Development of Antenna Starter Kits for Remote Education Antenna Laboratory (REAL) to Enhance Undergraduate Electrical Engineering Education

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Outline

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- Motivation
- Remote Laboratory Background
- Description of the Facility
- Operational logistics
- Antenna Starter Kits Development
- Development of Instructional Manual
- Summary and Future Work

Electromagetics and Antennas Education

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- Students can build things after 1 or 2 semesters of circuits or controls Course
- Students can rarely build anything after 2 semesters of electromagnetics!
- Common impression: abstract, mathematical, of little practical use
- Antenna is an integral component in a wireless communications and can be practically realized
- Many universities offer Antenna course/contents at undergraduate level as part of EM education

Antennas as a Solution

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- Many antennas are simple to make
  - Wires Antennas and Arrays

    (Omni-directional/Directional radiation patterns)
  - Printed Microstrip Antennas and Arrays (Aperture type antennas and Arrays (for high Gain) with Directional radiation Patterns)
- But they are hard to test (beyond SWR)
- Consequently most antenna courses with projects use simulation only

Proposed Solution: the Remote Educational Antenna Laboratory

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- Antenna “starter kits” available at low cost (designed by SDSU)
- Anechoic chamber available for scheduling and use by students and educators (CMU)
- Live control of the chamber and instruments via the web
- Provides opportunity for “hands-on” experience in antenna construction and the next best thing to “hands-on” for testing

Remote Laboratories for Education

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- Training for real-world experiences
- Resource leveraging
  - instrument sharing between schools
  - secure after hours use of existing equipment
- Enhanced Classroom demonstrations
  - avoids logistical difficulties of setting up demo in class
  - allows students to play with demo after class at their leisure
- Enables lab component for distance education

REAL Facility Description at CMU
(D. Stancil)

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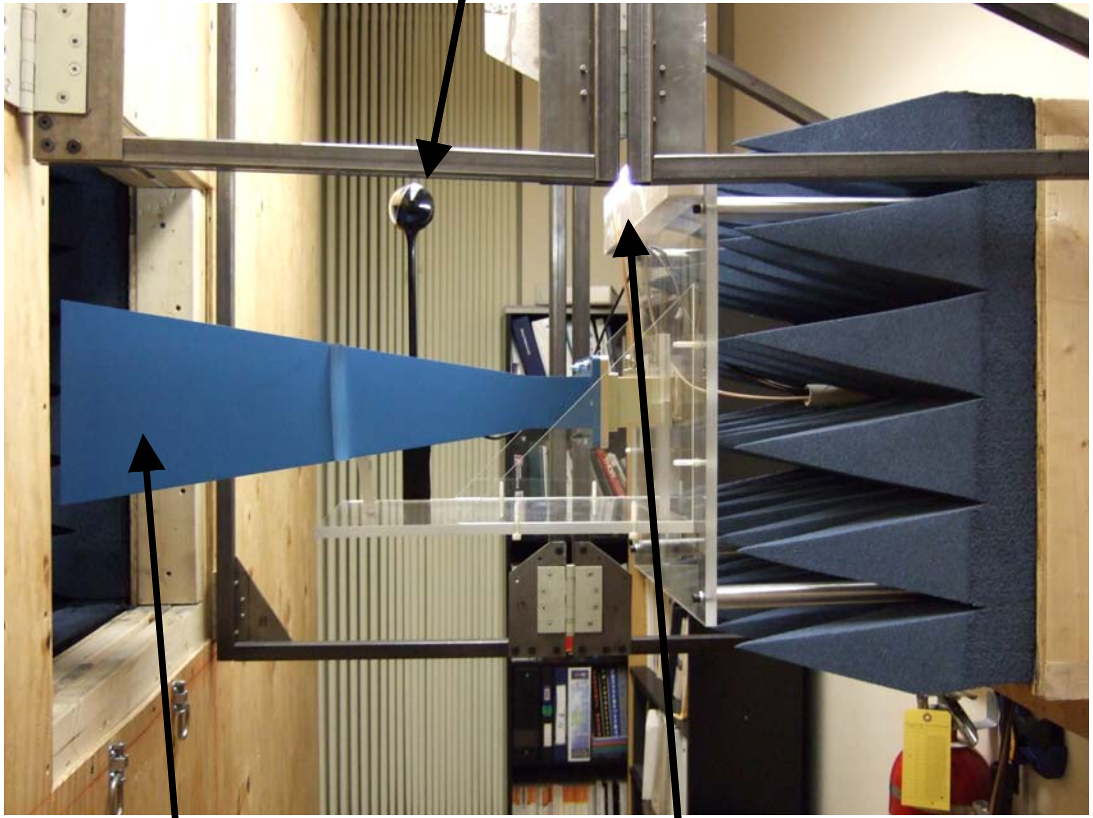
- Rectangular chamber 10'x18'x10'
- Designed for -40 dB quite zone VSWR above 2 GHz by Cuming Microwave
- Presently has a single axis of rotation
- Instrumentation available to 9 GHz
- Presently configured for 1-3 GHz measurements
- Available measurements:
  - Return Loss with frequency
  - Azimuth and Elevation patterns
  - Gain by comparison with standard

Chamber Antenna Mount
(D. Stancil)

Web cam



Chamber Antenna

Light

Screen Capture from Webcam (D. Stancil)

Measurement Interface
(D. Stancil)

