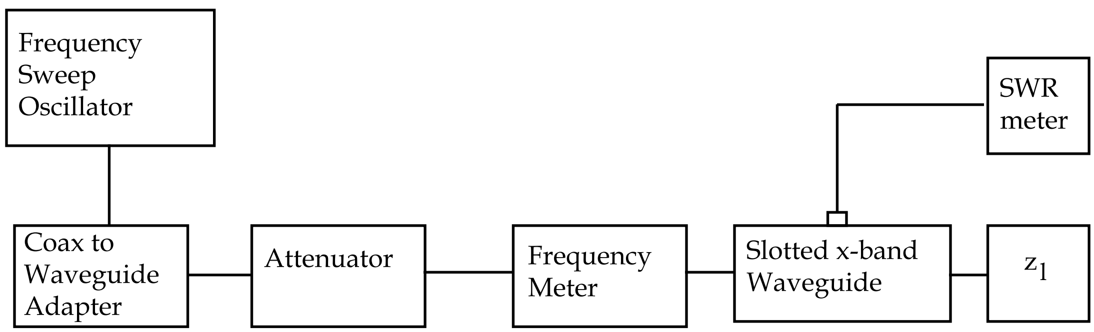


Fig. 1 Circuit Configuration

Procedure

Measurements are conducted in the X- band using the WR-90 waveguide (dimensions 0.4" x 0.9"). The recommended operating range for the TE_{10} mode is 8.2 to 12.4 GHz. The oscillator range is 8 to 12 GHz.

Part 1 - Dispersive Characteristic of Waveguides

(i) With a short circuit as the waveguide termination, measure the guide wavelength of the TE_{10} mode, λ_{10} , at discrete frequencies, in the range 8-12 GHz. Measure also, the frequency using the frequency meter.

(ii) While doing this, measure Standing Wave (SW) pattern at 10 GHz. (It is not required to measure the SW pattern at the other frequencies). Take measurements for a distance of one and a half wavelengths of the slot.

(iii) From your results:

- Plot standing wave pattern at 10 GHz. The meter reading is $\left|\frac{V_{max}}{V(z)}\right|$. Plot the reciprocal of the meter reading vs.distance, z, to generate the SW pattern
- In the frequency range 8 GHz to 12 GHz, tabulate the measured guide wavelength, λ_{10}
- Corresponding to the frequency range for the measurements, calculate the theoretical λ_{10} using the formula

$$\frac{1}{\lambda_{10}^2} = \frac{1}{\lambda_0^2} - \frac{1}{\lambda_{c,10}^2}$$

where the cutoff wavelength of the TE_{10} mode is:

$$\lambda_{c10} = \frac{c}{f_{c10}}$$

and the cutoff frequency of the TE_{10} mode is :

$$f_{c10} = \frac{c}{2a}$$

- Plot and compare theoretical and measured λ_{10}
- Plot the dispersion characteristic of the waveguide, that is, β_{10} as a function of ω

Part 2 - Comparison of slotted line and automated measurements

Using the microstrip antenna as the load terminating the slotted line, measure VSWR for the frequency range 8-12 GHz. The same result using the Network Analyzer has been provided to you. Choose the frequencies for measurement, necessary to duplicate this graph.

From your results:

- Plot VSWR vs. frequency, f
- Plot $|\Gamma|$ vs. f
- Determine the bandwidth for VSWR $\leq$ 2.0

Report

The report should contain the following.

(i) A title, an objective and a block diagram
(ii) Relevant theory and the derivation of the dispersion equation.
(iii)For each part
 an experimental procedure
 measured data presented comprehensively
 relevant calculations
(iv)Conclusion and discussion

Experiment II
Introduction to the Network Analyzer

I. Waveguide Calibration Procedure for PNA8363B

Make sure the System characteristic impedance (Z0) is set to 1Ω
System → Configure → System Z0 (set it to 1Ω)
Select Start (8GHz) and Stop (12GHz) frequencies
Cal

F1 (Cal Wizard)
Unguided Calibration: Use Mechanical Standards. (Create new Cal Set)
Click Next.
Full SOLT 2-Port (View or Select Cal Kit, Omit Isolation, 1 Set of Stds.).
Click Next.
ID #25 X11644A X-Band Waveguide SOLT/TRL Cal.
Click Next.
Port1: Attach λ/8 short, click short, click OK.
Port1: Attach 3λ/8 short, click offset short, click OK.
Port1: Attach matched load, click load, click X-Band fixed load, click OK.

Attach the ports together, click thru, click X-band thru, click OK.

Port2: Attach λ/8 short, click short, click OK.
Port2: Attach 3λ/8 short, click offset short, click OK.
Port2: Attach matched load, click load, click X-Band fixed load, click OK.
Click Next.
No. Finish now.
Click Finish.

II. Transmission Line Calibration Procedure for PNA8363B

Perform the calibration for a full two port for the X-band (8GHz to 12 GHz)

Make sure the System characteristic impedance (Z0) is set to 50 Ohms
Select Start and Stop frequencies
Calibration → Calibration Wizard
Select unguided calibration
Click NEXT
Choose 2 port SOLT → Click view select cal kit → Choose 85052D 3.5mm
Click OK and NEXT
Follow the procedure for each load

III. Microstrip Antenna

For the microstrip antenna provided to you, measure and plot the following

- Plot VSWR vs. frequency, f (8GHz – 10 GHz)
- Plot Return Loss vs. f (8GHz – 10 GHz)
- Determine the bandwidth for VSWR $\leq$ 2.0

Compare the above with measurements made for the same antenna using the WG slotted line

Experiment III
Characterizing and Calibrating Probe Susceptance

Objective

The objective is to measure and calibrate the susceptance of a tuning post vs. depth of penetration in an X-band waveguide. The graph that is generated will be used for impedance matching by a single stub tuner.

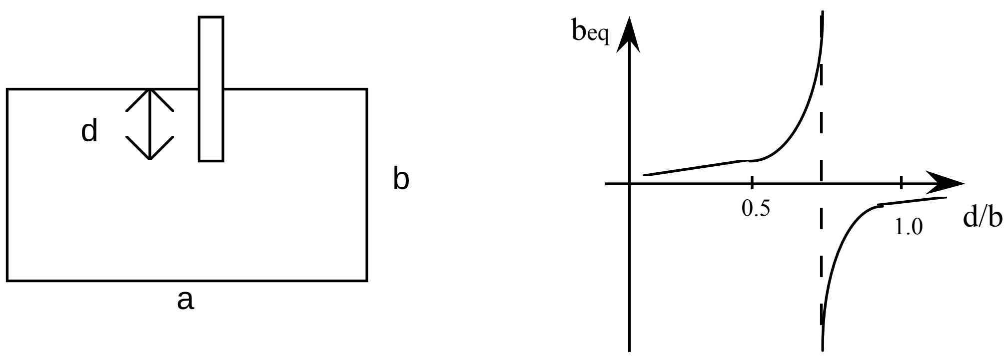


Figure 1 Probe Susceptance

The equivalent circuit of the post, inserted in a waveguide as shown in figure 1, is a symmetric T where both the series reactance and the shunt suseptance vary with insertion depth (The series reactance is relatively small and can be neglected here). At small insertion depths the susceptance is capacitive and it increases with the depth, d. This increase can be attributed to the increase of the capacitance between the tip of the post and the bottom surface of the waveguide. In series with this capacitance is the inductance of the exposed post and this inductance also increases with 'd'. At some depth, the post becomes a series resonant circuit (i.e. $b_{eq} = \infty$). and is inductive for greater depths up to and including maximum insertion, when d = b, the smaller WG dimension.

