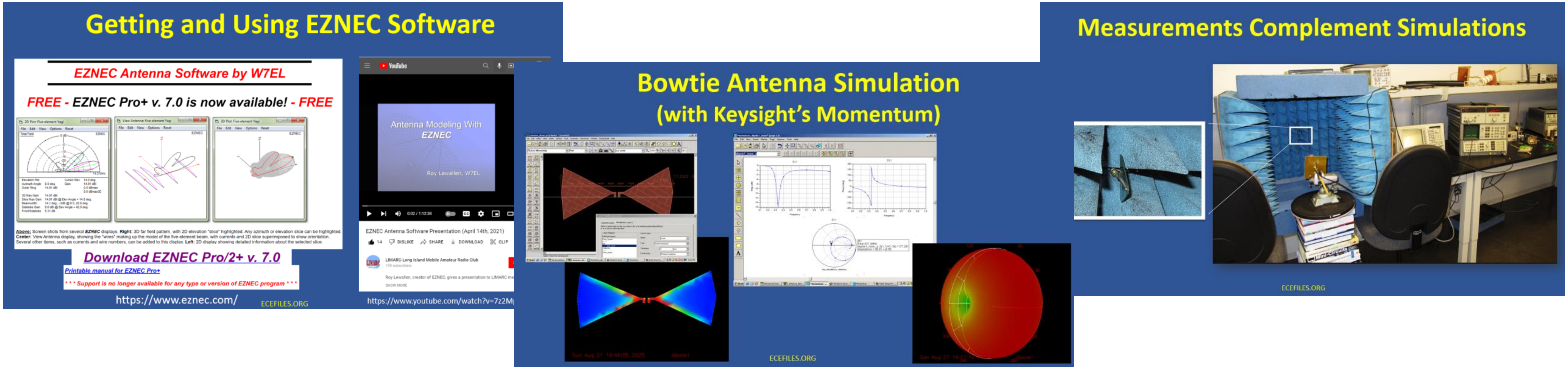
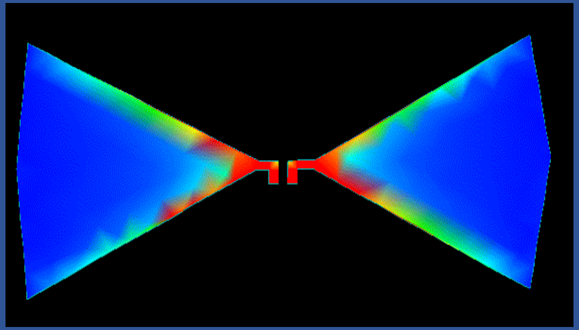
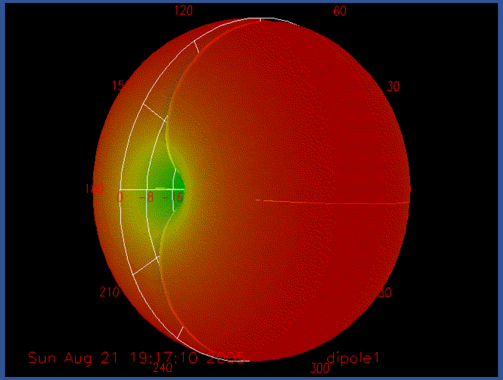
Antenna Briefs #6 -- Analysis, Simulation, and Measurements

Companion video at: https://www.youtube.com/watch?v=VFRIBtFwPiE

This episode looks at how antennas are analyzed and simulated. It starts with real-world measurements to set the stage and illustrate key issues like antenna patterns. We then dive briefly into some of the math behind antenna pattern formation. But as always, the focus is on understanding the theory that is relevant to engineering. Information on and examples of antenna simulation software products are also provided.

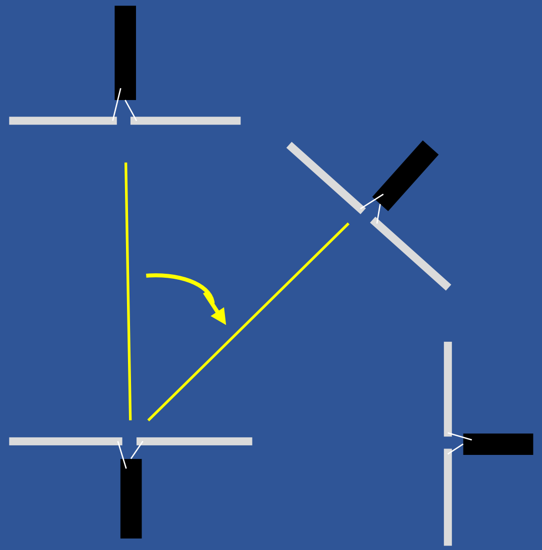


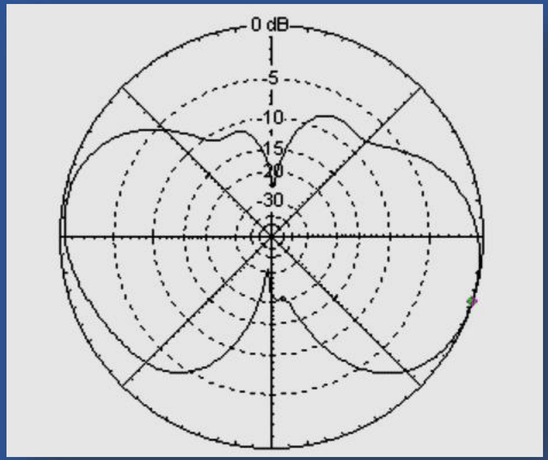




Antenna Briefs #6

Analysis, Simulation, and Measurements





Topics

Topics

→ Some quick measurements to set the stage

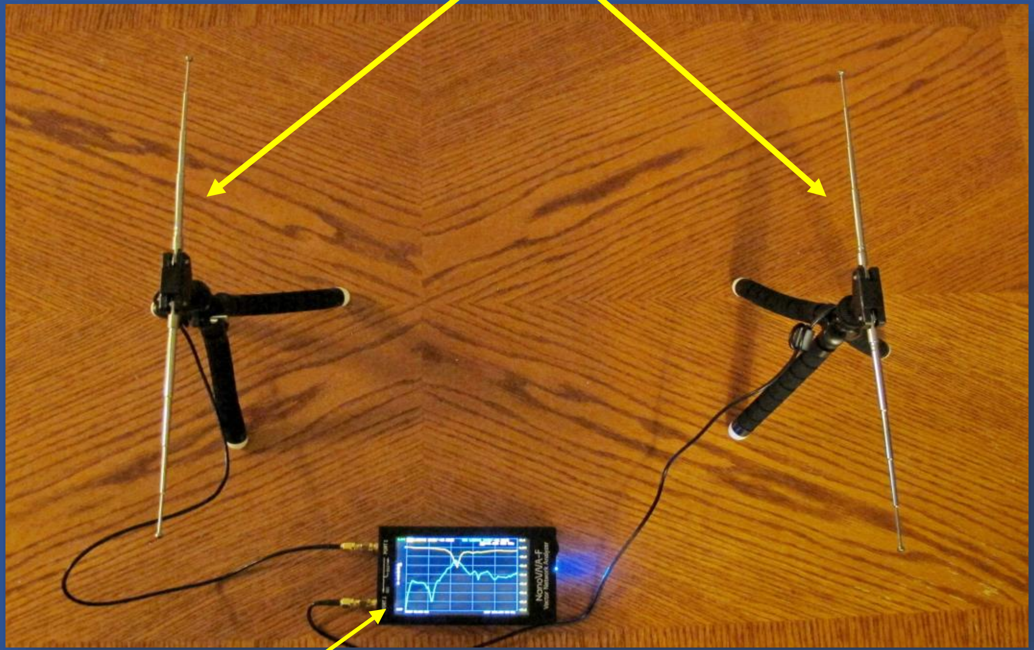
E-field and pattern calculations

Antenna simulation

E-fields and B-fields revisited

Recall From Previous Episodes

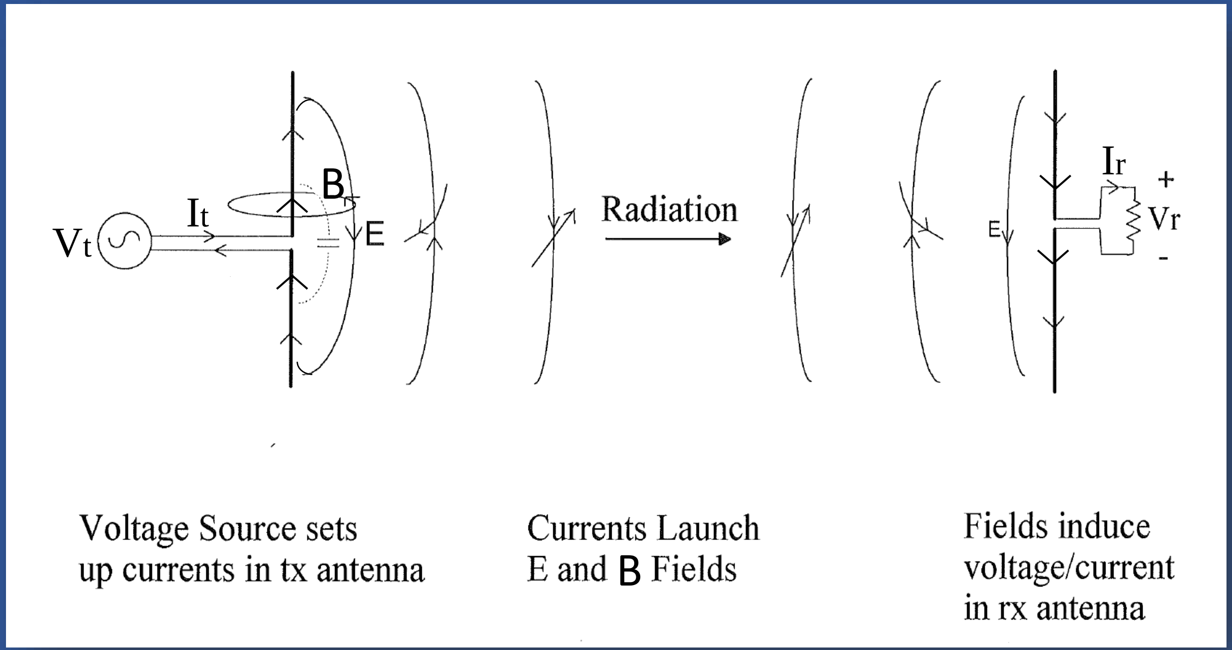
RTL-SDR Dipole Antennas



NanoVNA

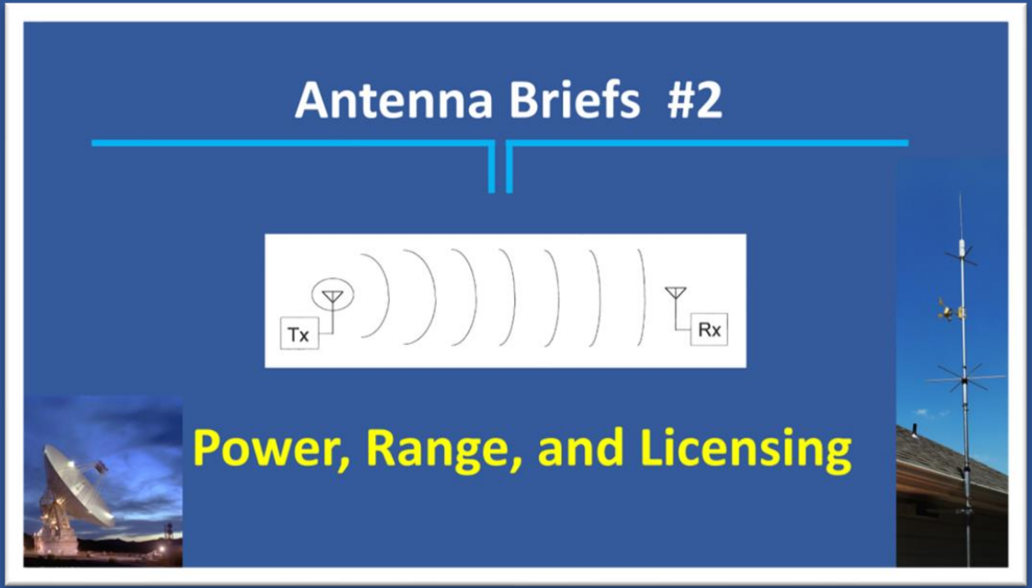
(Transmitter, receiver, display)

