RF (Radio Frequency): Antenna design & simulation

By

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Astronomical Techniques

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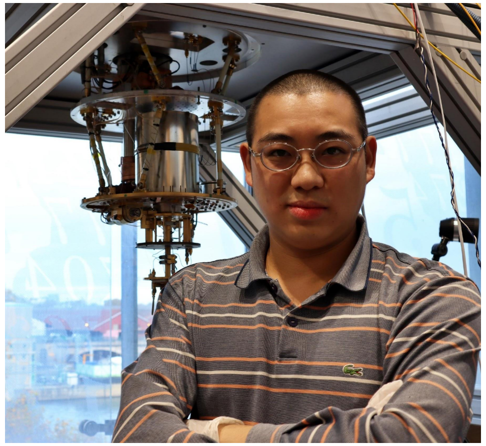
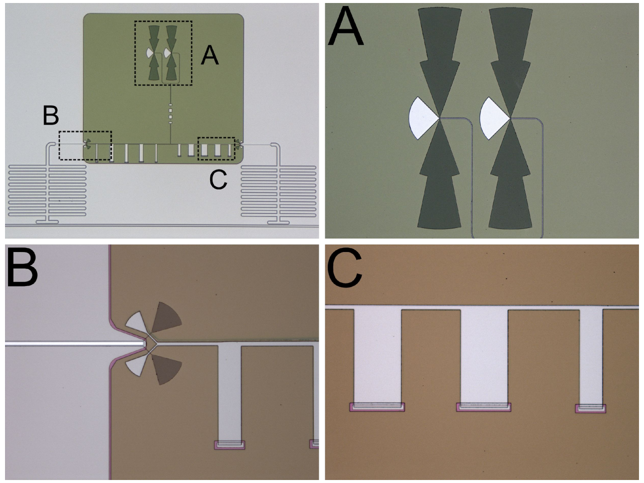
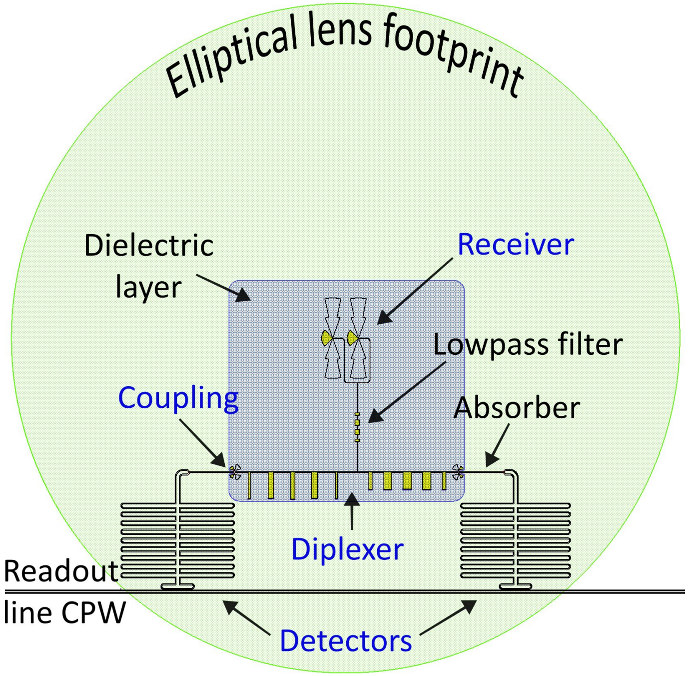
About me

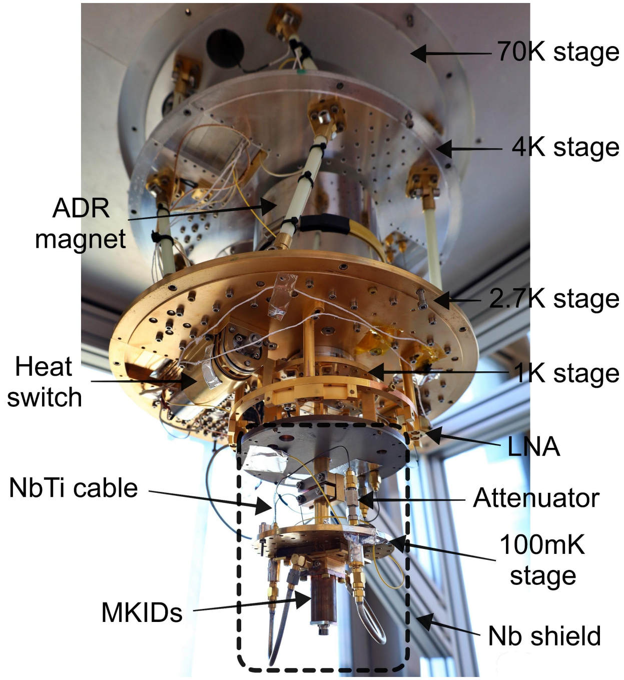
Ph.D. in Physics 2021 – 2024
Université Paris Cité – Doctoral School STEP'UP (ED560) Laboratoire AstroParticule et Cosmologie (APC) | Paris, France
•Major: Physics of the Universe
Master of Science 2017 – 2019
Université Paris Cité (UPC) & University of Science and Technology of Hanoi (USTH) | Hanoi, Vietnam
•Major: Satellite Technology
Bachelor of Science 2014 – 2017
University of Science and Technology of Hanoi (USTH) | Hanoi, Vietnam
•Major: Space and Applications