Method I- With Network Analyzer and a matched load termination

The experimental setup is shown below in figure 2.

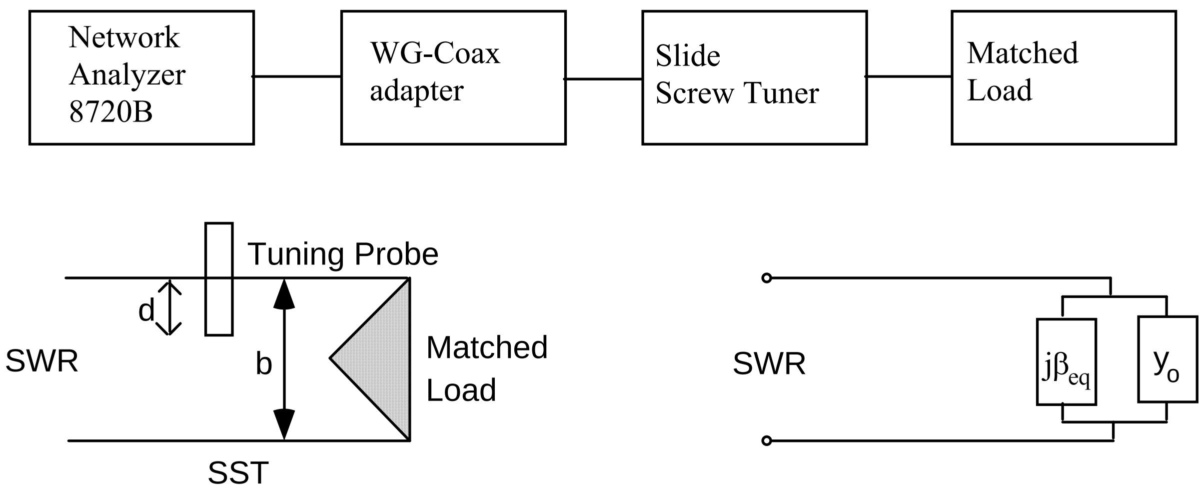


Figure 2 Experimental setup with a matched load termination

(i) Calibration the network analyzer for S_{11} measurements in the X-band waveguide for a frequency range 8-12 GHz

(ii) With the circuit as shown, measure the SWR at 10 GHz for insertion depth, d, ranging from 0 to b.

(iii) From the equivalent circuit shown above, obtain the following expression for b_{eq}.

$$b_{eq} = \pm\left[\frac{SWR - 1}{\sqrt{SWR}}\right]$$

(iv) Generate a calibration design graph (figure 3) by calculating and plotting b_{eq} vs. d/b shown in figure 1.

Method II - With the Waveguide Slotted Line and a short as termination

In this method, the probe susceptance is measured using a shorting plate as a termination. The experimental setup is shown in Figure 4.

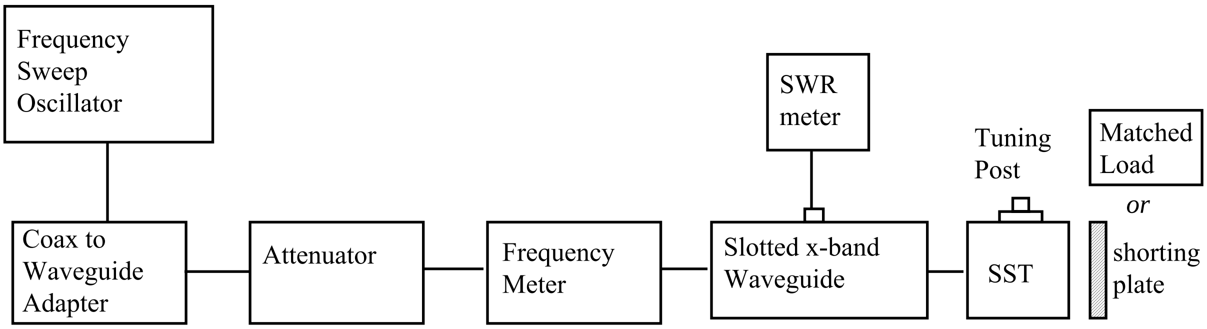


Figure 2 Waveguide slotted line with a short as termination

(i) Retract the probe of the SST fully (> 0.4" on micrometer screw)

(ii) Set the frequency to 10 GHz.

(iii) Terminate the end of the SST with a shorting plate and fix the position of the post a distance which is an odd multiple of $\lambda_g / 4$. This ensures that the shorting plate presents an open circuit at the plane of the tuning post of the SST. When the tuning post is inserted into the guide, the effective load will be the suseptance presented by the post.

(iv) For insertion depths starting from 0.4" on the micrometer screw, obtain the position of the first accessible voltage minimum in the slotted line. Take readings for every 0.05" insertion depth. Tabulate your readings as shown in Table 1.

d' Micrometer Reading	Depth, d= (b-d')	d/b	Position of 1st Vmin	$(\ell - \ell_o)$	$b_{eq} = -\tan[2\pi(\ell - \ell_o)/\lambda_{10}]$
0.4"	0.0"	0.0	ℓ_o		
0.35"	0.05"	0.125	ℓ		
:	:	:	:		
0.0"	:	:	:		

Table 1

(v) Calculate b_{eq} for each insertion depth and plot b_{eq} vs. d/b..

Experiment - IV
Impedance Matching - The Slide-Screw Tuner (SST)

Objective:

The waveguide equivalent of a single stub co-axial tuner is the slide-screw tuner which consists of a post that is inserted into the waveguide, through a slot, which is cut along the top surface. In the design of the single stub tuner, a susceptance is introduced in parallel at a location where the real part of the input admittance equals the characteristic admittance. The axial location, *l*, of the post is adjustable. The depth of insertion, d, yields the desired susceptance so that the design can be implemented.