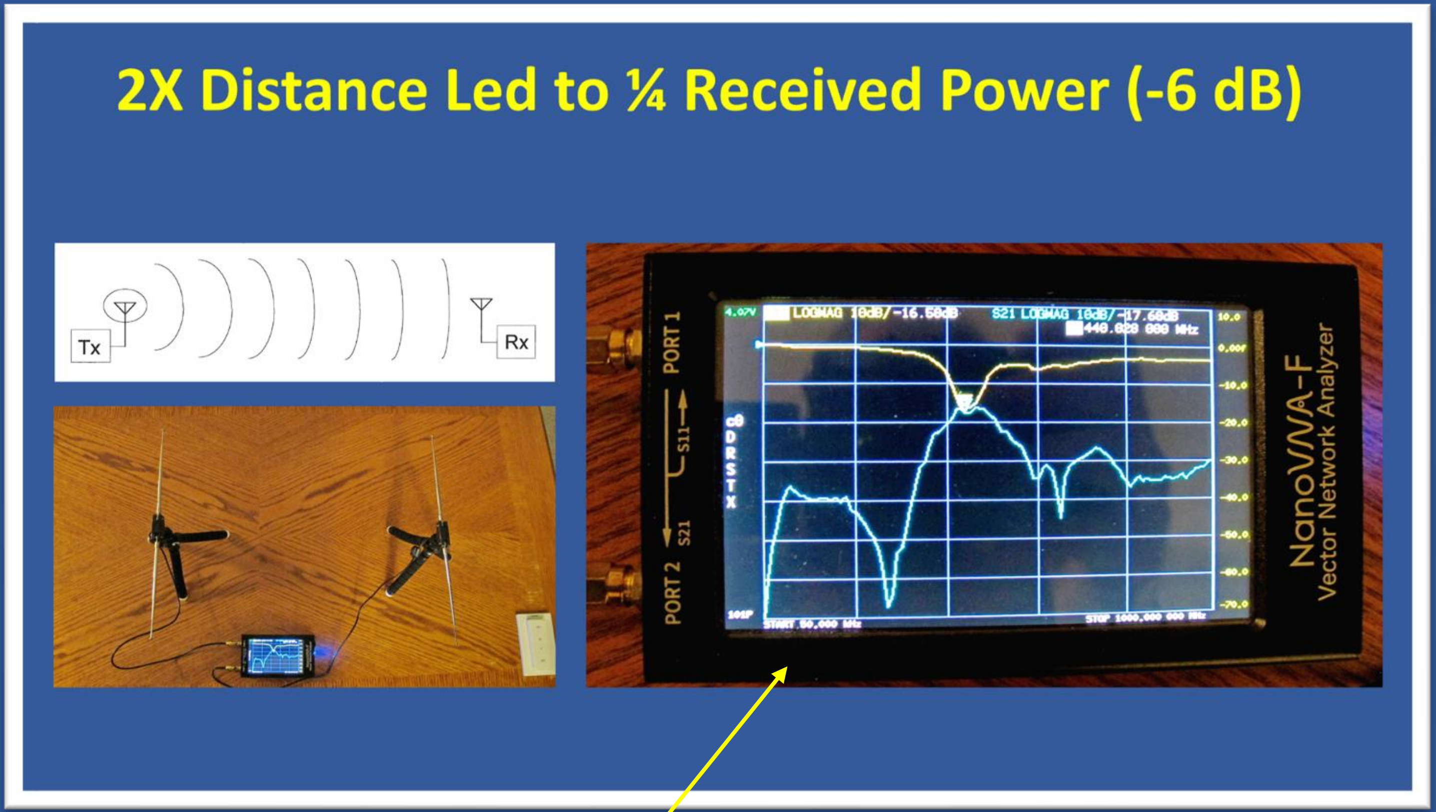
$$P_t = \frac{V_t^{\,2}}{R_{ant}} \qquad P_{density} = \frac{P_t\, G_t}{4\,\pi\, d^2} = \frac{|E|^2}{Z_o}$$



$$E = \sqrt{\frac{P_t\, G_t}{4\,\pi\, d^2}\, Z_o} \qquad V_r = E\; L_{eff}$$

Path Loss Measurement

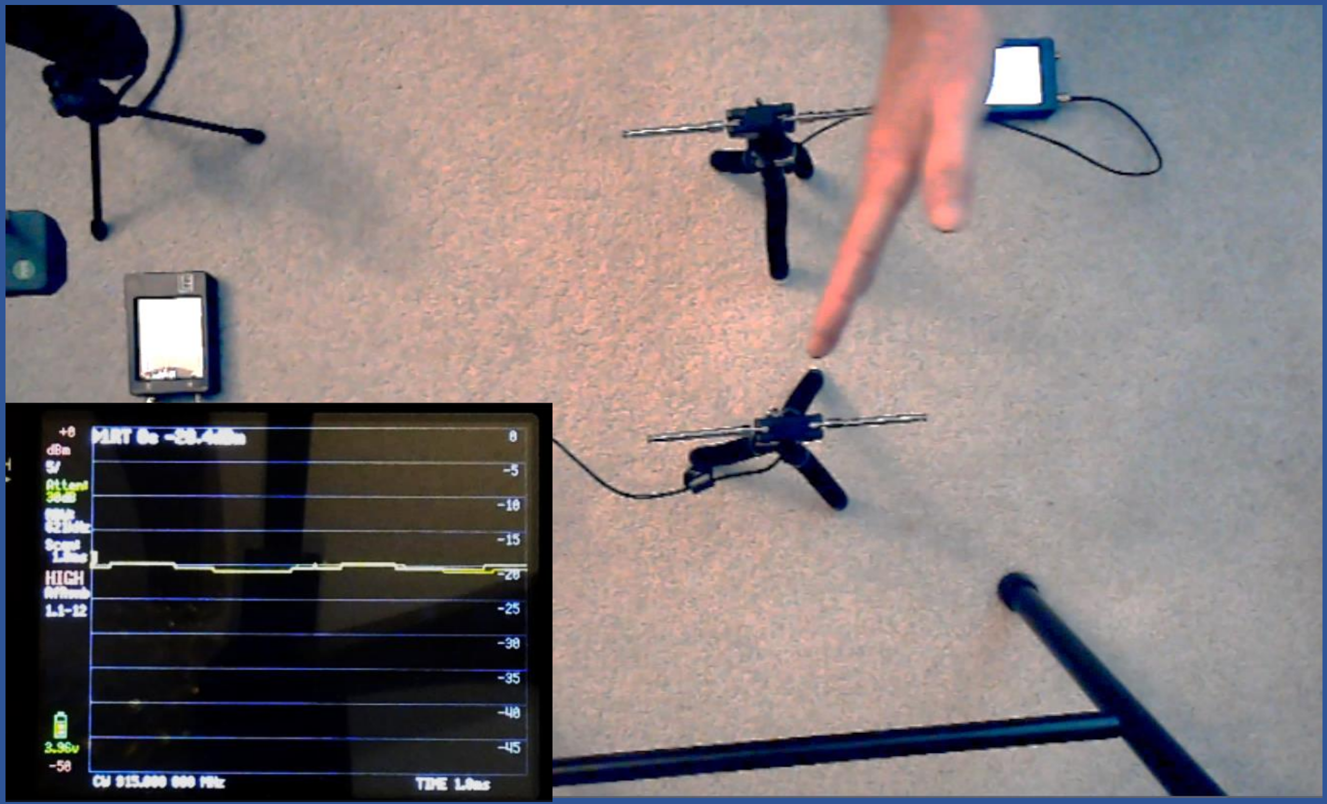


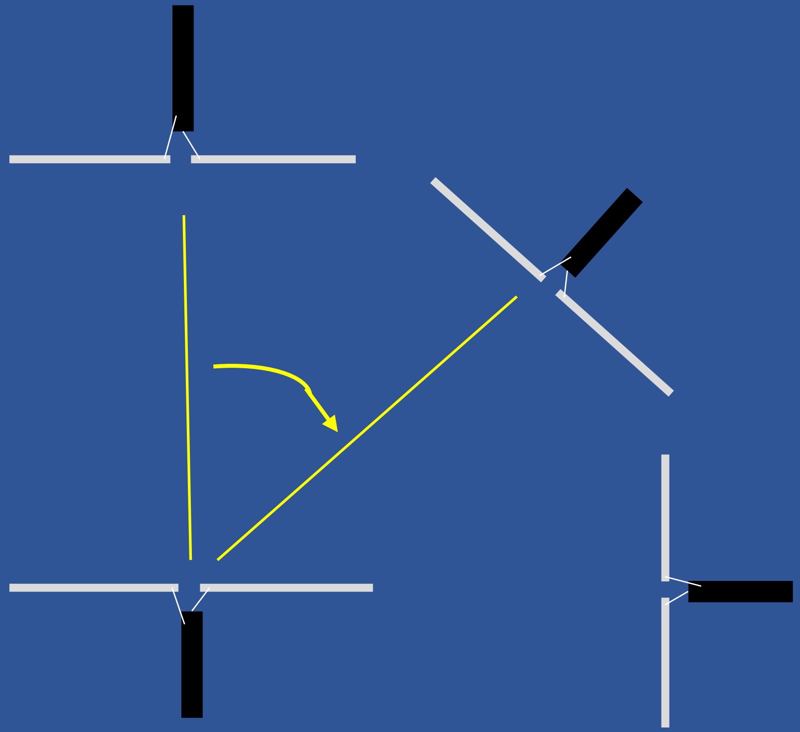


NanoVNA

(Measuring **S11** and **S21**)

Pattern and Polarization Measurements



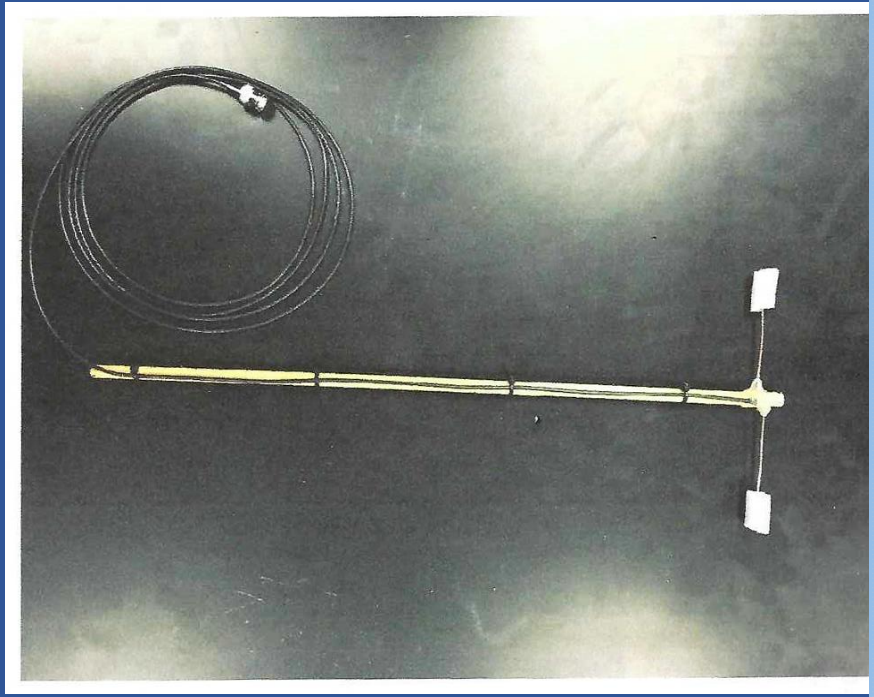


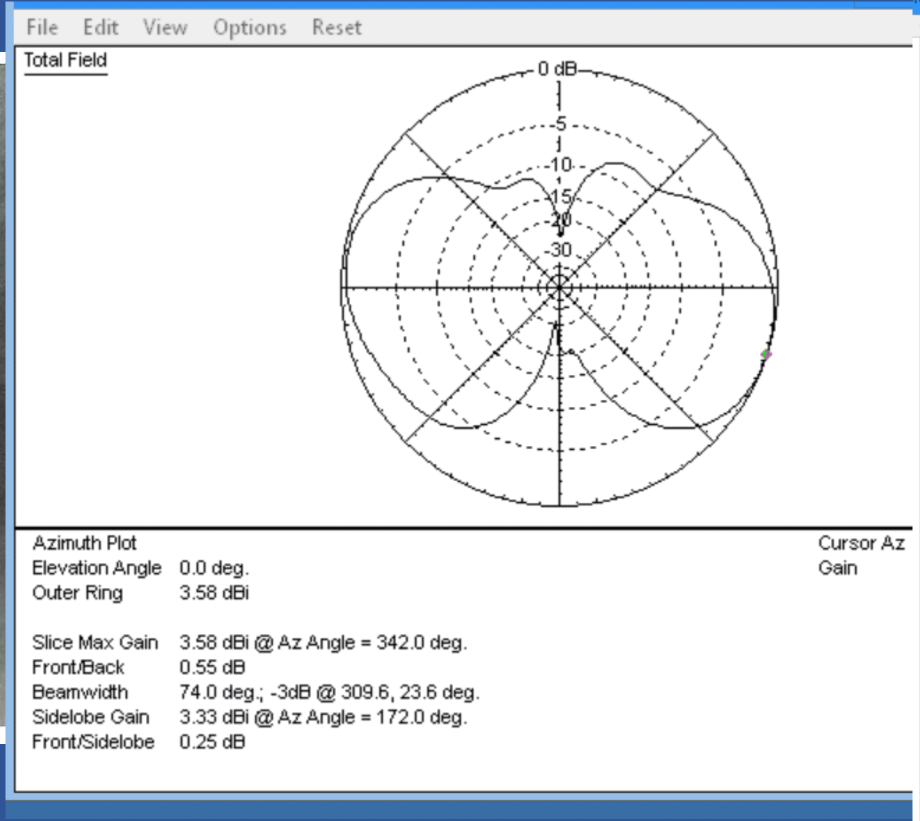
Using ***TinySA*** instruments with ***RTL-SDR antenna kits***

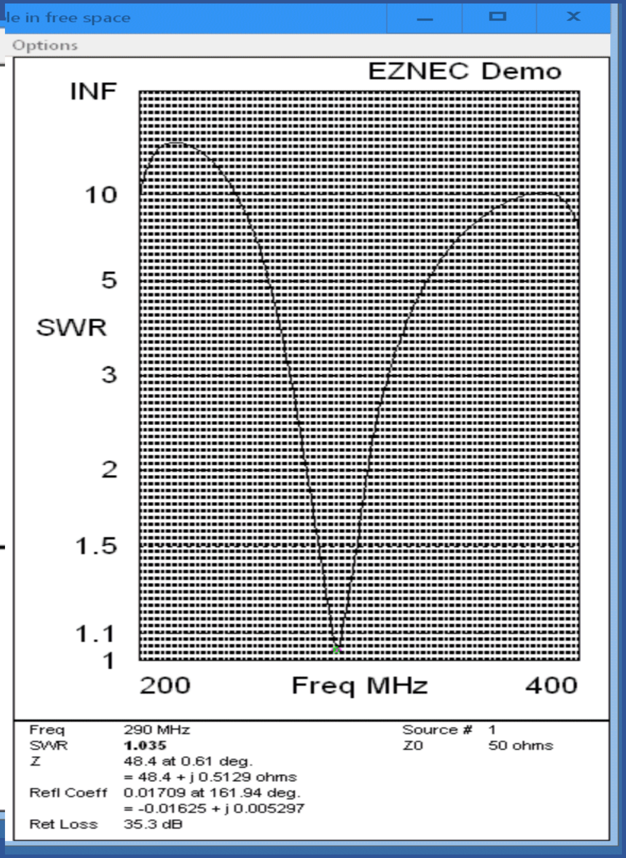
(in a not-so-good home “antenna range” ☺)

