KNUST
Telecomm.
Engineering

TE 474

LECTURE 1:

Introduction to Microwave Engineering

2017.01.11

Abdul-Rahman Ahmed

ICnSYS LAB

Telecommunications Today

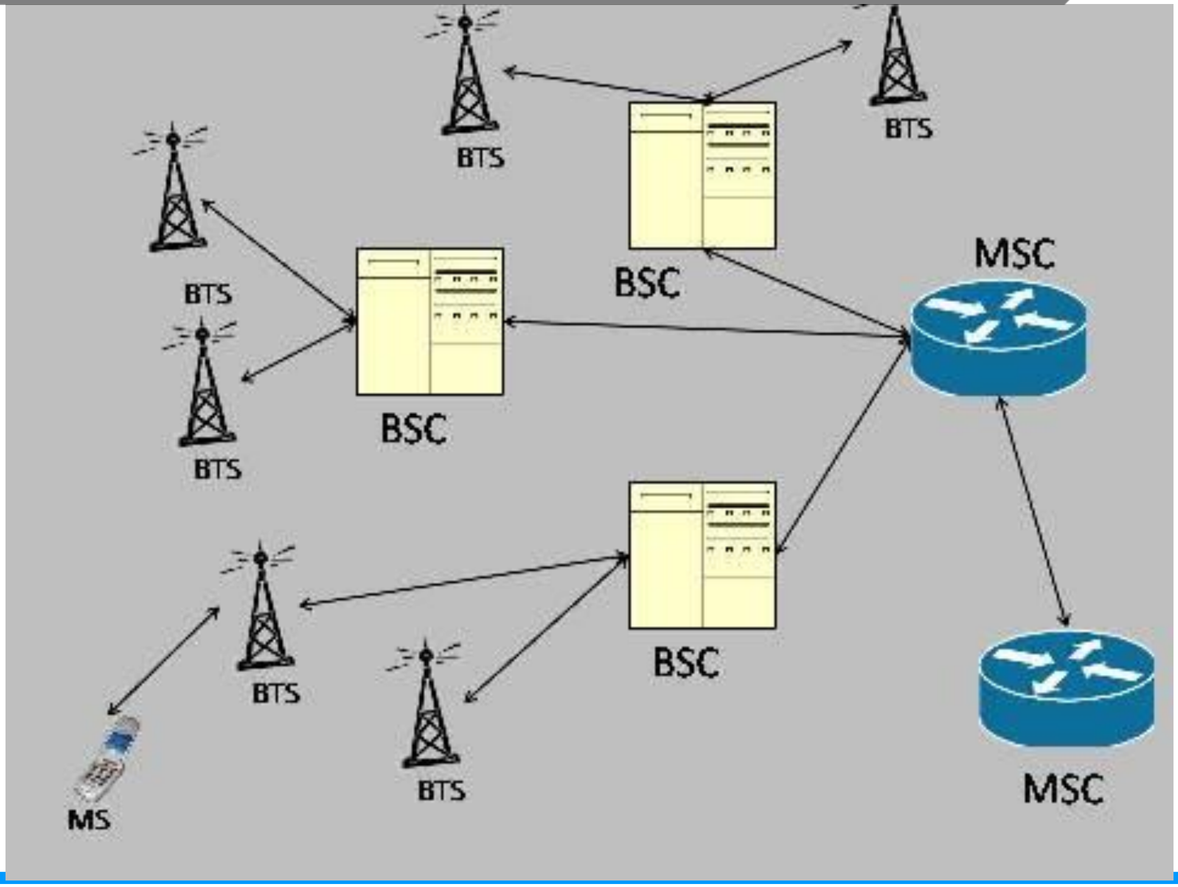


Fig. 1: Typical Mobile Communication System

Microwaves

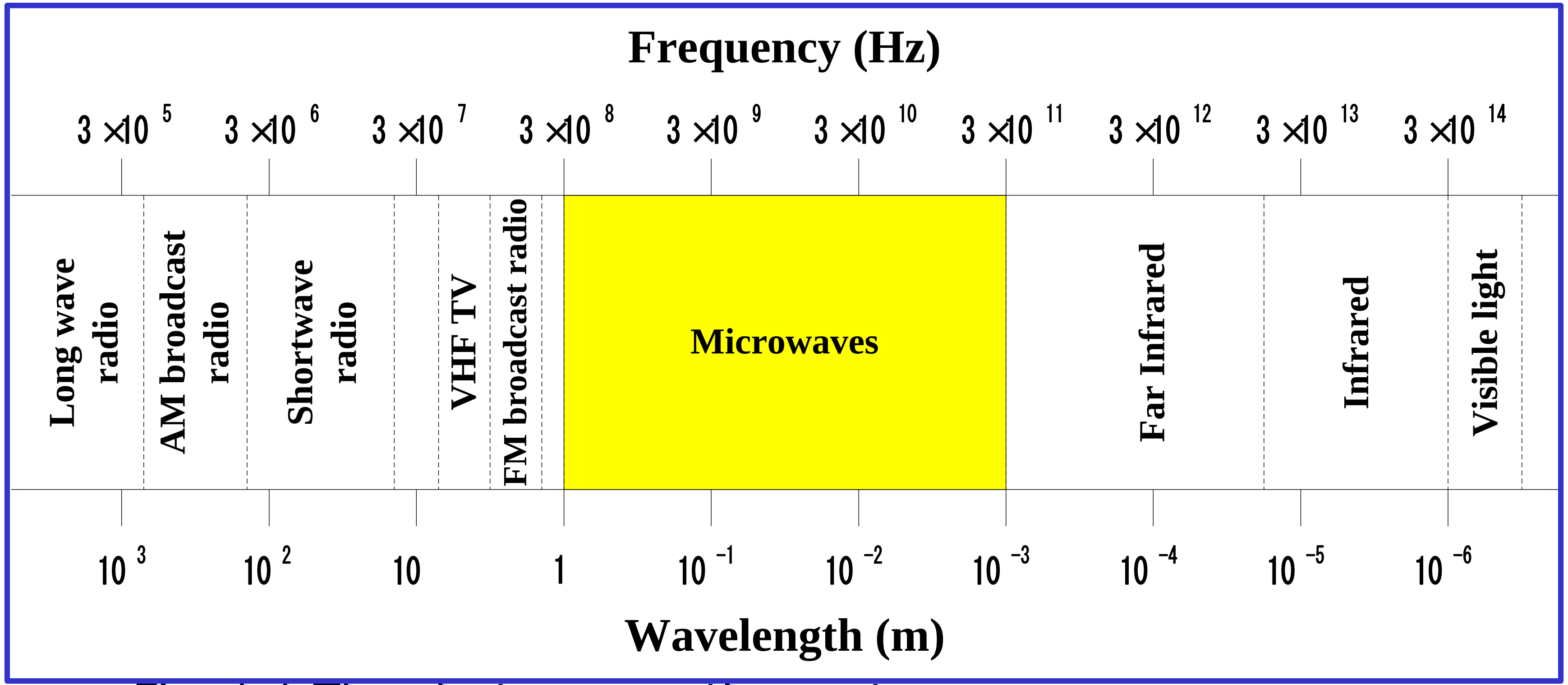


Fig. 1.1 The electromagnetic spectrum

Introduction to Microwaves Engineering

KNUST
Telecomm.
Engineering

Typical Frequencies		Approximate Band Designations	
AM broadcast band	335-1605 kHz	L-band	1-2 GHz
Shortwave radio	3-30 MHz	S-band	2-4 GHz
FM broadcast band	88-108 MHz	C-band	4-8 GHz
VHF TV (2-4)	54-72 MHz	X-band	8-12 GHz
VHF TV (5-6)	76-88 MHz	Ku-band	12-18 GHz
VHF TV (7-13)	174-216 MHz	K-band	18-26 GHz
UHF TV (14-83)	470-890 MHz	Ka-band	26-40 GHz
Microwave ovens	2.45 GHz	U-band	40-60 GHz