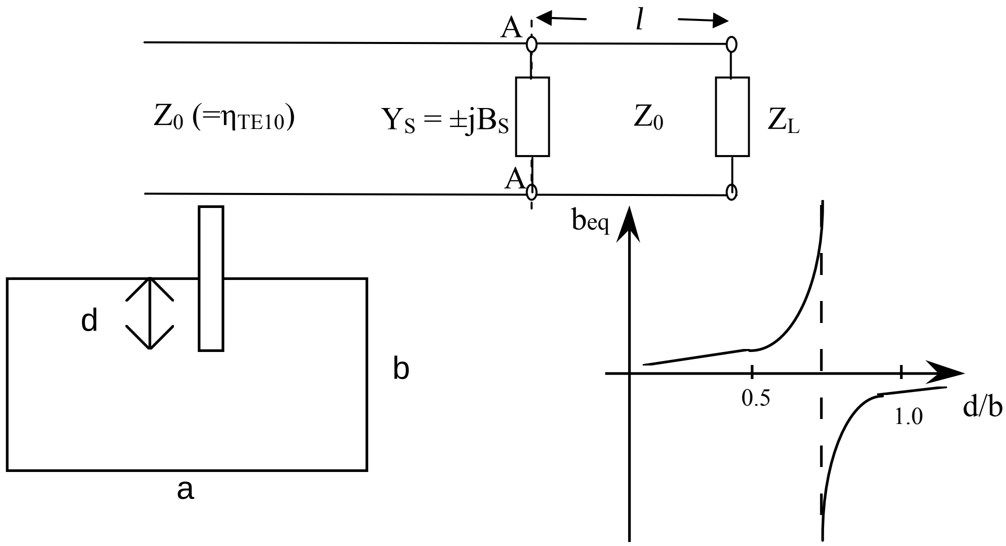


Figure 1 Single stub tuner

The calibration of the probe susceptance vs insertion depth shown in figure 1, has been obtained in experiment II At small insertion depths the susceptance is capacitive and it increases with the depth, d. At some depth, the post becomes a series resonant circuit (i.e. $b_{eq} = \infty$). and is inductive for greater depths up to and including maximum insertion, when d = b, the smaller WG dimension.

The objectives of the experiment are as follows:

(i) Calibrate the suseptance of the tuning post as a function of insertion depth, d. (This has been completed in Experiment #2)

(ii) Measure the unknown impedance of the open ended WR-90 waveguide

(iii)Using the slide screw tuner, design a single stub tuner to match the open-ended guide impedance, to obtain SWR = 1. That is,

- Find the distance of the tuning post from the open end
- Use the probe susceptance calibration graph to determine the depth of insertion of tuning post.

(iv) Implement the design and measure SWR. Report SWR before and after matching.

Procedure

Part 1: Calibration Graph for Suseptance vs. Probe Depth

Completed in Experiment #2

Part II: Measurement of unknown impedance of Open-ended Waveguide

(i) Slotted Line Measurement for Unknown Impedance

Any load impedance entered on the SC is completely defined by the SWR and the distance to the first voltage minimum or maximum.. However, the plane of the load is not always accessible as in the case of a slotted line. If the distance to the first maximum d_{max} (or to d_{min}) can be measured the unknown load impedance $\hat{Z}_L$ can be obtained. Since this s not possible, the following method is used. The two possible kinds of load impedances (capacitive or inductive) are considered, in the first case where voltage minimum occurs and in the other a voltage maximum occurs first from the load. The measurement methodology is outlined below.

(a) With an unknown load $\hat{Z}_L$ attached to the end of the slotted line

- Measure the SWR
- Locate the first accessible minimum at $d_{min,1}$

(b) Replace the load with a short

- Locate the first accessible minimum at $d_{min,2}$
- Note the direction of the shift, whether towards the generator or load.

(c) Perform calculations on the Smith Chart

- Draw the SWR circle corresponding to the unknown impedance
- Calculate $\Delta d = d_{min,1} - d_{min,2}$
- From the point of voltage minimum, rotate a distance $\Delta d/\lambda$ in the direction of the shift.
- Draw a line to intersect the SWR circle.
- Read z_L and de-normalize to obtain Z_L.

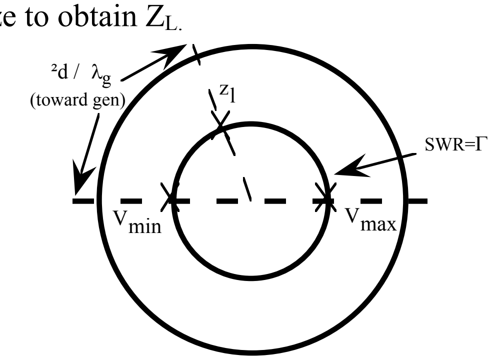
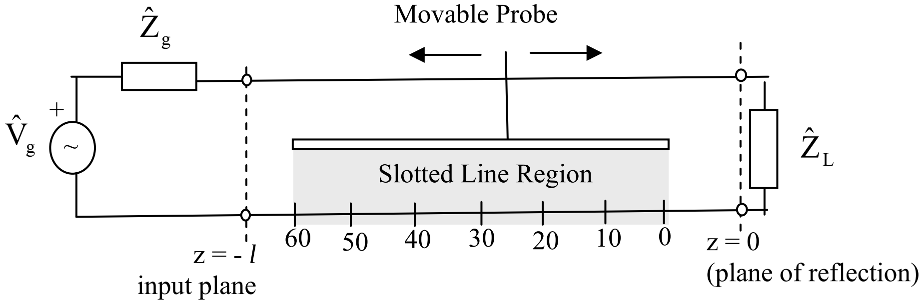
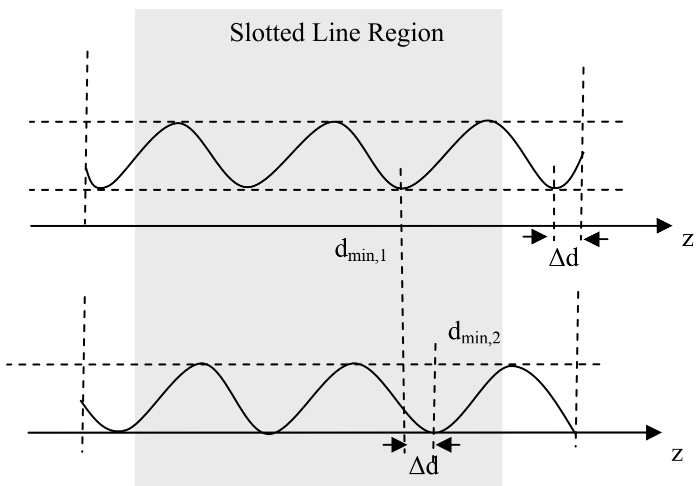


