Antennas and Radio Wave Propagation

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Department of Communication Engineering

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PREFACE

- **Prerequisites 预修课程:**
  - Electromagnetic Fields and Electromagnetic Waves
  - Microwave Technique
- **Textbook 教材:**
  - Antennas: For All Applications (Third Edition), John D. Kraus and Ronald J. Marhefka, Electronic Industry Press, 2008.
- **Reference Books 参考书:**
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  - 《天线与电波传播》，宋铮，张建华，黄冶编著，西安电子科技大学出版社

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2 Antenna Basic

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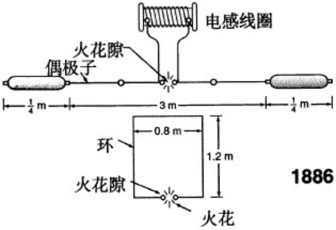
4 Point Sources

5 Array of Point Sources

6 Radio Wave Propagation

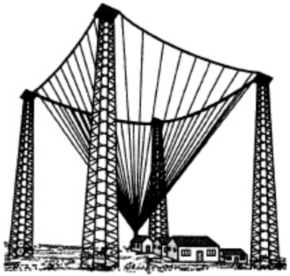
History

- In 1886, Professor Heinrich Rudolph Hertz demonstrated the first wireless electromagnetic system. He was able to produce in his laboratory at a wavelength of 4 m a spark in the gap of a transmitting $\lambda/2$ dipole which was then detected as a spark in the gap of a nearby loop.



History

- In 1901, Guglielmo Marconi performed the first transatlantic transmission from Poldhu in Cornwall, England, to St. John's Newfoundland. This was the dawn of the antenna era.



HISTORY

- In 1940s, antenna technology was primarily centered on wire related radiating elements and frequencies up to about UHF. World War II launched a new era in antennas (such as waveguide apertures, horns, reflectors).
- 1960s-1990s, advances made in computer architecture and technology have had a major impact on the advance of modern antenna technology, numerical methods were introduced that allowed previously intractable complex antenna system configurations to be analyzed and designed very accurately.

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Dimensions and Units

- A dimension defines some physical characteristic. There are 7 fundamental dimensions: length, mass, time, electric current, temperature, luminous intensity and amount of substance, represented as $L, M, T, I, \mathcal{T}, \mathcal{I}, N$
量纲定义某些物理特征，基本量纲有7个。
- A unit is a standard or reference by which a dimension can be expressed numerically. 单位是使量纲能进行数值表述的一种标准或参照。
- In the SI system, there are 7 fundamental units: meter, kilogram, second, ampere, kelvin, candela, and mole for the 7 fundamental dimensions. 国际单位制中有7个基本单位：米，千克，秒，安培，开尔文，坎德拉，摩尔。

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Dimensions and Units

- Second(s): duration of 9,192,631,770 periods of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium-133. 铯-133基态在两个超精细能级之间月前多对应的辐射周期的9,192,631,770倍
- Meter(m): path length traveled by light in vacuum in a time $t = 1/299,792,458$ second. 光在真空中传播$t = 1/299,792,458$秒所经历的路程长度。
- Kilogram(kg): the mass of the international prototype kilogram, a cylinder of platinum-iridium alloy kept at Sèvres, France. 等于保存于法国塞夫里斯的铂铱合金柱体国际千克原器的质量。

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- Mole(mol): an amount of a substance that contains as many elementary entities as there are atoms in 12 grams of pure carbon-12 (C^{12}). This corresponds to a value of $6.02214179(30) \times 10^{23}$. 12克碳-12所包含的原子数。