History of Microwave Engineering

- Modern electromagnetic theory was formulated in 1873 by James Clerk Maxwell solely from mathematical considerations.
- Maxwell's formulation was cast in its modern form by Oliver Heaviside, during the period 1885 to 1887.
- Heinrich Hertz, a German professor of physics understood the theory published by Maxwell, carried out a set of experiments during 1887-1891 that completely validated Maxwell's theory of electromagnetic waves.
- It was only in the 1940's (World War II) that microwave theory received substantial interest that led to radar development.
- Communication systems using microwave technology began to develop soon after the birth of radar.
- The advantages offered by microwave systems, wide bandwidths and line of sight propagation, provides an impetus for the continuing development of low cost miniaturized microwave components.

Lumped circuit element approximation is not Valid at microwave frequencies

- **lumped element**

At much lower frequencies, there is insignificant phase variation across the dimensions of a component.

- **distributed element**

At microwave frequencies, the phase of a voltage or current changes significantly over the physical extent of the device.

Maxwell's Equations

"point" or differential form

$$\nabla \times \vec{\mathcal{E}} = -\frac{\partial \vec{\mathcal{B}}}{\partial t} - \vec{\mathcal{M}}$$ (Faraday's law)

$$\nabla \times \vec{\mathcal{H}} = \frac{\partial \vec{\mathcal{D}}}{\partial t} + \vec{\mathcal{J}}$$ (Ampere's circuital law)

$$\nabla \bullet \vec{\mathcal{D}} = \rho$$

$$\nabla \bullet \vec{\mathcal{B}} = 0$$

(Gauss's law)

$\vec{\mathcal{E}}, \vec{\mathcal{B}}, \vec{\mathcal{H}}, \vec{\mathcal{D}}$ functions of (x, y, z, t)

Maxwell's Equations

$\vec{\mathcal{E}}$ is the electric field intensity, in V/m

$\vec{\mathcal{H}}$ is the magnetic field intensity, in A/m

$\vec{\mathcal{D}}$ is the electric flux density, in $\mathrm{Coul/m^2}$

$\vec{\mathcal{B}}$ is the magnetic flux density, in $\mathrm{Wb/m^2}$ (Tesla)

$\vec{\mathcal{M}}$ is the (fictitious) magnetic current density, in $\mathrm{V/m^2}$

$\vec{\mathcal{J}}$ is the electric current density, in $\mathrm{A/m^2}$

ρ is the electric charge density, in $\mathrm{Coul/m^3}$

Maxwell's Equations

Constitutive relation in free space

$$\vec{\mathscr{B}} = \mu_0 \vec{\mathscr{H}} \qquad \vec{\mathscr{D}} = \varepsilon_0 \vec{\mathscr{E}}$$

$\mu_0 = 4\pi \times 10^{-7}$ H/m : Permeability of free space

$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m : Permittivity of free space