Figure 2 Smith Chart Calculations



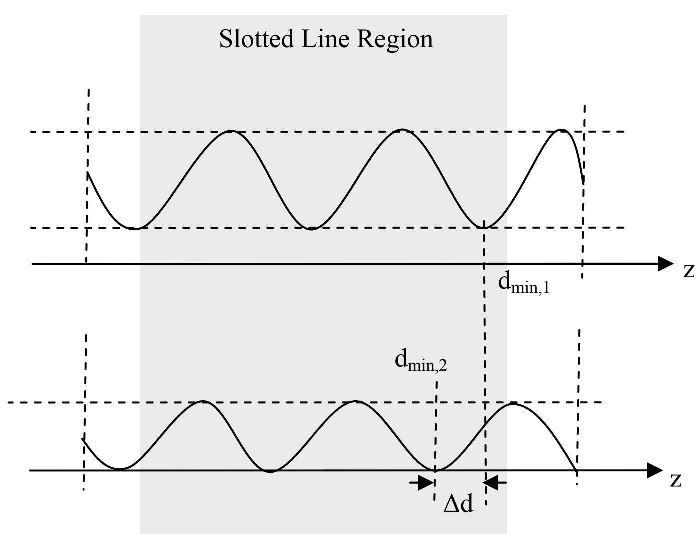
Capacitive Load



<u>SW Pattern with unknown Z_L</u>

<u>SW Pattern with short</u>
Note: shift in min is towards load

Inductive Load



<u>SW Pattern with unknown Z_L</u>

<u>SW Pattern with short</u>
Note: shift in min is towards generator

Figure 3 Measurement of Unknown Impedance

(ii) Network Analyzer Method for Unknown Impedance

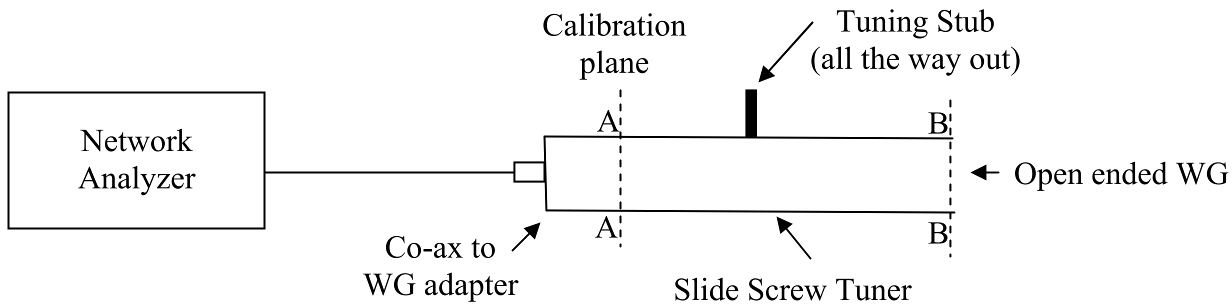


Figure 4 Impedance Measurement

Direct measurement of impedance can be made using the network analyzer. The experimental setup is shown in figure 4.

- At 10 GHz, calibrate the network analyzer for reflection at plane AA..
- Verify the calibration with a short at AA.(Use *Electrical Delay* if necessary)
- Attach the slide screw tuner and take the probe completely out of the WG .
- Place a short at the open end. Use electrical delay to move the reference plane to BB.
- Remove the shorting plate and measure impedance (displayed on the Smith Chart) of the open ended waveguide
- Compare this result with that obtained from slotted line measurements.

Part III Design of Single Stub Tuner.

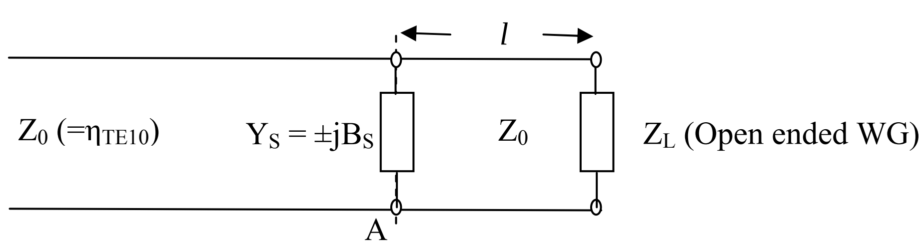


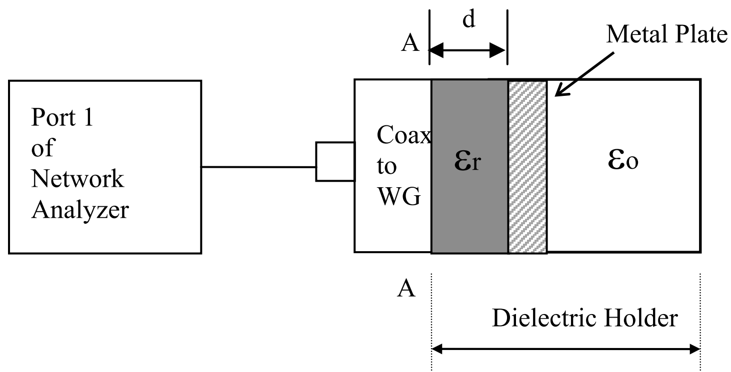
Figure 6 Single Stub Tuner

The single stub tuner uses shunt susceptance ($\pm jB_S$) connected in parallel at distance, *l*, from a load impedance, $\hat{Z}_L$ .The design is to obtain distance, *l*, and $\pm jB_S$ (and hence the required probe depth, d) such that at the plane, AA, of the stub the total impedance, $Z_{T,AA} = Z_0$. The arrangement is shown in figure 6. Design the single stub tuner. Set the probe of the SST to the design values. Measure SWR.(should be < 1.03).

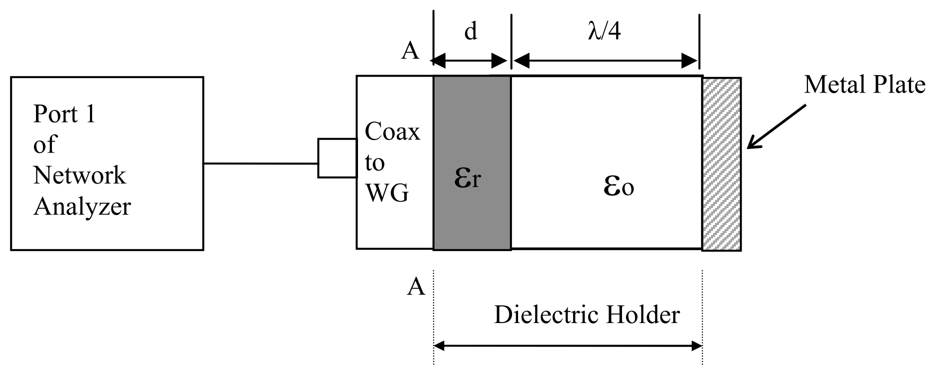
Experiment - V

Measurement of Dielectric Constant

Objective: To determine the dielectric constant of a given material by placing a sample in a rectangular waveguide and solving by using a transmission-reflection concept.



(a)



You are provided with four dielectric samples, two of which have the same dielectric constant but are of different thicknesses.

(i) Calibrate the Network Analyzer at plane AA

(ii) Using a movable short, create the conductor-backed dielectric configuration shown fig (a).