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SYMBOLS AND NOTES

Table 1: Metric prefix

Numerical value	Prefix	Symbol	U.S. Meaning	Chinese Meaning
10^{18}	exa	E	quintillion	艾
10^{15}	peta	P	quadrillion	拍
10^{12}	era	T	trillion	太
10^{9}	giga	G	billion	吉
10^{6}	mega	M	million	兆
10^{3}	kilo	k	thousand	千
10^{-3}	milli	m	thousandth	毫
10^{-6}	micro	μ	millionth	微
10^{-9}	nano	n	billionth	纳
10^{-12}	pico	p	trillionth	皮
10^{-15}	femto	f	quadrillionth	飞
10^{-18}	atto	a	quintillionth	阿

Symbols and Notes

Example 1.1

$$\mathbf{D} = \hat{\mathbf{x}}200\mathrm{pCm}^{-2}$$

means that the electric flux density $\mathbf{D}$ *is a vector in the positive x direction with a magnitude of 200 picocoulombs per square meter* ($= 200 \times 10^{-10}$ *coulombs per square meter). 电通量密度（矢量）为沿x方向200皮库仑每平方米。*

Example 1.2

$$S = 4\mathrm{Wm}^{-2}\mathrm{Hz}^{-1}$$

means that the flux density S *(a scalar) eqauls 4 watts per square meter per hertz. This can also be written as* $S = 4\mathrm{W}/\mathrm{m}^2\mathrm{Hz}$. *通量密度（标量）为4瓦每平方米赫兹。*

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Dimensional Analysis

It is a necessary condition for correctness that every equation be balanced dimensionally. Dimensional analysis is also useful for determining what the dimensions of a quantity are. 公式两端的量纲平衡是公式成立的必要条件。

Example 1.3

Newton's second law: $\text{Force} = \text{mass} \times \text{acceleration}$

Since acceleration has the dimensions of length per time squared (L/T^2), the dimensions of force are

$$\text{Force} = ML/T^2$$

力的量纲是质量×长度/时间平方，即ML/T^2。

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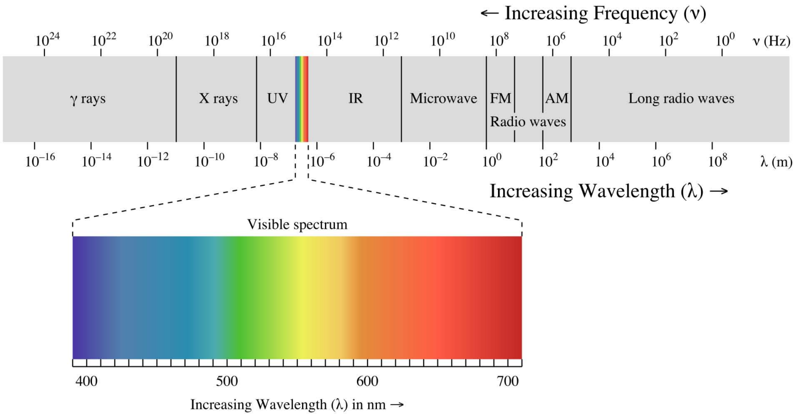
ELECTROMAGNETIC SPECTRUM

The types of electromagnetic radiation are broadly classified into the following classes:

- Radio waves
- Microwave radiation
- Infrared radiation (IR)
- Visible radiation
- Ultraviolet radiation (UV)
- X-ray radiation
- Gamma radiation

ELECTROMAGNETIC SPECTRUM



ELECTROMAGNETIC SPECTRUM

Table 2: ITU frequency band

Band name	Frequency	Wavelength in air	Example uses
ELF	3-30Hz	100,000km-10,000km	Submarine communication
SLF	30-300Hz	10,000km-1000km	Submarine communication
ULF	300-3000Hz	1000km-100km	Communication within mines
VLF	3-30Hz	100km-10km	Navigation, Geophysics
LF	30-300kHz	10km-1km	Navigation, Amateur radio, RFID, AM long-wave broadcasting
MF	300-3000kHz	1000m-100m	AM medium-wave broadcasts
HF	3-30MHz	100m-10m	Shortwave broadcasts, RFID, Over-the-horizon radar
VHF	30-300MHz	10m-1m	FM,TV,weather radio, Maritime Mobile communications
UHF	300-3000MHz	1m-100mm	TV, mobile phones, wireless LAN, Bluetooth, GPS, microwave ovens
SHF	3-30GHz	100mm-10mm	radio astronomy, radars, satellites
EHF	30-300GHz	10mm-1mm	remote sensing, energy weapon
THF or THz	300-3000GHz	1mm-100μm	Terahertz imaging,Terahertz computing/communications

