天线与电波传播
ANTENNAS AND WAVE PROPAGATION

LECTURE 1

Qingsha Cheng 程庆沙

投票 最多可选1项 Setting

Did you take microwave engineering or similar course?

A Yes

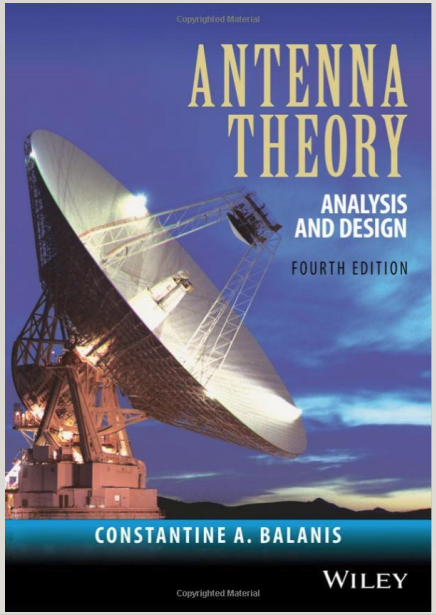
B No

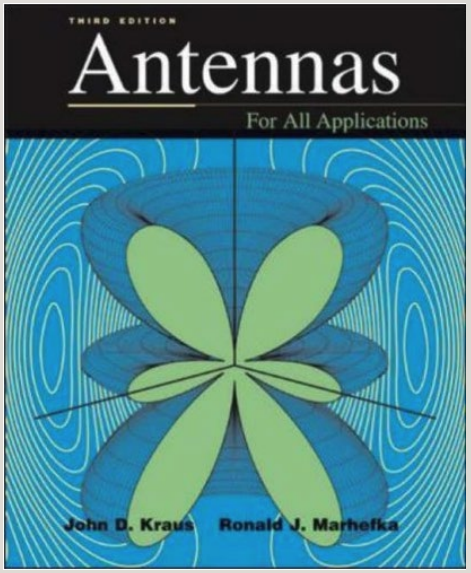
Submit

课程信息 COURSE INFO

- 参考书籍 Reference books

Constantine A. Balanis, *Antenna Theory: Analysis and Design*, 4th Edition.
John D. Kraus, Ronald J. Marhefka, *Antennas: For All Applications*, 3rd edition.





课程信息 COURSE INFO

- 课程内容 Course Contents

1. Introduction
2. Fundamental antenna parameters
3. Basic electromagnetic analysis
4. Dipole and linear antennas
5. Polarization
6. Microstrip antennas
7. Aperture antennas
8. Antenna arrays
9. Dielectric resonator antenna (DRA)
10. Emerging antennas
11. Wave propagation

课程信息 COURSE INFO

- Lab Instructor 董云阳
- 助教 TA 谭俊杰
- 课程网站 https://bb.sustech.edu.cn/
  Antenna EE307 spring2023
- Office Hour 10am-12pm, Wednesday,
  工学院南楼 234

考核方式 ASSESSMENT

期中考核Mid-term	20%
期末Final Project(Exam?)	30%
实验部分 Labs	30%
课堂 Quizzes	10%
平时作业 Homework	10%

Homework should be submitted online electronically.
作业通过网站提交电子扫描版（或用手机拍摄）

有问题请联系助教或我

Academic Integrity （学术诚信）

What Is Academic Integrity?

Honesty is the foundation of good academic work. Whether you are working on a problem set, lab report, project or paper, avoid engaging in plagiarism, unauthorized collaboration, cheating, or facilitating academic dishonesty.

https://integrity.mit.edu/

Academic Integrity （学术诚信）

Why Is Academic Integrity Important?

Your Reputation and Your Self-esteem

University Reputation and Value of Your Degree

Wellbeing of Society

Academic Integrity （学术诚信）

Plagiarism	
Do	***Don't***
Trust the value of your own intellect.	Don't purchase papers or have someone write a paper for you.
Undertake research honestly and credit others for their work.	Don’t copy ideas, data or exact wording without citing your source.

Unauthorized Collaboration	
Do	***Don't***
Trust the value of your own intellect.	Don’t collaborate with another student beyond the extent specifically approved by the instructor.

https://integrity.mit.edu/

Academic Integrity （学术诚信）

Cheating	
Do	***Don't***
Demonstrate your own achievement.	Don’t copy answers from another student; don’t ask another student to do your work for you. Don’t fabricate results. Don’t use electronic or other devices during exams.
Accept corrections from the instructor as part of the learning process.	Don’t alter graded exams and submit them for re-grading.
Do original work for each class.	Don’t submit projects or papers that have been done for a previous class.

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Academic Integrity （学术诚信）

Facilitating Academic Dishonesty	
Do	***Don't***
Showcase your own abilities.	Don’t allow another student to copy your answers on assignments or exams. Don’t take an exam or complete an assignment for another student.

https://integrity.mit.edu/

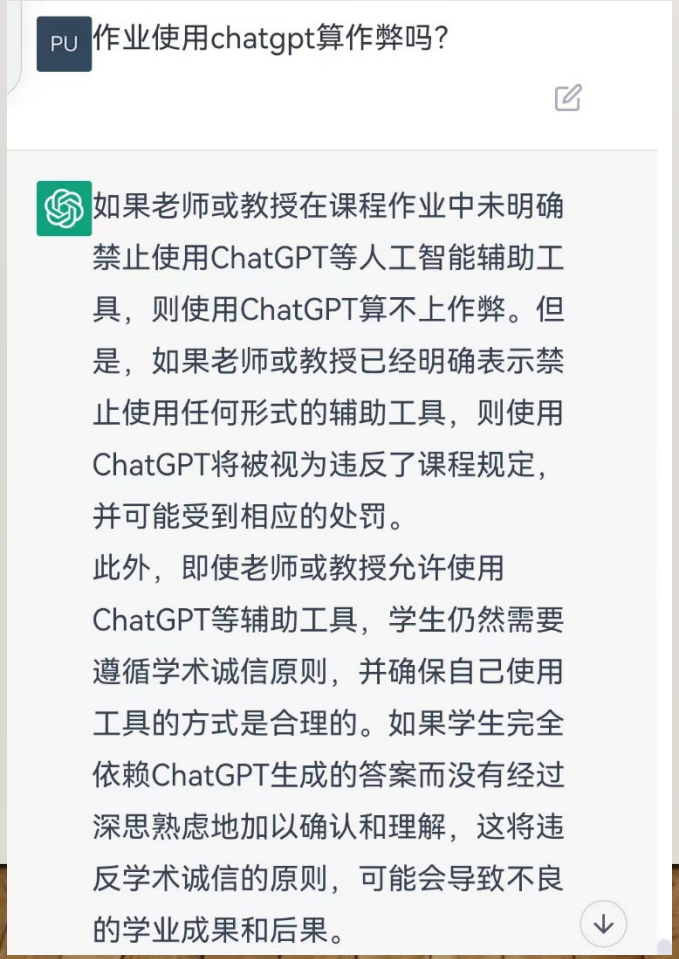
Academic Integrity （学术诚信）

Ways to Prevent Academic Dishonesty

- Manage your time – study ahead of time!
- Organize your priorities.
- Check your syllabus.
- Go to office hours.
- If you're unsure, ask your professor and/or TA.
- Be confident of your studies.
- Know the consequences of academic dishonesty!

Academic Integrity （学术诚信）

WHAT ABOUT CHAT GPT?



投票 最多可选1项

设置

Have you used Chat GPT for assignments?

A No

B Occasionally

C Frequently

D Every time!

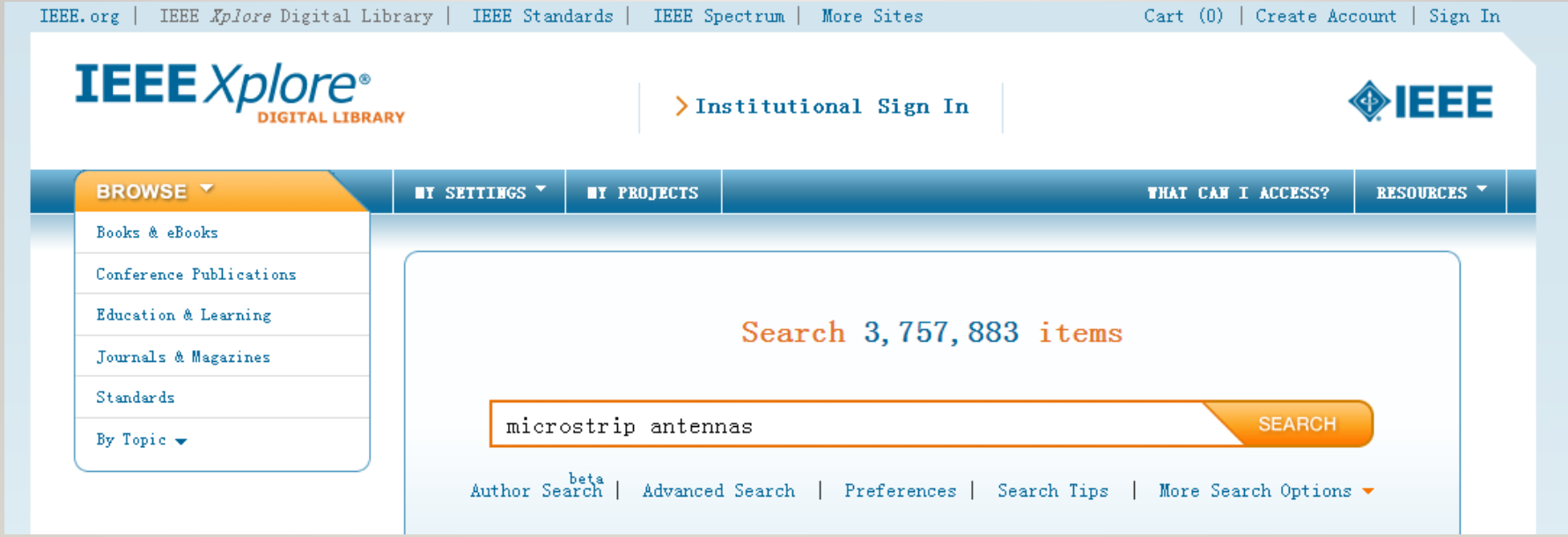
提交

天线国际会议 CONFERENCES

LAPC
Loughborough Antenna & Propagation Conference

文献搜索 REFERENCE SEARCH

http://ieeexplore.ieee.org/Xplore/home.jsp



IEEE 期刊：Transaction + Letter　　IEEE 会议论文

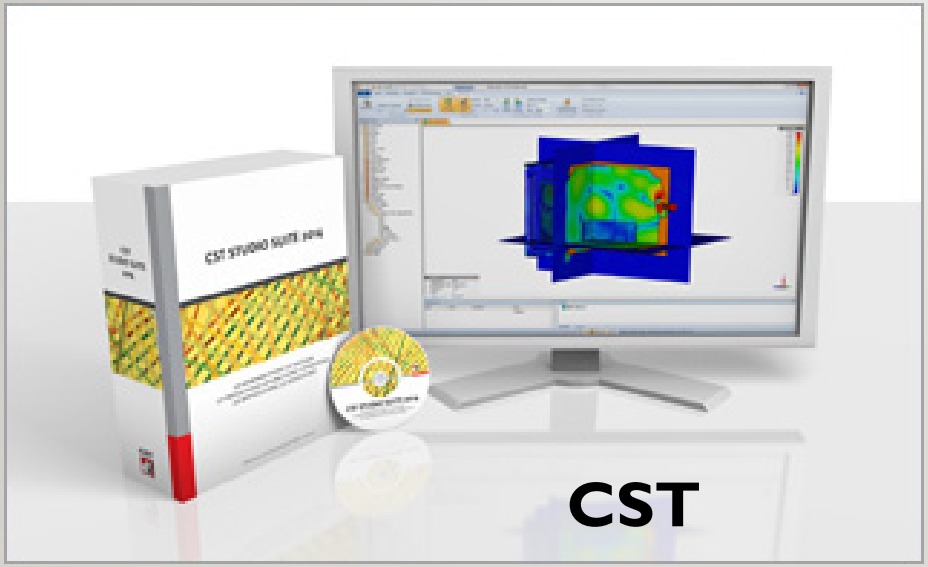
IEEE Trans. Antennas Propagat.

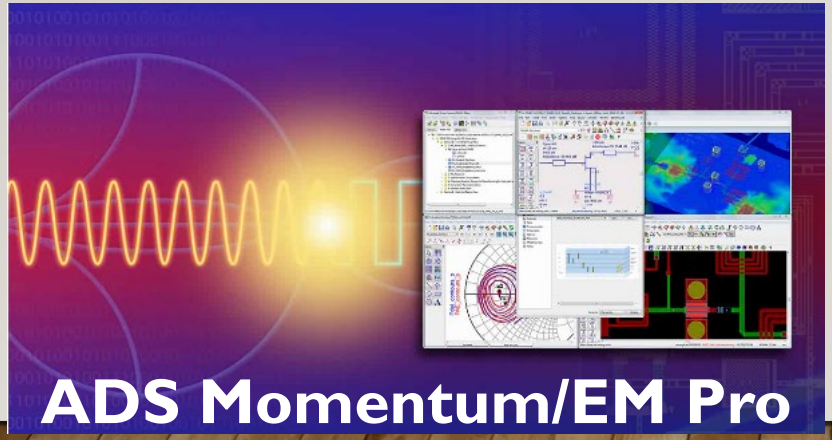
IEEE Antennas and Wave Propagat. Lett.

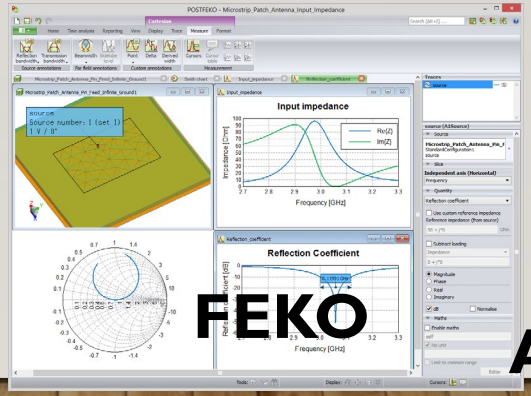
IEEE Trans. Microw. Theory Tech.

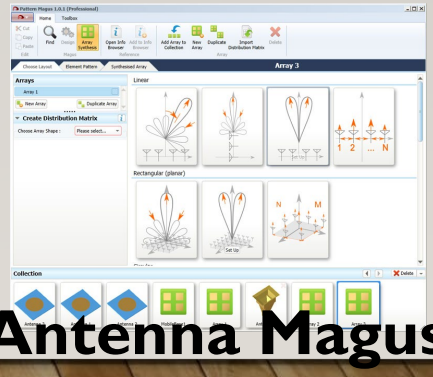
IEEE Microw. and Wireless Comp. Lett.

仿真软件 SIMULATION SOFTWARE

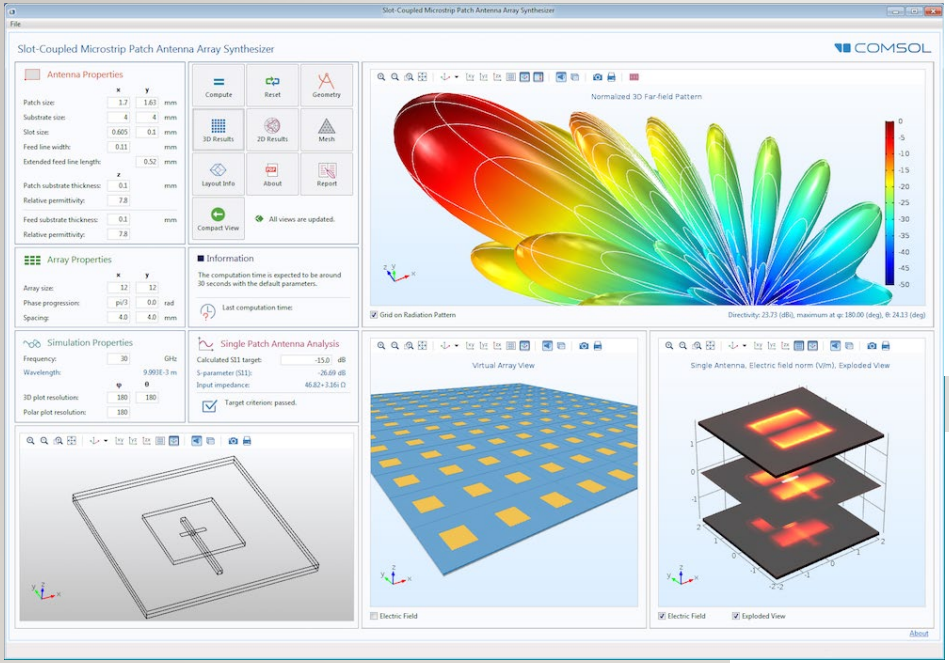


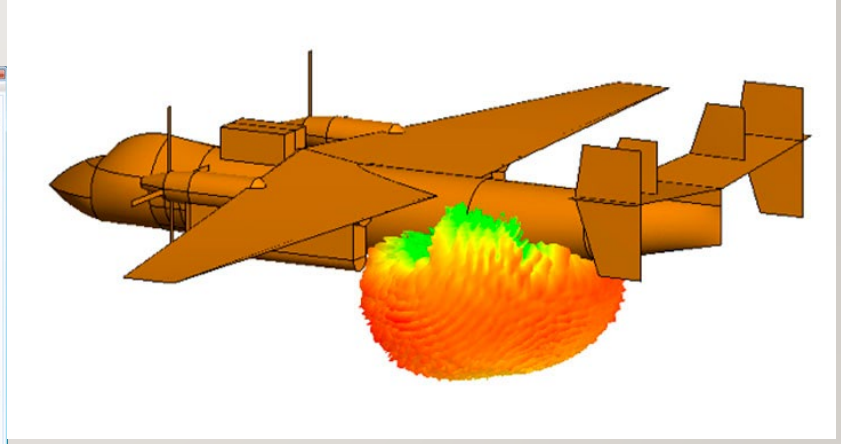


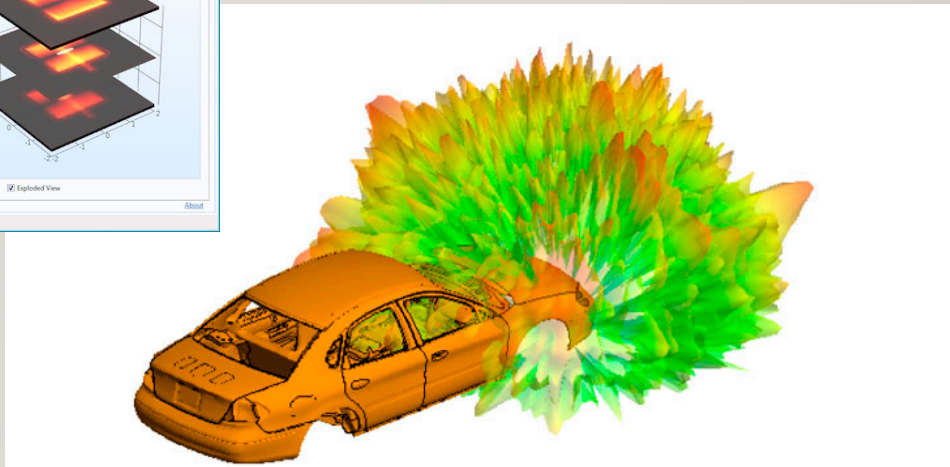




仿真软件 SIMULATION SOFTWARE







COURSE LEARNING OUTCOMES

(1) understand the basic principles and design approaches of antennas

(2) apply theory to analyze antennas

(3) solve typical antenna problems

(4) conduct basic analysis and design of antenna, by using simulating software and operating instruments