Fixed frequency at 915 MHz (unlicensed ISM band)

Pattern and Impedance Simulation



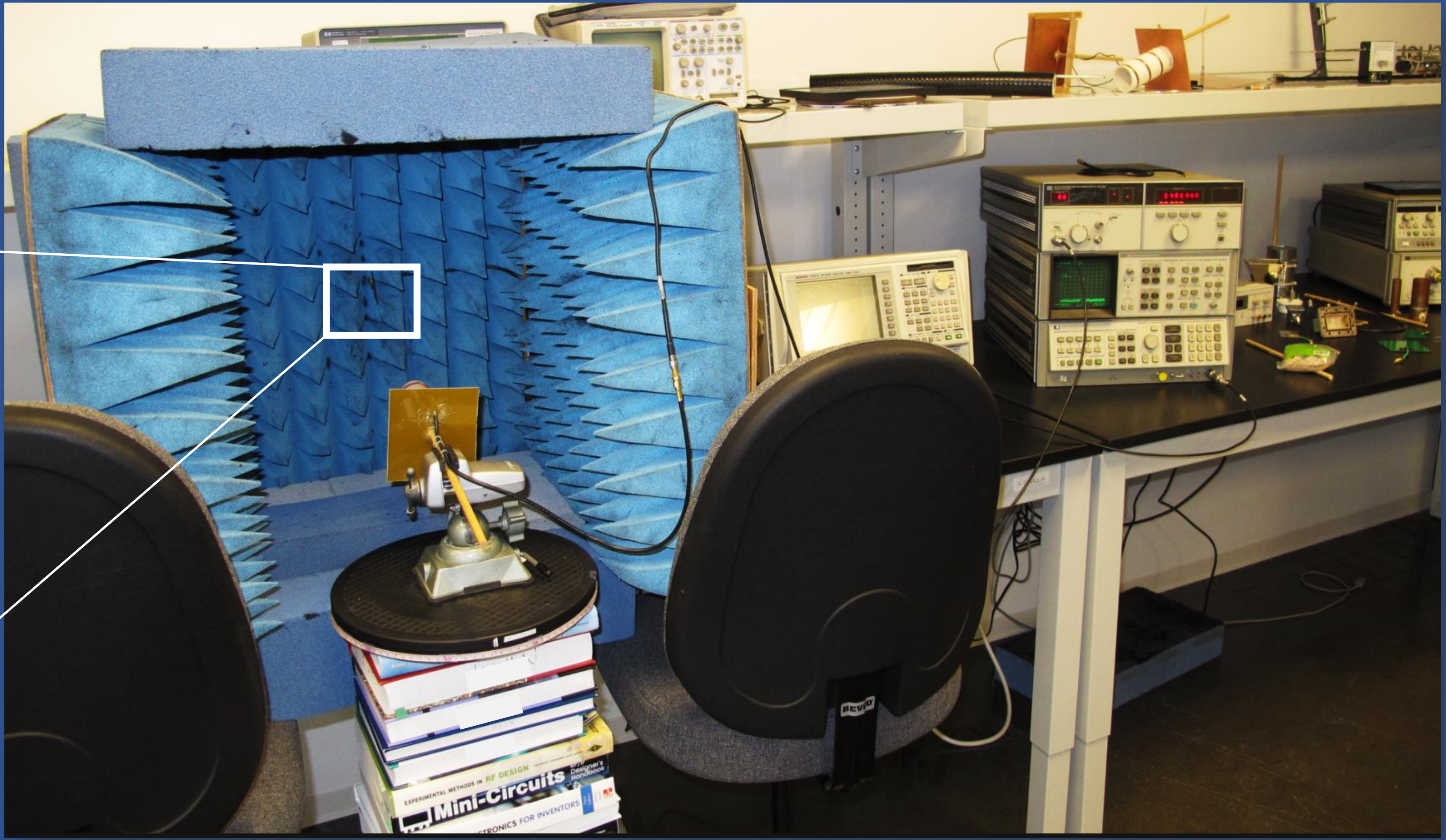




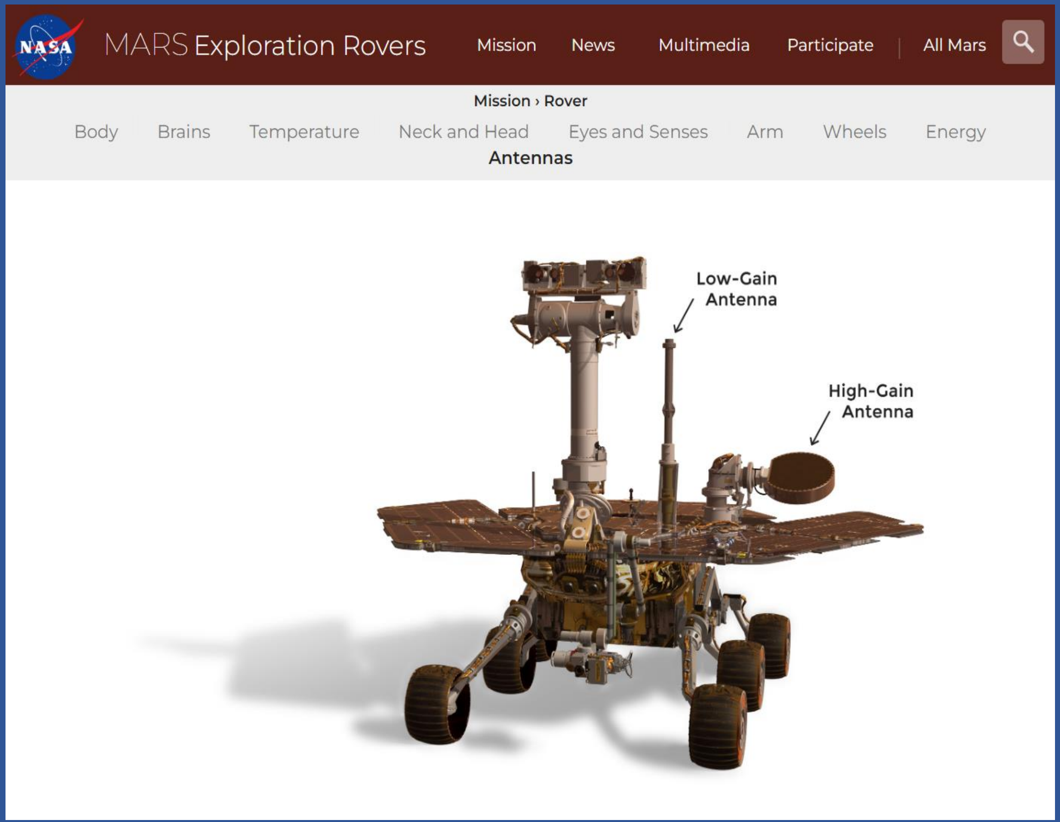
Far-Field 2-D Pattern and SWR, Z

Simulated using ***EZNEC*** Software

Measurements Complement Simulations



Measurements of Mars Rover Antennas



https://mars.nasa.gov/mer/mission/rover/antennas/

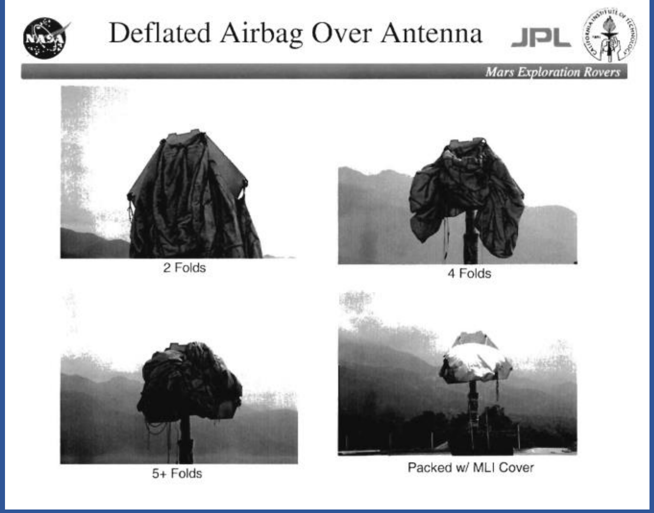
Jet Propulsion Laboratory
California Institute of Technology

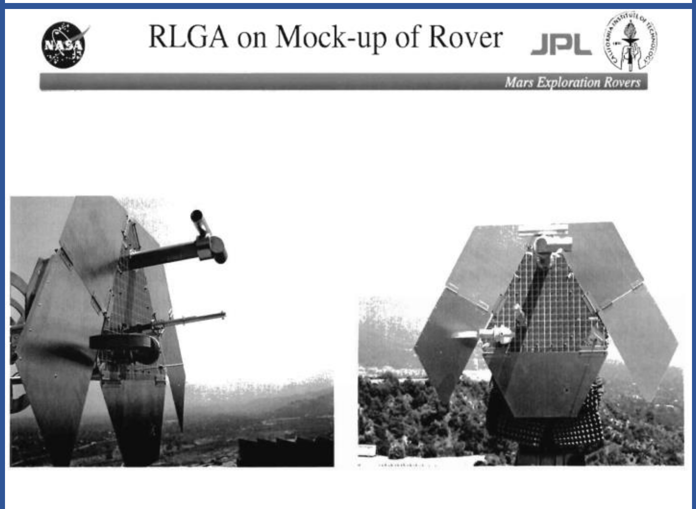
ANTENNAS and PROPAGATION SOCIETY
LOS ANGELES CHAPTER

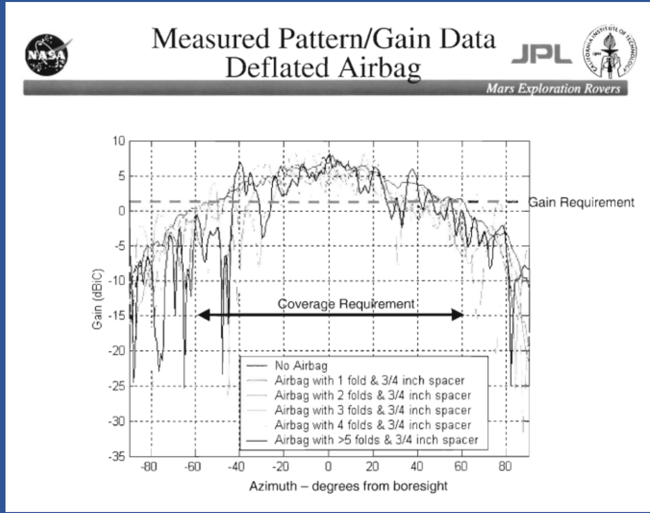
INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS

Antenna Designs for the Mars Exploration Rover (MER) Spacecraft, Lander, & Rover

Joseph Vacchione – Lead Antenna Engineer
Michael Thelen – Lead Mechanical Engineer
Paula Brown – Medium/Low Gain Horn Antenna Engineer
John Huang – Microstrip Patch Antenna Engineer
Ken Kelly – UHF Antenna Engineer
Vaughn Cable – Test Engineer
Satish Krishnan – High Gain Antenna Actuator Lead Engineer
Ball Aerospace & Technologies Corp. – High Gain Antenna Contractor
Kevlin Corp. – Rotary Joint Contractor
Atlantic Microwave Corp. – Septum Polarizer Contractor