Radio Frequency Band

Table 3: IEEE bands

Band	Frequency range
HF band	3-30MHz
VHF band	30-300MHz
UHF band	300-3000MHz
L band	1-2GHz
S band	2-4GHz
C band	4-8GHz
X band	8-12GHz
K_u band	12-18GHz
K band	18-27GHz
K_a band	27-40GHz
V band	40-75GHz
W band	75-110GHz
mm band	110-300GHz

Table 4: EU, NATO, US ECM

Band	Frequency range
A band	0-0.25GHz
B band	0.25-0.5GHz
C band	0.5-1.0GHz
D band	1-2GHz
E band	2-3GHz
F band	3-4GHz
G band	4-6GHz
H band	6-8GHz
I band	8-10GHz
J band	10-20GHz
K band	20-40GHz
L band	40-60GHz
M band	60-100GHz

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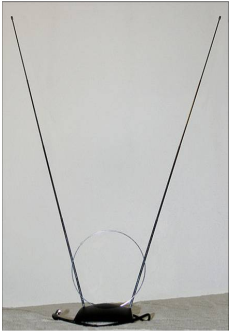
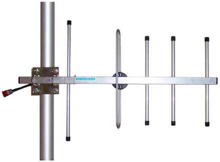
- Patterns
- Beam Area
- Directivity and Gain
- Antenna Apertures
- Radio Communication Link
- Fields From Dipole
- Antenna Field Zones
- Shape-Impedance Considerations
- Polarization

What is Antenna?







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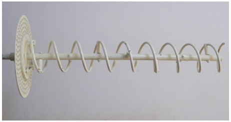

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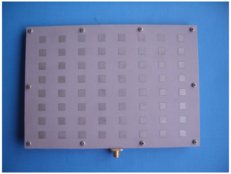

DEFINITION OF ANTENNA

Regardless of antenna type, all involve the same basic principle that radiation is produced by accelerated charge.
不论何种类型，天线都是基于加速电荷产生辐射的共同原理。

The **basic equation of radiation** may be expressed simply as

$$\dot{I}L = Q\dot{v} \tag{2.1}$$

where

$$\begin{aligned} \dot{I} &= \text{time-changing current, } \mathrm{A/s} \\ L &= \text{length of current element, } \mathrm{m} \\ Q &= \text{charge, } \mathrm{C} \\ \dot{v} &= \text{time change of velocity, } \mathrm{m/s^2} \end{aligned}$$

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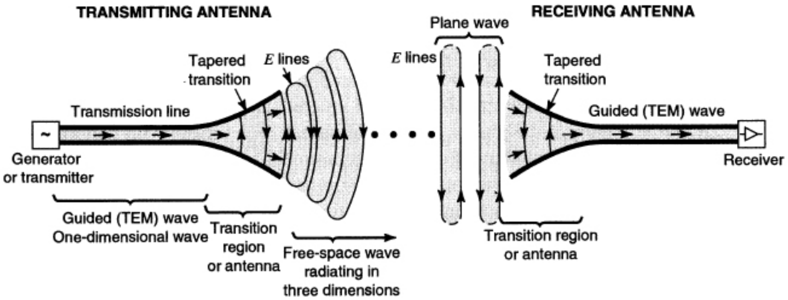