(5) apply theory and techniques to some projects

(6) conduct further study and research in antennas

LECTURE 1

- **Introduction**
- **Radiation Mechanism**
- **Historical Review**
- **Applications**
- **Types of Antennas**

Introduction

- **antenna = 触须 （pl. antennae [an·teh·nee]）**

Large antennae on a longhorn beetle

Introduction

- antenna = 触须 (pl. antennae)
- antenna = 天线 (pl. antennas)

A Yagi–Uda television antenna

Webster Dictionary:

A usually metallic device (as a rod or wire) for radiating or receiving radio waves)

IEEE Standard Def.:

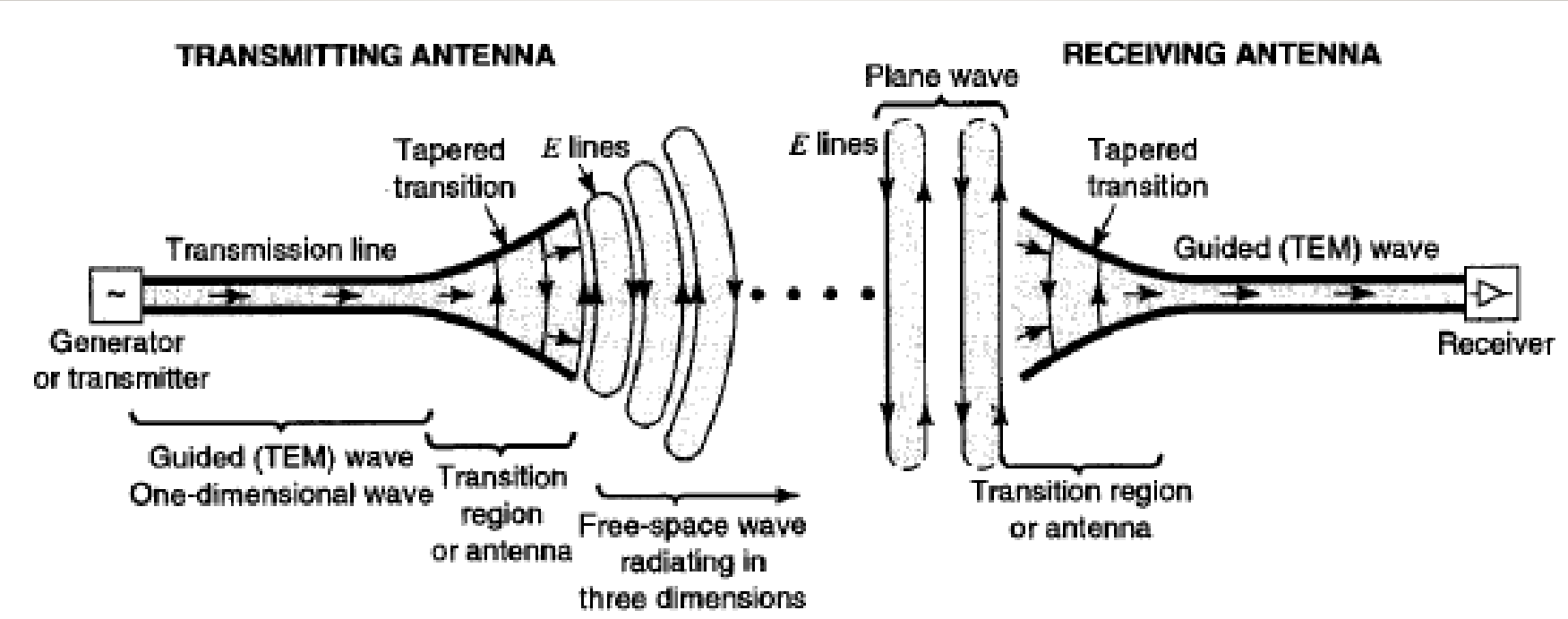
A means for radiating or receiving radio waves

Introduction

- **antenna = 触须 (pl. antennae [an·teh·nee])**
- **antenna = 天线 (pl. antennas)**
- **aerial = 天线 (pl. aerials)**

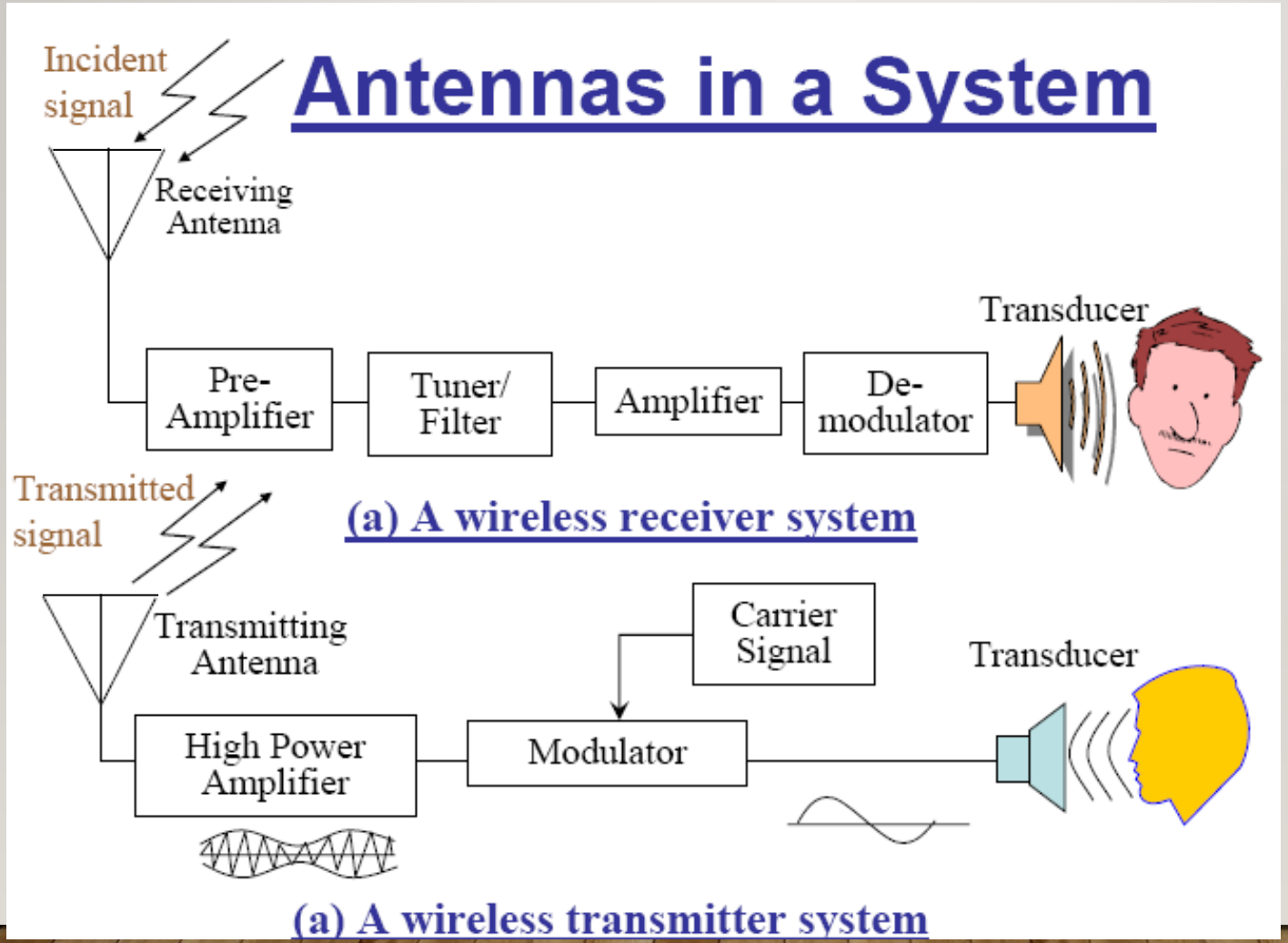
a rod, wire, or other structure for receiving or transmitting radio, television signals etc. [less common now]

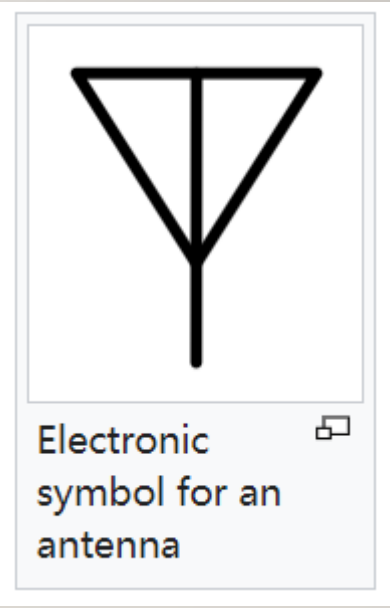
Introduction



an **antenna** or **aerial** is the interface between radio waves propagating through space and electric currents moving in metal conductors, used with a transmitter or receiver.

ANTENNAS IN COMMUNICATION SYSTEM





Electronic symbol for an antenna

ROLES OF ANTENNAS

- **Converter between oscillating current (accelerating charge) and electromagnetic wave**
- **Input and output ports for radio wave**
- **Most important part of wireless communication**

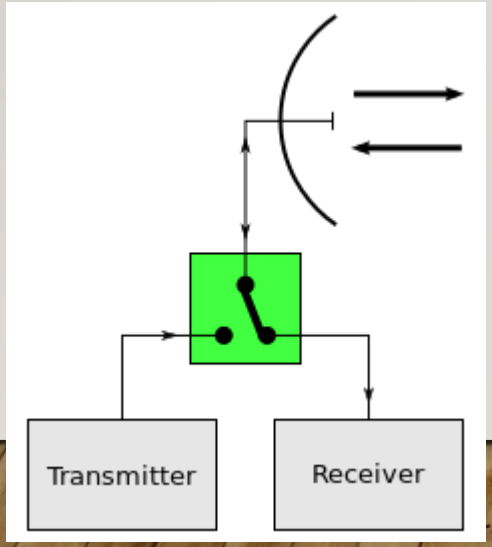
TYPES OF ANTENNAS

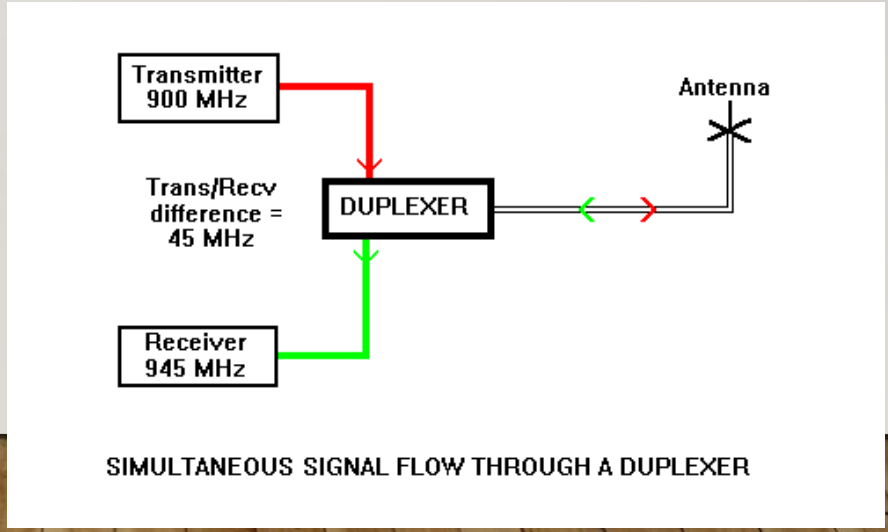
- **Transmitting antenna：convert high-frequency current energy to electromagnetic wave in certain direction(s)**
- **Receiving antenna：convert space electromagnetic wave to high-frequency electrical current and voltage**

TYPES OF ANTENNAS

Transmitting and receiving <u>can share one antenna</u>

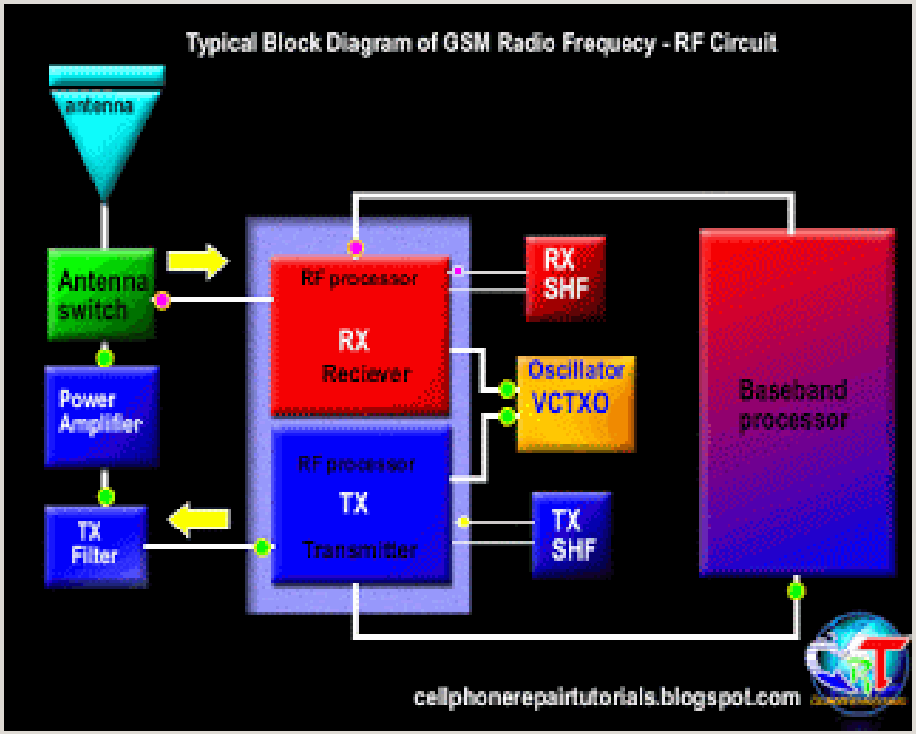
- Switch is used in GSM (2G) handset for transmitting and receiving using the same antenna
- Duplexer is used in radar system and most 4G/5G handsets for transmitting and receiving using the same antenna