(iii)Measure z_{AA} Obtain $Z_{AA} = z_{AA}\ \eta_{TE_{10}}^{(FS)}$

(iv)Measure z'_{AA} in the configuration shown in (b). Obtain $Z'_{AA} = z'_{AA}\ \eta_{TE_{10}}^{(FS)}$

(v) Calculate the dielectric constant using the following formula

$$\varepsilon_r = \frac{(120\pi)^2}{Z(AA)Z'(AA)} + \left(\frac{f_{c10}^{(1)}}{f}\right)^2$$

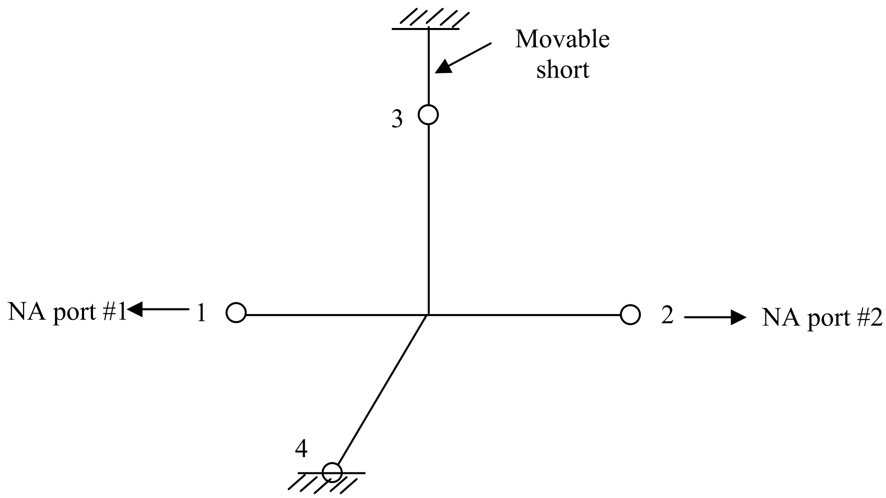
Experiment VI
Design of a Waveguide Phase Shifter

Objective

To design a phase shifter using the Magic Hybrid Tee.
Tomeasure the scattering matrix of the Magic Hybrid Tee.

Procedure

I. Phase Shifter



(i) Calibrate NA for a full 2-port in the X-band.
(ii) Connect the Magic Tee to the network analyzer as shown in fig. 1.
(iii)For four different frequencies (8.5, 9.0, 9.5 and 10.0 GHz) vary the length of the movable short. For each turn, measure the phase angle of S_{21} as follows.

MEASURE
Trans: FWD S21
FORMAT
POLAR
Use the MARKER menu to position markers at each of the desired frequencies.

(iv)Plot a graph of 'ϕ_{21} vs. l / λ_g' for each frequency.
(iv)For each graph superimpose theoretical graphs using the equation derived in Quiz #3.

II.Hybrid Tee Scattering Matrix

Determine the scattering matrix values at four frequencies (8.5, 9.0, 9.5 and 10 GHz).
(Note: Six different configurations as two port measurements will be necessary.

FORMAT
POLAR
MARKER menu to position markers at each of the desired frequencies.
MEASURE
S_{11}, S_{21}, S_{12} and S_{22}

Experiment VII
Waveguide Irises

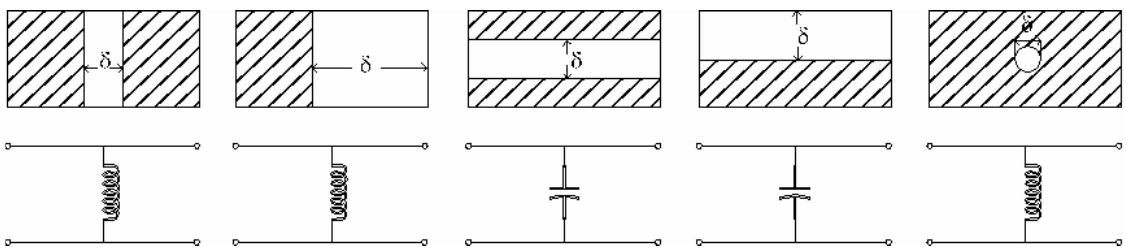
Objective

To measure the susceptance, b_{eq}, of capacitive and inductive irises.

Procedure

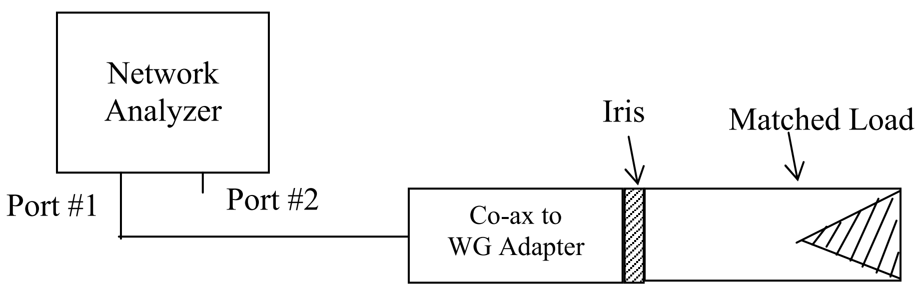
Part 1 Using the Network Analyzer and a Matched Load

1. Calibrate the Network Analyzer for a Full two port
2. Five different type of irises, shown below, are available in the lab, each type as a pair and each set with five different dimensions for δ.



Waveguide Irises and Equivalent Circuits

3. Connect each iris and matched load to the adapter at port #1 of the NA.



4. Do the following.
   MEASURE
      Refl: FWD S11
   MARKER (position markers at 8, 10 and 12 GHz)
   FORMAT
      SWR (record or plot the SWR)
5. Calculate susceptance for each iris and average for each pair.

$$b_{eq} = \pm \frac{(SWR - 1)}{\sqrt{SWR}}$$

6. Compare measured susceptance with graph provided

Part II. Using the Slotted Line and an Adjustable Short

1) Select one iris from each of the five iris pairs; hence, a total of five irises will be used. For each of the five irises, the susceptance at three different frequencies (8.0, 10.0, and 12 GHz) will be determined.

2) For each frequency, the adjustable short must be positioned at an odd multiple of λ_g / 4. Use the Network Analyzer to obtain the proper position.

   Connect the adjustable short to port 1.

   Under the MEASURE menu select: Refl: FWD S11

   Under the FORMAT menu select: SMITH CHART

   Use the MARKER menu to position a marker at a particular frequency.
   To ensure fast tracking select AVERAGING OFF under the AVERAGE menu.

   Adjust the short to obtain an open circuit at port 1.

3) Connect only the adjustable short to the slotted line.
4) Record the position of the reference voltage minimum, l_o, for the particular frequency.
5) Connect an iris and the adjustable short to the slotted line. Record the new position of the voltage minimum, *l*.

   NOTE: The absolute difference between the voltage minimum points, $(l - l_0)$ should not be greater than λ_g / 4.

6) Repeat step 5 for the remaining irises at the particular frequency.

7) Repeat steps 2 - 6 for each frequency.

8) Susceptance values may be calculated using the following equation:

$$b_{eq} = -\tan\left(\frac{2\pi}{\lambda_g}(l - l_0)\right)$$

Experiment VIII
Design and Analysis of a Waveguide Filter and Frequency Meter

Objective: To measure the resonant frequencies of waveguide filters and frequency meters. and to compare with predicted results.

Part A: Waveguide filters

I. Predicted Results

(i)Record the average susceptance value, at 10 GHz, for each iris pair from the data obtained inExperiment 6 on *Waveguide Irises*.)
(ii) Measure the length '*l*' of the waveguide that you will be using to construct the filter (fig 1).
(iii)Using the average susceptance values for an iris pair, calculate the resonant frequencies of each filter.