Pham Viet Dung at APC
sites.google.com/view/vdportfolio

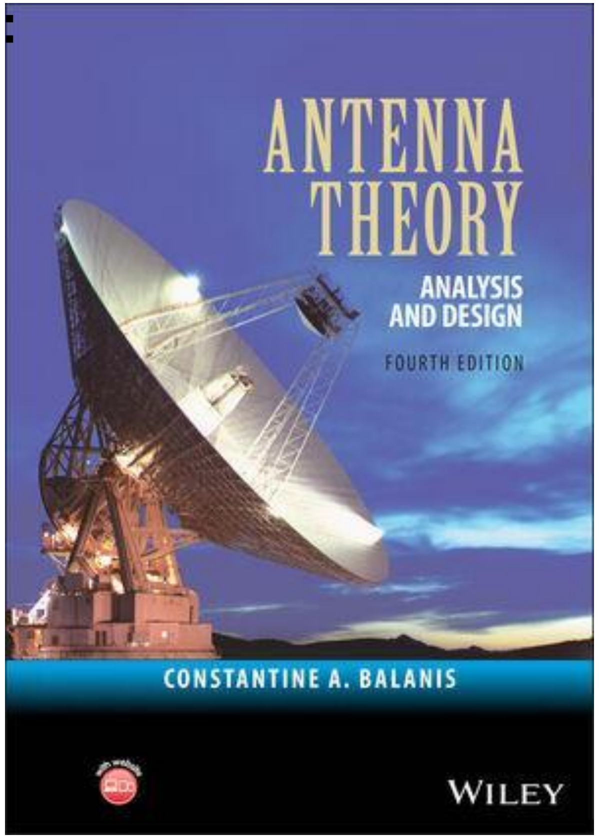


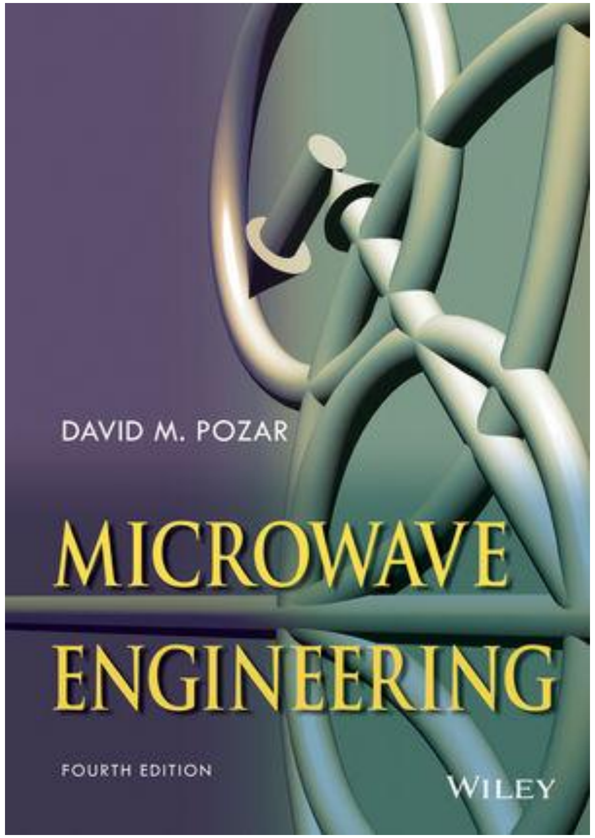




Learning materials

Textbooks





Learn computational electromagnetics (CEM):
https://empossible.net/
https://www.youtube.com/@empossible1577

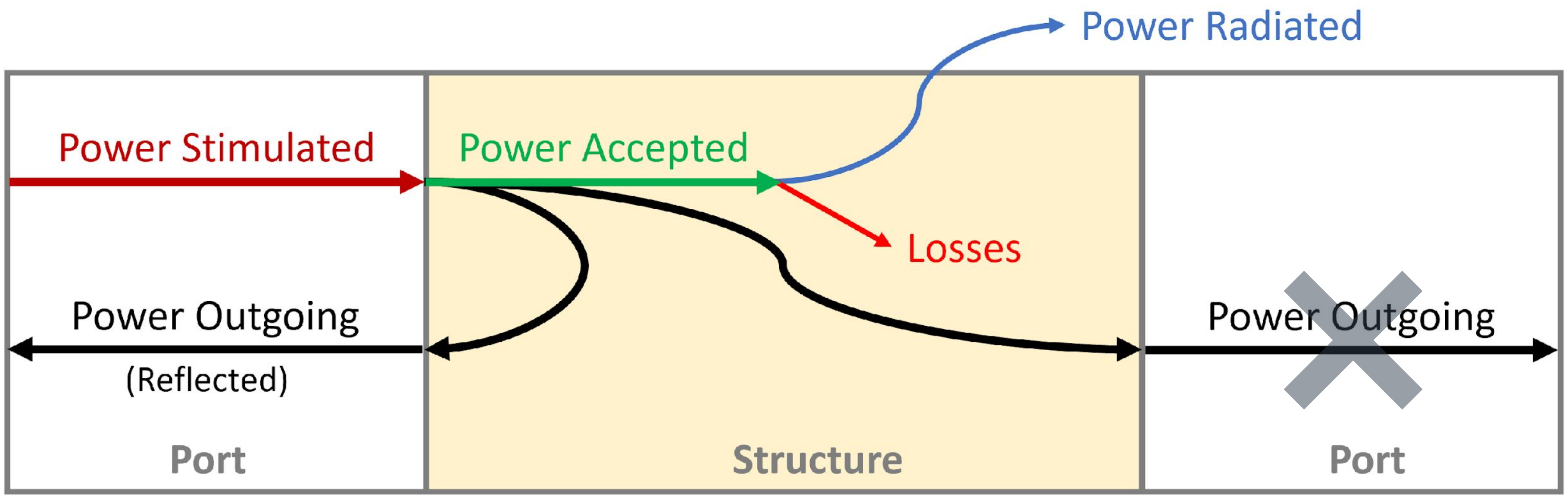
EMPossible

The Antenna Theory Website:
https://www.antenna-theory.com/

Antenna basic: VSWR, |S11|, Return Loss

Source: https://www.youtube.com/watch?v=jgjaFzsYd88

Antenna basic: VSWR, |S11|, Return Loss



Power Stimulated = Power Accepted + Power Outgoing (all Ports)

In antenna case:

Power accepted = Power stimulated (input power) – Power reflected (S11)

Return loss = loss in the return path → More loss means more power accepted by the antenna

Reflection Coefficient: $\text{Return loss (dB)} = -S_{11}(\text{dB})$

Design goal: S_{11} < -10 dB: less than 10% power reflected → > 90% of power accepted (~radiated).