TYPES OF ANTENNAS

- Transmitting and receiving **can share one antenna**

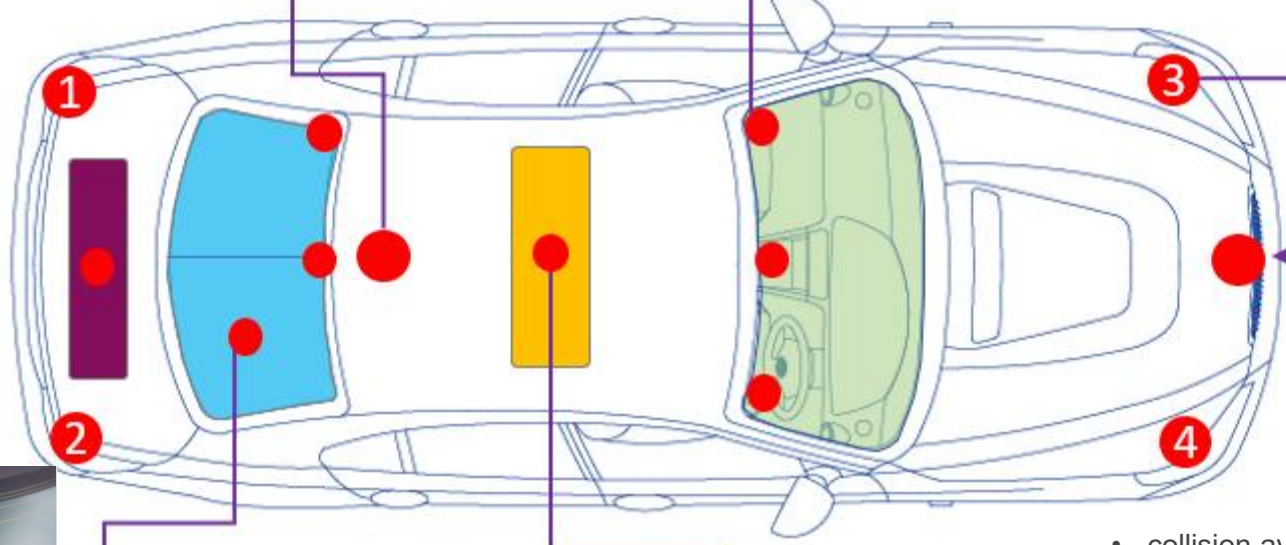


Antennas in a car

Shark fin multiband antenna module

Supporting antennas for diversity/MIMO

Supporting antennas for diversity/MIMO



Long Range Radar

FM-radio & terrestrial television

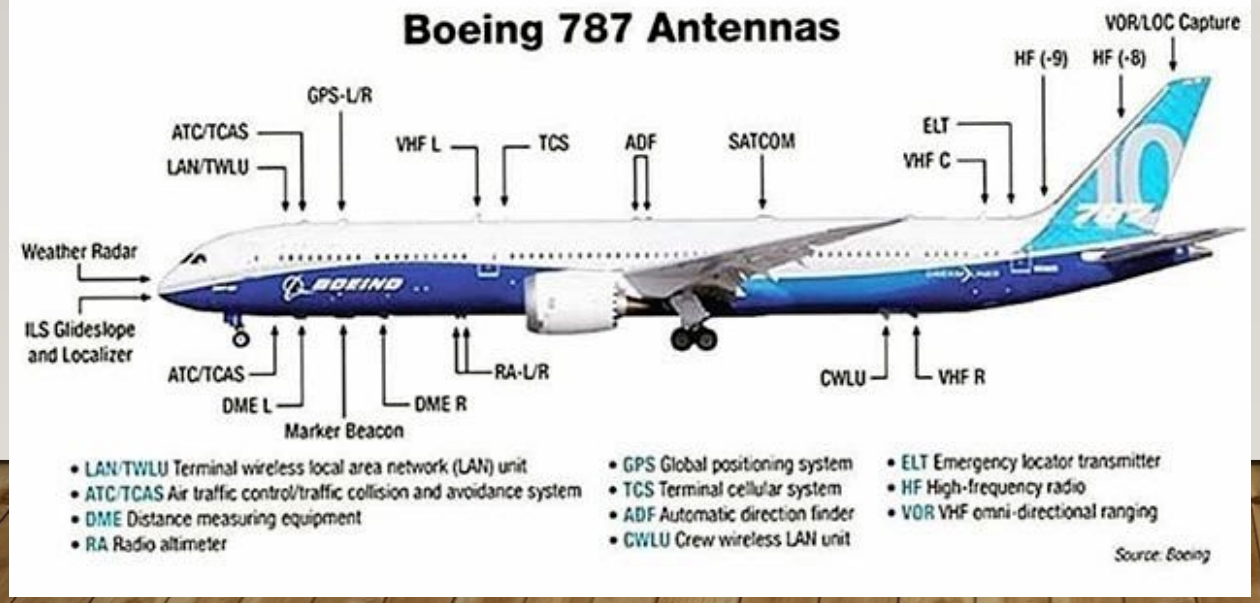
Multiband modules & satellite terminals

- collision avoidance system (CAS)
- pre-crash safety systems
- vehicle-to-vehicle communications
- global positioning systems (GPS)
- wireless local area network (WLAN)
- tire pressure monitoring system (TPMS)

Antennas on a Boeing 787

1. **Communications Antennas**
2. **GPS Antennas**
3. **Loran Antennas** (Long-range navigation)
4. **Marker Beacon Antennas**
5. **Nav Antennas**
6. **Radio Altimeters**

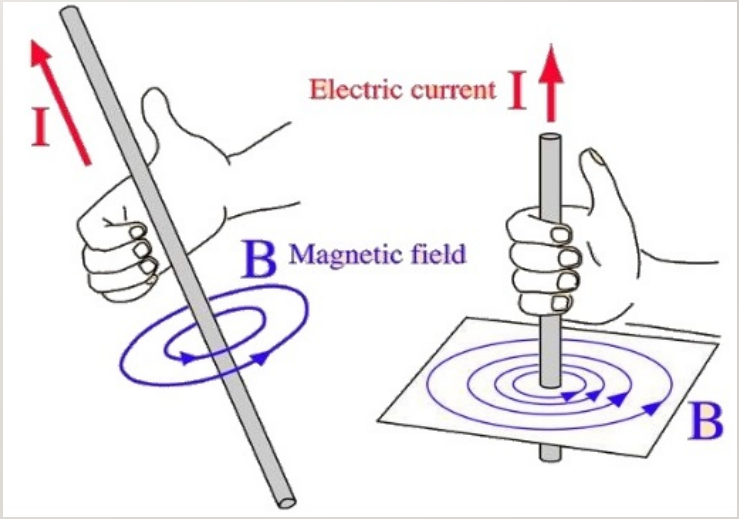
…



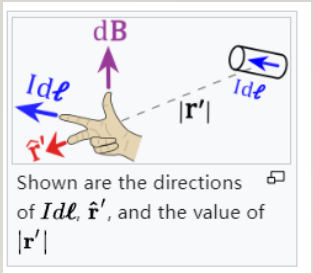
Why Antenna Radiates

- charge moving at constant velocity, as in a current, produces a static magnetic field.
- Biot–Savart law

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_C \frac{I\, d\boldsymbol{\ell} \times \mathbf{r}'}{|\mathbf{r}'|^3}$$



Why moving charge produces magnetic field?
How Special Relativity Makes Magnets Work [3'40"]



Antenna Radiation

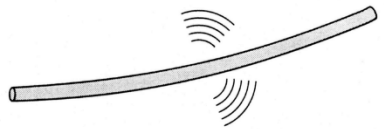
- **If charge is not moving, current is zero ⇒ no radiation.**
- **If charge is moving with a uniform velocity (DC)**
  - **If the wire is straight⇒ no radiation.**
  - **If charge is accelerated due to electromotive force or due to discontinuities, such as terminations, bends, curvatures ⇒ radiation occurs.**

Why Antenna Radiates

- To have the **fields change with time**, as in an electromagnetic wave, the charges must not be at rest or moving at constant velocity.
- $qa = q\dot{v}$ (accelerating charges) produces radiation, it follows that *dI/dt* (current changes) produces radiation. (Maxwell equations)
  - Use charges for transients and pulses discussion
  - Use currents for time harmonic variations discussion
- Pulses radiate a broad bandwidth (spectrum) of radiation. The shorter the pulse width, the broader the spectrum.
- A sinusoidal (smooth) waveform of current or charge leads to a narrow spectrum of radiation; ideally zero bandwidth at the frequency of the sinusoid, if it continues indefinitely.

CHARGES ARE ACCELERATED DUE TO VARIOUS SITUATIONS

Curved



(a) Curved

Fig. 1.10a

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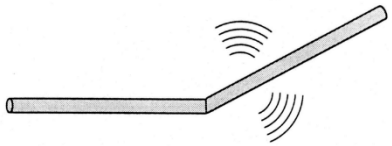
Bent



(b) Bent

Fig. 1.10b

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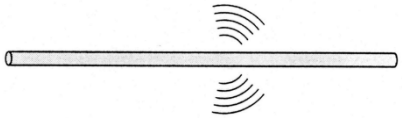
Truncated



(e) Truncated

Fig. 1.10e

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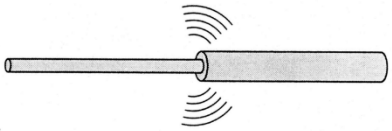
Discontinuous



(c) Discontinuous

Fig. 1.10c

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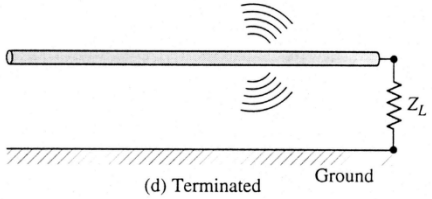
Terminated



(d) Terminated

Fig. 1.10d

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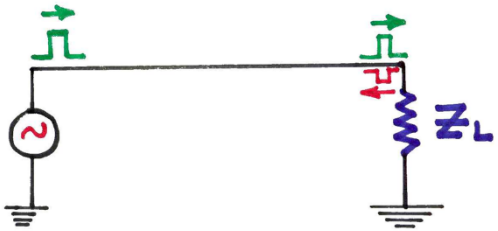
Terminated Line



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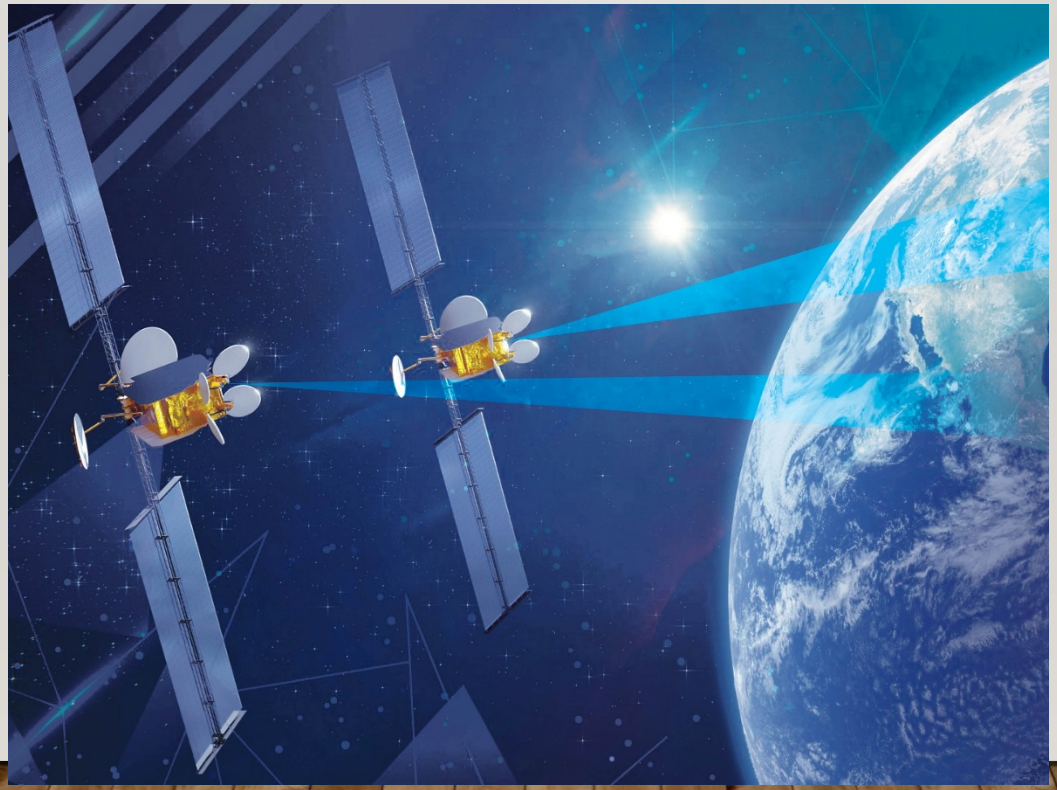
Ref. C.A. Balanis

Antenna Radiation

- **It is easy to produce radiation!**
- **The problem is to produce continuous radiation at the desired magnitude at the desired direction**

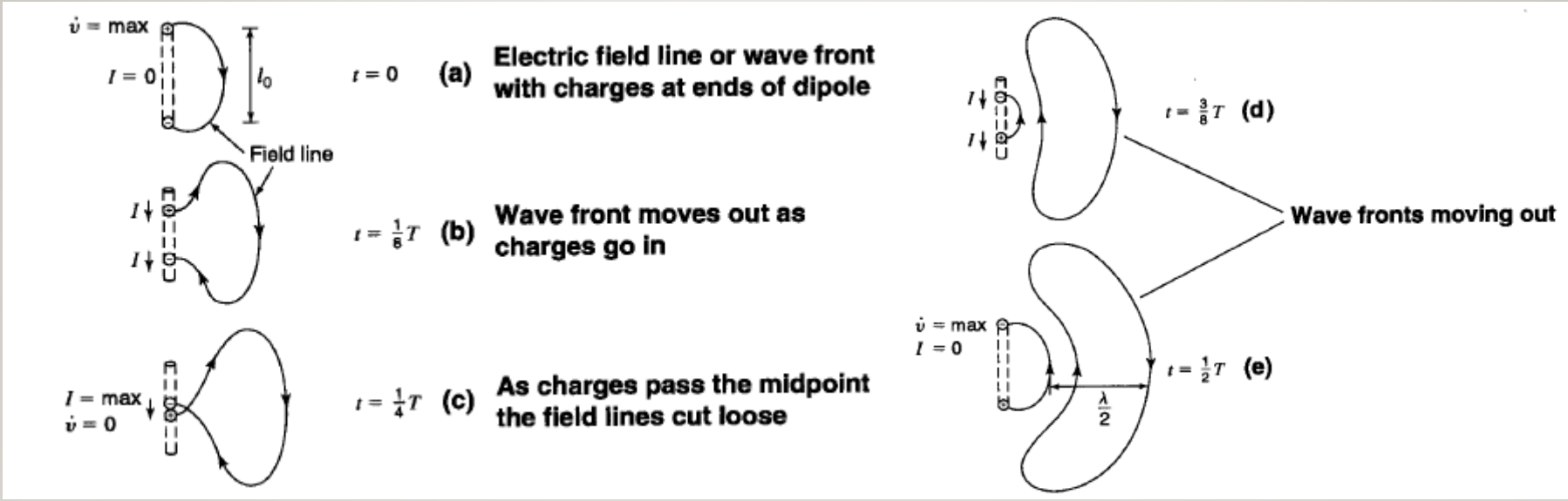


Antenna Radiation

- **If charge is oscillating in a time-motion (even a straight wire) ⇒ (electromagnetic wave) radiation occurs.**

What is electromagnetic wave? 3'40"

How to Produce Radiation



How does EM Wave "escape" from the antenna?