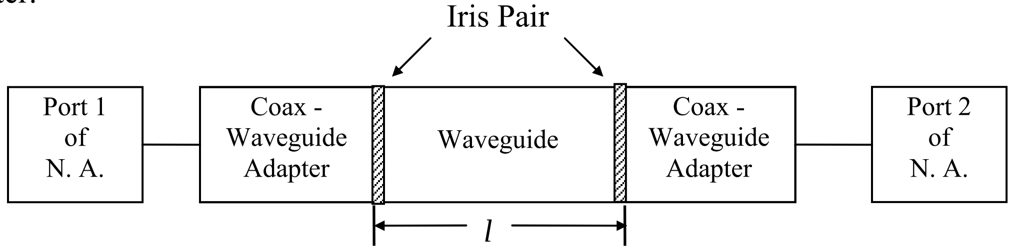


Fig.1 Block Diagram of Waveguide Filter

II. Measurements

(i) Using an identical pair of irises, construct each filter and use the Network Analyzer to plot the forward reflection, S_{11} and the forward transmission, S_{21}, over the frequency range of 8-12 GHz. Using the following steps.
- Calibrate the network analyzer for full 2- port measurements.
- Verify the Calibration
- For each filter, plot S_{11} and S_{21} on the same graph.

DISPLAY
: DUAL CHANNEL *ON*
MORE
SPLIT DISPLAY *OFF*
Select CHANNEL 1
FORMAT
LINEAR MAGNITUDE
MEAS
REFL: FWD S_{11}
Select CHANNEL 2
FORMAT

LIN MAG

MEASURE

TRANS: FWD S_{21}

(Note: Channel 1 and channel 2 have independent vertical axes. To bring both channels into full view, the scaling of the vertical axis may be required.)

Select CHANNEL 1

REFERENCE (adjust until a full view is obtained or use AUTO SCALE)

REFERENCE POSITION,

REFERENCE VALUE,

SCALE/DIV

Select CHANNEL 2 and similarly adjust its vertical axis scaling.

Channel 1 and/or Channel 2 may require averaging/smoothing.

Select the channel

AVERAGE

AVERAGING *(ON)*

SMOOTHING *(ON)*

Place markers at the resonant frequencies.

Be sure to title the plots before printing.

(ii) Referring to the measured data, choose one filter having well defined resonant frequencies. Experimentally determine the susceptance of each iris at each of the measured resonant frequencies. Use the Network Analyzer and a matched load to determine susceptance values.

Calculate susceptance values using the following equation:

$$b_{eq} = \pm \frac{(SWR - 1)}{\sqrt{SWR}}$$

Calculate the average susceptance at each of the resonant frequencies.

(iii)Recalculate the resonant frequencies, of the selected filter, using the average susceptance value obtained in step 2.

Part B: Frequency Meter

I. Predicted Results

1. Record the average susceptance value, at 10 GHz, for each iris from the data obtained in Experimental 6, Waveguide Irises.

2. Using the average susceptance values, calculate the resonant frequencies of each frequency meter to be built from an iris and a short. The length of the waveguide to be used for constructing the filters must be measured. The system is shown in Figure 2.

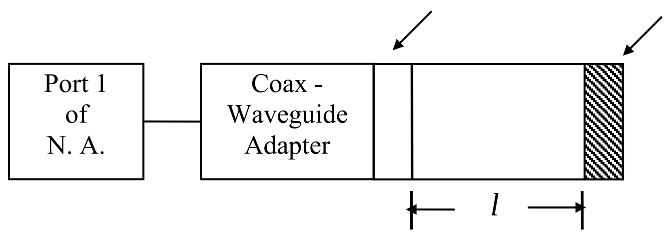


Fig.2 Block Diagram of Waveguide Frequency Meter

II. Measurements

1. Construct each frequency meter and use the Network Analyzer to plot the forward reflection, S_{11}, over the frequency range of 8-12 GHz. Follow the same procedure outlined in part A.

2. Referring to the plotted data, choose one frequency meter having well defined resonant frequencies (most likely the one with the circular iris). Experimentally determine the susceptance of each iris at the resonant frequencies indicated on the plot. Use the Network Analyzer and a matched load to determine susceptance values.

   Calculate susceptance values using the following equation:

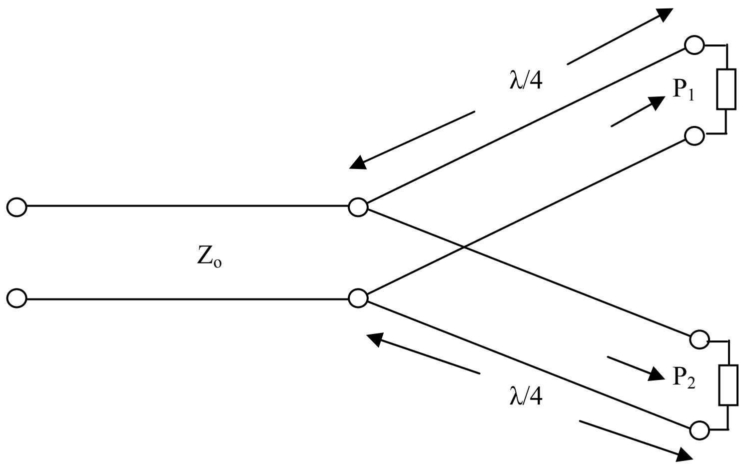
$$b_{eq} = \pm\frac{(SWR-1)}{\sqrt{SWR}}$$

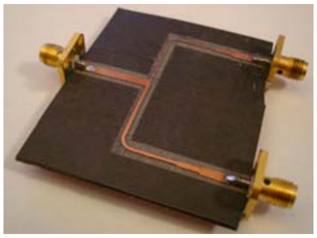
   Calculate the average susceptance at each of the resonant frequencies.

3. Recalculate the resonant frequencies, of the selected filter, using the average susceptance value obtained in step #2

Design Projects

Project I - Microstrip Power Divider for Arbitrary Power Division





(i) *Analytical Development*

For a power division ratio, $\alpha = \frac{P_1}{P_2}$ obtain expressions for Z_{01} and Z_{02}, such that $Z_{TAA} = Z_0$

Answer

$$Z_{01} = \sqrt{Z_0 \; Z_L} \; \sqrt{1 + \frac{1}{\alpha}}$$

$$Z_{02} = \sqrt{Z_0 \; Z_L} \; \sqrt{1 + \alpha}$$

(ii) Theoretical Design

Use Designer, to design in microstrip configuration the power divider shown above.
Frequency, $f = 10$ GHz
Substrate dielectric constant $\varepsilon_r = 2.33$
Substrate thickness, h = 1/32"
$Z_0 = 50\ \Omega$
Use a microstrip patch antenna for the load Z_L

(iii) Construction (coordinated with the entire class)

Layout using CAM350 and submit for chemical etching.

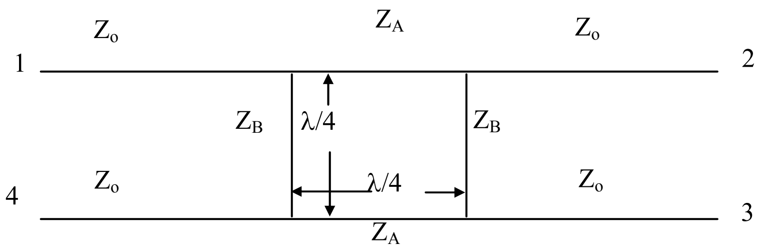
(iv) Testing and Characterization

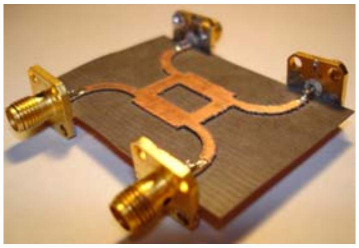
Measure the S-matrix, SWR, Return Loss to validate your design

(v) Report

Submit a complete report to include all of the above.