Antenna design

$$\begin{aligned} \nabla \cdot \mathbf{D} &= \rho \\ \nabla \cdot \mathbf{B} &= 0 \\ \nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\ \nabla \times \mathbf{H} &= \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \end{aligned}$$

- Antenna design fundamentally involves solving Maxwell's equations, which govern electromagnetic behavior at the macroscopic level.
- Fortunately, we have powerful simulation tools like HFSS, CST, and FEKO that help engineers model and analyze antenna performance efficiently.
- However, these tools often come at a high cost — for example, a single HFSS license can cost several thousand dollars, making them less accessible for individuals or small teams.

Ansys
HFSS

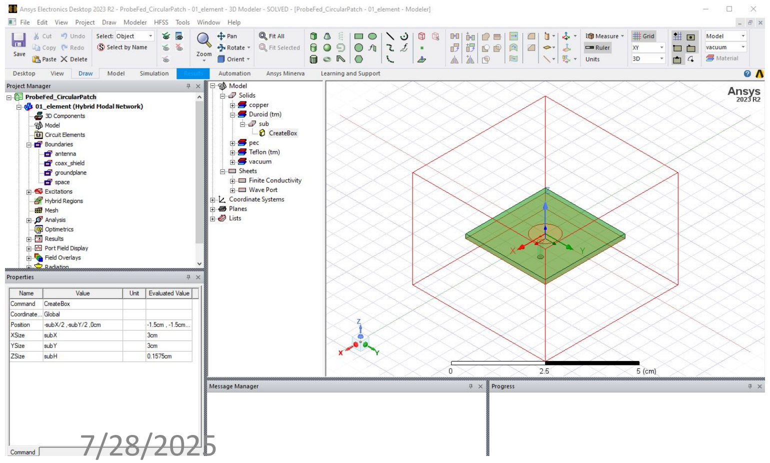
SIMULIA
CST STUDIO SUITE

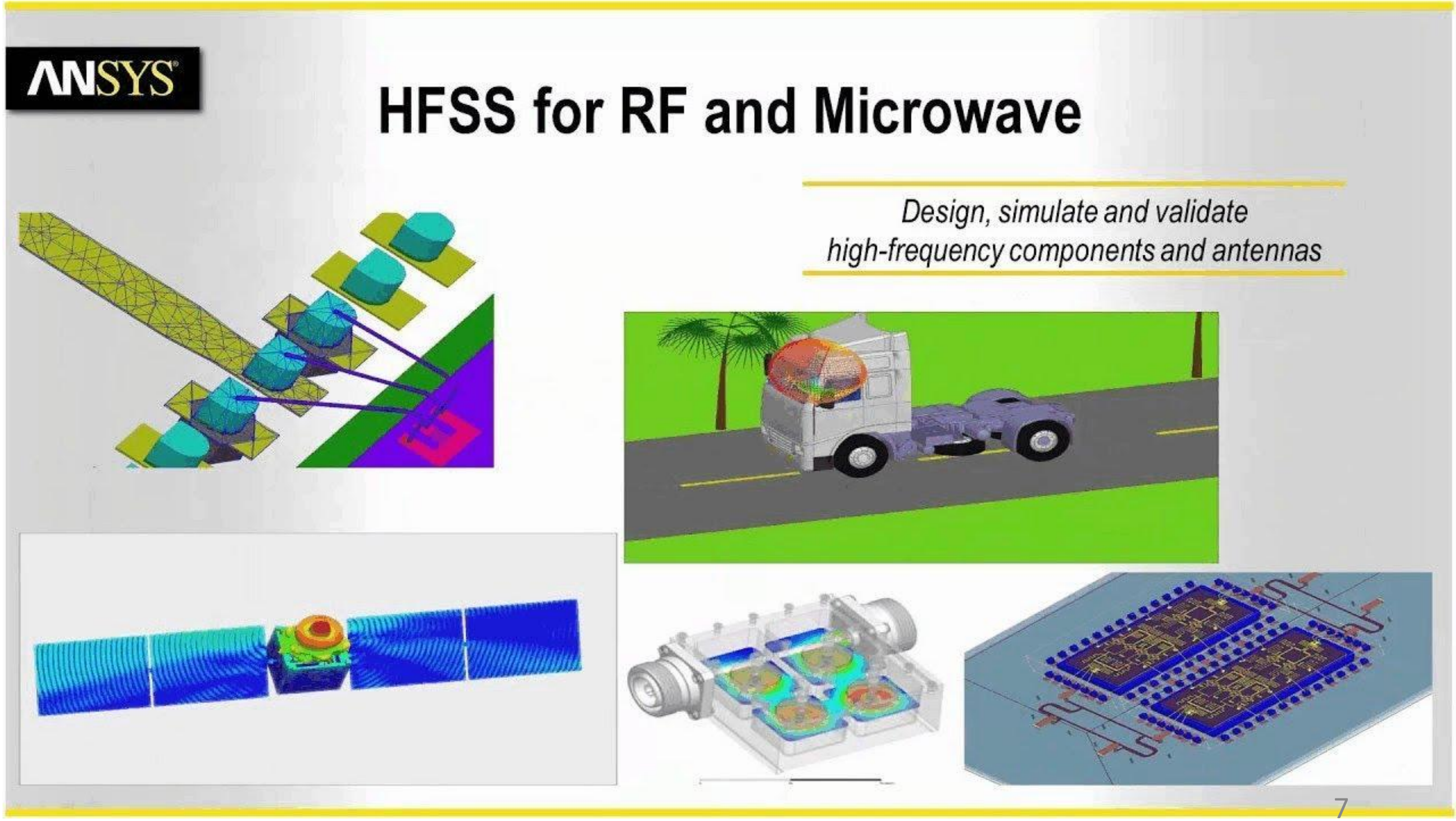
XFdtd

Altair FEKO
Comprehensive Electromagnetic Solutions

Software Tools

- **Ansys HFSS (High Frequency Structure Simulator):** Widely regarded as an industry standard, HFSS is a 3D EM simulation software that primarily uses the Finite Element Method (FEM). It's excellent for detailed analysis of complex antenna structures, including antenna arrays, RF/microwave components, and their interaction with surrounding environments. It also incorporates other solvers like SBR+ (Shooting and Bouncing Ray) for large-scale platforms and IE (Integral Equations).