Video halfwave length dipole radiation E-field

Antenna Radiation

E-Field Lines of λ/2 Dipole

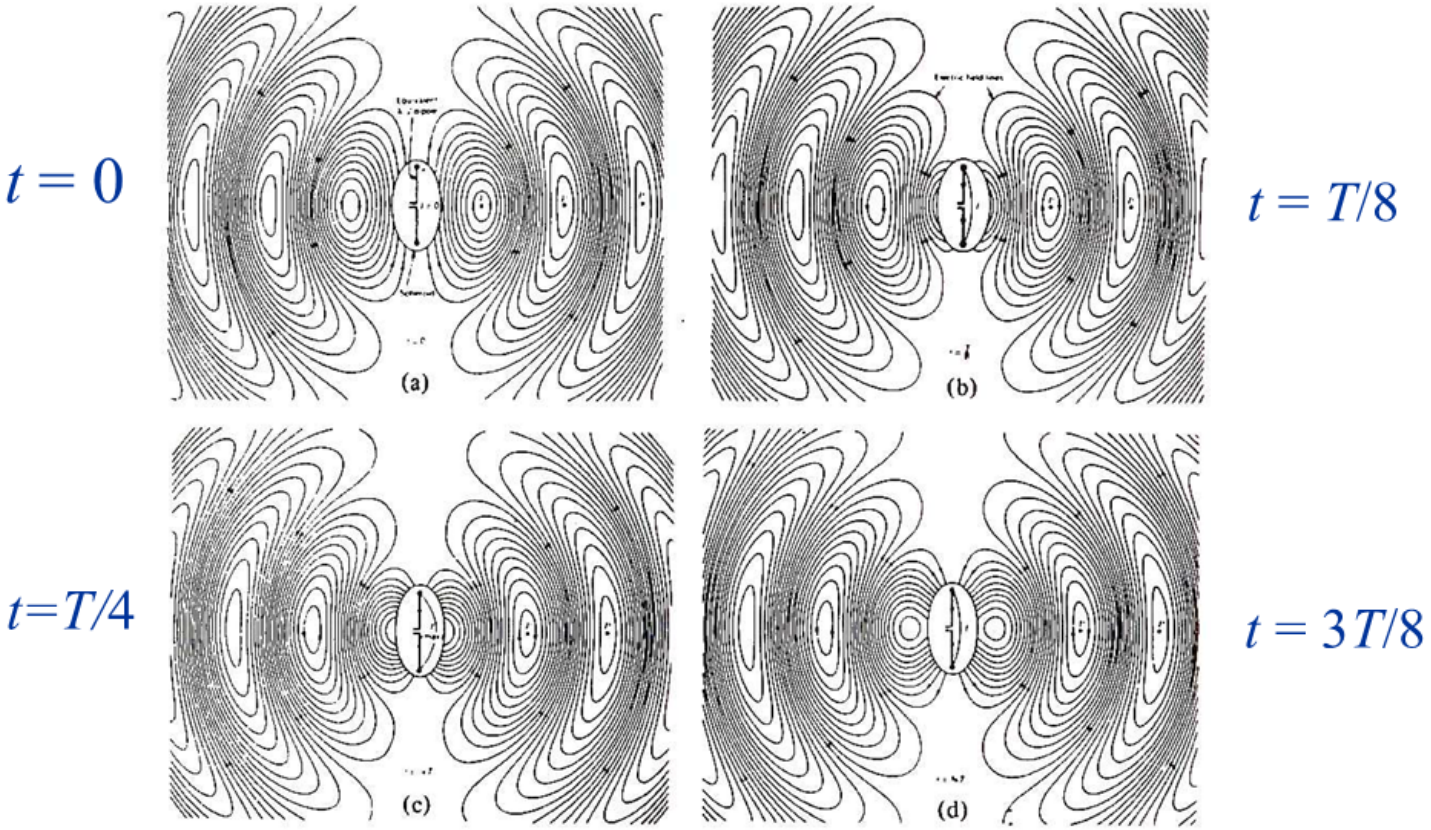


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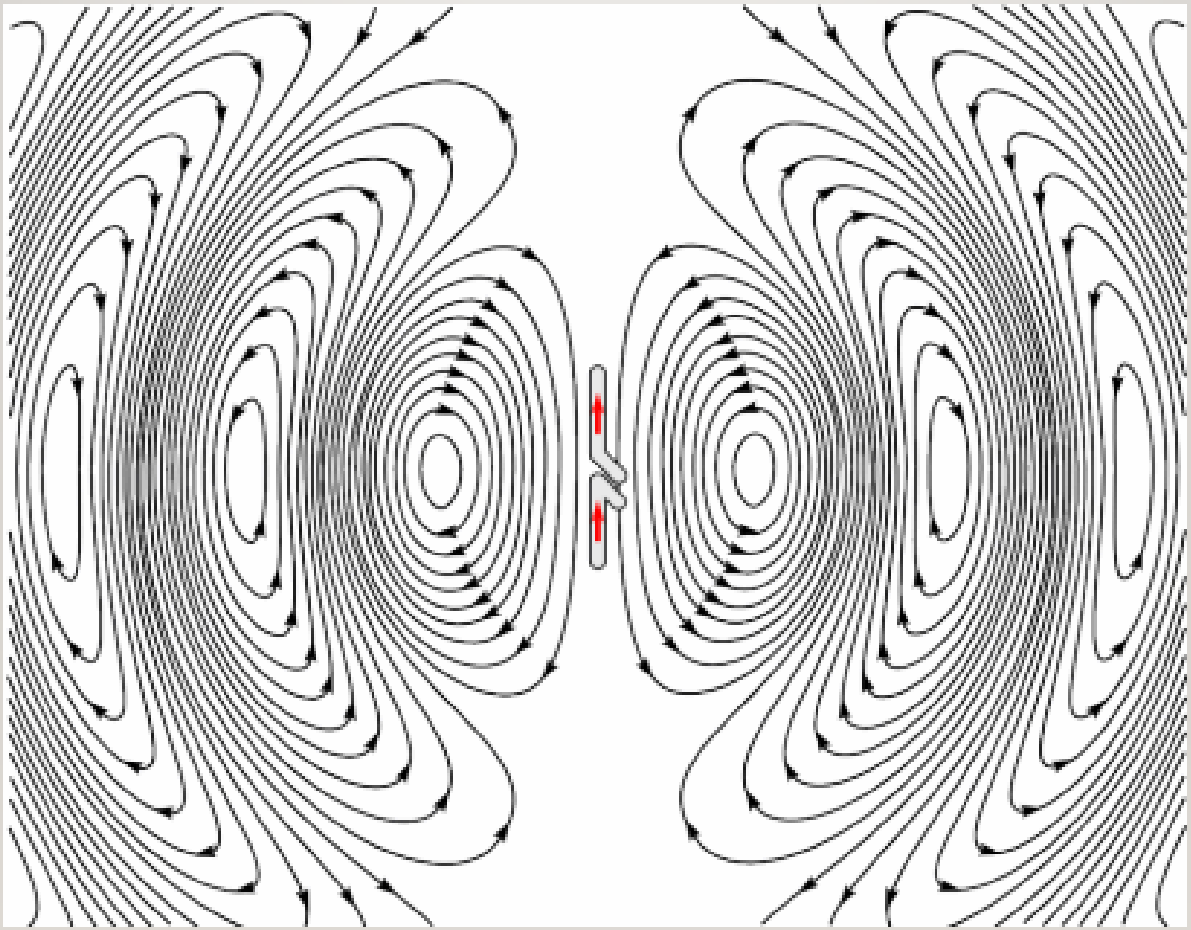
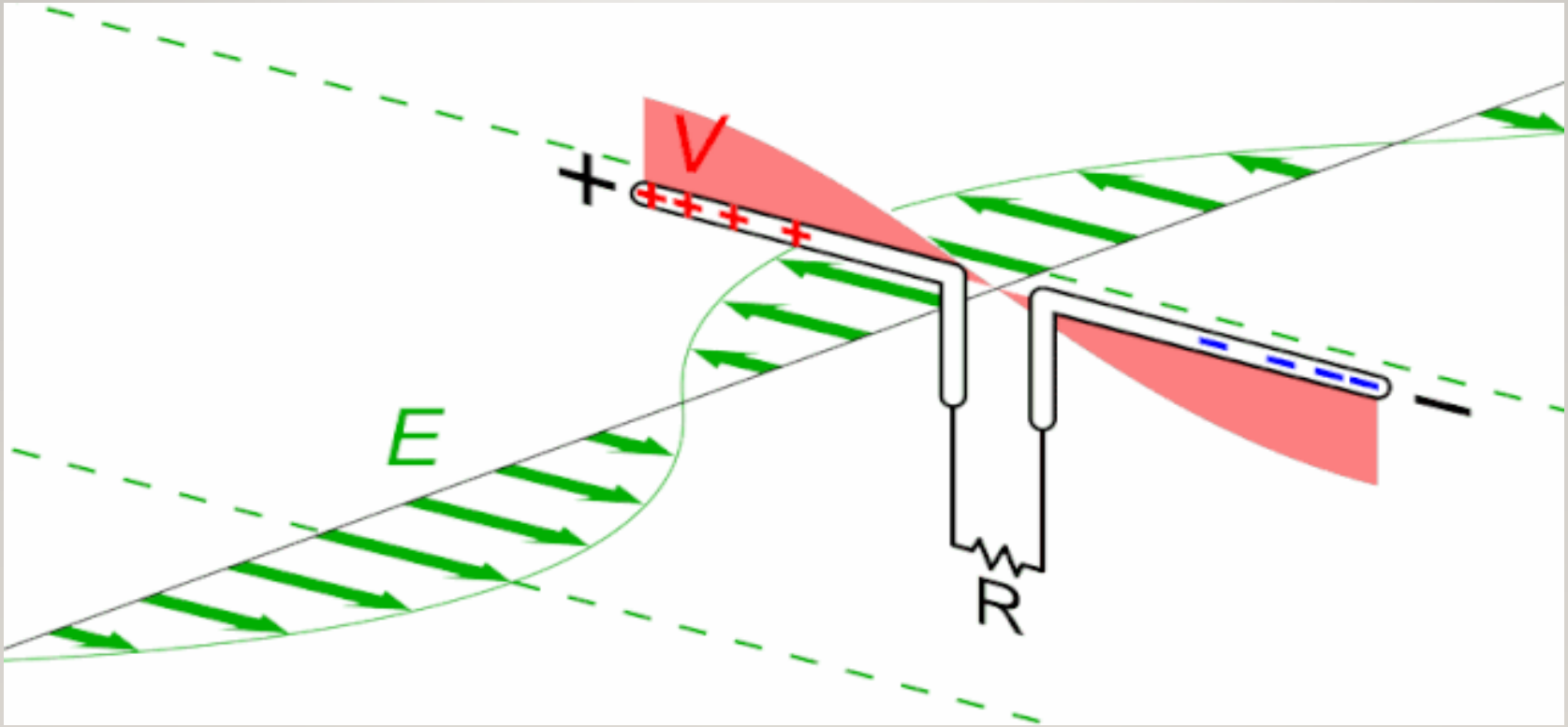
Fig. 1.12

Antenna Radiation

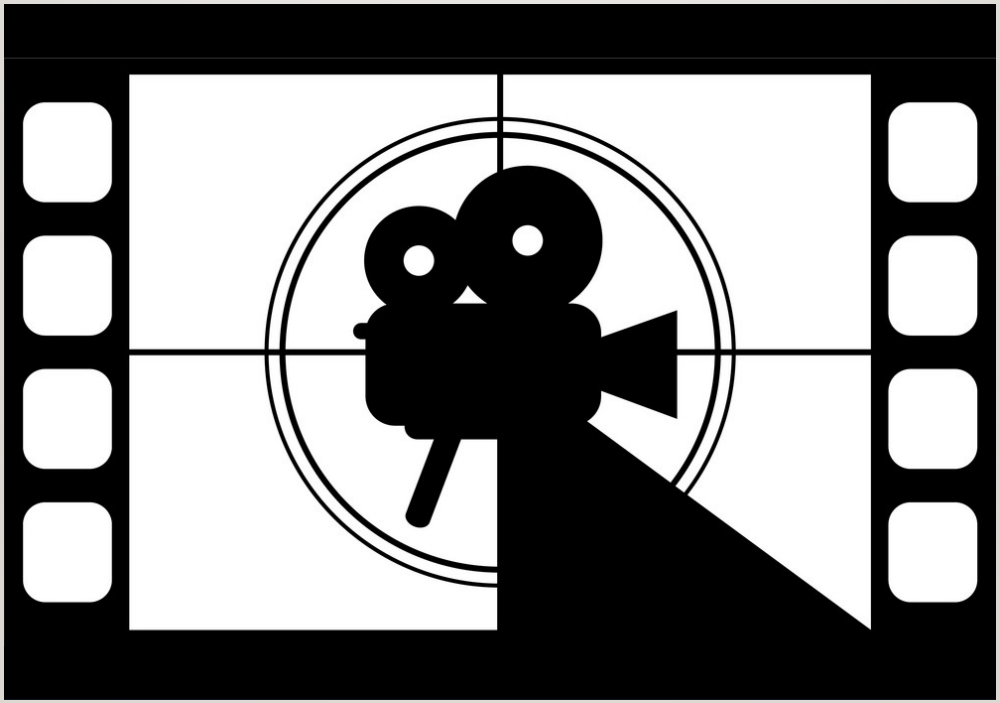


Antenna Receiving Radiation



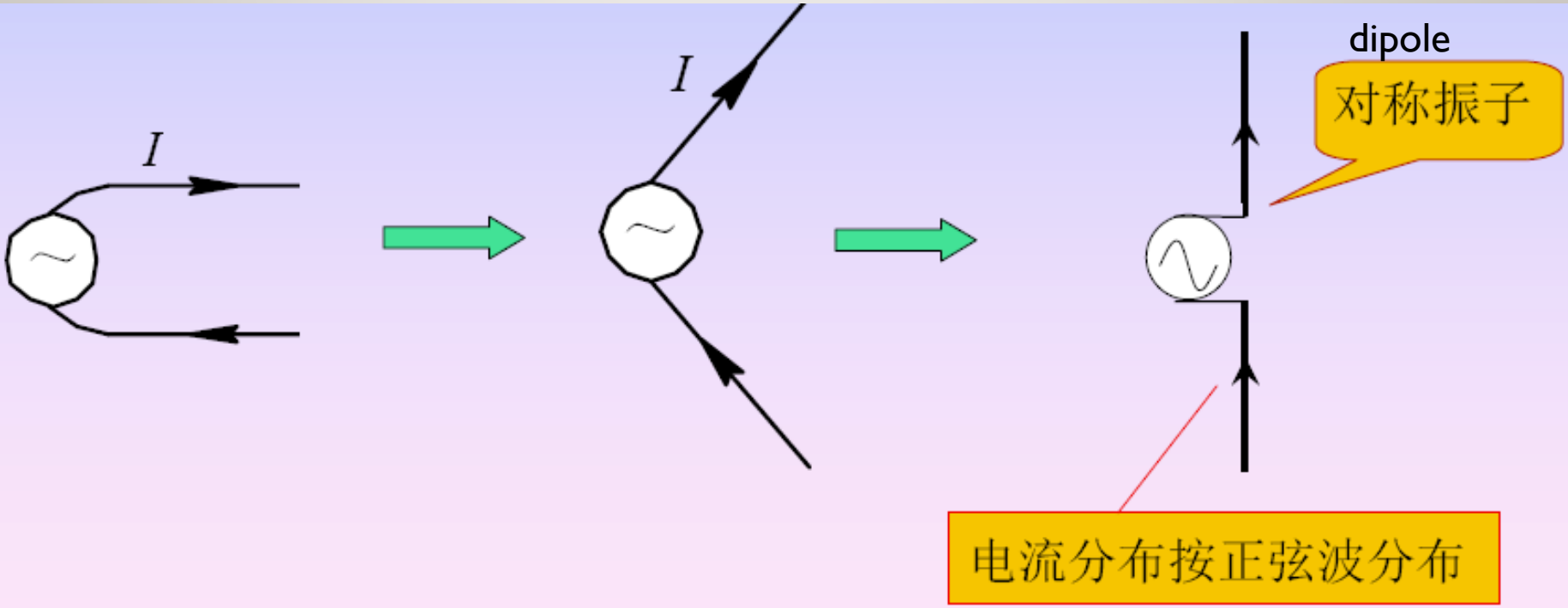
Animated diagram of a half-wave dipole antenna receiving a radio wave. The antenna consists of two metal rods connected to a receiver *R*. The electric field *(E, green arrows)* of the incoming wave pushes the electrons in the rods back and forth, charging the ends alternately positive *(+)* and negative *(−)*. Since the length of the antenna is one half the wavelength of the wave, the oscillating field induces standing waves of voltage *(V, represented by red band)* and current in the rods. The oscillating currents *(black arrows)* flow down the transmission line and through the receiver (represented by the resistance *R*).

Antenna Radiation

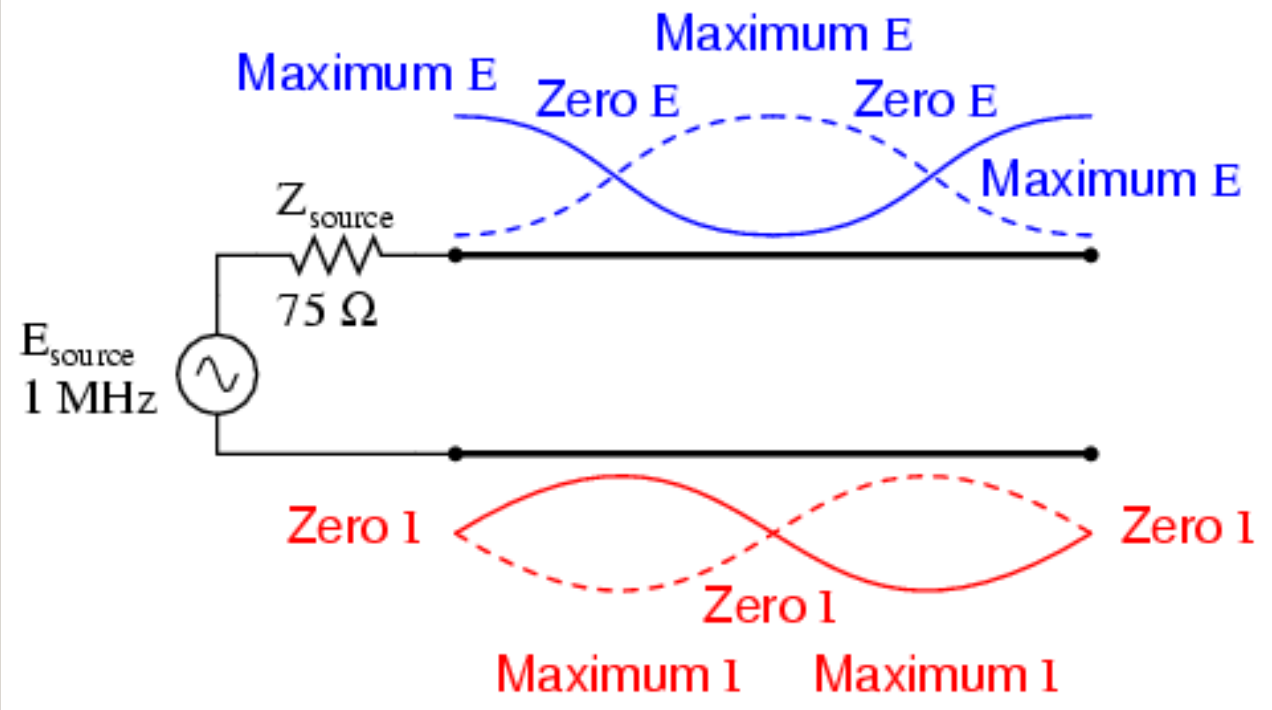


7’49”

Antenna Radiation



Standing Wave on Open Transmission Line



Video 33”

Antenna Radiation

Two-Wire Transmission Line

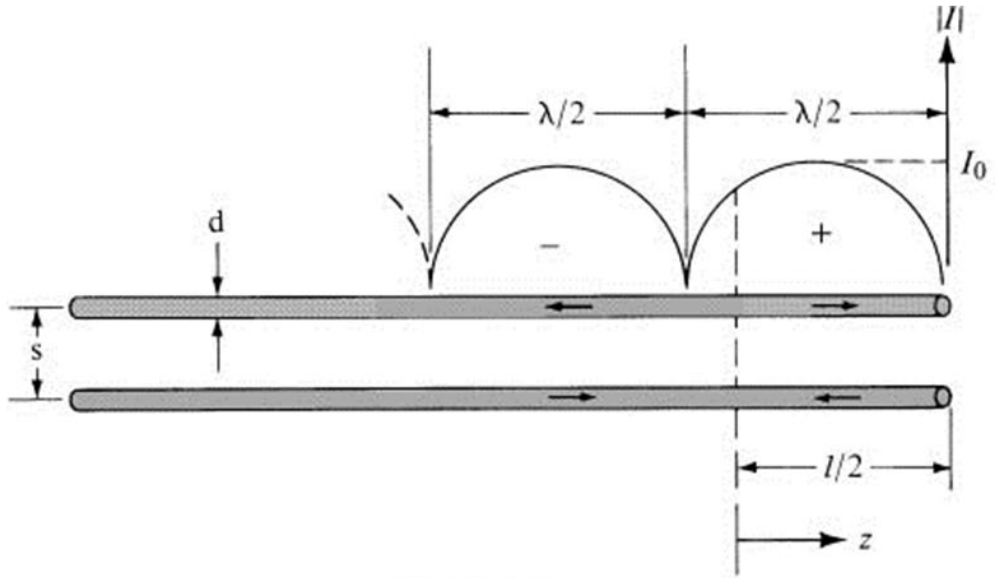


Fig. 1.15a

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Current is zero at the right end.

