Wire Antenna Basics

Physics and Engineering Fundamentals

Steve Stearns, K6OIK

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Abstract

Wire antennas are reviewed starting with the most basic of antennas – the dipole. A proper understanding of dipole properties and characteristics is essential to understanding many other antennas including complementary antennas such as slots. In this tutorial, Steve Stearns, K6OIK, starts with the basics of dipoles for transmitting and receiving. We learn that a dipole's transmit current distribution is not exactly sinusoidal, and the receive distribution can be entirely different. We learn about the physics of the mysterious dipole shortening factor *K*. We learn a dipole's effective receiving capture area is different from its physical cross-sectional area, and that resonance is a poor indicator of match. Next we consider end-fed wires, such as the Zepp, Extended Zepp, and J-pole. Steve will indicate which antenna properties are better determined from graphs and equations, and which other properties are better determined by numerical modeling.

Speaker's Biography

- **Stephen D. Stearns**
- **40 years experience in electronic systems**
  - Northrop Grumman, TRW, GTE Sylvania, Hughes Aircraft
  - Electromagnetic and signal processing systems for communications and radar surveillance, cochannel signal separation, measurement, identification, characterization, polarimetric array signal processing of ionospheric skywave signals for precision geolocating HF emitters, sensor fusion
  - Recent work: Antenna and scattering theory; Non-Foster circuits for antennas and metamaterials; antennas for radiating OAM Bessel-Vortex beams; reflectionless filters
- **FCC licenses**
  - Amateur Radio Extra Class
  - 1st-Class Radiotelephone
  - General Radio Operator License (GROL)
  - Ship Radar Endorsement
- **Education**
  - PhD Stanford – under Prof. T.M. Cover
  - MSEE USC – under Profs. H.H. Kuehl and C.L. Weber
  - BSEE CSUF – under Profs. J.E. Kemmerly and G.I. Cohn
- **10 patents**
- **More than 100 publications and presentations, both professional (IEEE) and hobbyist (Amateur Radio)**

ARRL Pacificon Presentations by K6OIK

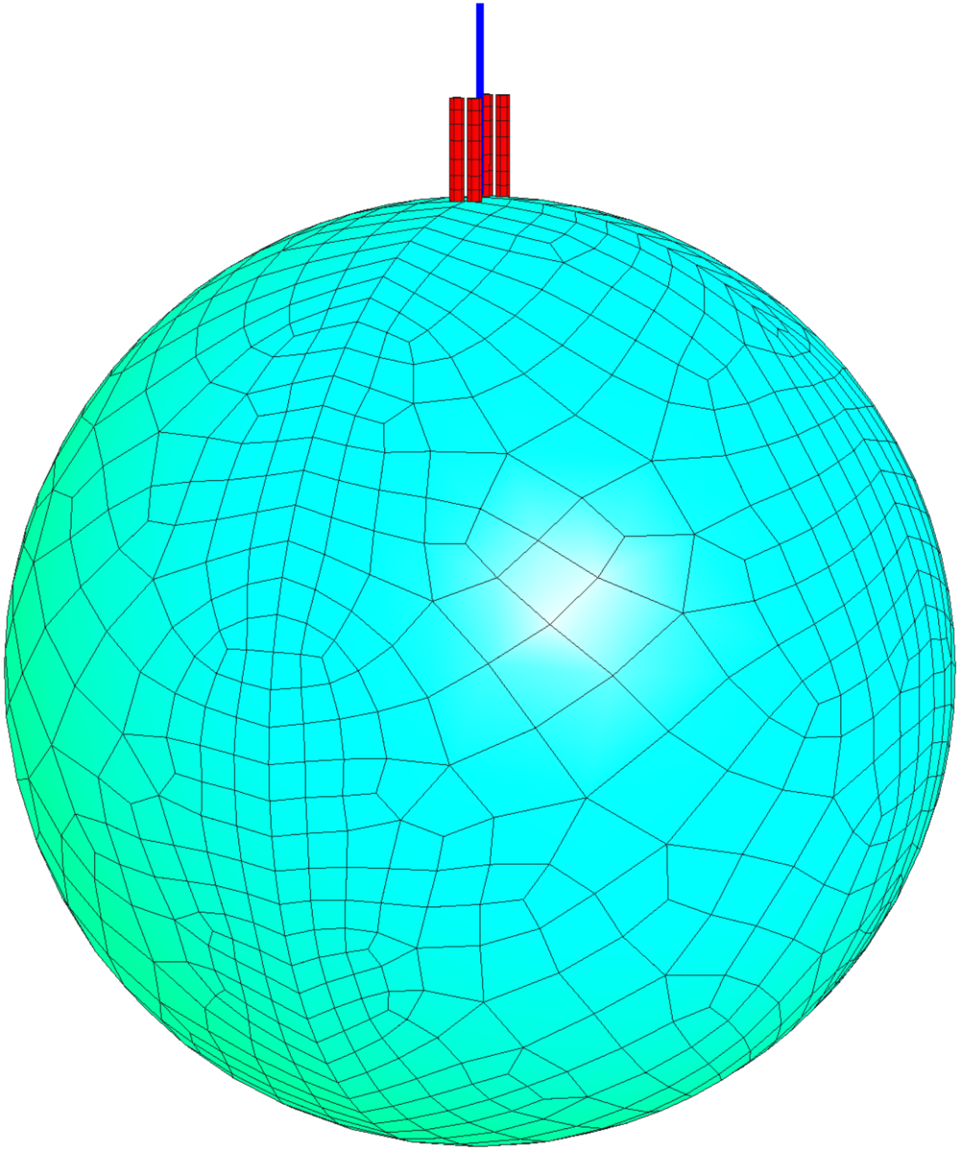
		Archived at http://www.fars.k6ya.org
1999	Mysteries of the Smith Chart	
2000	Jam-Resistant Repeater Technology	
2001	Mysteries of the Smith Chart	✓
2002	How-to-Make Better RFI Filters Using Stubs	
2003	Twin-Lead J-Pole Design	
2004	Antenna Impedance Models – Old and New	✓
2005	Novel and Strange Ideas in Antennas and Impedance Matching	
2006	Novel and Strange Ideas in Antennas and Impedance Matching II	✓
2007	New Results on Antenna Impedance Models and Matching	✓
2008	Antenna Modeling for Radio Amateurs	
2010	Facts About SWR, Reflected Power, and Power Transfer on Real Transmission Lines with Loss	✓
2011	Conjugate Match Myths	✓
2012	Transmission Line Filters Beyond Stubs and Traps	✓
2013	Bode, Chu, Fano, Wheeler – Antenna Q and Match Bandwidth	✓
2014	A Transmission Line Power Paradox and Its Resolution	✓
2015	Weird Waves: Exotic Electromagnetic Phenomena	✓
2015	The Joy of Matching: How to Design Multi-Band Match Networks	✓
2016	The Joy of Matching 2: Multi-Band and Reflectionless Match Networks	
2016-7	Antenna Modeling for Radio Amateurs – Revised and Expanded	✓
2017	VHF-UHF Propagation Planning for Amateur Radio Repeaters	✓
2018	Antennas: The Story from Physics to Computational Electromagnetics	✓
2018	Novel Antennas, The Mysterious Factor *K*, Impromptu Antenna Modeling	
2019	Dipole Basics	✓
2019	Antenna Modeling Half-day Seminar	
2021	Universal Equivalent Circuits for All Antennas	✓
2023	Grow an Antenna … from Seeds	✓
2024	The Best Shape for a Wire Antenna	

Recent Work

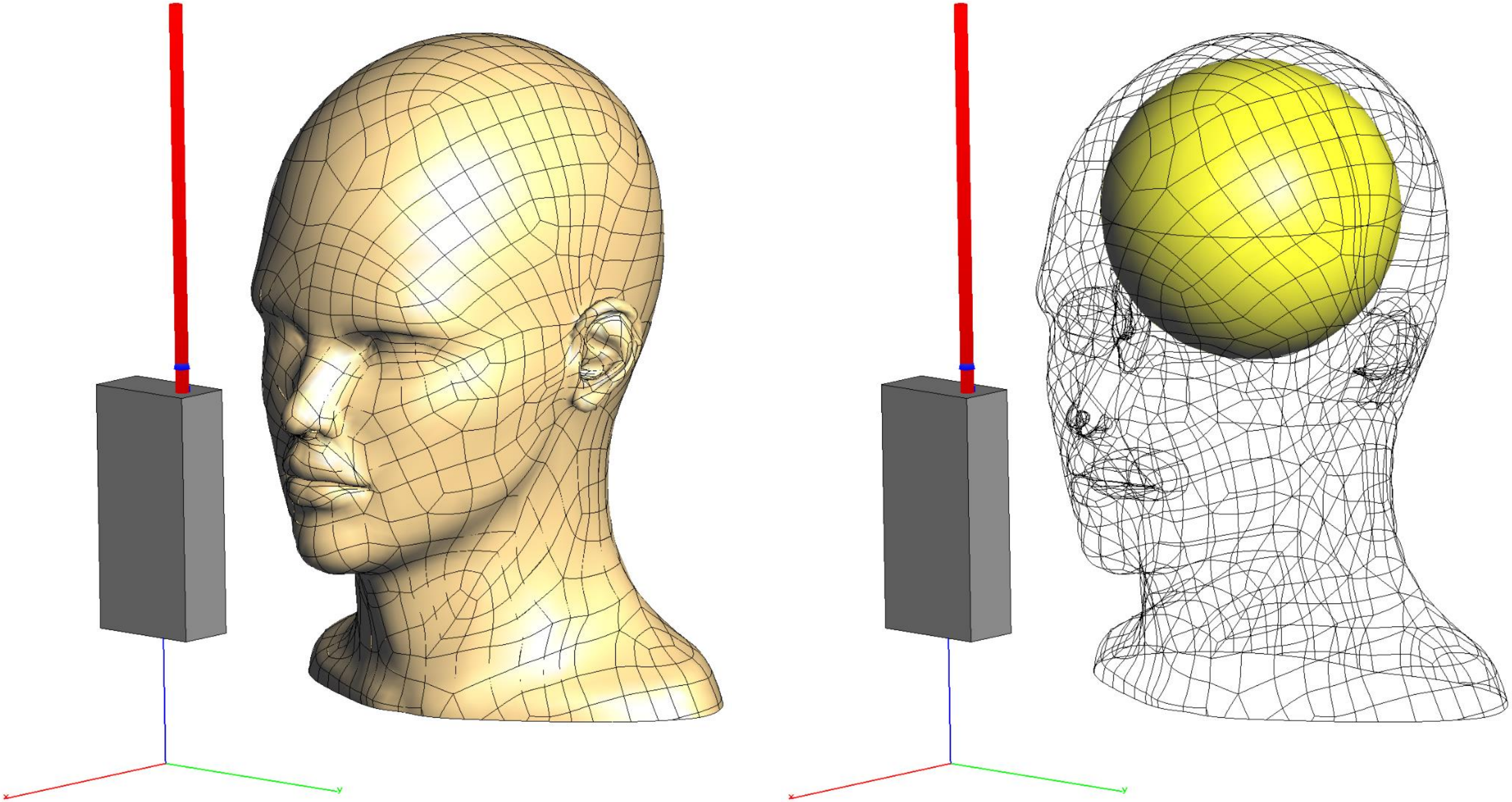
- **“Insulated Wire Models”**
  - *QEX*, November/December 2024
- **“Grow an Antenna … from Seeds”**
  - Presented at Pacificon Antenna Seminar 2023
  - How to model dielectric objects
  - Antenna performance can be enhanced (or degraded) by the presence of trees
  - Trees in the right configuration can make good antennas
  - Slides: https://www.fars.k6ya.org/docs/k6oik
- **“Universal Equivalent Circuits for All Antennas”**
  - Presented at Pacificon Antenna Seminar 2021
  - Invited talk at joint meeting of IEEE Antennas and Propagation and Microwave Theory and Techniques Societies
  - IEEE recorded lecture: https://www.youtube.com/watch?v=vQ9BFdmFHCM
  - Slides: https://www.fars.k6ya.org/docs/k6oik

Vertical Antenna on Non-flat Ground "Plane" with Trees

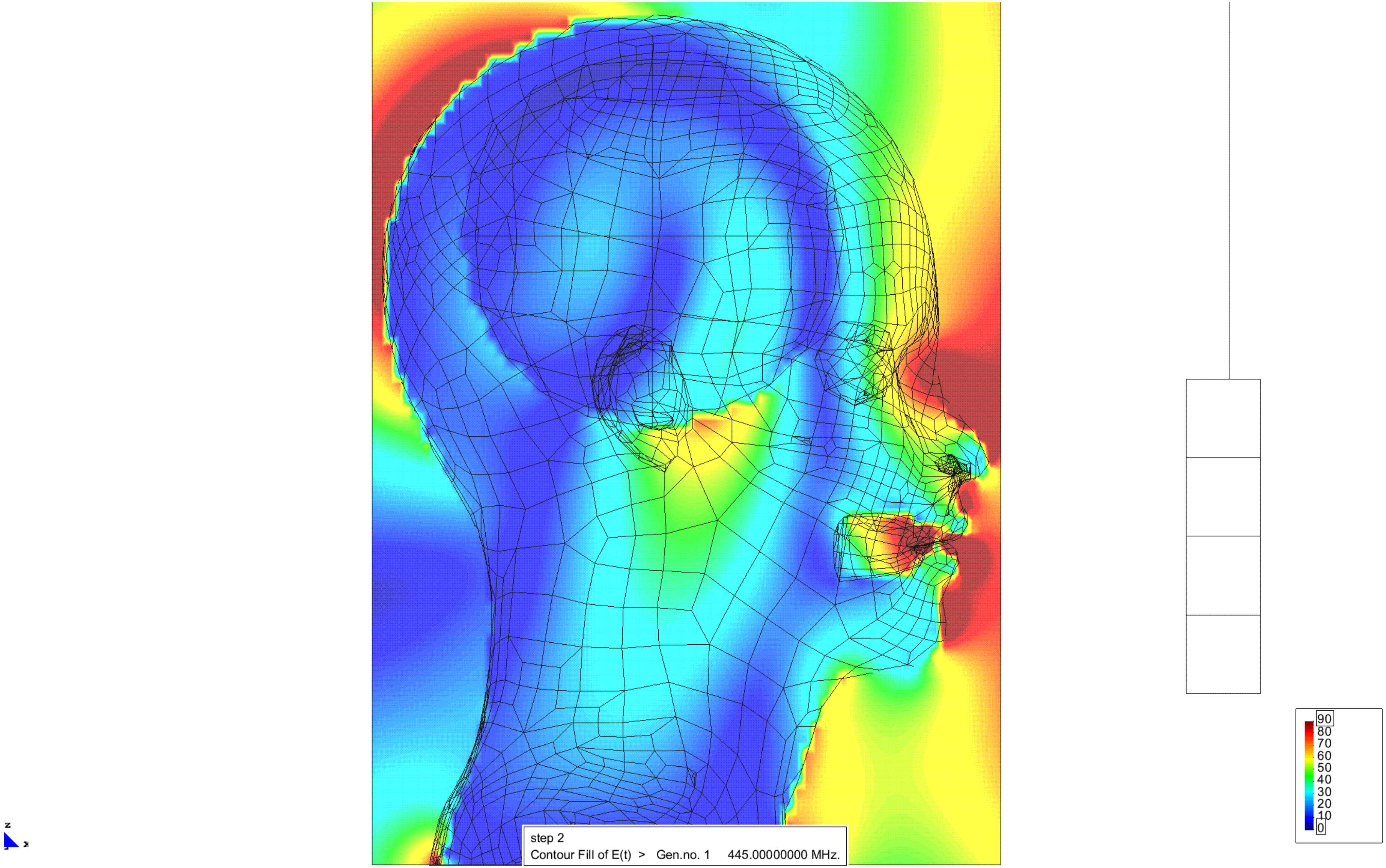
- 160-meter vertical monopole
- Fed against: a driven ground rod, buried radials, elevated radials
- Planet is: Arizona soil, sandy, rocky; or seawater
- Planet originally had an iron core, later removed
- 4 California redwood trees (trunks) surround vertical
- Planet kept small for fast run time
- HOBBIES computed fields and currents inside and outside of planet
- 2.5 minutes on a 12-core Windows 10 machine
- All 12 cores maxed at 100% for ~ 150 seconds



Fields and SAR in Human Head

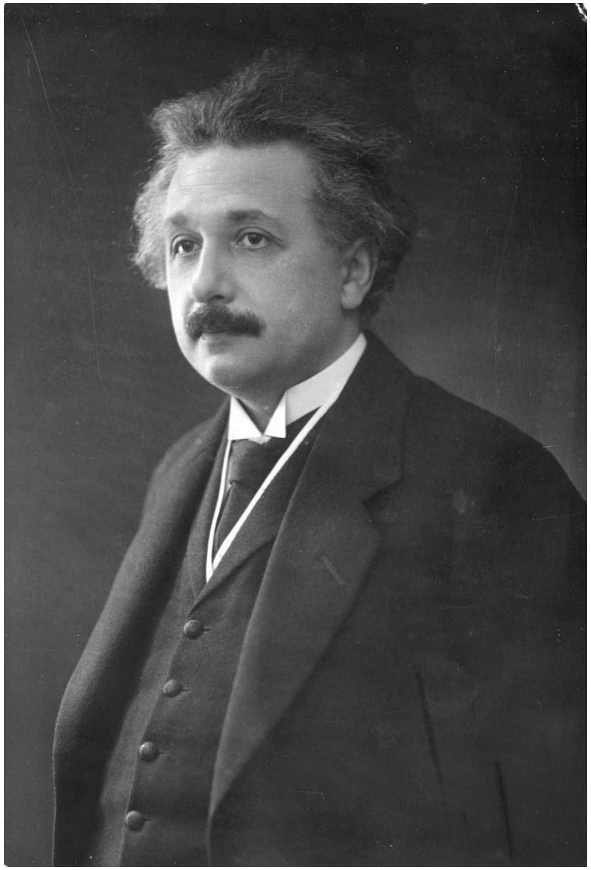


E Field in Head for 5 watt HT at 445 MHz



Question

- **Q1: What was Einstein's explanation of how radio works?**



Albert Einstein, 1879 – 1955

Answer

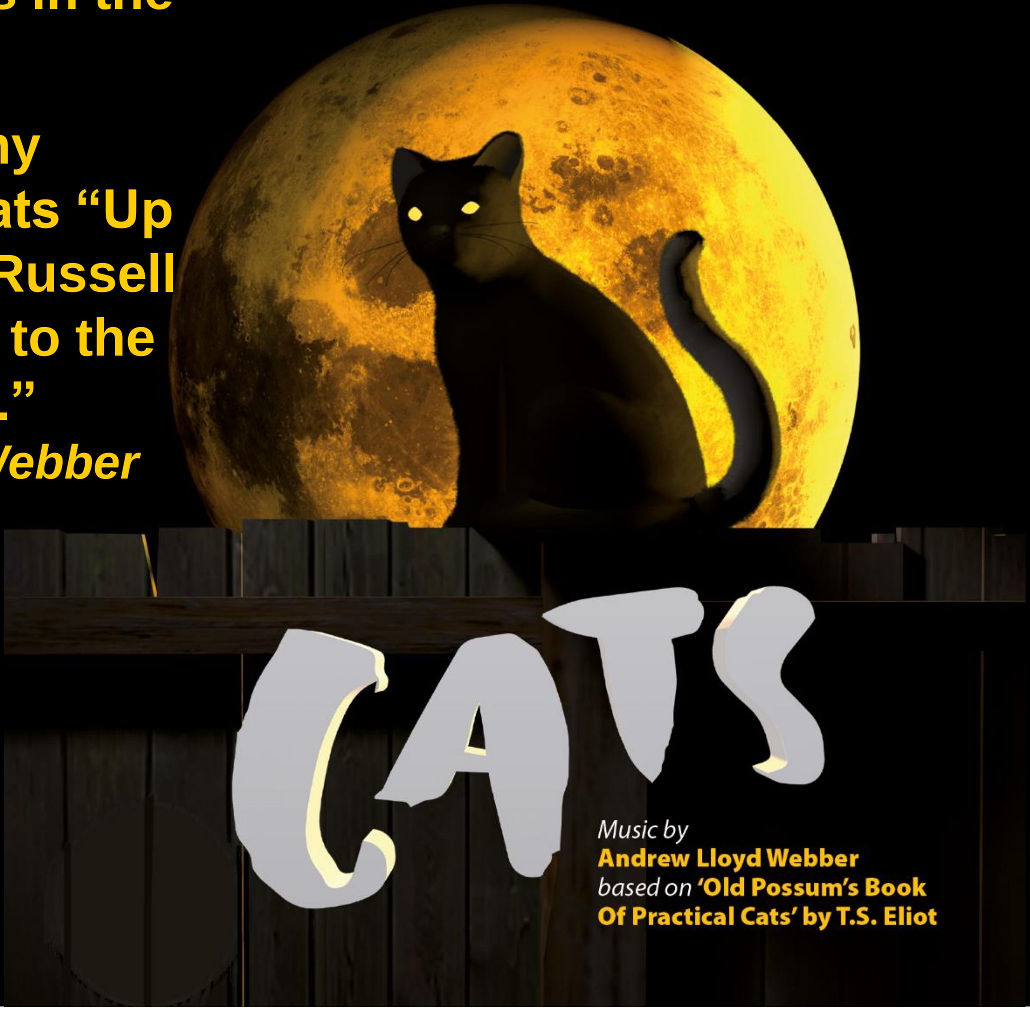
“You see, wire telegraph is a kind of a very, very long cat. You pull his tail in New York and his head is meowing in Los Angeles. Do you understand this? And radio operates exactly the same way: you send signals here, they receive them there. The only difference is that there is no cat.”

– *Albert Einstein*

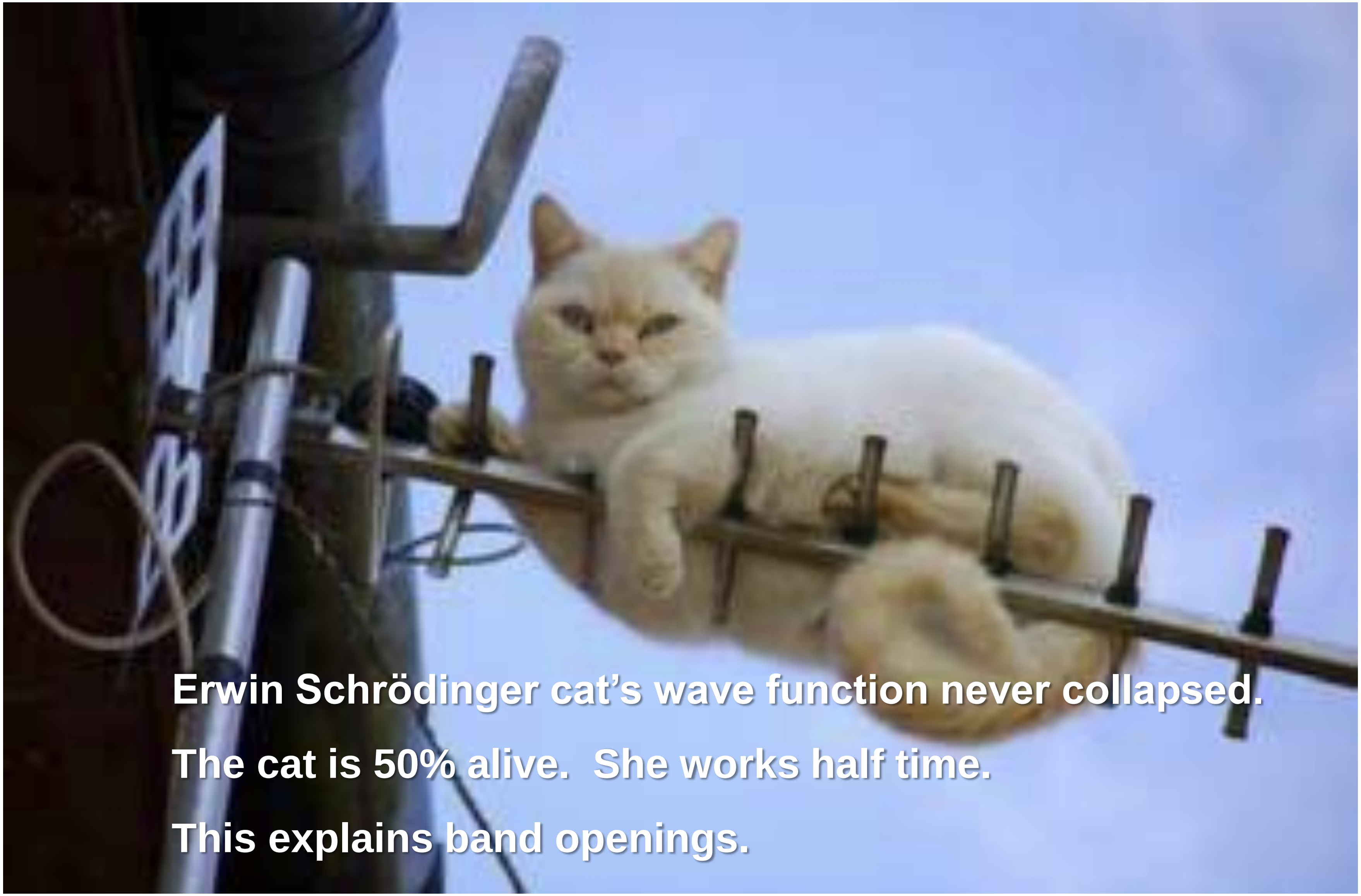
How HF Radio Works

Cats handle radio communications in the ionosphere !

Old Deuteronomy sends Jellicle cats “Up up up, past the Russell Hotel, up up up, to the Heaviside Layer.”
– Andrew Lloyd Webber



Was Einstein Correct? Hmm.



Erwin Schrödinger cat’s wave function never collapsed.

The cat is 50% alive. She works half time.

This explains band openings.