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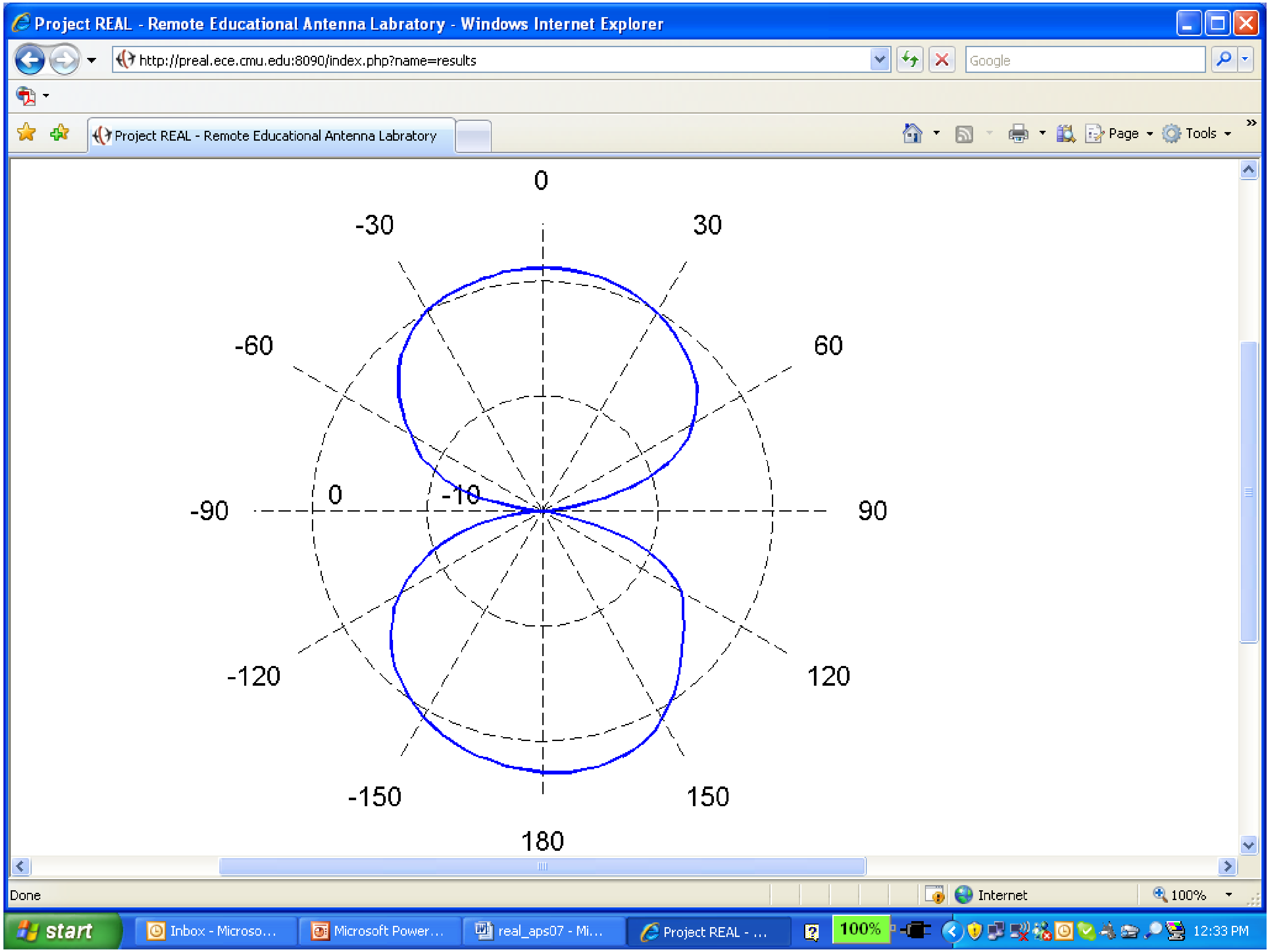
Pattern from "homemade" Dipole

(D. Stancil)



Anticipated Usage Logistics

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- Antennas fabricated at local institutions & time scheduled on facility
- Antennas shipped to CMU prior to scheduled time
- Antennas mounted in chamber by CMU student/technician
- Remote students take control of the chamber measurements
- Antennas returned to students
- All antenna designs and measurements taken with the facility will become part of a publicly-available data base

Antenna "Starter Kits" Development

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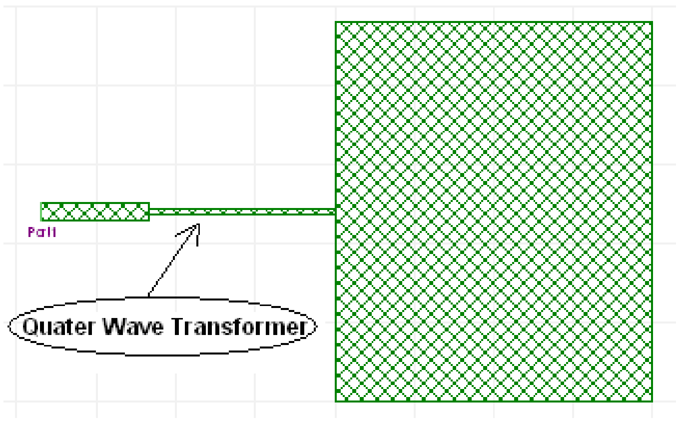
- Basic kit of parts to make simple antennas
- Includes instructions and example designs
- Available at low cost
- Examples: Patch Antenna