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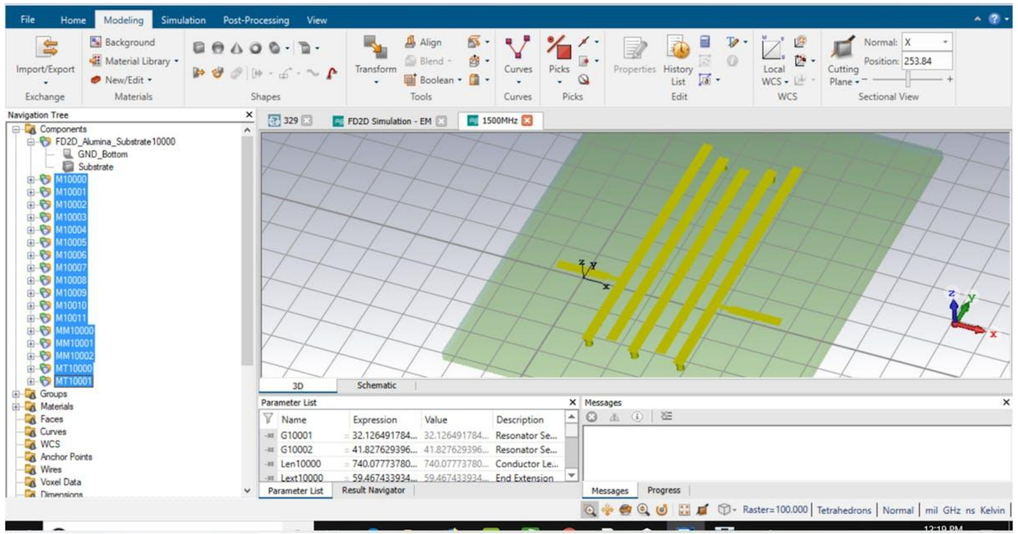
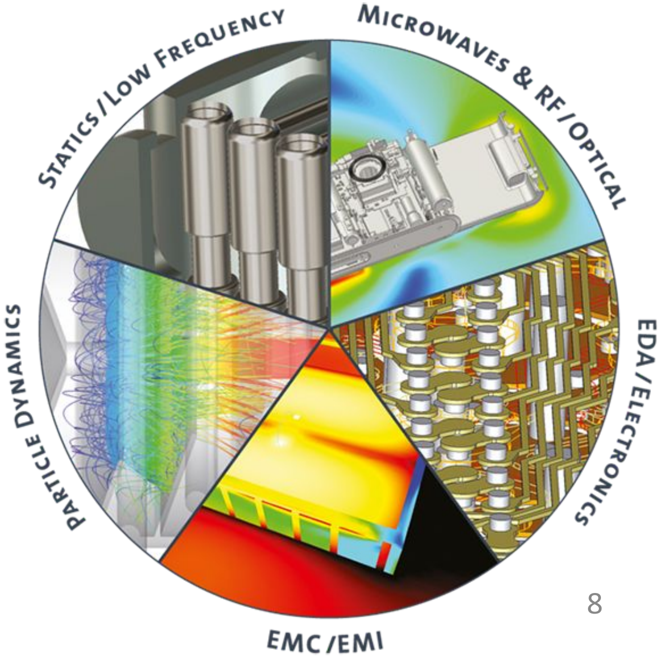
- **Dassault Systèmes CST Studio Suite (Computer Simulation Technology):** Another leading commercial EM simulation package, CST Studio Suite offers a comprehensive set of solvers, including Finite Difference Time Domain (FDTD), Finite Element Method (FEM), and Method of Moments (MoM). It's highly versatile and used for a wide range of applications, from individual antenna elements to complex systems and antenna placement studies.





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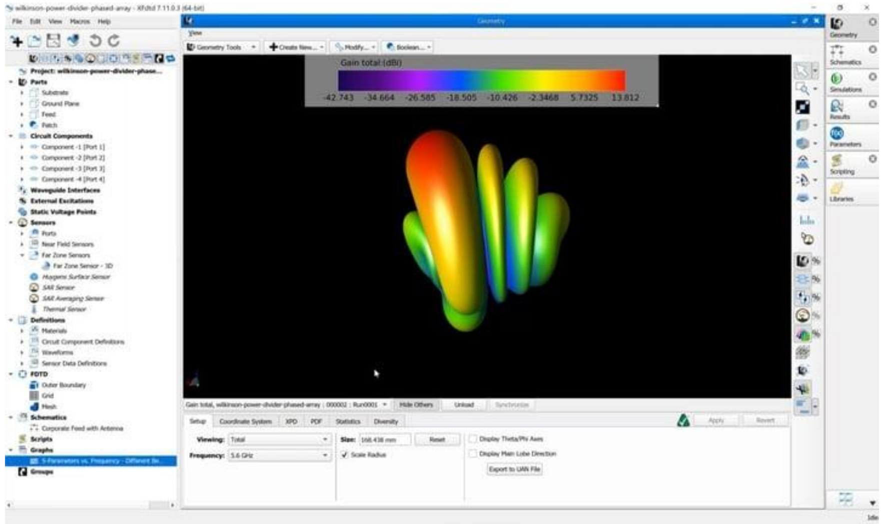

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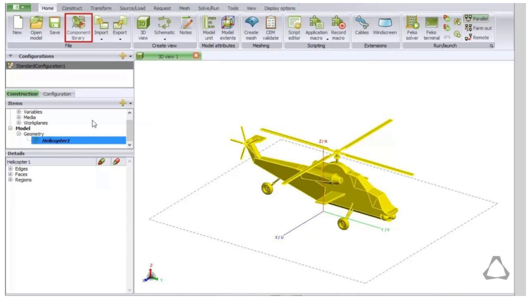