https://trs.jpl.nasa.gov/bitstream/handle/2014/41044/01-2249.pdf

Topics

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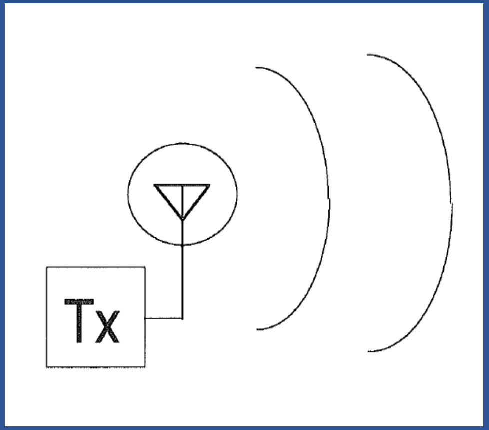
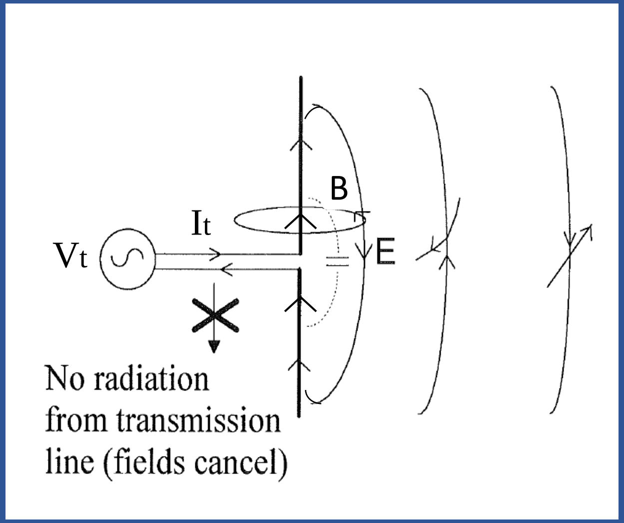
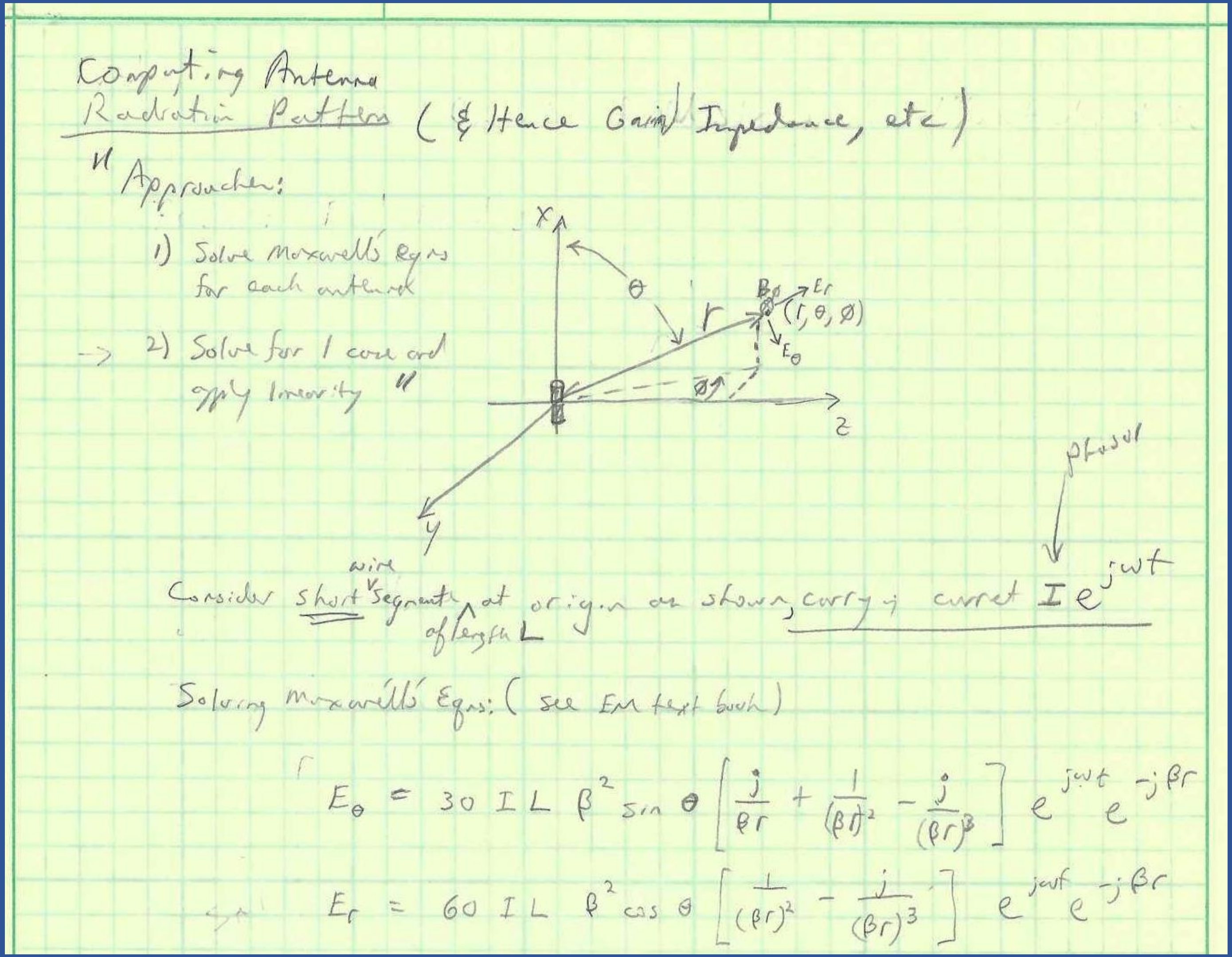
Antenna simulation

E-fields and B-fields revisited

Near and Far-Field Calculations







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

"Approaches:

1) Solve Maxwell's Eqns for each antenna

→ 2) Solve for 1 case and apply linearity"

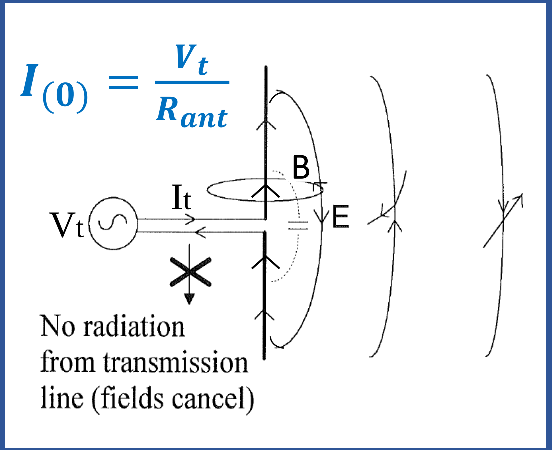
Consider short wire segment of length L at origin as shown, carrying current $I e^{j\omega t}$

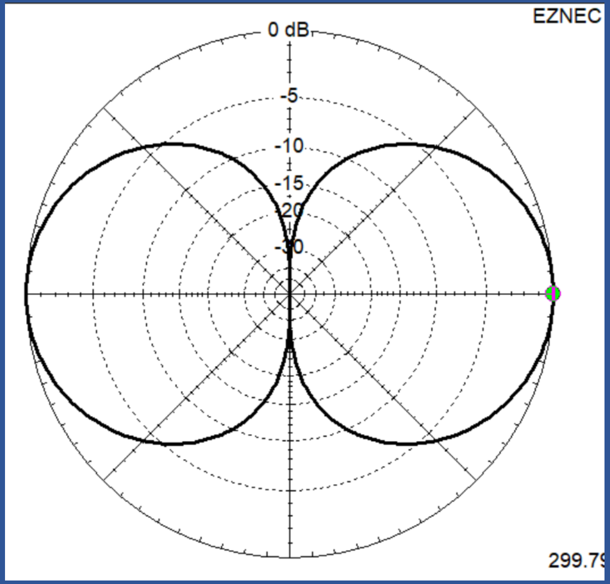
Solving Maxwell's Eqns: (see EM text book)

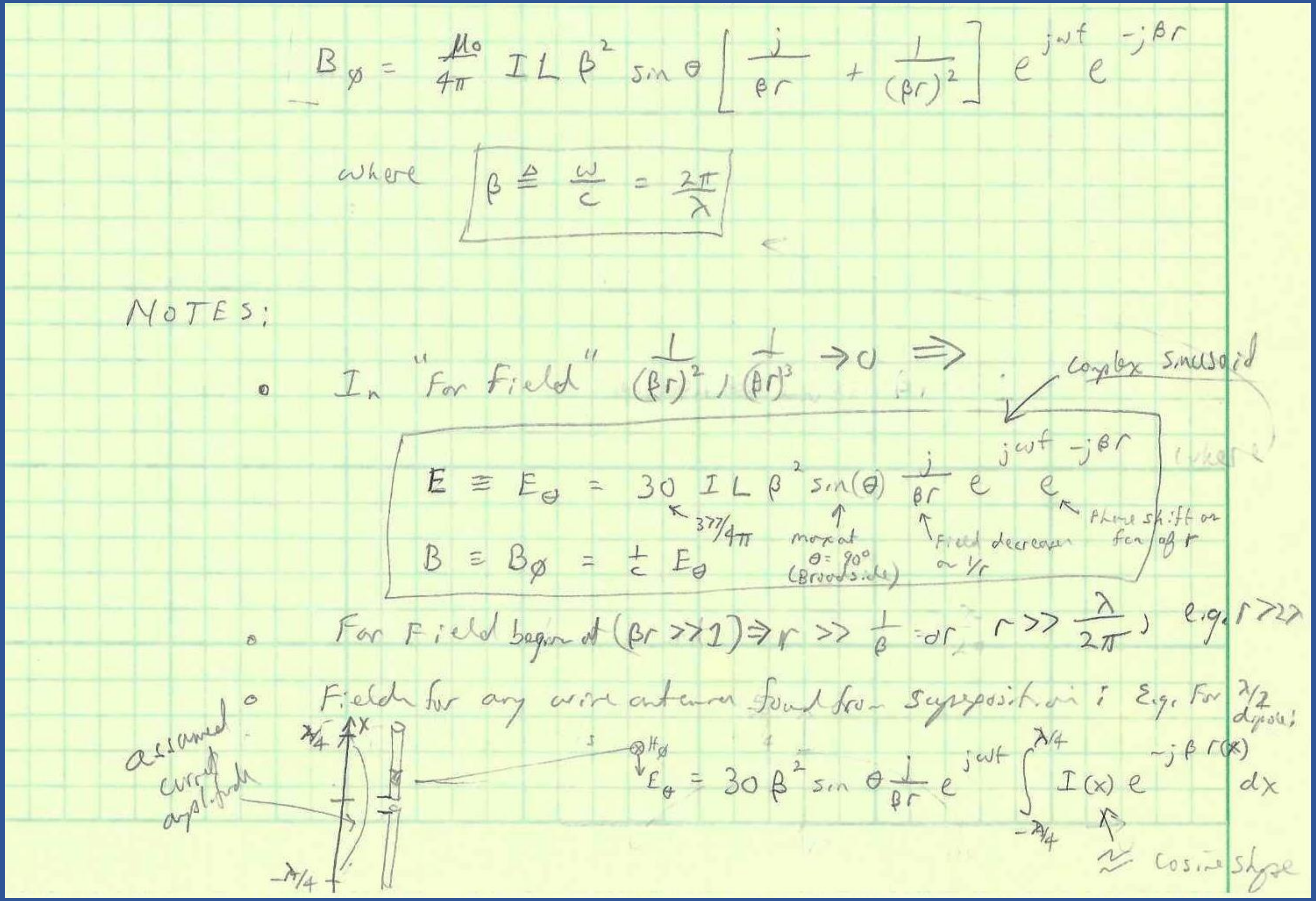
$$E_\theta = 30\, I L\, \beta^2 \sin\theta \left[\frac{j}{\beta r} + \frac{1}{(\beta r)^2} - \frac{j}{(\beta r)^3} \right] e^{j\omega t} e^{-j\beta r}$$

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

Far Field Pattern Calculation







Topics

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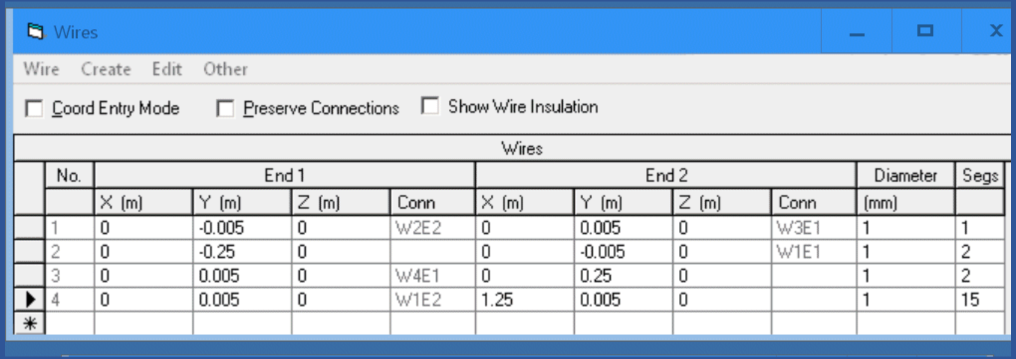
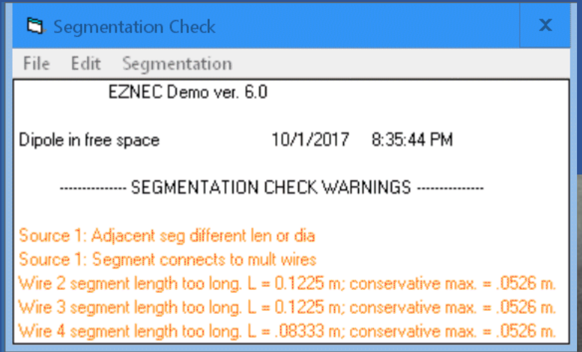
- Some quick measurements to set the stage
- E-field and pattern calculations
- → Antenna simulation
- E-fields and B-fields revisited

Antenna Simulation (with EZNEC) …



Wires

No.	End 1				End 2				Diameter	Segs
	X (m)	Y (m)	Z (m)	Conn	X (m)	Y (m)	Z (m)	Conn	(mm)	
1	0	-0.005	0	W2E2	0	0.005	0	W3E1	1	1
2	0	-0.25	0		0	-0.005	0	W1E1	1	2
3	0	0.005	0	W4E1	0	0.25	0		1	2
4	0	0.005	0	W1E2	1.25	0.005	0		1	15

