Lecture Note
on
Wireless Communication Engineering Ⅰ

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3. **Haykin, S.,** ***Adaptive Filter Theory*****, Prentice-Hall, 1991**
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Basic Electromagnetics

- **Four fundamental forces**
  - **Gravity force**
  - **EM force**
  - **Weak nuclear force**
  - **Strong nuclear force**

Basic Electromagnetics

- **Time Line of Electromagnetics Phenomena**

Time (sec)	Event	Effect
0	``Big Bang"	Four fundamental forces are coupled
10^{-43}	Gravity frozen out	Weak, strong nuclear and EM are still coupled
10^{-35}	Strong nuclear forces frozen out	Weak nuclear and EM are still coupled
10^{-6}	Protons able to form	The universe is cooling
1	Weak nuclear and EM forces dissociate	Maxwell's Equations are adequate to describe macroscopic field behavior
10^{18}	Maxwell's Equations written	Radio discovered, era of invention in the radio arts
Today	100 years since era of Maxwell	Personal radio communication

Basic Electromagnetics

- **History of Radio Wave Communications**
  - **In 1864, J.C. Maxwell placed the concept of electricity and magnetism into the language of mathematics.**
  - **1886 to 1891, H. R. Hertz demonstrated communications over several meter distances experimentally with his gap apparatus.**
  - **In 1901, G. Marconi had bridged the 3,000-km distance between St. John's, Newfoundland in Canada and Cornwall on the south west tip of England using Morse transmission of the letter ``S''. ー UWB**

Basic Electromagnetics

- **History of Radio Wave Communications**
  - **By the mid 1930s, two-way radio communications in the low VHF range (30 to 40MHz) were a reality.**
  - **By the mid 1940s, radio frequencies for land-mobile communication were allocated in the 150MHz range.**
  - **During the decade of 1960s, 450 MHz frequency range were allocated.**

Basic Electromagnetics

- **History of Radio Wave Communications**
  - **In 1980s, the most significant growth in personal analog (FM) radio communications was taken place at frequencies above 800MHz.**
  - **In 1990s, the digital mobile communications started in the 1.5GHz band.**
  - **In 4G, the high capacity multi-media mobile communications more than 100Mbps are now planned.**

Basic Electromagnetics

- **Communication is an information transmission in *space*.**

  (cf. Memory system is an information transmission in *time* from past to future.)

  Thus communication technology and memory technology are similar to each other, especially in *error control techniques*.

Basic Electromagnetics

- **Why Electromagnetic Waves ?**

  Physically, we need a *wave* for the information transmission in space.

- **Fastest waves have a velocity of light;**

  $c = 3\times10^{8}\left({}^{m}\!/\!{}_{s}\right)$ **(Relativity Theory)**

  - ***Electromagnetic wave*** **(Maxwell);**
    Easily generated and detected
  - ***Gravity wave*** **(Einstein); Hardly generated and detected**

3 Applications of EM Waves

- Information Transmission (Communication)
- Energy Transmission (RFID, SPSS)
- Sensing & Radar (GPS, Car Radar)

Basic Electromagnetics

- **Maxwell's Equation in free space (No current, No Charge)**

$$\nabla \times E = -\frac{\partial B}{\partial t} \qquad \nabla \times H = +\frac{\partial D}{\partial t}$$

$$\nabla \cdot D = 0 \qquad \nabla \cdot B = 0$$

E**: Electric Field,** $D = \varepsilon E$ **: Electric Displacement,**
H**: Magnetic Field,** $B = \mu H$**: Magnetic Displacement**

Basic Electromagnetics

- **Wave Equation**

$$\nabla^2 E = \mu\varepsilon \frac{\partial^2 B}{\partial t^2} \quad \nabla^2 H = \mu\varepsilon \frac{\partial^2 D}{\partial t^2}$$

Variations in space $\left(\nabla^2 = \partial^2/\partial x^2 + \partial^2/\partial y^2 + \partial^2/\partial z^2\right)$ **and variations in time** $\left(\partial^2/\partial t^2\right)$ **are coupled to each other to generate a wave. Electric** (E) **and Magnetic** (H) **fields can propagate with the same velocity of** $1/\sqrt{\mu\varepsilon}$ **.**

μ **: permeability,** ε **: permittivity, material magnetic and electric constants**

Basic Electromagnetics

- **Wave impedance, power Flow & Electromagnetic Energy**
  - **A ratio of E and H is $\sqrt{\mu/\varepsilon} = 377$ Ω. (*Wave Impedance*) ← Schelknoff (Bell Labs.)**
  - $E \times H = S$ **: Power flow per area, *Poynting Vector* directed to the wave propagation.**
  - **Electric energy is equal to magnetic energy; $\frac{1}{2}\varepsilon E^2 = \frac{1}{2}\mu H^2$(cf. We use a word of ``DENPA'' in Japan, but it is an improper wording.)**

Basic Electromagnetics

- **Plane Wave Assumption**

(z-axis is a propagation direction;) in free space →
Transverse Waves → Polarization
This is surprising result!
Because it can be derived from Coulomb's law (Electrostatic field is *longitudinal*)
Circular Polarization: Direct Satellite Broadcasting
Linear Polarization : TV Broadcasting on Ground
Basically, twice channel capacity can be obtained unless cross polarization coupling. (2×2 MIMO)

Basic Electromagnetics

- **Basic phenomena at the obstacle**
  - **Reflection Law; Incident angle = reflection angle**

    Reflection coefficient; $\Gamma = \frac{Z_1 - Z_2}{Z_1 + Z_2}$

    Z_1, Z_2: Wave Impedance
  - **Refraction; refraction angle is determined by Snell's law. (Boundary Condition)**

    Fresnel coefficient, Total reflection → Optical Fiber

    Wave impedance normal to the surface has a polarization dependency. → Polarizer Glasses Brewster Angle (Matching Condition)
  - **Edge Diffraction; Keller coefficient (1950') → GTD, UTD (Asymptotic Theory)**

Basic Electromagnetics

- **Wave and (Space) Signal Processing**
  - **Fourier Transform: Source space distribution ⇔ Far field radiation pattern**
  - **Complex angle → Beam Direction and Beam width**
  - **Polarization Filter: Brewster angle**
  - **Bragg Reflector: Semiconductor Laser, Modulation in space, Space higher harmonics**

  ⇒ **Aliasing in Space**

Basic Electromagnetics

- **Electromagnetic field analysis method**

$\lambda >> L$ **: Quasi-static analysis**

$\lambda \approx L$ **: Microwave (RF field) analysis**

$\lambda << L$ **: Geometric Optics analysis**

where

λ **: wavelength,** L **: typical obstacle size**