Radiation on each wire cancels each other

Antenna Radiation

Flared-Transmission Line

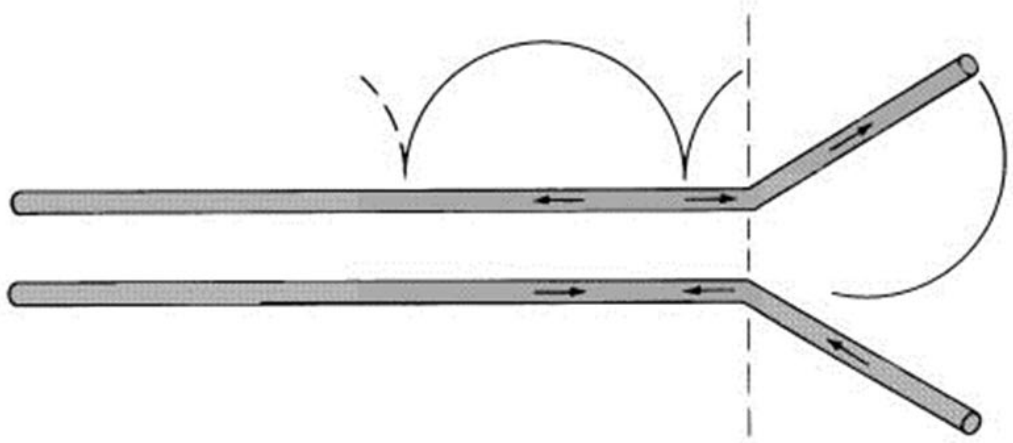

Fig. 1.15b

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Current distribution remains the same

Radiation on each wire cancels each other partially on the flared transmission line

Linear Dipole

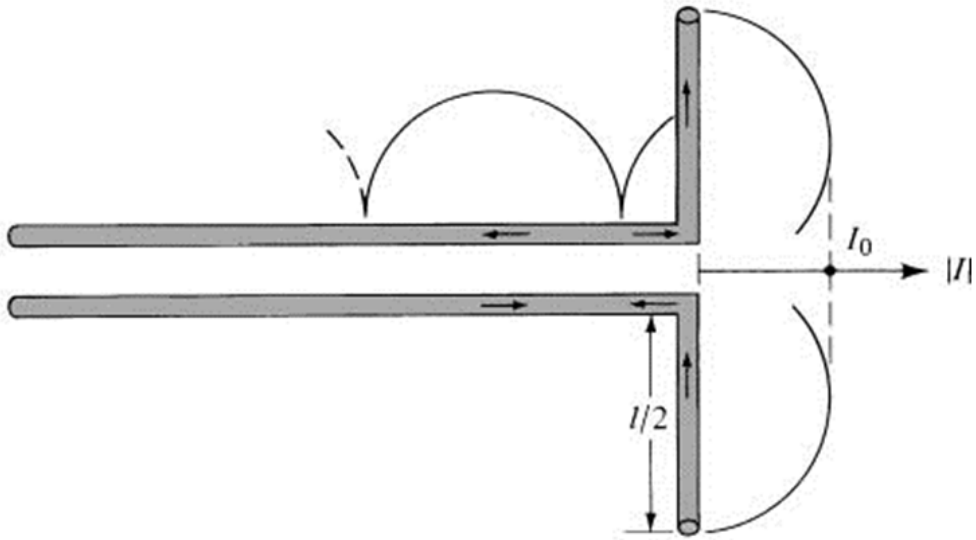

Fig. 1.15c

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Current distribution remains the same

Current flow directions are the same now

Radiation can propagate.

It is called linear dipole.

$\ell = \lambda/2$

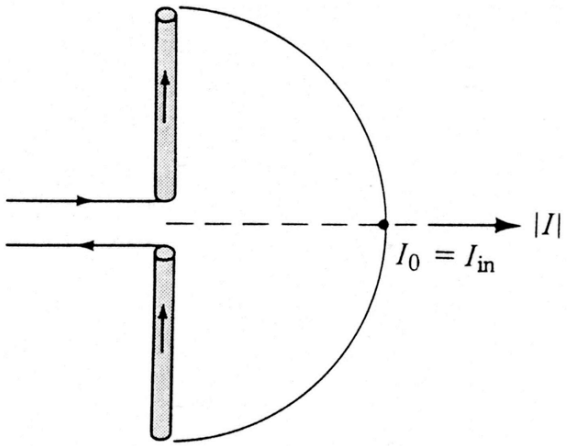

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Fig. 1.16b

$\lambda/2 < \ell < \lambda$

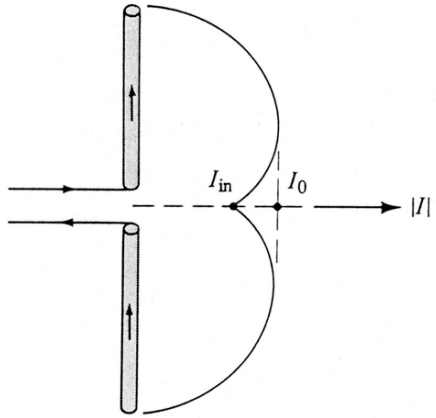

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Fig. 1.16c

$\lambda < \ell < 3\lambda/2$

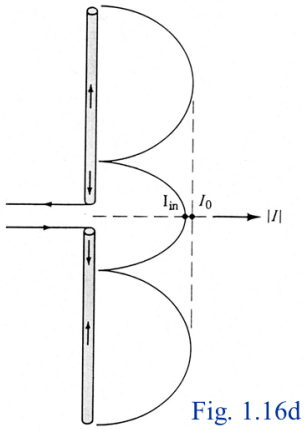

Fig. 1.16d

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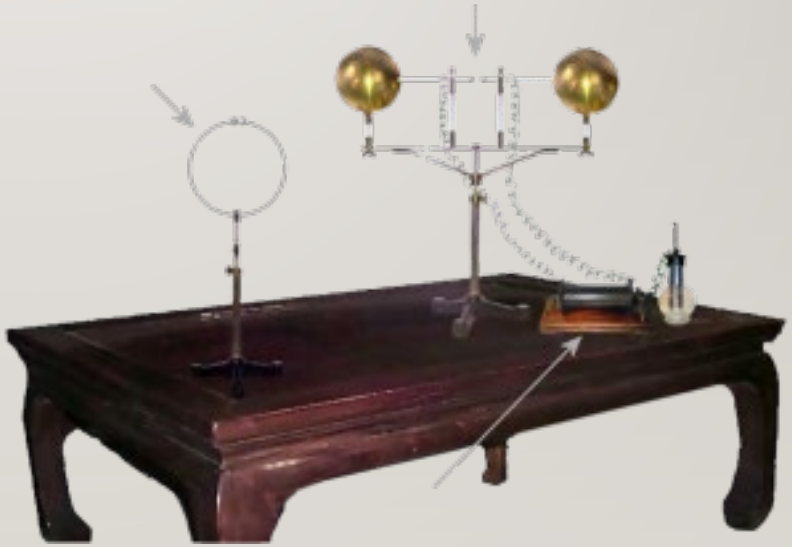
Current distribution changes depending on the length of the linear dipole.

Antenna History

In 1887, Hertz used a sub-wavelength antenna to generate (transmit) and detect (receive) radio waves – the first wireless broadcast. It is considered the first experimental proof of Maxwell's equations

Heinrich Hertz
1857 - 1894



Antenna History

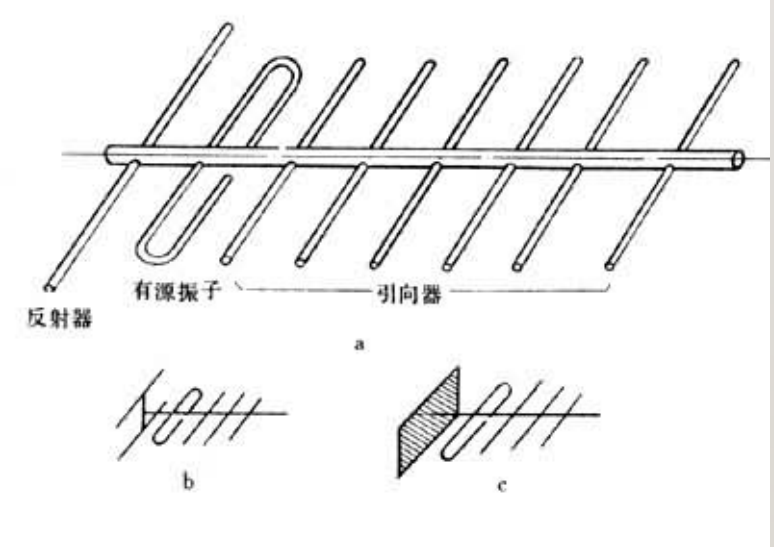
Guglielmo Marconi was sending information across the Atlantic in 1901. For a transmit antenna, he used several vertical wires attached to the ground. Across the Atlantic Ocean, the receive antenna was a 200 meter wire held up by a kite.

Guglielmo Marconi (1874-1937)

Marconi watching associates raising the kite used to lift the antenna at St. John's, Newfoundland, December 1901

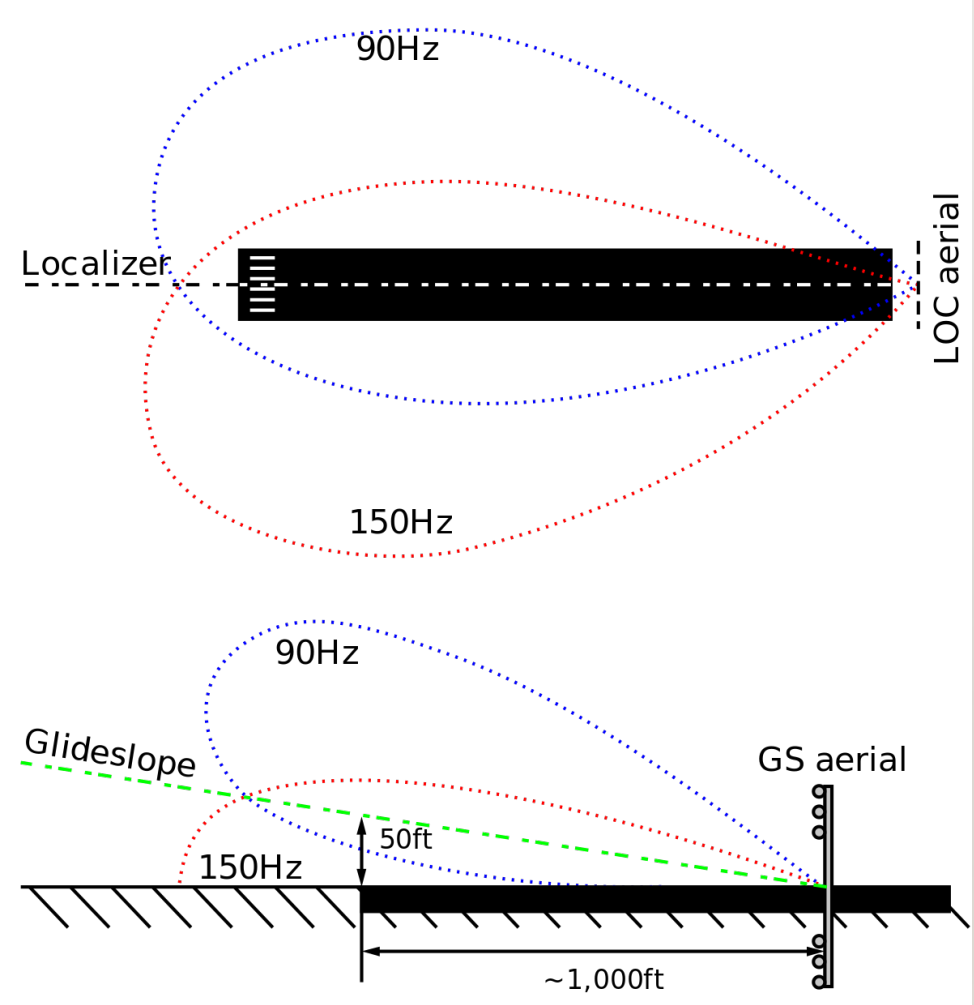
Antenna History

- Yagi-Uda antenna(八木一宇田) invented by Japanese Prof. Hidetsugu Yagi(八木秀次教授) and Shintaro Uda(宇田新太郎讲师) in 1926. Used for long distance communication up to 40km, radar and instrumental landing system (ILS).



How does an aircraft land using an ILS approach - Instrument Landing System explained [3'50"]

Antenna History

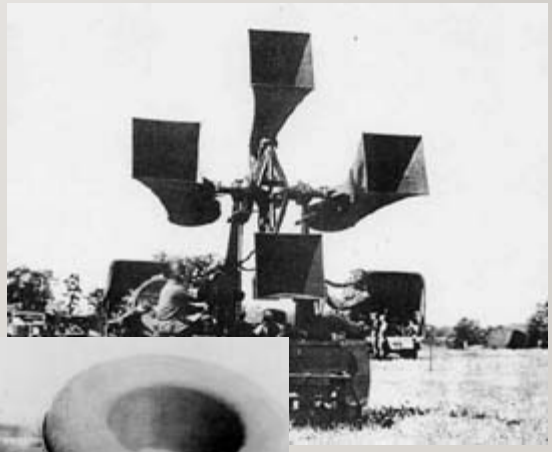


ILS Localizer antennas

ILS GS antennas

Antenna History

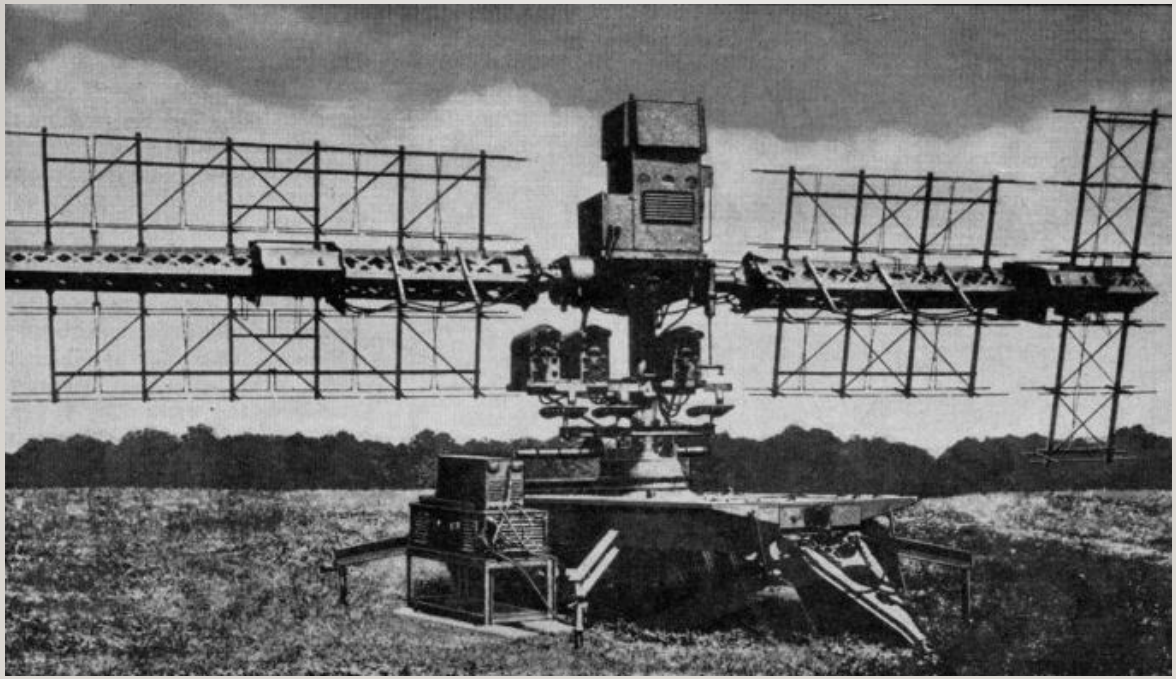
In 1939, the outbreak of World War II promoted the application of radar in military.