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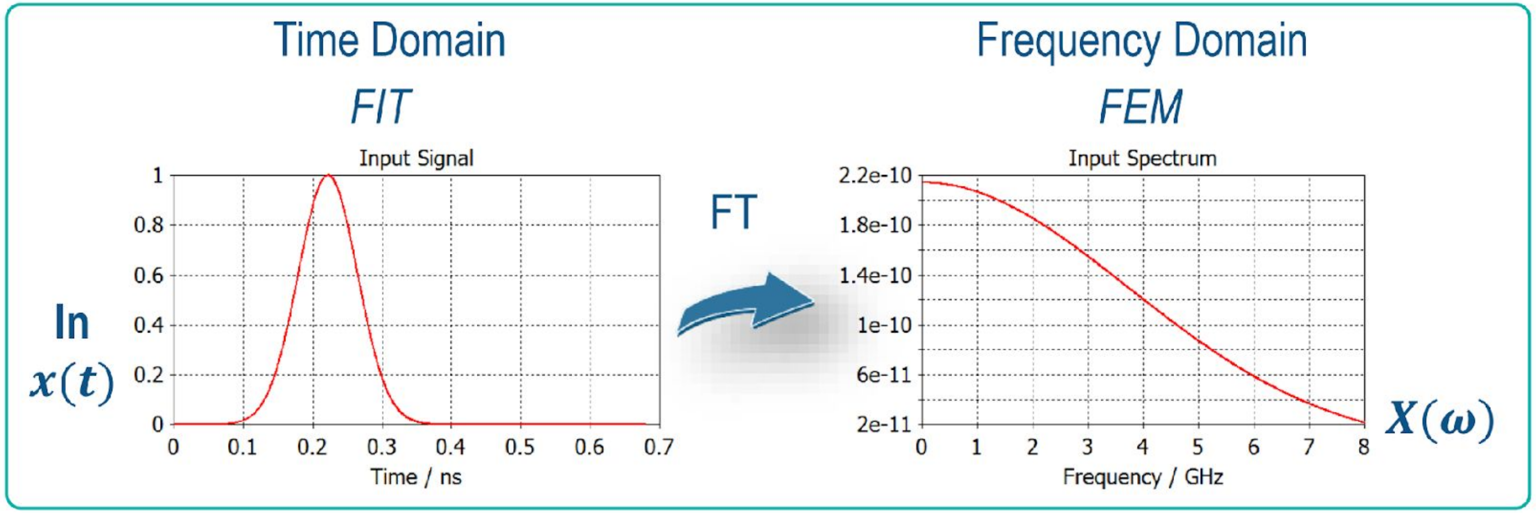
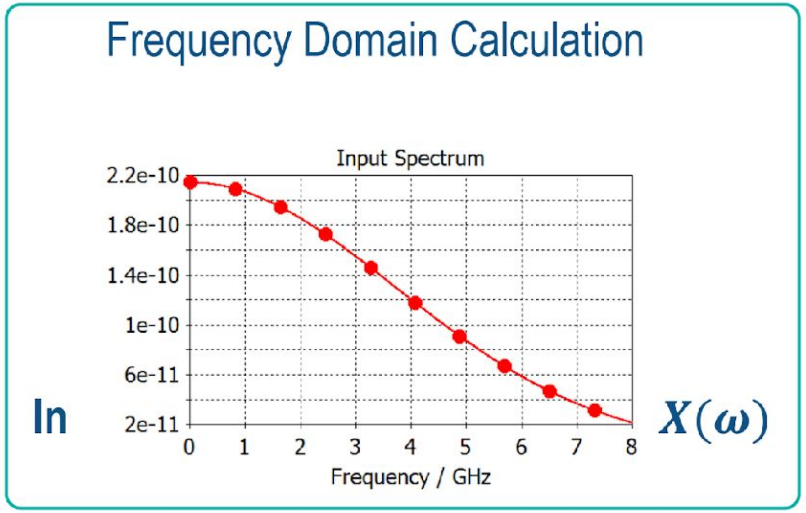
- **COMSOL Multiphysics:** While not exclusively an antenna simulation tool, COMSOL provides a powerful platform for multiphysics simulations, including electromagnetics. Its FEM-based solver can be used for antenna design and analysis, often in conjunction with other physics (e.g., thermal, structural).

COMSOL

Cross-Domain verification (*Solver Independence*)

How can you tell that your simulation is correct?





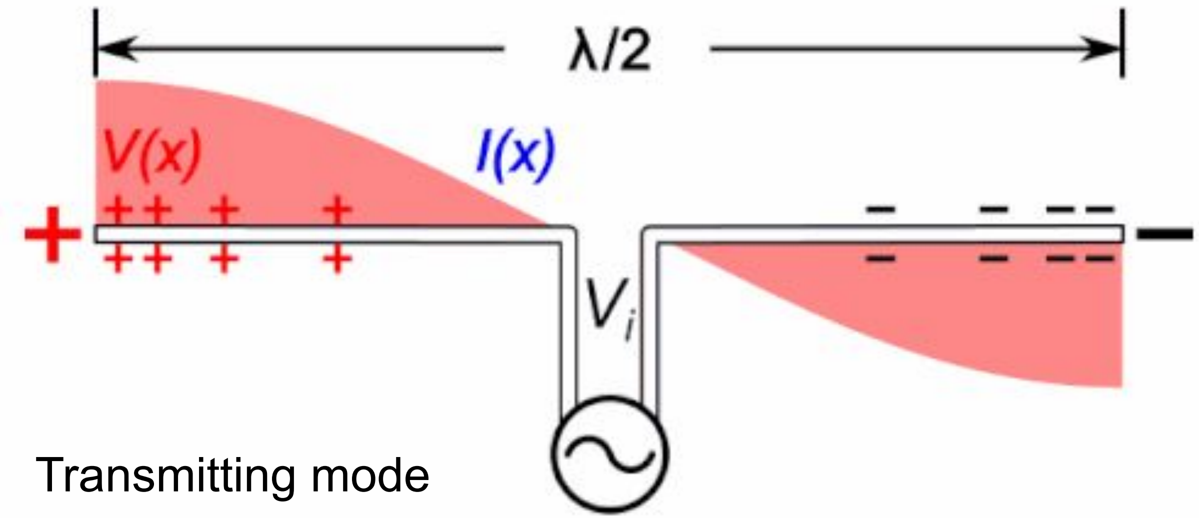
→ To insure that simulated results and settings of a selected solver are correct a cross domain verification between different solvers can be performed.