Basic Questions About Transducers

- **Q3: In acoustics, can a loudspeaker have an isotropic pattern?**
  A. Yes
  B. No
- **Q4: Can an antenna have an isotropic pattern?**
  A. Yes
  B. No

Answers

- **Q3: In acoustics, can a loudspeaker have an isotropic pattern?**

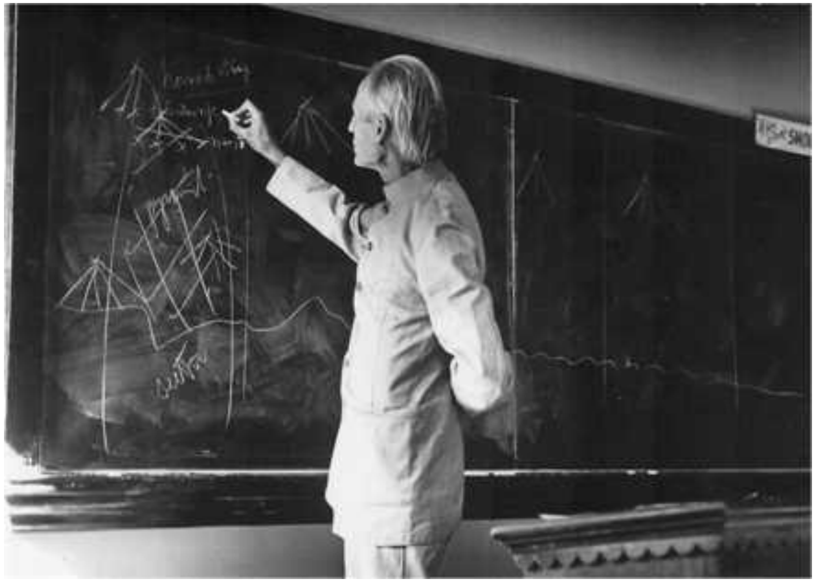
  A. Yes. Sound waves are longitudinal. Isotropic radiation is possible.

  B. No

- **Q4: Can an antenna have an isotropic pattern?**

  A. Yes

  B. No. Electromagnetic waves are transverse or TEM. Isotropic radiation is impossible – a consequence of the **Hairy Ball Theorem** proved in 1912 by Dutch mathematician L.E.J. Brouwer



Now for Some Questions About Dipoles

- **Assume a lossless dipole shrinks in size compared to a wavelength such that its length and diameter approach zero**
- **Q5: Does its maximum gain go to**
  - A. 0 (or –∞ dBi)
  - B. Some other number
- **Q6: Does its capture area (effective area) go to**
  - A. 0 (zero)
  - B. Some other number

Answers

- **Assume a lossless dipole shrinks in size compared to a wavelength such that its length and diameter approach zero**
- **Q5: Does its maximum gain in dBi units go to**
  - A. 0 (or –∞ dBi)
  - B. Some other number: $G \rightarrow 1.5 \quad \text{(or 1.76 dBi)}$
- **Q6: Does its capture area (effective area) go to**
  - A. 0 (zero)
  - B. Some other number: $A \rightarrow \dfrac{10,728}{f\,(\text{MHz})^2} \quad \text{square meters}$

This is good news for hams who operate in the 1750 and 2200 meter bands

The issues of electrically small antennas are not about directivity or effective area

The issues are antenna matching/coupling, *Q*, bandwidth, and losses

Outline

- **Dipoles**
  - Impedance
    - Impedance behavior vs frequency
    - *Q* and bandwidth
    - Resonance
    - Resonant length and the multiplying factor *K*
  - Transmit properties
    - Current distribution
    - Fields – near field and far field
    - Pattern, directivity, and gain
  - Receive properties
    - Scattering and receiving near field
    - Poynting vector field deflection
    - Effective area
- **Off-center fed and end-fed wire antennas**
- **Antenna modeling using Method of Moments programs**
- **Resources**

Linear Cylindrical Antennas

Terminology

- **A linear cylindrical antenna is a wire, rod, or tube driven at an arbitrary point (a gap) along its length**
  - Length is arbitrary
  - Feedpoint location is arbitrary
  - Arms are colinear
  - Wire cross-section need not be solid or circular (square tubes are okay)
- **A dipole is a linear cylindrical antenna that is symmetric about its feedpoint**
  - Equal arm lengths, balanced feedpoint, symmetric current distribution
  - The half-wave dipole is called a "Hertz" dipole or "doublet"
- **Examples**
  - A cage dipole is a dipole
  - An off-center fed (OCF) dipole is a linear cylindrical antenna but is not a dipole due to absence of symmetry
    - The term "OCF dipole" is an unfortunate, confusing misnomer
  - A fan dipole is not a dipole because it is not a cylindrical antenna

Truths

- **A simple dipole is symmetric and center fed**

A.C. = a cat

- **For lossless antennas, directivity and gain are the same**
- **An antenna’s radiation resistance is not unique. It depends on a reference current or location**
- **The resonant length of a dipole depends on its diameter**
- **Dipoles are resonant at lengths slightly shorter than an odd number of half-wavelengths**
  - The resonant length of a Hertz dipole or doublet is $L = \frac{K\lambda}{2}$
  - K depends on resonance number and dipole fatness
- **Dipoles are anti-resonant at lengths slightly shorter than an even number of half-wavelengths**
- **If a linear antenna is resonant, then its feedpoint impedance is real everywhere along its length**
- **If a dipole is a half-wavelength, then its current phase is ~30° everywhere along its length (taking feed voltage as reference phase)**

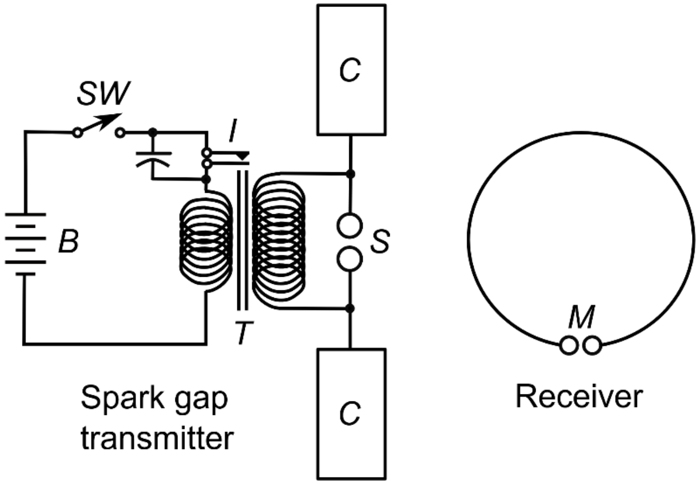
Fictions

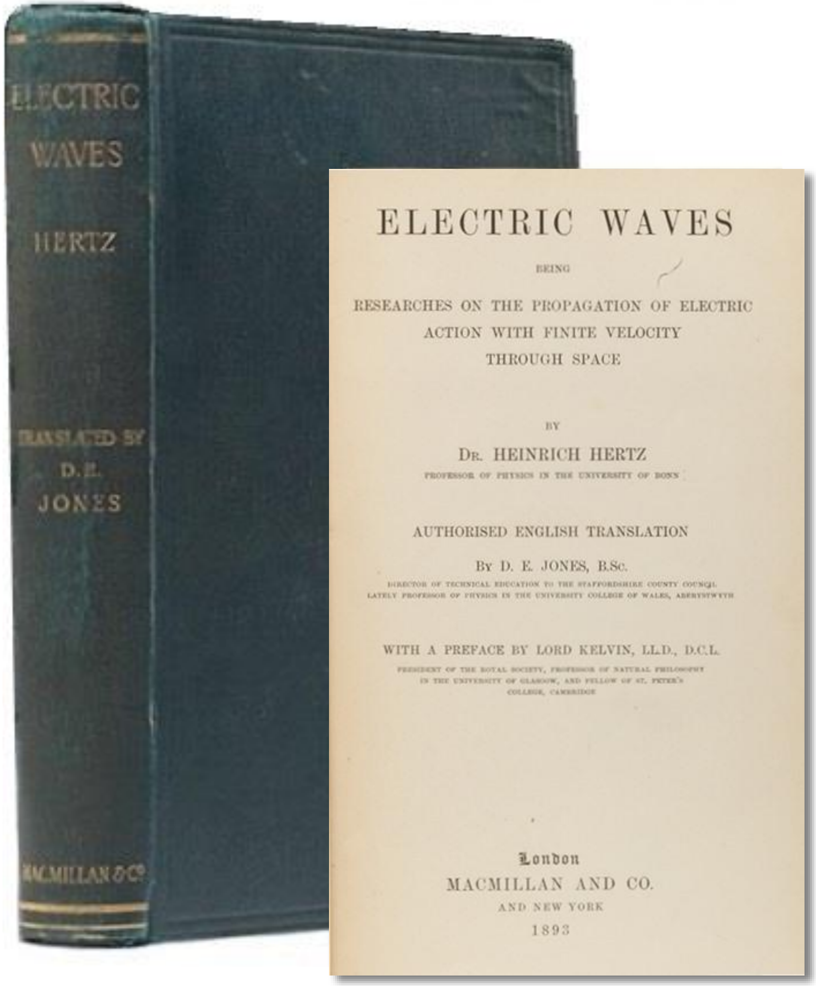
- A dipole should be one-half wavelength long
- A dipole should be resonant
- Half-wavelength dipoles are resonant
- Dipoles are 75 ohms
- In free space, a half-wavelength dipole has a real (resistive) feedpoint impedance
- A half-wavelength dipole is 50 ohms
- The feedpoint resistance of a half-wavelength dipole depends on its diameter
- The feedpoint reactance of a half-wavelength dipole depends on its diameter
- Dipoles are anti-resonant at lengths slightly longer than an even number of half-wavelengths

Dipole Current, Impedance, and Resonant Length

The Dipole's Origin – Heinrich Hertz, 1887

Heinrich Rudolph Hertz, 1857-1894





ELECTRIC WAVES

BEING

RESEARCHES ON THE PROPAGATION OF ELECTRIC
ACTION WITH FINITE VELOCITY
THROUGH SPACE

BY

DR. HEINRICH HERTZ
PROFESSOR OF PHYSICS IN THE UNIVERSITY OF BONN

AUTHORISED ENGLISH TRANSLATION

BY D. E. JONES, B.Sc.
DIRECTOR OF TECHNICAL EDUCATION TO THE STAFFORDSHIRE COUNTY COUNCIL
LATELY PROFESSOR OF PHYSICS IN THE UNIVERSITY COLLEGE OF WALES, ABERYSTWYTH

WITH A PREFACE BY LORD KELVIN, LL.D., D.C.L.
PRESIDENT OF THE ROYAL SOCIETY, PROFESSOR OF NATURAL PHILOSOPHY
IN THE UNIVERSITY OF GLASGOW, AND FELLOW OF ST. PETER'S
COLLEGE, CAMBRIDGE

London
MACMILLAN AND CO.
AND NEW YORK
1893

The first antenna book, 1893

Milestones in Cylindrical Antennas

- **Heinrich Hertz's experiments (1887)**
- **Pocklington's integro-differential equation (1897)**
  - Solved numerically in NEC
- **Induced EMF (IEMF) method (1922)**
  - L. Brillouin, *Radioélectricité*, April 1922
  - A.A. Pistolkors, *Proc. IRE*, March 1929
  - P.S. Carter, *Proc. IRE*, June 1932
  - S.A. Schelkunoff, papers and books 1941-1954
  - C-T. Tai, *J. Applied Physics*, July 1949
- **Hallén's integral equation (1938)**
  - E. Hallén at Uppsala University, Sweden
  - C.J. Bouwkamp at Philips Labs, Holland
  - R.W.P. King and students at Harvard University
    - F.G. Blake
    - C.W. Harrison
    - D. Middleton
  - S.A. Schelkunoff and M.C. Gray at Bell Labs

Integral Equations for Dipole Current

- **Pocklington's equation (1897)**

$$\int_{-l}^{l} I_z(z')\left[\left(\frac{\partial^2}{\partial z^2}+k^2\right)G(z,z')\right]dz' = -j\omega\varepsilon\, E_z^i(\rho=a)$$

- **Hallen's equation (1938)**

$$\int_{-l}^{l} I_z(z')\frac{e^{-jkR}}{4\pi R}\,d\,z' = -j\sqrt{\frac{\varepsilon}{\mu}}\left[B_1\cos(kz)+C_1\sin(k\,|\,z\,|)\right]$$

- **General form**

$$L(f)=g$$

Driving function

Linear operator

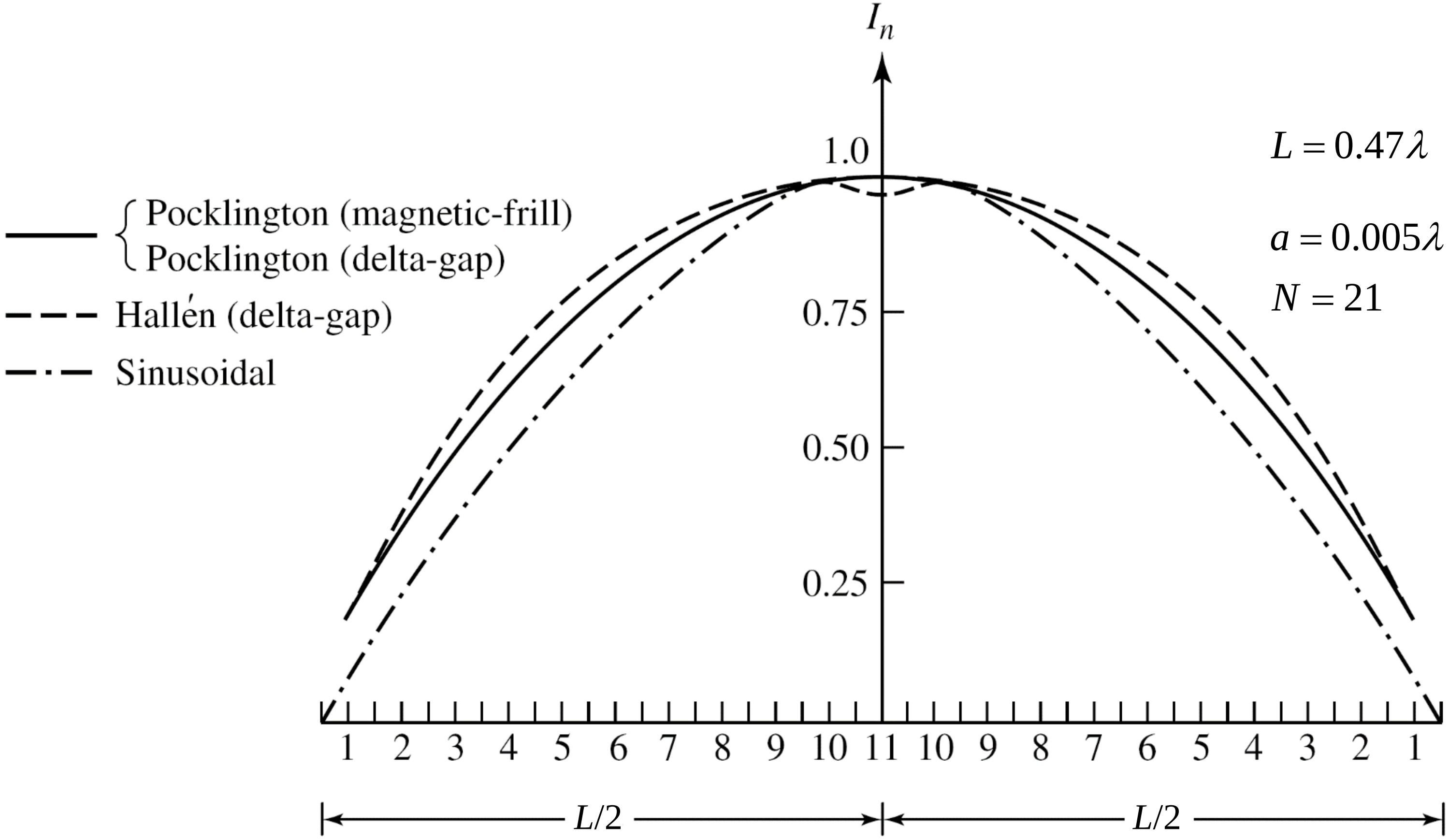
Unknown function

Linear Cylindrical Antennas

Ronald Wyeth Percival King, 1905-2006

- Speaking at his 100th birthday party, Oct. 2005
- Cruft Laboratories, Harvard University
- Authority on linear cylindrical antennas
- Spent his career on solving Hallén’s equation, starting in 1938
- Had many famous students who worked on ever better solutions to Hallén’s equation

Current Distribution of an Almost Resonant Dipole



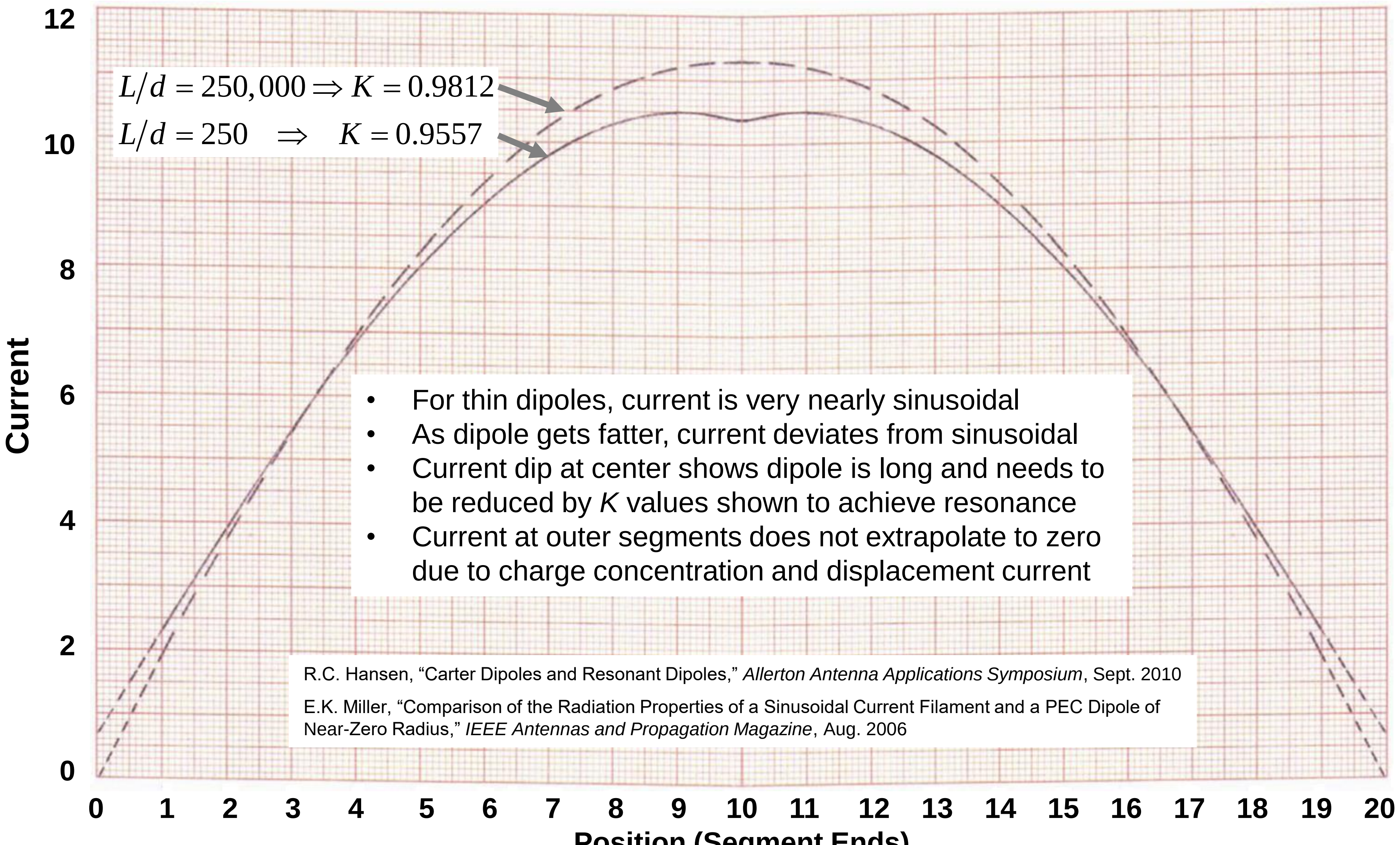
$$L = 0.47\lambda \quad \Rightarrow \quad \frac{L}{\lambda/2} = 0.9400$$

$$a = 0.005\lambda \quad \Rightarrow \quad K = 0.9352$$

$$N = 21$$

C.A. Balanis, *Antenna Theory: Analysis and Design*, 4th ed., p. 457, Wiley, 2016

Current Distribution on Two Halfwave Dipoles



$L/d = 250{,}000 \Rightarrow K = 0.9812$

$L/d = 250 \quad \Rightarrow \quad K = 0.9557$

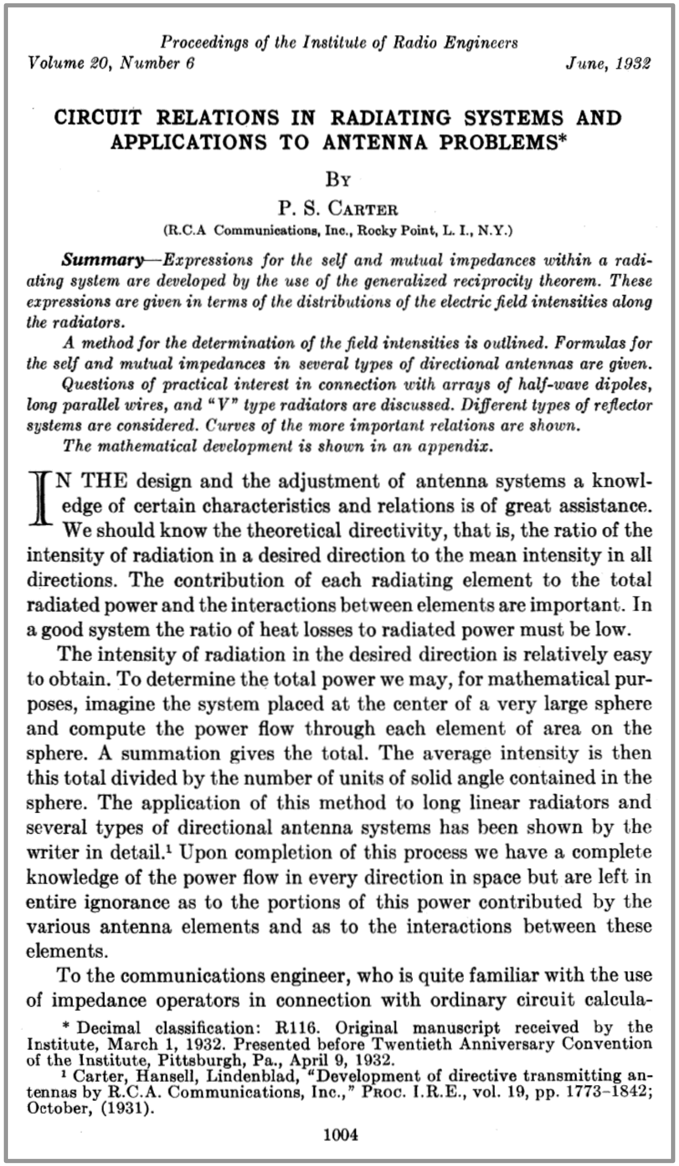
- For thin dipoles, current is very nearly sinusoidal
- As dipole gets fatter, current deviates from sinusoidal
- Current dip at center shows dipole is long and needs to be reduced by *K* values shown to achieve resonance
- Current at outer segments does not extrapolate to zero due to charge concentration and displacement current

R.C. Hansen, "Carter Dipoles and Resonant Dipoles," *Allerton Antenna Applications Symposium*, Sept. 2010

E.K. Miller, "Comparison of the Radiation Properties of a Sinusoidal Current Filament and a PEC Dipole of Near-Zero Radius," *IEEE Antennas and Propagation Magazine*, Aug. 2006

Induced EMF Method

- L. Brillouin, *Radioélectricité*, April 1922
- A.A. Pistolkors, *Proc. IRE*, March 1929
- P.S. Carter, *Proc. IRE*, June 1932
- C-T. Tai, *J. Applied Physics*, July 1949
- Assume sinusoidal current distribution
- Obtain pattern, radiation resistance and reactance
- Accurate for pattern and impedance of dipoles up to half-wavelength and verticals up to quarter-wavelength
- Inaccurate for impedance of dipoles longer than half-wavelength and verticals longer than quarter-wavelength
- Widely used for the design of AM broadcast towers
- Obsoleted by numerical methods



Proceedings of the Institute of Radio Engineers
Volume 20, Number 6 *June, 1932*

CIRCUIT RELATIONS IN RADIATING SYSTEMS AND APPLICATIONS TO ANTENNA PROBLEMS*

BY
P. S. CARTER
(R.C.A Communications, Inc., Rocky Point, L. I., N.Y.)

Summary—*Expressions for the self and mutual impedances within a radiating system are developed by the use of the generalized reciprocity theorem. These expressions are given in terms of the distributions of the electric field intensities along the radiators.*

A method for the determination of the field intensities is outlined. Formulas for the self and mutual impedances in several types of directional antennas are given.

Questions of practical interest in connection with arrays of half-wave dipoles, long parallel wires, and "V" type radiators are discussed. Different types of reflector systems are considered. Curves of the more important relations are shown.

The mathematical development is shown in an appendix.

IN THE design and the adjustment of antenna systems a knowledge of certain characteristics and relations is of great assistance. We should know the theoretical directivity, that is, the ratio of the intensity of radiation in a desired direction to the mean intensity in all directions. The contribution of each radiating element to the total radiated power and the interactions between elements are important. In a good system the ratio of heat losses to radiated power must be low.

The intensity of radiation in the desired direction is relatively easy to obtain. To determine the total power we may, for mathematical purposes, imagine the system placed at the center of a very large sphere and compute the power flow through each element of area on the sphere. A summation gives the total. The average intensity is then this total divided by the number of units of solid angle contained in the sphere. The application of this method to long linear radiators and several types of directional antenna systems has been shown by the writer in detail.[1] Upon completion of this process we have a complete knowledge of the power flow in every direction in space but are left in entire ignorance as to the portions of this power contributed by the various antenna elements and as to the interactions between these elements.

To the communications engineer, who is quite familiar with the use of impedance operators in connection with ordinary circuit calcula-

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* Decimal classification: R116. Original manuscript received by the Institute, March 1, 1932. Presented before Twentieth Anniversary Convention of the Institute, Pittsburgh, Pa., April 9, 1932.

[1] Carter, Hansell, Lindenblad, "Development of directive transmitting antennas by R.C.A. Communications, Inc.," PROC. I.R.E., vol. 19, pp. 1773–1842; October, (1931).

