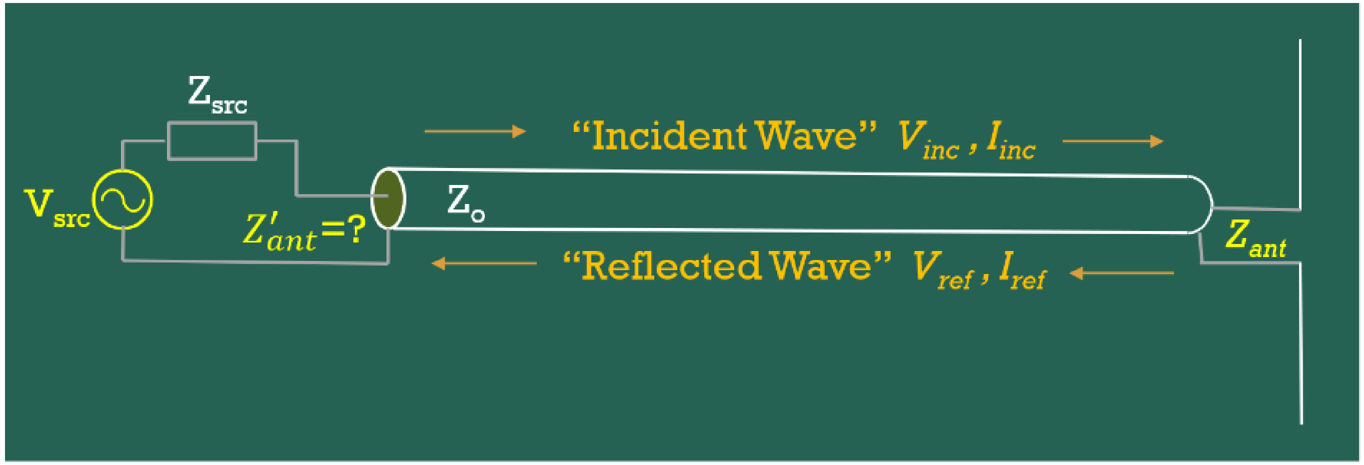
Radio Design 201 Microwave Circuits and Antennas

Episode 7, Part 1 – Antennas and Feedline Systems

Slides downloaded from: https://ecefiles.org/

Companion videos at: https://www.youtube.com/playlist?list=PL9Ox3wpnB0kpOb7NdpHAK-jDpsZm3Xedx

This video focuses on impedance matching between transmission lines and antennas - concentrating on the different measurements involved, including reflection coefficient, S11, Return Loss, and SWR. Examples of antenna designs are also shown. Derived from a university course, the material includes essential math formulas, but the presentation is intended for a wide audience from students to radio amateurs to practicing professionals.

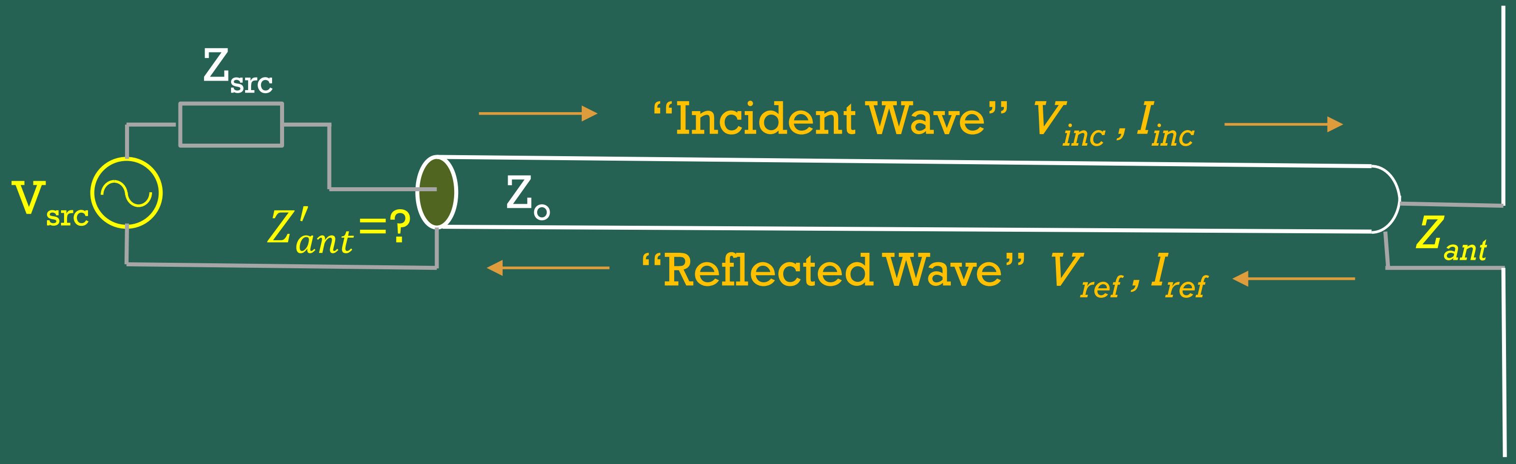


Microwave Circuits and Antennas

Radio Design 201 #7 Part 1

Antennas & Feedline Systems

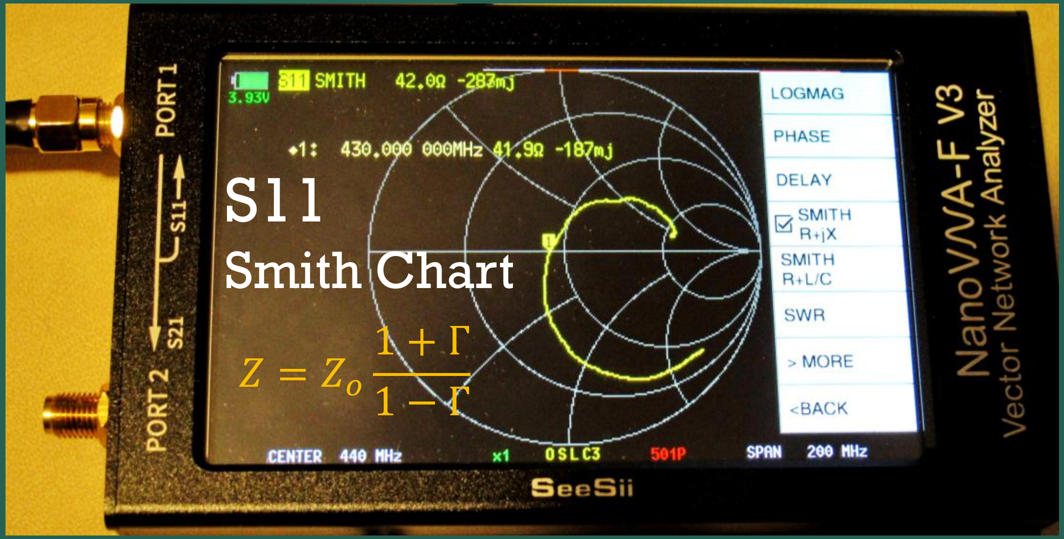
(Impedance, Reflection coefficient, S11, and SWR)

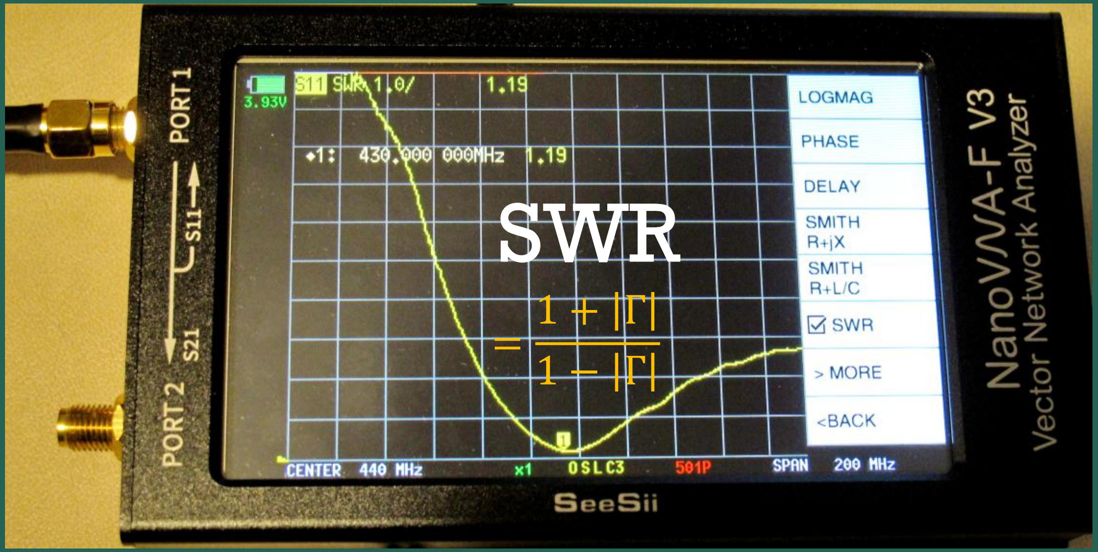


MegawattKS - YouTube

https://ecefiles.org

Formatting of $\Gamma = \frac{V_{ref}}{V_{inc}}$ Measurements





Today's "Lecture"

Announcements

Lab 1 "assigned" in Episode 6

Due Date: ??

