

**Lecture Note
on
Wireless Communication Engineering I**

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Basic Electromagnetics

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

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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
10^0	Maxwell's Equations written	Radio discovered, era of invention in the radio arts
Today	100 years since era of Maxwell	Personal radio communication

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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

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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.

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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.

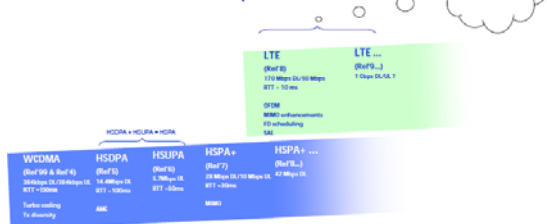
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Radio systems are evolving ...

Radio air interface development in 3GPP track



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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*.

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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

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Basic Electromagnetics

- **Why Electromagnetic Waves ?**
Physically, we need a *wave* for the information transmission in space.
- **Fastest waves have a velocity of light;**
 $c = 3 \times 10^8 \text{ (m/s)}$ (Relativity Theory)
 - *Electromagnetic wave* (Maxwell); Easily generated and detected
 - *Gravity wave* (Einstein); Hardly generated and detected

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3 Applications of EM Waves

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

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Basic Electromagnetics

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

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

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

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

$$\text{div} = \nabla \cdot = \nabla^T = \begin{bmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \end{bmatrix}$$

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

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

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

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

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Basic Electromagnetics

- Wave Equation

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

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

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

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Basic Electromagnetics

- Wave impedance, power Flow & Electromagnetic Energy
 - A ratio of E and H is $\sqrt{\mu/\epsilon} = 377 \Omega$. (*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; $\frac{1}{2}\epsilon E^2 = \frac{1}{2}\mu H^2$ (cf. We use a word of "DENPA" in Japan, but it is an improper wording.)

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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. (**2x2 MIMO**)

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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 \Leftrightarrow
 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
 \Rightarrow Aliasing in Space

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Basic Electromagnetics

- Electromagnetic field analysis method

$\lambda \gg L$: **Quasi-static analysis**
 $\lambda \approx L$: **Microwave (RF field) analysis**
 $\lambda \ll L$: **Geometric Optics analysis**
 where
 λ : wavelength
 L : typical obstacle size

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