Lecture Note
on
Wireless Communication Engineering I

Prof. Kiyomichi Araki
Department of Electrical & Electronics
Tokyo Institute of Technology
South III Bld. Room No. 912
TEL/FAX: +81-3-5734-3495
E-mail: araki@mobile.ee.titech.ac.jp

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References

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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

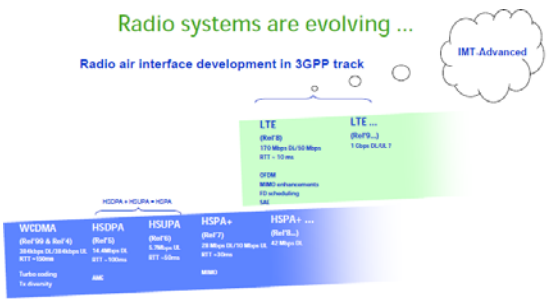
- History of Radio Wave Communications
  - In 1864, J.C. Maxwell placed the concept of electricity and magnetism into the language of mathematics.
  - 1886 to 1891, H. R. Hertz demonstrated communications over several meter distances experimentally with his gap apparatus.
  - In 1901, G. Marconi had 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". －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*.

General Solution to Wave Equation

$$\frac{\partial^2}{\partial x^2}F(x,t)=\frac{\partial^2}{c^2\partial t^2}F(x,t)$$

$$\Downarrow$$

$$F(x,t)=f(x-ct)+g(x+ct)$$

f( ) : Forward Wave
g( ): Backward Wave
c: Velocity of Wave

Basic Electromagnetics

- **Why Electromagnetic Waves ?**

  Physically, we need a *wave* for the information transmission in space.
- **Fastest waves have a velocity of light;**

  $c=3\times10^8\,(m/s)$ **(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)

$$\nabla \times E = -\frac{\partial B}{\partial t} \quad \nabla \times H = +\frac{\partial D}{\partial t}$$
$$\nabla \cdot D = 0 \quad \nabla \cdot B = 0$$

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

$$\text{grad} = \nabla = \begin{bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{bmatrix}$$

$$\text{div} = \nabla \cdot = \nabla^t = \left[\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right]$$

$$\text{rot} = \nabla \times = \begin{bmatrix} 0 & -\frac{\partial}{\partial z} & \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} & 0 & -\frac{\partial}{\partial x} \\ -\frac{\partial}{\partial y} & \frac{\partial}{\partial x} & 0 \end{bmatrix}$$

$$\text{div rot} = \nabla \cdot \nabla \times = 0$$

$$\text{rot grad} = \nabla \times \nabla = -(\nabla \cdot \nabla \times)^t = 0$$

$$\nabla \times \nabla \times = -\nabla^2 + \nabla \nabla \cdot$$

Basic Electromagnetics

- Wave Equation

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

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)

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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

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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

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