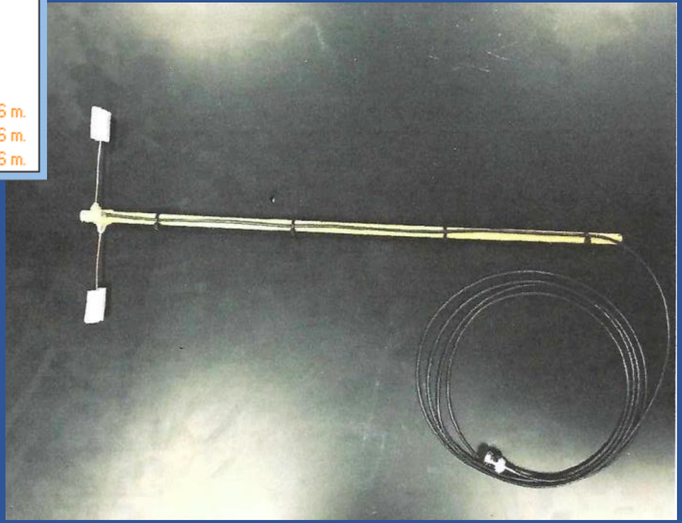


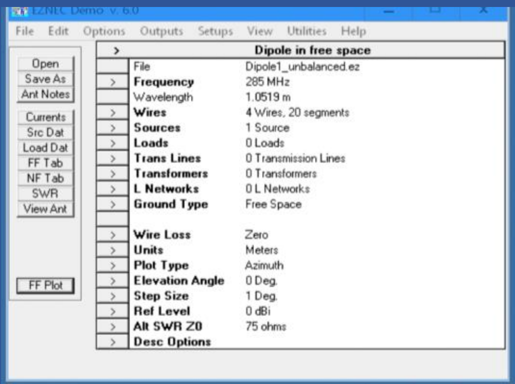
EZNEC Demo ver. 6.0

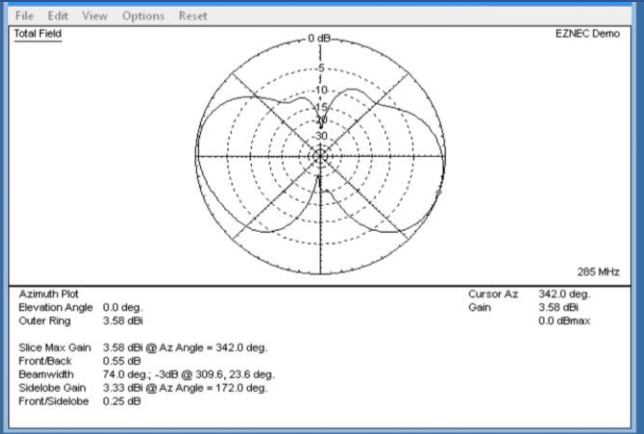
Dipole in free space 10/1/2017 8:35:44 PM

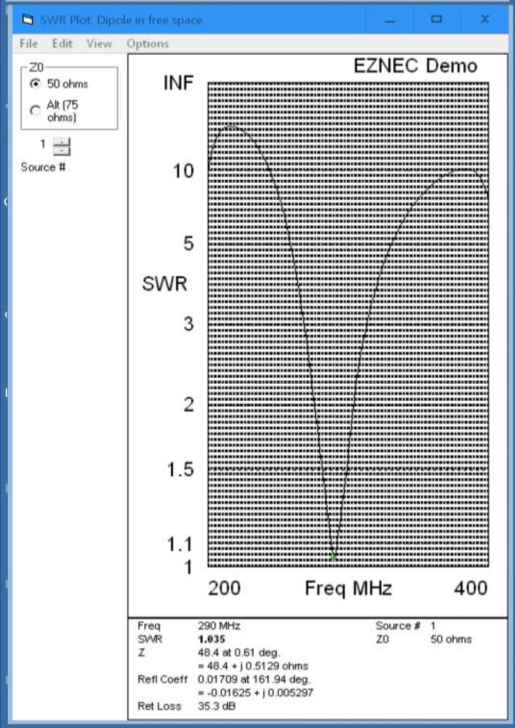
-------------- SEGMENTATION CHECK WARNINGS --------------

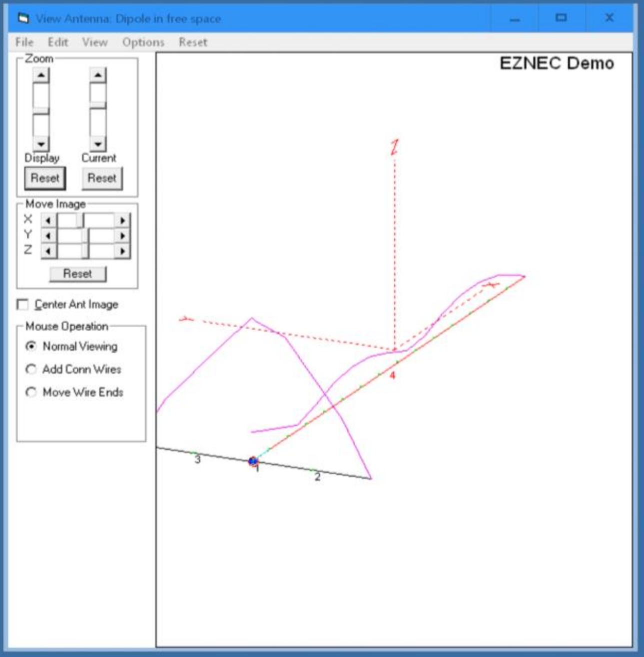
Source 1: Adjacent seg different len or dia
Source 1: Segment connects to mult wires
Wire 2 segment length too long. L = 0.1225 m; conservative max. = .0526 m.
Wire 3 segment length too long. L = 0.1225 m; conservative max. = .0526 m.
Wire 4 segment length too long. L = .08333 m; conservative max. = .0526 m.







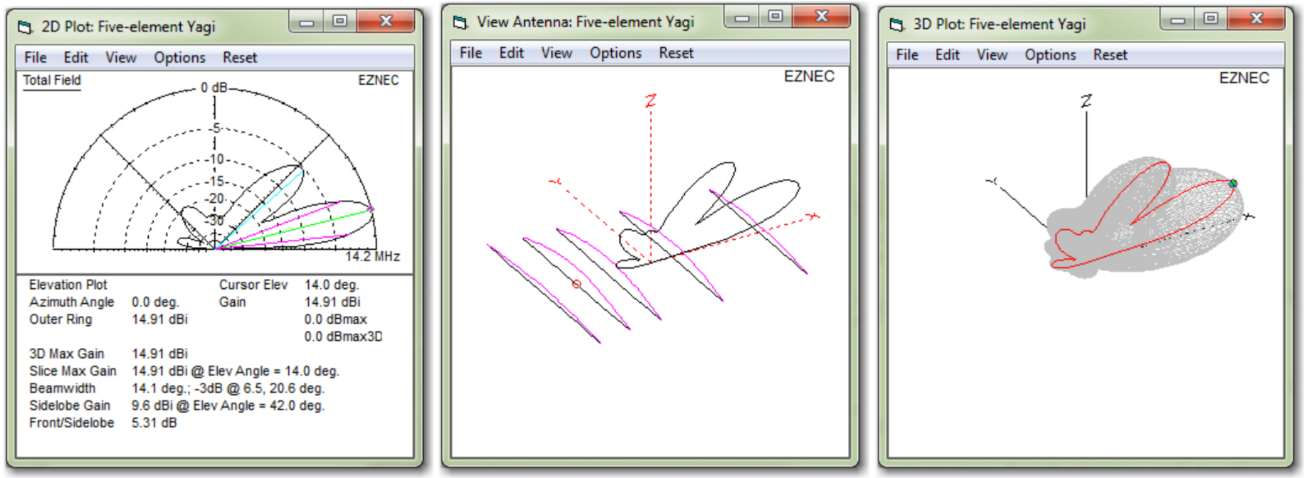




Getting and Using EZNEC Software

EZNEC Antenna Software by W7EL

FREE - EZNEC Pro+ v. 7.0 is now available! - FREE



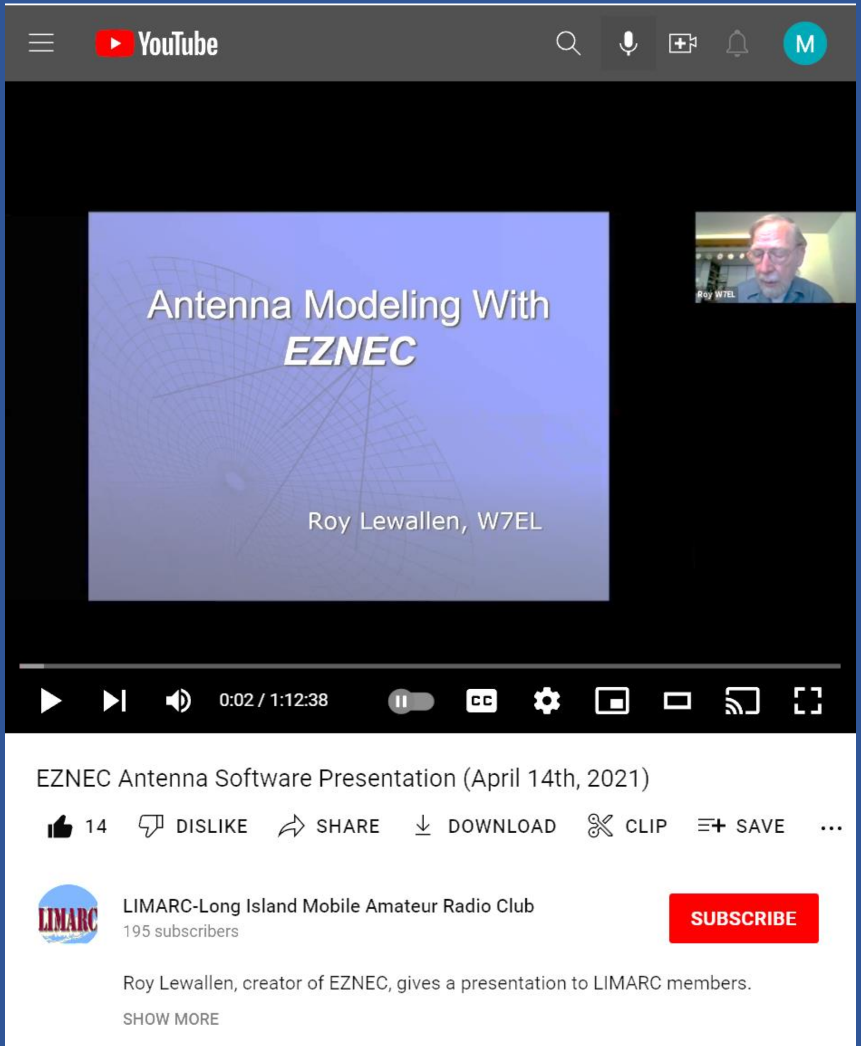
Above: Screen shots from several ***EZNEC*** displays. **Right:** 3D far field pattern, with 2D elevation "slice" highlighted. Any azimuth or elevation slice can be highlighted. **Center:** View Antenna display, showing the "wires" making up the model of the five-element beam, with currents and 2D slice superimposed to show orientation. Several other items, such as currents and wire numbers, can be added to this display. **Left:** 2D display showing detailed information about the selected slice.

Download EZNEC Pro/2+ v. 7.0

Printable manual for EZNEC Pro+

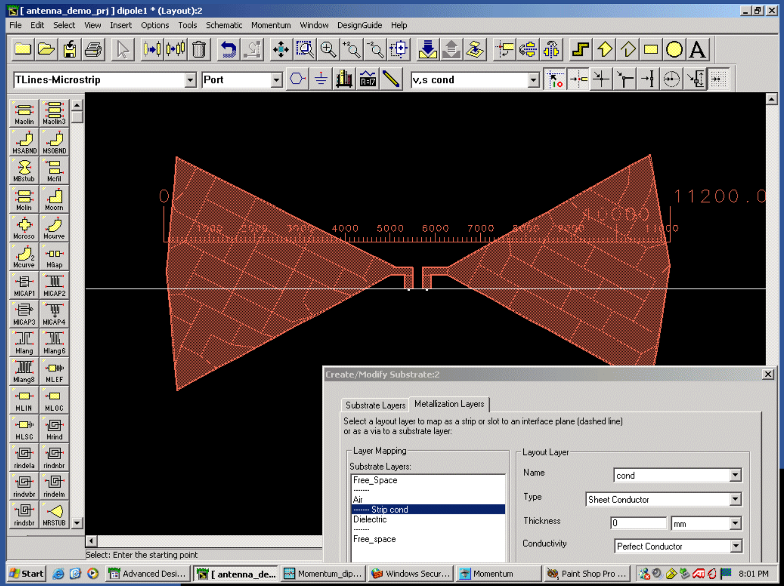
****** Support is no longer available for any type or version of EZNEC program * * ****