Antenna "Starter Kits" Development

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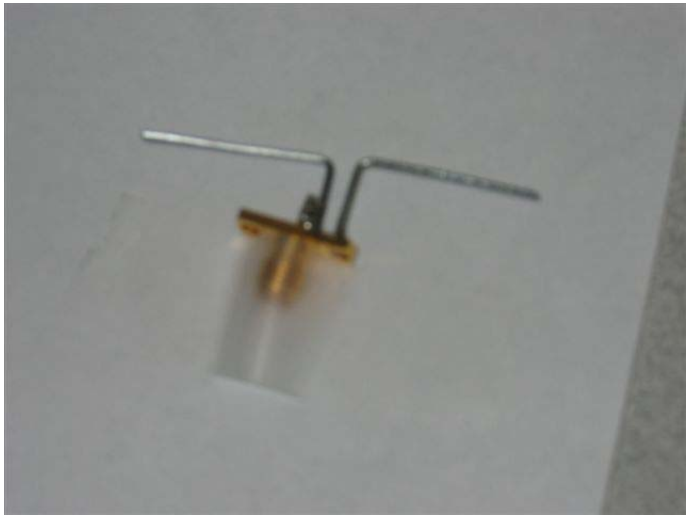
- **Antennas Under Developed (Frequency: between 2 to 3 GHz):**
- Rectangular Microstrip Antennas (Coaxial probe/microstrip line fed)
- Circular Microstrip Patch Antennas (Coaxial probe/microstrip line fed)
- Corporate fed Microstrip Linear/Planar Array Antennas

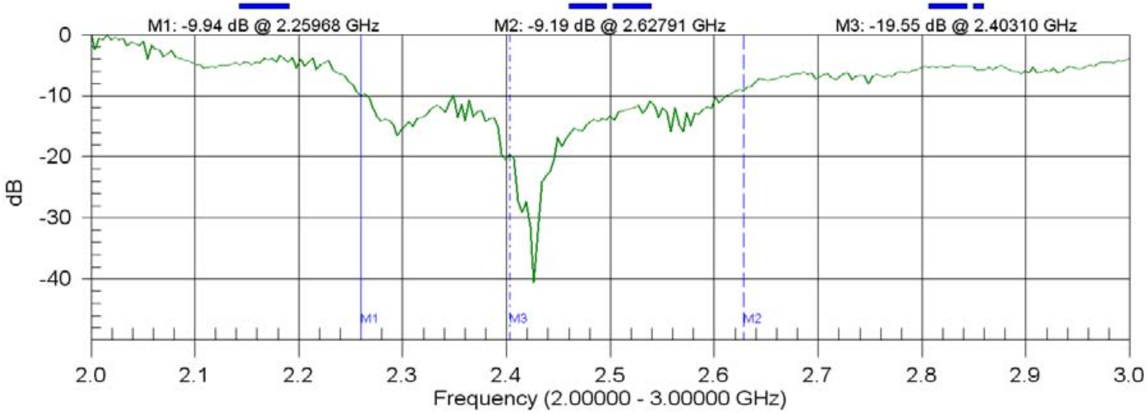
- Monopole Antenna
- Dipole Antenna
- Wire Rectangular Loop Antenna
- Wire Circular Loop Antenna
- Yagi-Uda and Log-Periodic Wire Antennas

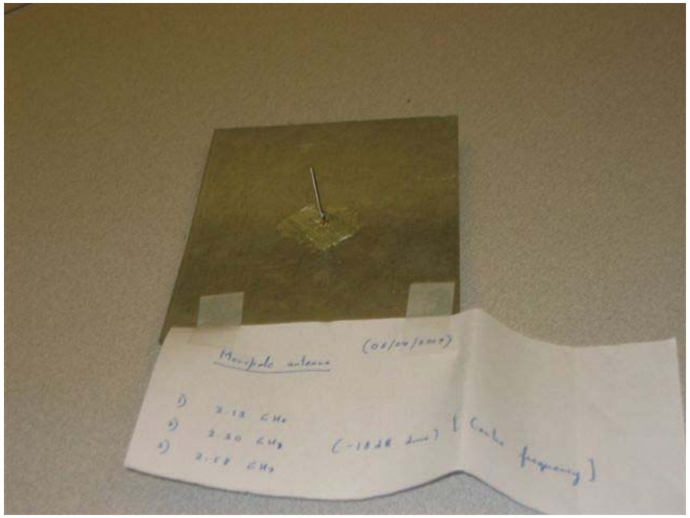
- **Design Tools:** Ansoft HFSS 10, Ansoft Designer 3.0, PCAAD v5, MININEC

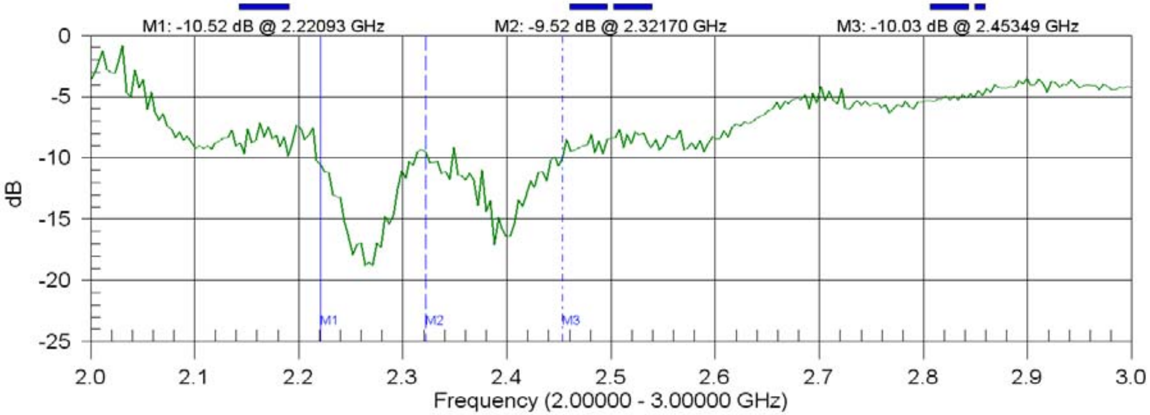
- **Fabrication Material:** Rogers 5880, FR-4, Cuming Foam, Copper Tape, Wire, Metallic sheet, SMA connectors