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Dipole Impedance via the Induced EMF Method

- **Resistance**

$$R_{in} = \frac{\eta}{4\pi \sin^2\left(kl\right)} \left\{ 2\gamma + 2\ln(2kl) - 2\mathrm{Ci}(2kl) \;+\; \sin(2kl)\left[\,\mathrm{Si}(4kl) - 2\mathrm{Si}(2kl)\right] \;+\; \cos(2kl)\left[\mathrm{Ci}(4kl) - 2\mathrm{Ci}(2kl) + \gamma + \ln\left(kl\right)\right]\right\}$$

Terms vanish when $l\,/\,\lambda$ is a half integer; impedance is independent of wire diameter for such lengths

- **Reactance**

$$X_{in} = \frac{\eta}{4\pi \sin^2\left(kl\right)} \left\{ 2\mathrm{Si}(2kl) \;-\; \cos(2kl)\left[\,\mathrm{Si}(4kl) - 2\mathrm{Si}(2kl)\right] \;+\; \sin(2kl)\left[\mathrm{Ci}(4kl) - 2\mathrm{Ci}(2kl) + \gamma + 2\ln\left(ka\right) - \ln\left(kl\right)\right]\right\}$$

Wire radius affects only reactance

- **Assumptions**
  - Circular cylindrical dipole
  - In free space
  - Made of PEC → no losses
  - Length $L = 2l \le \lambda/2$
  - Radius a

Halfwave Dipole – Impedance to 10 Digits

- **Resistance**

$$R_{in}\left(\frac{\pi}{2},ka\right)=\frac{\eta}{4\pi}\left[\gamma+\ln\left(2\pi\right)-\mathrm{Ci}\left(2\pi\right)\right]=\frac{\eta}{4\pi}\sum_{n=1}^{\infty}\frac{\left(-1\right)^{n+1}\left(2\pi\right)^{2n}}{2n\left(2n\right)!}=29.9792458\times 2.437653393$$

R_{in} = 73.07901025 ohms

- **Reactance**

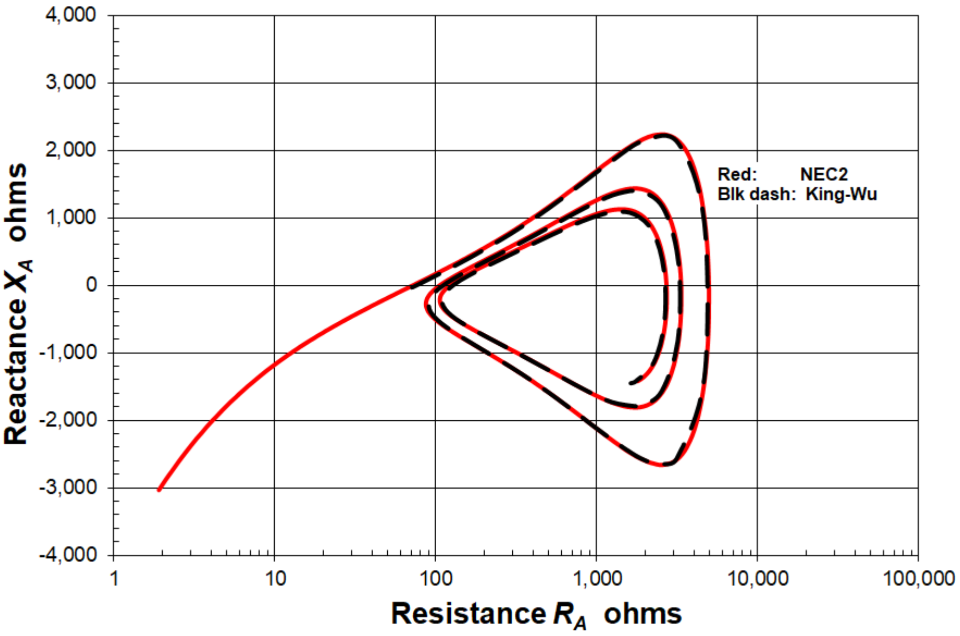
$$X_{in}\left(\frac{\pi}{2},ka\right)=\frac{\eta\,\mathrm{Si}\left(2\pi\right)}{4\pi}=\frac{\eta}{4\pi}\sum_{n=1}^{\infty}\frac{\left(-1\right)^{n}\left(2\pi\right)^{2n+1}}{\left(2n+1\right)\left(2n+1\right)!}=29.9792458\times 1.418151576$$

X_{in} = 42.51511468 ohms

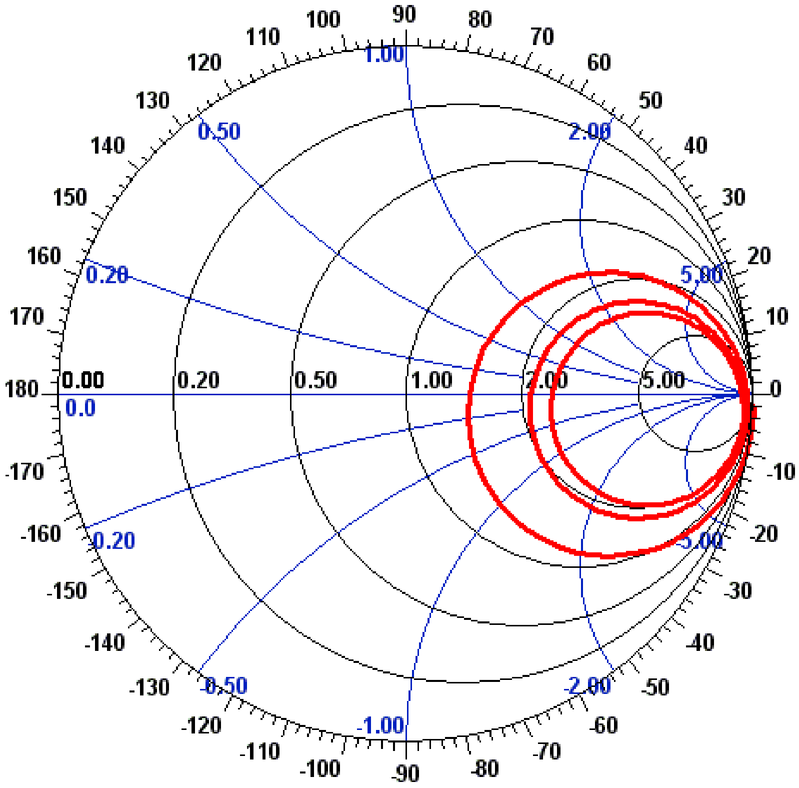
- **Is there practical value to such precise numbers?**
- **Yes, exact theoretical values are needed to validate the accuracy of numerical codes like NEC, FEKO, WIPL-D, and HOBBIES**

Complex Impedance as Frequency is Swept

ARRL Semilog Impedance Plane

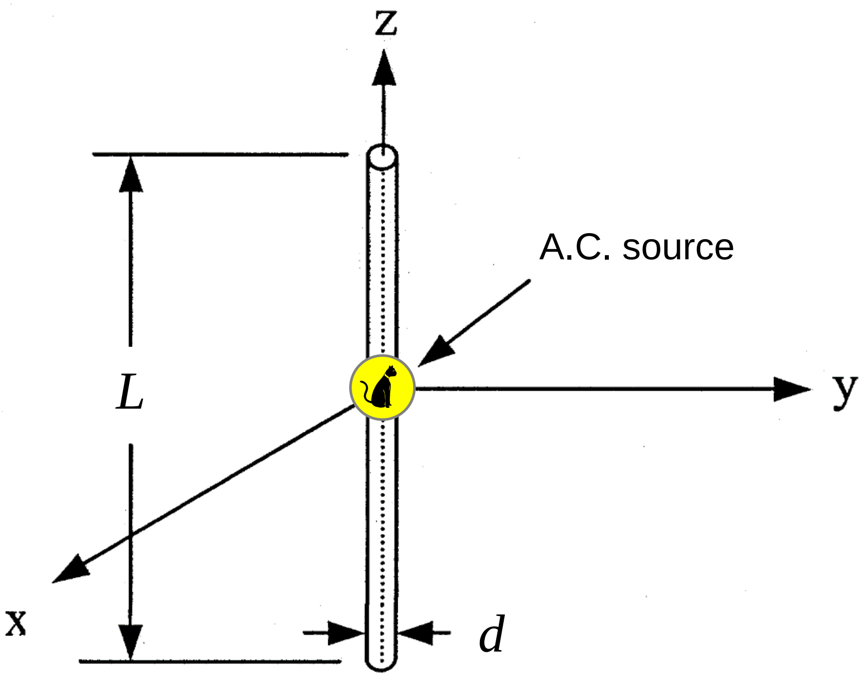


Smith Chart



- **Antenna: 98.4-foot dipole in free space**
- **Wire: #10 AWG**
- ***L*/*d* = 11,000**
- **Frequency: 1 MHz to 30 MHz**

Q of Small Dipole from Electromagnetic Field Analysis

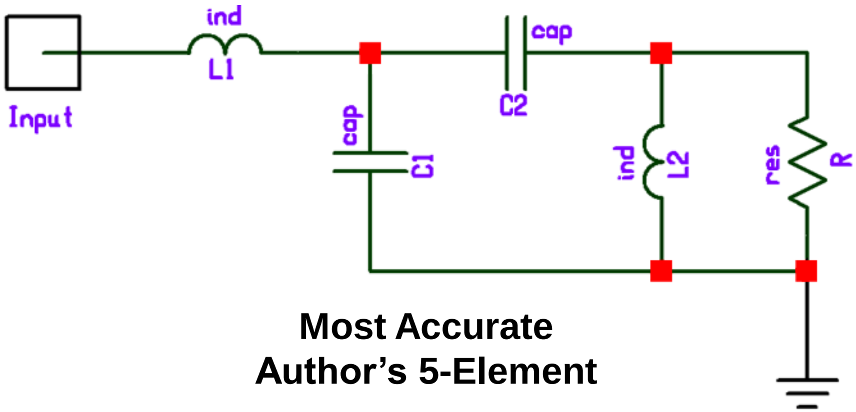


$$Q_{dipole} \approx \frac{6\left[\ln\left(\frac{L}{d}\right)-1\right]}{\pi^3\left(\frac{f\,L}{c}\right)^3}$$

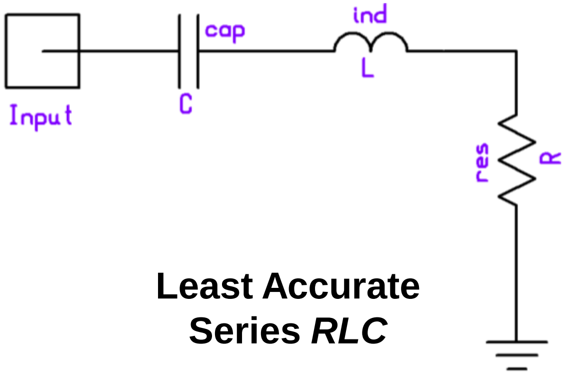
Equivalent Circuits for Dipole Impedance

Narrowband and Very Broadband

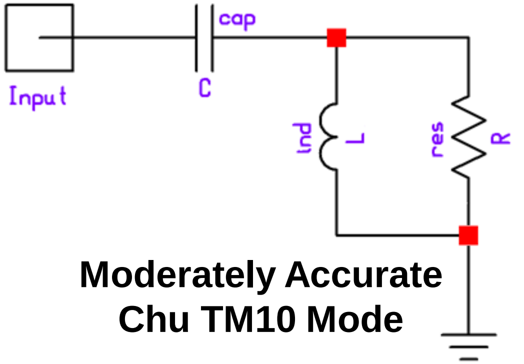
Narrowband Equivalent Circuits Near 1st Resonance



Most Accurate
Author's 5-Element



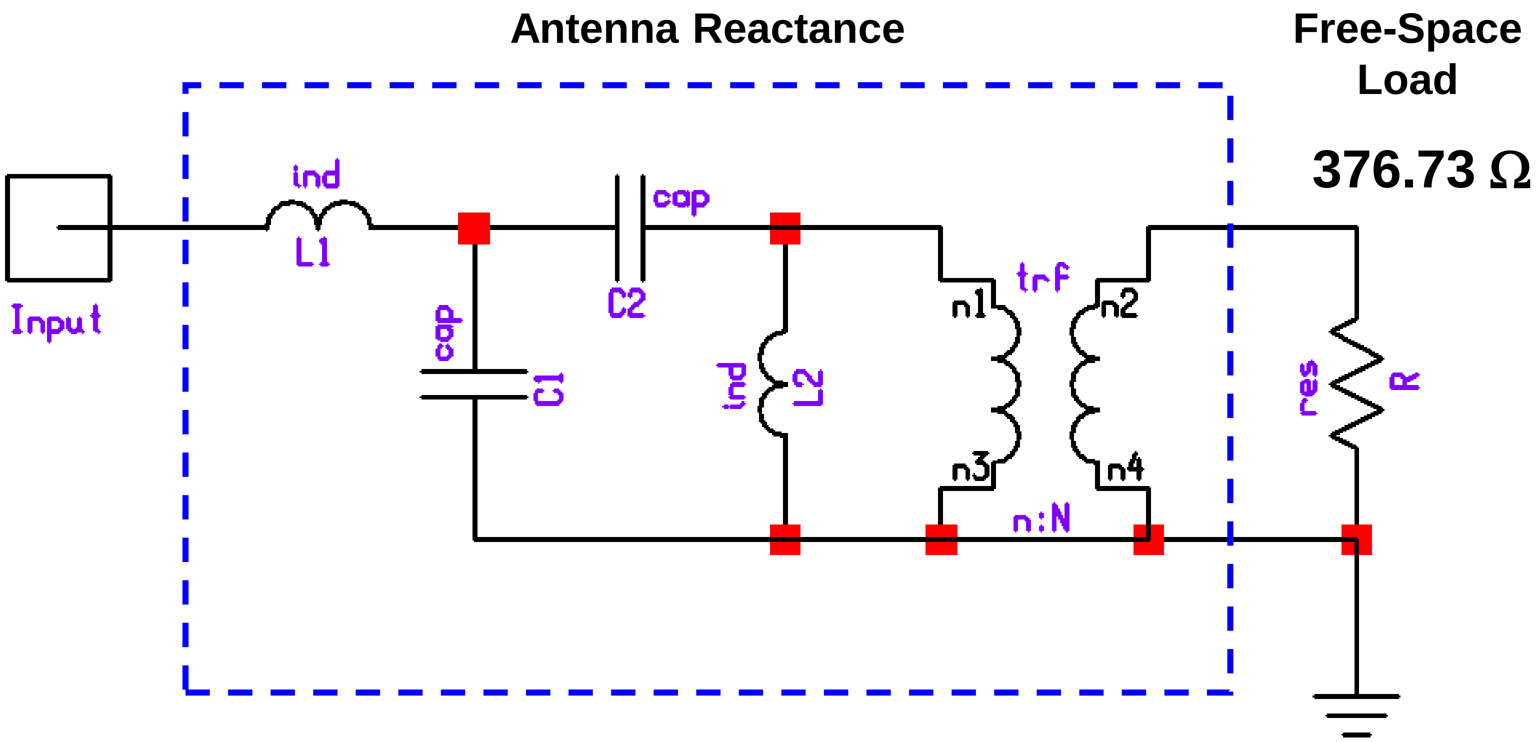
Least Accurate
Series *RLC*



Moderately Accurate
Chu TM10 Mode

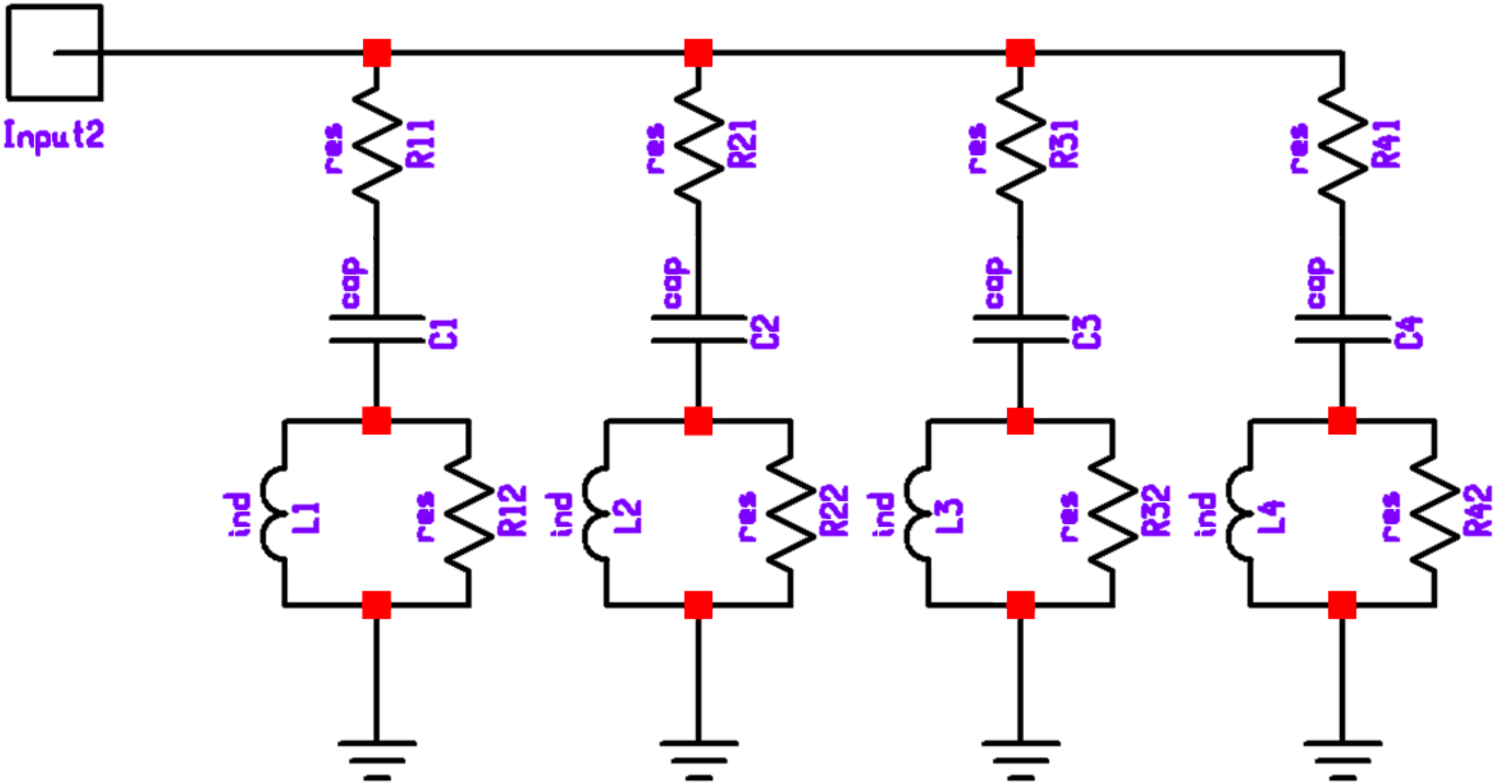
- **All are lumped element circuits in Darlington form**
  - Cauer reactance 2-port with resistor termination)
- **Resistor represents radiation plus loss resistances**
- **All are determined by fitting to dipole impedance data, computed or measured, or by continued fraction synthesis**

Antenna Emulator from a One-Port Darlington



Two-port emulators may be created from one-port equivalent circuits in Darlington form.

Broadband Equivalent Circuit for 98.4-foot Dipole (*L*/*d* = 11,000) from Zero to 30 MHz