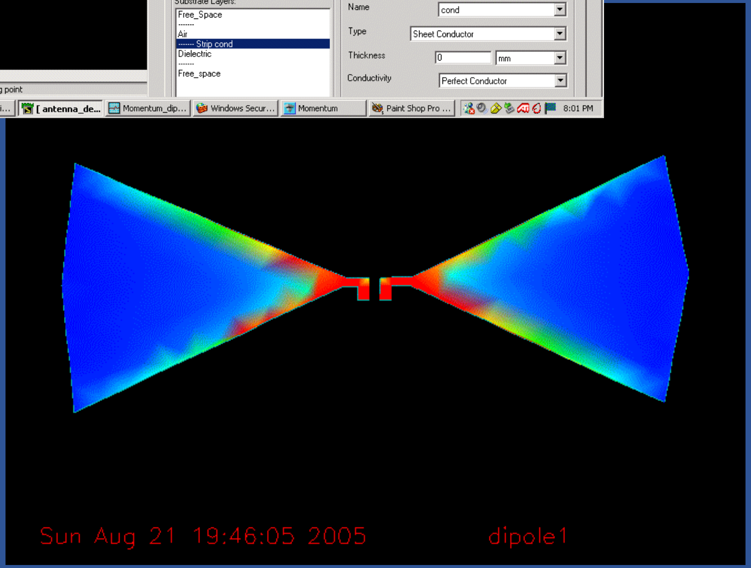
https://www.eznec.com/

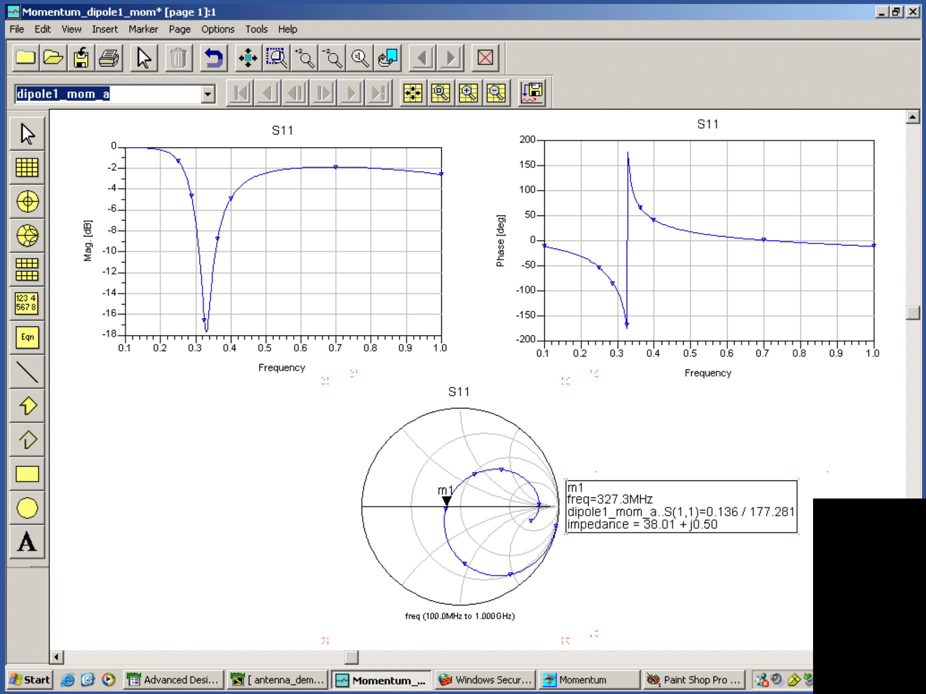


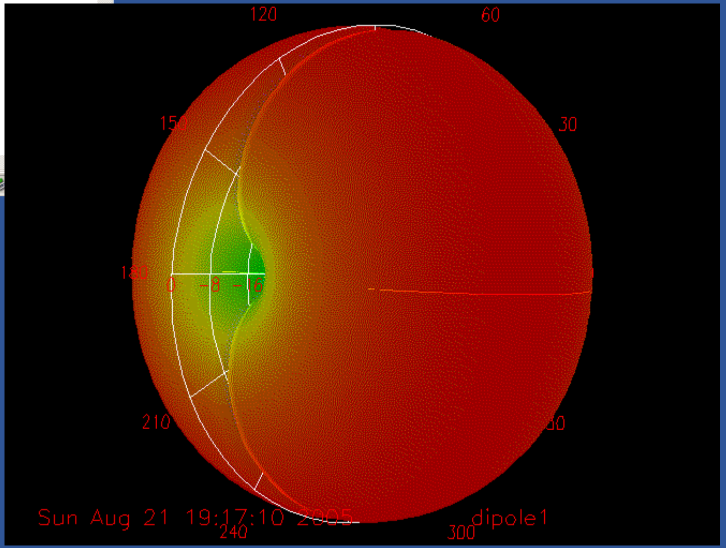
https://www.youtube.com/watch?v=7z2MpBeyt6U

Bowtie Antenna Simulation
(with Keysight's Momentum)









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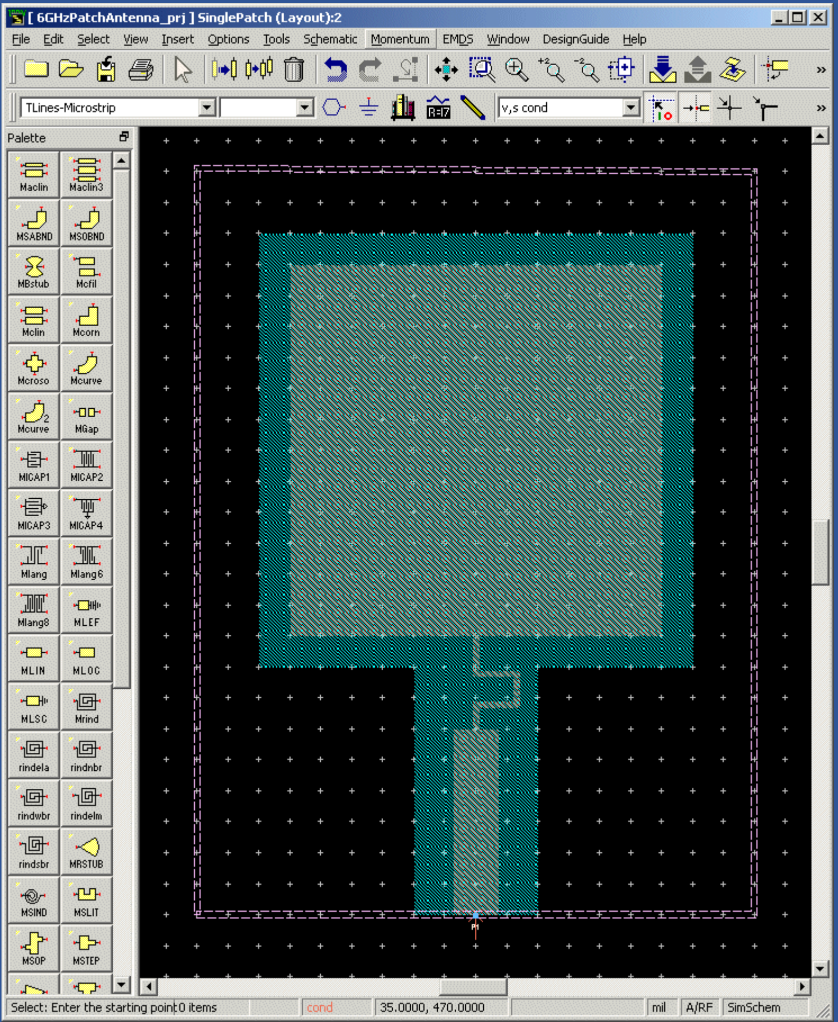
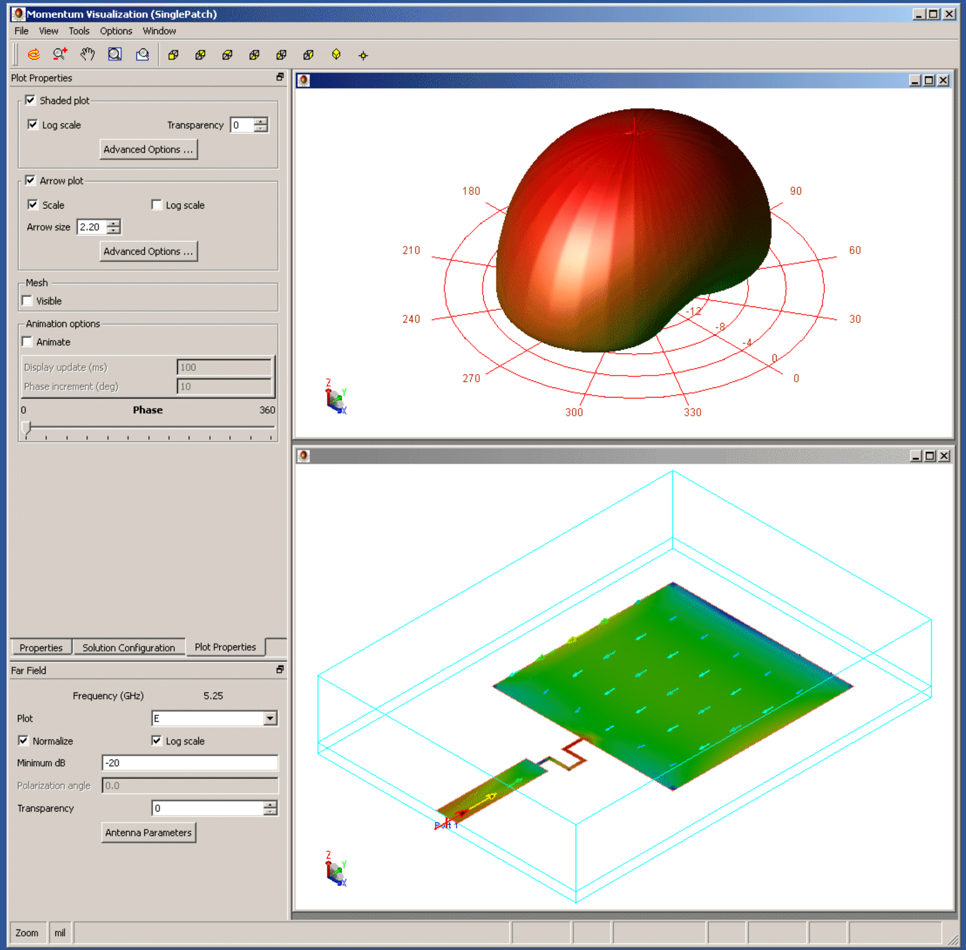
Patch Antenna Simulation
(with Keysight's Momentum)





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EM Simulation with MoM

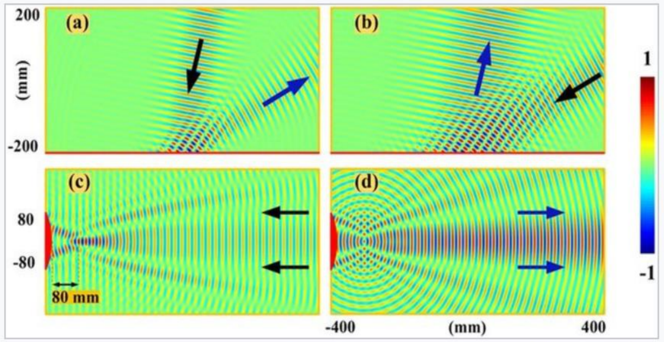
Method of moments (electromagnetics)

From Wikipedia, the free encyclopedia

> This article **may be too technical for most readers to understand**. Please help improve it to make it understandable to non-experts, without removing the technical details. *(September 2021)* (*Learn how and when to remove this template message*)

For the general integral equation method, see Boundary element method.

The **method of moments** (**MoM**), also known as the **moment method** and **method of weighted residuals**,[1] is a numerical method in computational electromagnetics. It is used in computer programs that simulate the interaction of electromagnetic fields such as radio waves with matter, for example antenna simulation programs like NEC that calculate the radiation pattern of an antenna. Generally being a frequency-domain method,[a] it involves the projection of an integral equation



Simulation of negative refraction from a metasurface at 15 GHz for different angles of incidence. The simulations are performed through the method of moments.

https://en.wikipedia.org/wiki/Method_of_moments_(electromagnetics)

A Tutorial on the Method of Moments

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Zeamet Sokak 21, Acıbadem – Kadıköy, 34722 Istanbul, Turkey

Abstract

Dedicated to the 87th birthday of Roger F. Harrington

The Method of Moments (MoM) is a numerical technique used to approximately solve linear operator equations, such as differential equations or integral equations. The unknown function is approximated by a finite series of known expansion functions with unknown expansion coefficients. The approximate function is substituted into the original operator equation, and the resulting approximate equation is tested so that the weighted residual is zero. This results in a number of simultaneous algebraic equations for the unknown coefficients. These equations are then solved using matrix calculus. MoM has been used to solve a vast number of electromagnetic problems during the last five decades. In addition to the basic theory of MoM, some simple examples are given. To demonstrate the concept of minimizing weighted error, the Fourier series is also reviewed.

Keywords: Numerical electromagnetics; Method of Mo
expansion functions; basis functions; Fourier series; te

1. Introduction

The Method of moments (MoM) is a general procedure solving linear equations. Many problems that cannot solved *exactly* can be solved *approximately* by this method.

For example, consider the simple problem of the parall plate capacitor. The approximate analytical formula for capacitance is $C_0 = \varepsilon A/d$ $C_0 = \varepsilon A/d$, where A is the area each plate and d is the distance between them. This form neglects the fringing fields, and is inaccurate except for v small d. In a later section, we use the MoM to compute a mo accurate capacitance (including the fringing effects) arbitrary d. Figure 1 shows the computed capacitance, normalized to C_0 as given above. The figure shows limitation of C_0 even for quite small values of d.

The MoM owes its name to the process of tak moments by multiplying with appropriate *weighing* functi and integrating. It has been applied to a broad range of el tromagnetic (EM) problems since the publication of the bo by Harrington [1]. A comprehensive bibliography is too v

3. Introduction to the MoM

Consider a linear-operator equation

$$L[f(x)] = g(x), \tag{9}$$

where L is a *linear* operator, $g(x)$ is a known function (usually, the excitation in a linear system), and $f(x)$ is the unknown function (usually, the response) to be found. Note that a linear operator must satisfy

$$L[\alpha f_1(x) + \beta f_2(x)] = \alpha L[f_1(x)] + \beta L[f_2(x)], \tag{10}$$

where f_1 and f_2 are two functions, and α and β are constants. The following is a set of examples of linear operators:

$$L[f(x)] = 5f(x), \tag{11}$$

$$L[f(x)] = \frac{df(x)}{dx}, \tag{12}$$

$$L[f(x)] = 5\frac{d^2f(x)}{dx^2} + 7\frac{df(x)}{dx} + 3f(x), \tag{13}$$

$$L[f(x)] = \int_0^x f(x')\sin(x - x')dx', \tag{14}$$

$$L[f(x)] = \nabla^2 f(x), \tag{15}$$

Here, the constants α_n are called the unknown *expansion coefficients* to be found. Note that the function $f_\alpha(x)$ $f_a(x)$ represented by the series in Equation (18) is an approximation to the exact unknown function, $f(x)$. Since the exact function is not known, the error function, defined by $e(x) = f(x) - f_\alpha(x)$, is also unknown. Substituting $f_\alpha(x)$ into Equation (9) yields

$$L[f_\alpha(x)] = \sum_{n=1}^{N} \alpha_n L[h_n(x)]$$
$$= \alpha_1 L[h_1(x)] + \alpha_2 L[h_2(x)] + .. + \alpha_N L[h_N(x)] \tag{19}$$
$$\approx g(x).$$

For a given $f_\alpha(x)$, the residual is defined by

$$r(x) = L[f(x)] - L[f_\alpha(x)]$$
$$= g(x) - L[f_\alpha(x)]. \tag{20}$$

Although we do not know the exact function, it is clear that if the approximate function, $f_\alpha(x)$, is equal to the exact function, $f(x)$, then the residual will be identically zero. Our purpose should hence be to minimize the residual. In the MoM, instead of minimizing the residual itself, we force the *weighted residual* to be zero.