CST Studio Suite

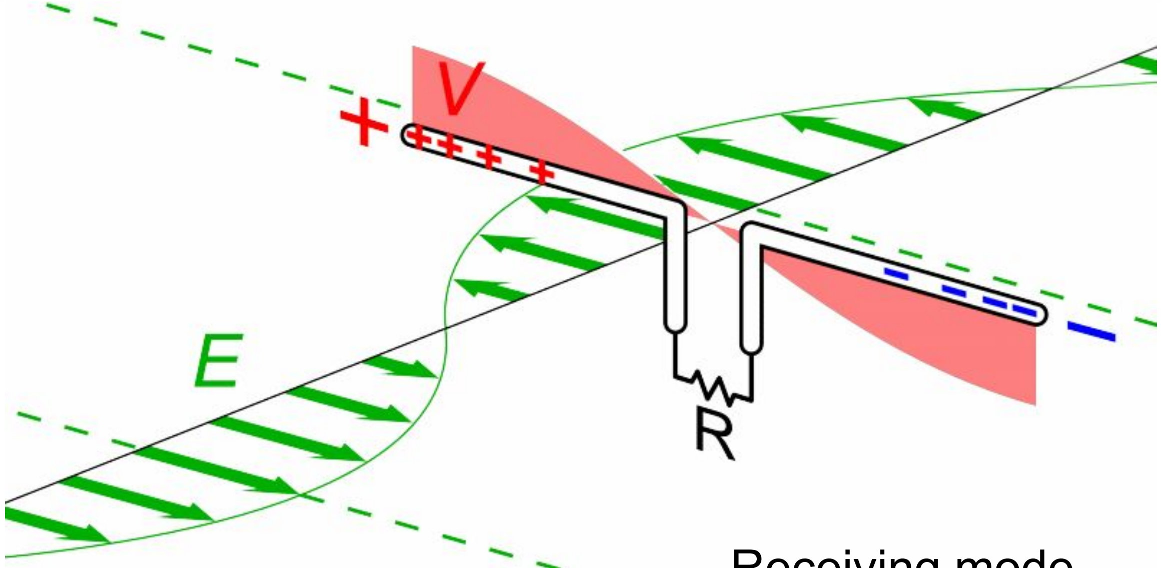
Free Version (Learning Edition):
CST Studio Suite is a commercial software, but Dassault Systèmes (the company behind CST) offers a **CST Studio Suite Learning Edition** which is free for students, educators, and researchers for personal and educational use.