Topics

- *Practical antennas and feedline systems*
  - *Examples and Essential Theory*
  - *Antenna Impedance and Reflection coefficient*
  - *S11 and VSWR with Demo*
- *Solving Maxwell's equations at antenna*
- *Finding currents, impedance, and far-field patterns*
- *EM Simulators (e.g. EZ-NEC)*

Today's Lecture in Context

Episode 3
(p/o 4-part intro)

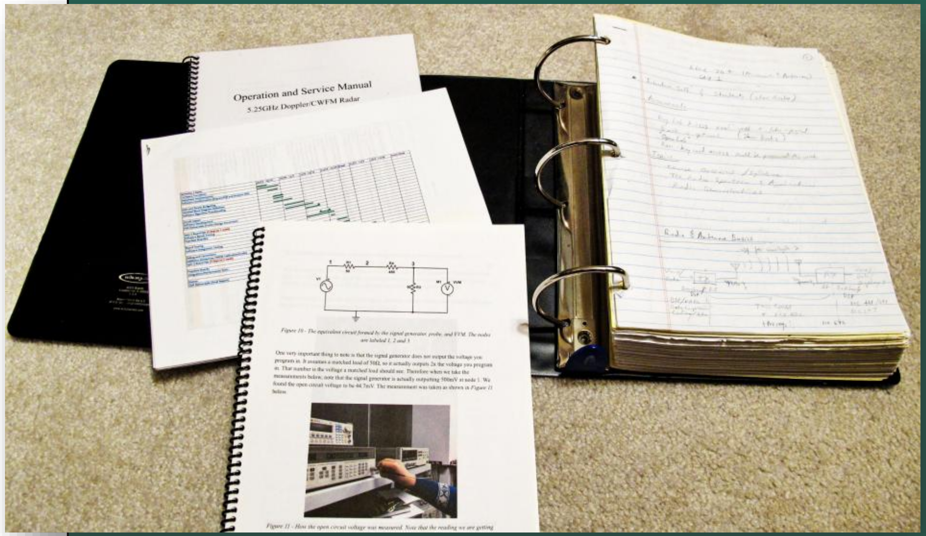
Episodes 5, 6

This Episode

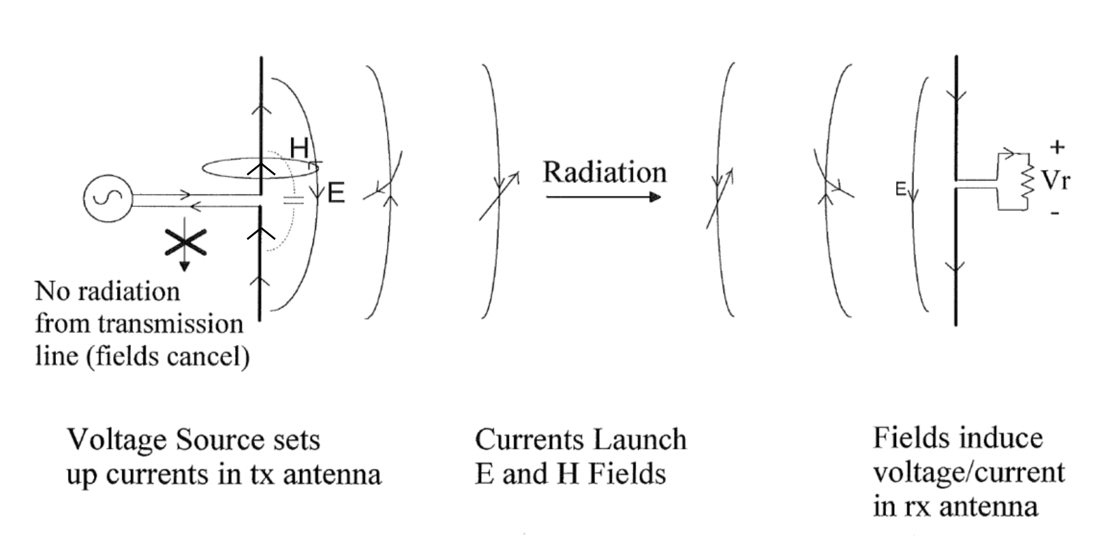
ECE 764 Spring 2017 Schedule

(Tentative)

Week	*Material*	*Assignments*
1	Introduction to comm systems, frequencies, and wavelengths Calculating and measuring received signal strengths	Verify you have lab access Lab 1 assigned
2	EM theory review and demos Basic antenna theory	Purchase lab kit
3	Basic antenna types: dipoles, monopoles, loops Antenna characterisitics: polarization, patterns, and impedance	Lab 1 due
4	Measurement of antenna patterns and signal reflection/transmission Transmission lines and reflection coefficient	Lab 2 assigned
5	Introduction to Smith Charts, plotting of impedance/admittance Simulation with Agilent ADS	
6	Lambda/4 lines and impedance transformation with microstrip Microstrip components and coupled-line microwave filters	Lab 2 due
7	PC board design, layout, and parasitics Two-port circuits and S-parameters	Lab 3 assigned
8	Circuit analysis and simulation with S-parameters Amplifier insertion gain, matching, stability, noise figure, and compression specs	Lab 3 due
9	Project discussion (including needed baseband, ADC and DSP functions) Basic mixer concepts and hybrid-ring microstrip implementations	Project assigned
10	Voltage controlled oscillators Frequency multipliers	Prototype design/layouts due
11	Project discussions (pads, RF connector test points, test planning)	Probotype boards back
12	Frequency synthsizers and phase-locked loops	
13	Project testing/debugging discussions	Test, debug, respin boards Submit final board layouts
14	Analysis and design of directional antennas: Array theory Dish antennas and antenna feeds: e.g. helix, horn, and patch antennas Antenna simulations with ADS, EZNEC and other tools	
15	Additional radar and wireless performance issues	



Review



Maxwell's Equations (source free):

$$Curl\ E = -\frac{\partial B}{\partial t}$$

$$Curl\ H = \frac{\partial D}{\partial t}$$

$$B = \mu H \quad D = \varepsilon E$$

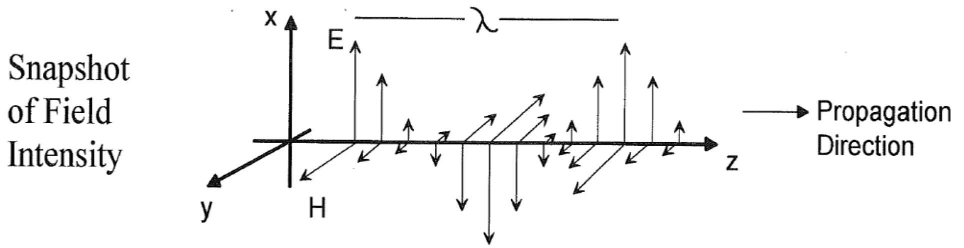
=>

Plane Wave Solution:

$$E = E_x(z)\cos\left(\omega_o\left(t - \frac{z}{v_p}\right)\right)$$

$$H = H_y(z)\cos\left(\omega_o\left(t - \frac{z}{v_p}\right)\right)$$

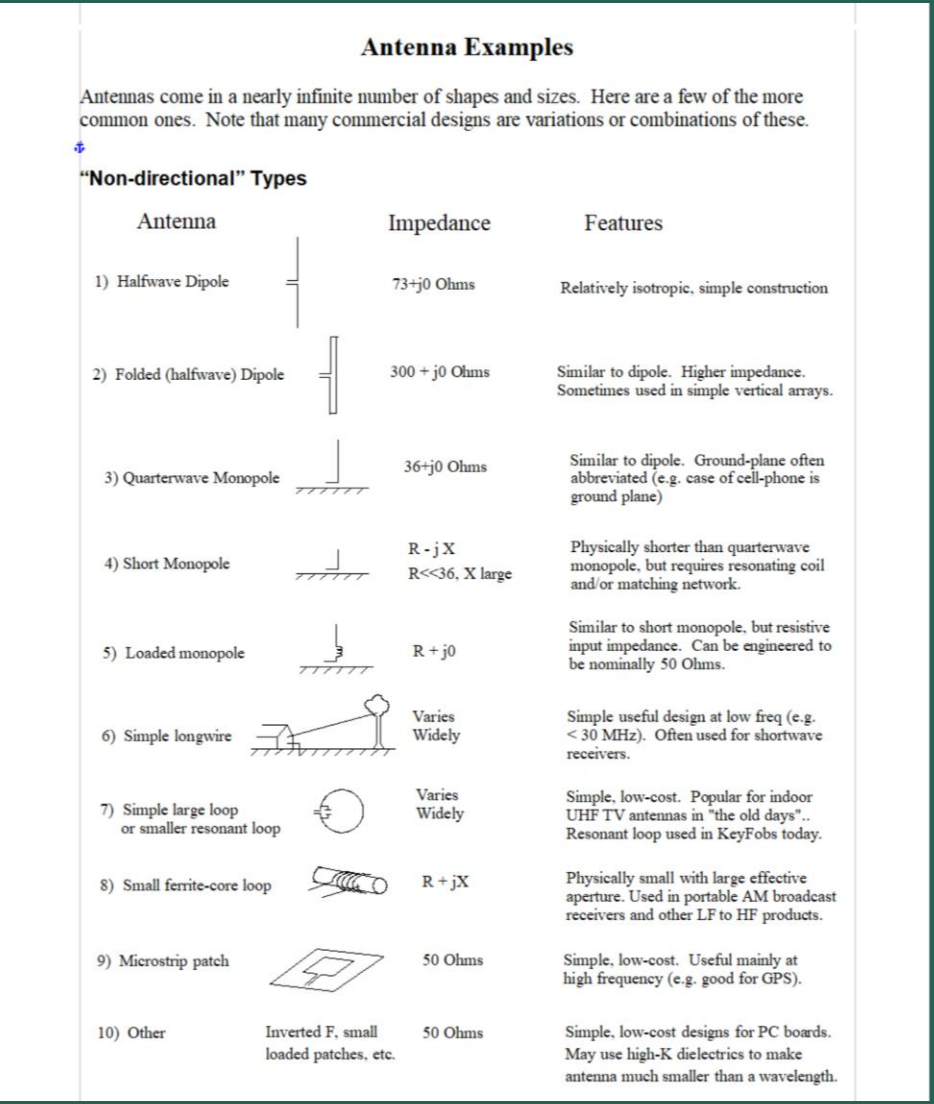
where v_p = velocity of propagation



In the "far field", we have a "plane wave", where E x H is power density in *Watts/meter-squared*

How do we design the transmitter antenna system?