*R*11 = 5.06 Ω

*C*1 = 39.9 pF

*L*1 = 27.1 μH

*R*12 = 10.1 kΩ

*R*21 = 0 Ω

*C*2 = 4.64 pF

*L*2 = 24.9 μH

*R*22 = 50.1 kΩ

*R*31 = 25.5 Ω

*C*3 = 4.69 pF

*L*3 = 2.26 μH

*R*32 = 2.68 kΩ

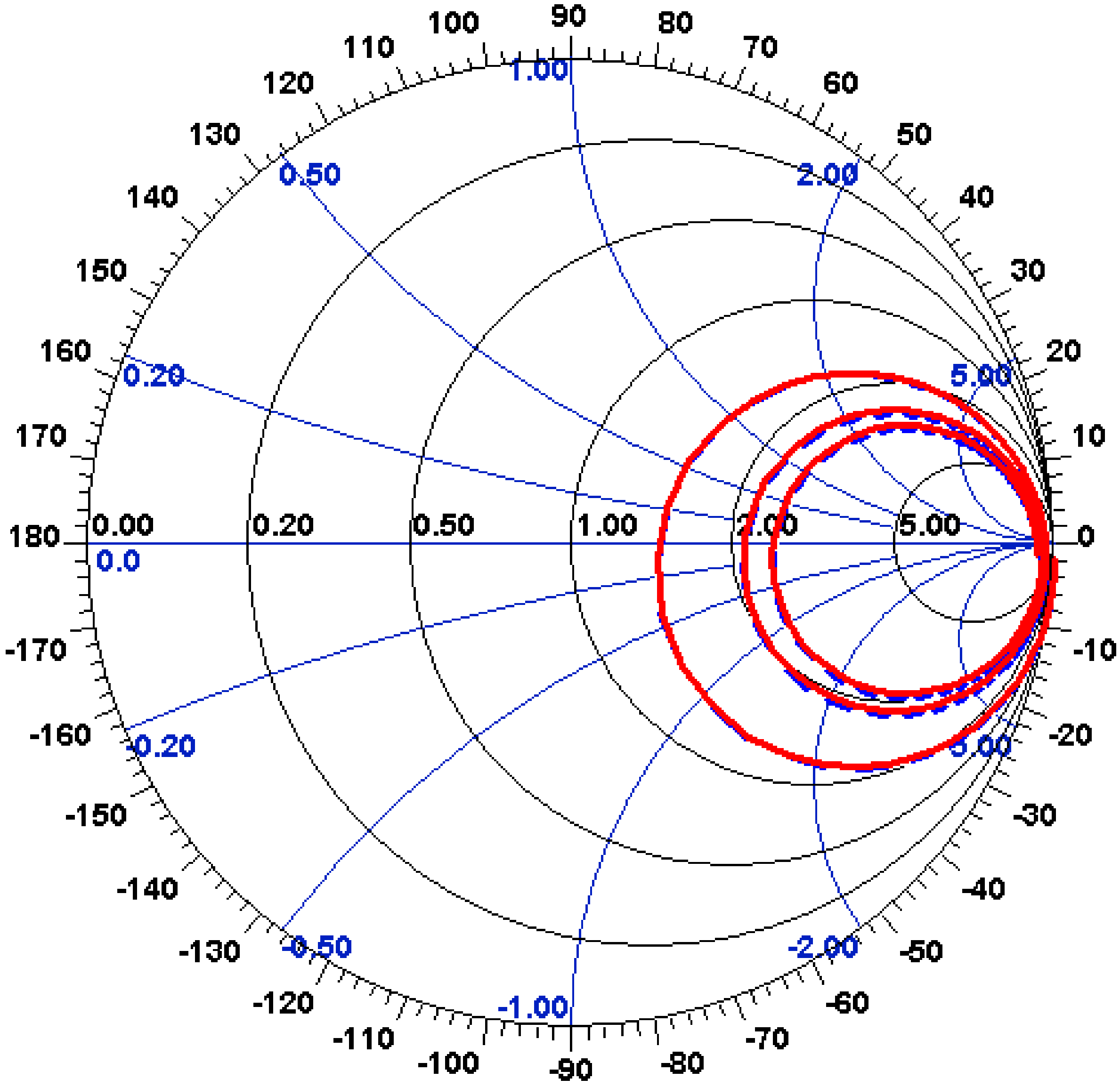
*R*41 = 0 Ω

*C*4 = 1.68 pF

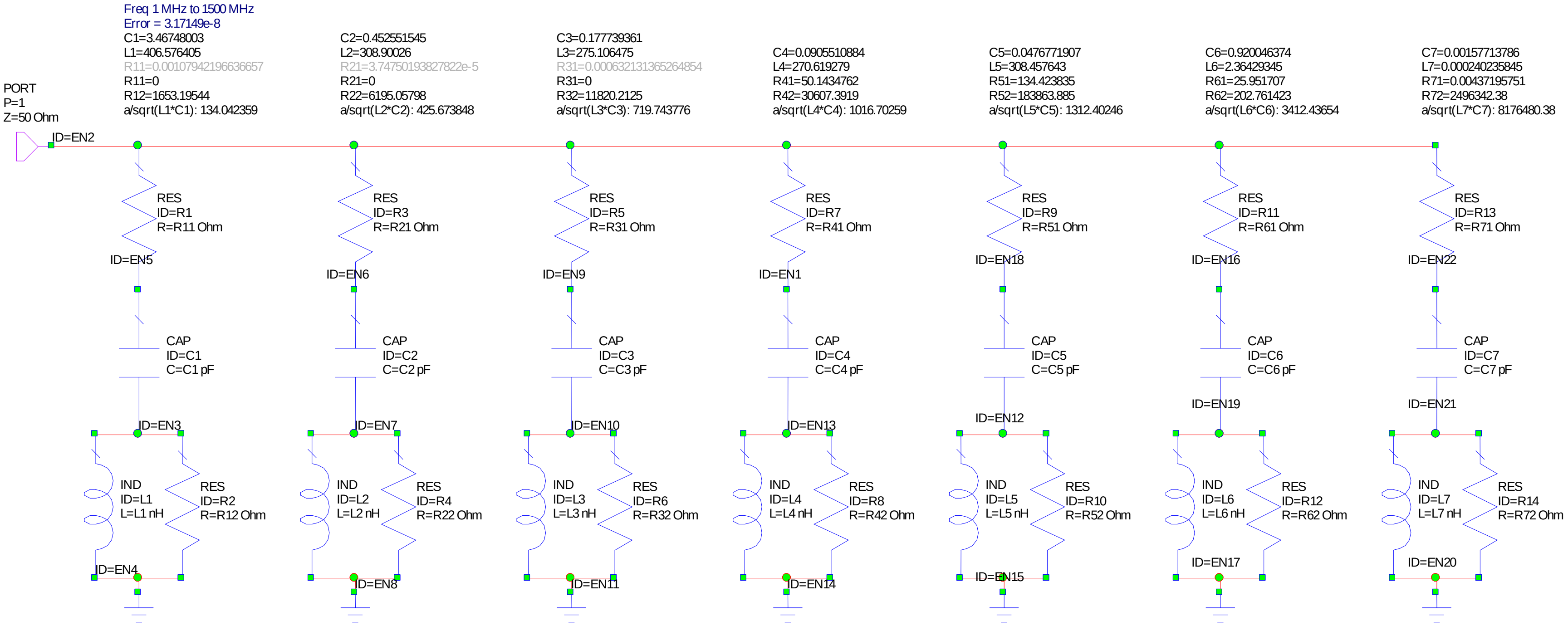
*L*4 = 24.5 μH

*R*42 = 116 kΩ

Accuracy of Broadband Equivalent Circuit

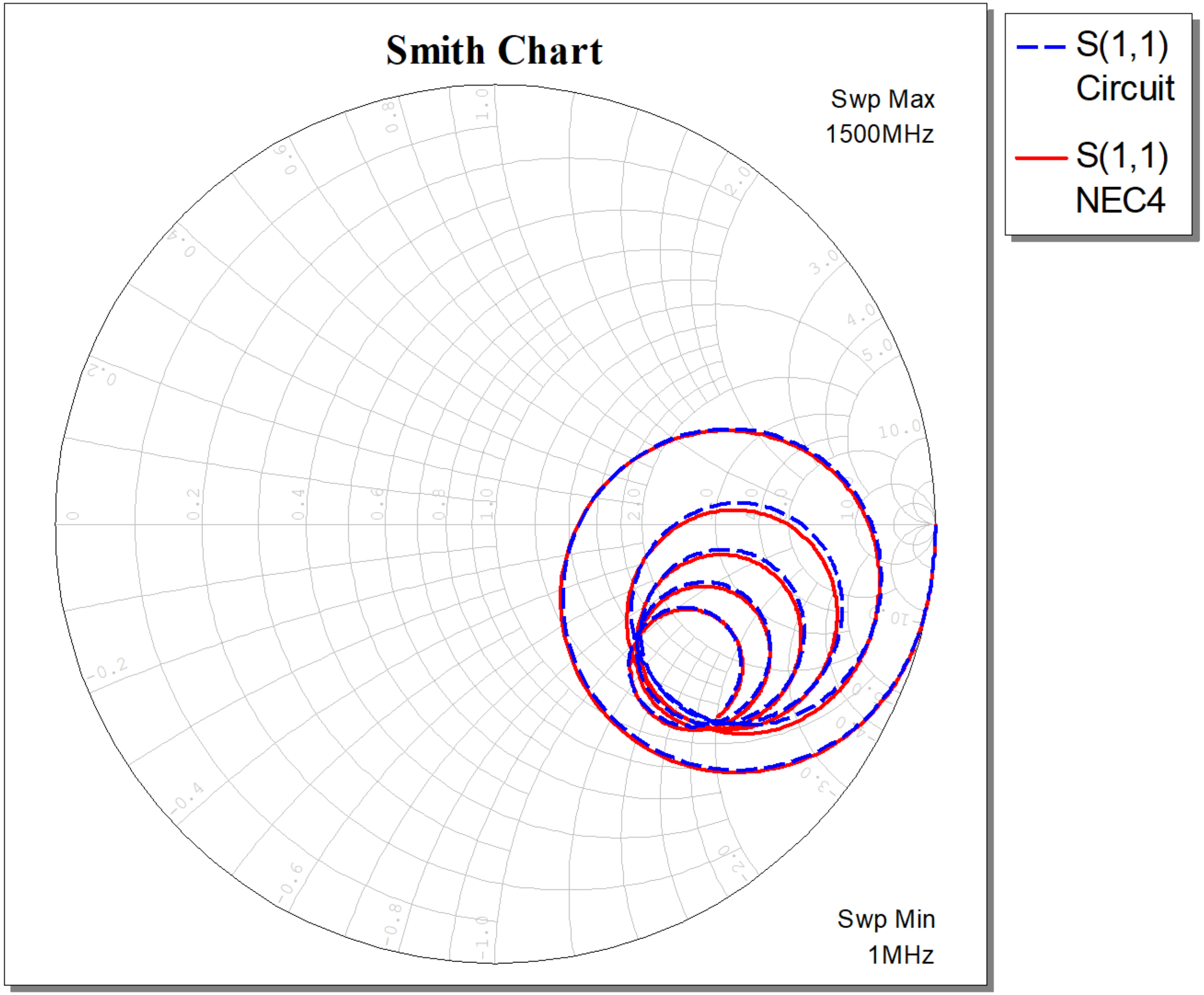


Broadband Equivalent Circuit for 2-meter Dipole (L/d = 50) from Zero to 1.5 GHz

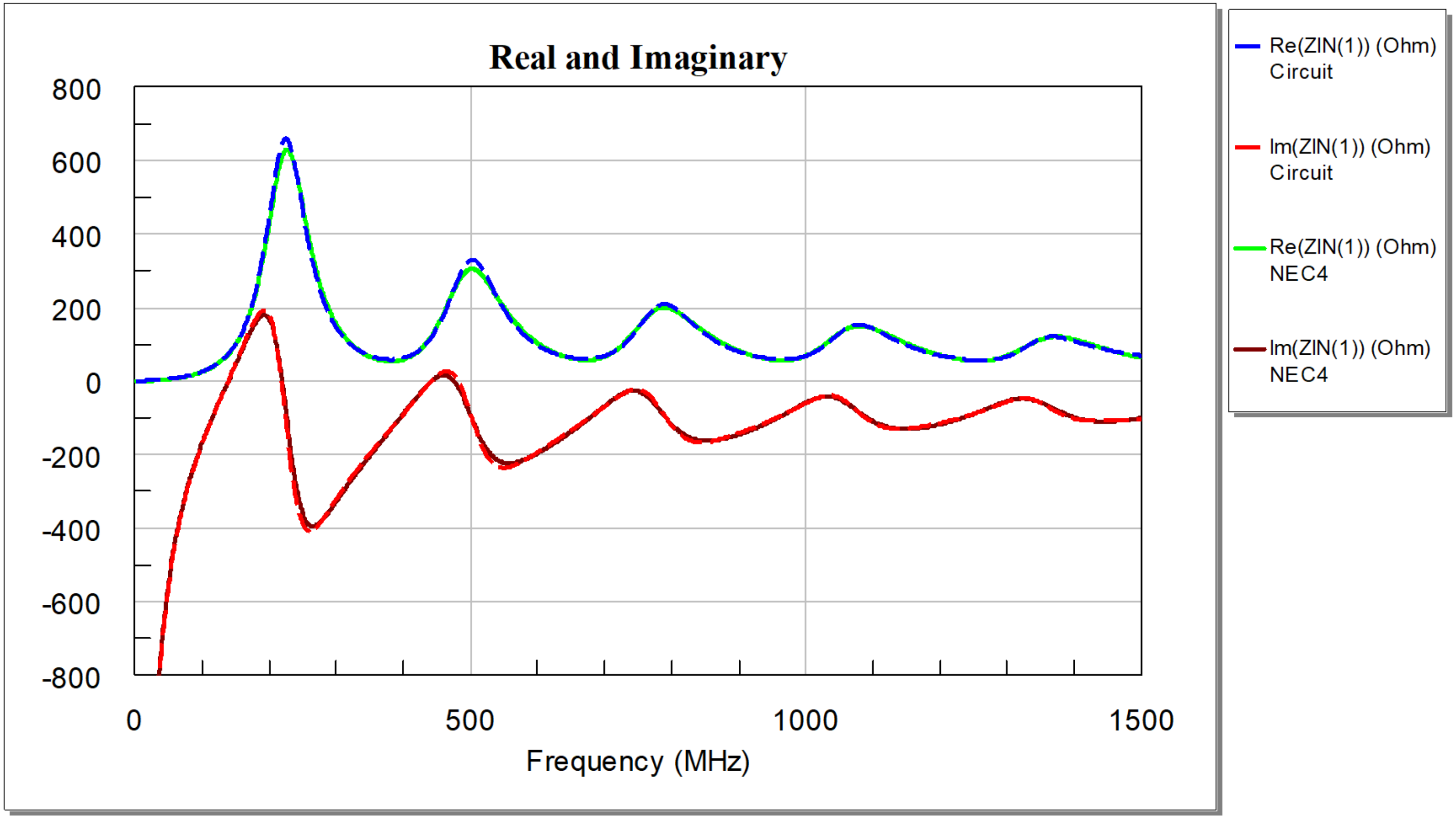


- **Introduced by the author (2007)**
- **Partial fraction expansion of dipole admittance**
- **A modification of Foster's 2nd canonical form**
- **More accurate than other broadband equivalent circuits for dipoles, viz. Hamid-Hamid (1997), Rambabu-Ramesh-Kalghatgi (1999), and Streable-Pearson (1981)**
- **Six stages sufficient to cover *d-c* to 1.5 GHz**

Accuracy of Broadband Equivalent Circuit



Impedance Accuracy of Broadband Equivalent Circuit



Dipole Resonance and Resonant Length

The Mysterious Factor *K*

Two Definitions of Resonance

- **Electric field energy equals magnetic field energy**

$$\iiint \left(\varepsilon_0 |E|^2 - \mu_0 |H|^2 \right) dV = 0$$

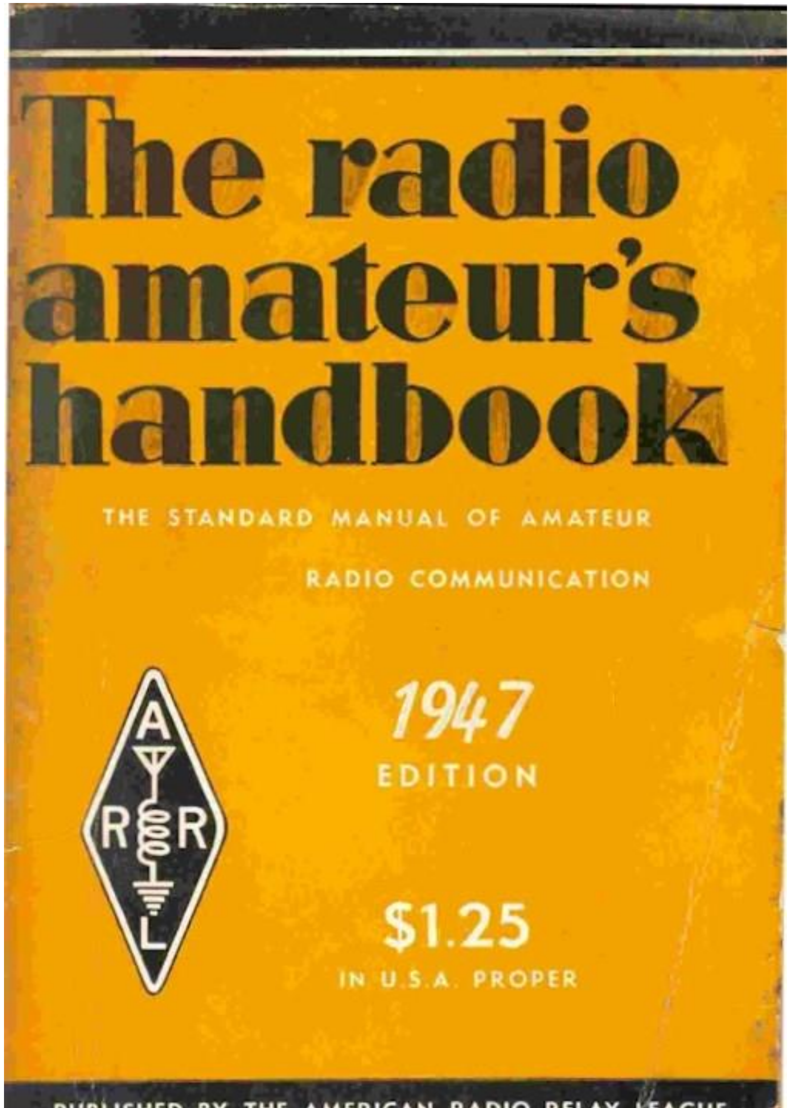
  - Some authors exclude radiation energy and consider only stored energy that is not associated with radiation, i.e. real power delivery to infinity

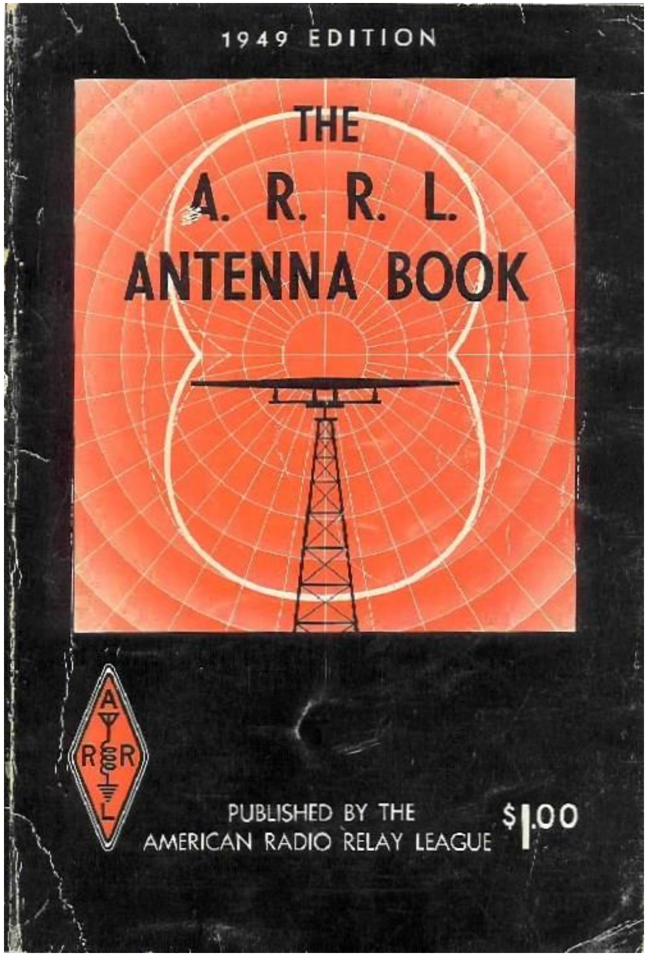
- **Feedpoint reactance is zero**

$$X(f) = 0$$

  - This definition is standard but less fundamental
  - A nonresonant antenna can be made resonant, and vice versa, by incorporating transmission line
  - If an antenna’s impedance curve lies entirely in the upper or lower half of the Smith chart and does not cross the horizontal X = 0 midline, then it has no resonances

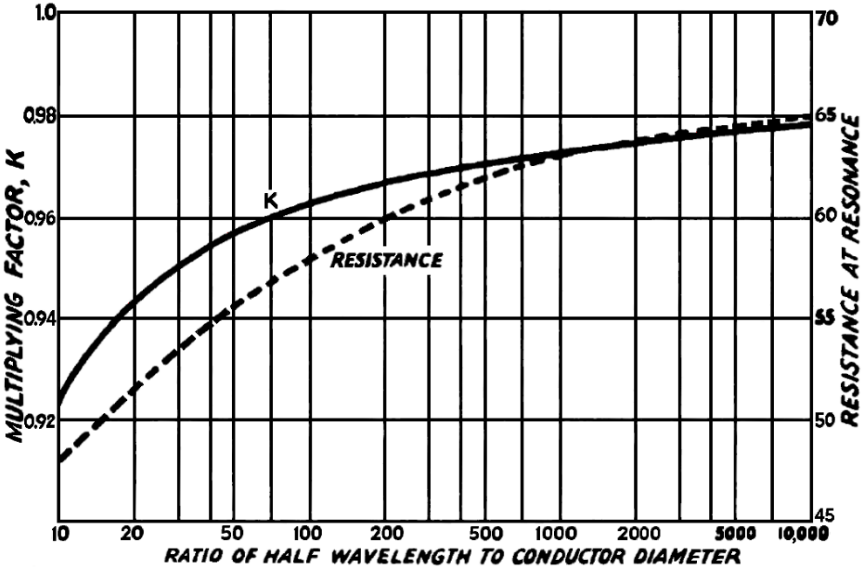
Dipole Resonant Length



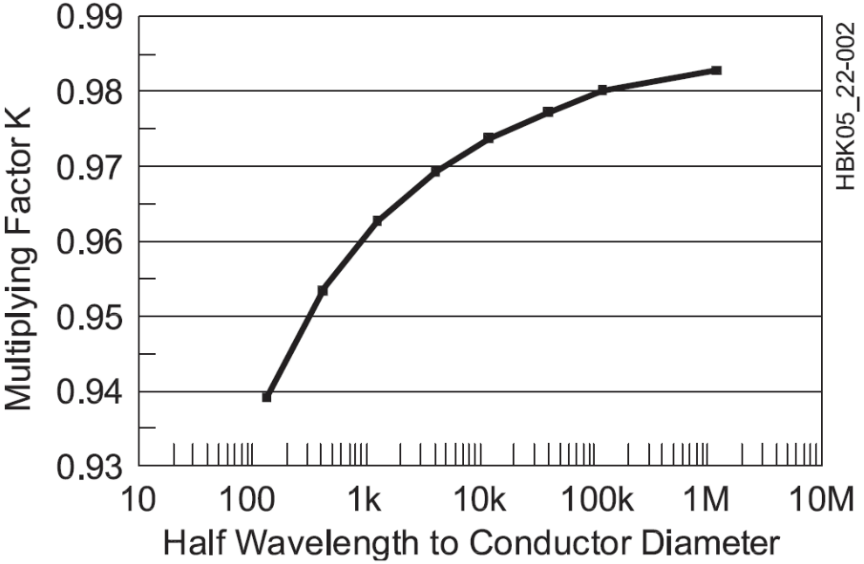


The Multiplying Factor *K*

ARRL 1947-1997



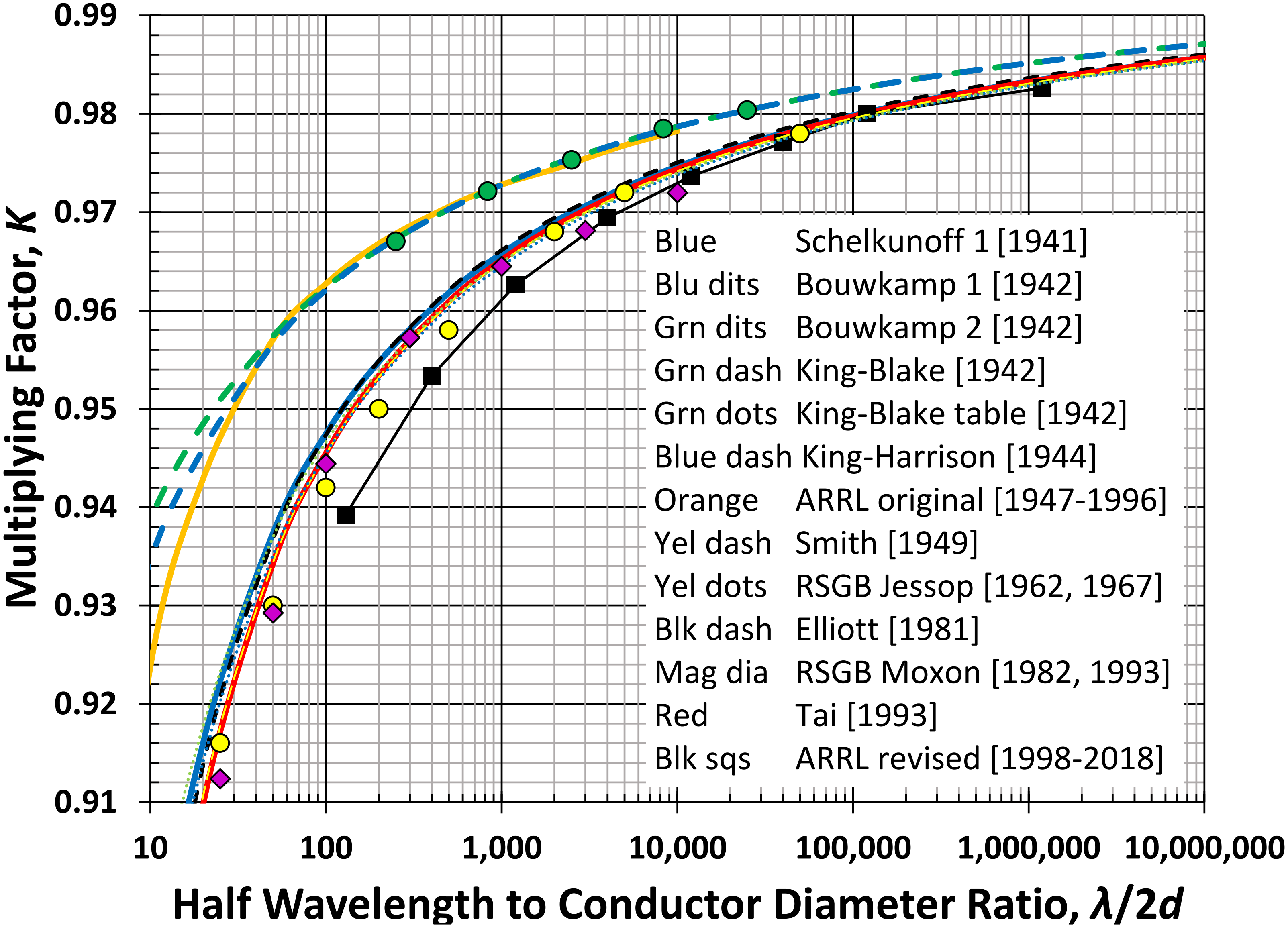
ARRL 1998-2018



$$L_{res} = K \times \frac{\lambda}{2} = K \times \frac{491.786}{f_{MHz}} \quad \text{feet}$$

K is not a velocity factor !

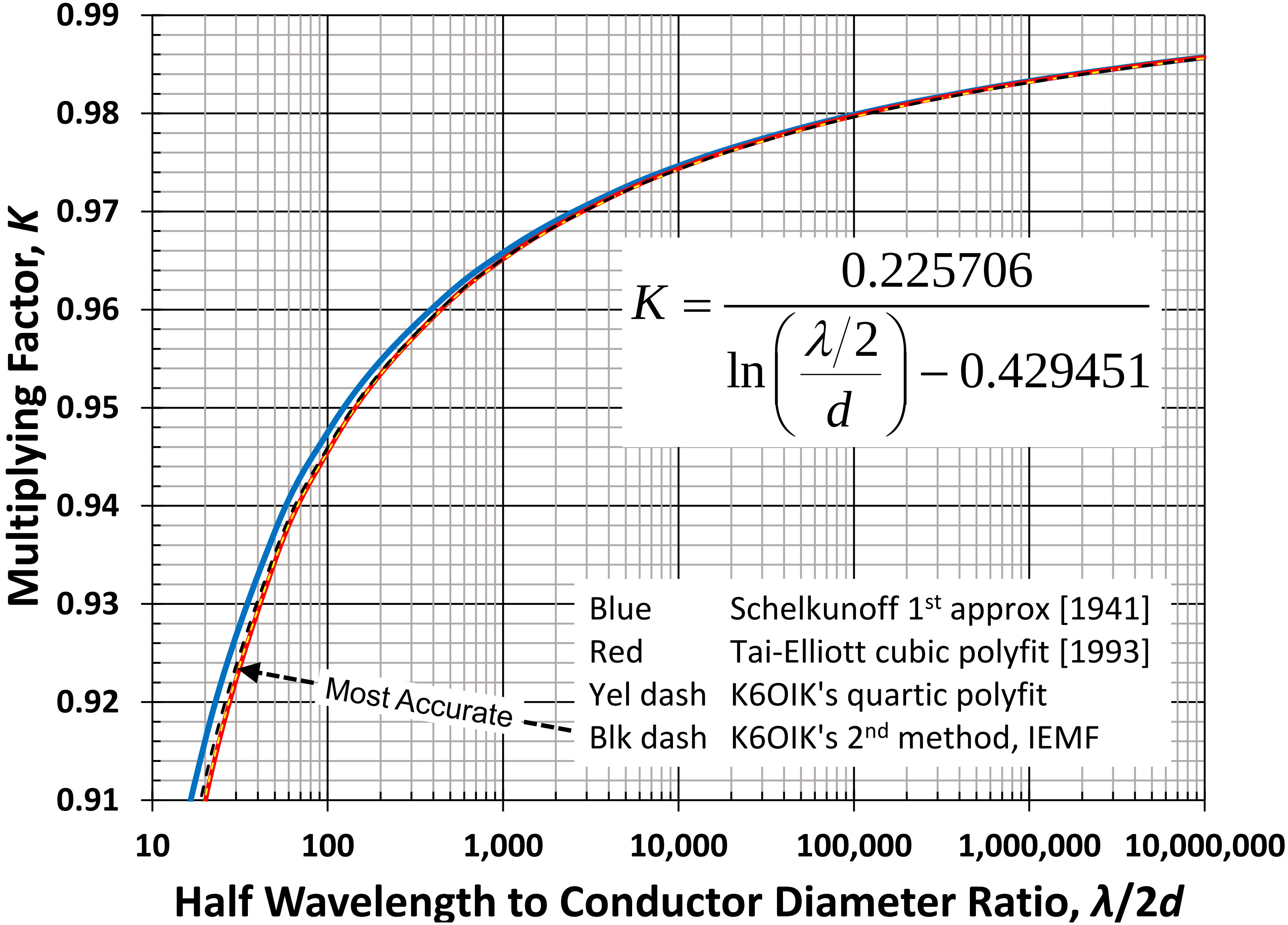
The "*K*" Universe – Who is Right?



Three Half-Baked Theories of the Multiplying Factor *K*

- **Theory 1: *K* is a velocity factor**
  - Claim: Dipole is a transmission line and *K* is a velocity factor
  - No physical basis exists for non-unity velocity factor
    - Only materials are PEC metal and vacuum, no dielectric or losses
  - Schelkunoff's wave theory of antennas has velocity factor = unity
- **Theory 2: *K* is an "end" effect**
  - Claim: Dipole is a quarter-wave transmission line, velocity factor = 1, but fringing capacitance at ends transforms to inductance at feedpoint
  - Forward and reverse traveling waves would give a sinusoidal current standing wave, but this is not the case
- **Theory 3: *K* is due to current distribution not being sinusoidal**
  - True, the magnitude of the current distribution deviates from sinusoidal as a dipole gets fatter, but this does not explain *K*
  - *K* is predicted accurately by the induced e.m.f. method which assumes sinusoidal current distribution; so non-sinusoidal current is not the explanation

The Real *K* – for a Dipole in Free Space



$$K = \frac{0.225706}{\ln\left(\frac{\lambda/2}{d}\right) - 0.429451}$$

Blue	Schelkunoff 1st approx [1941]
Red	Tai-Elliott cubic polyfit [1993]
Yel dash	K6OIK's quartic polyfit
Blk dash	K6OIK's 2nd method, IEMF

Comments on the Multiplying Factor *K*

- **Most popular expositions on *K* are partly correct at best**
    - *K* is not a velocity factor
    - *K* is not an “end” effect
    - *K* is not due to departure from sinusoidal current distribution
- ***K* can be determined by rigorous methods**
    - Induced e.m.f. method gives *K* accurately for the 1st resonance
    - Best method: Analyze a dipole as a boundary value problem
    - Solve Pocklington’s or Hallén’s equations for the current on the antenna
    - *K* is found from the dipole length for which the feedpoint reactance is zero
- **Numerical methods are fine, but MoM has a caveat**
    - Antenna models that use delta-gap sources and MoM do not predict resonance or *K* very accurately

Antenna models that use delta-gap sources and MoM do not predict resonance or *K* very accurately.