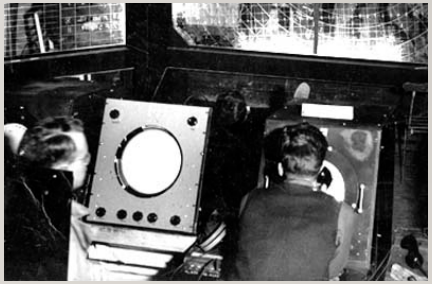


Before radar was invented, sound locator was used

Antenna History

In 1939, the outbreak of World War II promoted the application of radar in military.

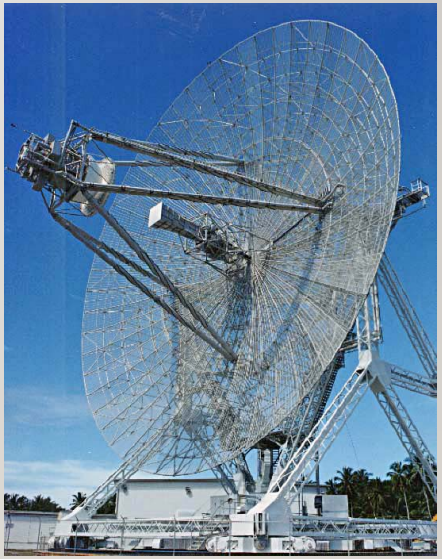




The SCR-268 radar, seen from the back, or control, position, showing the azimuth receiving array at left, the elevation receiving array at right, and the transmitting array in the center.

Antenna Applications

Antennas have many application in communication, navigation, weather forecast, astronomy, etc.



APPLICATIONS OF ANTENNAS

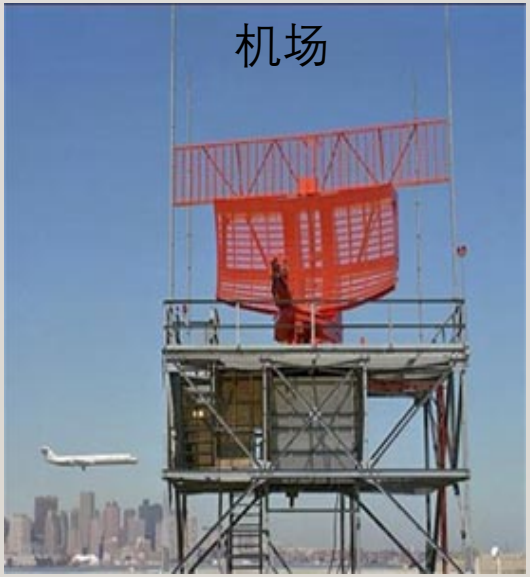
- Wireless communication
- Radar
- Navigation and Localization
- Astronomy
- RFID

WIRELESS COMMUNICATION

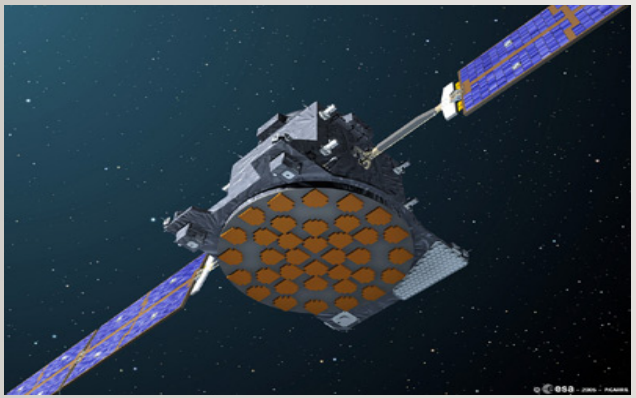
- point to point
- mobile communication
- satellite communication
- radio station broadcasting

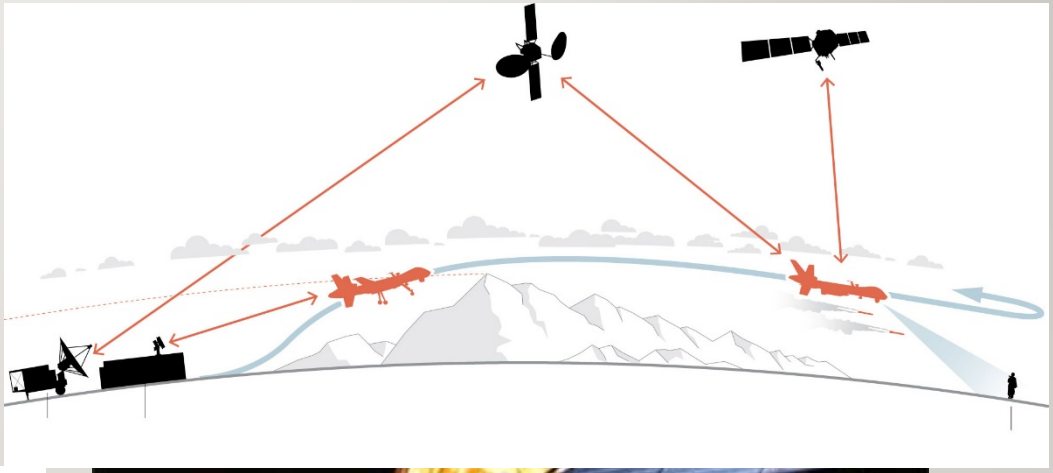
RADAR

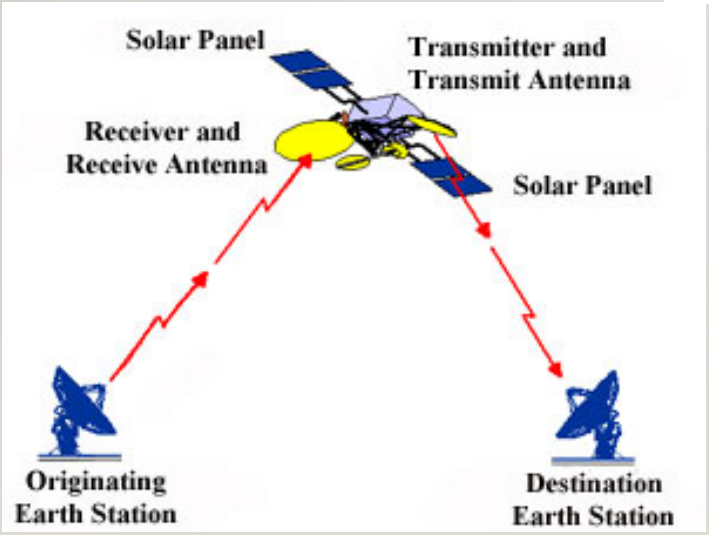
- navigation， surveillance, search (导航， 监测，搜寻）
- tracking, remote sensing, interference (追踪，遥测，干扰)



SATELLITE COMMUNICATION AND POSITIONING





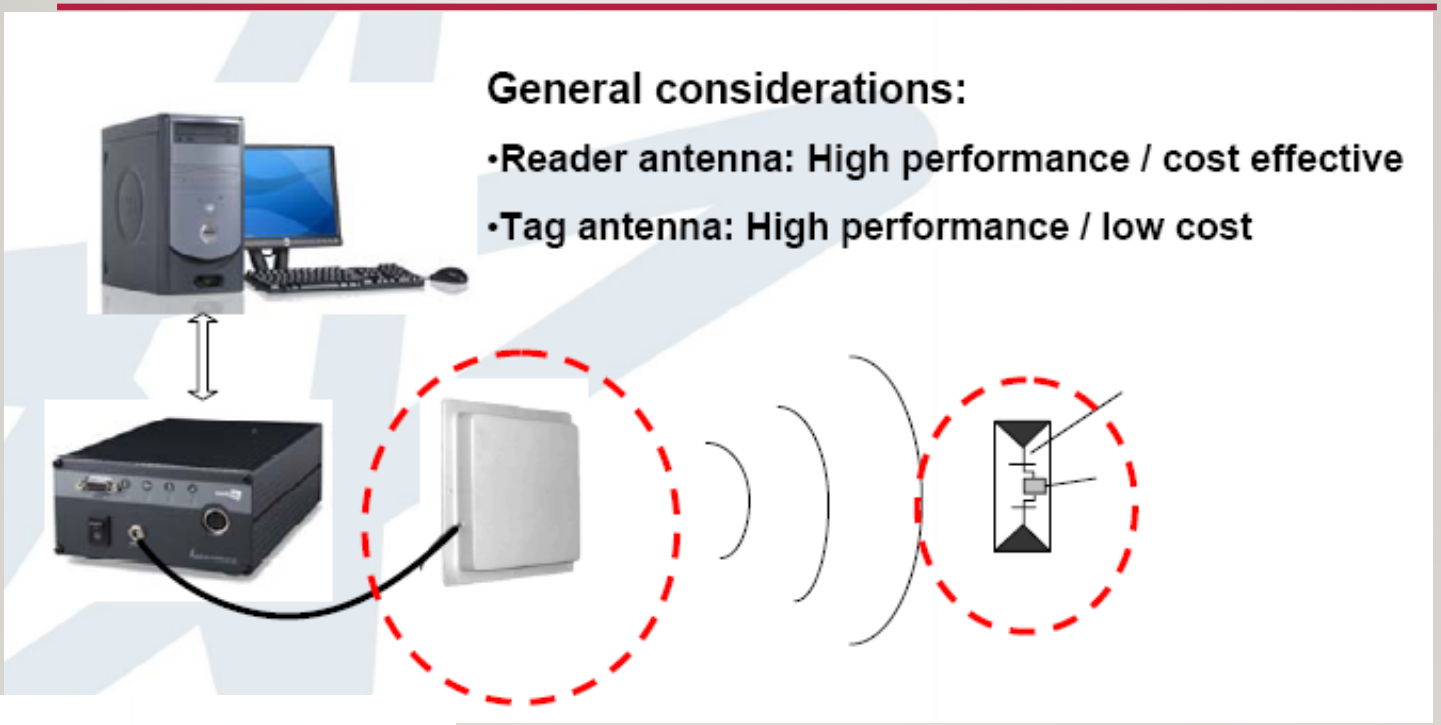


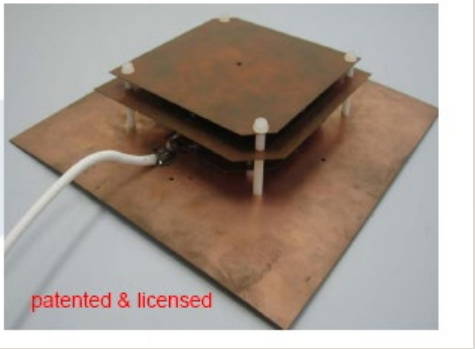
ASTRONOMICAL OBSERVATION

500米口径球面射电望远镜（Five-hundred-meter Aperture Spherical radio Telescope）FAST

图 8.4　俄亥俄州立大学射电观测站的射电望远镜。96 支 11 圈单绕轴向模螺旋天线的阵列，装置在50m长、可调倾斜度的接地平面上。该阵列曾用来测绘第一张最广幅的射电天文图

RFID

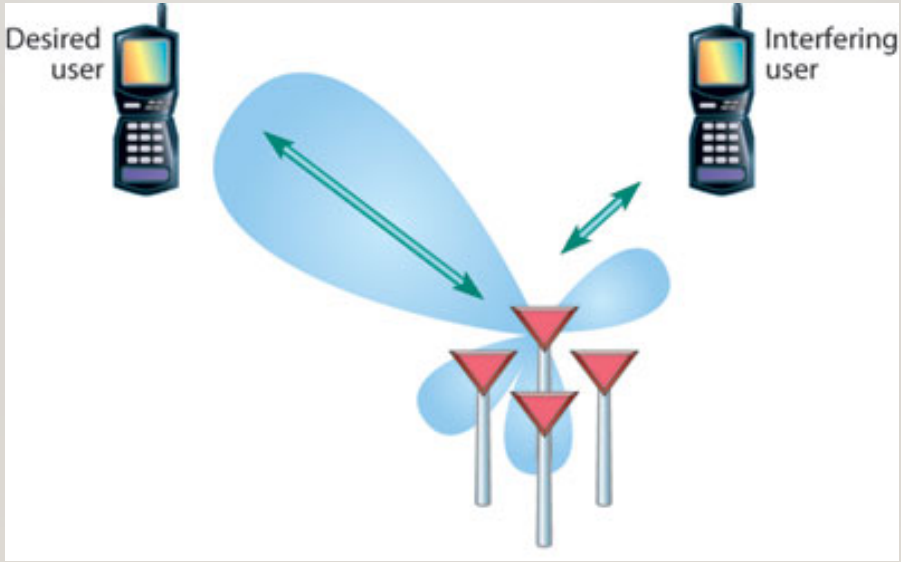

General considerations:
•Reader antenna: High performance / cost effective
•Tag antenna: High performance / low cost


patented & licensed


chip
antenna

SMART ANTENNA

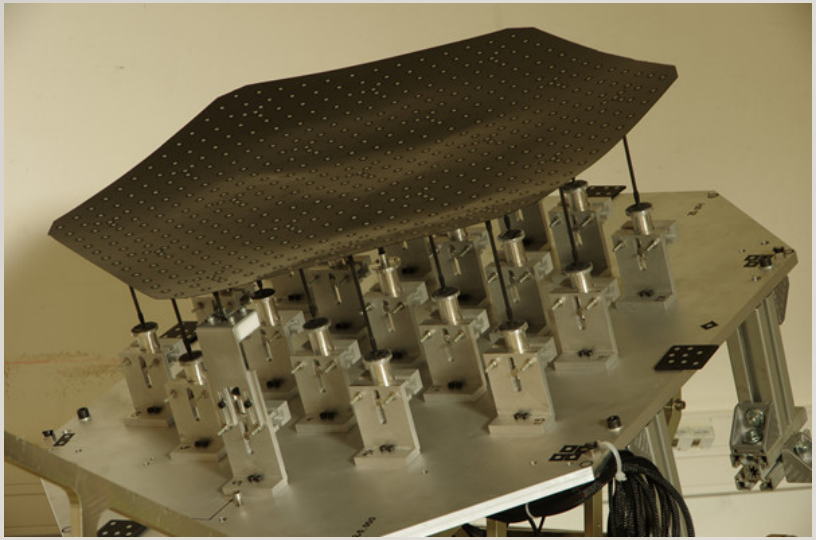
(also known as adaptive array antennas, digital antenna arrays, multiple antennas and, recently, MIMO)
antenna arrays with smart signal processing algorithms used to identify spatial signal signatures such as the direction of arrival (DOA) of the signal use them to calculate beamforming vectors which are used to track and locate the antenna beam on the mobile/target.



RECONFIGURABLE ANTENNA

Smart antennas should not be confused with reconfigurable antennas, which have similar capabilities but are single element antennas and not antenna arrays.

A **reconfigurable antenna** is an **antenna** capable of modifying its frequency and radiation properties dynamically, in a controlled and reversible manner.