Antenna “Starter Kits” Development









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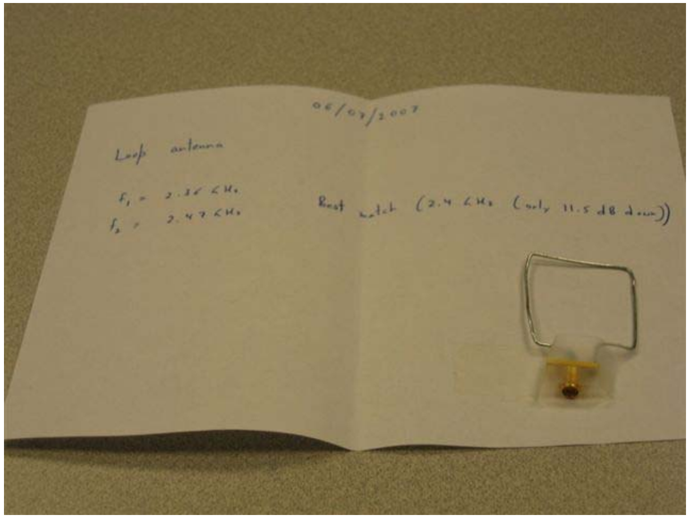

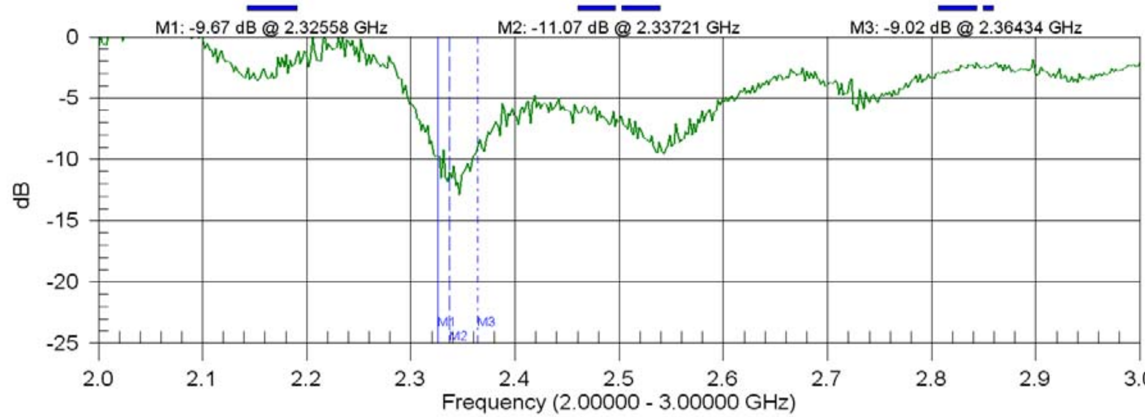

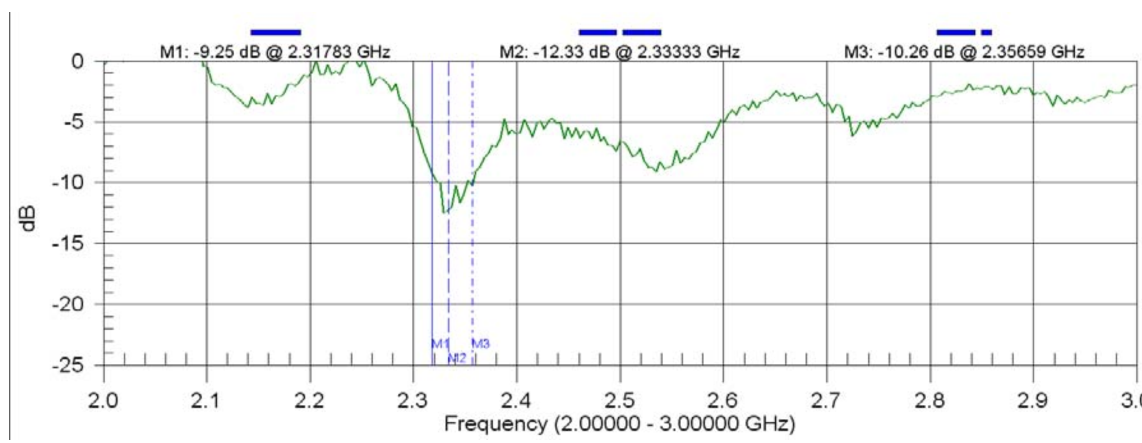

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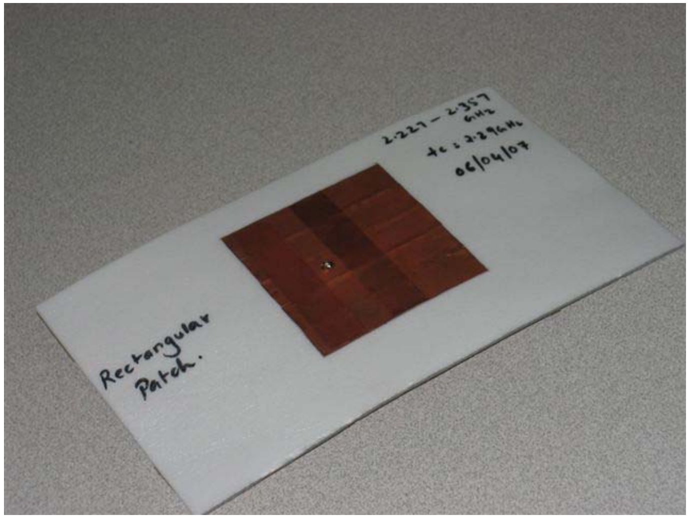