Off-Center Fed and End Fed Wire Antennas

Off-Center Fed Wire Antennas

- **OCF antennas are linear cylindrical antennas in which the feedpoint is shifted from center**
  - Arm lengths are not equal
- **Examples include**
  - End-fed antennas – an extreme case in which one arm is zero
  - Random wires
  - Zepps and Extended Zepps
  - J-poles
  - Some "end-fed" antennas are actually just OCF depending on counterpoise configuration
- **The feedpoint impedance is high. Coupling techniques include**
  - Wideband – Wound transformer (49:1 is common)
  - Narrowband – Quarter-wave line transformer
- **Good references**
  - Bert Henderson, W6MSD, "Build Your Own DIY Wire Antennas: End Fed, Off-Center-Fed, Baluns and Ununs" https://wp-cdn.wvara.org/wordpress/wp-content/uploads/2024/12/04183717/Some-DIY-Antennas-Transformers-WVARA-Nov-2024-v2.pdf
  - Richard Hall, K7RLH, "A Slightly Off-Center-Fed Dipole" https://fivecountyhre.org/a-slightly-off-center-fed-dipole
  - Serge Stroobandt, ON4AA, "Multiband HF Center-Loaded Off-Center-Fed Dipoles" https://hamwaves.com/cl-ocfd/en/index.html
  - Steve Ellington, N4LQ,"End Fed Half Wave Antennas vs Random Length End Fed Antennas" https://www.youtube.com/watch?v=xfqlun3bdI0
  - J.B. Still, NR5NN, "End Fed Wire Antennas" https://www.youtube.com/watch?v=CWkuCvhW28w
  - T.W. Longfellow, N7TWL, "The End-Fed Half-Wave (EFHW) Dipole Wire Antenna" https://n7tar.org/wp-content/uploads/2023/06/The-End-Fed-Half-Wave-Antenna.pdf

Radiation Behavior

Near field

Far field

Pattern

Directivity and gain

Effective Rx capture area

Radiation

- **DC and AC steady-state currents produce magnetic fields**
- **Only AC currents produce fields (electromagnetic) that radiate, propagate, or travel away from the source with low attenuation**
- **The acceleration of charge creates radiation**
    - Larmor’s equation: A charged particle radiates when accelerated, and the radiated power is proportional to the square of the acceleration
    - Time-varying current creates radiation
- **Many books erroneously state a time-varying electric field produces a time-varying magnetic field and vice versa**
    - Maxwell’s equations (and Ohm’s law) are descriptive, not causal
    - Time-varying electric and magnetic fields exist together. Neither causes the other. The current source causes both.
- **In modern physics, photon energy is *E* = *hf*, where *h* is Planck’s constant and *f* is frequency**
    - If an antenna radiates 100 W at 146 MHz,

      $E = 6.62 \times 10^{-34}$ Joule-sec x $146 \times 10^{6} = 9.67 \times 10^{-26}$ J/photon

      Photon rate = $100 / 9.67 \times 10^{-26} = 1 \times 10^{27}$ photons/sec

      = 1 billion billion billion photons per second

Electric and Magnetic Fields of an Infinitesimal Dipole

- **Fields of an infinitesimal dipole on Z axis in free space (or an infinitesimal monopole over an infinite PEC ground plane)**

$$H_r = H_\theta = 0$$

$$H_\phi = j\frac{kI_0 l\sin\theta}{4\pi r}\left[1+\frac{1}{jkr}\right]e^{-jkr}$$

$$E_r = \eta\frac{kI_0 l\cos\theta}{4\pi r}\left(\frac{2}{kr}\right)\left[1+\frac{1}{jkr}\right]e^{-jkr}$$

$$E_\theta = j\eta\frac{kI_0 l\sin\theta}{4\pi r}\left[1+\frac{1}{jkr}-\frac{1}{(kr)^2}\right]e^{-jkr}$$

$$E_\phi = 0$$

Near field terms assuming

- Uniform current distribution with
  - Current I_0
  - Dipole length l
- Triangular current distribution with
  - Peak current I_0
  - Dipole length $2l$

One radianlength defined as $r = 1/k = \lambda/2\pi$ is the distance at which far field and near field terms are equal.

Heinrich Hertz’s Drawings of Electric Fields of a Dipole circa 1888

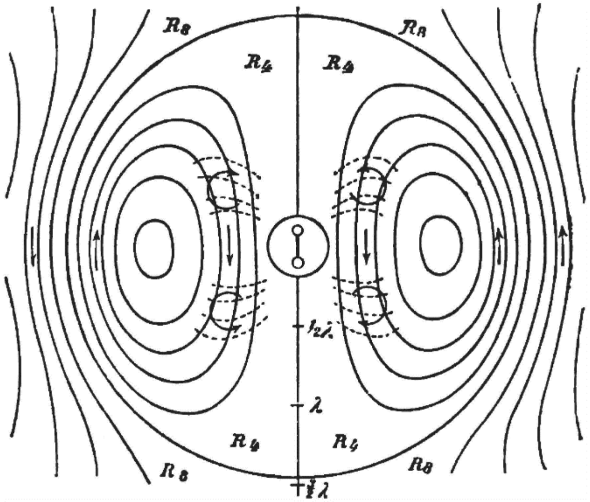


Fig. 27.

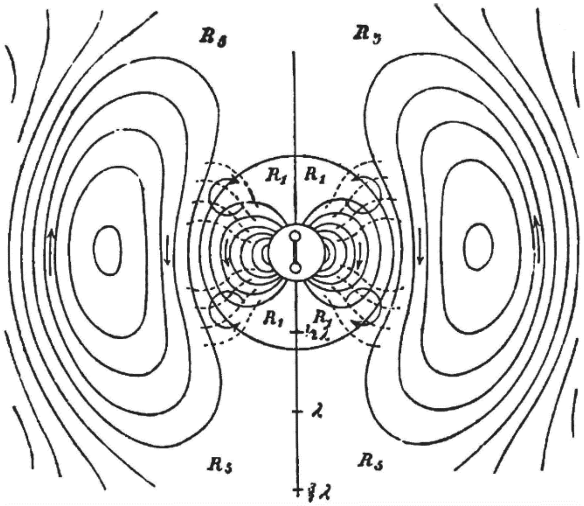


Fig. 28.

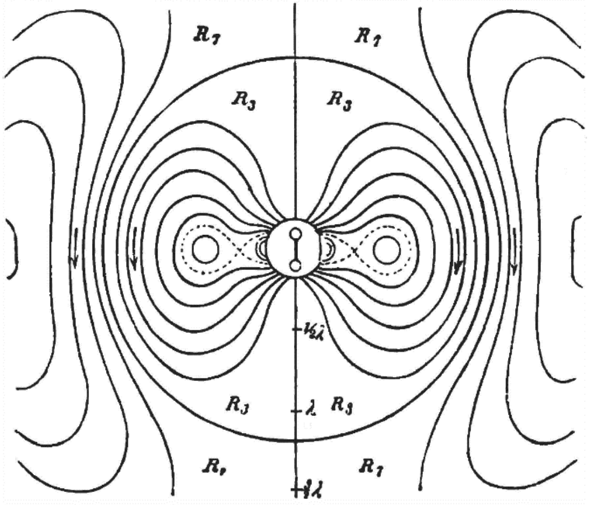


Fig. 30.

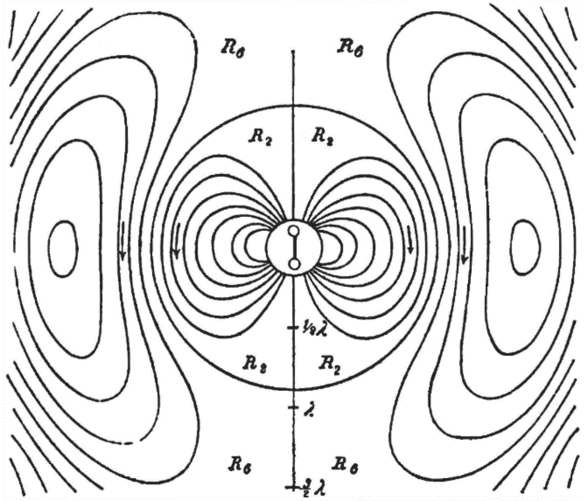
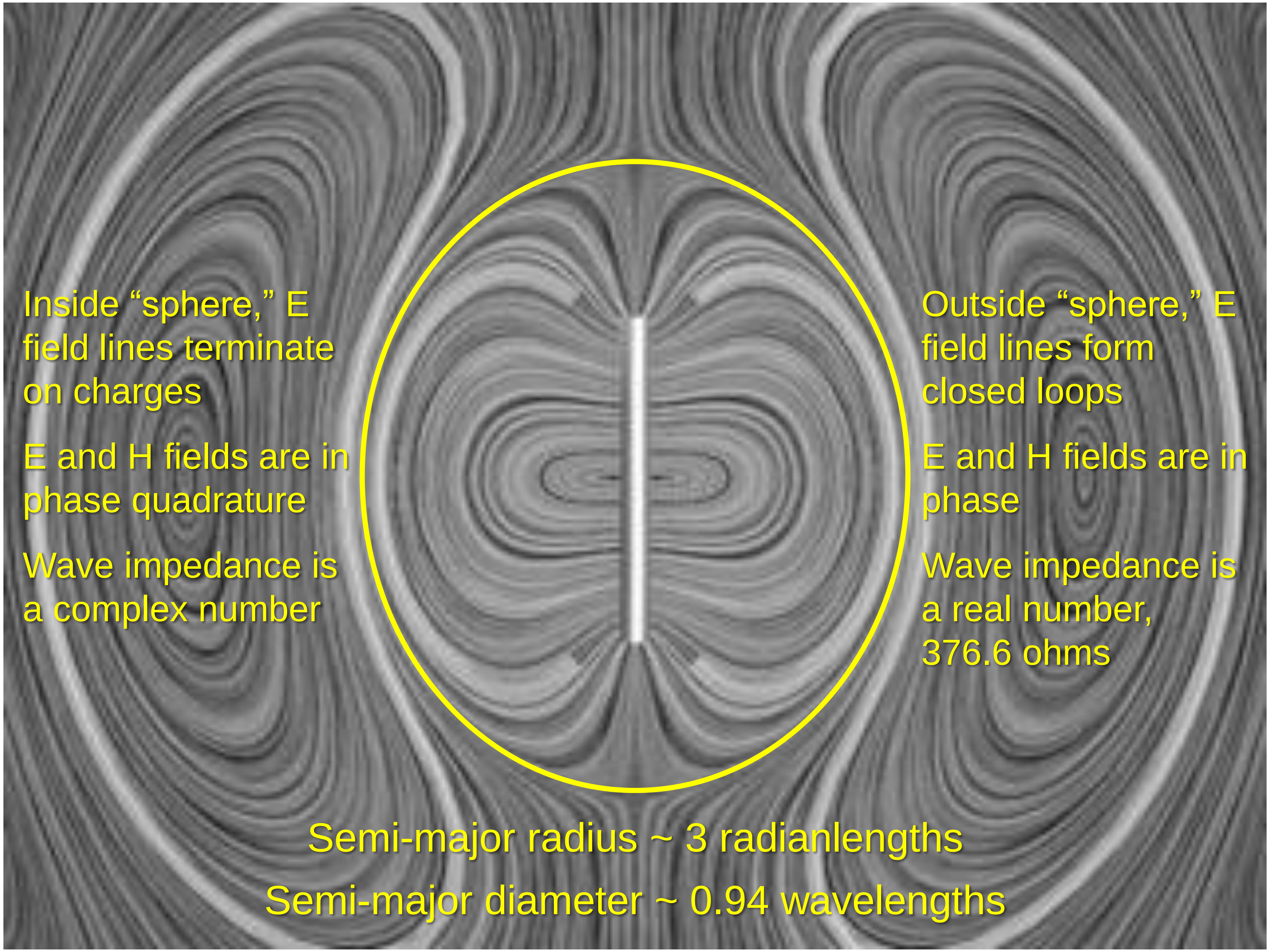


Fig. 29.

The Radiansphere: Electric Field of a Halfwave Dipole



Inside "sphere," E field lines terminate on charges

E and H fields are in phase quadrature

Wave impedance is a complex number

Outside "sphere," E field lines form closed loops

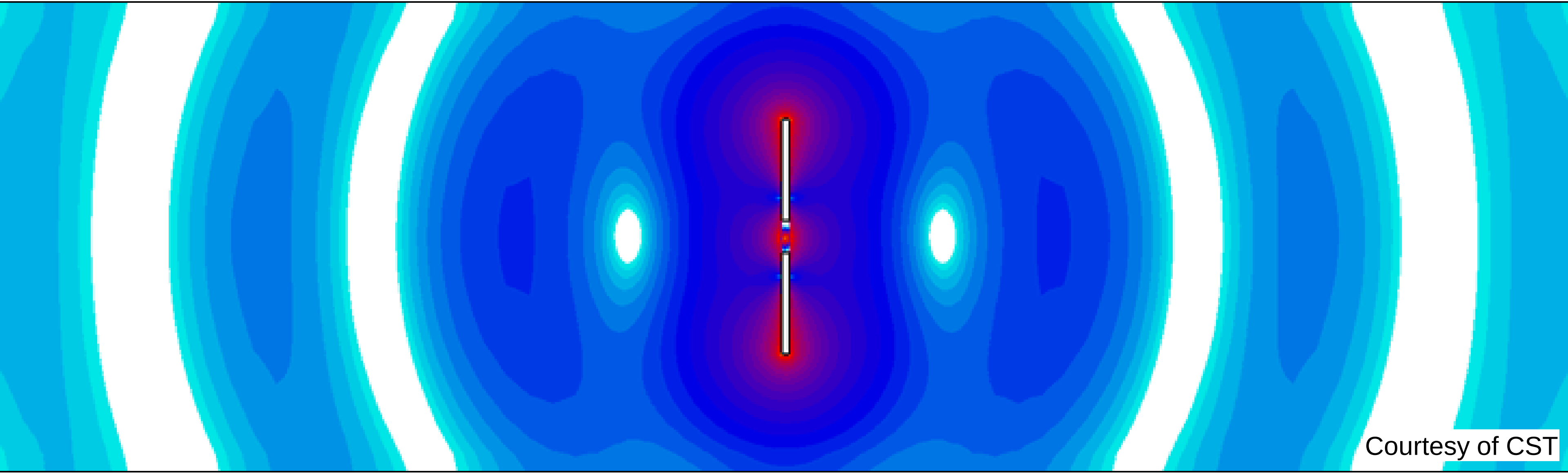
E and H fields are in phase

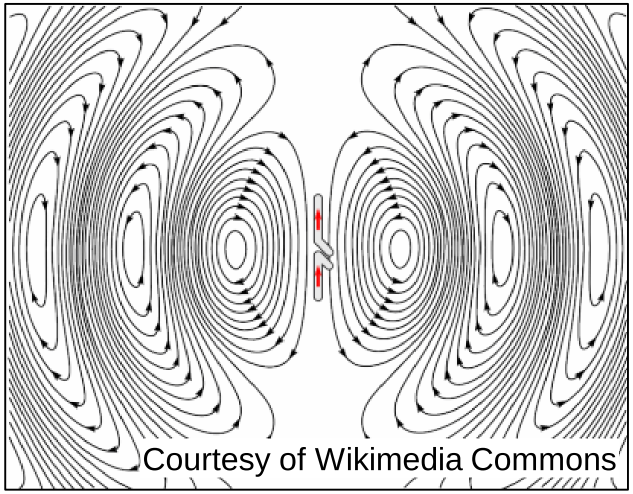
Wave impedance is a real number, 376.6 ohms

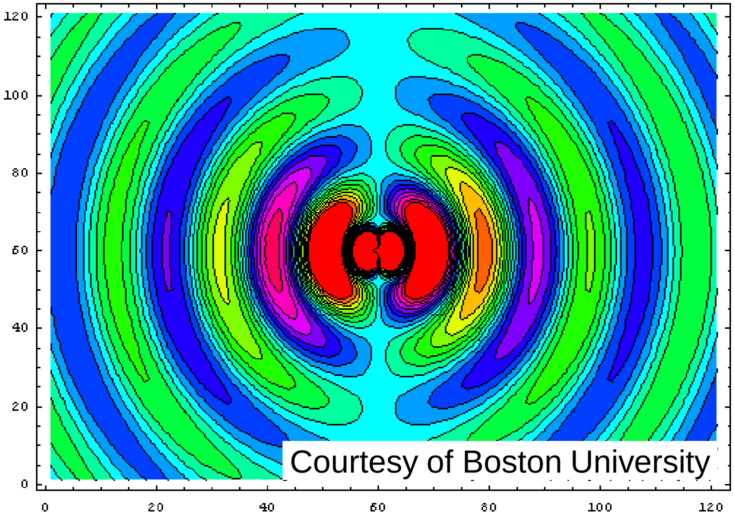
Semi-major radius ~ 3 radianlengths

Semi-major diameter ~ 0.94 wavelengths

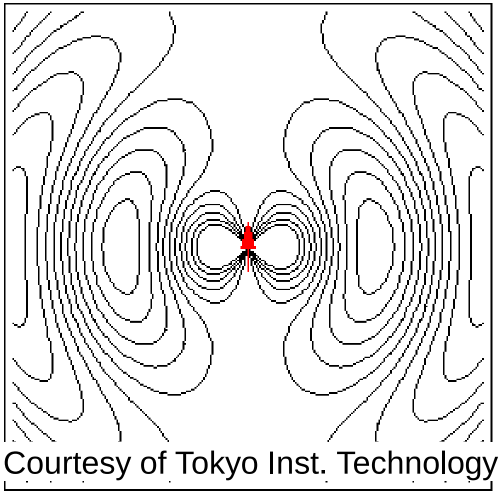
Dipole Fields Animations


Courtesy of CST


Courtesy of Wikimedia Commons



Courtesy of Boston University


Courtesy of Tokyo Inst. Technology

View PowerPoint in Slide Show mode (Shift F5) to see field animations.

Poynting Vector of the Infinitesimal Dipole

$$\mathbf{S} = \frac{1}{2}\mathbf{E}\times\mathbf{H}^* = \mathbf{a}_r S_r + \mathbf{a}_\theta S_\theta + \mathbf{a}_\varphi 0$$

$$S_r = \frac{1}{2}\left(E_\theta H_\varphi^* - E_\varphi H_\theta^*\right)$$

Real power

$$= \frac{\eta \sin^2\theta}{2}\left(\frac{kI_0 l}{4\pi r}\right)^2\left(1 - \frac{j}{(kr)^3}\right)$$

$$S_\theta = \frac{1}{2}\left(E_r H_\varphi^* - E_\varphi H_r^*\right)$$

Reactive power

$$= -j\frac{\eta \sin 2\theta}{4}\left(\frac{kI_0 l}{4\pi r}\right)^2\left(\frac{2}{kr}\right)\left(1 + \frac{1}{(kr)^2}\right)$$

$$S_\varphi = \frac{1}{2}\left(E_r H_\theta^* - E_\theta H_r^*\right) = 0$$

- **Power flow has real and reactive parts**
- **Real power flows radially from the origin out to infinity**
  - Real power density decreases as inverse square
- **Reactive power circulates in the near field**
  - Reactive power density decreases as inverse cube and inverse fifth power
- **In the far field, power flow is real**

Far Field Gain of Infinitesimal Dipole

- Gain and directivity are functions of direction
- Gain is directivity with losses included
- For lossless antennas, gain and directivity are the same
- Example: Infinitesimal dipole

$$G(\theta,\phi) = D(\theta,\phi)$$

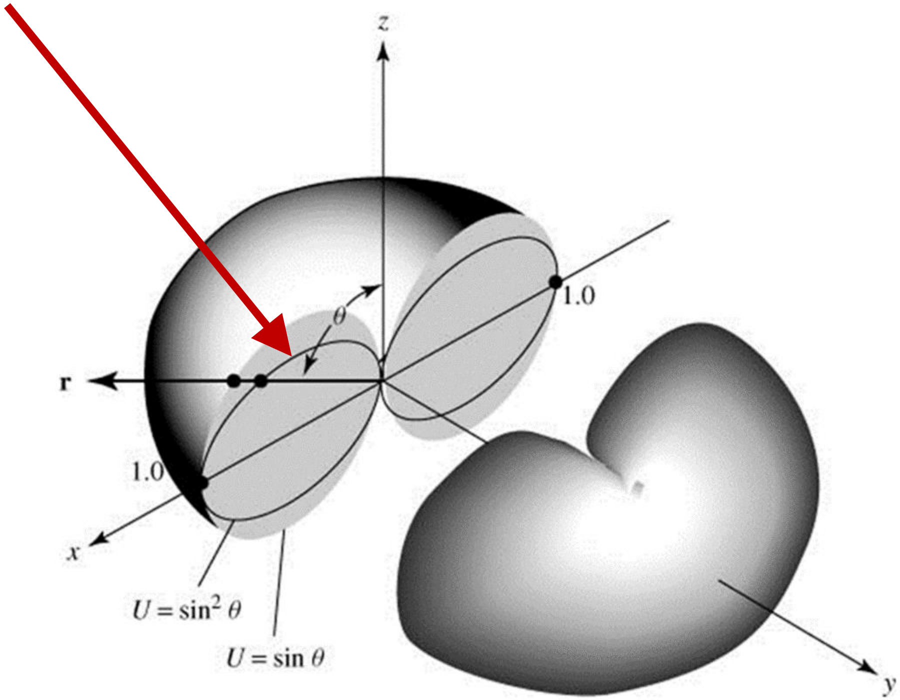
$$= \frac{S_r(\theta,\phi)}{\frac{1}{4\pi}\oiint S_r(\theta,\phi)\sin\theta\, d\theta\, d\phi}$$

$$= \frac{\sin^2\theta}{\frac{1}{4\pi}\oiint \sin^3\theta\, d\theta\, d\phi}$$

$$= \frac{3}{2}\sin^2\theta$$

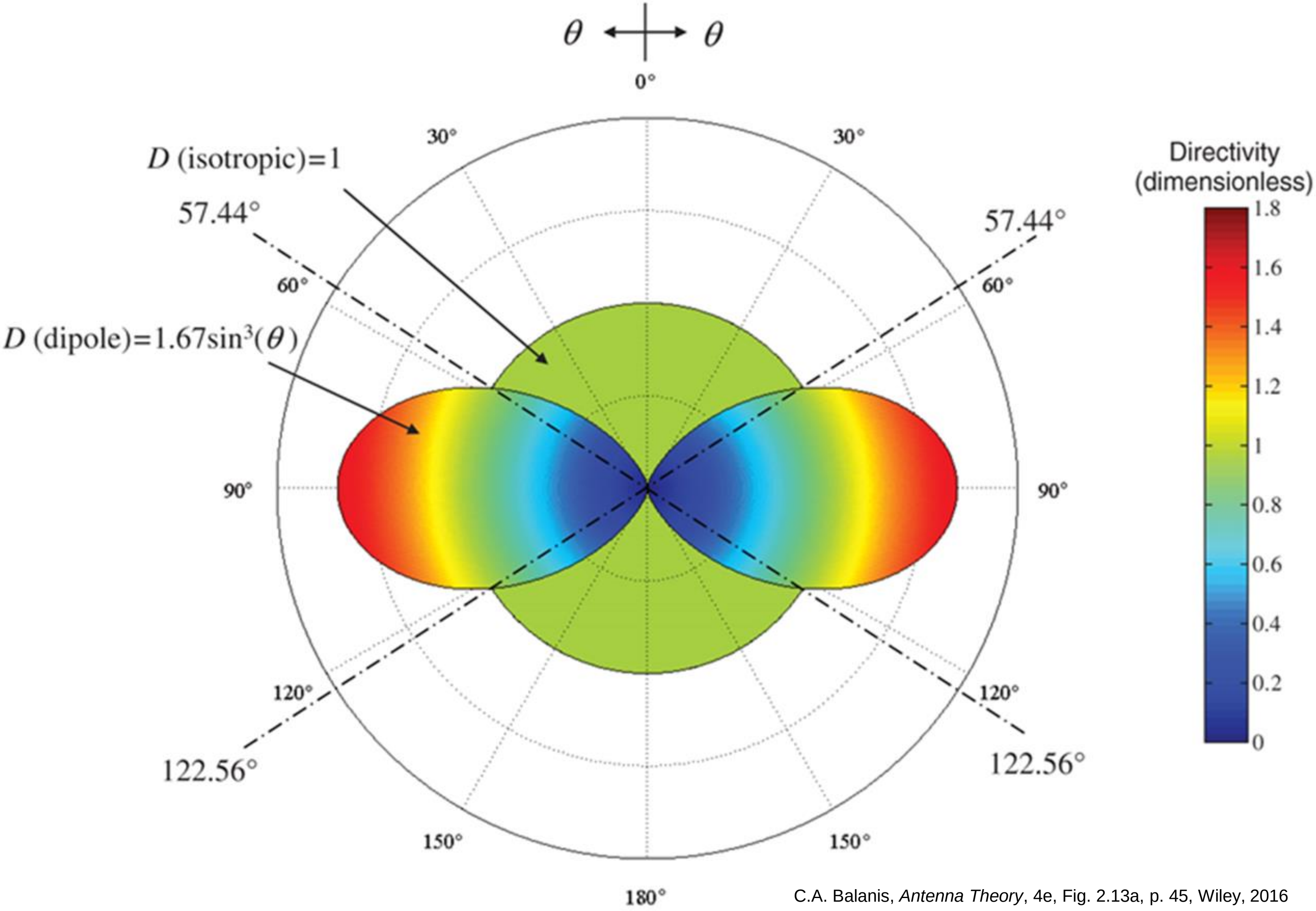
$$G_{max} = 1.5 \quad \text{for} \quad \theta = 90^\circ$$

(1.76 dBi or -0.39 dBd)



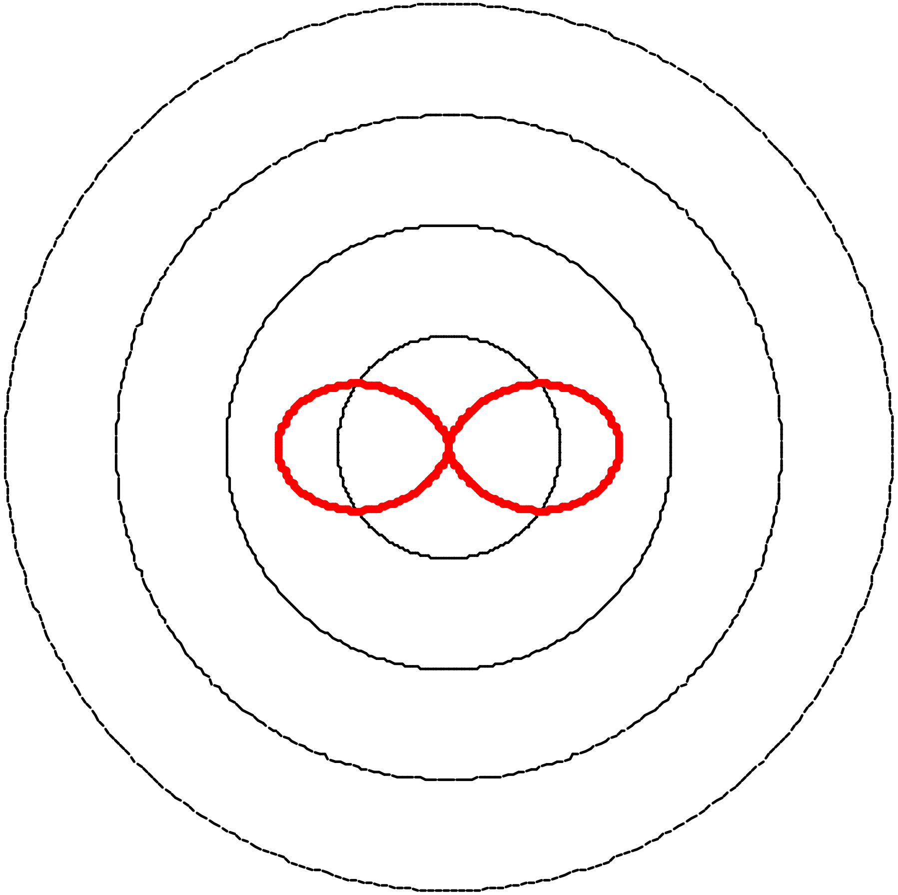
C.A. Balanis, *Antenna Theory*, 4e, Fig. 2.12, p. 44, Wiley, 2016