Maxwell's Equations

KNUST
Telecomm.
Engineering

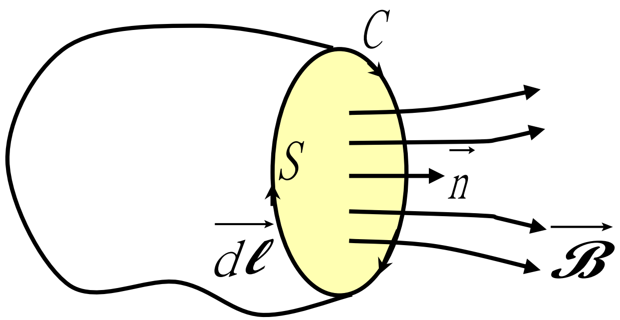
Integral form of Maxwell's equations

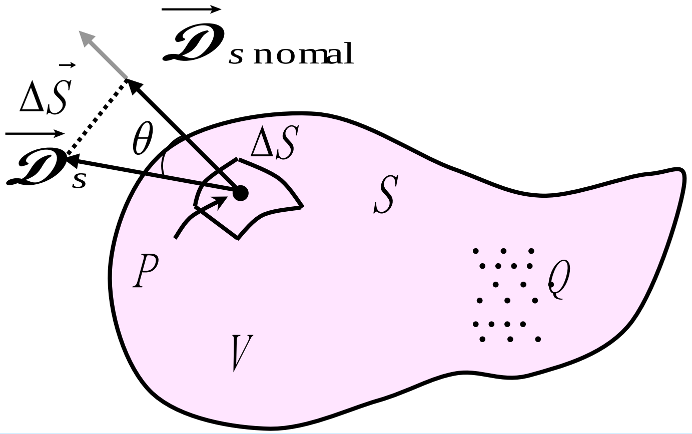
$$\oint_c \vec{\mathcal{E}} \bullet \vec{d\ell} = -\frac{\partial}{\partial t}\int_s \vec{\mathcal{B}} \bullet \vec{ds} - \int_s \vec{\mathcal{M}} \bullet \vec{ds}$$

$$\oint_c \vec{\mathcal{H}} \bullet \vec{d\ell} = \frac{\partial}{\partial t}\int_s \vec{\mathcal{D}} \bullet \vec{ds} + \int_s \vec{\mathcal{J}} \bullet \vec{ds}$$

$$\oint_s \vec{\mathcal{D}} \bullet \vec{ds} = \int_V \rho \ \mathbf{dV} = Q$$

$$\oint_s \vec{\mathcal{B}} \bullet \vec{ds} = 0$$





I - 15

Maxwell's Equations (Phasor Form)

KNUST
Telecomm.
Engineering

$\vec{\mathcal{E}}$: sinusoidal electric field in the x direction

$$\vec{\mathcal{E}}(x,y,z,t) = \hat{x}A(x,y,z)\cos(\omega t + \varphi)$$

$\vec{E}$: phasor of $\vec{\mathcal{E}}$ ➡ $\vec{E}(x,y,z) = \hat{x}A(x,y,z)e^{j\varphi}$

$$\therefore \vec{\mathcal{E}}(x,y,z,t) = \mathrm{Re}\left(\vec{E}(x,y,z)e^{j\omega t}\right)$$

Faraday's law in phasor form

$$\nabla \times \vec{\mathcal{E}} = -\frac{\partial \vec{\mathcal{B}}}{\partial t} - \vec{\mathcal{M}}$$

$$\nabla \times \mathrm{Re}[\vec{E}e^{j\omega t}] = -\frac{\partial}{\partial t}\mathrm{Re}[\vec{B}e^{j\omega t}] - \mathrm{Re}[\vec{M}e^{j\omega t}]$$

$$\mathrm{Re}[(\nabla \times \vec{E})e^{j\omega t}] = \mathrm{Re}[-j\omega\vec{B}e^{j\omega t}] + \mathrm{Re}[-\vec{M}e^{j\omega t}]$$