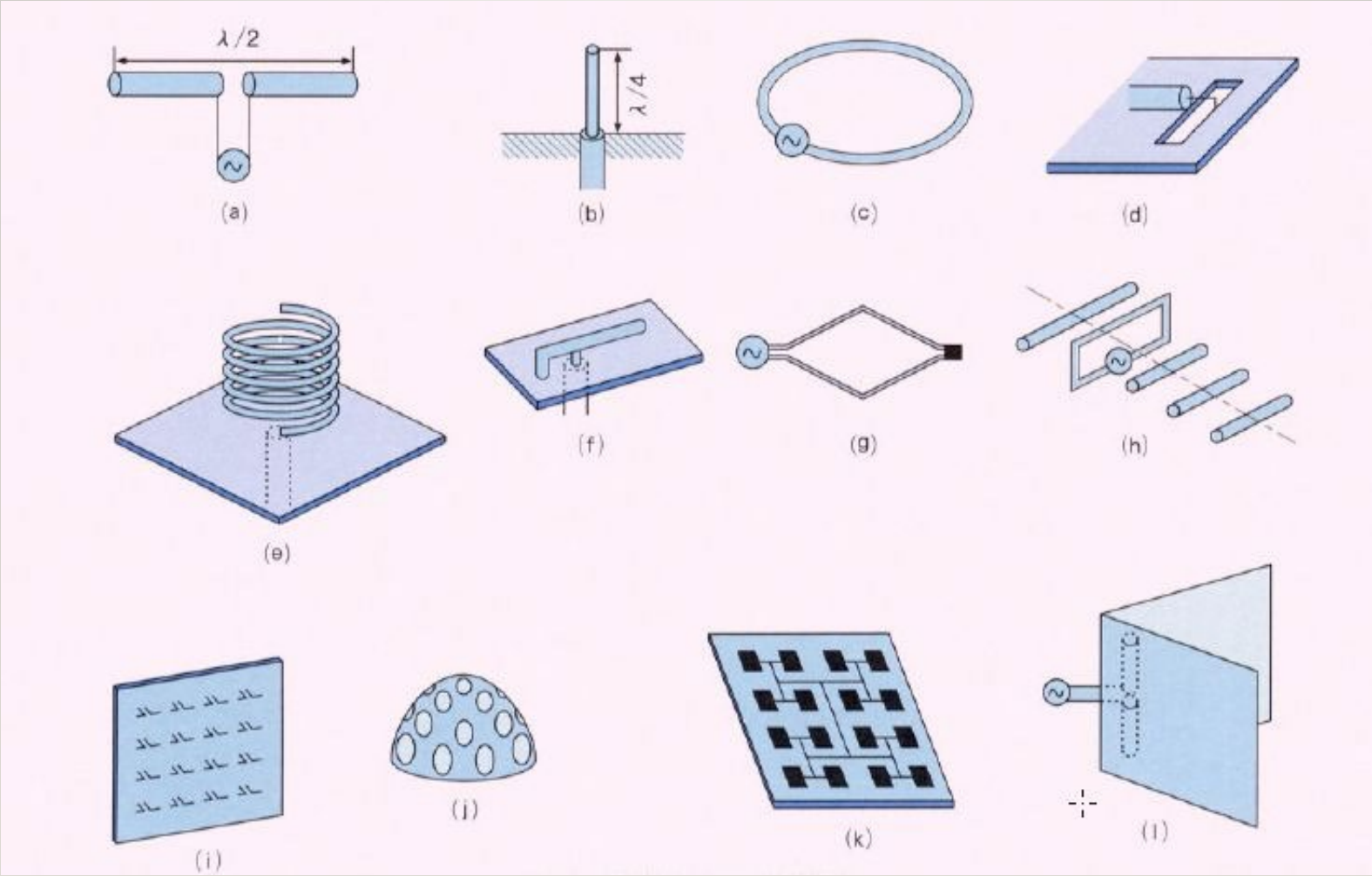


A matrix of linear actuators makes it possible to modify the reflective surface of this reconfigurable antenna using remote commands. Image credit: TAS-F

Classification of antennas

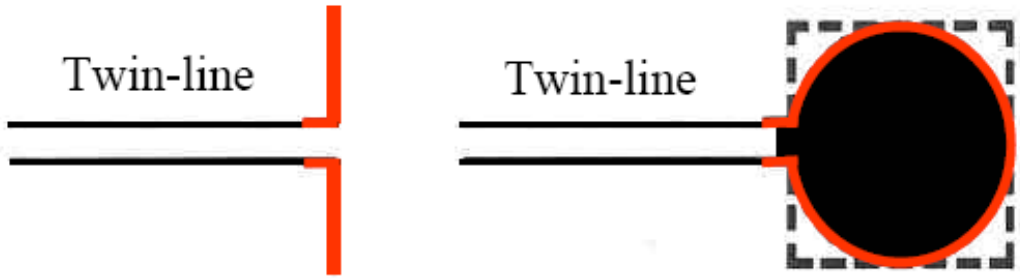
By functionality	Communication antennas, broadcast antennas, radar antennas、navigation antennas, direction finding antennas
directivity	Omni-direction, directional antennas
polarization	Linear, circular, elliptical
Wave type	Standing wave antenna, travelling wave antenna, antenna array
Beamforming (波束成形)	Fixed-beam antenna、electrically steered array (phased array antenna), mechanically steered array, smart antenna
structures	Wire antenna, parabola antenna, slot antenna、microstrip (patch) antenna
Electrical size	Electrically small: antenna size is much less than working wavelength Electrically large: antenna size is comparable to working wavelength

COMMON ANTENNAS



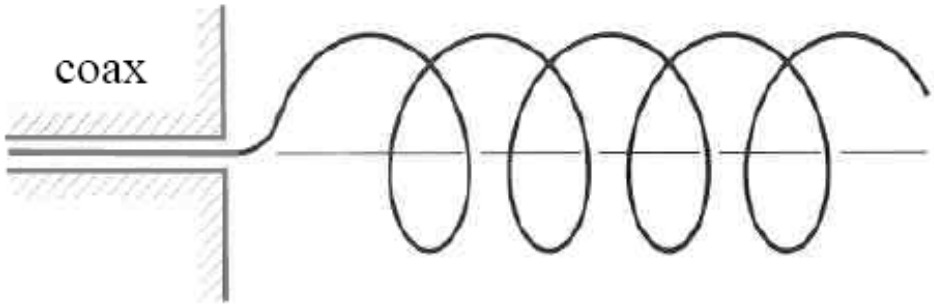
COMMON ANTENNAS

Wire Antennas



(a) Dipole

(b) Loop



(c) Helix

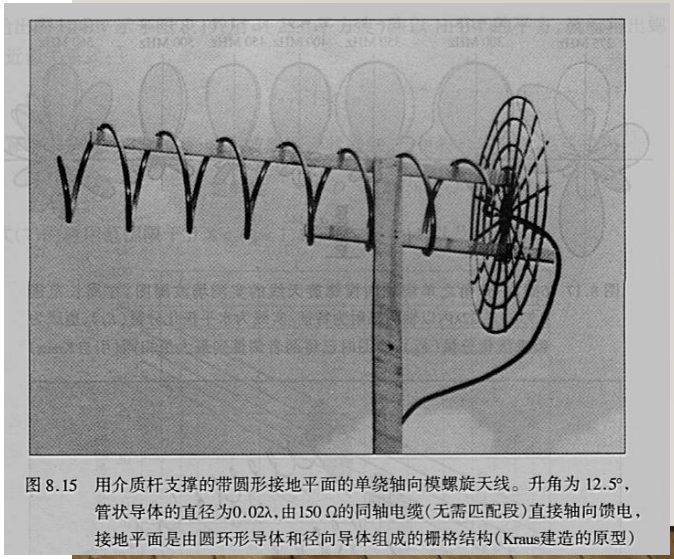
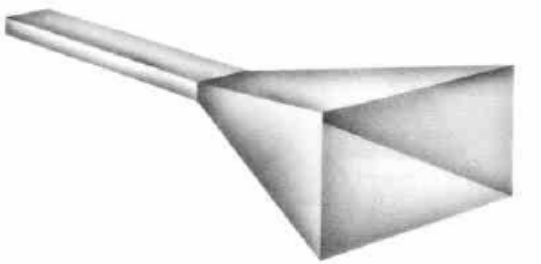


图 8.15 用介质杆支撑的带圆形接地平面的单绕轴向模螺旋天线。升角为 12.5°，管状导体的直径为0.02λ，由150 Ω的同轴电缆（无需匹配段）直接轴向馈电，接地平面是由圆环形导体和径向导体组成的栅格结构（Kraus建造的原型）