Available at: https://www.3ds.com/edu/education/students/solutions/cst-le

The Dipole antenna

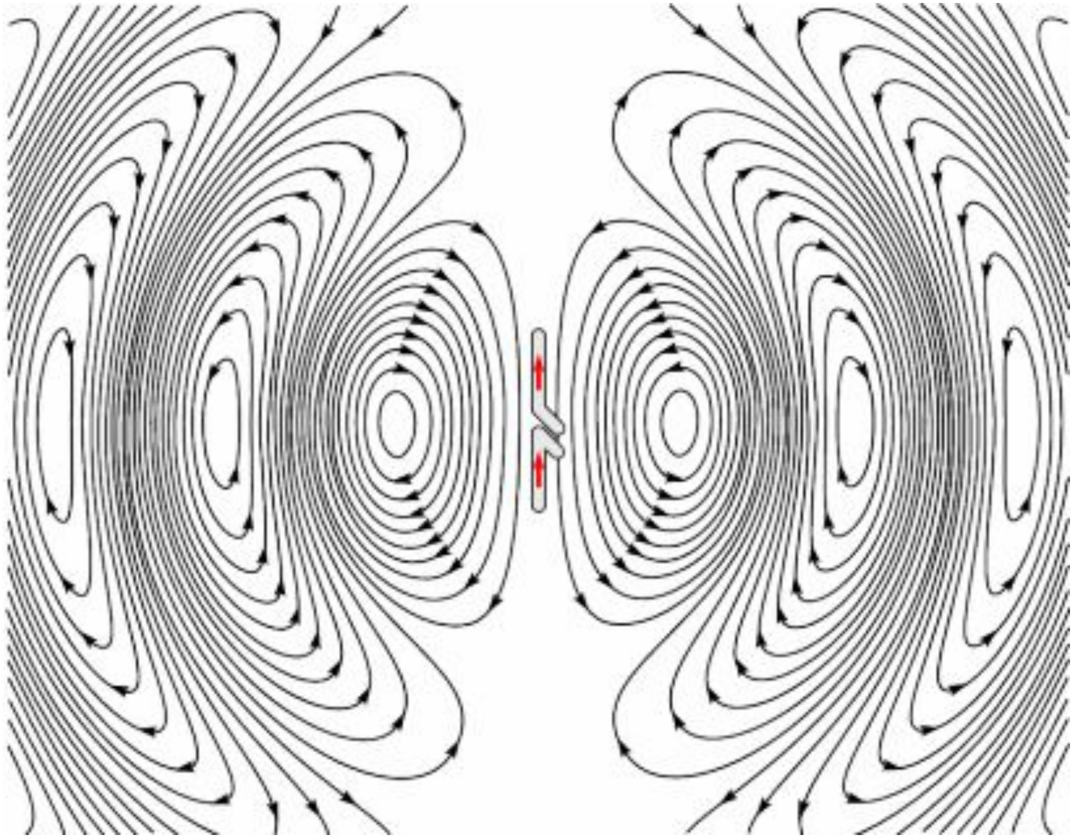


Transmitting mode



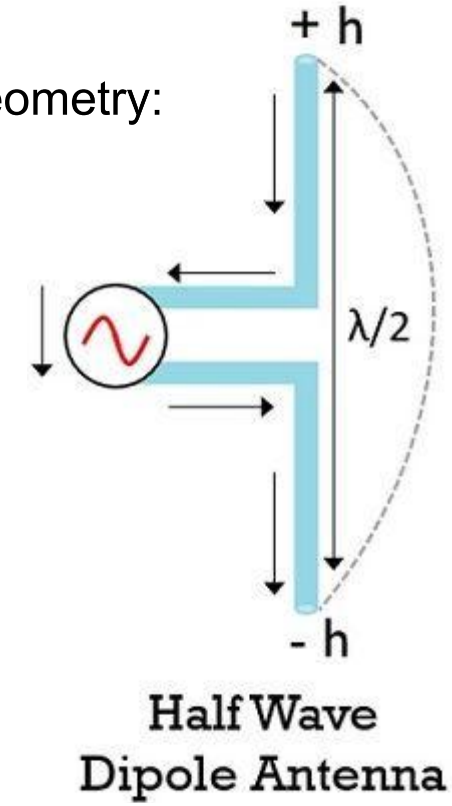
Receiving mode

Radiating mechanism

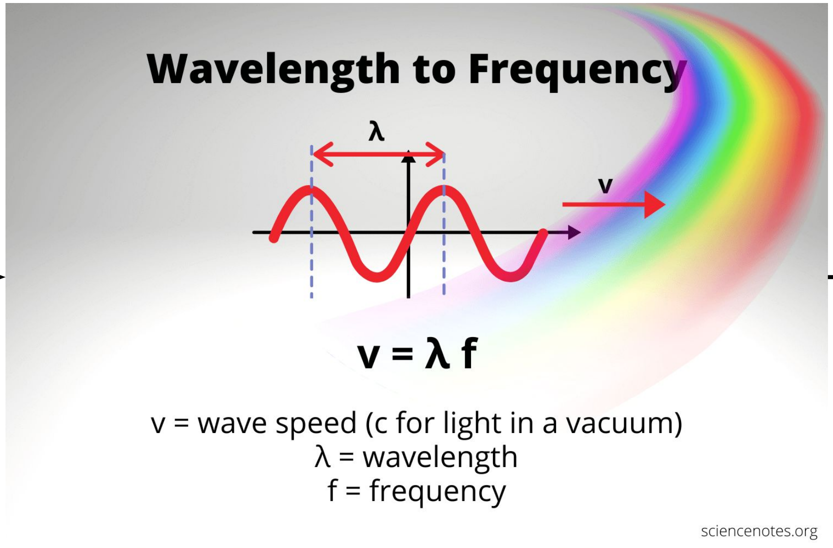


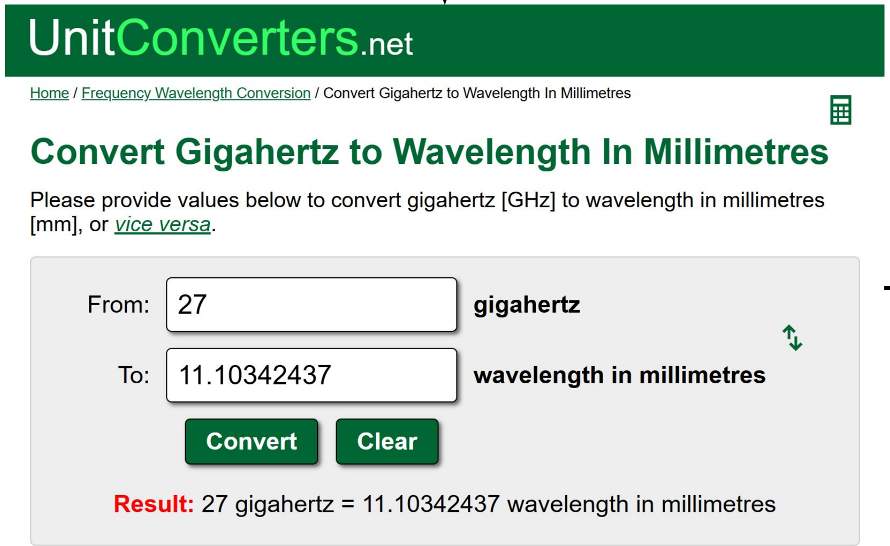
Antenna design: Half-wave Dipole antenna

Geometry:



- Target frequency: **27 GHz**

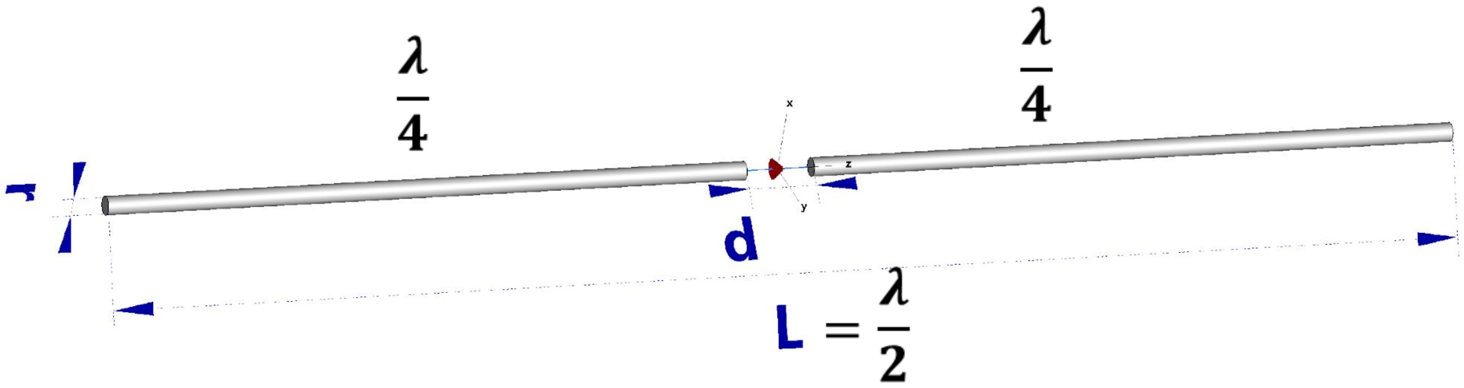




$$\boxed{Total\ length:\ L = \frac{\lambda}{2} = \frac{11.1}{2} = 5.55\ (mm)}$$

Antenna design: Workflow

1. 3D modeling: Parametric design
2. Setup: Port, boundary, mesh…
3. Simulation: Solver
4. Post processing: Optimization…