"A Tutorial on the Method of Moments"
IEEE Antennas and Propagation Magazine, June 2012

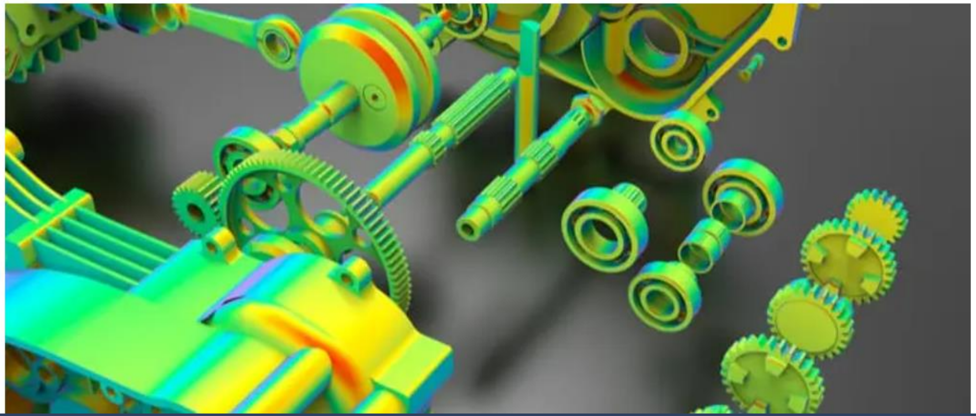
FDTD and FEM Methods

FDTD vs. FEM vs. MoM: What Are They and How Are They Different?

Cadence System Analysis

Key Takeaways

- Several numerical schemes are used to discretize electromagnetics problems and solve Maxwell's equations in arbitrary geometries.
- Complex systems like PCBs and ICs can be treated using one of these numerical methods, but they provide different benefits and should be used in different situations.
- Some field solvers will allow you to select which method you use to solve certain problems.



https://resources.system-analysis.cadence.com/blog/msa2021-fdtd-vs-fem-vs-mom-what-are-they-and-how-are-they-different

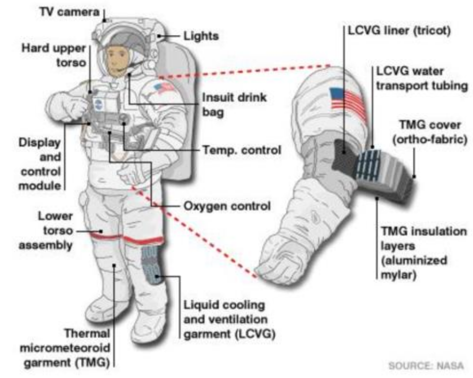


Figure 1. EMU Space Suit Structure with TMG insulation layers

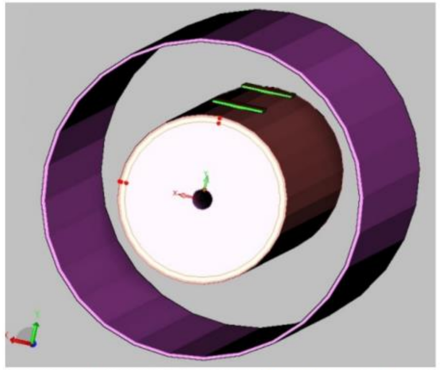


Fig. 2 Simulation setup for two antennas placed on human arm inside a section of spacesuit

Agilent EMPro's FDTD based solver was used to simulate S21 parameter according to each of the frequencies used; 433 MHz, 2.4 GHz and 5.2 GHz except for the S21 simulation using 433 MHz monopole antenna. In the case of 433 MHz helical monopole, Finite-Element Method (FEM) based solver was found to be more efficient for helical shaped antenna. In the

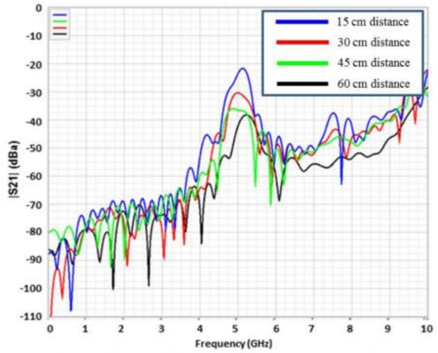


Fig. 6 S21 curve for two 5.2 GHz patch antennas for 4 antenna separation distances: 15, 30, 45 and 60 cm with corresponding values of 21.6, 30, 36 and 38.3 dB, respectively.

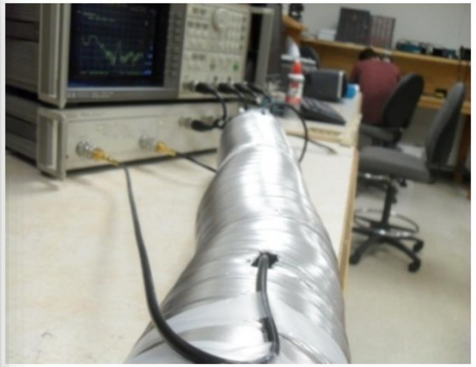


Fig. 7 Measurement Setup

"Investigation of practical antennas for astronaut body area networks," 2014 IEEE International Conference on Wireless for Space and Extreme Environments (WiSEE)

Future Topics

Upcoming episodes

- Reflection of EM Waves
- Antenna types, patterns, directivity gain, impedance, and polarization
- Counterpoise, baluns, and chokes
- Phase, superposition, and beamforming

Thanks for Watching

But wait ! There's more …

Topics

Topics

Some quick measurements to set the stage

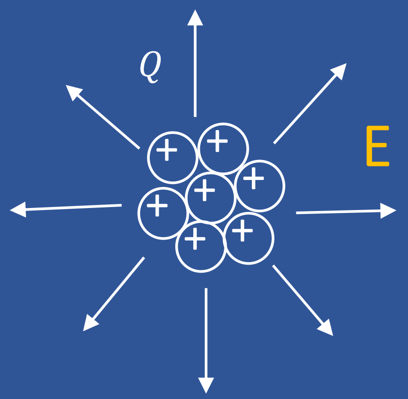
E-field and pattern calculations

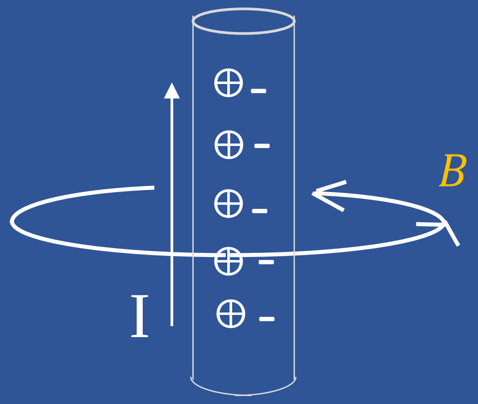
Antenna simulation

→ E-fields and B-fields revisited

(what 'is' a B field and EM Wave ??)

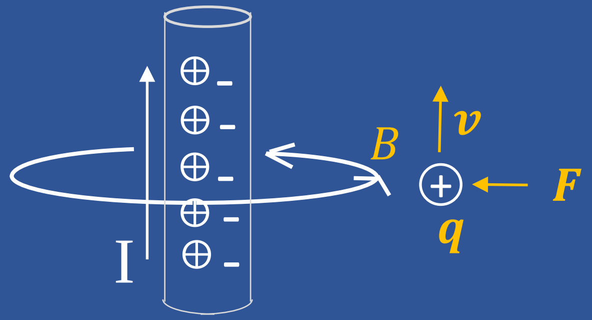
E and B Fields





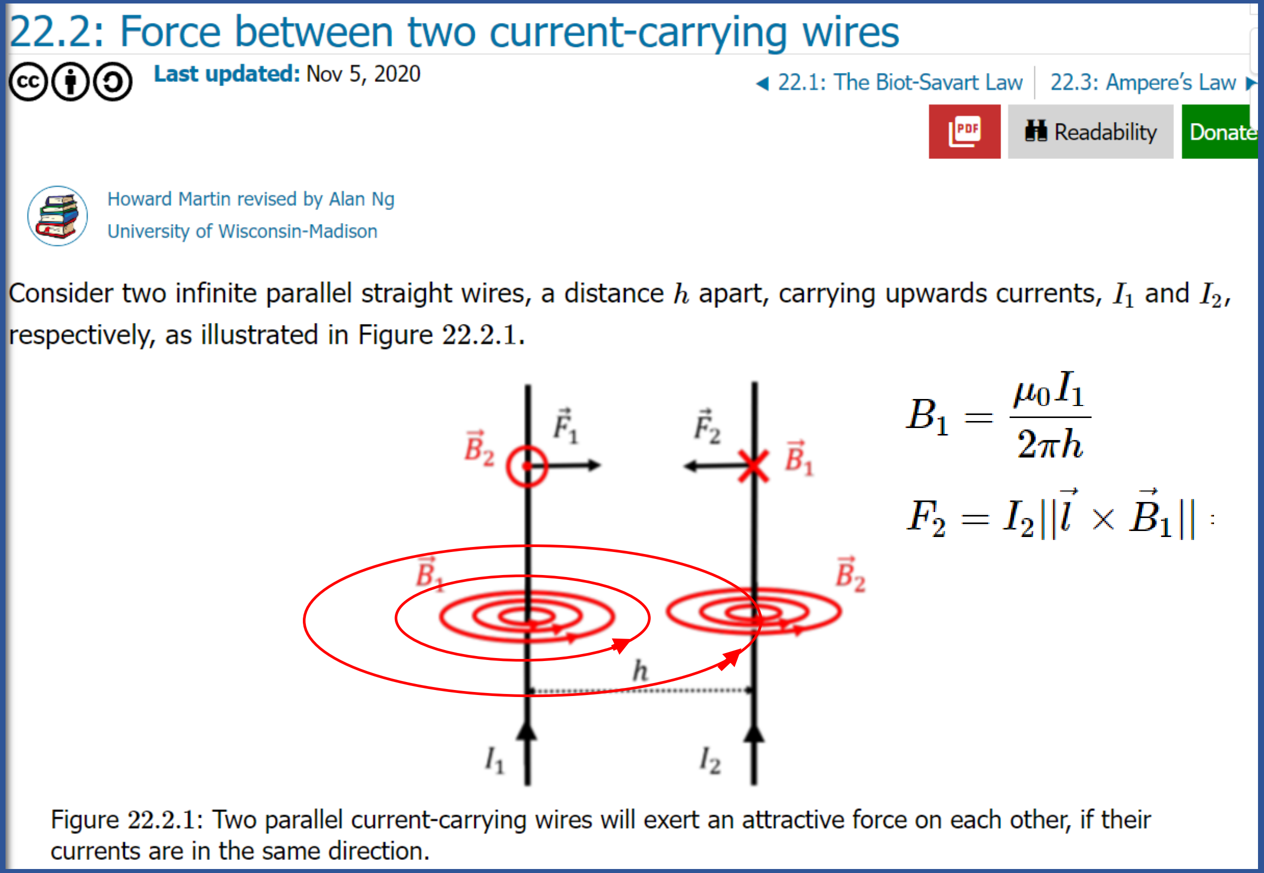
What "is" a B Field ?

B field "curls" around a current (***moving charges*** in wire)



A charge q in presence of B experiences a force:

$$\boldsymbol{F} = q\,(\boldsymbol{v} \times \boldsymbol{B})$$



22.2: Force between two current-carrying wires

◂ 22.1: The Biot-Savart Law | 22.3: Ampere's Law ▸

Howard Martin revised by Alan Ng
University of Wisconsin-Madison

Consider two infinite parallel straight wires, a distance h apart, carrying upwards currents, I_1 and I_2, respectively, as illustrated in Figure 22.2.1.