Project II - Microstrip Hybrid Quadrature for Arbitrary Power Division





(i) *Analytical Development*

Use the even-odd mode analysis to derive design equations for a quadrature hybrid coupler (find Z_A and Z_B)with an arbitrary power division of $\alpha = \frac{P_2}{P_3}$ with input at port #1 (and matched) and port #4 isolated.

(ii) Theoretical Design

Use Designer, to design in microstrip configuration the quadrature hybrid coupler shown above.

Frequency, $f = 10$ GHz
Substrate dielectric constant $\varepsilon_r = 2.33$
Substrate thickness, h = 1/32”
$Z_0 = 50\ \Omega$

(iii) Construction (coordinated with the entire class)
Layout using CAM350 and submit for chemical etching.

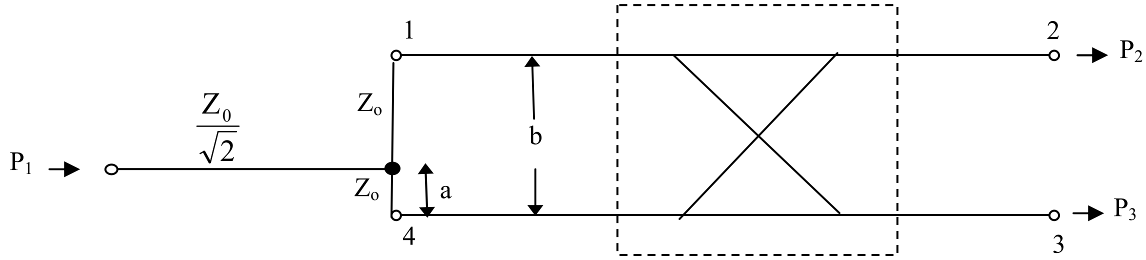
(iv)Testing and Characterization

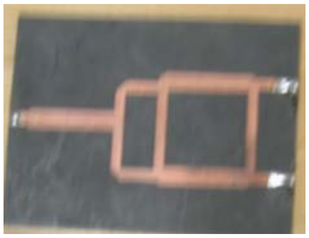
Measure the S-matrix, SWR, Return Loss to validate your design

(v) Report

Submit a complete report to include all of the above.

Project III - Bailey Unequal Split Power Divider





(i) *Analytical Development*
The Bailey unequal power divider uses a 90^0 hybrid coupler and a T-junction, as shown below. The power division ratio is controlled by adjusting the feed position 'a' along the transmission line of length 'b' that connects ports1 and 4 of the hybrid. A quarter wave transformer of impedance $\frac{Z_0}{\sqrt{2}}$ is used to match the input of the divider. For $b = \lambda/4$ the output power division ratio given by $\frac{P_3}{P_2} = \tan^2\left(\frac{\pi a}{2b}\right)$

(ii) Theoretical Design
Use Designer, to design in microstrip configuration the Bailey coupler shown above for

Power ratio $\frac{P_3}{P_2} = \frac{1}{2}$

Frequency, $f = 1$ GHz
Substrate dielectric constant $\varepsilon_r = 2.33$
Substrate thickness, h = 1/32"
$Z_0 = 50\ \Omega$

(iii) Construction (coordinated with the entire class)
Layout using CAM350 and submit for chemical etching.

(iv)Testing and Characterization
Measure the S-matrix, SWR, Return Loss to validate your design

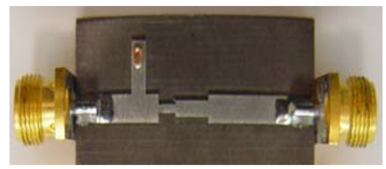
(v) Report
Submit a complete report to include all of the above.

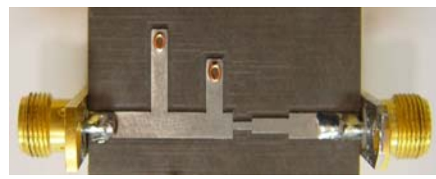
Project IV- Impedance Matching

(i) Analytical Development

Design the following impedance matching circuits to match 100 (Ω) to 50 (Ω) transmission line.

- Single stub tuner using a open circuited 50Ω stub (f = 10 GHz)
- Double stub tuner using open circuited 50Ω stubs placed 0.375λ apart and the first stub 0.125λ from the load. (f = 10 GHz)
- L-C circuit (f = 200 MHz)





(ii) Theoretical Design

Use Designer to design the circuits in microstrip configuration.

Substrate dielectric constant $\varepsilon_r = 2.33$
Substrate thickness, h = 1/32"
$Z_0 = 50\ \Omega$

(iii) Construction (coordinated with the entire class)

Layout using CAM350 and submit for chemical etching.

(iv)Testing and Characterization

Measure the S-matrix, SWR, Return Loss to validate your design

Project V - Low Pass Filter and Band Pass Filter

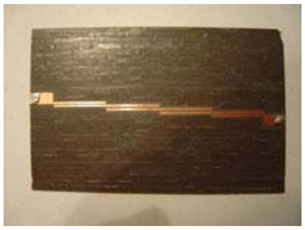
Objective

1.. Use the filter tool in Designer to design the following circuits in microstrip configuration

(a) Stepped Impedance Lowpass Filter

- Cutoff Frequency: 2.5GHz
- Filter Order: 5
- Filter Response: Maximally Flat
- System Impedance: 50Ω
- Stepped Impedance Sections 20Ω ≤ Z_0 ≤ 120Ω
- Relative Permittivity: 2.33
- Substrate Thickness: 31 mils

(b) Coupled Line Bandpass Filter (edge coupled)



- Lower Cutoff Freq: 2.6GHz
- Upper Cutoff Freq: 3GHz
- Filter Order: 5
- Filter Response: Maximally Flat
- Maximum Return Loss: -15dB (in the Passband)
- System Impedance: 50Ω
- Relative Permittivity: 2.33
- Substrate Thickness: 31 mils

(c) (C) Hairpin Bandpass Filter

- Lower cutoff frequency: 5.8 GHz
- Upper cutoff frequency: 6 GHz
- Filter order: 7^{th}
- Filter Response: Chebyshev, ribble 0.1 dB
- System Impedance 50 ohms
- T-line imp., 40 ohms (Z for filter sections)
- Relative Permittivity: 2.33, "Rogers 5870"
- Substrate thickness: 31 mils
- Check box for optimize bandpass corners

2. Import the filter into the circuit simulator and analyze
3. Change the transmission line lengths to optimize the design

(iii) Construction (coordinated with the entire class)
Layout using CAM350 and submit for chemical etching.