Antenna Designs

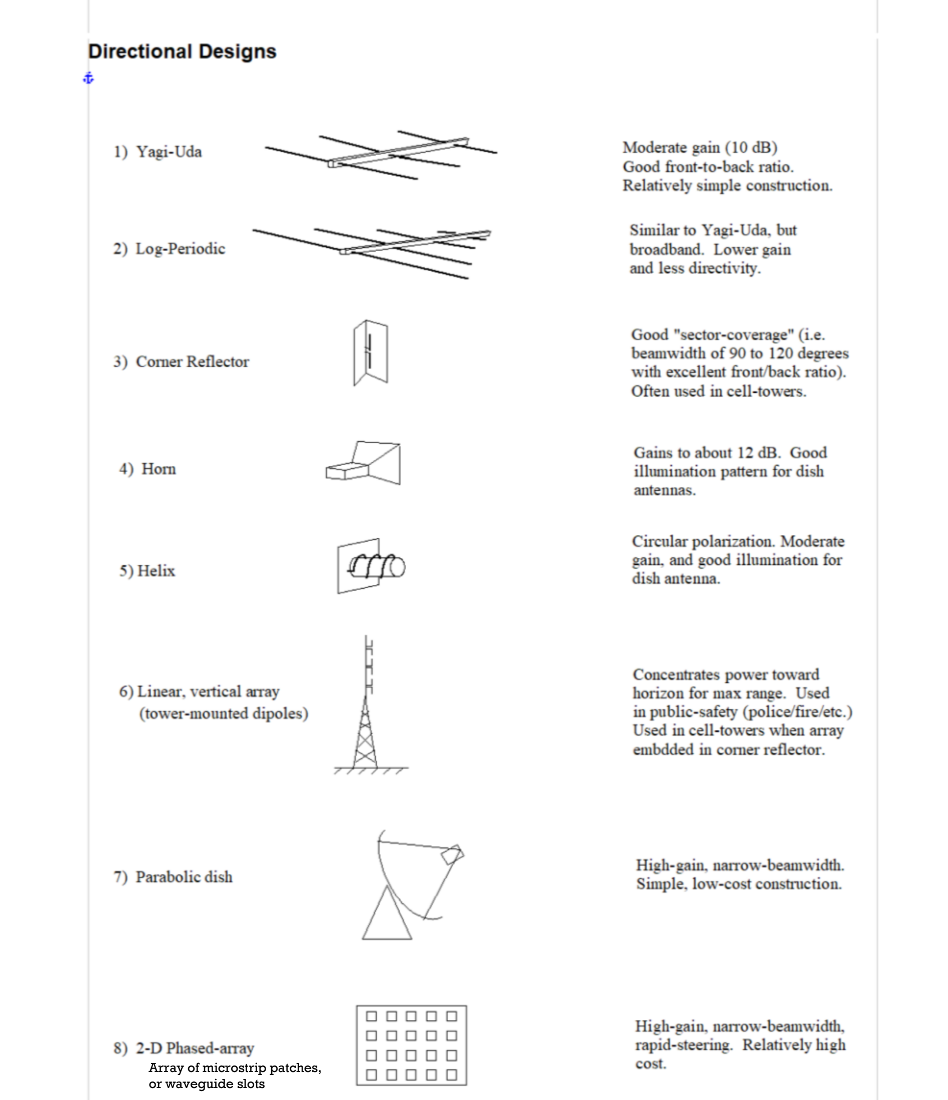


Antenna Examples

Antennas come in a nearly infinite number of shapes and sizes. Here are a few of the more common ones. Note that many commercial designs are variations or combinations of these.

"Non-directional" Types

Antenna	Impedance	Features
1) Halfwave Dipole	73+j0 Ohms	Relatively isotropic, simple construction
2) Folded (halfwave) Dipole	300 + j0 Ohms	Similar to dipole. Higher impedance. Sometimes used in simple vertical arrays.
3) Quarterwave Monopole	36+j0 Ohms	Similar to dipole. Ground-plane often abbreviated (e.g. case of cell-phone is ground plane)
4) Short Monopole	R - j X R<<36, X large	Physically shorter than quarterwave monopole, but requires resonating coil and/or matching network.
5) Loaded monopole	R + j0	Similar to short monopole, but resistive input impedance. Can be engineered to be nominally 50 Ohms.
6) Simple longwire	Varies Widely	Simple useful design at low freq (e.g. < 30 MHz). Often used for shortwave receivers.
7) Simple large loop or smaller resonant loop	Varies Widely	Simple, low-cost. Popular for indoor UHF TV antennas in "the old days".. Resonant loop used in KeyFobs today.
8) Small ferrite-core loop	R + jX	Physically small with large effective aperture. Used in portable AM broadcast receivers and other LF to HF products.
9) Microstrip patch	50 Ohms	Simple, low-cost. Useful mainly at high frequency (e.g. good for GPS).
10) Other — Inverted F, small loaded patches, etc.	50 Ohms	Simple, low-cost designs for PC boards. May use high-K dielectrics to make antenna much smaller than a wavelength.



Directional Designs

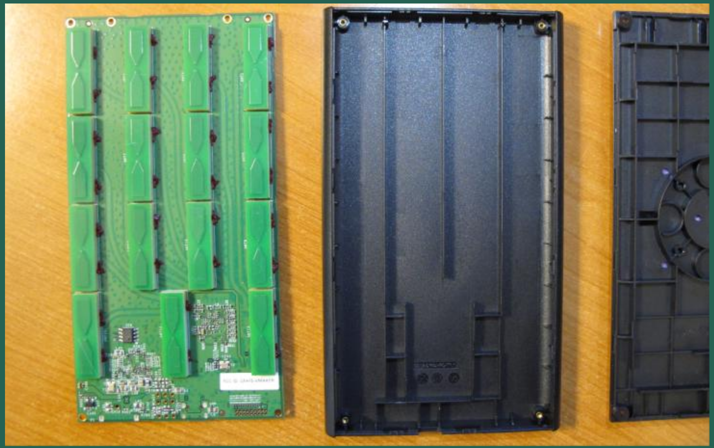
1) Yagi-Uda	Moderate gain (10 dB) Good front-to-back ratio. Relatively simple construction.
2) Log-Periodic	Similar to Yagi-Uda, but broadband. Lower gain and less directivity.
3) Corner Reflector	Good "sector-coverage" (i.e. beamwidth of 90 to 120 degrees with excellent front/back ratio). Often used in cell-towers.
4) Horn	Gains to about 12 dB. Good illumination pattern for dish antennas.
5) Helix	Circular polarization. Moderate gain, and good illumination for dish antenna.
6) Linear, vertical array (tower-mounted dipoles)	Concentrates power toward horizon for max range. Used in public-safety (police/fire/etc.) Used in cell-towers when array embdded in corner reflector.
7) Parabolic dish	High-gain, narrow-beamwidth. Simple, low-cost construction.
8) 2-D Phased-array Array of microstrip patches, or waveguide slots	High-gain, narrow-beamwidth, rapid-steering. Relatively high cost.

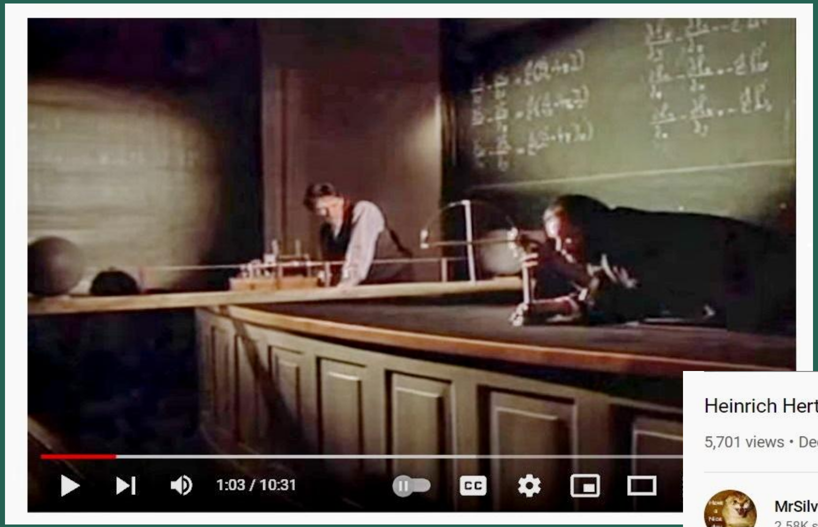
Dipole Examples

HF

VHF/UHF

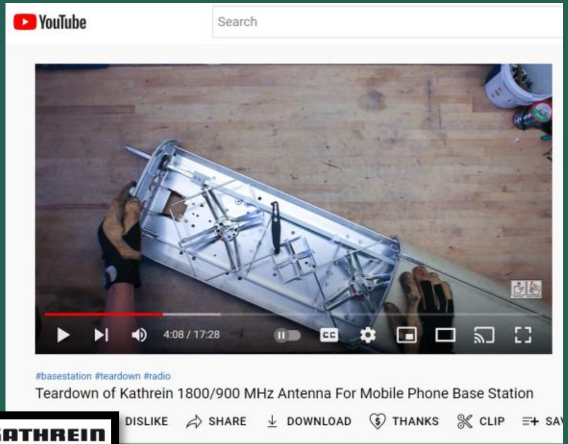
Microwave Array

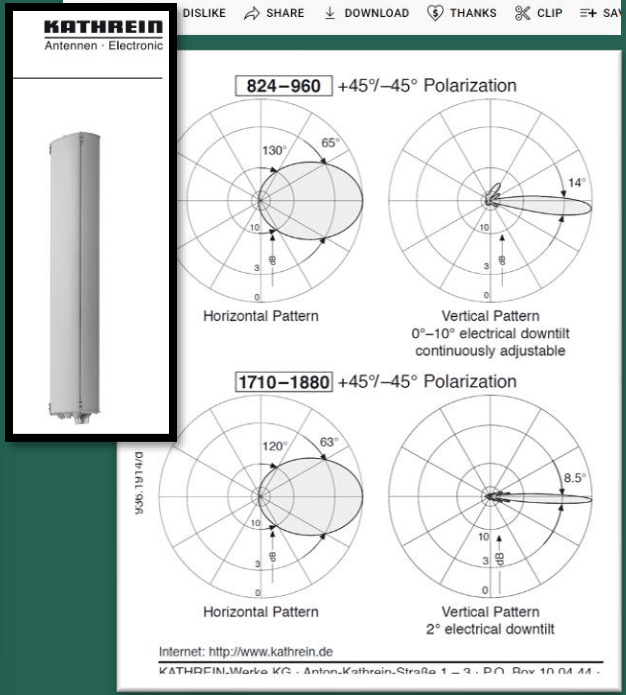


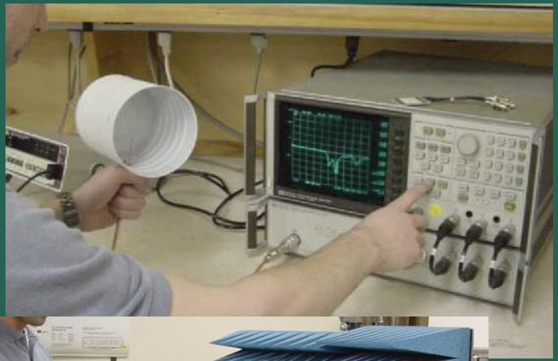


Hertz (World's First)

Directional Antenna Examples







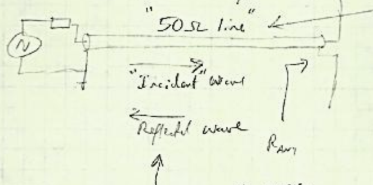
University Class Lecture Notes

Today (Part 1)

Measures of "Goodness of matching"

Antenna should be resonant and
For efficient TX, R_{ANT} should match the "characteristic impedance" of TX-Line

(looks like 50Ω resistor to source)



If $R_{ANT} \neq 50\,\Omega$, signal power from source is partially reflected

Define Refl Coeff $\Gamma = \frac{V_{ref}}{V_{inc}}$

$|\Gamma| < 0.3$ is OK

$|\Gamma| < 0.1$ is very good (less than 1% power reflected)

See Lab 2 for defn of RL & SWR ...