Halfwave Dipole Pattern Compared to Isotropic

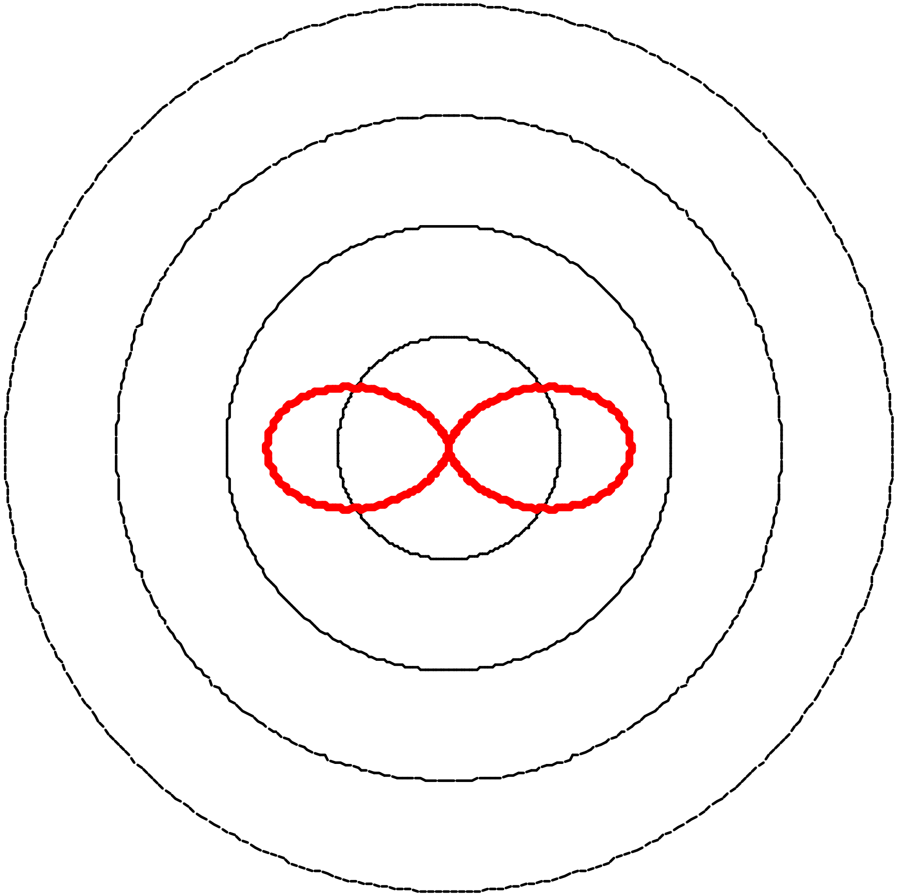


C.A. Balanis, *Antenna Theory*, 4e, Fig. 2.13a, p. 45, Wiley, 2016

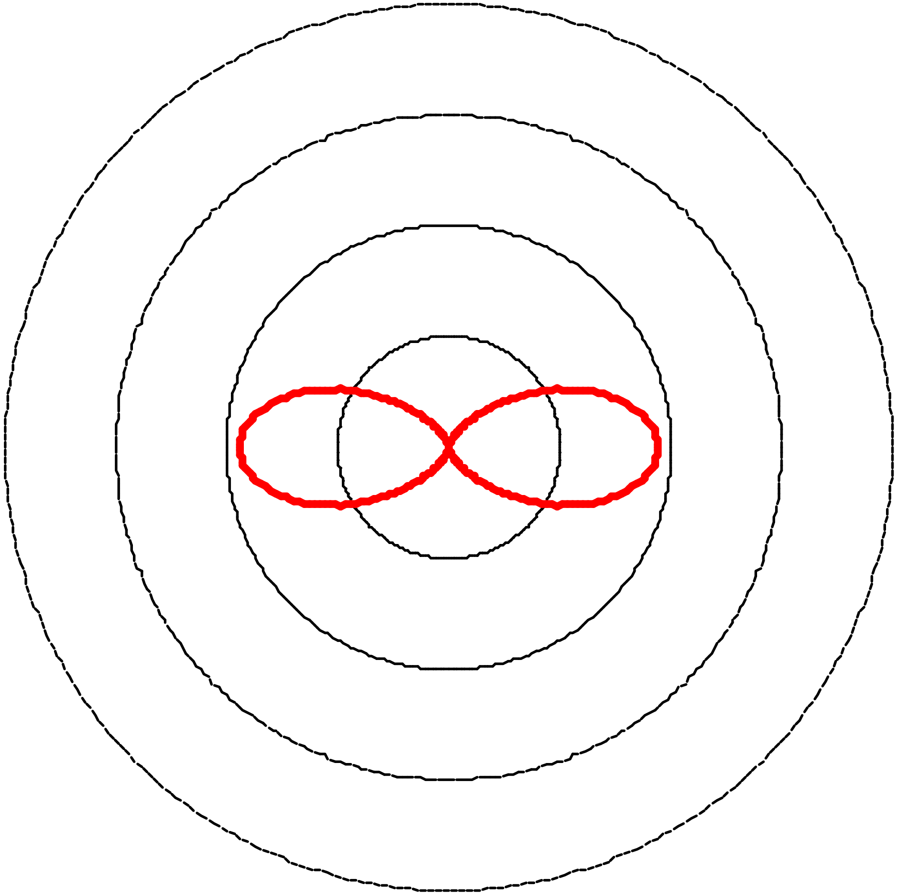
Gain Pattern of 0.25λ Dipole



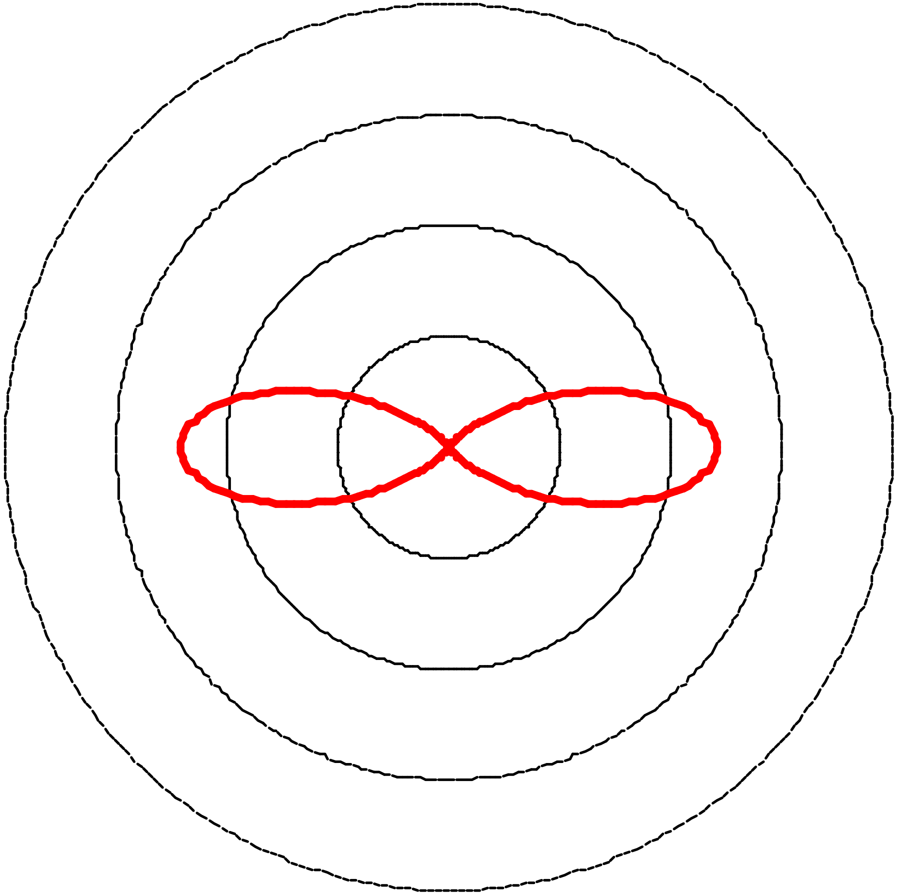
Gain Pattern of 0.5λ Dipole



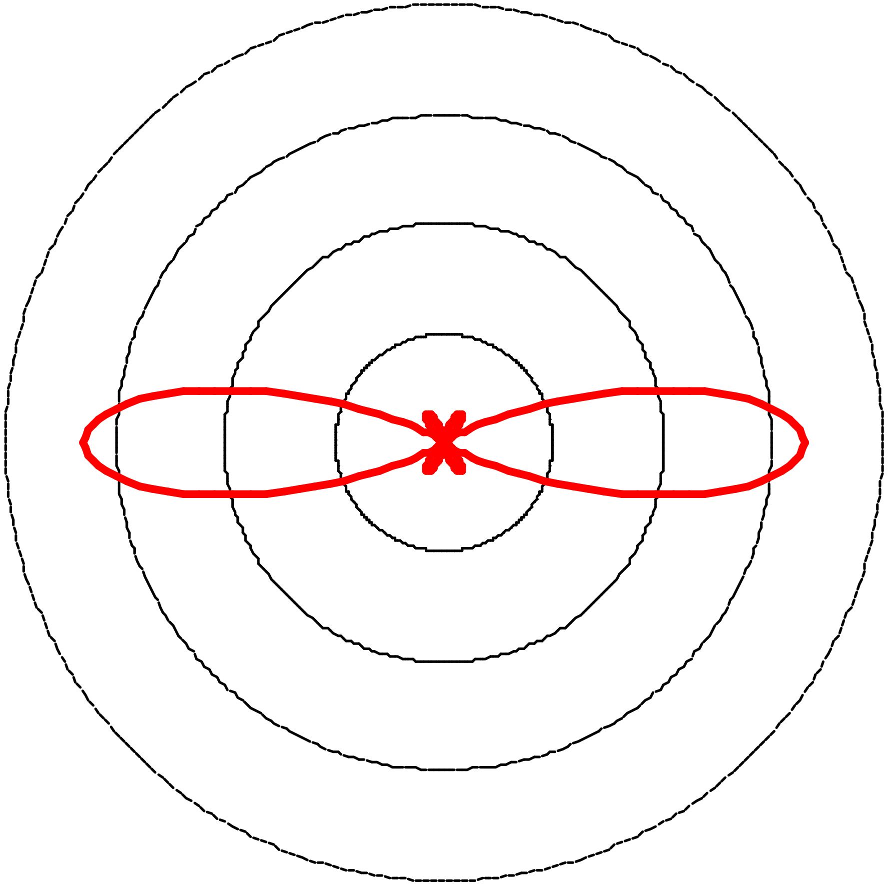
Gain Pattern of 0.75λ Dipole



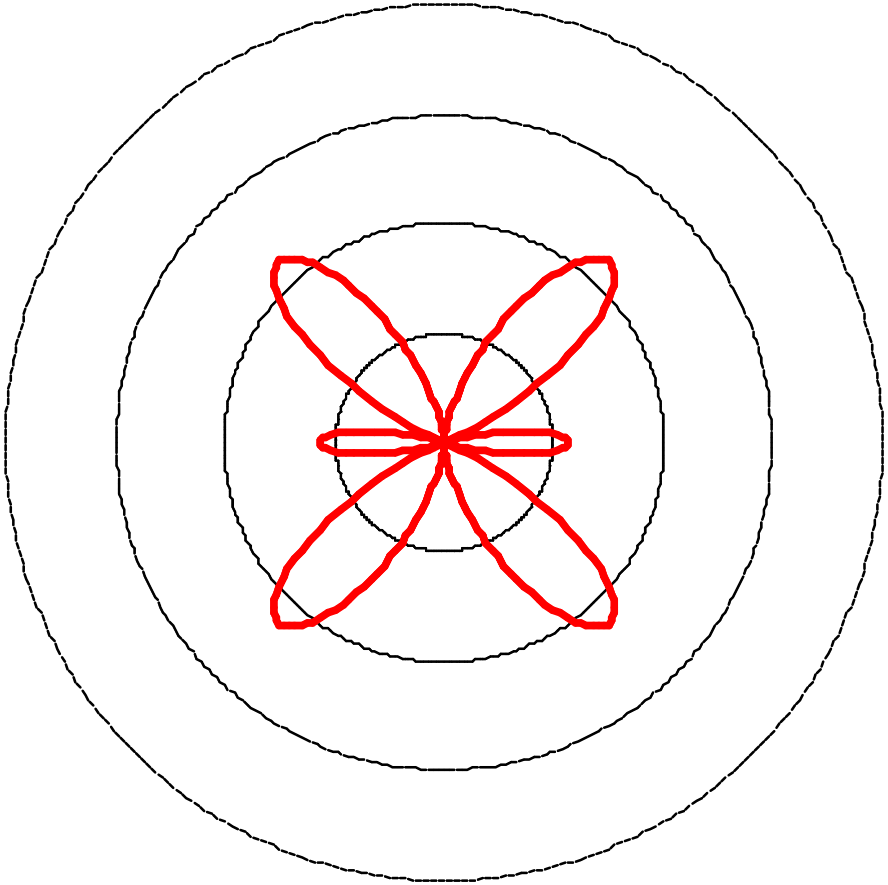
Gain Pattern of 1λ Dipole



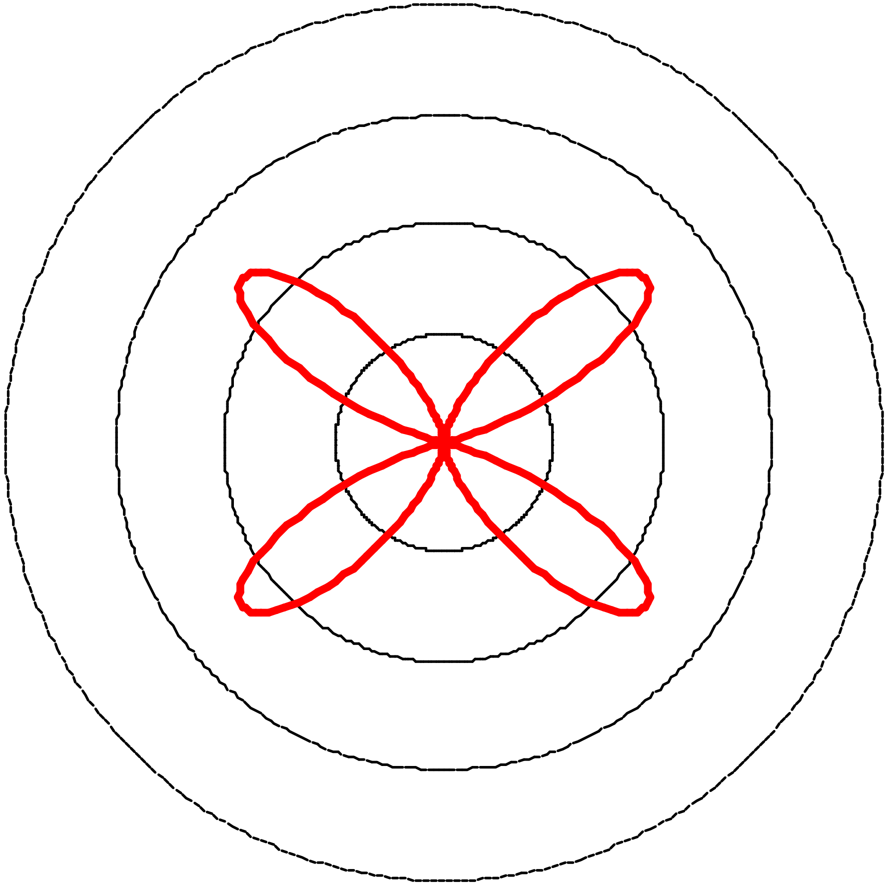
Gain Pattern of 1.25λ Dipole



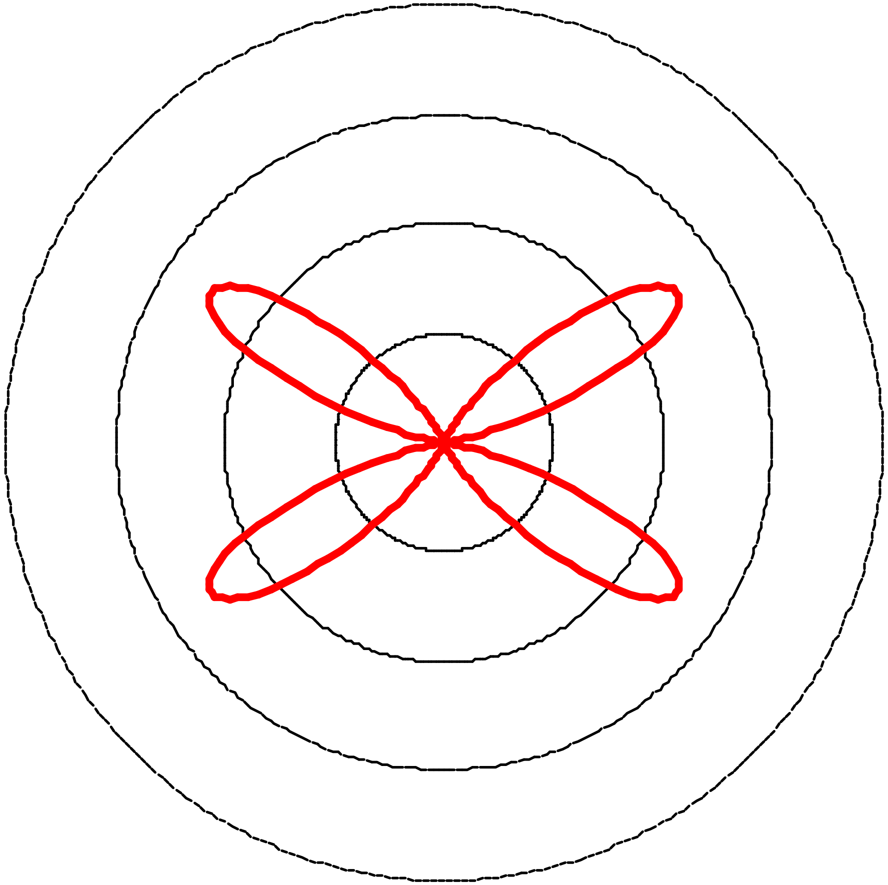
Gain Pattern of 1.5λ Dipole



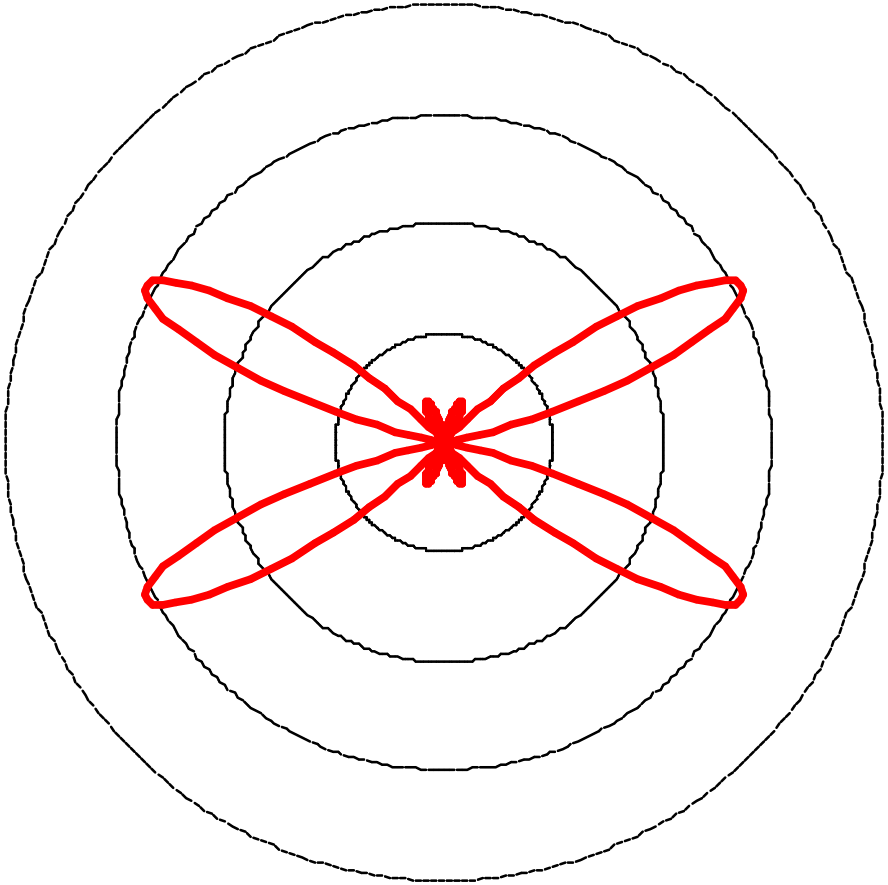
Gain Pattern of 1.75λ Dipole



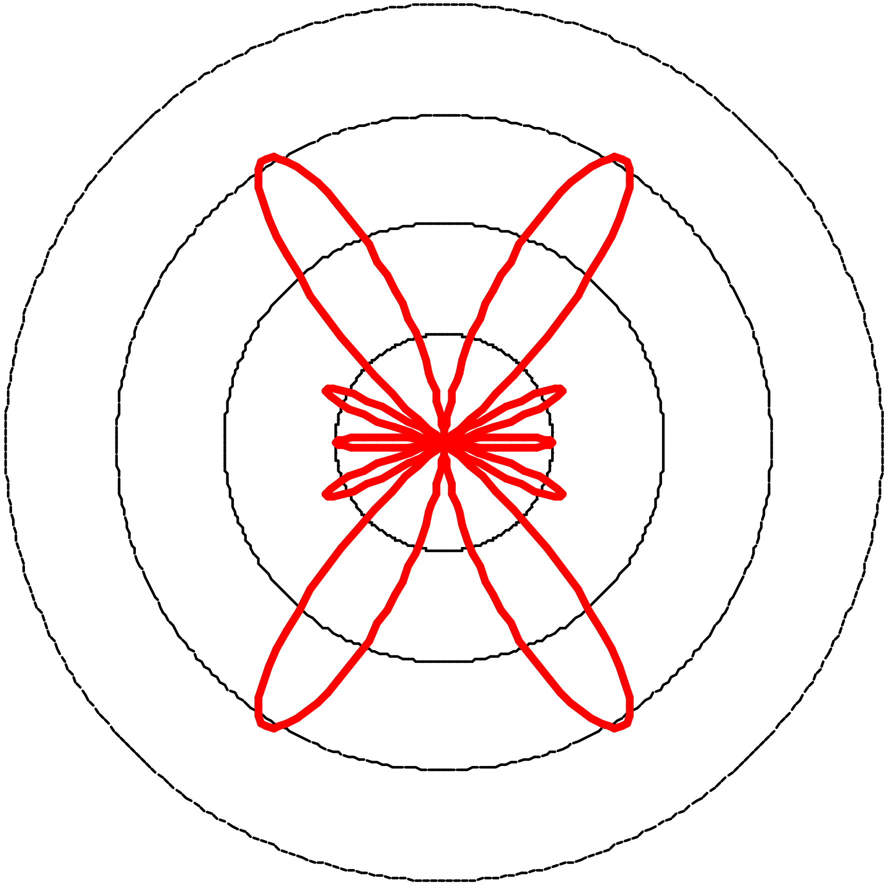
Gain Pattern of 2λ Dipole



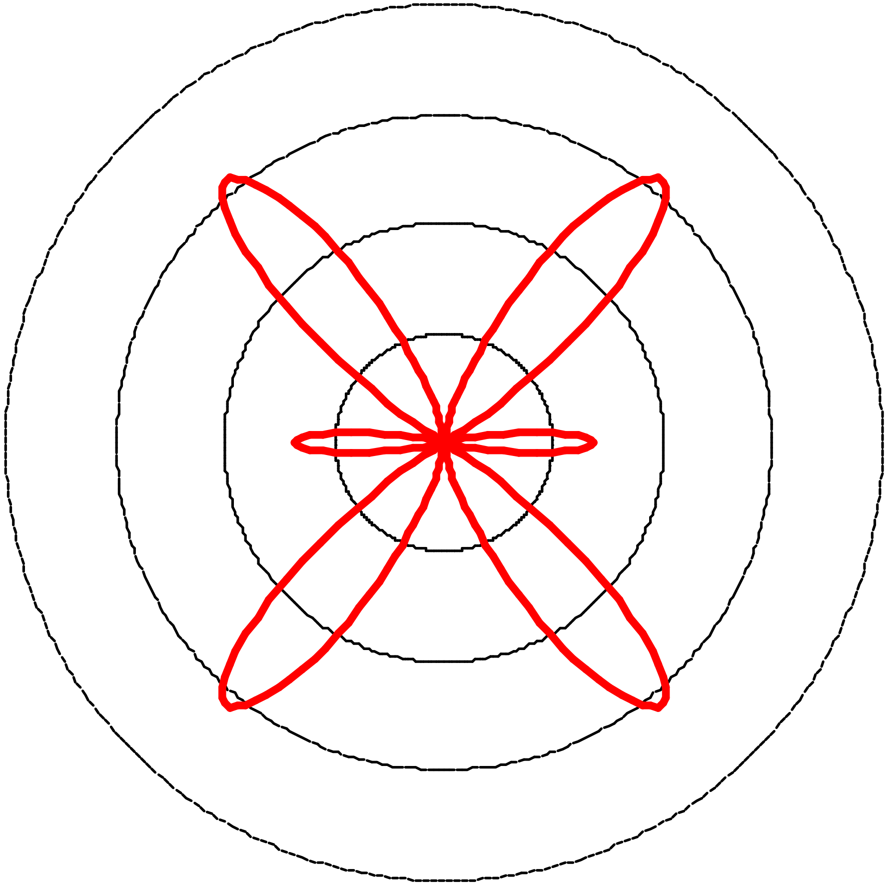
Gain Pattern of 2.25λ Dipole



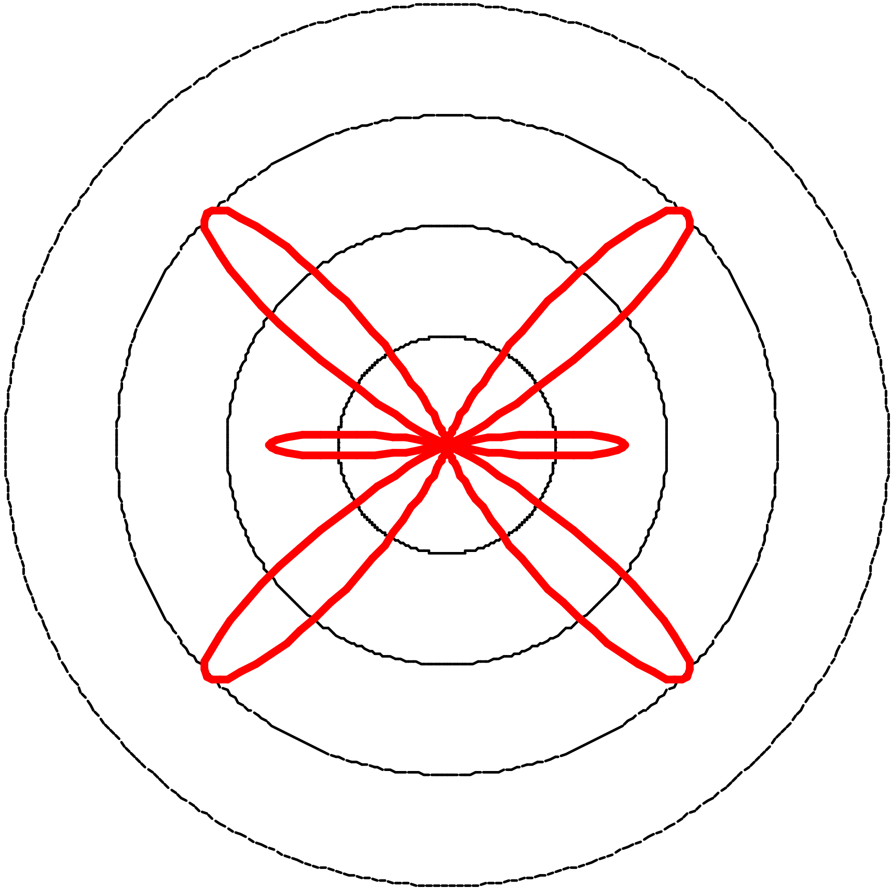
Gain Pattern of 2.5λ Dipole



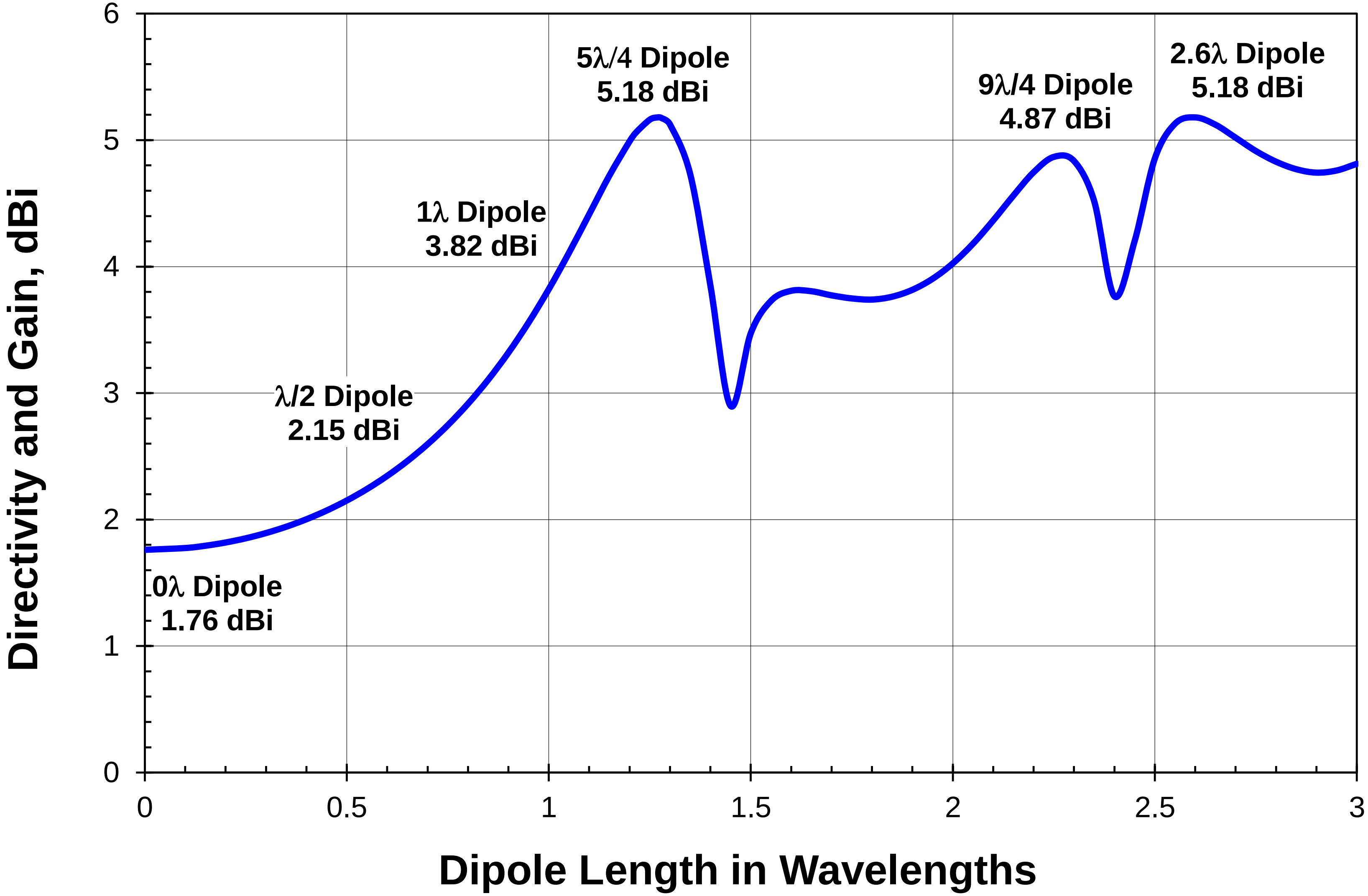
Gain Pattern of 2.75λ Dipole



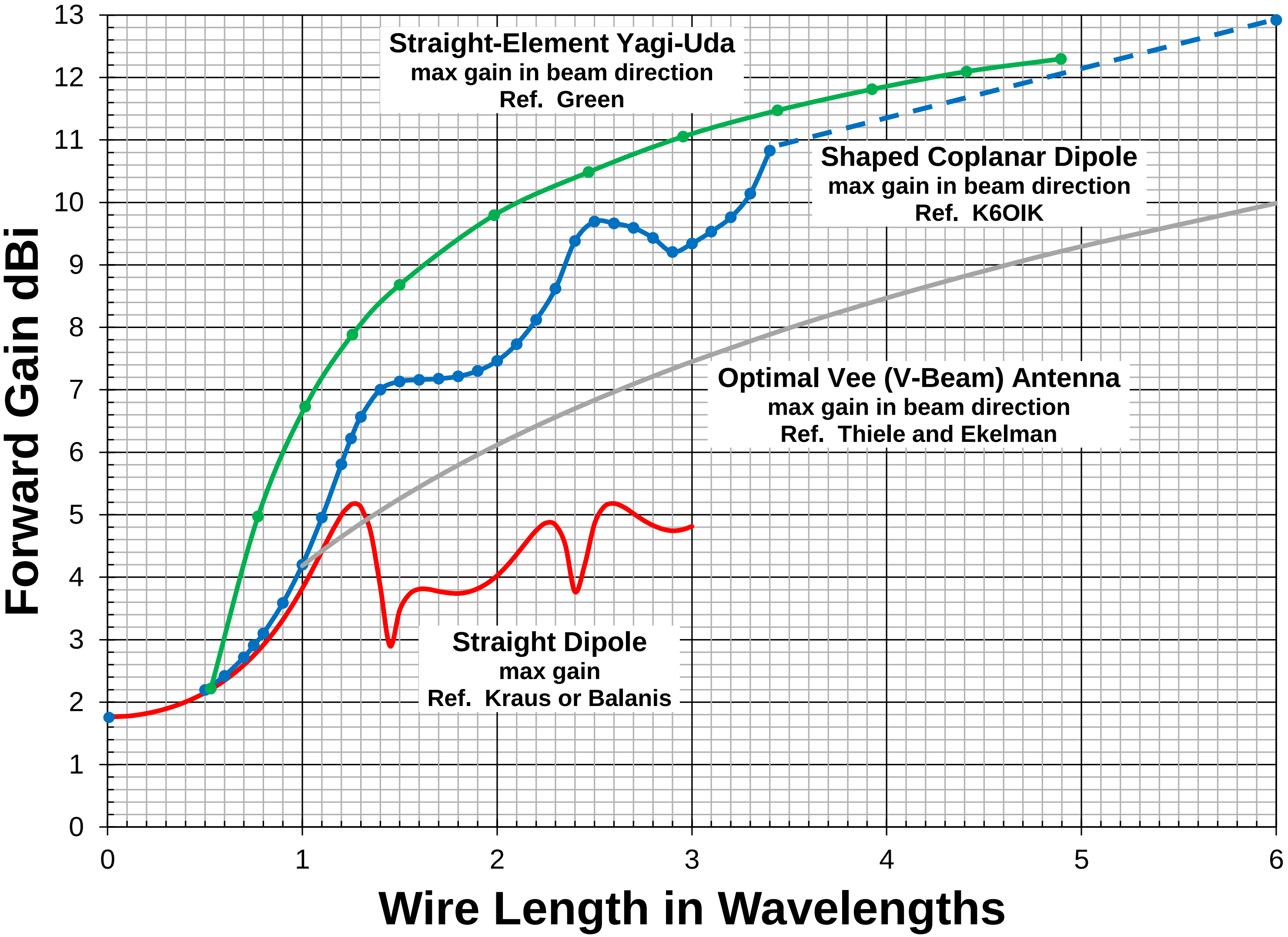
Gain Pattern of 3λ Dipole



Dipole Directivity and Gain versus Length



Gain Comparison by Antenna Type



Another Cat at Work

- **A dipole shrinks to nothing and disappears from view, yet positive gain remains**

Cheshire Cat Vanishing, by John Tenniel, 1865

- **In what is the cat sitting? A tree or maybe an antenna?**

Receiving

Friis Equation – Classical and Quantum Versions

- **Receive antenna power**

$$P_{Rx} = \frac{P_{Tx} G_{Tx} A_{Rx}}{4\pi d^2} \quad \text{watts}$$

- **Receive antenna photon capture rate**

$$R_{Rx} = \frac{P_{Tx} G_{Tx} A_{Rx}}{4hf\pi d^2} \quad \text{photons per second}$$

where

$$P_{Tx} = \text{Transmit power in watts}$$

$$G_{Tx} = \text{Gain of transmit antenna toward receive antenna}$$

$$A_{Rx} = \text{Capture area of receive antenna toward transmit antenna}$$

$$d = \text{Distance between antennas}$$

$$h = \text{Planck's constant}$$

Question

- If a dipole's size shrinks to zero, how can it capture any photons at all?
- Don't all the photons miss a target if it is infinitesimal?

Friis Equation – Alternate Versions

- Fundamental relation

$$A_{Rx} = \frac{\lambda^2}{4\pi} G_{Rx}$$

- Receive antenna power

$$P_{Rx} = P_{Tx} G_{Tx} G_{Rx} \left(\frac{\lambda}{4\pi d} \right)^2 \quad \text{watts}$$

- Receive antenna photon capture rate

$$R_{Rx} = P_{Tx} G_{Tx} G_{Rx} \frac{1}{hf} \left(\frac{c}{4\pi f d} \right)^2 \quad \text{photons per second}$$

- Since receive dipole gain is bounded away from zero, the photon capture rate becomes infinite as frequency decreases!

How Does a Receiving Antennas Receive?

- **When an antenna receives an incoming wave**
  - Incident wave excites currents in the antenna
  - The antenna creates “scattered” fields and radiates
  - Incident and scattered fields sum
  - Poynting vector changes direction

$$\mathbf{S} = \frac{1}{2}\left(\mathbf{E}_{incident} + \mathbf{E}_{scattered}\right) \times \left(\mathbf{H}^{*}_{incident} + \mathbf{H}^{*}_{scattered}\right)$$

  - Field energy and momentum follow the Poynting vector
- **Then magic happens**
  - The new Poynting vector goes to the antenna
  - The antenna absorbs energy from the incident wave field
- **Question: What do photons do?**
  - If photons only travel in straight lines, how do energy flux and momentum know to bend or curve through space?
  - The same question arises in other contexts such as OAM vortex beams
  - Is this nonlocality, entanglement, or what?

Classical physics permits us to calculate reception exactly.
Modern physics cannot even explain how photons travel.

Answer – Engineers Calculate, Physicists Pontificate

Professional discussion

Wave Interference

- Consider two plane waves of respective power densities 100 and 1 W/m² that are allowed to interact with each other
- One of the waves is only 1% in power density of the other
- The two waves interfere constructively or destructively
- The resulting variation in the power density received is not 101 or 99 W/m² but rather 122 or 82 W/m² – a 40% change, not 2%
- Reason: fields or voltages or currents add, not powers or field energy densities

$$\mathbf{S} = \underbrace{\frac{1}{2}\left(\mathbf{E}_{incident} \times \mathbf{H}^{*}_{incident}\right)}_{\text{100 W/m}^2} + \underbrace{\frac{1}{2}\left(\mathbf{E}_{scattered} \times \mathbf{H}^{*}_{scattered}\right)}_{\text{1 W/m}^2} + \underbrace{\frac{1}{2}\left(\mathbf{E}_{incident} \times \mathbf{H}^{*}_{scattered}\right) + \frac{1}{2}\left(\mathbf{E}_{scattered} \times \mathbf{H}^{*}_{incident}\right)}_{\text{Cross Terms}}$$

Classical field theory explains apparent nonlocality for which quantum physics offers no explanation.