(iv)Testing and Characterization

Measure the S-matrix, SWR, Return Loss to validate your design

Project VI - Microwave Circuit

Theoretical Design

Either

Design a microwave circuit to perform a specified task. The circuit should include at least one filter and one power divider from projects 1 through 4

Frequency, f = 2.5 GHz
Substrate dielectric constant $\varepsilon_r = 2.33$
Substrate thickness, h = 1/32"
$Z_0 = 50\ \Omega$

Or

Design a microstrip antenna array. The feed system should include at least one of the components that you have optimized in projects 1 through 4.

Frequency, $f = 10$ GHz
Substrate dielectric constant $\varepsilon_r = 2.33$
Substrate thickness, h = 1/32"
$Z_0 = 50\ \Omega$

(iii) Construction (coordinated with the entire class)

Layout using CAM350 and submit for chemical etching.

.

(iv)Testing and Characterization

Measure the S-matrix, SWR, Return Loss to validate your design

Appendix

CAM350 v9.0 Tutorial by: George Shieh

This is a brief tutorial on how to use the CAM350 program to import multiple gerber data, arrange the layout onto one single layer, and export it into one single gerber file. For a more detailed description of CAM350, please refer to the help file.

I. Getting Started

1) If the panel is 18"x24", the actual working space will be 16.5"x22" due to tooling holes, coupons, and borders. Make sure the units are in English by going to the **Settings** menu, and clicking **Units…**
2) To create a border, go to the **Add** menu, and click **Border**.
3) The bottom left side of the screen should read Border: Enter first point…
4) Input the X coordinate on the bottom left side of the screen, press enter, then input the Y coordinate, and press enter again. Proceed to do this for the next set of points. Right-click any where on the screen when the border is complete.
5) i.e. for the 16.5"x22" workspace
   X: -8.25 Y: -11
   X: -8.25 Y: 11
   X: 8.25 Y: 11
   X: 8.25 Y: -11
   X: -8.25 Y: -11
6) Next, from the **Tables** menu, click **Composites…**
7) Click **Add**, then rename the composite, and click **OK.**

II. Working with Gerber Data

1) To import a gerber file, go to the **File** menu, then to the **Import** sub menu, and click **AutoImport...**
2) Go to the directory with your gerber files, single click any one of them, and click **Next**.
3) Make sure the correct gerber data are selected to be imported, and click **Finish.**
4) Next, from the **Tables** menu, click **Composites…** Make sure the composite that was created earlier is highlighted. Click an available layer number**, i.e. 1**. The Layer list will appear, and then choose your gerber file. Click **Redraw** to verify that the correct layer has been selected. If not, then reassign the layer number. Finally click **OK.**
5) To move the layout, double click the gerber file name on the left hand window. In the **Edit** menu, click **Move**. Push W on the keyboard. Left-click once, drag the mouse to select the entire layout, and left-click again. Push W on the keyboard again. Left-click once to pick up the layout, and left-click again to drop it. Right-click to exit the **Move** mode.
6) All other manipulations in the **Edit** menu are done in the same way.
7) Measurements of length can be done in the **Info** menu, **Measure,** and **Point-to-Point.**

III. Exporting to Single Gerber File

1) To export the completed layout to a single gerber file, go to the **File** menu, **Export,** and click **Composites…**
2) Make sure that the Data Format is RS274-X. Pick the Export path, file name, and make sure that **EXP** is checked. Finally, click **OK.**

B. The 8720B Network Analyzer

To learn the following on the Network Analyzer (NA):

(a) To create a new CALKIT for waveguides
(b) To calibrate in the x-band for full 2-port
(c) To save both of the above on disk

(i) Create a User CALKIT for Waveguide Measurements

CAL
    MORE
        SET z_o *(Enter appropriate value)*
        RETURN
    CAL KIT [3.5 mm]
        MODIFY [3.5 mm]
            DEFINE STANDARD *(Enter number)*
                SHORT
                    SPECIFY OFFSET
                        OFFSET DELAY *(Enter value)*
                        OFFSET LOSS "
                        OFFSET z_o "
                        MINIMUM FREQ. "
                        MAXIMUM FREQ. "
                        WAVEGUIDE "
                        STD. OFFSET DONE
                    LABEL STANDARD
                        ERASE TITLE
                        SELECT LETTER *(Enter label)*
                        DONE
                    STD. DONE (DEFINED)
            DEFINE STANDARD *(Repeat for as many stds.)*
            SPECIFY CLASS S_{11} A
                SPECIFY: *(Press proper class)*
                    (Enter calibration standard # for all loads)
                CLASS DONE (SPEC'D)
            LABEL CLASS XSHORT 1
                LABEL: *(Press proper class)*
                    ERASE TITLE
                    SELECT LETTER *(Enter label)*
                    DONE
                LABEL DONE
            LABEL CLASS *(Repeat for rest)*
            LABEL KIT
                ERASE TITLE

SELECT LETTER *(Enter label)*
DONE
KIT DONE (MODIFIED)

SAVE USER KIT
RETURN

Standard		Offset			Frequency (GHz)			
No.	Type	Linear Delay (psec)	z_o (Ohms)	Loss	Min	Max	Coax or Wave-guide	Standard Label
1	$\lambda/8$ short	16.187	1	0	6.557	13.114	W/G	xshort1
2	$3\lambda/8$ short	48.560	1	0	6.557	13.114	W/G	xshort2
3	Load (fixed)	0	1	0	6.557	13.114	W/G	xload
4	THR11	0	1	0	6.557	13.114	W/G	thru

Table 1 Standard Definitions

Standard Class	Standard Number(s)	Class Label
s_{11} A	1	xshort1
s_{11} B	2	xshort2
s_{11} C	3, 5	xload
s_{22} A	1	xshort1
s_{22} B	2	xshort2
s_{22} C	3, 5	xload
Forward Transmission	4	thru
Reverse Transmission	4	thru
Forward Match	4	thru
Reverse Match	4	thru
Frequency Response	1, 2, 4	response

Table 2 Standard Class Assignment

(ii). **Calibration Procedure for 8720B Network Analyzer**

START *(Enter appropriate frequency range)*

STOP *(Enter appropriate frequency range)*
RECALL
    LOAD FROM DISK
        LOAD __________ *(Load proper CALKIT)*
        RETURN
CAL
    CAL KIT __________
        CAL KIT : *(Press USER KIT)*
        RETURN
    CALIBRATE MENU
        CALIBRATE: *(Press FULL 2-PORT)*
            REFLECT'N
                (Connect std's and press key)
                (Standard names should appear as in CAL KIT)
                LOAD
                    LOAD
                    DONE: LOAD
                REFLECT'N DONE
            TRANSMISSION
                (Connect ports and press keys)
                (Standard names should appear as in CALKIT)
                TRANS. DONE
            ISOLATION
                OMIT ISOLATION
                ISOLATION DONE
            DONE 2-PORT CAL

The SAVE menu will automatically be displayed.
The calibration data must be stored in a register.

TITLE REGISTER
    TITLE __________
        ERASE TITLE
        SELECT LETTER *(Enter appropriate title)*
        DONE
    RETURN
SAVE

Next Store the data on disk.

STORE TO DISK
    TITLE FILES
        COPY FROM REG. TITLES
        RETURN
    STORE _________