Demo

Return Loss $RL = 20 \log \frac{1}{|\Gamma|}$ > 10 dB is OK, > 20 dB is excellent

Standing wave Ratio $SWR = \frac{1+|\Gamma|}{1-|\Gamma|}$ < 2:1 is OK, < 1.2:1 is excellent

$= \frac{\max V \text{ on line}}{\min V \text{ on line}}$

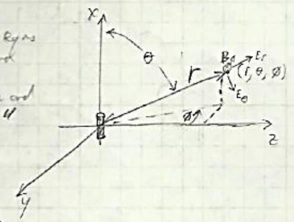
Part 2

Computing Antenna Radiation Pattern (& Hence Gain, Impedance, etc)

"Approaches:

1) Solve Maxwell's Eqns for each antenna

2) Solve for I case and apply linearity"



Consider short wire segment at origin of length L as shown, carrying current $I e^{j\omega t}$ (phasor)

Solving Maxwell's Eqns: (see EM text book)

$$E_\theta = 30\, I L\, \beta^2 \sin\theta \left[\frac{j}{\beta r} + \frac{1}{(\beta r)^2} - \frac{j}{(\beta r)^3}\right] e^{j\omega t} e^{-j\beta r}$$

$$E_r = 60\, I L\, \beta^2 \cos\theta \left[\frac{1}{(\beta r)^2} - \frac{j}{(\beta r)^3}\right] e^{j\omega t} e^{-j\beta r}$$

$$B_\phi = \frac{\mu_0}{4\pi} I L\, \beta^2 \sin\theta \left[\frac{j}{\beta r} + \frac{1}{(\beta r)^2}\right] e^{j\omega t} e^{-j\beta r}$$

where $\beta \triangleq \frac{\omega}{c} = \frac{2\pi}{\lambda}$

NOTES:

- In "Far Field" $\frac{1}{(\beta r)^2}, \frac{1}{(\beta r)^3} \to 0 \Rightarrow$ (complex sinusoid)

$$E \cong E_\theta = 30\, I L\, \beta^2 \sin(\theta)\, \frac{j}{\beta r}\, e^{j\omega t} e^{-j\beta r}$$

$$B = B_\phi = \frac{1}{c} E_\theta$$

(377/4π; max at θ = 90° (broadside); field decreases ~1/r; phase shift vs. r)

- For Field begins at $(\beta r \gg 1) \Rightarrow r \gg \frac{1}{\beta}$ or, $r \gg \frac{\lambda}{2\pi}$, e.g. $r > 2\lambda$

- Fields for any wire antenna found from superposition: Eg. For λ/2 dipole:

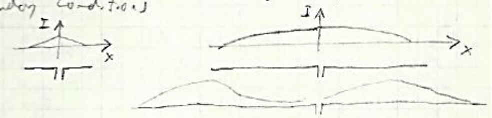
$$E_\theta = 30\, \beta^2 \sin\theta\, \frac{j}{\beta r}\, e^{j\omega t} \int_{-\lambda/4}^{\lambda/4} I(x)\, e^{-j\beta r(x)}\, dx$$

assumed current amplitude; cosine shape

Part 3

Finding I(x) Function

- Estimate based on velocity of propagation & boundary conditions



- Use EM Simulator
  - Ansoft HFSS — Full 3-D Structures
  - Agilent ADS/Momentum — 2.5 D Structures
  - CST
  - NEC or EZ NEC — 3D-wire antennas

Finding Far Field Pattern
- Do integral
- Use software (e.g. EZ NEC, ADS momentum, CST, Other)
- Build/measure!

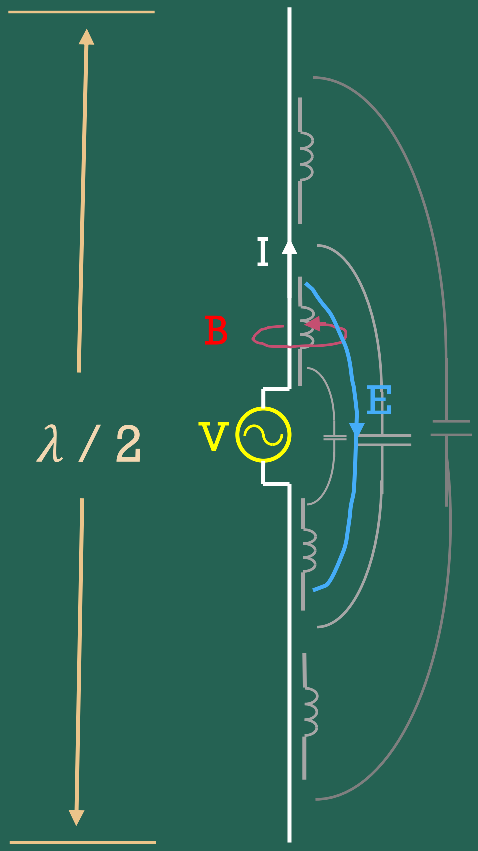
EZ NEC Demo

Google for EZ NEC

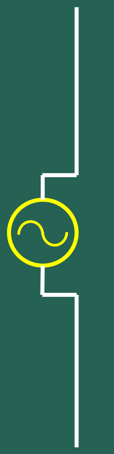
Define antenna elements & # of segments for each & Verify Visually

Compute / Display
- Currents
- Patterns 2-D or 3-D
- SWR vs Freq
- Etc

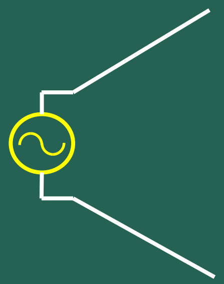
Antennas and Feedlines



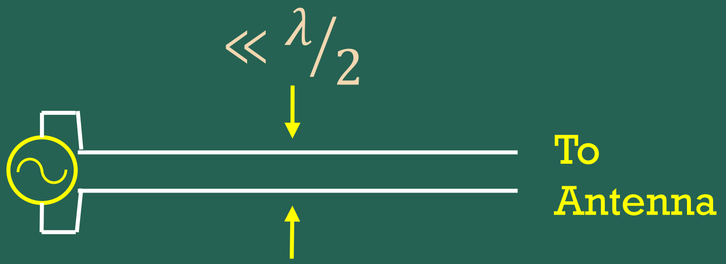
Resonant Dipole



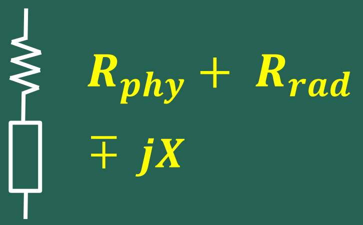
Short Dipole



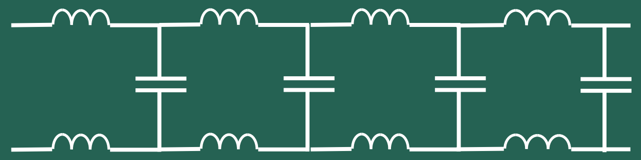
Sorta Dipole



Transmission Line
(e.g. Coax, twinlead ...)



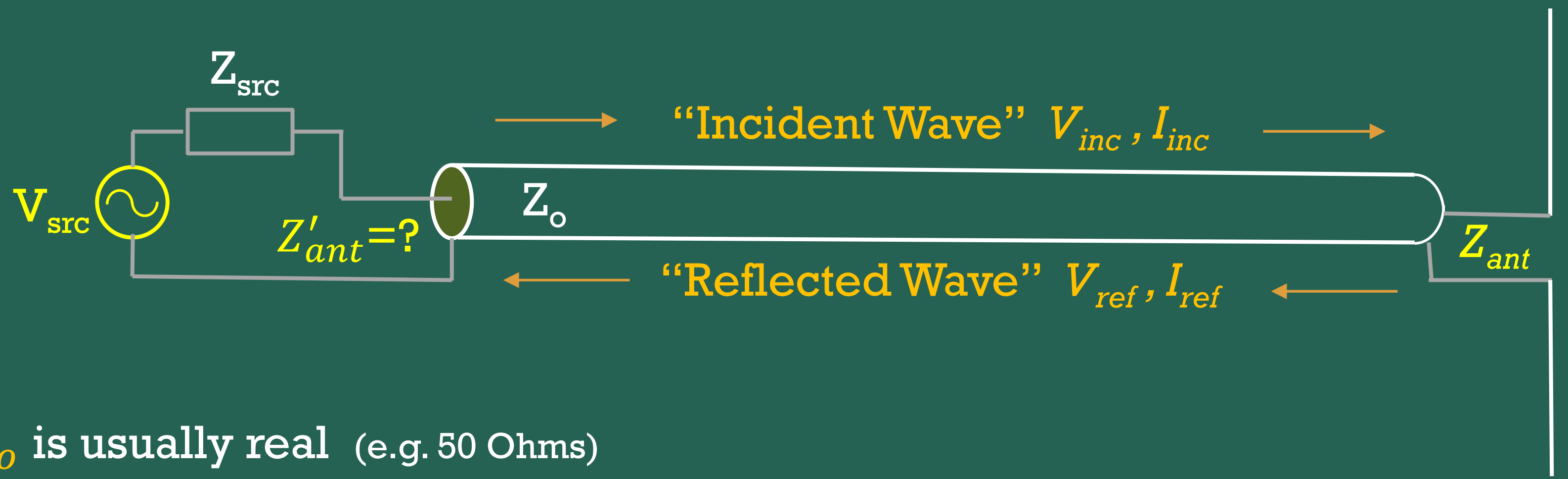
Antenna Circuit Model



Transmission Line Model (Lossless)

Antenna to Feedline Matching

For best performance, antenna should be resonant, ($Z_{ant} = R_{ant} + j0$) and R_{ant} should match the "characteristic impedance" (Z_o) of the feedline.