Comments on Dipole Radiation Patterns

- **Transmitting**
  - A dipole’s gain depends on its length
  - In free space, a non-resonant 1.25λ dipole has the maximum possible directivity and gain among all single-lobed dipole radiation patterns
  - Directivity is 3.28 compared to 1.64 for a half-wavelength dipole
  - Gain is 5.16 dBi
  - As a dipole shrinks in size, its directivity does **NOT** go to zero
  - An infinitesimal dipole has directivity 1.5
  - A nonresonant lossless infinitesimal dipole has gain 1.76 dBi
  - This is the smallest gain that a lossless dipole can have
- **Receiving**
  - Effective area of a lossless dipole is

$$A = \frac{\lambda^2}{4\pi} G = \frac{c^2}{4\pi f^2} G$$

  - As a lossless dipole shrinks in length:
    - Gain *G* converges to 1.5
    - Effective area *A* converges to a positive number that depends on frequency
    - *Q* converges to infinity
    - Bandwidth converges to zero (in accordance with the Chu limit)

E. Socher, et al., “On the Relationship between the Physical Aperture and the Scattered Power from a Receiving Antenna,” *IEEE Int. Symp. Antennas and Propagation*, July 2014.

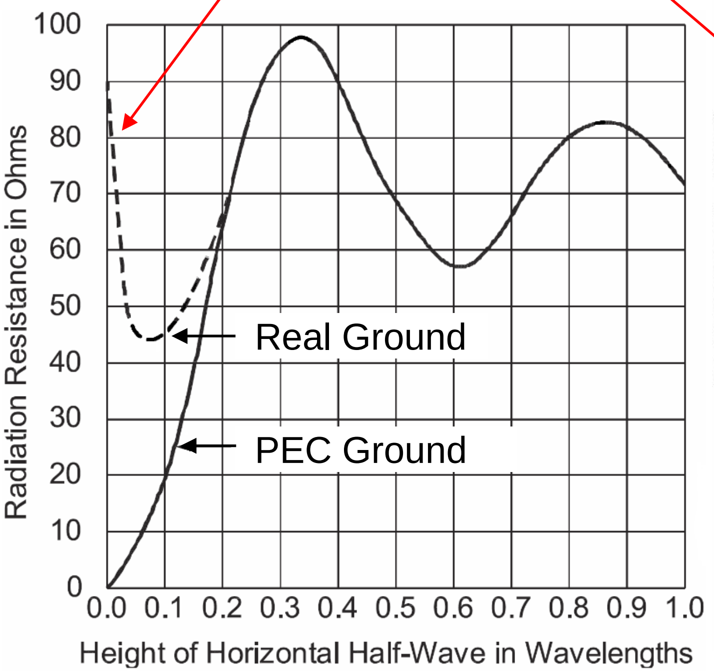
G and A do not converge to zero !

Effect of Ground

On impedance and pattern

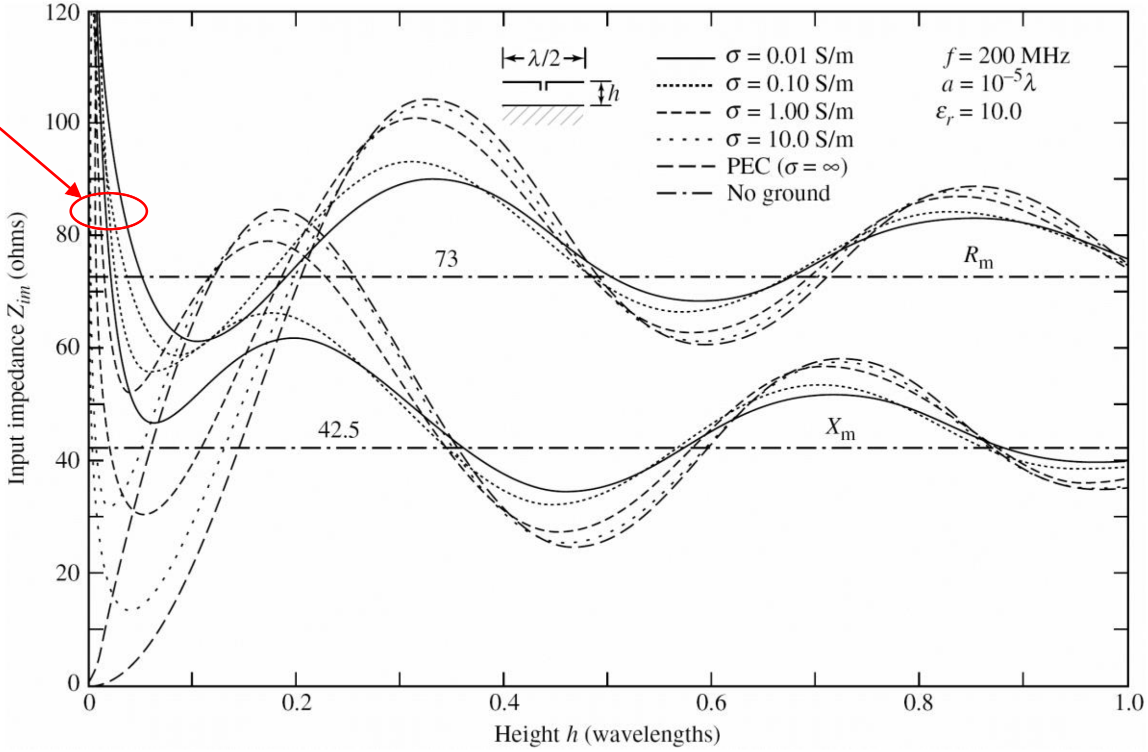
Impedance of Horizontal Halfwave Dipole over Ground

Absorption loss from
dipole proximity to ground



Real Ground

PEC Ground



C.A. Balanis, *Antenna Theory*, 4e, Fig. 2.13a, p. 45, Wiley, 2016

Field Patterns of Vertical Halfwave Dipoles over Ground

Frequency 15 MHz

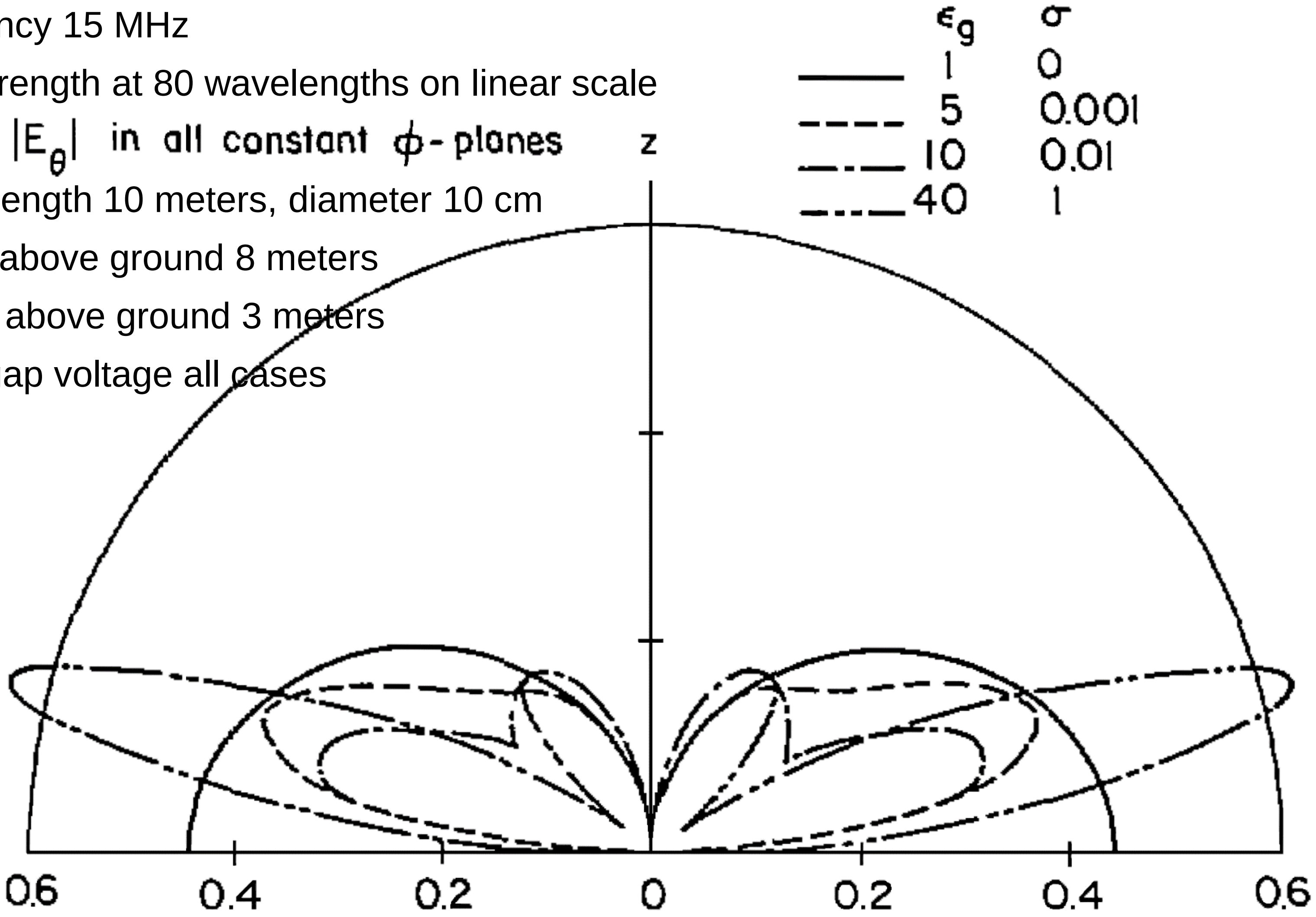
Field strength at 80 wavelengths on linear scale

Dipole length 10 meters, diameter 10 cm

Center above ground 8 meters

Bottom above ground 3 meters

Equal gap voltage all cases



P. Parhami and R. Mittra, “Wire Antennas over a Lossy Half-Space,” *IEEE Trans. Antennas and Propagation*, May 1980

Comments on Ground Effects

- **Only isolated dipoles in free space can be analyzed easily**
- **In real cases, an antenna’s pattern and/or impedance are affected by objects near the antenna**
  - Parasitic radiators
  - Random metal objects such as feed lines, guy wires, and fences
  - Complex dielectric objects such as insulation on wire or transmission lines, PVC pipe, houses, trees, people and animals
  - Ground and terrain
- **Use CEM (modeling) programs to investigate such effects**
  - Not all modeling programs are equal
  - Modern programs are more capable and accurate than older ones
    - Bigger models
    - More choices of materials and shapes
    - Compute more things (near fields and scattering analysis)
    - Faster computation
    - Better visualization of results (graphs and animations)

Conclusions

- **A simple dipole is a basic antenna whose understanding should be mastered before considering more complicated antennas**
- **Basic properties are impedance and radiation behavior**
- **Radiation is characterized by near-fields, far-fields, and pattern**
- **Receiving antenna analysis and link performance**
  - Directivity, gain, and effective area are used to calculate received power, signal-to-noise ratio, and link performance by the Friis equations
  - "Vector effective length" is used to calculate received voltage, response to polarization or OAM, and "array manifolds" of direction finding arrays
- **Practical effects are best found by antenna modeling programs**
  - How impedance depends on materials or presence of nearby objects
  - How 3D pattern depends on height above ground or terrain shape
  - Use modern software that's been validated for accuracy against known cases

Resources

References, Software, and Books

Off-Center-Fed and End-Fed Wire Antennas

- **Bert Henderson, W6MSD, “Build Your Own DIY Wire Antennas: End Fed, Off-Center-Fed, Baluns and Ununs”**
  https://wp-cdn.wvara.org/wordpress/wp-content/uploads/2024/12/04183717/Some-DIY-Antennas-Transformers-WVARA-Nov-2024-v2.pdf
- **Richard Hall, K7RLH, “A Slightly Off-Center-Fed Dipole”**
  https://fivecountyhre.org/a-slightly-off-center-fed-dipole
- **Serge Stroobandt, ON4AA, “Multiband HF Center-Loaded Off-Center-Fed Dipoles”**
  https://hamwaves.com/cl-ocfd/en/index.html
- **Steve Ellington, N4LQ,”End Fed Half Wave Antennas vs Random Length End Fed Antennas”**
  https://www.youtube.com/watch?v=xfqlun3bdI0
- **J.B. Still, NR5NN, “End Fed Wire Antennas”**
  https://www.youtube.com/watch?v=CWkuCvhW28w
- **T.W. Longfellow, N7TWL, “The End-Fed Half-Wave (EFHW) Dipole Wire Antenna”**
  https://n7tar.org/wp-content/uploads/2023/06/The-End-Fed-Half-Wave-Antenna.pdf