$$\therefore \nabla \times \vec{E} = -j\omega\vec{B} - \vec{M} \qquad (1.14a)$$

Similarly (1.14b~1.14d) are obtained

Analog Transceiver System

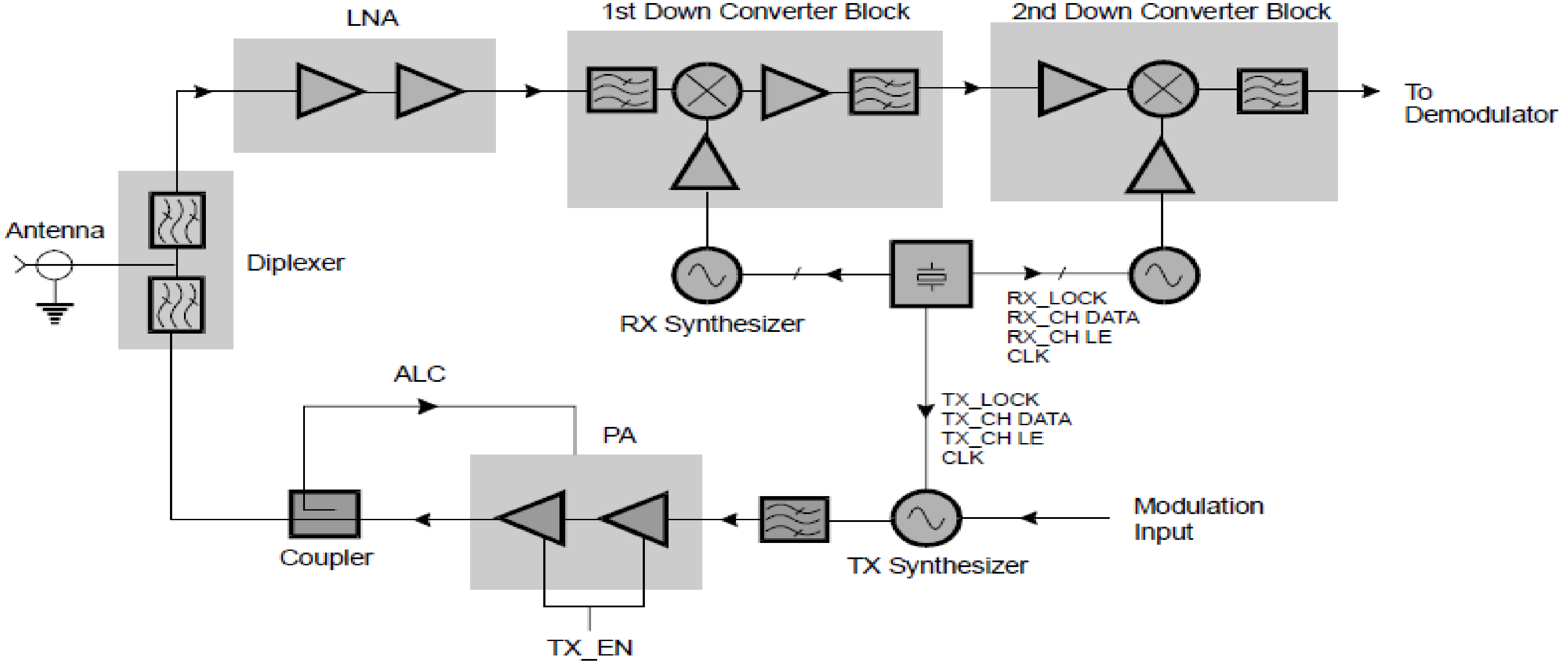


Fig. 2: A block diagram of an analog mobile phone handsets

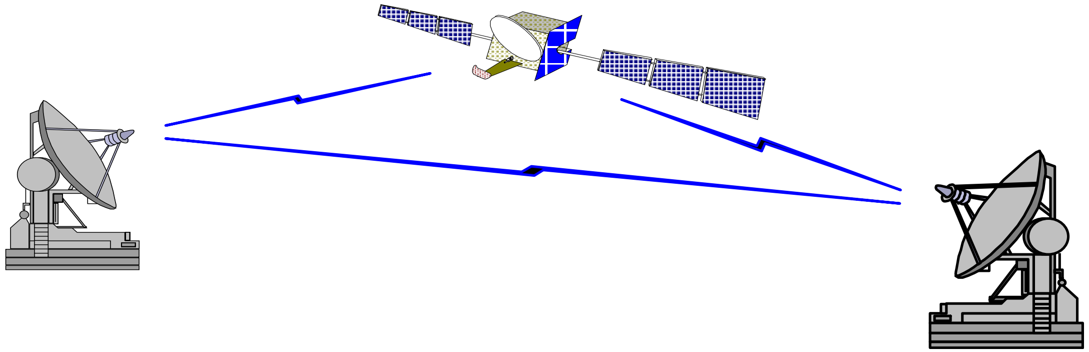
Characteristics and Application of Microwaves