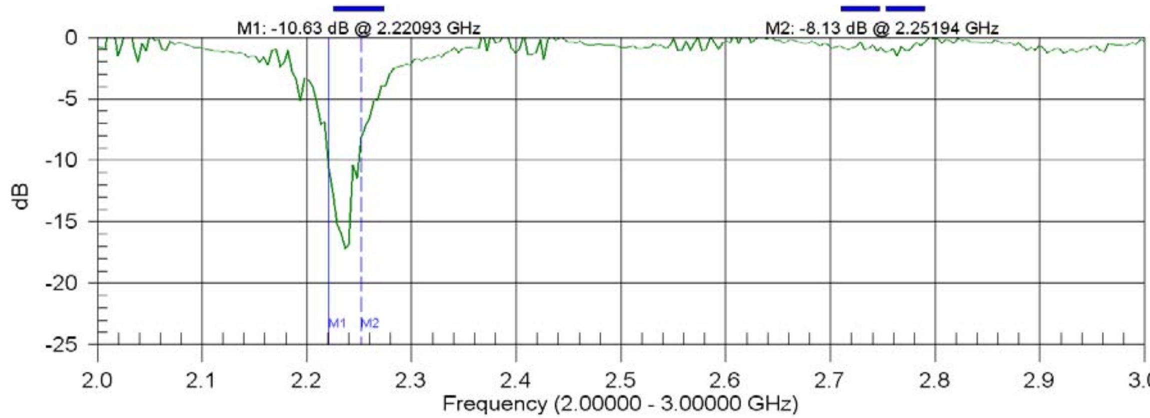

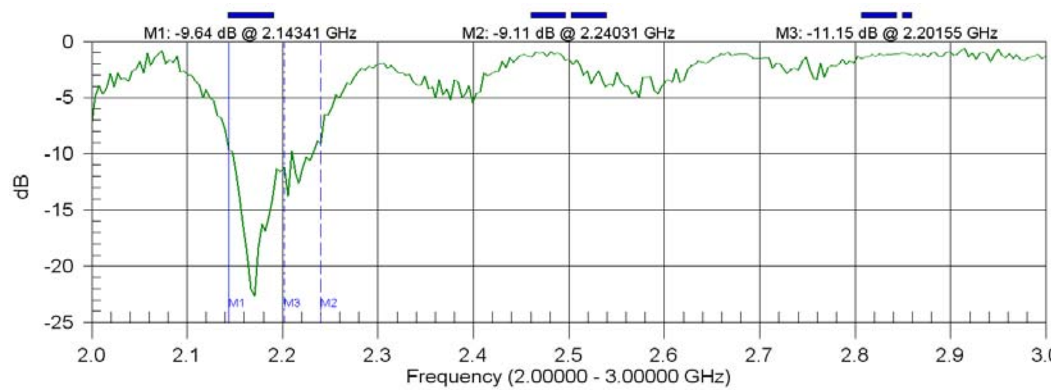

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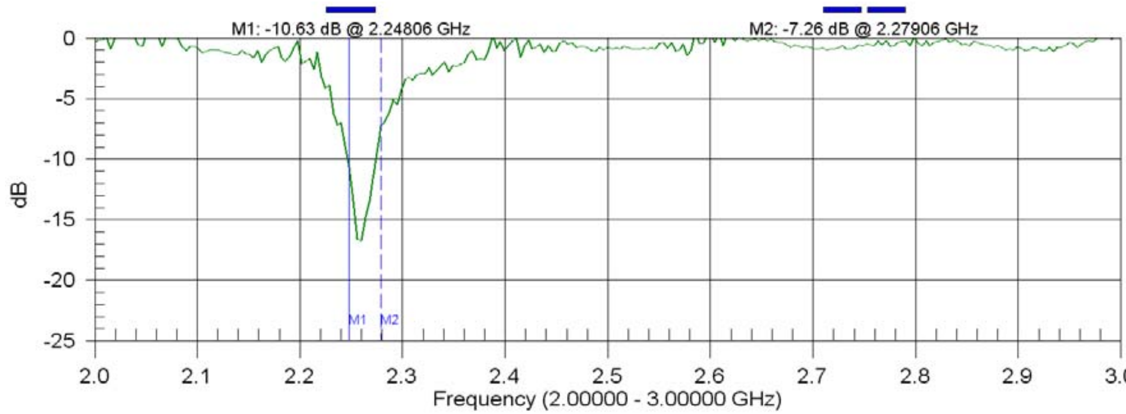