Baluns, Ununs, and Transformers

- **Discussion of transformer loss**
  https://www.eham.net/community/smf/index.php/topic,141970.msg1331361.html#msg1331361
- **Colin Summers, MM0OPX, "Can The Best 100w End Fed Half Wave Get Any Better?" (reports cylindrical 43 cores are more efficient)**
  https://www.youtube.com/watch?v=8SHvOE8dV3w
- **John Oppenheimer, KN5L, "KN5L EFHW Unun" (a 49:1 Unun without capacitor)**
  https://www.kn5l.net/kn5lEfhwUnun
- **Ian Miles, G0CNN, "A Better Off-Centre Fed Dipole – Part 1" (4:1 transformer and 1:1 choke / balun)**
  https://www.youtube.com/watch?v=aYLseBPbxng
- **Balun Designs 4116, 4:1 hybrid balun, 1.5 to 54 MHz, 3 kW**
  https://www.balundesigns.com/model-4116-4-1-hybrid-balun-1-5-54mhz-3kw
- **Peter Miles, VK6YSF, "HF Feed-Line Interface Choke and 1:4 Balun"**
  https://vk6ysf.com/hf_feed_balun_choke.htm
- **Steve Hunt, G3TXQ, tutorial on balun types**
  http://www.karinya.net/g3txq/baluns/baluns.pdf
- **Steve Hunt, G3TXQ, "High Performance Common Mode Chokes,"** ***RadCom Plus*****, May 2015**
  https://gm3sek.com/wp-content/uploads/2019/01/G3TXQ-RC.pdf
- **Tom Rauch, W8JI, "4:1 Balun Design and Operation"**
  https://www.w8ji.com/balun_single_core_41_analysis.htm
- **Pulse Electronics, "Introduction to Transformer Magnetics"**
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- **Jerry Sevick, W2FMI, articles**
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  https://www.highfrequencyelectronics.com/Jan10/HFE0110_DesignNotes.pdf
- **Chris Trask, N7ZWY, articles**
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  https://www.highfrequencyelectronics.com/Jan06/HFE0106_TraskPart2.pdf
- **U. Sengal and W. Yu, "Demystifying Transformers: Baluns and Ununs," Mini-Circuits, July 2020**
  https://blog.minicircuits.com/demystifying-transformers-baluns-and-ununs
- **Marki Microwave, "Current versus Voltage Baluns," Oct. 2014**
  https://markimicrowave.com/technical-resources/application-notes/current-vs-voltage-baluns
- **Roy Lewallen, W7EL, "Baluns: What They Do and How They Do It,"** ***ARRL Antenna Compendium*** **Vol. 1, 1985**
  https://www.eznec.com/Amateur/Articles/Baluns.pdf

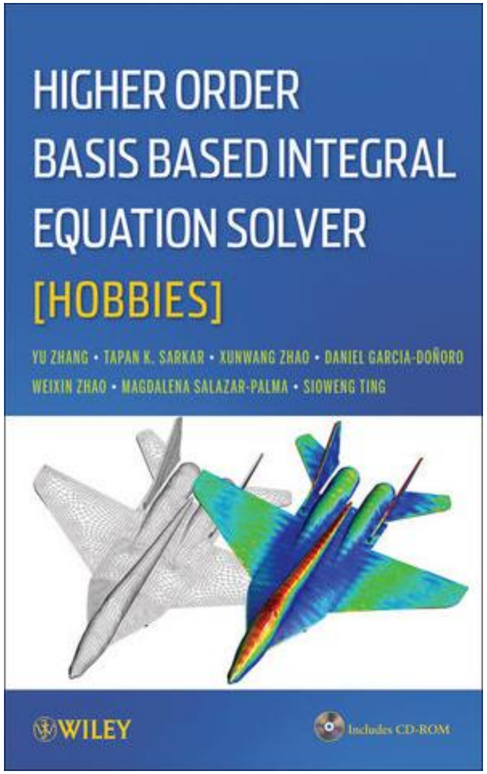
Free or Low Cost Antenna Modeling Software Links at https://www.fars.k6ya.org/others

- **Thin Wire MoM Codes**
  - ANSim – by Mark Tilson, Multiradius Bridge Current method is more accurate than NEC-4
  - AN-SOF – by Tony Golden, similar accuracy to NEC-5, uses exact kernel and integral equation
  - NEC-5 (2019) – Improved accuracy, replaced kernels with exact kernel and integral equation, fewer artifacts, improved numerical stability, less strict geometry rules, similar accuracy to AN-SOF
  - NEC-4 (1992) – Improved accuracy for stepped-radius wires and electrically-small segments, end caps and insulated wires, catenary-shaped wires, improved error detection
  - NEC-2 (1981) – Sommerfield-Norton ground interaction for wire structures above lossy ground; numerical Green's function allows modifying without repeating whole calculation
  - MiniNEC (1980) – by Jay Rockway and Jim Logan, N6BRF, different algorithms from NEC, used inside MMANA-GAL
  - AWAS 2.0 (2001) – by Tony Djordjević, predecessor thin-wire formulation to that in WIPL-D and HOBBIES, has exact kernel, higher-order polynomial basis functions, minimal geometry restrictions, high numerical efficiency
- **User Interface Programs**
  - AutoEZ – by Dan Maguire, AC6LA. GUI for EZNEC that adds useful features
  - EZNEC Pro+ v7.0 – by Roy Lewallen, W7EL. Free GUI for NEC-2, NEC-4, and NEC-5
  - 4nec2 – by Arie Voors. Free GUI for NEC-2 and NEC-4
  - MMANA-GAL – GUI for MiniNEC (popular in the UK)
- **Yagi Design**
  - QY4 (Quick Yagi) – by Sidney Smith, WA7RAI, a calculator for Yagi-Uda design
  - Yagi Calculator – by John Drew, VK5DJ, a calculator for DL6WU VHF/UHF Yagi-Uda design
  - YagiCAD – by Paul McMahon, VK3DIP, a calculator for VHF/UHF Yagi-Uda design
  - YO (Yagi Optimizer) – by Brian Beezley, K6STI, a MiniNEC based DOS program for Yagi-Uda antenna design, v6.5.1 archived by IW5EDI
  - YW 2.0 (Yagi for Windows) – by Dean Straw, N6BV, for monoband Yagi-Uda design, included with the *ARRL Antenna Book*
- **Surface MoM Code**
  - HOBBIES (2010) – Similar to WIPL-D except has out-of-core solver. Development was led by T.K. Sarkar, Syracuse University, based on algorithms developed at University of Belgrade. No longer supported. Software licenses no longer available.
- **Finite Difference Time Domain (FDTD) Codes**
  - GprMax
  - Meep
  - OpenEMS

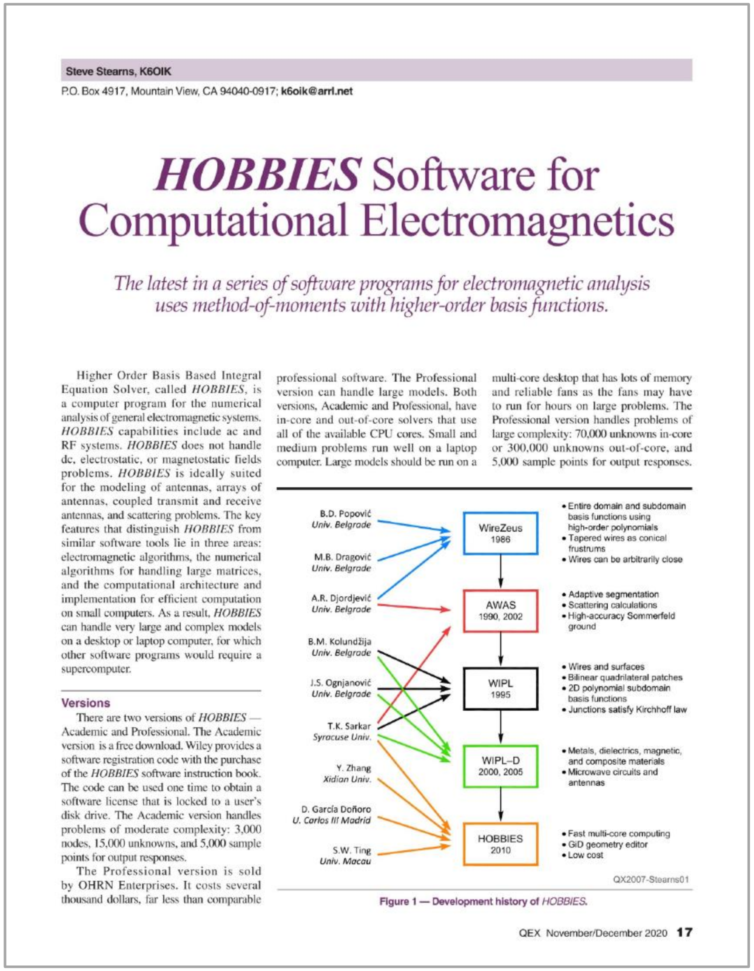
Accessory Software

- **AutoEZ by Dan Maguire, AC6LA, https://www.ac6la.com**
  - Recommended accessory software for EZNEC
  - Excel/Visual Basic program
    - Free demo version (30 segment limit)
    - Regular version, $79
  - Requires Excel and EZNEC installed on computer
  - Controls EZNEC to make multiple runs
    - It’s a GUI for a GUI for NEC
  - Optimizer – Nelder-Mead algorithm
  - Reads NEC, AO, and MMANA-GAL files
- OPTENNI **https://optenni.com**
  - Automated match network synthesis. Free trial on request
- **Ampsa Impedance Matching Wizard https://www.ampsa.com/c/imw-technical-overview**
  - Automated match network synthesis. Free trial on request

HOBBIES – No Longer Supported



Y. Zhang, et al., *Higher Order Basis Based Integral Equation Solver*, Wiley, 2012



Steve Stearns, K6OIK
P.O. Box 4917, Mountain View, CA 94040-0917; **k6oik@arrl.net**

HOBBIES Software for Computational Electromagnetics

The latest in a series of software programs for electromagnetic analysis uses method-of-moments with higher-order basis functions.

Higher Order Basis Based Integral Equation Solver, called *HOBBIES*, is a computer program for the numerical analysis of general electromagnetic systems. *HOBBIES* capabilities include ac and RF systems. *HOBBIES* does not handle dc, electrostatic, or magnetostatic fields problems. *HOBBIES* is ideally suited for the modeling of antennas, arrays of antennas, coupled transmit and receive antennas, and scattering problems. The key features that distinguish *HOBBIES* from similar software tools lie in three areas: electromagnetic algorithms, the numerical algorithms for handling large matrices, and the computational architecture and implementation for efficient computation on small computers. As a result, *HOBBIES* can handle very large and complex models on a desktop or laptop computer, for which other software programs would require a supercomputer.

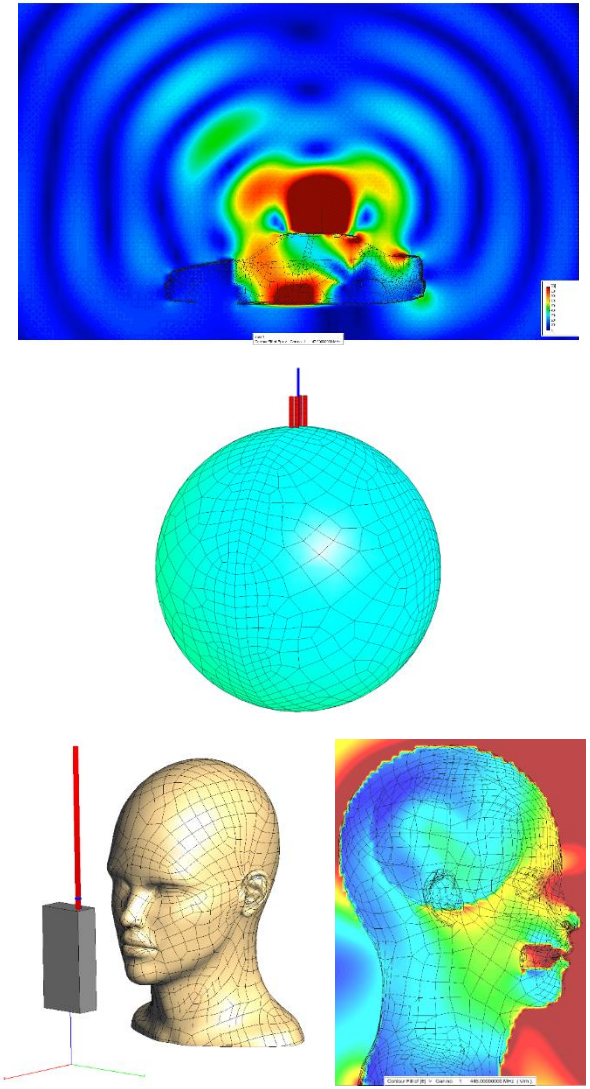
Versions

There are two versions of *HOBBIES* — Academic and Professional. The Academic version is a free download. Wiley provides a software registration code with the purchase of the *HOBBIES* software instruction book. The code can be used one time to obtain a software license that is locked to a user's disk drive. The Academic version handles problems of moderate complexity: 3,000 nodes, 15,000 unknowns, and 5,000 sample points for output responses.

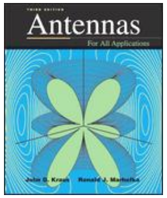
The Professional version is sold by OHRN Enterprises. It costs several thousand dollars, far less than comparable professional software. The Professional version can handle large models. Both versions, Academic and Professional, have in-core and out-of-core solvers that use all of the available CPU cores. Small and medium problems run well on a laptop computer. Large models should be run on a multi-core desktop that has lots of memory and reliable fans as the fans may have to run for hours on large problems. The Professional version handles problems of large complexity: 70,000 unknowns in-core or 300,000 unknowns out-of-core, and 5,000 sample points for output responses.

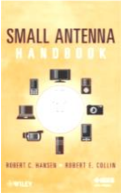
Figure 1 — Development history of *HOBBIES*.

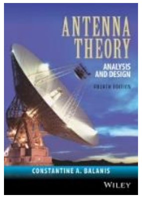
QEX November/December 2020 **17**



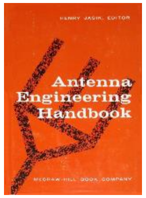
Good Antenna Books



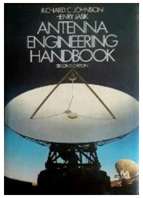




- **Books for antenna engineers and students**
  - C.A. Balanis, *Antenna Theory: Analysis and Design*, 4e, Wiley, 2016
  - R.C. Hansen and R.E. Collin, *Small Antenna Handbook*, Wiley, 2011
  - J.D. Kraus and R.J. Marhefka, *Antennas*, 3e, McGraw-Hill, 2001
- **Antenna research papers**
  - IEEE Xplore subscription online archive, https://ieeexplore.ieee.org/Xplore/home.jsp
  - Allerton Antenna Applications Symposium DVD archive 1952-2018
  - ACES Journal Archives http://www.aces-society.org/journal.php
  - Progress in Electromagnetics Research https://www.jpier.org
- **Antenna Engineering Handbooks – 5 editions**

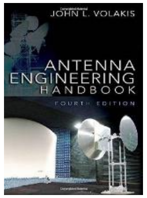


1961

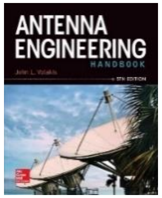


1984

1993

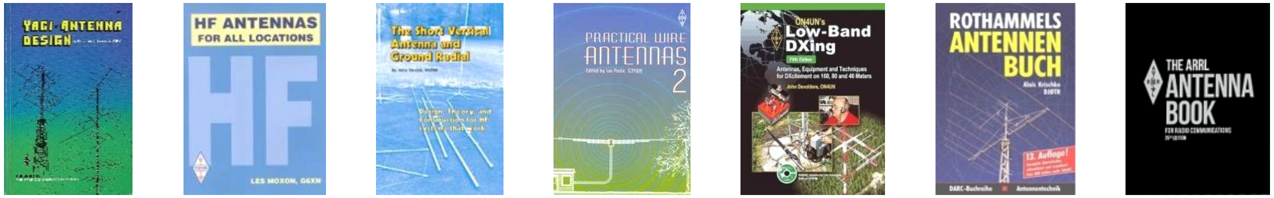


2007

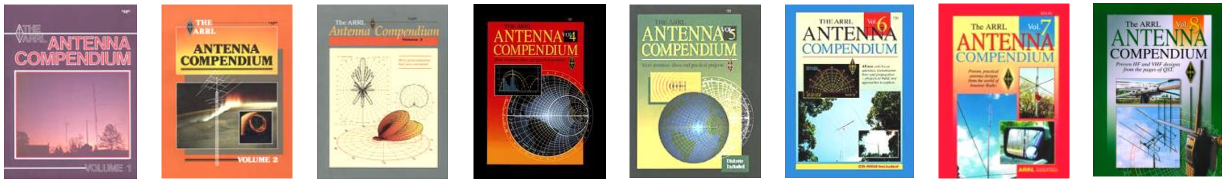


2019

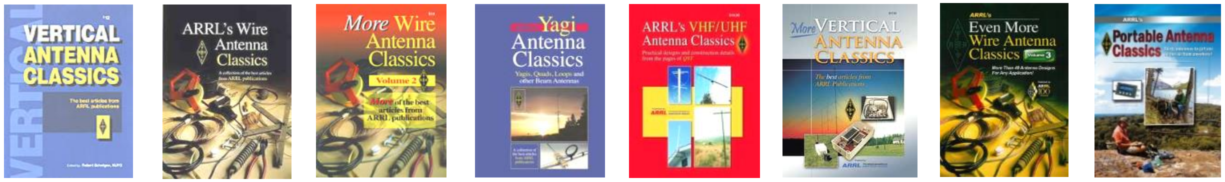
Good Antenna Books continued



- **Books for Radio Amateurs**
  - H.W. Silver, N0AX, ed., *ARRL Antenna Book*, 25e, ARRL, 2023
  - A. Krischke, DJ0TR, ed., *Rothammel's Antenna Book*, 13e, English, DARC, 2019
  - J. Devoldere, ON4UN, *ON4UN's Low-Band Dxing*, 5e, ARRL, 2011
  - I. Poole, G3YWX, ed., *Practical Wire Antennas 2*, RSGB, 2005
  - J. Sevick, W2FMI, *The Short Vertical Antenna and Ground Radial*, CQ, 2003
  - L. Moxon, G6XN, *HF Antennas for All Locations*, 2e, RSGB, 1983
  - J.L. Lawson, W2PV, *Yagi Antenna Design*, ARRL, 1986
- **ARRL Antenna Compendium series – eight volumes**

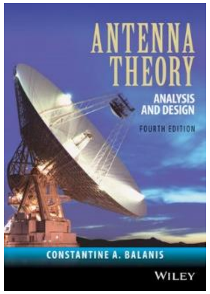


- **ARRL Antenna Classics series – eight titles**



Recent Antenna Books of Interest

B.M. Kolundžija and A.R. Djordjević, *Electromagnetic Modeling*, Artech, 2002



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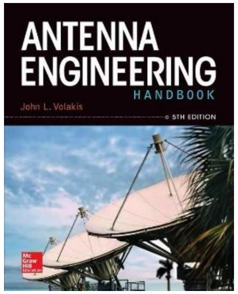

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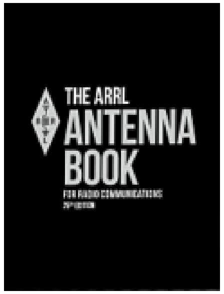
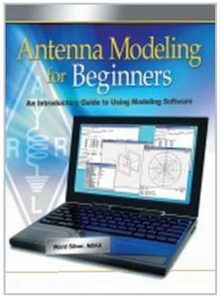


H.W. Silver, N0AX, ed., *ARRL Antenna Book*, 25e, ARRL, 2023



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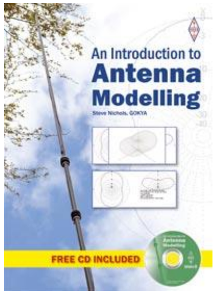
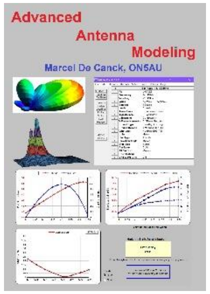


S. Nichols G0KYA, An *Introduction to Antenna Modelling*, RSGB, 2014



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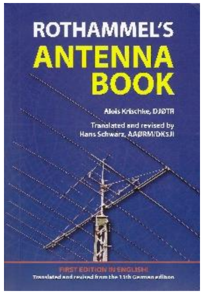
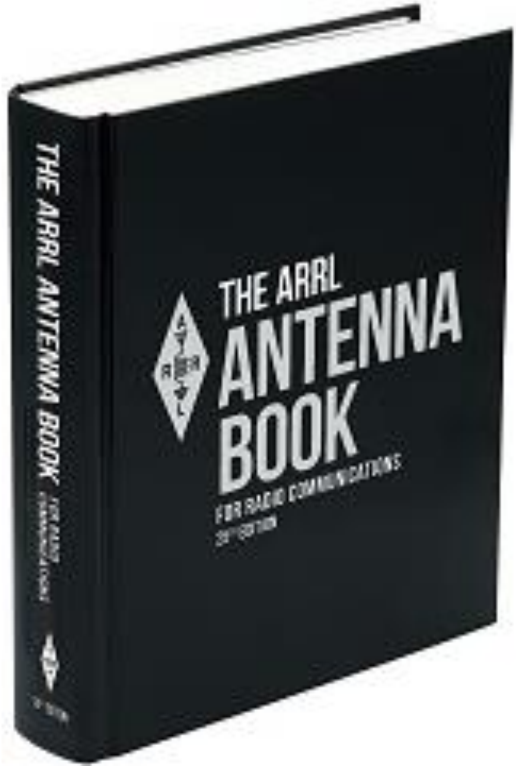


A. Krischke, DJ0TR, ed., *Rothammel's Antenna Book*, English transl., 13e, DARC, 2019

The ARRL Antenna Book, 25th Edition

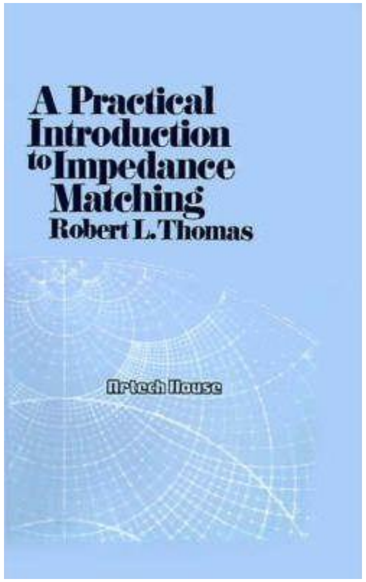


H. Ward Silver, N0AX, ed.

***ARRL Antenna Book*, 25th Edition**

ARRL, 2023

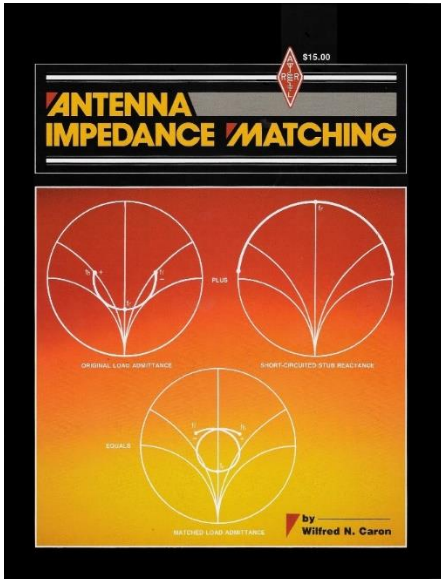
Impedance Matching for Beginner and Professional



A Practical Introduction to Impedance Matching
Robert L. Thomas

Artech House

R.L. Thomas, *A Practical Introduction to Impedance Matching*, Artech House, 1976

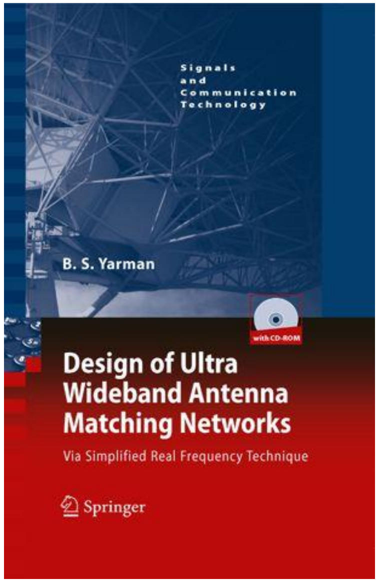


$15.00

ANTENNA IMPEDANCE MATCHING

by Wilfred N. Caron

Wilfred N. Caron, *Antenna Impedance Matching*, ARRL, 1989



Signals and Communication Technology

B. S. Yarman

with CD-ROM

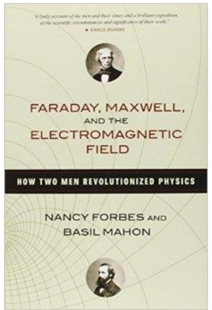
Design of Ultra Wideband Antenna Matching Networks

Via Simplified Real Frequency Technique

Springer

B.S. Yarman, *Design of Ultra Wideband Antenna Matching Networks*, Springer, 2008

General Interest Books



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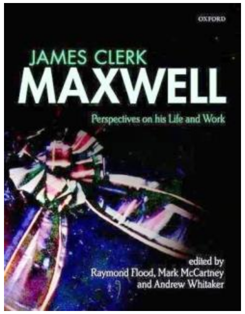

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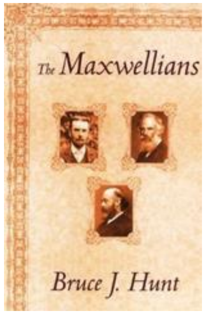

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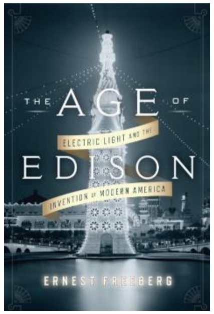

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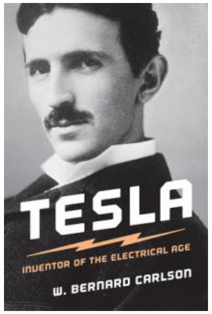

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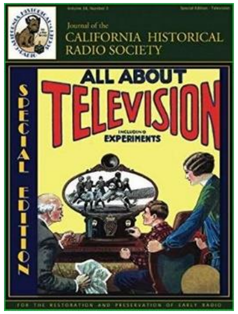

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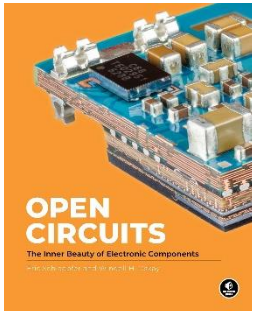

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