NOTE: Z_o is usually real (e.g. 50 Ohms)

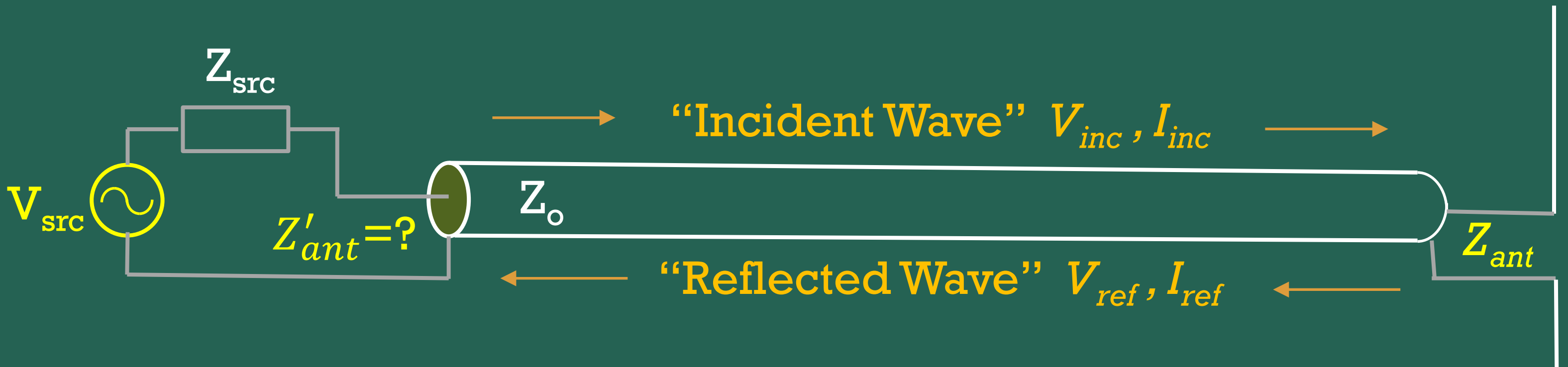
So …

$$I_{inc} = \frac{V_{inc}}{Z_o} \qquad P_{inc} = |V_{inc}|\,|I_{inc}| = \frac{|V_{inc}|^2}{Z_o}$$

$$I_{ref} = \frac{V_{ref}}{Z_o} \qquad P_{refl} = |V_{ref}|\,|I_{ref}| = \frac{|V_{ref}|^2}{Z_o}$$

Define Reflection Coefficient as $\Gamma \triangleq \frac{V_{ref}}{V_{inc}}$

Return-Loss, S11, and SWR



$$\frac{P_{ref}}{P_{inc}} = \frac{\frac{|V_{ref}|^2}{Z_o}}{\frac{|V_{inc}|^2}{Z_o}} = |\Gamma|^2$$

$|\Gamma| < 0.3$ is OK: (about 90% of incident Power is radiated)

$|\Gamma| < 0.1$ is Excellent: (99% of incident Power is radiated)

S11 (in dB)

$20\ log\ |S11|$

<-10 dB is OK

<-20 dB is Excellent

Note: $S11 \equiv \Gamma$

For this "one-port" situation

Return Loss (in dB)

$20\ log \frac{1}{|\Gamma|}$

>10 dB is OK

>20 dB is Excellent

SWR (a.k.a. VSWR)

$$SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

<2 (or "2:1") is OK

<1.2 is Excellent

SWR is a legacy measurement method and defined as (max V on line)/(min V on line)

Lab 2 (pages 1-3 of 6)

Available at: https://ecefiles.org/microwave-circuits-and-antennas-course-notes/

ECE 764 Lab 2 - Antennas and Propagation

Due Wednesday, Feb 27, 2019 at actual COB (5pm)

Overview

In this lab, we will build simple halfwave dipole antennas and use them in several experiments to learn about:

- Design and construction techniques
- Loading effects of antennas on sources (impedance)
- Antenna/feedline-system reflection coefficient, return-loss, and SWR
- Electric field strength versus distance
- Polarization
- Antenna directivity and patterns
- Radio wave reflections and standing waves
- EM simulations with EZNEC

Lab Partners and Writeups

For this lab you should work in ***2-persons teams***. As before, this will prove necessary in taking the measurements. Unlike the previous lab however, ***you should split the workload in the writeup*** making it a true team effort. Each person should document about half the required experiments (the first half or the second half). The person doing the first half should also do a one page intro to the entire lab. The person doing the second half is responsible for the final conclusions section at the end. ***On the cover page and in the writeup, be clear on who did what portion(s)***

In your report, you should document the experiment setups, the measurements, and the calculations. As before, include ***a narrative*** that describes the goal, the procedures used, problems you encountered (plus the resolution if any) in each part. Also include observations you made about how the theory compared with experimental results - especially in the conclusions. As before, grades will be based on the Completeness, Correctness, and overall Quality (CCQ) of your results and writeups.

Frequencies of Operation and Warnings

In this lab, you and your lab partner will each build an antenna, but you should use the ***same*** *frequency.* The choices include the 462-467 MHz UHF band of the Family Radio Service (FRS), the 902-928 MHz ISM band used by the digital radios, or the DECT6.0 1.92 - 1.93 Ghz band used by the cordless phones. Thus, your team must decide whether you want to target 467 MHz, 915 MHz, or 1.93 GHz in designing, building, and testing your antennas. Note that the HF CB and the VHF MURS bands are not included since the wavelengths associated with 27 MHz and 150 MHz are too large for use in the lab experiments we will be performing.

Pictures

Photos are strongly encouraged to *help* document what you did (remember - a picture is worth 1000 words, saving you some writing and me some reading ;-) It's also more clear in many cases.

Procedures

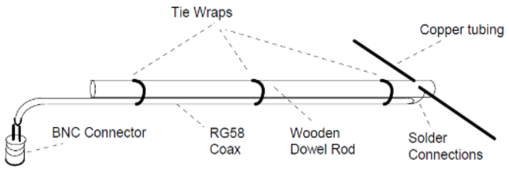
1 Antenna Design

Calculate the length of a half-wave dipole at the operating frequency selected above. For a real lambda/2 dipole (one for which Z is purely resistive), the physical length should be about 2% to 5% ***less*** than the length calculated using the velocity of light, depending on the diameter of the antenna elements. This is due to an effective slowing of the wave in the presence of the wire structure and to capacitance present at the tip of the antenna. The exact percentage depends on the ratio of the rod/wire thickness to its length and other factors such as the feedpoint dimensions. For this design, use 3%. But ...

In determining the precise length of your antenna elements, be sure to account for the length of the exposed coax braid and center lead where they separate from each other and connect to the antenna elements at the "feedpoint" since these segments will become part of the radiating structure (see drawing below). Also, make sure the wooden rod and coax are perpendicular to the antenna and long enough that the antenna elements will not couple excessively to the test equipment you drive it from. See the figure below. (Generally, one or two wavelengths should be OK, but make the coax long enough to get the antenna away from stuff in the lab and see footnote below about the use of baluns in some antennas).

2 Construction

Construct your antenna using the materials and tools provided in the lab. ***USE SAFETY GLASSES*** when appropriate (e.g. Drilling). In your writeup be sure to sketch an assembly drawing showing how your antenna was constructed. A rough drawing of a recommended construction technique is shown below[1]. ***Yours should be more detailed.*** *Carefully show the feedpoint and dimensions in your diagram.*



3 Antenna Impedance Estimation

To learn about antenna impedance and to check for major errors in antenna construction ***before*** progressing through all the measurements below, let's look at how our antenna loads a signal generator source. For this we will use an HP8656 RF signal generator, an RF voltmeter (the HP8505 vector voltmeter), and a 10:1 RF probe. **Do the following for both antennas, since you'll need both in the subsequent measurements !**

[1] Note that we really should use a "balun" between the end of the coax and the antenna to make the antenna pattern closer to ideal. Without it, the fields from the center-conductor will couple to the coax shield outer surface (undesired) as well as to the other element (desired). For simplicity, we will try to get away without a balun. Hence, impedances and patterns may be a little off from theory. You will investigate that issue using the EZNEC simulator at the end of the lab.

Setup the RF generator for the frequency you have chosen and set its output voltage to a moderately large (e.g. 0.25V). Then measure the open-circuit voltage out of the generator using the vector voltmeter (VVM) with one of the brown 10:1 RF probes (***DO NOT USE a 10:1 oscilloscope probe!!***). To do the measurement, ***gently*** place the probe tip into the center of the generator's BNC RF output connector while holding the ground-pin of the probe tip against the BNC connector shell.

Note that the RF probe contains an internal 450 Ohm series resistor. When connected to an RF test instrument such as the VVM with a 50 Ohm input impedance, the probe scales the voltage it is seeing by 50/(50+450) = 1/10. This is done so that it can present a relatively light load (450+50 = 500 Ohms) to the circuit being measured. Thus, the measured voltage should be *approximately* 1/10th of the ***unloaded*** voltage from the generator. Verify that this is the case after reading and understanding this additional issue/complication:

> IMPORTANT: *The RF generator has a Thevenin output impedance of 50 Ohms and the* ***displayed*** *voltage is the value that would be presented to a "matched load" of 50 Ohms - NOT necessarily the value at the output.* For example, if left open-circuited, the actual output voltage will be two times the displayed value.

In your writeup, show a schematic diagram representing the generator with a Thevenin source (with 50 Ohm source resistance), and the probe and VVM as discussed above. Compare the calculated value you should see with the value you measured. It should be reasonably close. What does resonably close mean? How much error would you expect if both the signal generator and VVM could each have errors of up to 0.5 to 1 dB - which is a reasonable assumption for moderate cost test RF equipment.

Next, place a BNC "T" connector onto the generator's output connector ***with one side of the T connected to your antenna*** and the other open to allow checking the (loaded) voltage with the probe as above. Measure and record this *loaded* voltage (with the antenna connected).