1. As frequency increases, high gain antennas can easily be implemented

2. Higher Bandwidth (higher information Capacity) can be realized.

- 1% bandwidth at 600 MHz : 6 MHz
- 1% bandwidth at 60 GHz : 600 MHz

3. Microwave signals travel by line of sight - not bent by the ionosphere and thus satellite and terrestrial communication links with very high capacities are possible.



4. Large Radar cross section makes it easy for use in radar communication system.

- airport traffic-control
- automobile collision-avoidance systems
- weather prediction

5. Various molecular, atomic, and nuclear resonances occur at microwave frequencies, creating a variety of unique applications in the areas of basic science, remote sensing, medical diagnostics and treatment, and heating

Applications of Microwaves-Microwave Systems

1. Mobile communication system (cellular, PCS, IMT-2000 etc)
2. DBS (Direct Broadcast Satellite) TV and other satellite Communication systems
3. Wireless Local Area Network (W-LAN)
4. GPS (Global Positioning Satellite) system
5. Radar System

Applications of Microwaves-Microwave Systems

6. Worldwide Interoperability for Microwave Access (WiMax)

7. 4G systems

8. Software radio

9. Ultra Wide Band radio

10. BlueTooth

Course Outline

❖ **Introduction to Microwaves**

Brief History of Microwaves Eng., Microwave Frequency bands, Applications of Microwaves: Introduction to Microwave Systems.

❖ **Transmission Line Theory**

Transmission Line Parameters
[phase velocity, wavelength and Characteristics Impedance], Coaxial and Microstrip lines, Sinosoidal Responses, Applications of transmission lines.

❖ **Microwave Network Analysis: S-parameters**

Voltage S-parameters definition, Definitions and Properties of S-parameters, Ports, S-parameters Conversion, Shift in reference planes, insertion loss and Return loss, and input reflection coefficient.

Course Outline

KNUST
Telecomm.
Engineering

- **Power Dividers and Directional Couplers**

  Basic Properties of Dividers and Couplers, The T-junction power divider, Wilkinson Power Divider, Quadrature (90°) Hybrid and 180° Hybrid

- **Impedance Matching**

  Maximum Power Transfer Theorem, Discrete Matching Circuit, Transmission Line Matching Circuits.

- **Low Noise Amplifier**

  Gains, Stability and Conjugate Matching, Gains and Noise Circles.

Learning Activities

- **Two hours of lectures weekly/ One Hour Tutorial Session (May be used for lectures initially)**
- **Quizzes to evaluate understand of Microwave Theory and Techniques**
- **Design and Simulations:**
  - **Transmission Lines**
  - **Sparameters**
  - **Matching Circuit**:
- **Class Term Project: Design of Low Noise Amplifier**

  Class divided into groups of three, each assigned different design frequency. Students will submit reports on their design.

Recommended Text

Text 1

Microwave Engineering, 4th Ed.

ISBN 0-471-17096-8

Author

David M. Pozar

(Professor, University of Massachusetts at Amherst)

Publisher

John Wiley & Sons, Inc. , New York

Recommended Text

KNUST Telecomm. Engineering

Text 2

Microwave Circuit Design:

A Practical Approach Using ADS

ISBN 978-0-13-408678

Author

Kyung-Whan Yeom

(Professor, Chungnam Nat. Univ., Korea)

Publisher

Prentice Hall. , New York