Lecture Note
on
Wireless Communication Engineering I

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Contents

Contents

Contents

Contents

4. Noise and Interference
   – Noise and Interference in Transmitter
   – Noise and Interference through Channel
   – Noise and Interference in Receiver
   – Noise Reduction and Interference Canceller

2013/04/12 4

Contents

5. Voice／Data／Image Transmission
   – Voice Transmission
   – Voice Coding - Data Compression
   – Data Transmission
   – Image Transmission
   – MPEG

2013/04/12 5

Contents

6. Error Control Codes
   – ARQ
   – Block Code
   – Convolution Code
   – Turbo Code, LDPC Code
   – Algebraic Decoding
   – Viterbi Algorithm
   – MAP Decoding, BP(Belief Propagation)

2013/04/12 6

Contents

7. Digital Modulation/Demodulation
   – Modulation
   – Demodulation
   – Signal Detection and Decision
   – ASK, FSK, PSK
   – Quadrature Modulation, QAM
   – Narrow Banding
   – Circuit Design
   – Trellis Code Modulation
   – Adaptive Modulation

2013/04/12 7

Contents

8. Multiple Access
   - FDMA
   - TDMA
   - Spread Spectrum, CDMA
   - SDMA
   - User Scheduling

Contents

9. Diversity
   - Diversity Techniques
   - Diversity Reception
   - Multiple Base Station Diversity
   - Route Diversity
   - Diversity and Adaptive Algorithm
   - Space-Time Code

Contents

10. Antennas
   - Fundamental Antenna Parameters
   - Mobile Station Antenna
   - Base Station Antenna
   - Multiplexer
   - Feeding Cable
   - Array Antenna
   - Smart Antenna
   - Adaptive Antenna

Contents

11. RF Circuits
   - Design Issues of Transmitter/Receiver
   - RF Filter Circuits
   - Miniaturization/Low Power Operation
   - Power & Frequency Efficient Amplifier Design
   - RF Components
   - MMIC
   - Software Defined Radio
   - Direct Conversion, Low-IF Conversion

Contents

12. Base-band Signal Processing
   - Multiple Signal Classification
   - Beam Forming
   - Equalizer for Inter-symbol interference
   - Equalizer for Co-channel interference

2013/04/12 12

Contents

13. Cryptography and Security Technique for Mobile Communication
   - Public Key Scheme, Secret Key Scheme
   - Digital Signature, Authentication
   - Encryption

2013/04/12 13

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2013/04/12 14

Basic Electromagnetics

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

2013/04/12 15

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^{8}	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".** －Origin of **UWB**

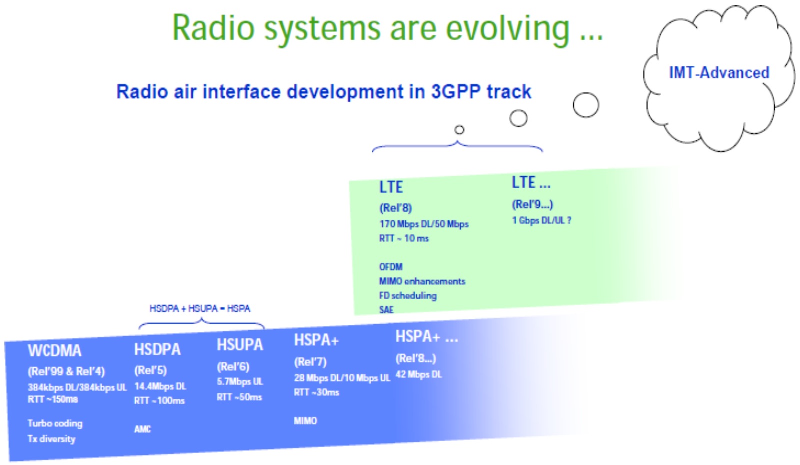
Basic Electromagnetics

- **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

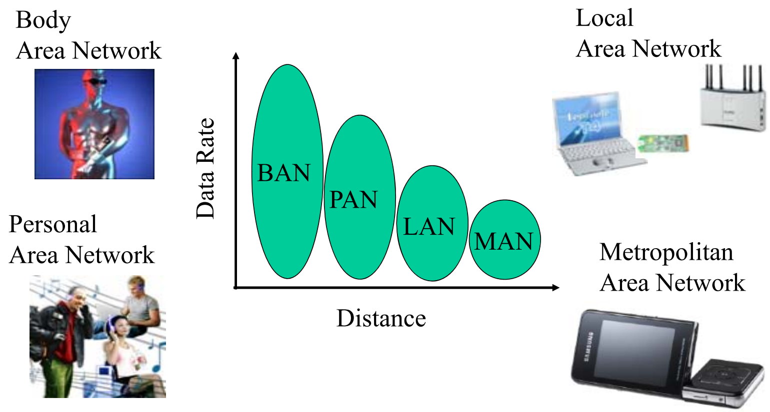
- **History of Radio Wave Communications**
  - **In 1980s, the most significant growth in personal analog (FM) radio communications was taken place at frequencies above 800MHz.**
  - **In 1990s, the digital mobile communications started in the 1.5GHz band.**
  - **In 4G, the high capacity multi-media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

Radio systems are evolving ...



2013/04/12 20

Wireless Communication Systems



2013/04/12 21

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*.

2013/04/12 22

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

2013/04/12 23

Basic Electromagnetics

- **Why Electromagnetic Waves ?**
  Physically, we need a *wave* for the information transmission in space.
- **Fastest waves have a velocity of light;** $c = 3\times10^{8}\left(\frac{m}{s}\right)$ **(Relativity Theory)**
  - ***Electromagnetic wave*** **(Maxwell); Easily generated and detected**
  - ***Gravity wave*** **(Einstein); Hardly generated and detected**

2013/04/12 24

3 Applications of EM Waves

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

2013/04/12 25

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**

2013/04/12 26

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

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

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

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

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

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

2013/04/12 27

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

2013/04/12 28

Basic Electromagnetics

- **Wave impedance, Power Flow, Electromagnetic Energy**
  - **A ratio of E and H is $\sqrt{\mu/\varepsilon} = 377\ \Omega$.**
    (*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;**
    $\frac{1}{2}\varepsilon E^2 = \frac{1}{2}\mu H^2$

2013/04/12 29

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)

2013/04/12 30

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)**

2013/04/12 31

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**

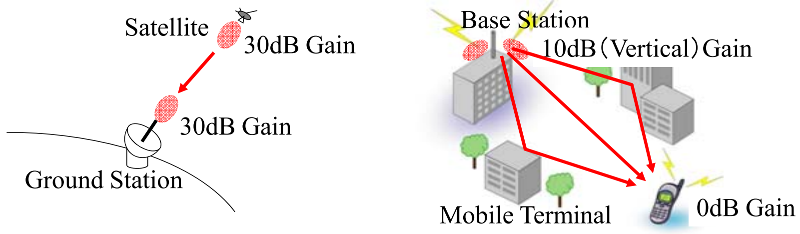
  ⇒ **Aliasing in Space**

2013/04/12 32

Fixed and Mobile Wireless

Satellite Communication
Circular Polarization

Mobile Communication
Linear Polarization



2013/04/12 33

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**

2013/04/12 34