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- An antenna, a means for radiating or receiving radio waves. 天线是发射或接收电磁波的方法。(IEEE Std 1974 - 1983)
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- Array of Similar Sources
- Array Pattern Synthesis
- Array of Dissimilar Sources
- Linear Array of n Isotropic Point Sources
- Null Direction for Arrays

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- Ionospheric modes
- Direct modes
- Tropospheric modes

BASICS

Radio waves propagation characteristics depends on both the medium structure characteristic and characteristic parameters of the waves. 电波传播特性同时取决于媒质结构特性和电波的特征参量。

In the atmosphere, radio propagation is affected by the daily changes of water vapor in the troposphere and ionization in the upper atmosphere, due to the Sun. Understanding the effects of varying conditions on radio propagation has many practical applications, from choosing frequencies for international shortwave broadcasters, to designing reliable mobile telephone systems, to radio navigation, to operation of radar systems. 在大气层中，电波的传播与对流层中的水蒸气浓度以及大气层上层的带电离子浓度有关。

Basics

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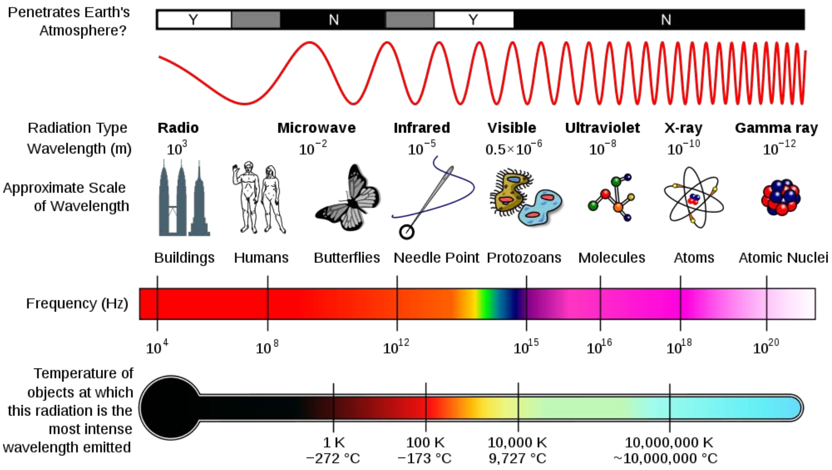
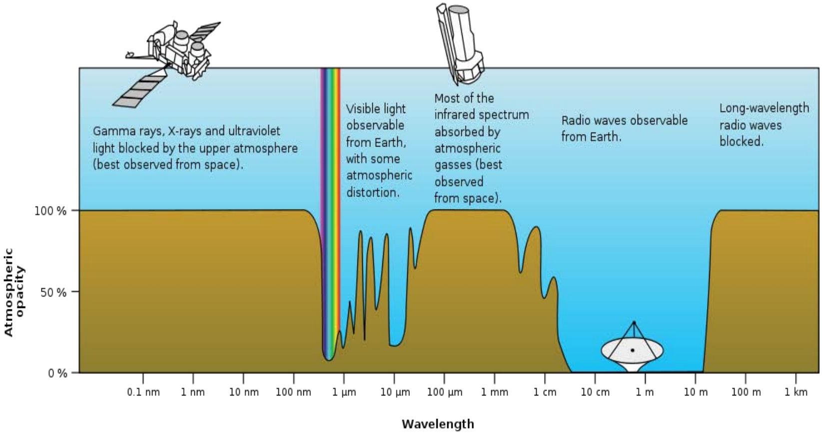


OPACITY OF THE ATMOSPHERE



Main Mode of Radio Propagation

Wave of certain frequency and polarization matches medium with specific conditions, and will have a dominant mode of transmission.一定频率和极化的电波与特定媒质条件相匹配，将具有某种占优势的传播方式。

Generally, radio waves propagate in the following modes:

- Surface modes (ground wave)
- Ionospheric modes (sky wave)
- Direct modes (line-of-sight)
- Tropospheric modes

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