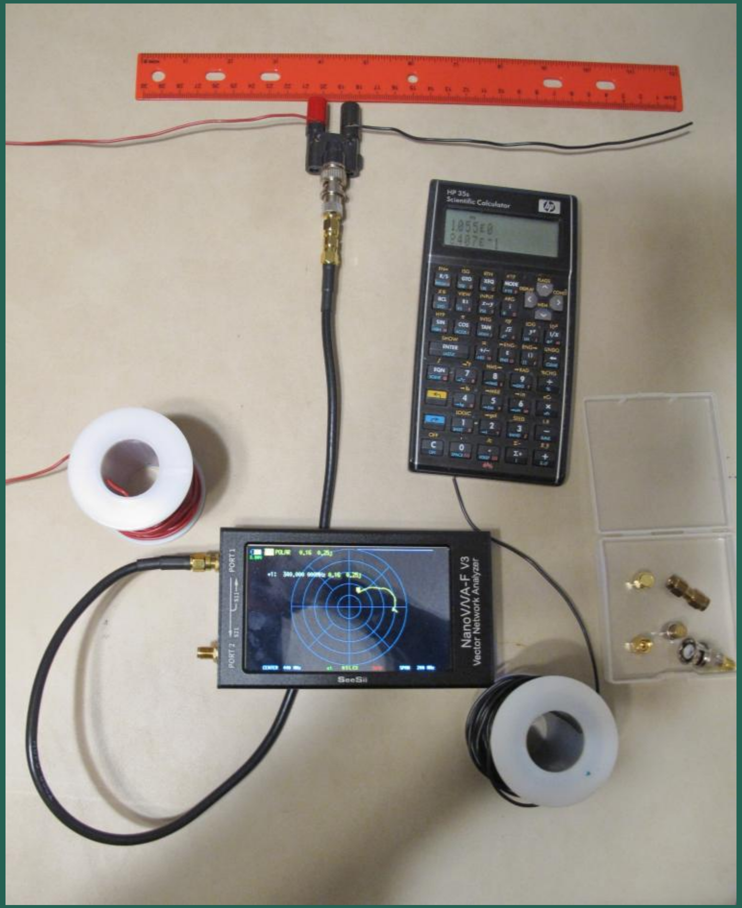
Assuming your half-wave dipole antenna is "resonant" (so that it's impedance is a purely real "radiation resistance"), ***sketch another schematic diagram representing the equivalent circuit for the antenna plus probe both connected to the generator***. Use your measurements to calculate the antenna's radiation resistance (under the assumption it is real-valued). How does it compare to the expected value? If it is not exactly equal to the value you expect from a half-wave dipole antenna, do not worry. We don't have a balun and the coax modifies the impedance somewhat from that of an ideal dipole. ***HOWEVER*** - if it is wildly off, re-read the above and make sure you accounted for all the factors of 2, 10, etc. If it is still widely off (more than 50% or so), check for shorts or opens in your coax connector, etc and ask for help.

Finally, try measuring the impedance at the antenna "feedpoint" (at the location where the metal rods are mounted to the wooden rod). This measurement may be closer to the predicted value for a 73 Ohm load. Is it? Remember that this is not a great dipole since we do not have a balun, so don't expect perfect results here either. We will learn to deal with these issues and learn how to make more precise (and full complex impedance) measurments later this semester...

4 Reflection Coefficient, Return Loss, and SWR

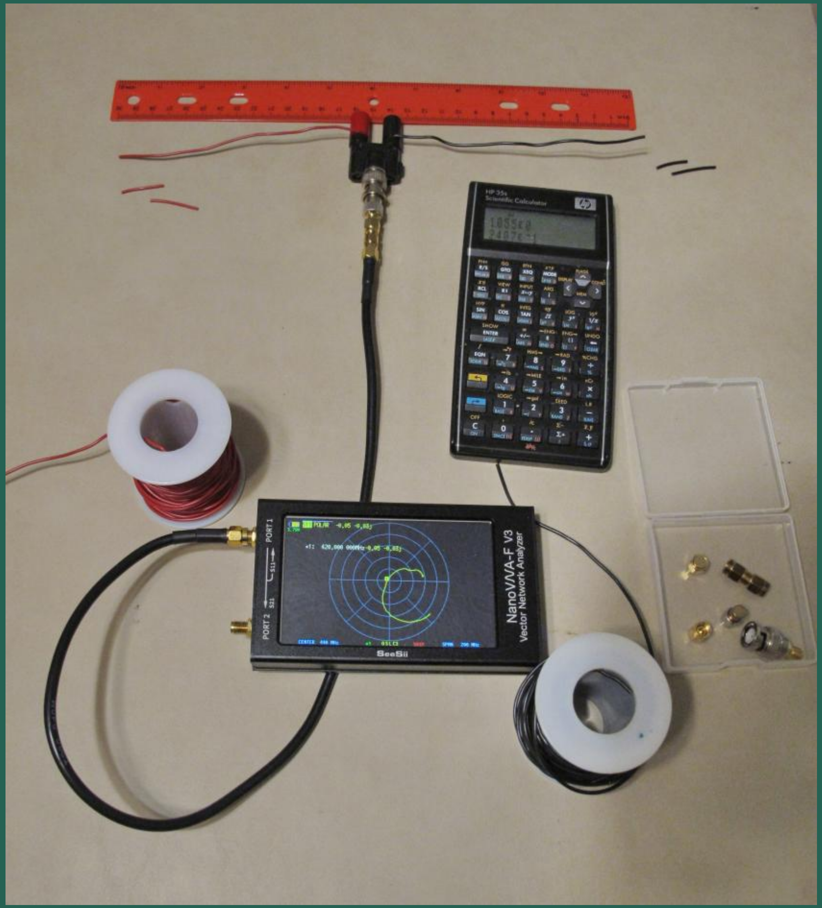
An issue related to the impedance measurement made above is how well your antenna matches the so-called "characteristic impedance" of the transmission line (coax) used to "feed" it. As we discussed, if the antenna impedance does not match that value, the signal that travels down the transmission line (coax) to the antenna will be partially reflected back toward the source and less signal will be radiated.

UHF Dipole Home-Lab Construction/Test



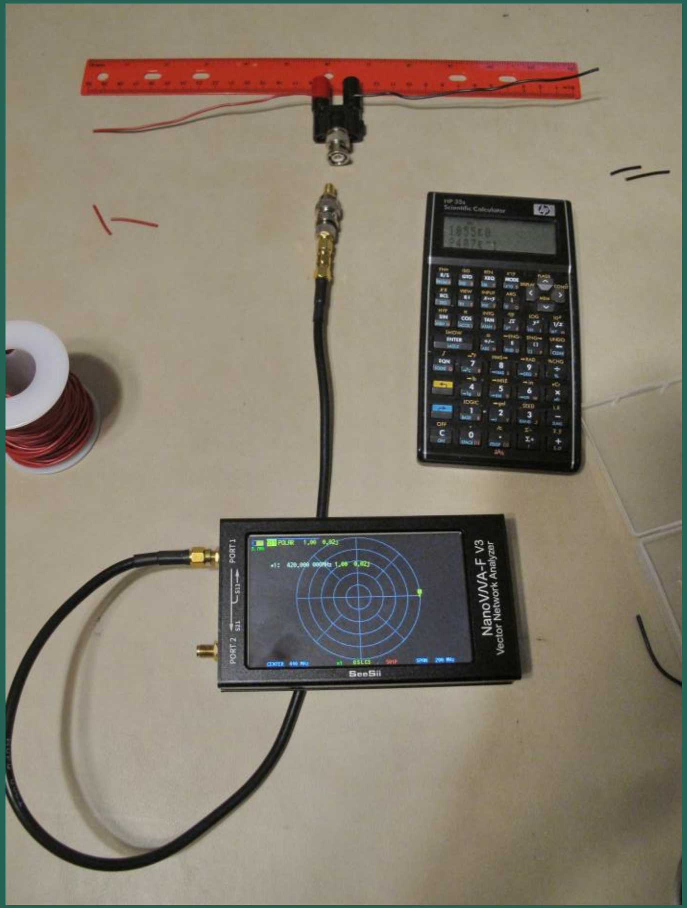
Elements too long & freq too low

$\Gamma = S11 = 0.16 + j0.25 = 0.30\angle 57^o$
@ 340 MHz



Trimmed and measured at 420 MHz

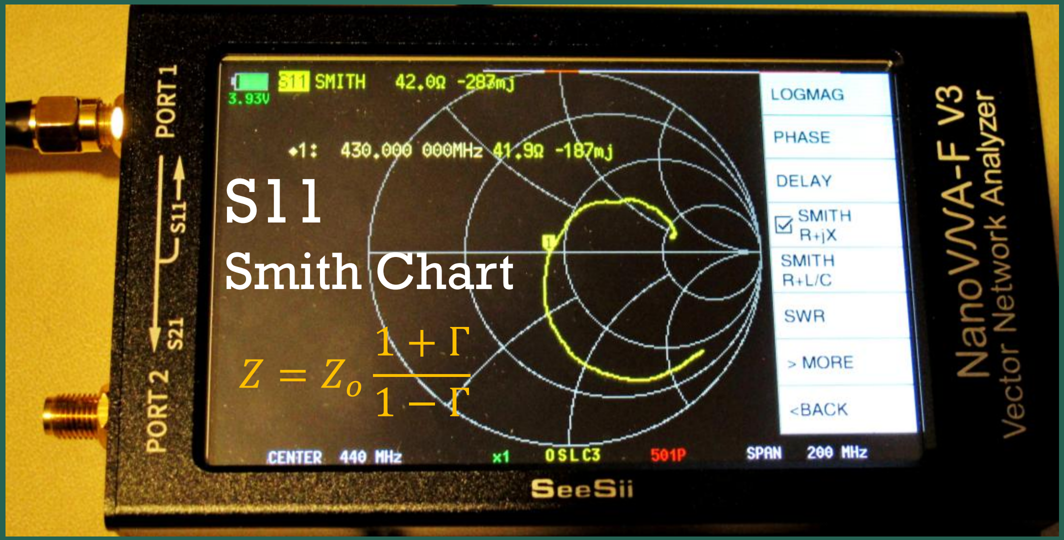
$|\Gamma| = 0.06 \quad RL = 25\ dB \quad SWR = 1.1$