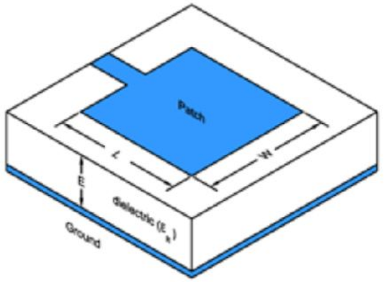
- Total length – **L**
  As calculated L = 5.55 mm
- Wire Radius (or Diameter) – **r**
  r/λ < 0.01 (electrically thin) ≈ λ/300
- Feed Gap between arms – **g**
  Typical feedpoint gap: ≈ λ/50 (0.1–2 mm)
- Input impedance target – **Z**
  Z for half-wave dipole is around 65–75 Ω

Antenna design: Patch antenna at 2.4 GHz

- Microstrip calculator: https://www.pasternack.com/t-calculator-microstrip.aspx?srsltid=AfmBOopS_NagaPW5Qc-5jeR8eRh0JwCsbjzaZQtCnCQ3GA48YnhA7tPn
- Patch antenna calculator: https://www.pasternack.com/t-calculator-microstrip-ant.aspx?srsltid=AfmBOorEfNmMO0IbxCrev5uHhvc4oFuOBcZJGx3aVUlJ-EhwnFoJaRzU

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}}; \quad \varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

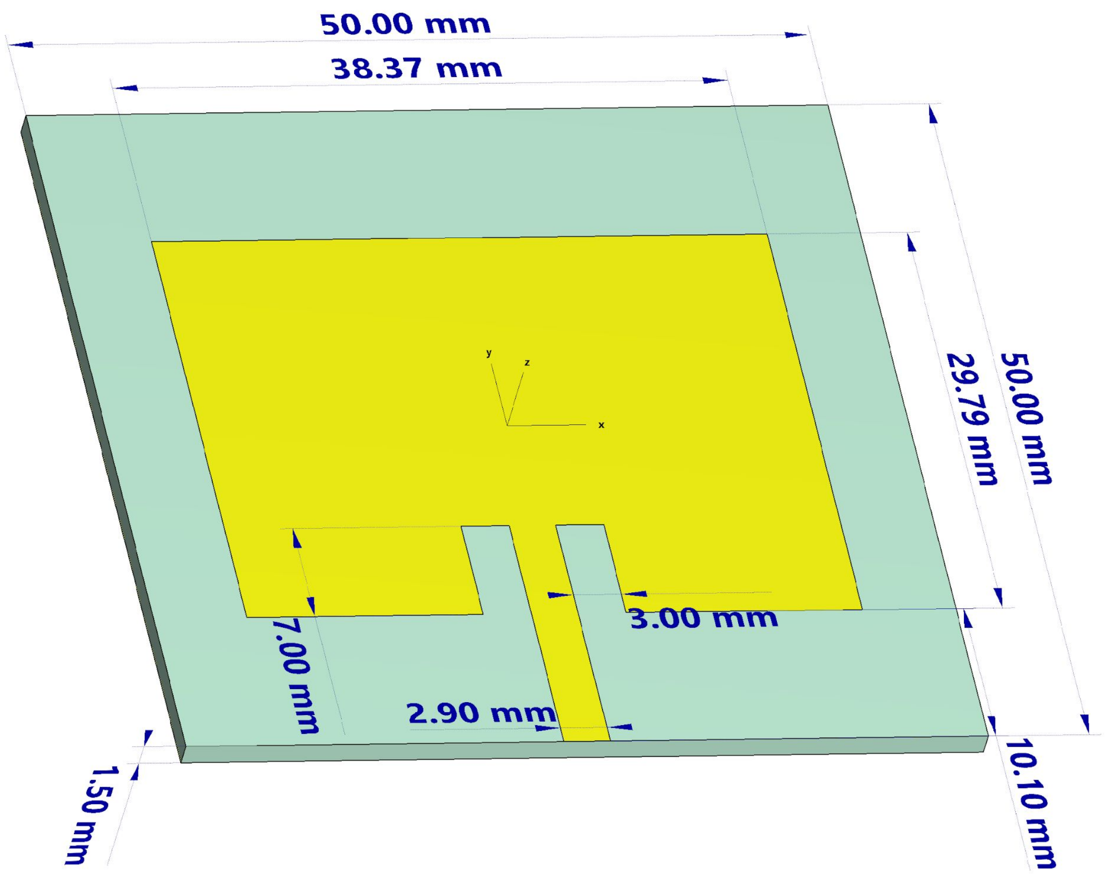


Microstrip Patch Antennas (or simply patch antenna) are increasingly useful because the antenna is printed directly onto a circuit board. Additional benefits of patch antennas is that they are easily fabricated making them cost effective. Their low profile design, often square or rectangular, allows them to be mounted to flat surfaces.

Pasternack carries a variety of panel and patch antennas which can be seen here.

**Note: All of our calculators allow SI prefix input. For example, if you wish to input "25000000", just type "25M" instead. See the quick-reference table below for all compatible SI prefixes.

Antenna design: Patch antenna at 2.4 GHz



- Substrate: FR-4 (loss free), $\varepsilon_r = 4.3$
- Substrate thickness: 1.5 mm
- Microstrip impedance: 50 Ω