Hardware Project-Based
Microwave Engineering Education

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Example Project 50 MHz 10 mW Sig Gen

Analyzed in class Winter 2009

Commercial Product here:

www.kangaus.com/6and2_meter_cw_source.htm
Educating an Engineer

Prerequisites:

Curiosity
Math
Physics
Familiarity with stuff

Engineers use math, physics, and experience to build models

Use model to understand and optimize “The Real Thing”
All of these are Models:

Analysis
examples: equation of motion, Ohm’s law

Graph
examples: Periodic Table, Smith Chart

Simulation
when there are too many interacting variables
examples: LTspice, EZNEC

Hardware
examples: circuit block, Indy car, RC plane
Ironic Note:

In Engineering, the model is often more expensive than the real thing....
What do we do with Models?

Get them working

Validate them against reality

Break them

Think about them

Evolve them

Use new model to improve solution to real problem

Engineer’s essential tool in applying the Scientific Method
In modern Engineering Education, we emphasize Analysis, simulation, and lovely graphs presented in Power Point Presentations.

But the art of the hardware model has fallen from favor--a victim of perceived expense and academic demographics.

Analysis, simulation, and lovely graphs without working hardware are scholarly, but irrelevant.

Playing with Hardware without analysis, simulation, and graphs of model vs. measurement is tinkering.

A person who embraces all of the above is scholarly, relevant, enjoys work, and can probably get your car running again by tinkering under the hood.
How do we learn?

Role of Hardware in Learning

What comes first, and when?

Hardware first:
   Cool! How does it work?

Analysis first:
   Cool! How can I apply this?

“Active Learning”
Honorable Mention:

Dave Rutledge at Cal Tech

Use of the Norcal 40 HF transceiver to teach undergraduate Electrical Engineering

Zoya Popovic at UC Boulder

Project Based RF Design course, with 40+ new amateur radio licenses in the past year alone

Robert Caverley at Villanova

A decade of using RF hardware projects in undergraduate teaching.
And the winner is....

(arduino synthesized drum roll)
And the winner is....

the students, of course.
Project Example -- Directional Coupler Design

Pre-CAD era:

Signal Flow Graphs, Even-mode Odd-mode transmission line theory, S-matrix, Linear Algebra....

Post-CAD era:

We go straight from Maxwell’s equations to basic RLC circuit theory, and from there quickly to a complete, buildable design.

Then use 3D EM simulator to implement our basic understanding in guided wave hardware.
Since this is a presentation and not a class, we’ll skip the Maxwell’s equations, vector calculus, and complex algebra, but make a few observations:

**Inductance is a volume in space with Magnetic fields.** We calculate inductance by integrating over the volume—not the wire.

**Capacitance is a volume in space with Electric Fields.** We calculate capacitance by integrating over the volume—not the metal plates.
Project Example -- Directional Coupler Design

Textbook Microstrip Directional Coupler

In the coupled region, the E fields and H fields of the transmission lines interact.

Port 1

Port 2

Port 3

Port 4
To analyze, terminate all ports in characteristic impedance $R$. 

![Diagram of a network with ports 1, 2, 3, and 4, and a source and load connected to the network. The diagram shows the network configuration with impedance elements.]
Now replace the microstrip version with a circuit model:

H field coupling is modeled with a coupled inductor

E field coupling is modeled with a capacitor

“Active Learning”
Now that we have an elementary circuit model, we can use superposition to treat the E and H behavior separately. Start with H:
Bearing in mind that what we want is the voltage drop across the coupled branch inductor, start redrawing, using circuit basics and what we know about transformers:
Now replace the coupled inductor model with a simplified model:

What would a more complete 1:1 transformer model include?

Note how much more information this simple transformer model provides than the usual rule of thumb $xL > 10R$. 
In this circuit model, the ideal 1:1 transformer does nothing.

Note: 1:1 transformers are common in cost-driven applications from near DC to THz. Why?
Finally, invoke Thevenin equivalent circuit to obtain simple circuit model for the voltage drop across the inductor:

Exercise for the student: write the expression for $V_L$
Now, on to E, bearing in mind that what we want is the voltage on the coupled branch due to the E field:
Again, invoke Thevenin equivalent circuit:
We obtain an equally simple circuit to find the voltage drop across the capacitor:

Exercise for the student: write the expression for $V_c$

In these simple circuits it is trivial for the EE student to obtain currents from voltages using ohms law
It is less trivial when those currents and voltages are substituted back into the original R C coupled L network...

...but it is still a basic circuit analysis problem, and a few pages of careful algebra provide a result that agrees with the LTspice simulation.
Observe the E (capacitor) and H (inductor) currents that flow in the coupled branch:

Solid line is E coupling and dashed line is H coupling. Note the polarity of the resulting voltages across the resistors R.
For an enjoyable afternoon puzzle, find the relationship between L, C and R such that the voltages cancel at port 4.

The surprising result is that cancellation at port 4 is independent of frequency over a very wide range.
Now obtain the voltage at port 3 under the R, L, and C constraint...wait...you’re still working on the last puzzle?

Hint: the voltage at port 3 rises at 6 dB per octave when a small amount of signal is coupled.

Why is it only 6 dB/octave with both E and H coupling?
If the coupled port output increases at 6dB/octave, how does a Bird Wattmeter have a flat response from 3 - 30 MHz?

What’s in the black box?
Bird Wattmeter measuring forward power into load $Z$

detector diode

50 uA meter

$Z$

RC
Bird Wattmeter measuring reflected power from load Z

Pretty cool! Now you can make your own custom Bird Wattmeter elements
Null when: \[ L = R^2 C \]

The Dark Side of Measurements.....
About 5 years ago a student designed and built a one-port network analyzer to tune up the input circuit of his class project receiver.

Another student connected the class receiver and transmitter to a half wave dipole and communicated with another station 60 miles away.

Two students guest lectured, one speaking while the other started from scratch and built the complete working project.
Exercise: Design, build, and measure a directional coupler forward and reverse power sensor to optimize a 50 MHz antenna driven by a 10 mW signal source.
Thank you for your attention and participation. Come down and visit me at my Office at Portland State University:

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