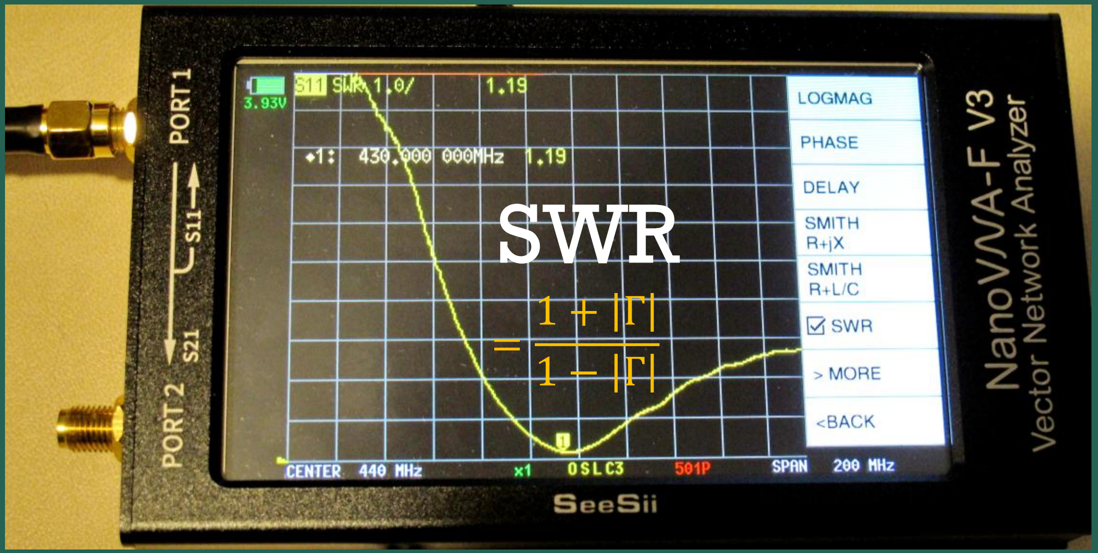


O/C Calibration Checking

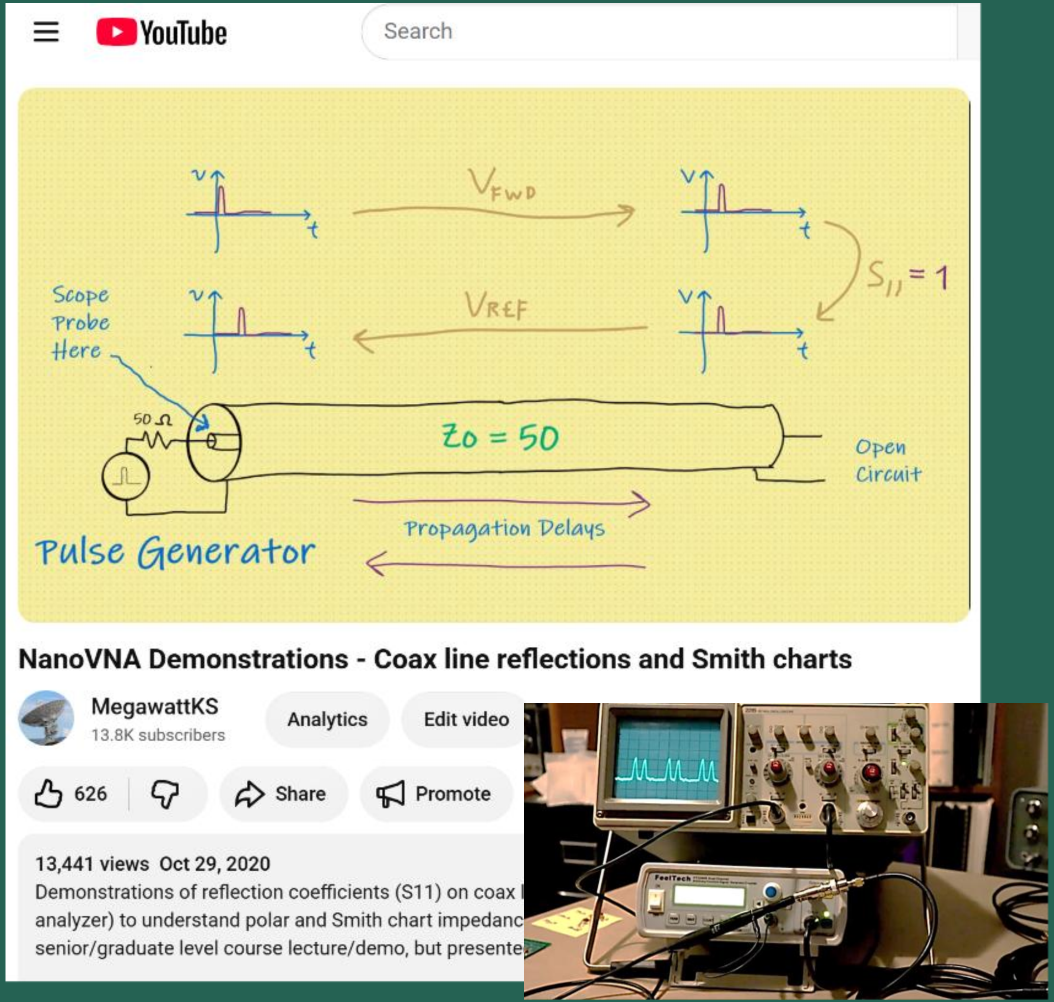
BNC-M to SMA-F added to move
"Reference Plane" beyond BNC