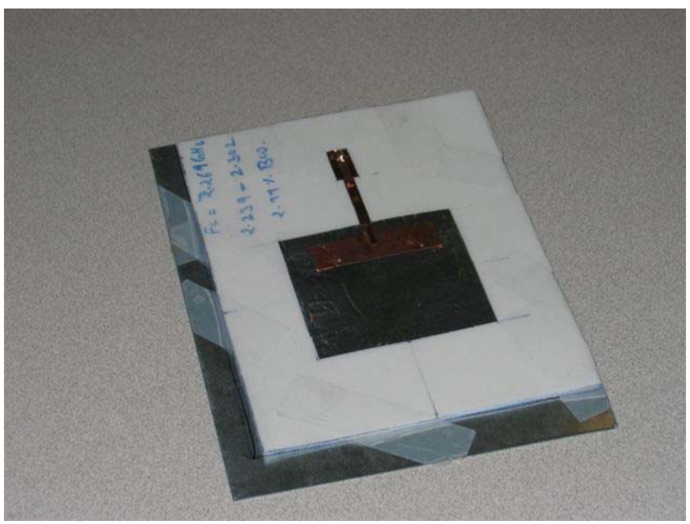

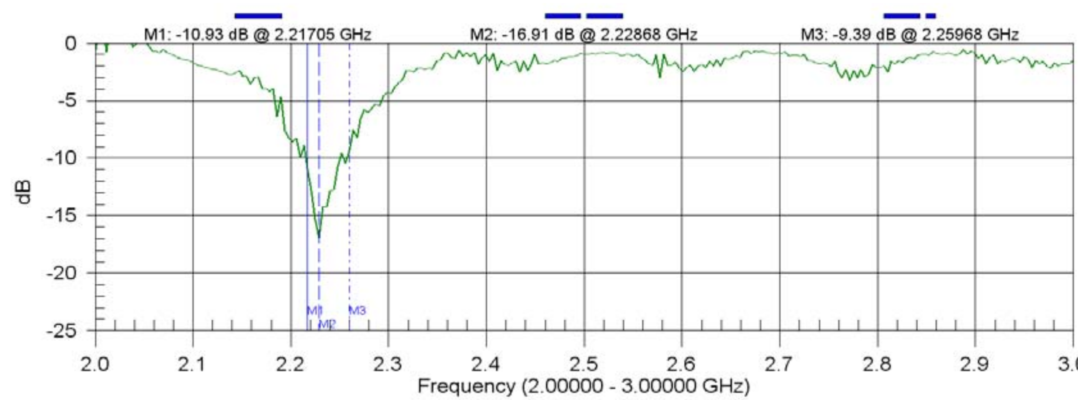

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Experiment No. 6

Microstrip Rectangular Patch using microstrip line feed

Objectives: To study the impedance characteristics and radiation pattern behavior of Microstrip Rectangular Patch antenna using microstrip line feed.

Theory: Microstrip antennas are low profile, conformal to planar and non planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology and mechanically robust when mounted on rigid surfaces. Rectangular patch is by far the most widely used configuration as it is easy to fabricate and analyze. Patch antennas can also be fed through microstrip line feed. This feed technique is also simple to implement and also widely used. For matching of the patch and line feed, a quarter wave transformer is used between the two. The dimension of the quarter wave transformer is calculated using the estimator function in Ansoft designer software. For this the output load i.e the patch impedance and the input load i.e the line impedance needs to be specified. Generally a 50 Ω line impedance is used.

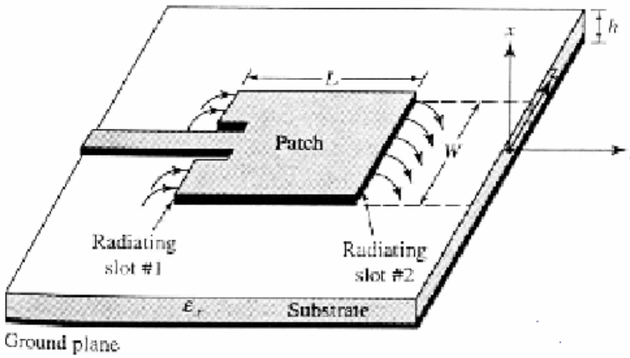

Figure (a): Microstrip Rectangular Patch [1]

For the design of microstrip rectangular patch the dielectric constant of the substrate 'Єr', the resonant frequency 'f_r'and the height 'h' of the substrate are generally pre-selected. The design procedure/equations are as follows [1]:

1) First the width 'W' of the patch is calculated using the following formula.

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}}$$

2) Then determine the effective dielectric constant of the microstrip antenna.

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$$

3) Then the extension of the length ΔL is determined using the given formula.

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

4) The actual length is calculated using the formula.

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L$$

Note: Above formulas can be found in "Antenna Theory: Analysis and Design" 3rd edition book by C.A. Balanis, John Wiley and Sons, INC.

Design Parameters: In this manual a design frequency of 2.4GHz is selected, as most of the wireless communication applications lie around this band. The following are the values of the design parameters for three different substrate.

Case I: FR4
1) Length 'L' = 29.5mm
2) Width 'W' = 37.68mm
3) Quarter wave Transformer dimension = 24mm * 0.7mm
4) Dielectric Constant 'Єr' = 4.4
5) Substrate Height 'h' = 1.58mm
6) Tangent Loss δ = 0.0001

Case II: Foam
1) Length 'L' = 61.375mm
2) Width 'W' = 62.5
3) Quarter wave Transformer dimension = 25mm * 2.1mm
4) Dielectric Constant 'Єr' = 1
5) Substrate Height 'h' = 1.58mm
6) Tangent Loss δ = 0.0001

Case III: Rogers RT Duroid 5880
1) Length 'L' = 41.8mm
2) Width 'W' = 49.41mm
3) Quarter wave Transformer dimension = 23.54mm * 0.7mm
4) Dielectric Constant 'Єr' = 2.2

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6) Tangent Loss δ = 0.0001

Fabrication Material and Methodology: Though three design parameters are presented only foam is used. For this we need foam material, copper tapes, SMA connector, scissors, knife, soldering iron and soldering wire. Steps for fabrication are as follows:

Step 1: Take foam material of dimensions double the required length and width of the patch

Step 2: Sketch the outline of the patch, quarter wave transformer and line feed on one side of the foam.

Step 3: Stick copper tapes for the outline drawn.

Step 4: Stick copper tapes on the other side which denotes the ground plane. The backside is then the ground plane.