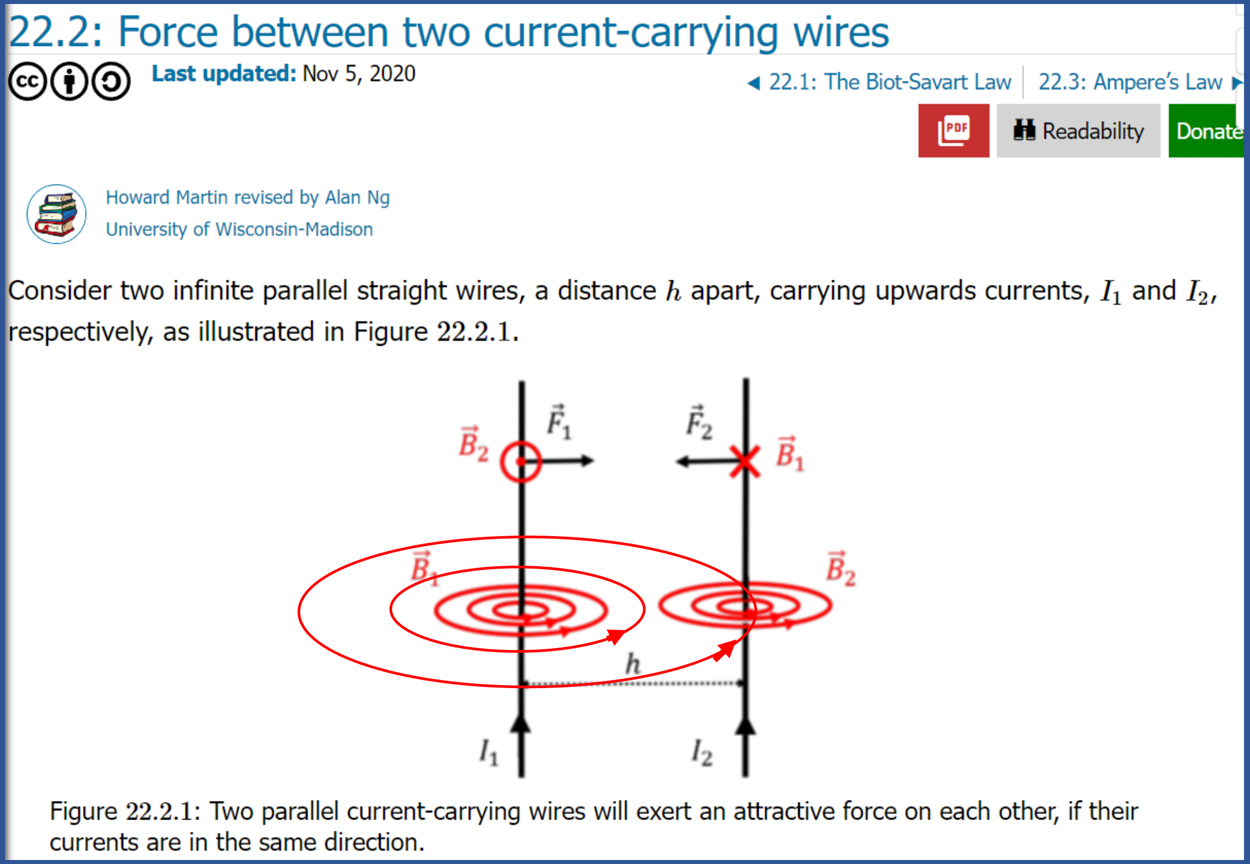
$$B_1 = \frac{\mu_0 I_1}{2\pi h}$$

$$F_2 = I_2 ||\vec{l} \times \vec{B}_1||$$

Figure 22.2.1: Two parallel current-carrying wires will exert an attractive force on each other, if their currents are in the same direction.

https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_Introductory_Physics_-_Building_Models_to_Describe_Our_World_(Martin_Neary_Rinaldo_and_Woodman)/22%3A_Source_of_Magnetic_Field/22.02%3A_Force_between_two_current-carrying_wires

Where Does Force Come From ?


22.2: Force between two current-carrying wires

Last updated: Nov 5, 2020

◂ 22.1: The Biot-Savart Law | 22.3: Ampere's Law ▸

Readability Donate

Howard Martin revised by Alan Ng
University of Wisconsin-Madison

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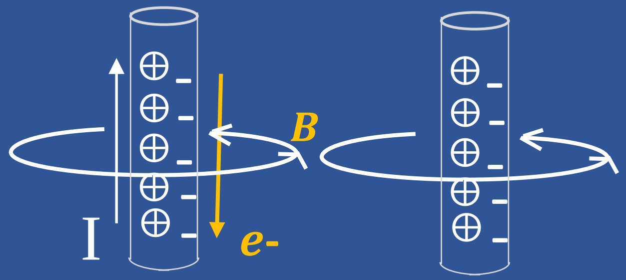
In rest-frame, electrons **e-** are moving downward producing a current **I**



In reference frame of electrons,

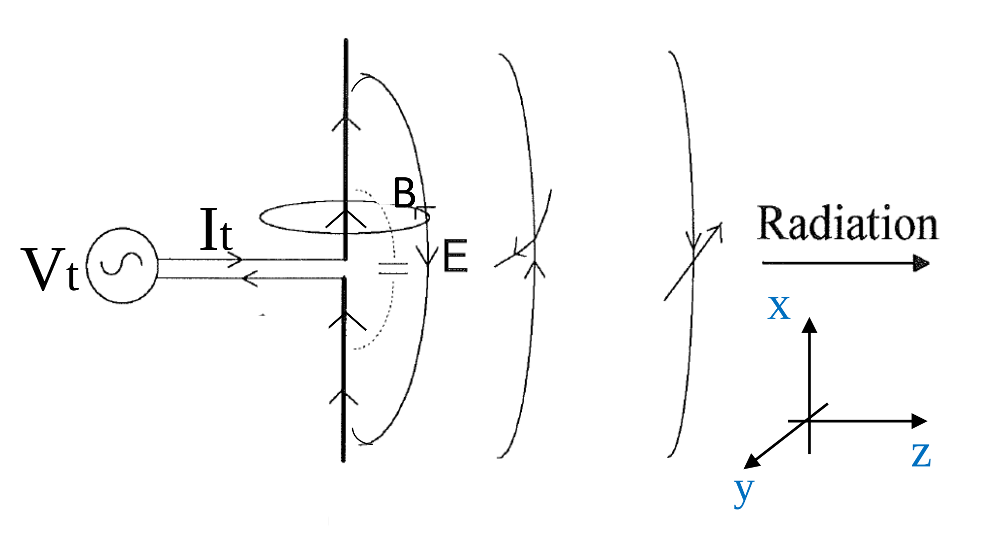
Positive charges of opposite wire are moving upward.

With length dilation, + charge appears stronger…

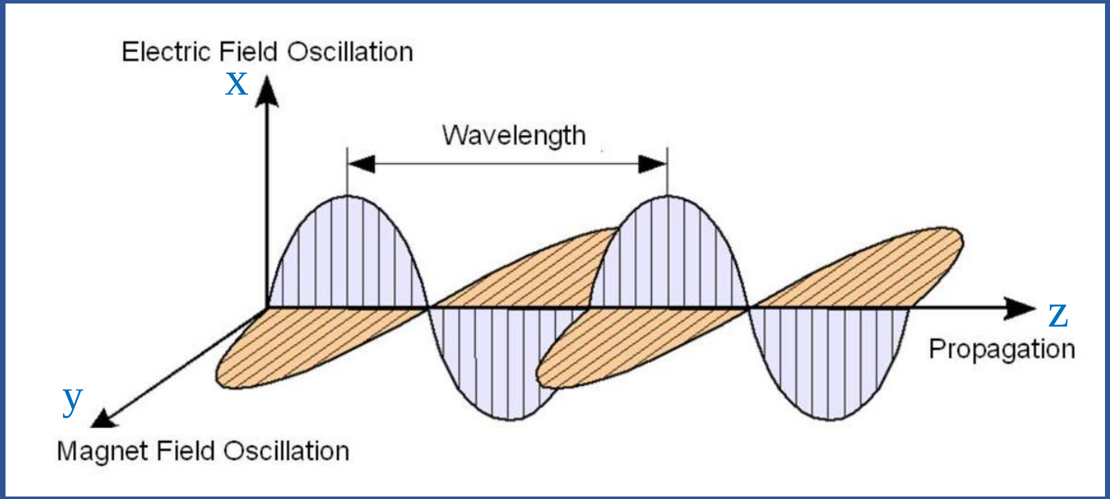
So is B field force just Coulombs Law plus Special Relativity ?

OK (maybe), So What "is" an EM Field ?

(**NOTE**: it comes from **<u>accelerating</u> charges** ...)



From: http://cleanenergywiki.org/index.php?title=File:Emwavepropagation.jpg



In the Far-Field region:

$$\frac{\partial E_x}{\partial z} = -\frac{\partial B_y}{\partial t}$$

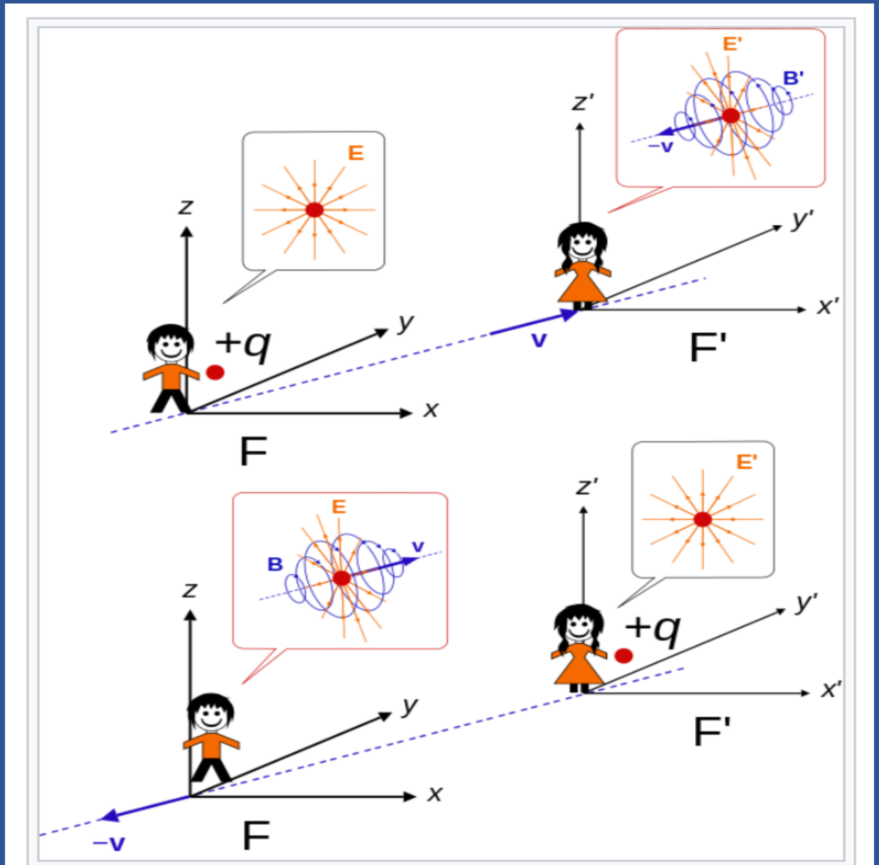
$$-\frac{\partial B_y}{\partial z} = \mu_o \varepsilon_o \frac{\partial E_x}{\partial t}$$

$$\Rightarrow \boldsymbol{E_x = E_o \cos\left(2\pi f\left(t - \frac{z}{c}\right) + \theta\right)} \quad \text{and} \quad \boldsymbol{B_y = \frac{1}{c} E_x}$$

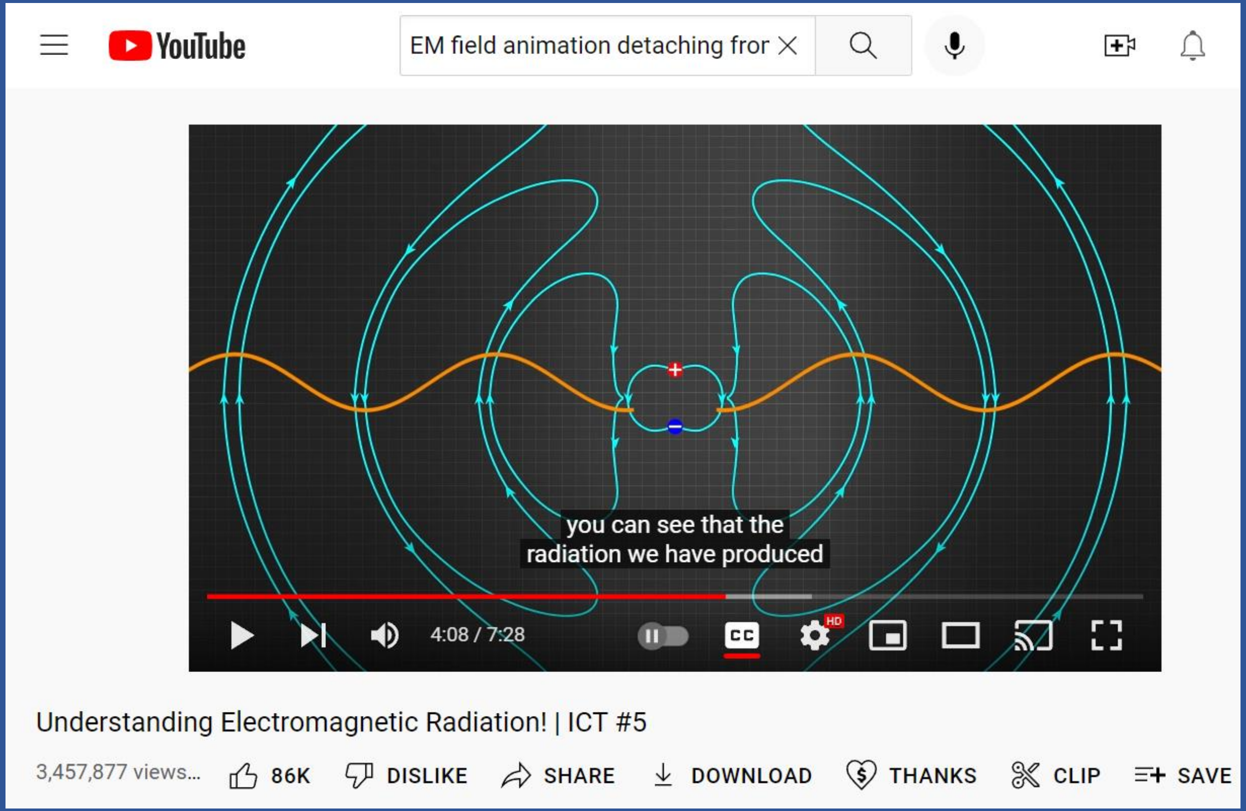
Where $\boldsymbol{c = \sqrt{\frac{1}{\mu_o\, \varepsilon_o}} = 2.998E8}$ meters/second

Other Explanations/views …

From **Joules-Bernoulli** equation discussion in:
https://en.wikipedia.org/wiki/Classical_electromagnetism_and_special_relativity



Lorentz boost of an electric charge.



https://www.youtube.com/watch?v=FWCN_uI5ygY

Thanks for Watching

…all the way to the end ☺