Formatting of $\Gamma = \frac{V_{ref}}{V_{inc}}$ Measurements

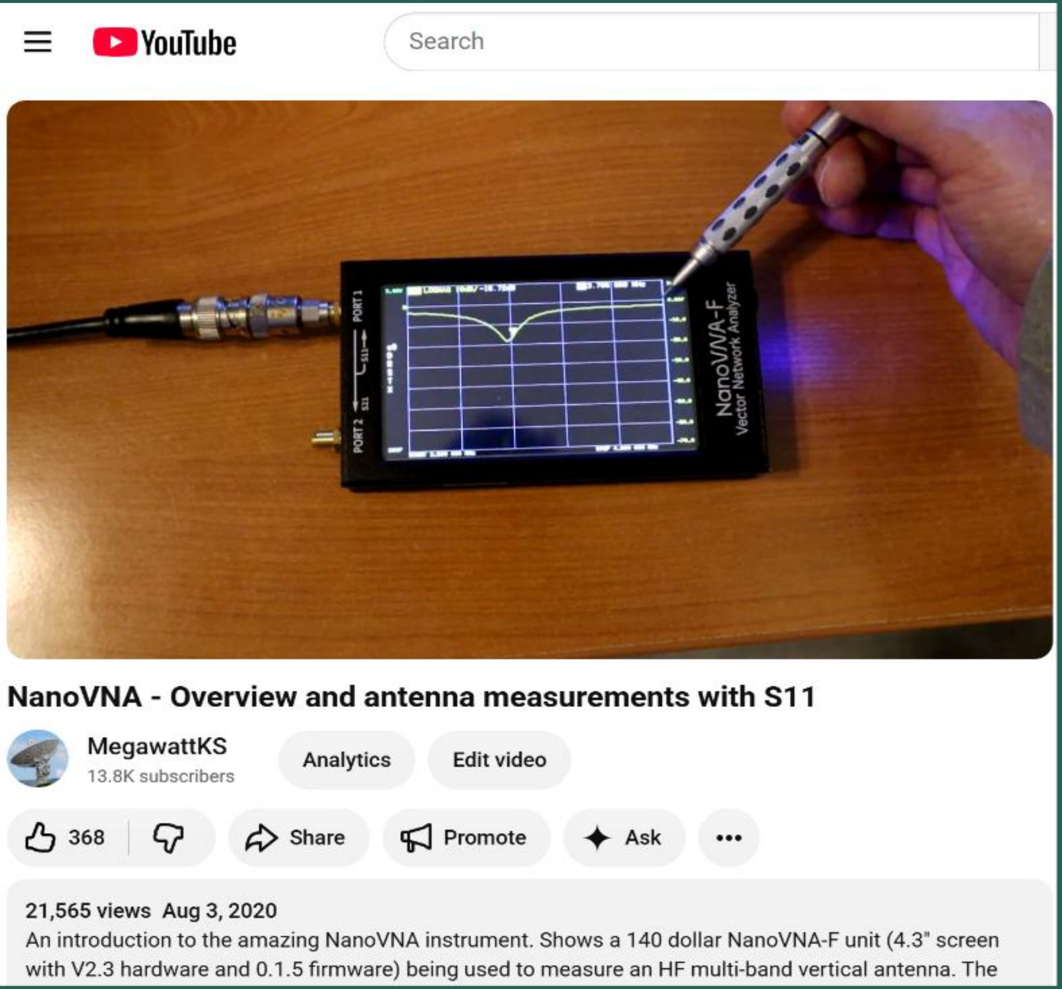




More Demos

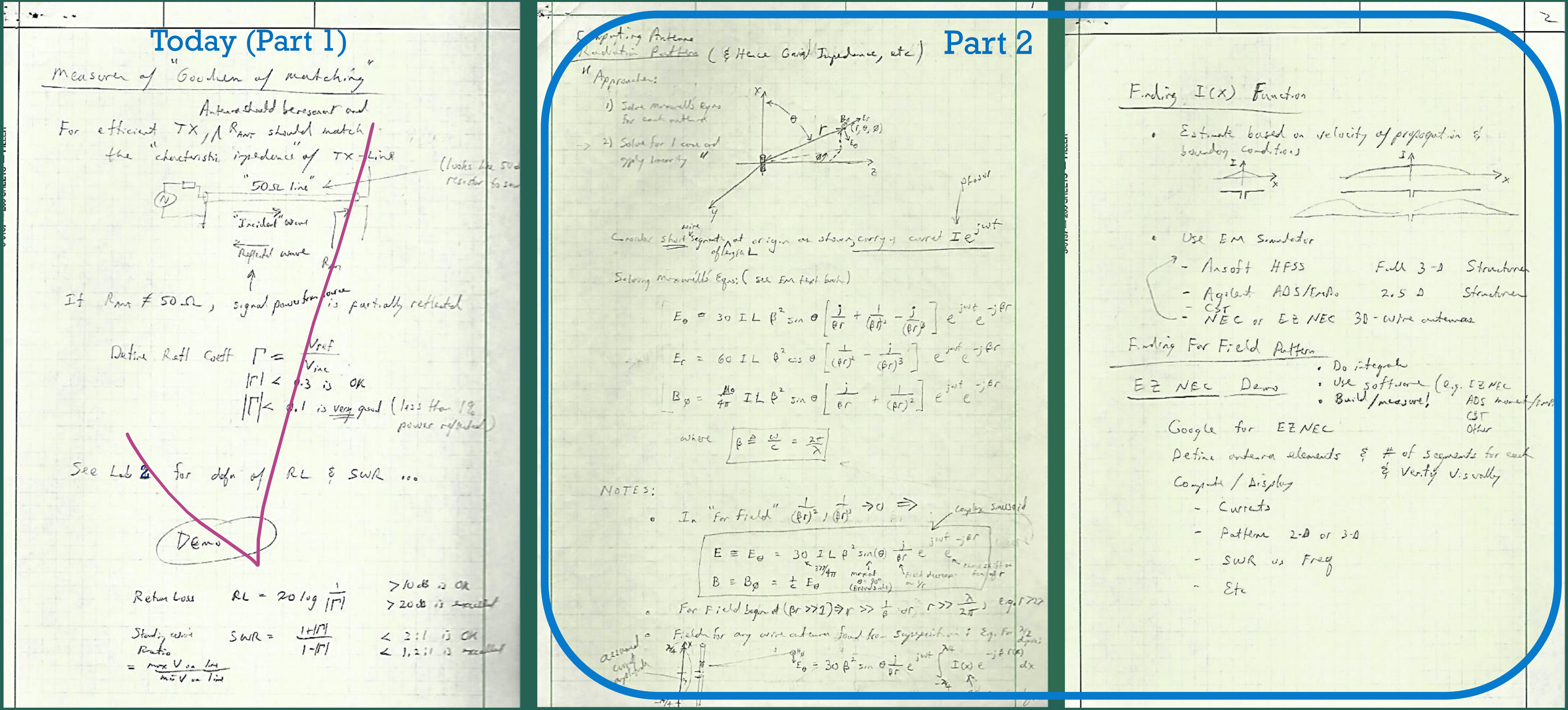


https://www.youtube.com/watch?v=jo6H5ZeBuYM

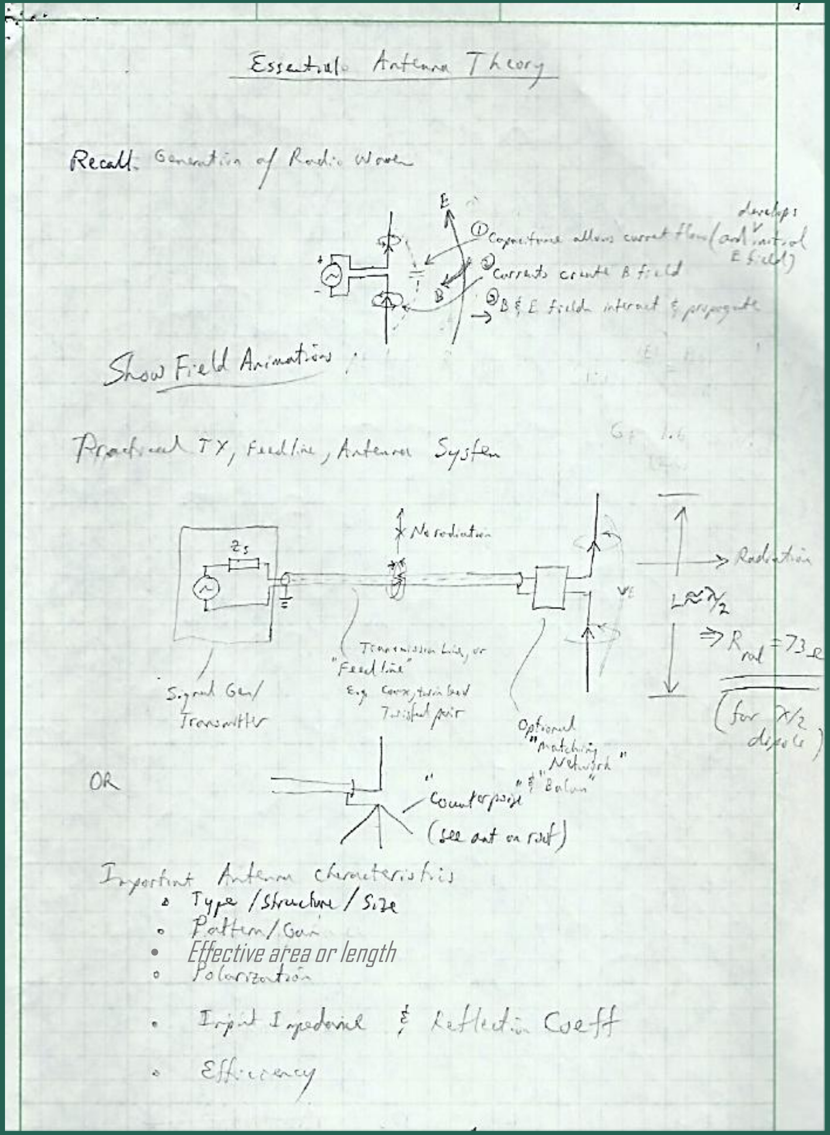


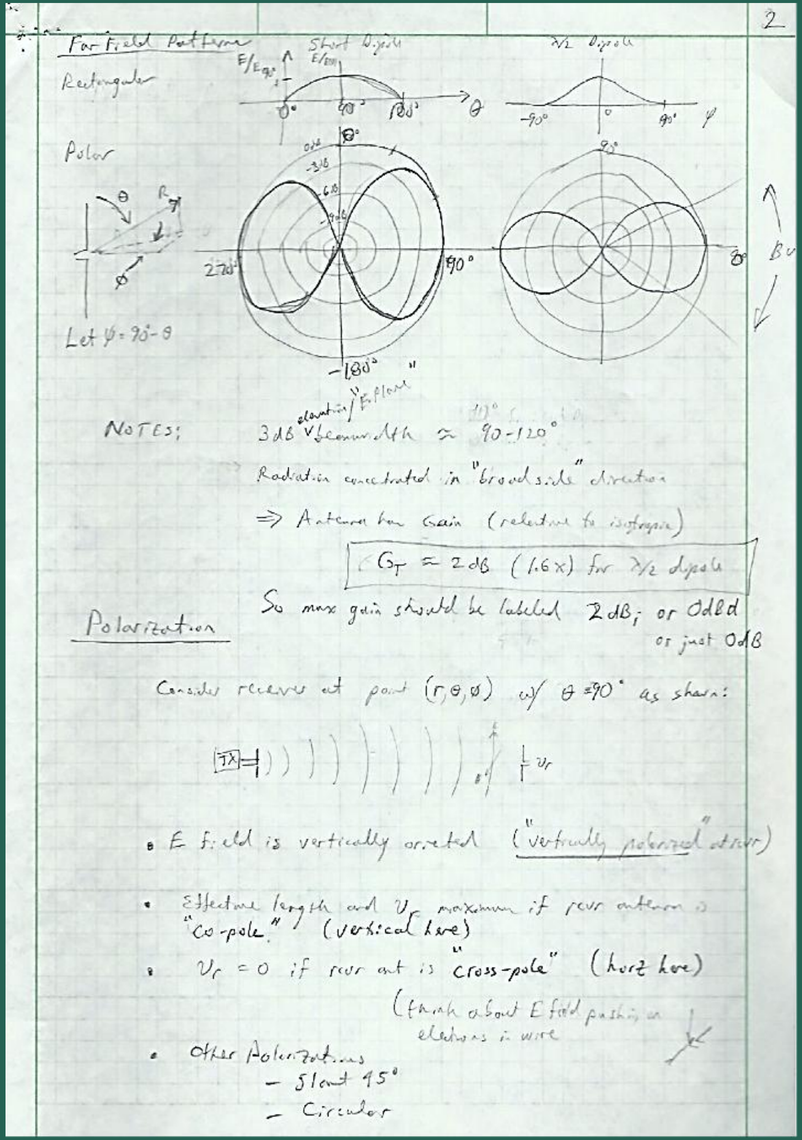
https://www.youtube.com/watch?v=hLPNOp0RXD8

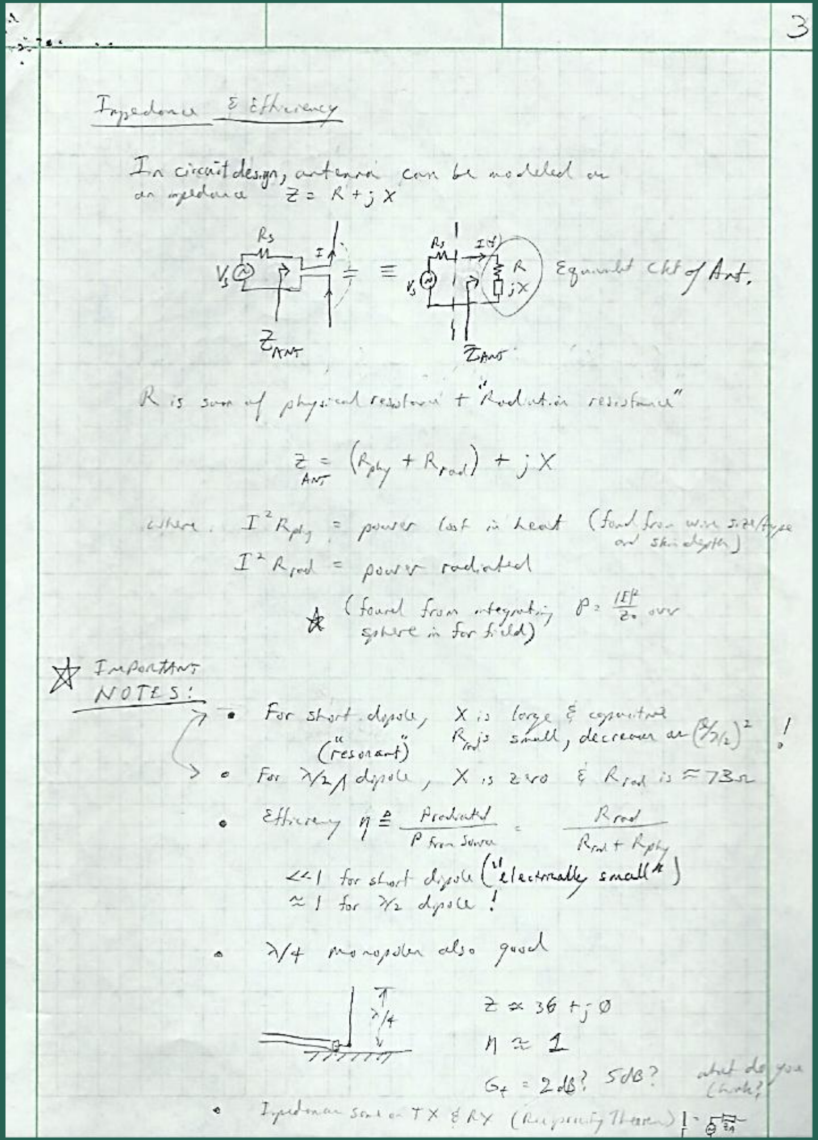
Upcoming Lecture (Ep7, Part 2)



Additional Upcoming Lectures







Thanks For Watching !

MegawattKS - YouTube

https://ecefiles.org