Step 5: Drill a hole at the end of the microstrip line feed and insert a SMA connector and solder it. Or a edge port connector can be used.

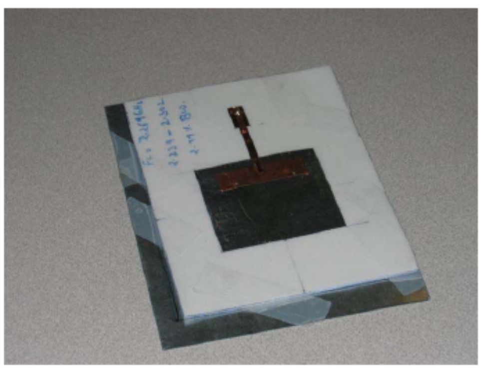

Figure (a): Microstrip Rectangular Patch using Microstrip line feed on Foam substrate

It is easy to fabricate using foam substrate. Students may select to design their antennas on FR4 and Roger substrate, but will need milling or chemical etching for fabrication

Simulation Result: HFSS, PCAD and Ansoft Designer are the software’s which can be used for simulation. Based on the availability, Matlab code can be written by the students. Ansoft Designer is the software used for simulation in this manual.

Ansoft Designer

- Simulation is done using Moment Method (MoM).
- Designer employs the mixed-potential integral equation method (MPIE).
- It is a Full Wave model.
- It is very accurate, very versatile and can treat single elements, finite and inf arrays, stacked elements, arbitrary shaped elements and couplings.

The simulated results for the rectangular patch using foam substrate are as follows [2]

1) Return Loss Vs Frequency

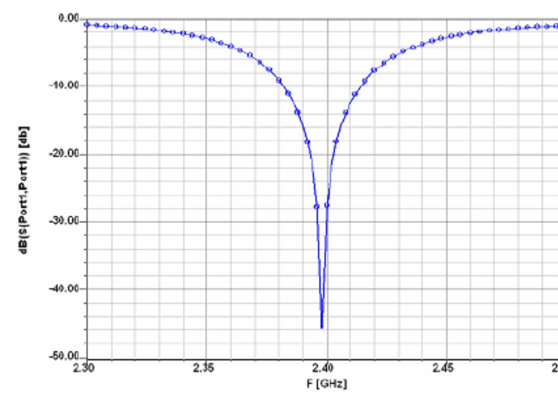

Figure (b): Return Loss Vs Frequency

2) Smith Chart

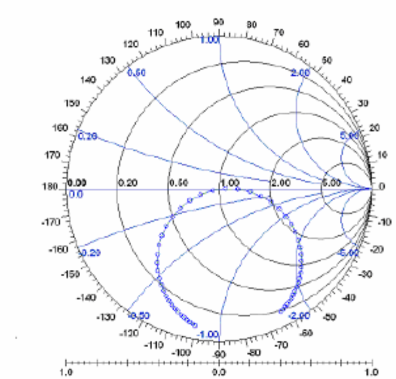

Figure (c): Smith Chart

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3) Radiation Pattern (Gain Accepted)

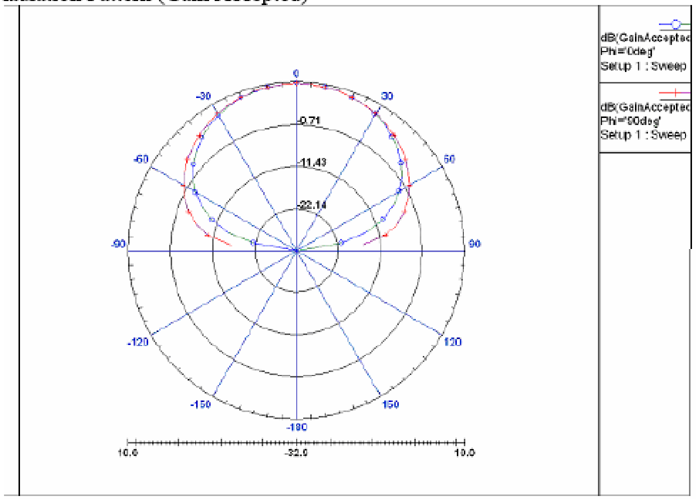


Figure (d): Radiation Pattern

4) Gain Plot

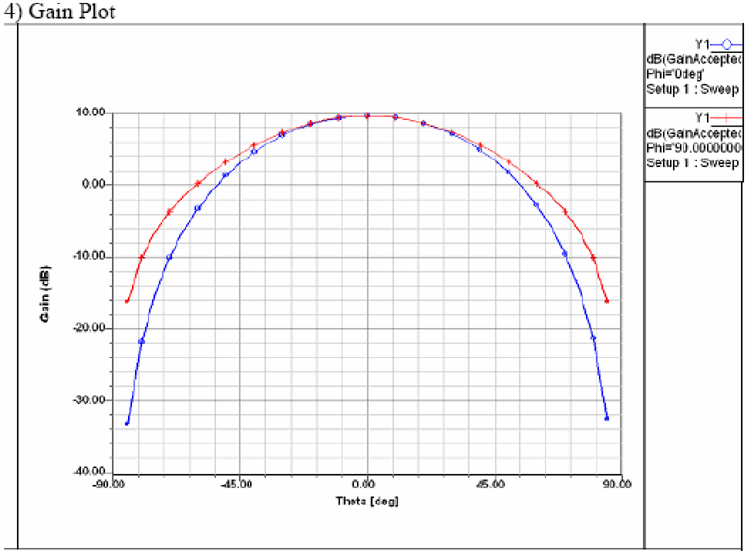


Figure (e): Gain Pattern Plot

Measurement Verification: The return loss measurement verification is done using Network Analyzer. The radiation patterns are measured at Remote Educational Antenna Laboratory (REAL) at Carnegie Mellon University, Pittsburgh, Pennsylvania. The measured results are as follows:

Return Loss Plot

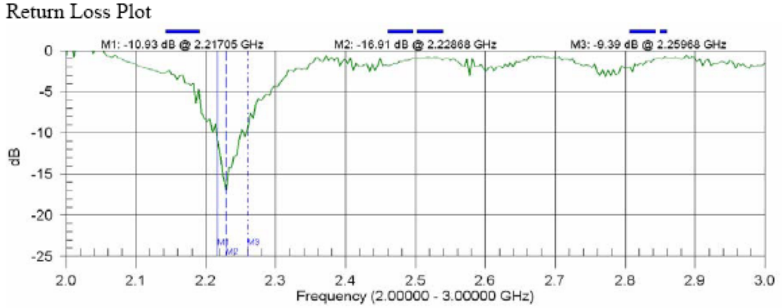


Figure (f): Measured Return Loss

Radiation Pattern

Waiting from CMU

Conclusion and Discussion: From the return loss plot, in the simulated result the resonance is at 2.397 GHz while in case of the measured result it is at 2.22GHz. Also the graph is smooth in case of the simulated result than the measured one. The disagreement between the simulated and measured data is due to the error in fabrication as it was hand made. This experiment shows that it is easy to fabricate a rectangular patch using foam substrate but at the expense of some losses.

Future Study

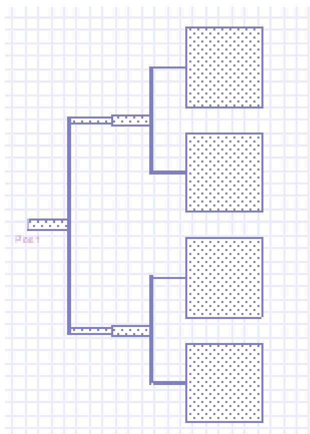
1) Calculate the width of a 100 Ω line.
2) In a patch where it is high impedance? At the edge of the patch or at the center.
3) What should be done to get circular polarization using microstrip line feed technique?
4) List the importance of quarter wave transformer. Whats the consequence if the quarter wave transformer is not used?

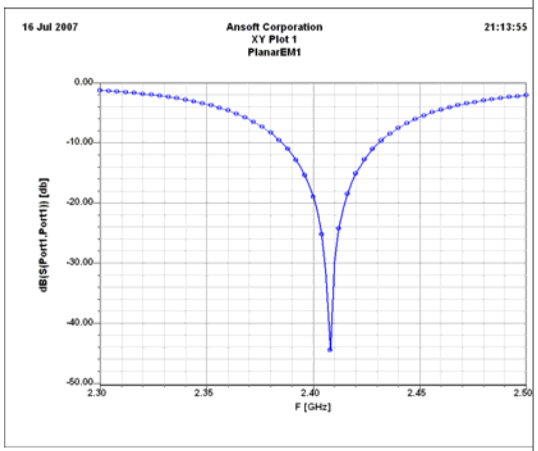
Reference

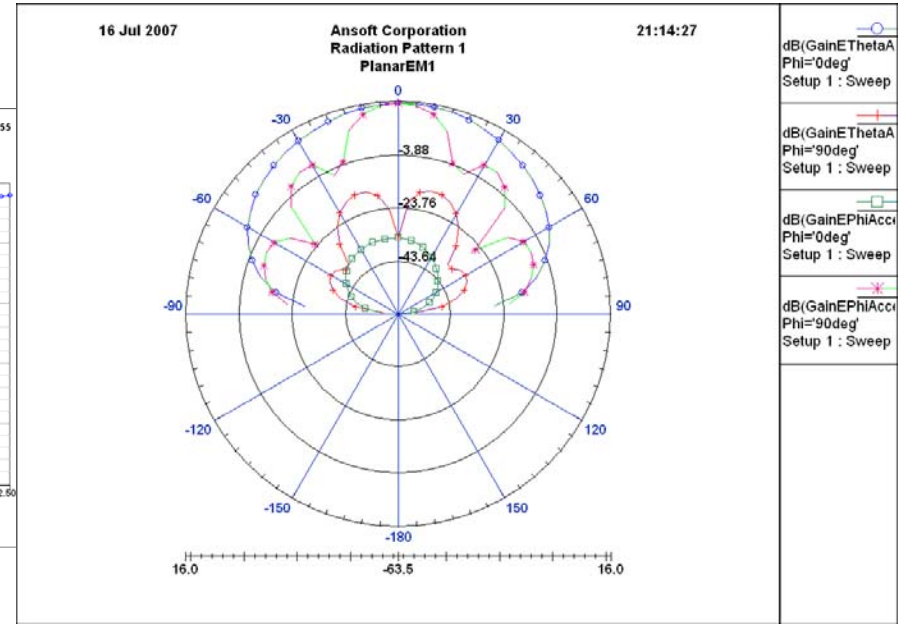
[1] "Antenna Theory: Analysis and Design" 3rd edition book by C.A. Balanis, John Wiley and Sons, INC.

[2] Ansoft Designer v3.0

Future Antenna and Instruction Manuals







Under Development

- **Planar (4x4) microstrip array antenna**
- **Yagi-Uda Antenna**
- **Log-Periodic Antenna**

Summary

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- Some Antenna Starter Kits are ready
- Remote Educational Antenna Laboratory operational (http://preal.ece.cmu.edu)
- Will be used in for teaching Antenna course in coming semester as a TEST
- Anticipated Schedule:
  - Beta testing during AY07-08
  - General scheduling AY08-09