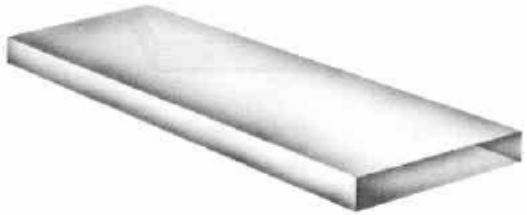
APERTURE ANTENNA

Aperture Antennas



Rectangular Horn

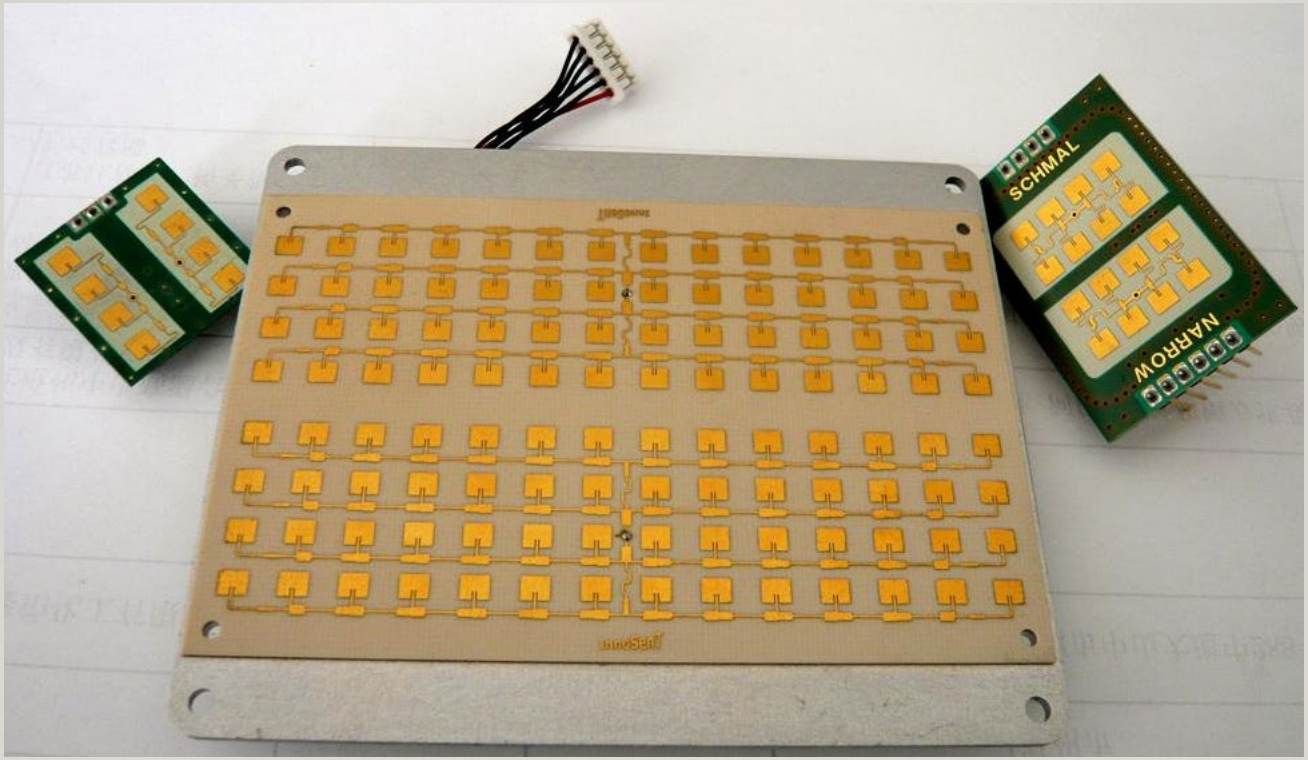
Circular Horn



Rectangular Waveguide

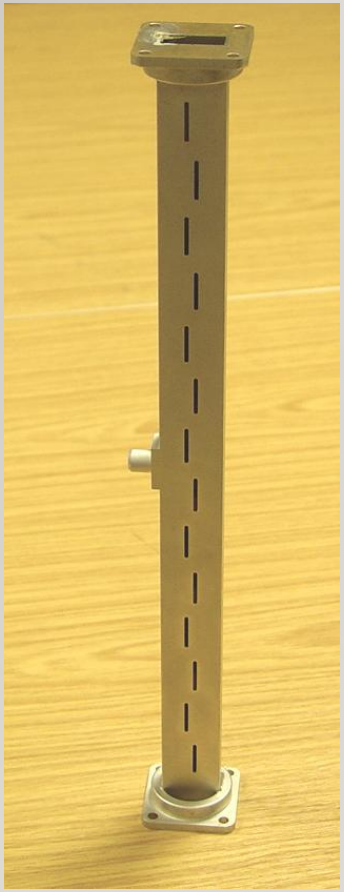
High frequency
High power

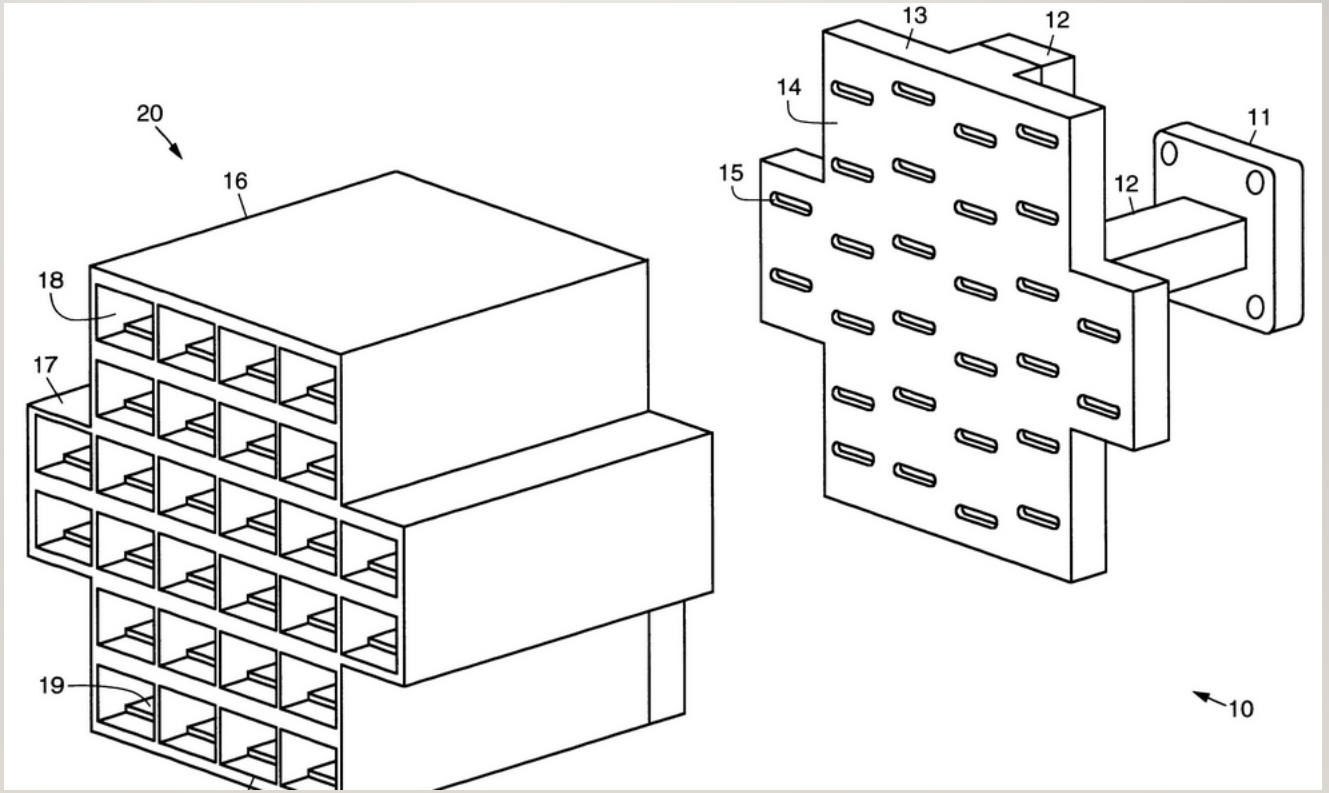
PATCH ANTENNA



Easy Fabrication and Integration

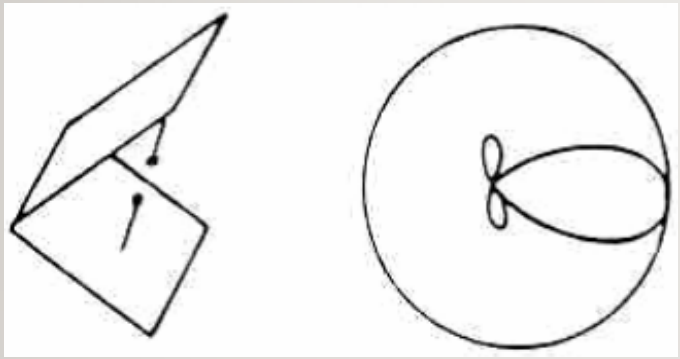
SLOTTED WAVEGUIDE ANTENNA





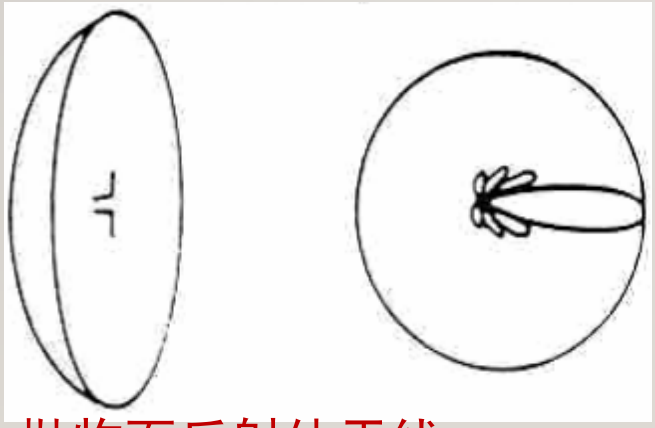
High frequency, High power

Reflector Antenna



角反射天线

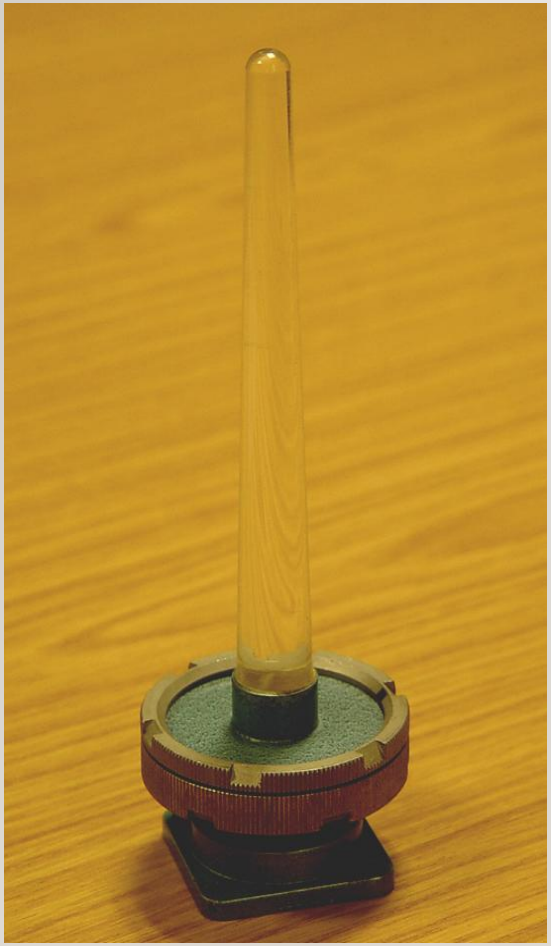
corner reflector antenna

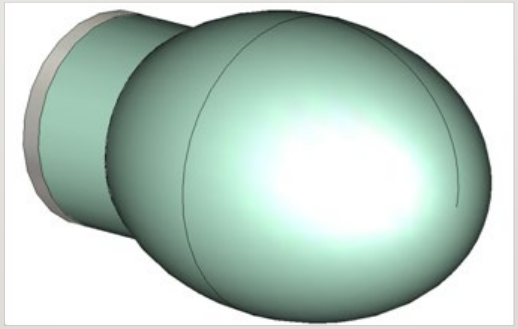


抛物面反射体天线

Parabola reflector antenna

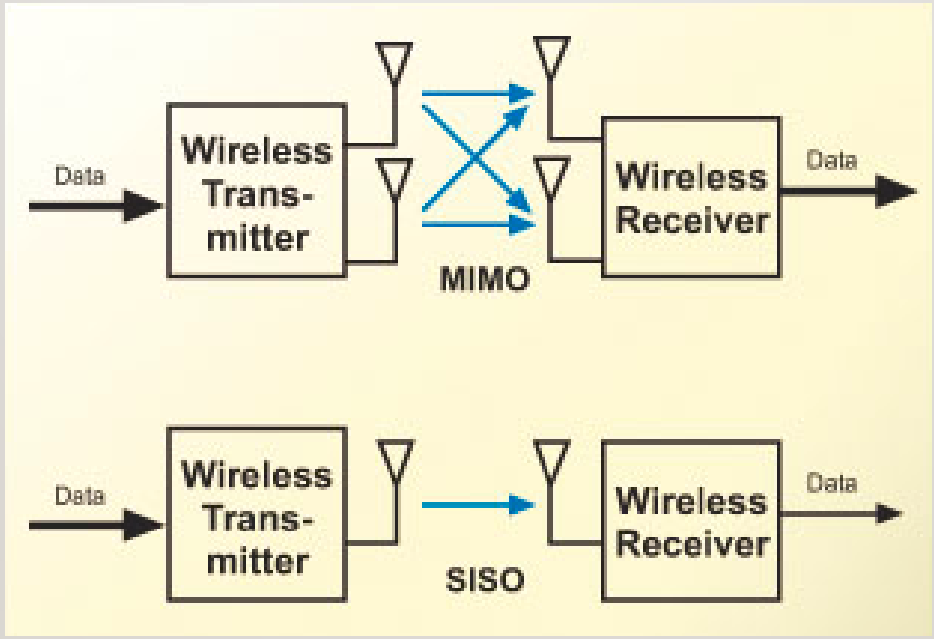
DIELECTRIC RESONATOR ANTENNA (DRA)介质天线





CELLPHONE ANTENNAS

MIMO ANTENNA



推荐论文：水介质天线

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Digital Object Identifier 10.1109/ACCESS.2015.2420103

A Water Dense Dielectric Patch Antenna

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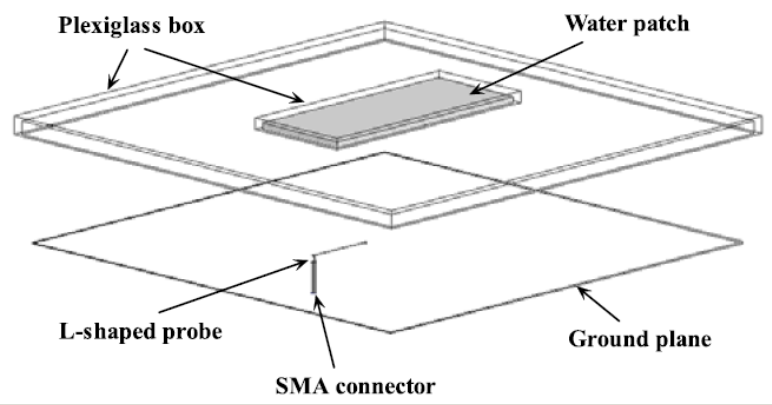
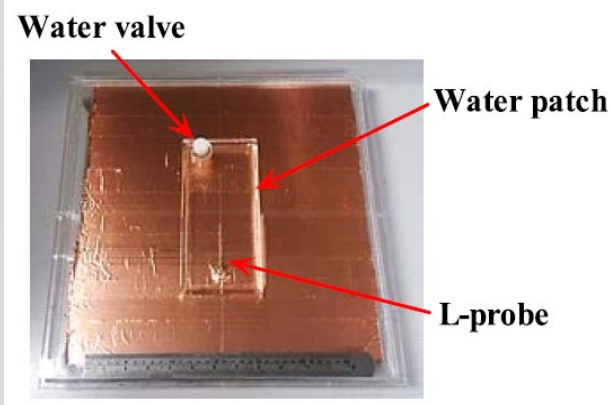
State Key Laboratory of Millimeter Waves, Department of Electronic Engineering, City University of Hong Kong, Hong Kong, China
Corresponding author: Y. Li (lyj870630@gmail.com)

This work was supported by the Research Grants Council through the Hong Kong Special Administrative Region under Project CityU 118412.

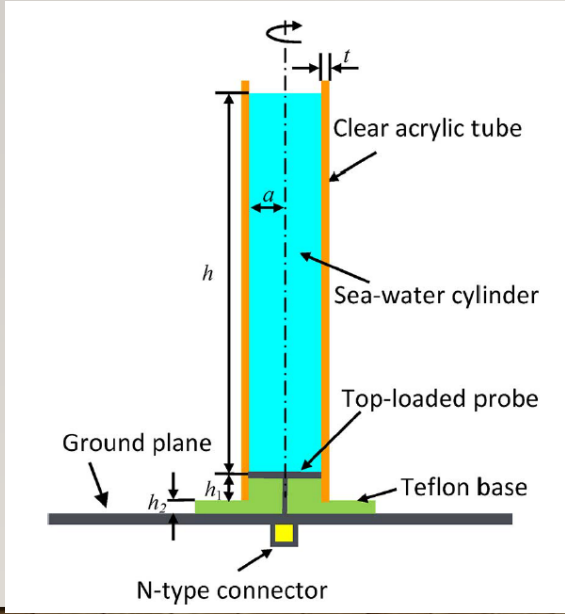




推荐论文：海水天线

High-Efficiency Sea-Water Monopole Antenna for Maritime Wireless Communications

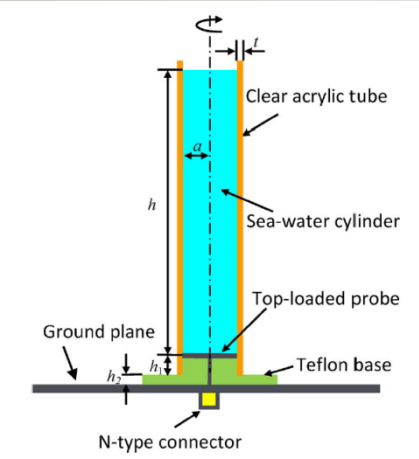
Changzhou Hua, Zhongxiang Shen, *Senior Member, IEEE*, and Jian Lu

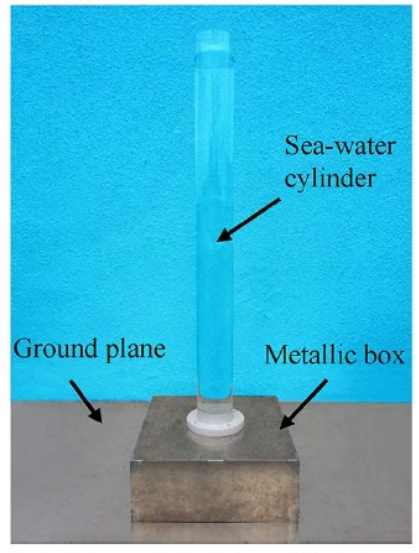


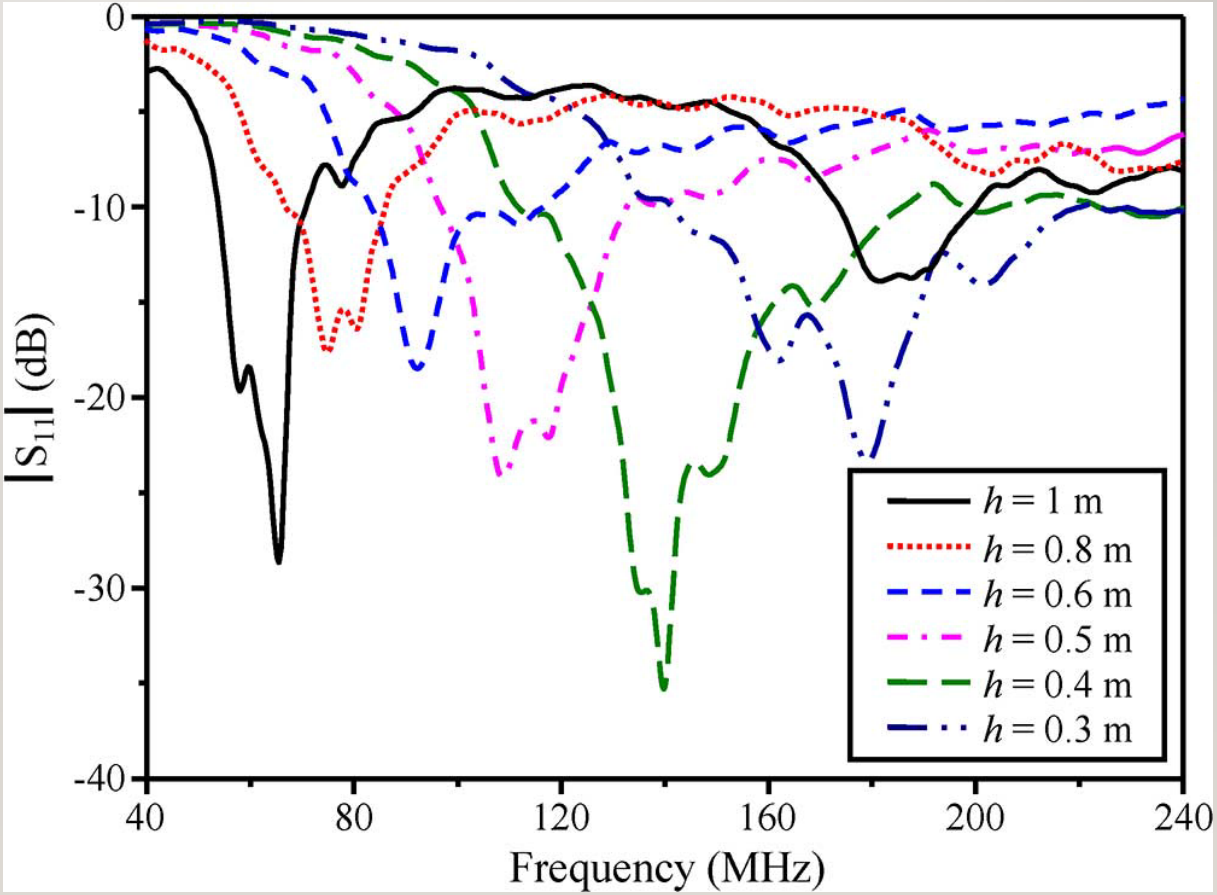
medium. Due to the fluidity, the fluid can be pumped into a plastic tube and thereby "deployed" when the antenna is activated. When deactivated, the fluid can be pumped out or drained and the tube can also be removed, resulting in very small occupation space and radar cross section (RCS). As a special case of fluid antenna, water antenna is probably the most popular, due to its low cost and easy access. Many kinds of water an-

water antenna has high radiation efficiency. Meanwhile, due to the transparency and liquidity of sea water, the proposed antenna is almost optically transparent and can be easily reconfigurable. The center frequency of the antenna is tunable by lengthening or shortening the water cylinder, while the bandwidth of the antenna can be adjusted by widening or narrowing the water cylinder.

推荐论文：海水天线（续）


t
Clear acrylic tube
a
h
Sea-water cylinder
Top-loaded probe
Ground plane
Teflon base
h_1
h_2
N-type connector


Sea-water cylinder
Ground plane
Metallic box


0
-10
-20
-30
-40
$|S_{11}|$ (dB)
40
80
120
160
200
240
Frequency (MHz)
h = 1 m
h = 0.8 m
h = 0.6 m
h = 0.5 m
h = 0.4 m
h = 0.3 m

SEAWATER ANTENNA NOT IN A CYLINDER

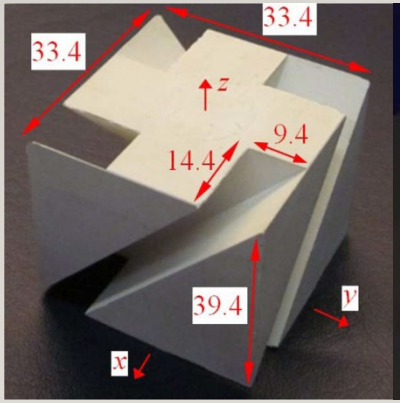
Video 5’39”

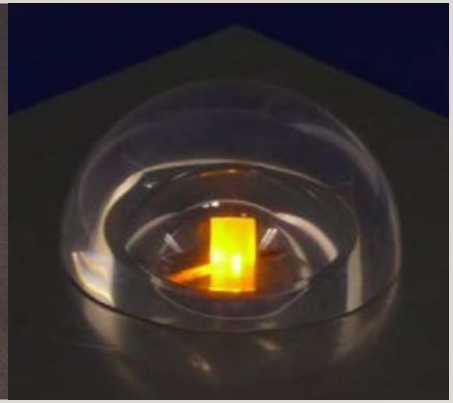
推荐论文：艺术介质天线

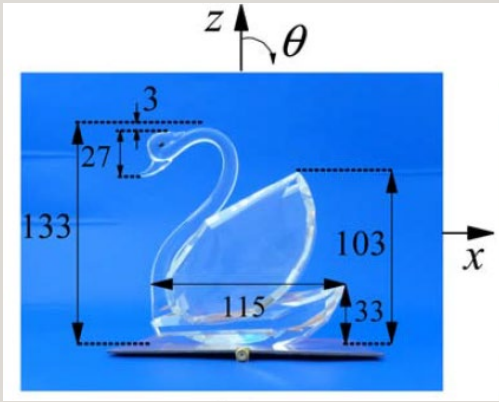
Dielectric Resonator Antennas: From the Basic to the Aesthetic

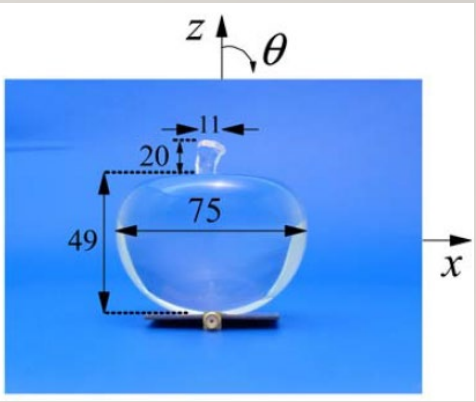
Basic characteristics and low-cost integration design advances in dielectric resonator antennas are discussed, and the use of glass blocks as a decorative technique for these antennas is presented.

By Kwok Wa Leung, *Fellow IEEE*, Eng Hock Lim, *Member IEEE*, and Xiao Sheng Fang, *Student Member IEEE*









Swan antenna video

推荐论文：分形天线

2015 International Conference on Pervasive Computing (ICPC)

Design of Compact Multiband Fractal Antenna for WLAN and WiMAX Applications

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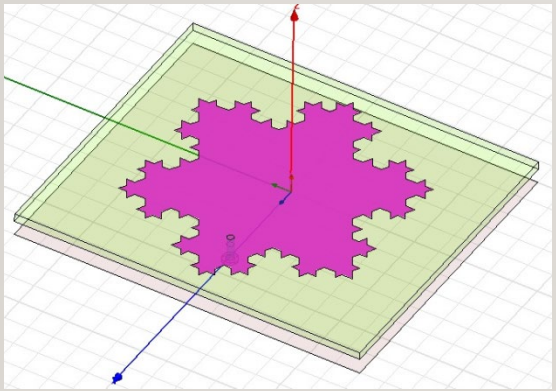
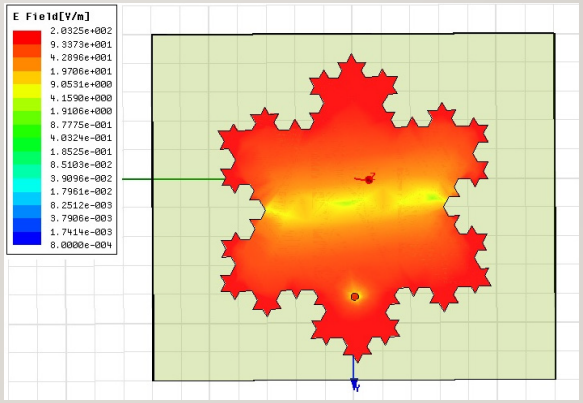
jvajpai@gmail.com





Video

HOMEWORK

Explain why antenna radiates

Use Matlab or Python to plot the current distribution along the halfwave dipole and full wave dipole.

Due: 11:55pm, Feb. 27